Nikos Hatziargyriou
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Energy-Efficient Computing and Networking

First International ICST Conference, E-Energy 2010
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Revised Selected Papers

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Preface

The European target of a 20% contribution from renewable energies by 2020 will have a major impact on its energy structures. Together with increased energy efficiency, integration of very large amounts of renewable energy sources as well as distributed co-generation units, new grid architectures and grid management strategies are required.

Developing a smart grid has become an urgent global priority as its economic, environmental, and societal benefit will be enjoyed by generations to come. Information and communications technologies are at the core of the smart grid vision as they will empower today's power grid with the capability of supporting two-way energy and information flow, isolating and restoring power outages more quickly, facilitating the integration of renewable energy sources into the grid and empowering the consumer with tools for optimizing their energy consumption.

The Conference on E-Energy provided a highly interactive forum where researchers and technologists had the opportunity to present and discuss leading research, developments and future directions in the usage of ICT in power systems. The main goal of the E-Energy 2010 Conference was not only to present the best research efforts in the area, but also to provide the field with new concepts to be introduced and further explored.

The conference included two workshops and a paper session. The aim of the first workshop, called "Real Smart Grids Applications," was to present the latest technologies, current deployments and pilot schemes around smart grids. Through the examination of regulatory, legal, commercial, market and industry issues, it looked thoroughly at present and future industry challenges including meeting the demands of the EU 2020 carbon targets, increasing penetration of renewable sources and rising to competitive market chances.

The second workshop, called "Energy Efficiency Through Distributed Energy Management in Buildings," focused on the work done within the frame of various research projects in the area of smart grids and distributed energy management in buildings, including also real demonstrations in test sites across Europe. The workshop was intended to facilitate in-depth discussions about technological concepts, field experience and scenario analyses, as well as hurdles, challenges and necessary framework conditions for enabling and enhancing demand flexibility in buildings.

Finally, the paper session presented the recent research efforts of universities, research centers and companies in the area of smart grids.

More specifically, the fields of concern were the following:

- Smart grids
- Active houses
- Smart meters
- Intelligent applications

- Communication and control protocols
- Multi-agent systems
- SCADA, EMS, and DSM
- Power system automation
- Complex interactive networks
- Electric vehicles
- Information technology
- Competitive environment
- Renewable energy
- Distributed generation

For further information please see the conference's website: www.energyware.org.

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E-ENERGY 2010

Technical Session 1: Energy Market and Algorithms

Towards an Energy Internet: A Game-Theoretic Approach to Price-Directed Energy Utilization

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Abstract. The growing interest towards internet-inspired research for power transmission and distribution invariably encounters the barrier of energy storage. Limitations of energy storage can be offset, to a degree, by reliable forecasting of granular demand leading to judicious scheduling involved and incentivized by appropriate pricing signals. The anticipation of energy demand and future system state is of great benefit in scheduling capacities offsetting storage limitations. In this paper, a game is formulated that shows the effect of the synergy between anticipation and price elasticity to achieve lower Peak-to-Average Ratios and minimize waste of energy. The results demonstrate that the final demand signal can be smoother and energy efficiency increased.

Keywords: Energy Internet, intelligent meters, energy anticipation, decision-making.

1 Introduction

Although modern civilization is characterized by ever increasing per-capita energy consumption, energy security, resource limitations, environmental constraints, call for systematic energy efficiency gains and appropriate technological advancements towards sustainability. Electric power is emblematic of modernity and of paramount importance for human progress and economic development. Electricity generation, distribution and utilization are obviously of great significance to both the industrialized and the developing world. A typical and complete path of energy flow rooted in power plant generation from where power is transported at the speed of light through the electric power grid (or simply "the grid") to devices and machinery of all types (the consumers) is often viewed as a gigantic machine in itself.

The electric power grid is the essential and primary medium for power distribution. It is a system of high complexity with evolved characteristics − often resulting in significant deviations from design specifications and hence vulnerable to instabilities which may result in brownouts or even blackouts. Instabilities are common in highly complex systems and need to be countered effectively and cautiously. If the time of failure (blackout) is long then the consequences in various aspects of social and economic life can be very severe. To avoid that, it is desirable to have "self-healing"

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capacities where restorative action following a disturbance can be taken effectively before a brownout or a blackout [1]. Hence, accurate prediction and prognosis of destabilizing events is of great importance in managing disturbances and preventing destructive effects and their cascade-type or domino propagation through the network.

Usually, widespread failures in power networks require significant amount of human resources that may entail high cost. On the other hand, prognosis of non normal states is preferable since it reduces the cost of restorative activities and maintains overall network availability. Because of the importance of this system, regulation of the power grid necessitates short term forecasting of the load and when possible forecasting at the nodal level of individual devices and machines [2] [3]. Indeed, anticipation of nodal energy demand helps in scheduling proper actions so as to prevent the grid from failure. Towards that goal, several models and systems have been proposed for predicting load patterns and managing the grid.

The term *Energy Internet* [4] is found in efforts to embed information and automation technologies in the power grid to achieve intelligent energy distribution [5] and management [6]. Many techniques and protocols utilized by the information Internet may also be adopted in an Energy Internet [7]. However, the lack of satisfactory energy storage makes it difficult (if not impossible) to develop such approaches. In that direction, the notion of virtual buffers [8] is applied to the Energy Internet to compensate for this shortcoming. Virtual buffers are entities that exploit load anticipation capabilities within the grid so as to balance, as much as possible, the generated and the consumed energy. The difference in these two quantities comprises a crucial, but unstable, factor for the distribution network and, as such, needs to be carefully monitored and computed.

In this paper, a new algorithm is introduced with the aim of extending an Energy Internet's capabilities. The proposed methodology is coupled with the anticipated module of an intelligent meter in order to enhance intelligent decision-making. The overall goal is to incentivize a customer's financial benefit through pricing signals, a smart schema of anticipation and sequential placing of orders to the supplier.

In the next section, a brief introduction to the proposed concept of Energy Internet is presented and the role of energy anticipation is described. Also, related work by the Consortium for the Intelligent Management of the Electric power Grid (CIMEG) is presented. Section 3 presents the game-based approach used to show the role of anticipation. Additionally, anticipation is demonstrated through a simulated example and the advantage presented by its use is clarified. Lastly, the paper is summarized and the main directions derived from the game-based approach are outlined.

2 Energy Internet

This section is devoted in the concept of the Energy Internet. Specifically, there are two sections: the first summarizes the fundamentals of the principle idea, and, the second briefly describes work done in that direction by CIMEG [9].

2.1 The Concept of the Energy Internet

The notion of an Energy Internet is a novel idea that is an implementation of a more advanced smart grid [10]. It possesses features of conventional smart grids have such as quick detection of abnormal states and self healing. Its principle perspective considers energy flows through the grid in a way analogous to data packets in data networks.

The main concern addressed by the Energy Internet is the lack of energy storage. Due to this, the contribution of energy anticipation [10] and virtual buffering are of great significance. Initially, consumers predict their short term energy demand pattern [11] and then forward an order to the supplier's site. Through its infrastructure the supplier will provide the customer the amount of requested energy. After the order is approved by the supplier, the requested energy can be considered as stored or buffered. It should be mentioned that physically the energy has not been generated yet. Towards that, this hypothetical stored energy defines a virtual buffer as it is presented in figure 1.

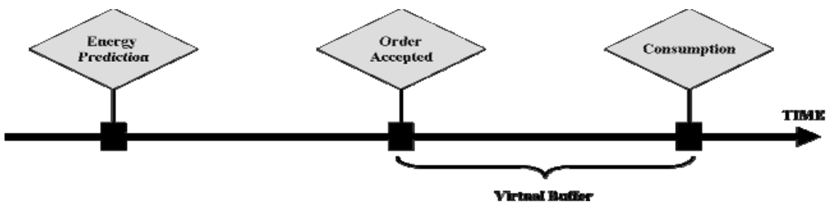

Fig. 1. The notion of Virtual Buffer

The scheme of collecting and accumulating energy orders makes possible the utilization of dynamic power generation level. The latter means that power generation is adjusted to the power needs and the wasted amount of energy is reduced significantly compared to that of a fixed generation level (figure 2).

The basis for the efficient function of the Energy Internet is the use of intelligent meters. Each intelligent meter stands for one customer of the electric grid. Its role is to perform a variety of functions including purchases of the required energy. In doing that, such a meter possesses intelligence capabilities in the sense that it processes data and makes predictions. In fact, such meters are software agents since they have their own agenda, seek their own goal, react to and communicate with their environment.

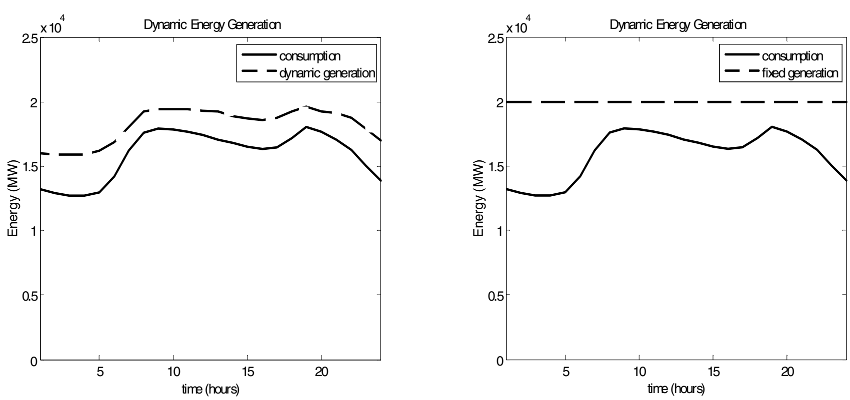

Fig. 2. Schemes for Dynamic and Fixed Generation of Energy

A crucial part of an intelligent meter is its anticipation module. In that subsystem, algorithms for prediction of customers energy need are implemented. Specifically, the meter uses previous energy profiles in order to come up with a prediction. The result of the prediction is submitted to the power supplier as energy that is pre-ordered. The latter necessitates the need for a type of identification for the meter. In that direction the meters are supplied with a unique IP address which is assigned to them upon registration to the network. Overall, Energy Internet can be considered as one step ahead in evolution of smart energy grids and as a good mimic of the data networks.

2.2 Consortium for Intelligent Management of Electric-Power Grid (CIMEG)

In 1999, CIMEG was funded by EPRI and DOD with the aim to develop intelligent methodologies for the management of the electric grid. Its principle objective was to develop new tools for mitigating potential threats for the normal operation of the grid. Led by Purdue researchers CIMEG involved several partners from The University of Tennessee, Fisk University, TVA and ComEd (Exelon).

CIMEG's approach models the grid as a demand-driven system. A bottom up approach is followed in order to determine the health of the system at higher levels and ultimately its global state of health. The latter necessitated the introduction of the notion of a Local Area Grid (LAG). A LAG can be characterized as the clustering of several different customers and is responsible for keeping its own stability by taking appropriate actions when necessary. The implementation of LAGs was based on development of on a multi-agent system named Transmission Entities with Learning-capabilities and On-line Self-healing (TELOS). In TELOS, intelligent agents perform the anticipation process for the LAG and might act to prevent possible future faults.

The ultimate vision of CIMEG was the creation of a platform that controls the power grid in an autonomous and intelligent way. More specifically, intelligent meters are given the responsibility to negotiate with suppliers and place orders. On the other hand, suppliers and generators intend to maximize gain by keeping demand below optimal generation levels. The latter can be accomplished via elasticity models which can affect demand by generating appropriate pricing signals.

3 Regulation of Power Market

This section is devoted to description of the approach followed for regulation of the power demand curve through price elasticity. Specifically, a game is set up [12], in which players aim in achieving regulation by achieving an agreement beneficial to all parts.

3.1 Description of Game

An important goal in the power system is to harmonize the power generation-demand equilibrium; implicitly, by smoothing out demand signals the electric power grid becomes more stable thus assuring effective distribution of energy. In order to illustrate that let us consider a game in which short term pricing is determined through a series of negotiations between players [13].

As expected, players in the game are identified either as a) *energy consumers*, or b) *electricity suppliers*. Specifically:

- ***Consumers*** can be classified as *residential* or *industrial*. The distinction is based on the energy consumption profiles, which appear to have significant differences and possess specific characteristics. For the purposes of the game in this work, no distinction is made between the various customers. Moreover, their individual demand curves are aggregated to yield a global demand profile (D_p). Generally speaking, a global demand profile is created by registered customers of a specific geographical area.
- ***Suppliers***, who are also the electricity generators in order to simplify the presented approach, have an upper limit in energy production and distribution (G_{max}). The latter constraint once exceeded by uncontrolled demand, can result in destabilization of the power grid and subsequent failure of providing power to all consumers. In other words, the grid may collapse. It should be emphasized that in the current work, it is considered that there is only one electricity supplier. In addition to that, it should be stated that the supplier's generation capacity is assumed to be above the electricity demand at all times, that is,

$$G_{max} > D_p \, . \tag{1}$$

In this paper, the presented game adopts the principles of the Energy Internet. So it is considered that the power demand is predicted for a horizon of an hour ahead. Exploiting the anticipation information, the purpose of applying the game approach is to drive all players into a kind of agreement called equilibrium. To be more specific, equilibrium includes:

- Smoothening of power demand (reduce PAR) – consumers change their consumption schedule,
- Keeping the profit of suppliers as high as possible.

The methodology followed for regulating the power demand curve is variation of the price of electricity. Accomplishing that, the concept of price elasticity (see (2)) is applied as the mechanism to determine a suitable price that might drive customers to reduce consumption or alter their schedules. The latter will lead the overall demand towards the predetermined goal.

$$E = \frac{\Delta Q_d / Q_0}{\Delta P / P_0} = \frac{\%\_change\_in\_demand}{\%\_change\_in\_price} \tag{2}$$

More specific, the game is based on initial demand prediction and subsequent adjustment of price through price elasticity. It should be emphasized that the initial goal might not be achieved with the first iteration and more adjustments of price might be needed. Although there are several models developed for estimation of elasticity, in the current game use is made of a constant value for elasticity and specifically one of those provided in [14].

The initial price is sent to all registered users. Each one of them replies back with the anticipation of its demand. Aggregation of all demand signals yields the total demand. In the next step, the supplier using the formula shown in (2) computes the new price and broadcasts it to the customers waiting for their updated anticipation response. In case the updated demand signal reaches the predetermined goal then the current price is used for the transactions of the next half hour.

Customer reactions are limited to three choices; increase their demand, stay at the same level, or, reduce it. Following a rationale approach, if the price changes upwards then the demand will decrease since customers do not want to pay more than their initial budget allows. In order to model the behavior of the consumers we use a probability distribution schema:

$$\begin{aligned} P_{in} &= \text{increase demand} \\ P_{dec} &= \text{decrease demand} \\ P_{same} &= \text{same demand} \end{aligned} \tag{3}$$

Getting into more details, each of the three expected reactions is assigned a values which stands for the probability that the customers might reach respectively. As a result, an action is selected randomly according to the probability distributions in each pass. Moreover, probabilities are not constant but are rather updated in each iteration according to:

$$P_{xi} = P_{x(i-1)} + k_{xi} \tag{4}$$

where, x denotes the type of action, i is the iteration number, and k is a constant of update. In all cases probabilities should the follow Kolmogorov's axioms. Hence:

$$P_{ini} + P_{deci} + P_{samei} = 1 \tag{5}$$

which implies that

$$k_{ini} + k_{samei} = k_{deci} \tag{6}$$

Updated probabilities stand for the rational change of customers' response to market changes. The more one has to pay the more willing is to alter his schedule of power consumption. Once an action is chosen then the consumption should change. In the current work either increase or decrease is done by an amount which is equal to:

$$(demand - regulated)/\#customers \tag{7}$$

From the supplier point of view the maximum profit is obtained by shaping the demand curve to the maximum value which regulates the market and assures stability of the power grid. In other words the predetermined goal demand is put by supplier to the maximum possible in each case.

3.2 Application of the Game and Results

Application of the game will show the efficiency of the model for regulation of the power market via price elasticity. For this reason, some simple assumptions are made to simplify the game. Specifically, reaction probabilities are given random values in the beginning, through the rationale that once prices go up it is more likely that a consumer will reduce his demand, less that he will ask for the same amount and even less that he might increase it. The constants k_x take the values 0.04, -0.015 and -0.025 for decreasing, ask for the same and increase the demand respectively. Demand data and prices signals are taken from [15]. To simplify for the purposes of the paper, it is assumed that the registered customers are 6,500,000 and all of them share the same probability distributions for reaction.

Furthermore, a fixed elasticity value is adopted for the current game and is equal to -0.88 as shown in [14]. It should be mentioned that the fixed value allows little space for flexibility and might lead to high variations. In addition to that, we set for some a higher boundary for approaching the desired curve smoothening. To be more specific, it is difficult to reach the exact predetermined demand values and as a result a margin of +/- 10 MW is set. For the purposes of the game it is assumed that the module is not aware of the demand and price signal so as to have a virtual real time demonstration. Figure 3 shows the initial demand curve, the desired regulated signal and the prices before changes based on elasticity. Observation of figure 3 provides that the peak of the demand to be smoothed is the time between 17:00 and 21:00.

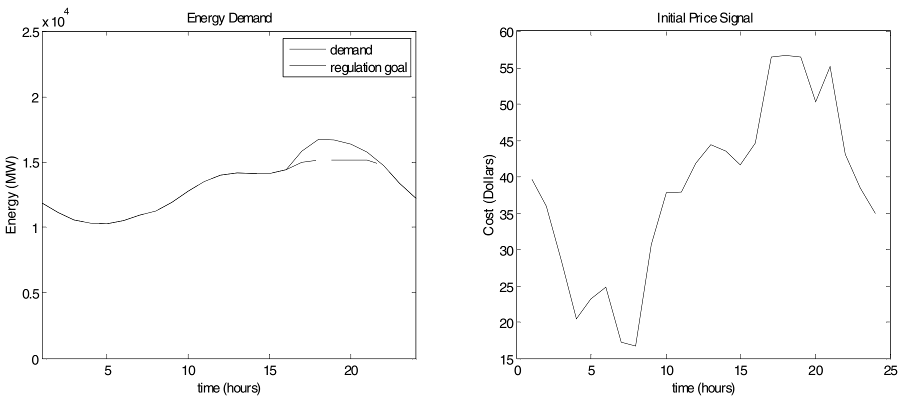

Fig. 3. Curves for Energy demand, regulation of its peak and price signal over a period of one day (source NE ISO)

For demonstration purposes, it is assumed that at 16:00 the customers report their anticipated demand to the supplier. The demand is as shown in figure 3 at 16:00. The supplier observes the rise in the demand and tries to suppress the demand by changing the price of the electricity. Accomplishing that, a fixed elasticity model is adopted and a new price is computed.

Customers react to the new price according to their probability distributions. It should be said that in the first each customer decides whether to reduce consumption, ask for the same, or to increase with probabilities of 0.5, 0.35 and 0.15 respectively. From the latter values, it is obvious that the rational behavior of reducing consumption if cost goes up is modeled. Table 1 shows the negotiations among supplier and customers for energy consumption at 18:00. Specifically, the evolution of price and demand through a fixed elasticity for achieving the desired smoothing goal is presented.

Table 1. Price and Demand Evolution during game negotiations for energy needs at 18:00

	Initial	*Round 1*	*Round 2*	*Round 3*	*Round 4*	*Round 5*	*Round 6*	*Round 7*
Price - LMP($)	56.61	62.64	65.32	66.31	66.62	66.69	66.71	66.72
Demand (MW)	15826	16146	15711	15448	15307	15240	15213	15203

Following the same process at times 18:00, 19:00, 20:00 and 21:00, the energy demand is reduced to the desired level and the peak is eroded. This is observed in figure 4, in which the initial demand has been reduced to the desired levels. Precisely, the energy demand after the game is almost the same as the initial desired regulated curve. To be more specific, the regulation goal was achieved with high accuracy for the interval 18:00 to 21:00 and with less as 17:00. Therefore, figure 4 shows the flattening of the demand curve.

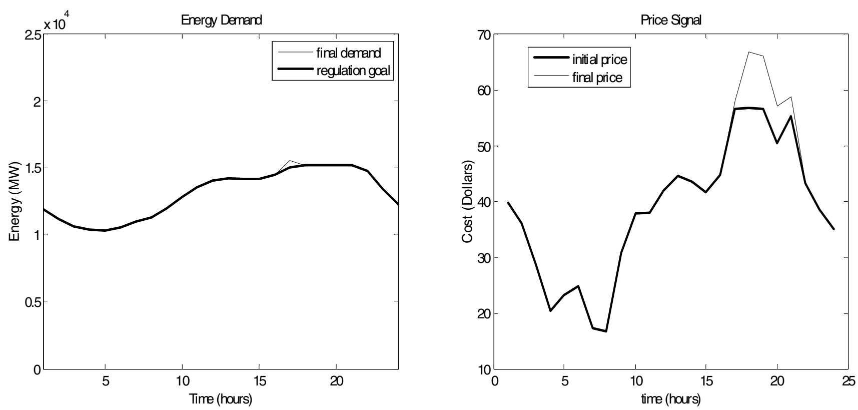

Fig. 4. Final demand and price signal at the end of the game superimposed to initial signals

4 Conclusions

In this paper, a new model of control (regulation) of the power market based on negotiations and change of the cost of electricity is discussed. More specifically, the underlying idea states that the power grid could become more intelligent once coupled with information services such as anticipation of energy consumption. For that reason, the proposed concept of an Energy Internet and the research work done in that direction by CIMEG was briefly presented.

Furthermore the idea of suppressing the energy demand, which is anticipated ahead of time, through price elasticity models was demonstrated by a game based approach. The game described in this work assumed as players the registered customers and one supplier. Behavior of customers in the market was modeled by probability distribution. The case presented used data from NE ISO and showed that regulation of market can be achieved by alteration of the price electricity. The example examined illustrated how the erosion of peak demand may be achieved through increase of the cost of electricity supplied.

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Microgrid Modelling and Analysis Using Game Theory Methods

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Abstract. Game theory is a branch of applied mathematics that is, most notably, used in economics as well as in engineering and other disciplines. Game theory attempts to mathematically capture behaviour in strategic situations, in which an individual's success in making choices depends on the choices of others. The microgrid encompasses a portion of an electric power distribution system that is located downstream of the distribution substation, and it includes a variety of DER units and different types of end users of electricity and/or heat. Microgrids promote the use of new technologies, under the general Smart Grids' umbrella, in order to achieve more efficient use of electric energy, better protection, improved control and provide services to the users. For the materialization of the infrastructure needed to implement this model, engineers have nominated technologies like smart agents, distributed computing, smart sensors and others, as well as, a solid and fast communication infrastructure. In this decentralized environment, multiple decision making participants interact, each striving to optimize its own objectives. Thus, a game theoretic approach is attempted to model and analyse the strategic situations arising from the interactions.

Keywords: Microgrid, game theory, decision makers.

1 Introduction

The Microgrid encompasses a portion of an electric power distribution system that is located downstream of the distribution substation, and it includes a variety of DG units and different types of end users of electricity and/or heat. DG units include both distributed generation (DG) and distributed storage (DS) units with different capacities and characteristics. The electrical connection point of the microgrid to the utility system, at the low-voltage bus of the substation transformer, constitutes the microgrid point of common coupling (PCC). The microgrid serves a variety of customers, e.g., residential buildings, commercial entities, and industrial parks. Depending on the type and depth of penetration of Distributed Generation (DG) units, load characteristics and power quality

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constraints, and market participation strategies, the required control and operational strategies of a microgrid can be significantly, and even conceptually, different than those of the conventional power systems [7] [4] [8].

The model introduced here is based on the general Multi-agent Microgrid model. The economic operation of the Microgrid is undertaken by a company (ESCO/ Aggregator) which has the responsibility of meeting the energy demand of the consumers, buying energy from the distributed generation units and the wholesale markets. All of the distributed generator units and some of the consumers are equipped with Local Controllers (Smart Agents) capable of receiving signals from the ESCO/ Aggregator and alternating the distributed generation or the consumption respectively. The LCs aim in maximizing the revenue of the DG units or consumers, locally, by following a predefined action course, or a *strategy*. In other words, we have multiple decision makers interacting, with each striving to achieve its goal.

2 Game Theoretic Analysis

Game Theory is called upon to model and analyse situations where multiple decision makers interact, with each participant trying to achieve its objective. In this way, Game Theory attempts to mathematically capture behaviour in strategic situations. The primary notion deriving from the Game Theoretic analysis of a strategic situation is the Nash Equilibrium.

2.1 Nash Equilibrium

One way to motivate the definition of Nash equilibrium is to argue that if game theory is to provide a unique solution to the game theoretic problem then the solution must be a Nash equilibrium, in the following sense. Suppose that game theory makes a unique prediction about the strategy each player will choose. In order for this prediction to be correct, it is necessary that each player be willing to choose the strategy predicted by the theory. Thus, each player's predicted strategy must be that player's best response to the predicted strategies of the other players. Such prediction could be called *strategically stable* or *self-enforcing*, because no single player wants to deviate from his or her predicted strategy [12]. Such a prediction is called Nash equilibrium:

Definition 1. *The strategies $(s_1^*, s_2^*, \ldots, s_i^*, \ldots, s_n^*)$ are a Nash equilibrium if, for each player i, s_i^* is player i's best response to the strategies specified for the $n-1$ players, $(s_1^*, s_2^*, \ldots, s_{i-1}^*, s_{i+1}^*, \ldots, s_n^*)$:*

$$R_i(s_1^*, s_2^*, \ldots, s_i^*, \ldots, s_n^*) \geq R_i(s_1^*, s_2^*, \ldots, s_i, \ldots, s_n^*)$$

that is, s_i^* solves:

$$\max R_i(s_1^*, s_2^*, \ldots, s_i, \ldots, s_n^*)$$

where R_i denotes the revenue of i player as function of the strategies followed by every player.

2.2 Subgame Perfect Nash Equilibrium

A subgame perfect Nash equilibrium is a reinforcement of the Nash equilibrium notion for coping with dynamic games (that is games of more than one rounds). It's an equilibrium such, that players' strategies constitute a Nash equilibrium in every subgame of the original game. It may be found by **backward induction**, an iterative process for solving finite extensive form or sequential games. First, one determines the optimal strategy of the player who makes the last move of the game. Then, the optimal action of the next-to-last moving player is determined taking the last player's action as given. The process continues in this way backwards in time until all players' actions have been determined [11] [3].

2.3 Computing Nash Equilibria

The analysis of a strategic interaction lies with the problem of finding the Nash equilibrium of a given game. This notorious problem has been described as the "most fundamental computational problem" at the interface of computer science and game theory (Papadimitriou, 2001). Despite several decades of research into this problem it remains thorny; its precise computational complexity is unknown, and new algorithms have been relatively few and far between.

An equilibrium concept should be efficiently computable if it is to be taken seriously as a prediction of what participants will do. Because, if computing a particular kind of equilibrium is an intractable problem, of the kind that take lifetimes of the universe to solve on the world's fastest computers, it is ludicrous to expect that it can be arrived at in real life. This consideration suggests the following important question: *Is there an efficient algorithm for computing a Nash equilibrium?*

Although in many strategic interactions (games) the answer is negative, in some games Nash Equilibrium can be compute directly or approximated with the use of an heuristic method.[1]

2.4 Use of Nash Equilibrium Solutions

Another question one may ask is the utility of the results arising from the game theoretic analysis of a situation. The results may be used in two ways: Descriptive or Prescriptive.

Descriptive. The first known use is to describe how individuals behave. Finding the equilibria of games we can predict how the actual participants will behave when confronted with situations analogous to the game being studied. In other words, game theoretic analysis gives us an insight to the strategic situations arising [5]. In the microgrid model we can investigate how the players will act in different situations. In this way we can predict technical or economical disadvantages of a model and decide whether to modify or discard it.

[1] A heuristic method is used to come to a solution rapidly that is hoped to be *close* to the best possible answer, or 'optimal solution'.

Prescriptive or Normative. On the other hand, game theory can be used not as a predictive tool for the behaviour of the participants, but as a suggestion for how individuals ought to behave. Since a Nash equilibrium of a game constitutes one's best response to the actions of the other players, playing a strategy that is part of a Nash equilibrium seems appropriate. Normative aspects of game theory may be sub-classified using various dimensions. One is whether we are advising a single player (or group of players) on how to act best in order to maximize pay-off to himself, if necessary at the expense of the other players; and the other is advising society as a whole (or a group of players) of reasonable ways of dividing pay-off among themselves [5].

The distinction between the descriptive and the normative modes is not as sharp as might appear, and often it is difficult to decide which of these two we are talking about. For example, when we use game or economic theory to analyse existing norms, is that descriptive or is it normative? We must also be aware that a given solution concept will often have both descriptive and normative interpretations, so that one will be talking about both aspects at the same time. Indeed, there is a sense in which the two aspects are almost tautologically the same [1].

3 Application to the Microgrid Model

An example of modelling and analysing a Microgrid model using game theory is presented below. We model the interaction between the LCs of consumers, DG units and the ESCO as a Game Theory game and analyse it using game theoretic tools and methods.

3.1 Microgrid Model

The model used is shown in the schematic figure 1. All Consumers and Distributed Generators are equipped with Smart Meters. With this technology, the application of a variable pricing scheme for the consumers and variable payment scheme for the distributed generation is possible. In other words, we have price-responsive demand and generation inside the Microgrid [2]. Moreover, the Smart Meters commute real-time measurements of the consumption of each individual consumer and the generation of each individual DG to the DNO/ DSO. The ESCO/ Aggregator is informed of these values from the DNO/ DSO and can use this information to define the pricing in the Microgrid.

3.2 Game Description

The players defined by the game consist of the ESCO/ Aggregator, the DG units and the consumers equipped with LCs. We assume that all players seek to maximize their revenue. The game is described as follows: The ESCO/ Aggregator plays first and chose its action, which consists of pair of values (π_1, π_2), representing the variable pricing values. Following, each DG unit, having received the value π_1, acts on it modifying its generation P_{DG}. At the same time, each

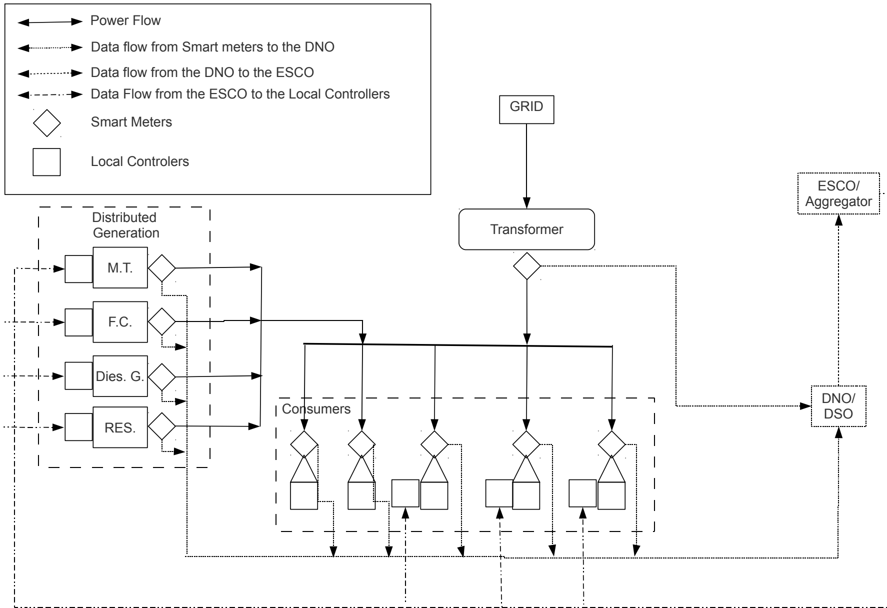

Fig. 1. Microgrid Model

consumer, having received the value π_2, acts on it modifying its consumption Q_{LC} [10]. The game then ends and each player receives his revenue as a function of all the actions in the game:

$$R_{player}(\pi_1, \pi_2, P_{DG_1}, ..., P_{DG_n}, Q_{LC_1}, ..., Q_{LC_m})$$

3.3 Modelling as a Game

The Microgrid model can be examined under the class of games called "Dynamic Games of Perfect Information". Dynamic games are games with sequential move order, meaning, some players move or act only after having observed someone else's move or action. Perfect Information denotes that at every round of the game, the player whose turn is to chose an action knows the actions other players have chosen before him. The game formed by the Microgrid model can be of complete information, meaning that every players revenue function is common knowledge, or incomplete information [6]. We can see the extensive form representation of the game in 2.

3.4 Game Analysis

As noted previously, the goal of each player is to maximize his revenue function. For doing so, the ESCO/ Aggregator has to choose the best price values (π_1, π_2) from the strategy space of feasible values $([\pi_{1min}, \pi_{1max}]$,$[\pi_{2min}, \pi_{2max}])$. Each

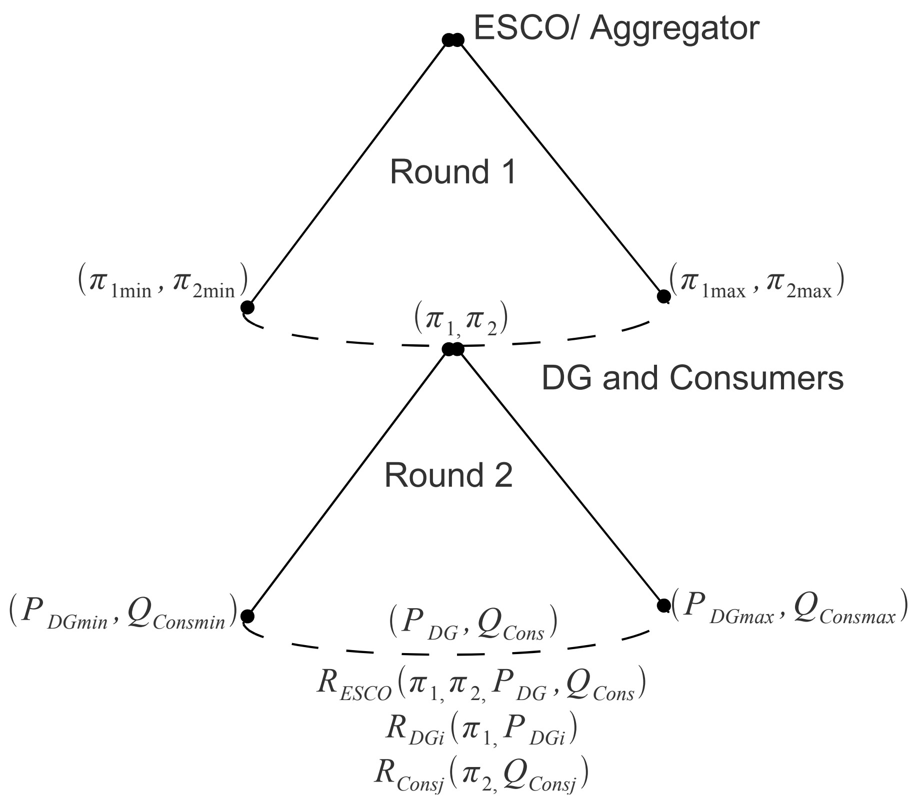

Fig. 2. Extensive form representation of the game

DG unit chooses the best power generation $P_{DG}(\pi_1)$ from the strategy space of feasible values $[P_{DG_{min}}, P_{DG_{max}}]$. Each consumer chooses the best consumption level $Q_{LC}(\pi_2)$ from the strategy space of feasible values that is constructed according to the controllable loads available to the LC.

Using the *backwards-induction* method we begin the analysis from the second round of the game (schematics 2). DG units and consumers will face the following optimization problems:

$$\max\{R_{DG_i}(\pi_1))\} \quad and \quad \max\{R_{Consumer_i}(\pi_2))\}$$

respectively.

Assuming that for every value π_1 the DG problem has a unique solution $P_{DG}(\pi_1)$ and for every value π_2 the consumer's problem has a unique solution $Q_{LC}(\pi_2)$. Then, at the first stage of the game, the ESCO/ Aggregator has to solve the problem:

$$\max\{R_{ESCO}(\pi_1, \pi_2, P_{DG}(\pi_1), Q_{LC}(\pi_2))\}$$

Assuming the ESCO/ Aggregator also has a unique solution, denoted $\{\pi_1^*, \pi_2^*\}$, then the solution $\{\pi_1^*, \pi_2^*, P_{DG_1}^*, ..., P_{DG_n}^*, Q_{LC_1}^*, ..., Q_{LC_m}^*\}$ is called *backward-induction outcome* of the game. Although this kind of games have several Nash Equilibria, the only subgame-perfect Nash equilibrium is the equilibrium associated with backward-induction outcome [6].

4 Concluding Remarks

Situations of strategic interactions always occur when multiple decision makers, like smart agents, smart devices and local controllers, coexist within a system. Such decision makers are programmed to strive to optimize a local revenue function taking into consideration the system's state and the actions of others. The reasons for integrating these distributed decision makers (like smart agents) into the Smart Grids have been thoroughly presented in many papers [8]. Some of the reasons being the large amount of data needed to be processed otherwise, making the system more robust and reliable; and providing various services to the system's users. The strategic interaction of many decision makers in the Smart Grid, leads to the need of new ways of mathematically capturing and analysing the occurring situations.

The strategic interaction of distributed decision makers has been examined extensively by computer science researchers [9]. Game Theory has been proposed to provide the tools and methods for modelling and analysing such situations. Using the knowledge obtained from that research, we can customize the algorithms to solve and predict situations modelled with game theoretic tools in Microgrids and other Smart Grid models. The results from this analysis can be used to compare different variations of a model. We can can compare the anticipated profit yielding from applying a certain technology with the estimated cost of implementing and integrating it. Moreover, we can investigate the impact that modifying the protocols governing the model has on them.

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Implementation of Gossip Algorithms in Power Systems

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Abstract. The main objective of the paper is to describe gossip algorithms and discuss their potential use in power systems, especially in future intelligent networks. The paper presents a generic gossip algorithm, its general and some more specific properties. In addition, general classification of the gossip algorithms is also presented. The final part of the paper presents an overview of the recent research and implementation of gossip algorithms in power systems.

Keywords: gossip algorithms, power systems.

1 Introduction

The need to disseminate information among interconnected nodes in a highly dynamic environment has motivated the development of distributed algorithms based on epidemic theory. Inspired by the idea that a single infected entity eventually infects an entire susceptible population, these algorithms use the analogy between information and infection. The objective is to disseminate information between the nodes in a network as quickly as possible, in a similar manner as infection is spread among population, while avoiding network overloads and high costs. The first use of epidemic based algorithms, also known as gossip algorithms (GA) was in 1987, by Demers et al. [1] with the aim to solve the problem of replicating database updates from one site among others within the Xerox Corporate Internet. Since than, following the development in Information and Communication Technologies (ICT), these algorithms are implemented for solving different problems, including: peer sampling, aggregation, group management, load balancing, topology management, failure detection, multicasting, etc. In recent years researchers also try to correlate GA with particle swarm optimization, heuristics intelligence and population and community protocols [2], [3].

The implementation of gossip-based algorithms is not limited to ICT applications only. Recent research of new concepts as Microgrids or Smart Houses [4], [5] indicates that ICT applications will play an important role in the process of development and implementation of these concepts. Characteristic for these concepts is the capability of interaction between the entities within the network, as well as with the external distribution network. The interaction is enabled by ICT applications which facilitate establishing bidirectional communication paths between the entities, exchange of information and distributed execution of specific tasks. The gossip

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algorithms, being by nature reliable and scalable, have the properties to provide the required interaction environment. They enable fast information dissemination among entities which have limited knowledge of the global network and decentralized execution of tasks at each entity, thus facilitating the aim to achieve a global objective by using local knowledge only.

2 Gossip Algorithms

The definitions on the gossip concept could be roughly narrowed to the following: for each process participants communicate periodically their knowledge about the system state to a random subset of participants or to other processes. For example, the state of the system can be database replications or messages containing measured values and the actual message exchange is done via the Internet.

The principles of the gossip algorithm can be explained using the generic gossip algorithm [2], [3], [6], [7]. Although there are minor differences even in the generic form of the algorithm, the same conclusions can be driven. In this section fig.1 presents algorithm described in [3].

Active thread	Passive thread
do once for each T time units at a random time	**do forever**
begin	**begin**
p = SelectPeer()	**receive** $info_p$ from p
send DataExchange (*state*) to p	**send** DataExchange (*state*) to q
receive $info_p$ from p	*State* = DataProcesing($info_q$)
state = DataProcesing($info_p$)	**end**
end	

Fig. 1. Generic gossip algorithm, from [3]

The algorithm consists of two threads which are executed at each node. As presented in the fig. 1, in the active thread a node periodically selects a node (peer)[1] p from the population through the function *SelectPeer()*. This function is used to define the way by which the node selects his gossip partner. In some cases the node selection is deterministic, but in most cases it is random. It is argued that deterministic selection in GA is allowed if it enables acceptable node diversity. The random peer (node) selection can be uniform, distance-based (spatial), hierarchical or connection based selection.

Uniform selection is made based on uniform distribution and is frequently used, even though is related with router overload. According the uniform selection, each node selects a partner node uniformly and randomly, from the same set of nodes. According

[1] In the literature both terms are used. The use of the term peer comes from the use of GA for peer sampling, one of the most frequent GA applications. This also relates to the fact that GA emerged from research in the area of information and communication technologies.

the distance based selection the node selects the nearest (in distance) nodes with higher probability than the more distant ones. Despite the traffic relief obtained by this solution, it is important to provide conditions for gossip with the more distant nodes in order to achieve better message propagation in further areas and not to leave certain local areas without information. According the hierarchical approach in gossip partner selection, the gossiping is mainly done in the local domain, with exchange rates decreasing outside the local domain. According the connection-based selection, the node selects less connected nodes with higher probability, with main aim to improve the connectivity in weakly connected graphs. The selection is done using edge weight, which is defined as the minimum number of edges that need to be removed in order to disconnect the node from its neighbors. The idea is that the node floods neighbors with small weights and gossips with others. The probability for sending out the messages after uniform node selection and the probability for node selection in the spatial gossip are calculated in [9].

It is easy to notice that after the gossip partner is selected, in the passive thread the algorithm is executed in such a manner that it mirrors the operations executed by the active thread. *DataExchange()* function returns the information which should be exchanged by gossiping, while the *DataProcessing()* function returns the resulting state of the interaction between the nodes. The algorithm is executed with the assumption that each node possesses a restricted knowledge of the system it exists in by maintaining a local view of a certain size of this system. As the two nodes involved in gossiping are exchanging information, the generic GA uses push & pull message exchange method. In the next section, the differences between push, pull and push & pull message exchange are discussed.

As the algorithm presented in fig. 1 is a generic algorithm, it can be adapted for different purposes. For instance, if used for information dissemination, the algorithm would use only *SelectPeer()* which will return a randomly chosen peer and *DataExchange()* which will contain the message which needs to be disseminated. The generic gossip algorithm can be adapted in order to be used for different distributed computations. For example, it can be adapted for performing aggregation (for example, average or sum calculations). In the case of averaging, the *DataProcessing()* function will return updated state of the two gossiping nodes which will be average of their local states. Each node will update its own state to the new average state. In this way, the average function as a global function is calculated over a distributed set of values.

2.1 General Properties

In overall, the following characteristics are associated to the GA [2]:

- node selection must be random, or at least guarantee enough node diversity;
- only local information is available at all nodes;
- communication is round-based (periodic);
- transmission and processing capacity per round is limited;
- all nodes run the same protocol.

The operations are executed in a decentralized manner and are driven by probabilistic decisions, thus, the above mentioned characteristics prove the decentralized approach of gossip algorithms. In other words, nodes obtain global information by local communication. Furthermore, the GA are proven to be fault tolerant. Due to the probabilistic and distributed nature of these algorithms, even if some of the nodes are not able to perform their operations, the system still manages to behave properly, as the operations of each node is not dependant to any other node. The probabilistic and decentralized nature leads to other important gossip properties. GA are resilient to changes in the system configuration (e.g., topological changes) as they do not rely on the existence of one or more known processes. The interactions can be performed in dynamic environment, where the nodes have the capability to join and leave the network at any moment. GA also prove to have the property of scalability, meaning that their other properties are preserved in case of system increase.

2.2 Specific Properties

The messages are the essential part of GA. Depending on the purpose of the algorithm, they can be organized in a different manner. The messages can be organized as structures which include information on: origin and type of the message, target node, counters for determining the total number of nodes which have received the information, and etc, as proposed in [11]. This type of message structure is more specific for GA used for information dissemination. In order to avoid sending large packets in the networks, before exchanging the actual message packets, the nodes exchange message headers only, which is a practical way to limit the overload. Messages also might carry time stamps or other time related identification in order to determine if one message is newer than another. Another message structure is the so called digest [12], which can contain a short description of information about previous, history events. The digest is usually compared to the local content of the node and if some parts of the information are missing, the node sends request for its missing parts to the owner of the digest. The process ends when the informed node retransmits the missing part. In [9] some additional information is available on alge- GA, which promotes the idea of network coding. The transmitted messages are coded and treated as algebraic entities on which arithmetic operations can be performed. As the coded information has finite dimensions, arithmetic operations can be used to recover the once coded message. In this way, the transmitted packets are smaller, so traffic is generally reduced.

Another important aspect of GA is the message exchange. There are generally three types of message exchange: push, pull and push & pull message exchange. They define the message exchange direction. The pull gossip means that gossip senders (initiators) are pulling information from their receivers, i.e. upon their requests they're updated with information from their gossip partners. Via the push message exchange, a node periodically sends information to a receiver, from which the receiver takes the missing parts, or the whole message and sends it further. The push & pull mode encompasses both types of message exchange, so the nodes update each other with information. The research so far presents best convergence for push & pull, followed by push and than by pull.

Message exchange is facilitated by the nodes' view of the network, more specifically, the amount of information of other nodes in the system. The decision for selection of a gossip partner is actually based on the set of nodes that can be "seen". In general, the following views are distinguished: global – when each node has complete knowledge of the other nodes; local – when each node is aware of its neighbors only; hierarchical – each node has better knowledge of its closest neighbors and lesser of the nodes which are further away; partial randomized – when each node maintains a uniform random list of nodes and anonymous – when the node doesn't know the nodes in the system and uses the underlying structures for message transfer. The view of the nodes is correlated to the complexity of the computational operations executed with the algorithm. According to [3] the computational power of protocols based on GA with anonymous and uniform views is smaller than the gossip protocols using the other view types.

The GA time models are also associated to the node selection. Generally, there are two time models for node communication: synchronous and asynchronous. The common ground for both models is that each node communicates with only one other node at a given time. In the synchronous time model (STM), the nodes communicate simultaneously, whereas in the asynchronous time model (ATM), only one node communicates with its partner at a given time, according to its own clock. It is important to note that in the STM time is measured in slots or rounds, which are common for all the nodes in the network, so all nodes are in the same communication round in which each node communicates with only one other which is randomly chosen. In the ATM, each node has an independent clock which ticks according the Poisson process of rate 1 and time is discretized according to the ticks of the separate clocks of the nodes. When the clock ticks, the node communicates with only one other node chosen randomly. The global clock ticks at a Poisson process of rate n and at each tick of the global clock, a node in the network is chosen at random, so the global clock tick is actually the tick of the chosen node.

Other specific characteristics of GA are convergence time, gossip rounds time length and time synchronization. These properties are more specific to an actual developed algorithm and therefore are very briefly explained in this section. An interesting approach for clock synchronization in combined with GA is presented in [16]. The idea is to use the coupled oscillators phenomenon, which shows enormous systems of oscillators spontaneously locking to a common phase, despite the difference of the natural frequencies of the separate oscillators. According to this approach, each clock (process) explicitly asks clock values from neighboring processes in order to calculate their difference in phase. Then, following the Kuramoto-like model, the differences in phase are combined and multiplied by a so- called coupling factor, expressing the coupling strength, in order to adjust the local clock. The other above mentioned characteristics have also been in the scope of research especially when more complex computations were expected of the GA (for ex. aggregation). In the definition on the properties of GA in [15] is declared that the GA performs at most $O(d_i \log n)$ amount of computation per unit time, where d_i is the degree of the node i (the number of edges which connect i to certain number of nodes in the network) and that the algorithm maintains $O(\text{poly}(\log n)+\text{abs}(F_i))$ amount of storage, where F_i is the amount of storage required at the node i to generate its output. This definition, however rules out the so called "trivial GA" where computations as summation at each node are performed, although it is also an aggregation function. The reason is because they essentially require more storage space.

One of the most important aspects of GA is the information propagation per round. Past research has indicated that the sequential approach in information dissemination (spreading information one after another in terms of propagation rounds) has shown better propagation per round than GA. The spatial (geographic) GA have shown increased probability for spreading information per round, as explained in [12]. Observing the aggregation function problem, where the nodes each have local information and should all establish new values equal to a global value, the authors of [12] propose geographic gossip which is basically a modified GA which uses geographical information of the sensors in a wireless network to reduce convergence time for random geometric graphs. Their results are based on the research done in [13] which shows that the number of rounds is related to the mixing time of the Markov chain defined as a weighted random walk on a graph and proposed a method for optimizing the node selection probability for each node in the graph with the aim to find the fastest mixing Markov chain in the graph. The analyses in the paper are made from the aspect of averaging problem in an arbitrary network graph, accounting the constraints of gossip. New approach to averaging problem in terms of achieving faster convergence time in wireless sensor network can be found in [14].

2.3 Classification

According to the main classification of gossip-based protocols [6], [7], two different classes of protocols exist: anti-entropy and rumor-mongering protocols. Anti-entropy protocols spread the information until it is replaced by newer information, while with rumor-mongering protocols the information is spread until there is high probability that all the nodes have received it. The message spreading with rumor-mongering can be stopped by when the informed node (the receiver) is aware that rumor has spread sufficiently, so it stops sharing via: feedback-based probability – stops spreading with probability *1/k* if the node was already informed; blind probability – always stops with probability *1/k*; fixed count – stops after *k* nodes report that they are informed. This classification is actually related to the epidemic algorithm classification according to which the gossip algorithms can be simple or complex. The simple epidemics allow for two states of the participants: susceptive and infective (SI model). As soon as one of them becomes infective and starts spreading, the susceptible participants that have been "infected" continue to spread the "infection". This group actually encompasses the anti-entropy protocols. The complex epidemics allow for a third state, named removed or recovered (SIR model). The idea is that if susceptive and infective participant come in contact with a removed one, than no exchange happens. This is actually a way to start decreasing the infection rate, which in some manner is related to the rumor-mongering protocols.

Another classification can be made on the basis of the views the nodes have for the network and the use of the underlying structure. According [3] two main classes of gossip protocols can then be defined. Anonymous gossip protocols do not require being aware of any node for executing any of the three functions in the generic GA. GA where nodes are selected uniformly at random also belong to this class. In the Non-Anonymous gossip group belong protocols where the nodes are "aware" of the other nodes in the network, no matter if they communicate with them or not. In this case, the execution of the functions in the generic GA requires the identities of the nodes.

GA are also classified according the time models, which are explained in the previous section. Refined classification is done in [3] in order to distinguish GA with greater computational power. According the paper, there are four classes: Anonymous STM and ATM and Non-anonymous STM and ATM. The computational power of Non-anonymous GA is generally greater but the two classes (STM and ATM) can be considered equivalent. On the other hand, the computational power of anonymous ATM is smaller than the computational power of anonymous STM.

Often GA are classified according the way the gossip partner is chosen, which was explained above or according the area of application.

3 Gossip Algorithms in Power Systems

The properties of gossip algorithms indicate that their use is not limited to IT applications only. As they provide execution of tasks and information dissemination in a decentralized manner, they can be successfully implemented in various decentralized control concepts. So far, the application of GA based secondary and tertiary control for Microgrids is proposed by the authors of [19], [20]. In [19] the authors have proposed distributed secondary and tertiary control based on GA, while using an overlay communication network. They have proposed primary control based on *P-f* and *Q-v* droops in order to secure frequency and voltage regulation in case of communication failure, while the secondary and tertiary controls are based on GA. The secondary control itself is used for correction of the actions of the primary control. It is implemented via distributed PI controller which adapts all P_{sec} and Q_{sec} such that the system converges to state where the average of all deviations of active and reactive powers (P_{prim}, Q_{prim}) at each DER unit equals zero. In other words, the secondary control aims to provide minimum voltage and frequency deviations by ensuring that the average of deviations of active and reactive power at each DER unit equals zero. In this context, GA is used to calculate the average of the active and reactive power deviations of all DER units. The tertiary control redistributes P_{sec} and Q_{sec} among the DER units while satisfying some economic constraints. Namely, the marginal cost functions of the DER units are compared and it is considered that the optimum operation is achieved when all units have equal marginal costs. The GA in the tertiary control is executed in the following manner: each DER unit periodically gossips with a partner from its neighborhood with the aim to match their marginal costs, as explained in detail in [20]. Eventually, all units will have common marginal costs.

According to [20] which describes in detail only the tertiary control, for practical implementation of the proposed control the DER units need to be equipped with standard processors and to have Internet connection. The DER can use agent software for self-organizing in an overlay network which is than used to execute the GA. The actual laboratory implementation is done by inverters representing the front end of the DER units. They are controlled by digital signal processors running the droop control software and they are connected to standard PCs via UART serial lines. The overlay and the GA software are located in the PCs, which are connected to the Internet. The communication is done by XML messages via TCP/IP. The similar approach is done in [19], only with more inverters and including secondary control.

Apart from providing secondary and tertiary control, the GA can be used in solving different problems in intelligent grids, especially in providing voltage and reactive power support, implementing load shedding schemes for different purposes, building functionalities for load following, handling reserves etc. The common ground for solving all these issues is providing the entities in the grids with fresh information about the current states and processes and executing tasks in a decentralized manner. It is envisaged that the interactive ICT infrastructure will enable interactions between the entities within the intelligent networks, where based on information and knowledge gained from these interactions, local decisions can be made at each entity. In this context, the entities can be actual responsive devices, as air-conditioners or water heaters. More detailed description of the communication technologies and data formats which can be used for the purpose of interaction among devices within the smart grids is presented in [21].

4 Conclusion

The detailed description of the GA properties shows that they could be interesting alternative for information dissemination and knowledge based local decision making in the future power systems. Their properties show that they are both reliable and scalable and perform well in highly dynamic environments, where nodes join and leave the networks, both purposefully and because of failures. Based on current research, it can be actually assumed that these would be some of the characteristics of the future intelligent networks, thus making GA more attractive approach for information dissemination or other purposes.

The recent development in ICT allows creating suitable environment for implementing gossip based protocols in the framework of the new intelligent networks. The recent successful implementation of secondary and tertiary GA based controls in a test Microgrid proves this and it is an indicator more of the future practical implementation of this concept.

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Demand Side Management in Private Households – Actual Potential, Future Potential, Restrictions

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Abstract. Demand Side Management (DSM) is one way to keep the balance between energy generation and energy consumption and is therefore important in grids with fluctuating renewable energy sources. To explore how typical households with their specific electricity consumptions are able to take part at DSM the DSM potentials were calculated. First the DSM potentials for the single types of load in households that are practical were calculated as actual potential with actual types of appliances. Then they were calculated as future DSM potential with today's high efficient appliances that will have replaced the actual types in households in the future. The future potential considers also expected changes like less distribution of storage heaters and much higher distributions of heat pumps and electric vehicles. Restrictions in case of DSM are considered as well because they reduce the theoretical DSM potential remarkable. Finally the financial benefits through DSM for a typical household with four persons were calculated on base of a tariff with four different prices.

1 Introduction

The increasing energy generation of non controllable renewable energy sources like photovoltaic and wind power makes high demands on the flexibility of the remaining energy producing units and loads. Therefore Demand Side Management (DSM) is becoming more and more important to keep the balance between energy generation and energy consumption. In private households DSM today is only applied for loads like storage heaters or heat pumps.

Part of the E-Energy-Project (http://www.e-energie.info/) "Regenerative Modellregion Harz (RegModHarz)" (https://www.regmodharz.de/) is to find out, how private households in the rural district Harz can take part in DSM. For that it is necessary to have an overview about the specific electrical consumption in households.

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2 Specific Electrical Consumption in Households

The rural district Harz has 237653 inhabitants [1]. For the estimation of the DSM potential the households have been categorized according to the number of persons living in it. Most households are single households (38%), whereas most people live in households with two persons (38%).

The electricity consumption of all households is 331 GWh per year [2]. To determine the specific consumption of electrical energy in households the EnergyAgency.NRW has made a detailed survey [3] with about 28000 households in 2006. All usual loads in households were considered. The results of this survey were used in combination with the above-mentioned types and numbers of households in the rural district Harz to get the distribution of energy consumption on different appliances in households in the rural district Harz (Fig. 1).

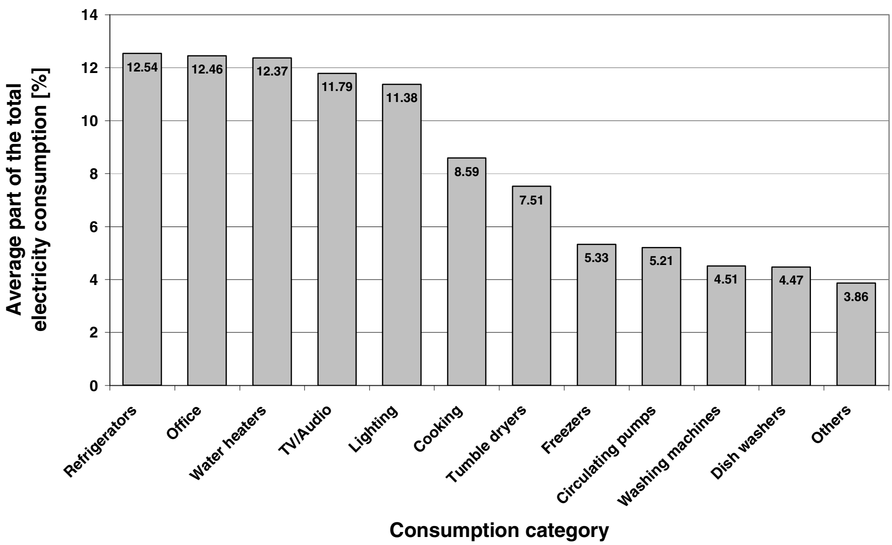

Fig. 1. Distribution of energy consumption on different appliances in households in the rural district Harz

The categories office, TV/audio, lighting, cooking and circulating pumps were not regarded for the calculation of the DSM potential of the rural district Harz because load shifts in that categories are not possible or will cause inadmissible inconveniences to the people in their households. Additionally to the regarded categories of Fig. 1 storage heaters were considered. Therefore the regarded appliances for the actual and future potential are storage heaters, water heaters, refrigerators, freezers, dish washers, washing machines and tumble dryers. The regarded appliances only for the future potential are heat pumps and electric vehicles. Air conditioners were not explored and therefore not regarded for the calculation of the future potential.

3 Actual Potential

The appliances suited for DSM were separated into three different groups. The **first group** includes all appliances whose utilisation depends on the temperature (e.g. electric storage heaters). The electric power consumption of circulating pumps is also depending on the temperature. Nonetheless this appliance was not considered since the usage of circulating pumps for DSM is connected to a perceptible reduction of home comfort. The average electricity consumption of electric storage heaters in Germany is 17.4 MWh per household and year [4]. In the rural district Harz about 2600 households have electric storage heaters which results in a total electricity consumption of 44.53 GWh. It is estimated that this electricity consumption is equal to the DSM potential. Since it was not possible to identify the energy demand for space heating for different sizes of households it was assumed that the electricity consumption of different households is proportional to the energy demand for space heating.

The **second group** includes all appliances whose energy consumption depends on the season and the day of the week. These are washing machines, tumble dryers and dish washers. The average electricity consumption of washing machines was calculated with 0.87 kWh per application. The calculated power consumption is 6.38 kWh per application for tumble dryers and 1.09 kWh per application for dish washers. The power consumption per year depends on the number of uses per year and thereby to the size of the household. The DSM potential of all households considered in Fig. 2 is 10.8 GWh for washing machines, 16.5 GWh for tumble dryers and 11.3 GWh for dish washers.

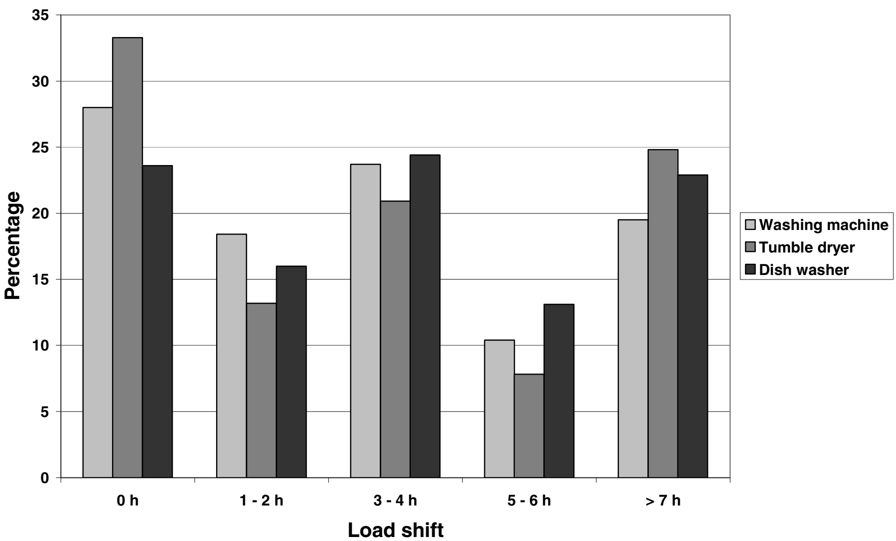

Fig. 2. Maximal load shift per appliances as a result of a household survey in the rural district Harz

Furthermore the information about the maximal load shift of the application is needed. In [5] a maximal load shift of 24 hours is estimated. Fig. 2 shows the results of a household survey in the rural district Harz where questionnaires were send to 2500 households. The results of the 424 returned questionnaires differ remarkably from the 24 hours.

The **third group** includes all appliances which have nearly constant electric power consumption at every day of the year. These are refrigerators, freezers and storage water heaters. The demand of hot water varies irregular from household to household and from day to day. Therefore it was estimated that over all households in the rural district Harz the electric power consumption for water heating is constant at every day of the year. Suited for DSM are only storage water heaters. Usually Storage water heaters consume energy at the hours between 10 p.m. and 6 a.m., when electricity is cheap. Consequently storage water heaters are already used for DSM. It was calculated that about 13000 households have a storage water heater with a DSM potential of 10.3 GWh.

Refrigerators and freezers usually consume electric energy for 20 Minutes at every hour [6]. The starting time of the refrigerator respectively freezer within this hour can be varied and therefore used for DSM. The DSM potential of refrigerators is 41.5 GWh per year and the potential of freezers is 17.7 GWh per year.

Table 1. Electric power consumption of different appliances suited for Demand Side Management in the rural district Harz separated into different sizes of households

Appliance	People in household and their DSM potential [GWh/a]					Overall
	1	2	3	4	5+	
Electric storage heaters	11.5	17.5	9.5	4.7	1.3	44.5
Washing machines	2.3	4.1	2.6	1.4	0.4	10.8
Tumble dryers	1.7	6.2	4.8	2.8	0.9	16.5
Dish washers	1.5	4.6	3.0	1.7	0.5	11.3
Storage water heaters	3.2	4.0	1.9	0.9	0.3	10.3
Refrigerators	15.2	15.7	6.9	2.9	0.7	41.5
Freezers	3.3	7.8	4.0	2.0	0.6	17.7
Overall	38.7	59.8	32.8	16.5	4.7	152.6

Table 1 shows the actual DSM potential in the rural district Harz separated in different sizes of households and different appliances. It must be mentioned that the values in the table also includes households which do not have such an appliance. Therefore storage water heaters have almost the same DSM potential as washing machines, even though storage water heaters consume much more energy per appliance.

4 Future Potential

Two effects have to be considered for the estimation of the future potential. On the one hand the future DSM potential is reduced by the usage of more efficient appliances. On the other hand the future potential increases with new appliances like electric vehicles or with the extension of appliances like tumble dryers, dish washers and especially heat pumps.

The reduction by using more efficient appliances can be estimated by comparing the energy consumption of the appliances in the households in the rural district Harz with the nowadays most efficient appliances. In [7] the most efficient appliances are listed. It is not possible to exactly compare the most efficient appliances with the appliances in the households, since the usage (e.g. washing program) and the size of the appliances is unknown. Therefore the following reduction potentials are rough estimations.

Refrigerators and tumble dryers have the biggest reduction potential each with 72%. Dish washers have a reduction potential of 23.8%, freezers with 21.9% and washing machines have the lowest reduction potential with 5.2%.

Moreover the usage of electric storage heaters is estimated to be zero in the future, since there is an act (Energieeinsparverordnung [8]) that will lead to a continuously reduction of electric storage heaters. The reduction potential of storage water heaters is nearly zero [9].

Thereby the DSM potential of the appliances considered in the actual potential will decrease to 58 GWh respectively 38% of its actual value, if the number of appliances per household remains constant. Fig. 3 shows the difference between the actual energy demand and DSM potential of the appliances and the future potential.

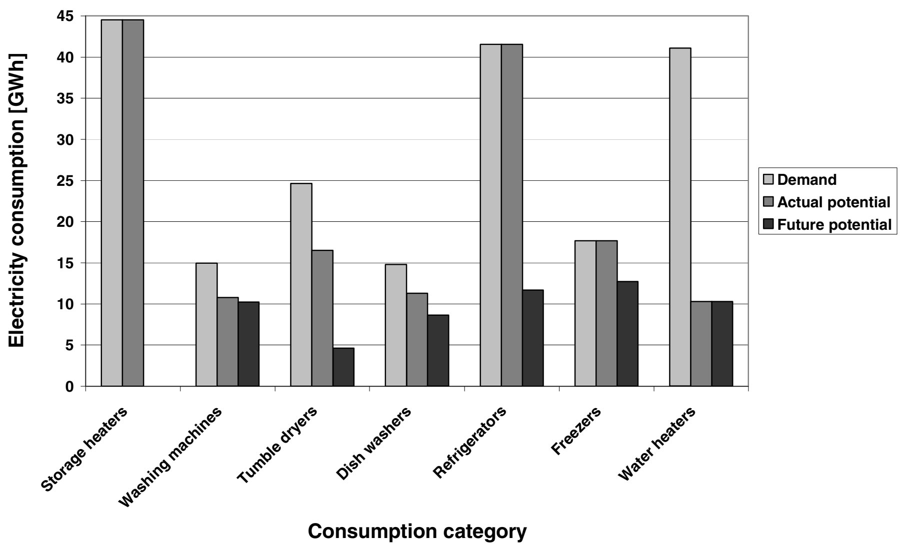

Fig. 3. Actual electricity demand and actual DSM potential as well as future DSM potential of all households in the rural district Harz

In return new appliances like electric vehicles, heat pumps or air conditioners offer a big potential for the future. The average power consumption of an electric vehicle can be estimated to 2.33 MWh per year. If all households in the rural district Harz use an electric vehicle, this would result in an electricity consumption of 280 GWh per year, which is as one appliance 80% bigger than today's DSM potential of all other appliances. Another interesting application are heat pumps. They can only be used for DSM in combination with a heat store. The average electricity consumption for space heating in Germany is 11.5 MWh per year and household [10]. If this energy is delivered by heat pumps with a coefficient of performance of 3.3, this would result in an electricity consumption of 3.5 MWh per household and year or 422 GWh per year for the rural district Harz.

Consequently new appliances like electric vehicles or heat pumps offer a great potential for DSM, which is much bigger than the actual and especially the future DSM potential of the common appliances.

5 Restrictions

The use of Demand Side Management is often involved with a lot of restrictions. The probably strongest restriction is to change the daily routine in order to achieve a load shifting. Therefore loads like computers, TVs, radios, lamps and stoves were not regarded. But there are also restrictions for other appliances.

When loads like washing machines, tumble dryers and dish washers are used in the night, the generated noise may disturb residents and neighbours. Because of that in apartment buildings the usage of washing machines in the night and partially on Sunday is often prevented by the house rules. Modern appliances are often more quiet than older appliances and the market offers washing machines with features like "Extra quiet" to allow using the appliances in the night.

Another restriction by using washing machines, tumble dryers and dish washers is the household insurance. The household insurance expects an attended use of washing machines, dish washers and tumble dryers. If they were used unattended and a water or fire damage happens the insurance will probably not pay for the damage. To avoid water damages washing machines and dish washers often have a safety system for detecting a leakage. But it is not sure, if the unattended use of an appliance with safety system is handled equally as an attended use of an appliance without safety system by the insurance company.

Not only the washing machine and the tumble dryer have to be suitable for load shifting, also the clothes have to be. If sensible clothes like shirts lay in wet condition some hours in a washing machine or a tumble dryer, then it is most certain that they are no more wrinkle-free. Even when sensible clothes lay in dry condition some hours in a tumble dryer the risk of wrinkle exists.

All the listed restrictions reduce the DSM potential remarkable. They are likely to be the reasons for the small load shifts in Fig. 2. Modern appliances, new insurance conditions and more "wash and wear" textiles could decrease the influence of the restrictions.

If the maximal load shift for refrigerators and freezers is increased by allowing a bigger temperature range, the home comfort could decrease. By maintaining the actual home comfort refrigerators and freezers are only suitable for short time load shifting.

Electric vehicles and heat pumps in combination with heat stores have not only a DSM potential that is much higher than the DSM potential of washing machines, tumble dryers, dish washers, refrigerators and freezers, they also have not the mentioned restrictions. The more the use of an electric vehicle is predictable, the less restrictions DSM has in this case.

6 Financial Benefits through Demand Side Management

DSM will only work, if the monetary incentives are sufficient that the households will change their behaviour. In the following the monetary incentive is calculated for some appliances for a household with four people with the help of the flexible tariff of the Stadtwerke Bielefeld [11]. The tariff EnerBest Strom Smart consists of four different prices in the week between 14.21 Cent/kWh and 25.11 Cent /kWh and two different prices at the weekend (14.21 Cent/kWh and 18.56 Cent/kWh). The maximum monetary incentive for the household can be calculated by multiplying the electric power consumption of the appliance with the difference between the lowest price of the flexible tariff (14.21 Cent/kWh) and the normal tariff of the Stadtwerke Bielefeld (EnerBest Strom 19.10 Cent/kWh) which is 4.89 Cent/kWh. The monetary incentives for a household with four persons for different appliances are listed in Table 2.

Table 2. Monetary incentives for DSM for different appliances of a household with four persons in the rural district Harz

Appliance	Electricity consumption [kWh/a]	Monetary incentive [€/a]
Washing machine	231.3	11.31
Tumble dryer	1062.7	51.96
Dish washer	329.7	16.12
Electric vehicle	2330.0	113.94

The monetary incentives are relatively low, except for the electric vehicle and the tumble dryer. But it can be expected that for people who can afford an electric vehicle the monetary incentive is also too low. Consequently it can be assumed that the monetary incentives by itself is not sufficient to change the behaviour of the people in households.

7 Conclusion and Outlook

The analysis of usual appliances in households shows that storage heaters, water heaters, refrigerators, freezers, dish washers, washing machines and tumble dryers are suited for DSM.

For the determination of the DSM potential in the rural district Harz the appliances were separated into three different groups. The first group includes all appliances whose usage depends on the temperature (storage heaters). This group has a DSM potential of 44.5 GWh per year. The second group includes all appliances whose energy consumption depends on the season and the day of the week (washing machines, tumble dryers and dish washers). This group has a DSM potential of 38.6 GWh per year. The third group includes the appliances whose energy consumption is nearly constant at every day of the year (refrigerators, freezers and water heaters). This group has the biggest DSM potential of 69.5 GWh per year.

Actual the total DSM Potential in the district Harz is 152.6 GWh per year. It can be expected that the DSM potential of the appliances will decrease in the future because of more efficient appliances and a decreasing number of storage heaters. It is estimated, that the future DSM potential in households will go down to 38% of the actual

DSM potential by the usage of the today most efficient appliances, supposing that the number of households and appliances remains constant. But there are new loads that are suited for DSM like heat pumps and especially electric vehicles. The new loads have a DSM potential that is much higher than the actual DSM potential. If all vehicles in the rural district Harz would be replaced by electric vehicles this would result in a DSM potential of 280 GWh per year, which is 180% of the actual DSM potential.

Restrictions like the house rules or household insurances also affect the DSM potential. These restrictions can be faced with improved appliance technologies (e.g. quieter washing machines) and new insurance conditions for appliances with safety systems.

The financial benefits of DSM are rather low for households. For an electric vehicle e.g. the benefit per year is about the costs of one gasoline bill at a gasoline station. The benefits for other appliances like washing machines, tumble dryers and dish washers are even lower. Therefore it can be assumed that the monetary incentives by itself are not high enough to change the behaviour of the households.

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E-ENERGY 2010

Technical Session 2: ICT Technology

A Review of ICT Considerations in Actual AMI Deployments

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Abstract. As transitioning to Advanced Metering Infrastructure (AMI) begins to make more sense for Energy companies and actual deployment projects are increasing, field players need to effectively answer a set of business and technical challenges posed either as tradeoffs or as investment feasibility / viability problems. This review aims to provide an overview of current offerings and solutions sought, relevant to the business / technical challenges faced as well as future opportunities identified for work in this section.

Keywords: Energy companies, utilities, metering infrastructure, advanced metering infrastructure, AMI, ICT, smart grids.

1 Introduction

Recent technology advancements as well as regulatory directives (e.g. 2006/32/EC) have motivated Energy companies' interest in transforming their infrastructure to a Smart Grid.

Smart Grid can be defined as one that uses information and communications infrastructure technology to manage grid information flows to make the power grid observable, controllable, automated, and integrated [1].

2 Current Situation

2.1 Legacy and Advanced Metering Reading

As of today, legacy energy consumption meters are manually polled at large regular intervals to produce each customer's bill; the sampling frequency does not exceed quarter yearly field measurements. As a major breakthrough, advanced metering reading (AMR) enables more frequent automatic measuring of consumption, aggregation and upload to central information systems in a non-interactive manner. This way, more fine grained measurements are available to energy retailers, so that future needs are predicted more accurately, distribution systems can be better tuned and energy theft is tracked.

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2.2 Drivers to Transition

Since transitioning to AMR entails a large scale infrastructure transformation, it is prudent to extensively study and quantify the available alternatives optimizing the transition strategy based on the following factors:

- Regulatory demands: Constraints set by market regulation are hard and constitute the baseline of the transformation strategy. For example UK, Canada and Australia governments have already set relevant deadlines to their energy markets.
- Transformation business case: Deploying a smart metering infrastructure may not increase sales but will allow energy companies to leverage on the technology enablement so as to achieve:
    - Costs reduction (meter reading, accuracy errors elimination, energy theft limitation, etc.)
    - Enablement of advanced marketing campaigns for encouraging customer loyalty, based on usage patterns
    - Economies of scale by turning off low priority devices in an ad-hoc manner (provided that customer consent has been acquired) and shifting their operation when cost of energy production is lower
- Funding: Built into the business case, funding for AMI installation is considered as a decisive factor for kicking-off a transformation project (US has already awarded more than $600M to Smart Grid projects).
- Technology maturity: Feasibility of implementing the transformation is dependent on technology maturity and on specific company demands / operating model;

2.3 Challenges Related to AMI Deployments

AMI deployment feasibility studies need to convincingly provide an approach to the following key technology sectors:

- Communications Infrastructure: Data network supporting the communication between smart meters and the centralized management system.
- Network Operations: Maintaining a large number of metering nodes (management and operation) requires deployment of functionalities new to energy companies (like NOC).
- Sophistication of Metering Equipment: The services that metering equipment provide may extend beyond the requirement of measuring and transmitting the results to a centralized system. Of course the level of sophistication directly affects the integration and operation (maintenance) cost of the devices.

3 Future Developments

As evident from the above, the ICT infrastructure component of a smart grid constitutes a critical factor of the deployment, introducing a different operating environment from what utilities have been used to until now. As identified in [1], four emerging trends influence the way the smart grid will be build, operated and controlled:

1. Shift from centralized to peer-to-peer control
2. Shift from centralized to distributed energy resources: A traditional consumer may become a supplier, providing excess renewable energy production to neighbors on an ad-hoc basis
3. Shift from few dumb end points to many smart end points
4. Shift from low data volumes / slow response times to high data volumes with low latency (periodic legacy meter readings vs real-time measurment aggregation and monitoring) Challenges faced by companies will be driven by the above factors.

3.1 Metering Equipment Sophistication

It can be easily established that the more intelligence built in a device, the more capabilities and flexibility is provided. At the same time, increasing the complexity of metering devices leads to increased CAPEX (for acquiring the device) but also OPEX (for operation and maintenance). The right level of sophistication should be a result of current needs as well as planning for future expansion (the device selection is a delicate process, since the cost of replacing them for complying to future needs would be enormous). For acquiring the maximum flexibility the chosen devices should:

- Follow open (and commonly adopted) standards as far as integration is concerned
- Be firmware-upgradable over the network (soft-update), for implementing changes avoiding the cost of field visits
- Be modular expandable; if update over the network is not possible, modular expansion may be a decent approach to limiting extra costs and possibly avoiding on-site visits (customer may acquire the expansion and install it with the support of service line)
- Provide alternative [physical] interfaces. More than one interfaces (even if not used) may be considered for providing flexibility through alternatives.

3.2 Communications Infrastructure

Business decisions on communications infrastructure involve evaluation of the following options:

- Build a private network, owned by the energy company
- Lease an existing network, from a telecom carrier, for example. Internet may be considered as a candidate as well, provided that performance and security risks are assessed and mitigated appropriately
- Build and share a common network with other utilities: this option seems more appealing if also collocation of companies' metering devices is considered

In order to decide on the above, the utility needs to study the economic models associated with each of the above options, building a business plan and evaluating the impact of each decision to the company's CAPEX / OPEX.

On the technologic side of the ICT infrastructure, different paradigms can be identified for achieving connectivity and reliable transmission of data from metering devices to the central management systems and / or to peer devices. Implementations should consider using one or more of the following media for connecting a metering device to the company's network:

- Landline internet connection (e.g. existing ADSL)
- Wireless connection over a telecom operator's network: GSM / UMTS / WiMax
- Wireless connection to other device: Forming a dense network of standalone nodes each equipped with a radio interface may allow for creation of an ad-hoc private network (message routing can be implemented using any of available algorithms, e.g. the one presented in [3]).
- Data over power lines: Metering data can be transmitted using the existing power line towards distribution station.

3.3 Network Operations

Efficiently managing network applications and monitoring of end devices operation requires adoption of a framework, especially since the utility is expected to deploy millions of devices in the field. Service assurance and availability metrics (e.g. 99.999% availability) need to be tracked by NOCs (Network Operating Centers) which will either have to be built from scratch or result as an extension of an existing department. Paradigms of such frameworks may be reused, leveraging on telecom experience, for example using eTOM (enhanced Telecom Operations Map [4]) or ITIL (IT Infrastructure Library [5]).

Implementing the framework processes and deploying the required applications, NOC can obtain an end-to-end view of the services deployed over the network and additionally will be able to implement service provisioning and commissioning activities.

3.4 Meter Data Management – Application Architecture

Meter data management (MDM) solutions provide data storage and management and act as an intermediate between the metering system and various business applications such as the company billing platform, executive forecasting, customer service, customer relations, operation and support.

Aside from the functionalities deployed, application architecture needs to be carefully studied and defined, taking into consideration the following:

- Definition of data model: The data model adopted should be open and covering all modeling requirements of the company's operation (e.g. CIM – Common Information Model, is such a model developed by DTMF [6]).
- Design the integration interfaces and decide on implementing (or customizing) an enterprise service bus for service delivery. The design should consider all involved systems (e.g. Billing, Customer Care, Operations, etc.) and sensor capabilities.

4 Conclusions

From the above it is evident that the transition of any traditional energy company towards an advanced metering infrastructure is the next required evolutionary step. The change implies a business transformation, since energy companies are called to deal with extensive IT operations, which may have not been the case in the past. In this context, utilities will need to deploy or revitalize existing communications infrastructure by taking a holistic approach considering different aspects such as specific present and future functional requirements, network ownership and management approach.

As a consequence, it seems unlikely there will ever be a single paradigm-fits-all smart grid communication solution because of the fact that utilities vary greatly in requirements and constraints, based on internal structure, geography, population demographics, local regulation, and economics.

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Coordinating Energy Based Business Models and Customer Empowerment in Future Smart Grids

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Abstract. Future sustainable energy systems are in focus of several national and international R&D programs. The transition from today's tariff-based energy systems towards future sustainable energy markets has to be supported by addressing and solving a range of challenges. Among the identified barriers are doubts of user acceptance of future Smart Grids due to lack of experiences, opportunities and possibilities: hence lack of experimental validations. Our suggestion of SLA-Agents experimental facility is aiming at filling some of those shortcomings, not the least issues related to trust by stakeholders.

Keywords: Smart Grids, Service Level Agreements (SLAs), Energy efficiency, Business models, Customer Empowerment.

1 Setting the Scene

The following Figure 1 adopted from deliverables from the EU funded TN SEESGEN-ICT (Supporting Energy Efficiency in Smart Generation grids through ICT) illustrates the main characteristics behind the transition of electric grids from today to tomorrow.

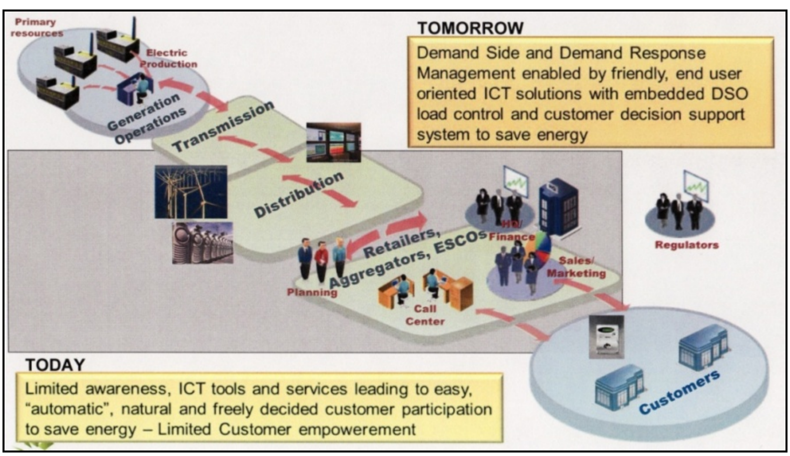

Fig. 1. Main drivers behind the transition towards Smart Grids

N. Hatziargyriou et al. (Eds.): E-Energy 2010, LNICST 54, pp. 44–53, 2011.

In Figure 1 the main stakeholders and roles are depicted as well as the path of transformation from Today to Tomorrow, related to effects due to the unbundling of the energy market. The deregulations and increased intelligence in the Transmission and Distribution networks enabled by smart programmable electronic components and smart ICT information management systems are the two main drivers of this transition. Figure 1 depicts the main architectural components related to the energy flow of the future Smart Grid. The following Figure 2 outlines the information flows between groups of stakeholders to enable and support new business models as well as empowerment of the customers.

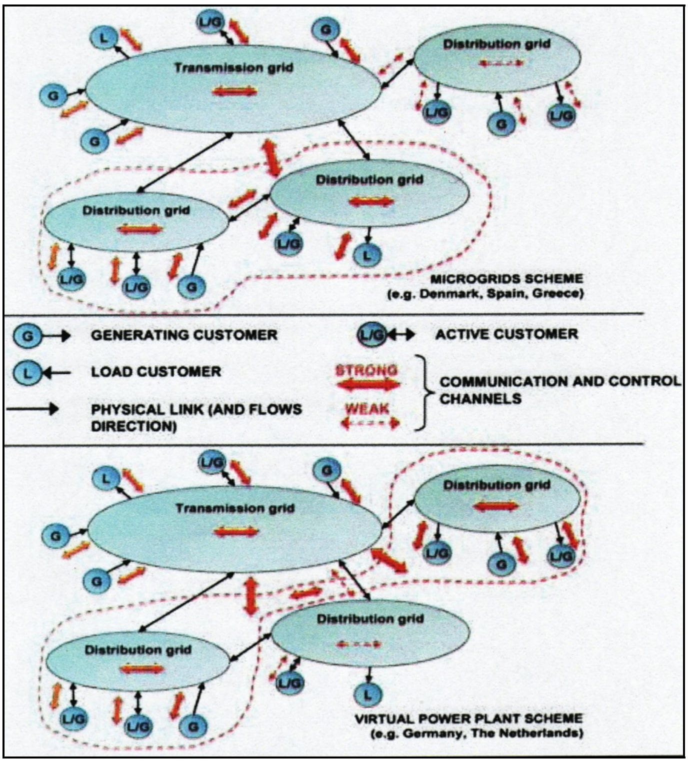

Fig. 2. Information flows in future Smart Grids (adapted from SEESGEN-ICT[1] deliverables)

As it is indicated in Figure 1 and Figure 2 the role of new stakeholders, i.e. Aggregators and Retailers will interact in Smart Grids between Distribution System Operator (DSOs) and Customers, and *secondly*, we will have *flexible configuration* of stakeholders, such as *Virtual Power Plants* (VPP). *Finally*, we will need communication networks that must support the energy flow as well as the customer based business information flows. In short, present Supervisory Control and Data Acquisition (SCADA) systems have to be supported by novel ICT based information systems to meet the requirements of future Smart Grids for empowerment of customers [1].

[1] SEESGEN-ICT home page: `http://seesgen-ict.erse-web.it/`

As a consequence, the *monitoring task* of present day energy systems has to be *re-assessed* and re-designed. To that end we propose to extend the monitoring task by introducing the concept and mechanism of *Service Level Agreements* (SLAs) to:

- Allow flexible grouping of stakeholders
- Allow flexible empowerment of users

1.1 Identified Barriers

Several international assessments of the transition from present day energy systems towards future Smart Grids have identified a set of barriers that have to be resolved, for instance[2]:

- *Regulatory barriers*. New types of stake holders and new kinds of business processes[3]
- *Technical barriers*. Architectures and technologies supporting new kinds of ICT systems complementing and enforcing SCADA systems[4]
- *Customer acceptance*. Trust in value-added services provided[5]
- *Lack of experiences*. Today, there is a lack of experience from large-scale field tests or demonstrators addressing key challenges on the road towards smart grids. For instance, the roles and amounts of DER or RES that can be utilized and trustworthy managed[6].

In this paper we describe a configurable agent-based platform addressing coordination in future smart grids in the form of monitoring SLAs (Section 2). The initial focus is on customer acceptance and to gain experiences of possible new business processes in Smart Grids.

2 Service Level Agreements as a Basis for Coordination in Smart Grids

Classical SCADA systems are tailored to monitor the energy flow processes in energy systems. The need of supplementary ICT support for information management related to business cases and customer support is indicated in figure 1 and figure 2.

Of course, there are interdependencies between monitoring energy flows and information flows [2]. For example, increasing the amounts of Distributed Energy Resource (DER) and Renewable Energy Systems (RES) requires additional voltage control/frequency control to maintain the quality of service. We also have to address several aspects of data protection and data integrity [2, 3], not the least since we have

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[2] *Technology Action Plan: Smart Grids*. Report to the Major Economies Forum (MEF) on Energy and Climate by Italy and Korea, December 2009.

[3] SEESGEN-ICT home page: `http://seesgen-ict.erse-web.it/`

[4] INTEGRAL homepage: `http://www.integral-eu.com/`

[5] Smart Grids home page: `http://www.smartgrids.eu/`

[6] The EUROPEAN future INTERNET initiative: `http://www.future-internet.eu/news/view/article/the-europeanfuture-internet-initiative-effi.html`

different (potentially competing) stakeholders and customers (prosumers) in each *Virtual Power Plant* configuration (Figure 2). Identification of and harnessing such interdependencies are key challenges in future Smart Grids [4].

To attain system flexibility, a good approach is to *virtualize the physical system components* and *groups of stakeholders* into different non-overlapping *virtual infrastructures*. We propose that the coordination in those virtual infrastructures can be modeled as bundles of services under SLAs related to given business processes [4].

Our starting point in setting up SLAs is thus:

- Business process
- Stakeholders
- Services
- Contract (Key indicators)
- Monitoring parameters
- Assessments of contract
- Billing
- Non-compliance of SLAs

Tight coupling of components provides stable platforms like current SCADA systems; however, there is lack of flexibility to add more stakeholder and business needs. A new approach towards improvement in Smart Grid is to restructure controlling and monitoring mechanisms accordingly to the present day need of customer empowerment from change in tariff based system to service based system. It is desirable for Smart Grid to have a flexible ICT platform by loose coupling the component to achieve the objectives. The ICT infrastructure provides more abstraction layers where components can collaborate and coordinate in a trustworthy and flexible way [4].

In such complex system the internal and external dependencies create a global phenomenon that is unable to comprehend without actually running of the system. Simulation is a viable alternative for examining these types of complex systems, which will help the researchers to learn more about the occurring problems and to provide solutions. To cater for that, the best available practices are to use *Service Oriented Architecture* [5] or *Agent Systems* to model the information processing systems as needed. The change of system control component from physical to more logical and distributed emphasis that the quality aspects must to be redesigned. We argue to manage such a complex system a better approach is to define and use Service Level Agreements (SLA). SLAs are mutually agreed contract between the service providers and the service users for the quality aspect in provisioning of services.

2.1 Business Cases as High-Level Goals

The business case sets the goals, constraints, pre- and post conditions of the SLAs. In service oriented computing SLA is presented in the Figure 3 below. Normally the SLAs represent an agreement between two parties, one is the producer and the other is consumer/client to exchange values/services in the presence of Publisher that can act as a market. In order to facilitate negotiations/transactions different parameters or Service Level objectives (SLOs) defines the measurement and monitoring criteria for effective and efficient delivery of the services. In our case we will extend the SLAs to typically involve more than two stakeholders. Occasionally the stakeholders can be grouped as classes of consumers or providers.

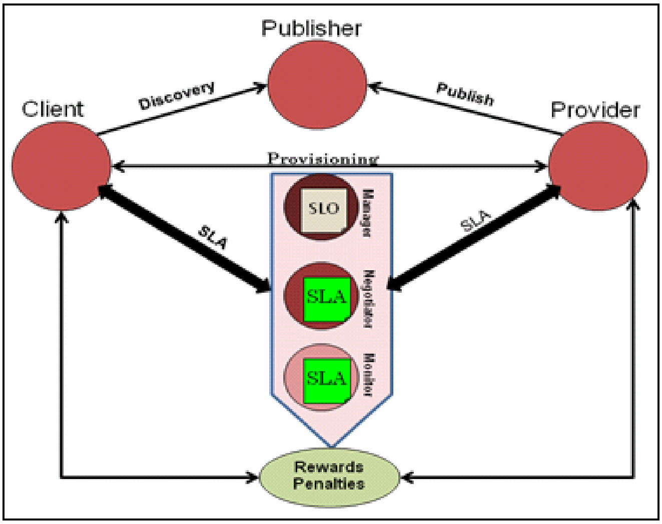

Fig. 3. Model of Service Level Agreements (SLAs)

A business use case can be presented on a template identifying stakeholders, their roles and responsibilities, action points and the flow of information within the specified entities. In the next section we have included a business model from the EU project FENIX and indicate a translation based on that business model into a SLA. A business use case has the following general sets of parameters in the corresponding SLA.

- Descriptions of the activities involved in the business processes (Goals/Objectives)
- The actors involved: (roles and responsibilities)
- Coordination of tasks and responsibilities to achieve a goal
- Billing
- Conflict resolution

The SLAs also defines the types and parameters to be monitored such as set points (allowed intervals) and Key Performance Indicators (KPI). Furthermore, it may have rules for SLA violation criteria's to apply at breakdowns.

3 Case Study: Customer Empowerment Enabling Increased Energy Efficiency in Smart Grids

Business case from the FENIX[7] project is stated below

Business Case: *Access to the Market through commercial aggregator, in* ***absence*** *of strong pressure to integrate DER.*

[7] FENIX Project Homepage: `http://www.fenix-project.org/`

Short description: *"A Commercial Virtual Power Plant (CVPP) is a competitive market actor that aggregates DER units (not necessarily constrained by location). This kind of aggregator helps the DER to gain market access with the optimal returns prospective and market visibility. It carries out the economical transactions between the market and the DER and so it looks to the market like an imaginary single physical plant. The DER units, through this kind of aggregation, are enabled to participate not only in the wholesale market but also in the TSO-organized balancing market and in the Guarantees of Origin (GO) market. Note that, in this business model, the CVPP does not absorb the balancing risks but shifts them to his clients. So, in this scenario, there will be only a financial aggregation of DER units without an operational integration. It is policy scenario that assumes the absence of strong societal pressures to really integrate DER into the electrical grid. Under these conditions, the current "fit and forget" practices will endure in the European operational network management. So distributed generation will penetrate fast, but it will not change the passive network operating philosophy."*

Further details can be viewed in the FENIX documentation.

3.1 Translation of Extended FENIX Business Case into SLAs

Adjusted Business Case: The case study addresses customer empowerment and constraints of DER inclusion. Customer empowerment will derive the future energy business by giving the customer more control of use of energy and also the type of energy to be utilized. *The energy flows* and *economic/information flows* between actors are as in Figure 1 and Figure 2.

Stakeholders

- *CVPP (Aggregator)*: Commercial Virtual Power Plant
- *DER* units: Distributed Energy Resources might include RES Renewable Energy Sources
- *TSO:* Transmission System Operator
- *DSO:* Distribution System Operator
- *Consumer/Prosumer*

The following adjustments of the FENIX business case are assumed:

- *The CVPP* will have the role of *Aggregato*r coordinating the energy between producers and the energy consumers by smart Demand Side Management (DSM).
- *The CVPP* will empower the *active consumer* to adjust their profile to meet Energy Efficiency criteria and/or other consumer related services.
- The CVPP will balance incorporating of (vast amounts) of DER while maintaining electrical constraints such as voltage/frequency control in the grid ensuring *quality of power service*.

The Product/Services related Transaction and Contracts from the FENIX case are replaced by several *Service Level Agreements* (SLAs):

- *SLA_Consumer_CVPP*: Coordinating services between the Consumer and the Aggregator CVPP. Supports *empowerment* of the consumer (active consumer)
- *SLA_CVPP_DSO*_DSO: Coordinating services between the CVPP and TSO/DSO mainly related to *energy balancing* (Voltage control/ frequency control)

Synopsis

Each CVPP is coordinating Group of Energy providers including a set of DERs and associated TSOs and DSOs, together with a set of Consumers. The associated set of services is coordinated with two reciprocal sets of Service Level Agreements. On one side we have the coordination of energy providers on the other side is the coordination of the corresponding consumers.

In the SLAs the energy profile of each consumer is specified: type and amount of energy per unit interval. The lower and upper bounds of allowed change of DER (ΔDER) per unit interval and other constraints are also specified.

At given time points t_0, t_1, ., the following control cycle is performed:

1. *Establishing energy balance of the CVPPs asserting Quality of power.*
2. *Collecting DDERs from empowered Consumers related to CVPPs.*
3. *Checking that the proposed changes in DDER are in accordance with the SLAs.*
4. *If YES, updating of databases.*
5. *Go to 1.*
6. *If NO, try to reconfigure the grid (eventually including load shedding) to achieve compliance with the SLAs.*
7. *Updating of databases.*
8. *Go to 1.*

Key parameters

- DER_j resource j: Geographic position in the network (Pos_j, t_0), Energy production (KWh (j, $\Delta t(t_0)$), Constraints (C, j, $\Delta t(t_0)$)) during time interval $\Delta t(t_0)$,
- ΔDERj: Amount of DER resources that could be changed by the Consumer j during a time interval $\Delta t(t_0)$ starting at time t_0.

Obviously, there are several ancillary services to be provided by different stakeholders in order to perform the tasks of the control cycle given above. The empowerment of the consumer could be provided by a support tool based on, e.g., a *Smart meter*. This support tool should then also include a SCADA system controlling smart equipment in the home and visualizing important status parameters of the equipment and networks. Of specific concerns for the empowered prosumer are:

- Information security and protection.
- Reliable and traceable consumption and billing.

4 The SLA-Agents Experimental Environment

The SLA-Agent tool is an effort towards trustworthy coordination between the stakeholders and especially focusing on empowerment of the customers. Our SLA-Agents platform is based on the JADE agent platform. However, we have improved the performance and scalability [6] by introducing and implementing distributed shared memory mechanisms in the Jade Directory component. Our SLA-Agents platform can be implemented as a distributed system, which allows us to perform experiments on a distributed agent environment where we can model and evaluate communication and connectivity models [7]. Having validated architectures and mechanisms of SLA-based coordination on SLA-Agents we can in a structured way deploy some of the virtualized components into physically grounded components of a virtual infrastructure. The environment itself provides the following functionalities:

- Support for dynamically changing of role of stakeholders.
- Measure the effects of customer empowerment on aggregator role and impact on DERS accordingly.
- Monitoring of information on business layers and effects on network configuration.
- Support of dynamic change of the Meta-Data information during run time and measure the impact.
- Produce alerts based on the threshold and penalty/reward the concern stakeholders.
- Multi-level coordination mechanism with feedback and calibration support.

5 Setting Up SLA Experiments

The above business case present a scenario where increased customer based demand for DER/RES integration in the energy sector is sustainable supported. This will eventually leads to higher energy efficiency and lower CO_2 emission partly due to empowering the customer. This in turn will increase customer awareness and acceptance of potentials of Smart Grids.

The SLA-Agents environment for experiments and exploring possibilities and challenges of future Smart Grids is based on extensions of the JADE agent platform[8]. The agents implemented are firstly, agents corresponding to stake holders, secondly, ancillary support agents. We thus have the following agents and databases in our SLA-Agents environment:

Agents:

- *Controller*: Configures and executes experiments
- *Setup SLA*: An ancillary service to the Controller
- *Change profile*: An ancillary service to the Consumer
- *Aggregator* (CVPP). Trusted third party between producers and consumers of energy

[8] `http://jade.tilab.com/`

- *SLA management*: Collects, processes and distributes data related to SLAs
- *TSO:* Transmission System Operator
- *DSO:* Distribution System Operator
- *Consumer/Prosumer:* Active end user
- *Monitor:* Collects data of delegated monitoring tasks by Aggregator, TSO or DSO
- *Billing:* Collect and validate data related to billing
- *Evaluator:* Evaluates the conformance of SLAs to business processes

Databases:

- SLA Database:
- Experiments: Configurations and data
- DER/RES: Capacities and positions
- Billing data: Verified against SLAs
- Network configurations: Position and distribution of network resources

The following Figure 4 depicts the main architecture of SLA-Agents. The main access points to the environment are by the *Controller* or *Customer*. The Controller sets up the preconditions for an experiment. That is, *configures* the experiment and *sets up* the SLA that is going to be tested. The customer initiates experiments based on profile changes by first invoking the agent/service *change profile*.

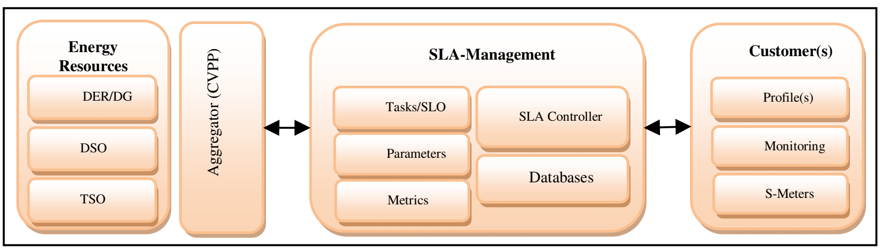

Fig. 4. Empowerment of customer by active participation in energy utilization based on SLAs

The request is sent to the Aggregator to verify the amount of resources required by this profile change, if the profile requirement is like more Green Energy than the Aggregator will calculate the existing amount of Green Energy and either allows the profile change requirement or put it on hold depending on the calculations. If more customers want to change their profiles due to some business incentive provided by the Aggregator or DSO then it is more feasible to allow that change based on the energy resources, instead of business incentives. With our flexible architecture design we can dynamically implement the changes and get the results by running the simulation using multiple time scales.

6 Conclusions and Future Work

We have proposed SLAs as a flexible approach to model and monitor inter-stakeholder coordination between different actors of future Smart Grids. Furthermore, we have presented a real case scenario from the FENIX project giving emphasis on customer empowerment. We present work in progress, specifying tools under development supporting identified models and methods of experimentation. Specifically, we will address traceability and trustworthy challenges of information exchange. Our emphasis is the necessity of real time experimentation in large scale is necessary for proper design and implementation of the future Smart Grid.

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Performance Evaluation of a Web Service Enabled Smart Metering Platform

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Abstract. A key issue for the success of a smart grid is the capability to accommodate efficient smart metering. Following the trend towards timely monitoring of energy consumption and production via Internet related technologies and in-network metering platforms, we need to investigate performance-related aspects of smart metering and how they affect the overall operation. We present here our experiences implementing a prototype framework for smart metering, discuss on some of its aspects, and evaluate its performance.

Keywords: smart grid, web service, smart metering.

1 Motivation

The emerging Internet of Energy [2], and more specifically its core entity, i.e. the Smart Grid, is a highly dynamic complex ecosystem of energy production and consumption parties that heavily use Information and Communication Technologies (ICT) in order to be more efficient compared to current traditional operation. Additionally, the Smart Grid enables the creation of new innovative services based on the bidirectional interaction of its stakeholders. The formation of new relationships between energy providers, distributors, dealers, and customers who themselves can act as producers (prosumers), has dramatically increased the complexity of the energy market.

Recent market statements for the smart-grid era, even considered with a grain of salt, provide some hints on the expected growth and business significance: Marie Hattar, vice president of marketing in Cisco's network systems solutions group, estimated in 2009 that the smart grid network will be "100 or 1000 times larger than the Internet". Similarly, Vishal Sikka, CTO of SAP, stated in 2009 that "The next billion SAP users will be smart meters".

Linking networked embedded systems (smart meters, energy control units, etc.), handling security and trust, modeling and transacting for highly distributed business processes, developing market-driven mechanisms for load balancing, proactive planning of system load profiles using derivatives, development of new business and market models, allowance for planning and scheduling, and assurance of interoperability are just a few of the topics that need to be specially defined and developed in this area [3].

N. Hatziargyriou et al. (Eds.): E-Energy 2010, LNICST 54, pp. 54–63, 2011.

The Internet Protocol (IP) is seen as one of the key technologies [1] that has big potential for the smart grid domain, including smart metering. It is expected that metering aggregation points, e.g. concentrators, will communicate over IP with online metering platforms and submit the collected metering measurements. Smart meters could also periodically connect and report their data not only to a single platform, for example, for billing, but also to multiple online services that could provide added-value [3]. Generally, due to the emergence of IP everywhere, such as the 6LoWPAN [4], it will be possible for any networked (embedded) device (meter, laptop, TV, etc.) to attach to the global IP network and report its energy consumption or production.

2 Smart Metering

The true power of SmartGrids can be realized once fine-grained monitoring, that is, metering of energy consumption or production, is in place. The promise of an Advanced Metering Infrastructure (AMI) is that we will be able to measure, collect, and analyze energy usage from advanced devices, such as electricity meters, gas meters, and/or water meters, through various communication media on demand or on a predefined schedule. Today, many utilities have already deployed or are currently deploying smart meters in order to enable the benefits of the AMI. A typical example is the world's largest smart meter deployment, which was undertaken by Enel in Italy and installed over 27 million smart meters to its entire customer base. AMI is empowering the next generation of electricity network, as for example the one depicted in the SmartGrid [5, 2] vision. Smart meters will be able to not only measure and report energy consumption in a timely manner, but also, in cooperation with online services or other devices, possibly provide management capabilities or information to the local network. These smart meters will be multi-utility, and their services will be interacting with various systems, not only for billing but for other value-added services as well [3].

We envision an infrastructure that will follow the Software as a service (SaaS) approach, where software vendors may host the application on (distributed) Internet servers and provide access to the value-added servers via a variety of media, such as on mobile devices, web portals, etc. While SaaS was initially widely deployed for sales force automation and Customer Relationship Management (CRM), its use has become commonplace in businesses for tasks such as computerized billing, invoicing, human-resource management, service-desk management, and sales-pipeline management, among others; we consider this approach to also be interesting for the SmartGrid era.

Within the scope of SmartHouse/SmartGrid (www.smarthouse-smartgrid.eu) and NOBEL (www.ict-nobel.eu) projects, we are defining and implementing a smart metering infrastructure that would glue heterogeneous systems and provide them common smart metering services. Although the concepts have been tested in a laboratory, the earliest real-world trials, which will start in mid-2010, are expected to deliver more results and hands-on experiences. An overview of

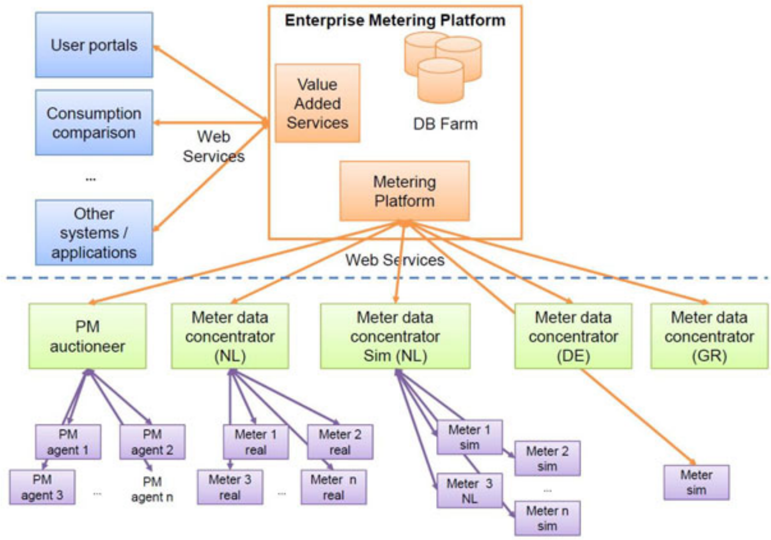

Fig. 1. Overview of smart metering in SmartHouse/SmartGrid project

the first trials is depicted in Figure 1. A commonality among them is the enterprise integration that is done towards two directions, (i) the metering data is reported for traditional business purposes, e.g. billing, and (ii) value-added services can be realized in conjunction with the context-specific info in each location.

The Internet-based metering platform features several components that implement the necessary services, such as MeterReading service to report real-time measurements, and is hosted in an Internet server. Currently, the main way to communicate among the platform and the different metering data-collections points is via web services [6], although in the future we envisage to experiment also with REST (Representational State Transfer) approaches. As such a concentrator, a smart meter or any other metering data entity can contact the necessary web service and submit the collected data.

3 Metering Platform Implementation

A metering service was realized as a web service. This service is used to submit the measurements acquired by the metering point to the platform. The smart meter web service is defined as a stateless Enterprise Java Bean (EJB). An EJB is a server-side component used to encapsulate business logic. The EJB is responsible for managing database operations for the insertion, update, deletion, and querying of meter reading data. The clients communicate with the server through the Simple Object Access Protocol (SOAP), a standard web service protocol used for exchanging the messages between clients and servers.

A key issue in the scalability of any smart metering platform is its ability to handle large numbers of requests, that is, the volume of smart meter readings should be handled in a timely manner by one or more instances of the platform (for load balancing). For simplicity, we assume that each platform instance may be hosted on a server, and by evaluating the limits of it, we can get a good indication of how many servers would be needed to reliably handle the targeted volume of data (scalability considerations). To this end, the time taken to handle a metering insertion request was measured at different stages of the incoming request life-cycle.

As can be seen in Figure 2, when a request arrived at the Application Server (realized by JBoss in our prototype), the appropriate EJB method was called and the data was inserted into the database. Subsequently, control propagates back to the server, which completed the request by sending a response to the client. The time required to execute these three stages, the total request time, EJB time, and database insert time, was measured.

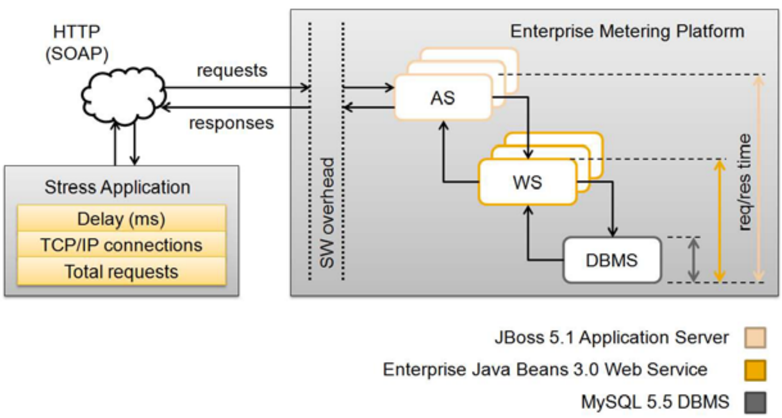

Fig. 2. Web service enabled Smart Metering

In order to realize the performance tests, we developed a prototype stress test application (in Java) that employed raw socket connections to communicate with the server and sent the generated meter readings. The data was wrapped in a SOAP message and sent via a POST request to the web service's URL address. The response from the server was acknowledged but no further processing was performed. The application enabled the tweaking of its functionality via three parameters:

- Number of sockets to use: a number of active connections established between the client and the server;
- Message delay: a wait time (in milliseconds) before the client sent the next request; and
- Total number of messages: the total number of the requests to be sent to the server. This value is independent to the number of the connected sockets.

From the operational point of view, the application generated requests and called the respective web service on the server at the specified interval until the total number of requests was reached. If the application was configured to use more than one socket connection, the requests were sent using each available socket in a Round-Robin fashion. Each request contained the exact message that a real metering point would submit (payload in XML), but in our prototype we generated these automatically and populated them with dynamic data, such as measurement value, meter ID, etc.

In the metering platform depicted in Figure 2, we can see that the web service layer (deployed with EJB 3.0) could have multiple parallel instances. Since the metering platform was able to handle parallel requests, the new Session Bean instances would be initialized if the metering platform started to receive data from multiple TCP connections. As with the socket connections, for every web service request a new thread would run on the server side, but an overall limit was defined within the Session Bean pool size. As we note later, this may be one of the bottlenecks towards achieving higher performance, which might be resolved with the usage of multiple application servers.

4 Performance Tests

Our initial aim was to investigate the ability of an online metering platform (hosted on a single server) to handle a relative heavy load of metering requests. This was done by stressing the server, that is, sending as many requests as possible, under different client configurations, in order to better understand the server behavior under peak load. This should provide some insight on how servers may be configured to reliably handle large numbers of requests, such as from one million smart meters. To achieve this, three scenarios were defined in terms of the number of workstations sending requests to the server and the number of sockets used by each workstation. The stress test application was used on each workstation to generate the load. Table 1 provides an overview of each scenario, its parameters, and performance. For all of the scenarios, we did not set any delays between the requests generated by the stress application, that is, generating (a lot) more requests than the server could handle.

Table 1. Performance Test Overview

Scenario ID	**clients**	**sockets/ workstation**	**requests/ workstation**	**requests/ second**	**requests/ 15 Min**
1	1	1	10000	435	391500
2	1	10	10000	672	604800
3	2	5	5000	769	692100

The tests were performed with several clients running Ubuntu Linux 9.10, Windows Vista, and Windows XP. On the server side, where the measurements were made, we used a COTS machine with an Intel Core Duo 6600 (2x2.4GHz)

CPU, 4x2GB DDR2 667MHz memory, and a gigabit (one hop) Ethernet connection between the clients and the server. The server was running Ubuntu 9.10 64bit (2.6.31-21-generic kernel), with application server JBoss 5.1.0.GA and MySQL 5.1.37 DBMS. It should be noted that JBoss can be configured to deploy different server profiles, consisting of different service and module configurations. For the purposes of this experiment, the default server profile, which ships with the JBoss application server, was used. However, the Tomcat component of the JBoss server had to be configured with the maxKeepAliveRequests parameter on the HTTP/1.1 connector set to "-1" in order not to limit the the number of requests that can be made from a single connection.

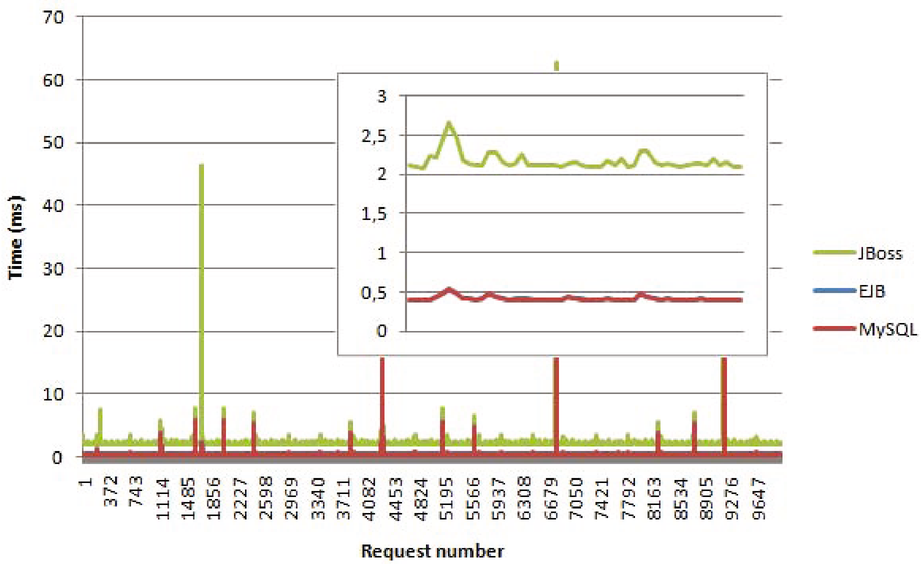

Fig. 3. Scenario 1 – Total request handling time

Scenario 1 is depicted in Figure 3, where we see the request handling times for each request. The EJB time is almost entirely comprised of the database insert time (both graphs overlap in Figure 3). We can see that there iss a big difference between total request handling time and the EJB time. This is probably due to overhead related to processing of the SOAP message, both at the request side (extracting the required information to perform the database insert) and on the response side (sending an empty SOAP response). Another interesting observation are the periodical spikes in message response time. As it can be seen in Figure 3, there are four peaks in response time, and a few smaller peaks throughout. This may be the result of reoccurring operating system or database procedures.

Scenario 2 is depicted in Figure 4, and demonstrates the response time of the server for requests made from one workstation using 10 sockets (in contrast to

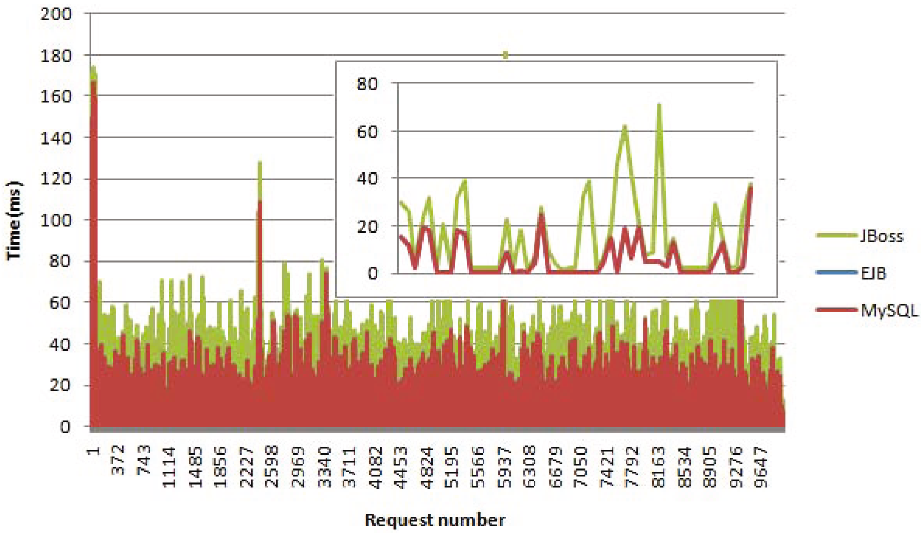

Fig. 4. Scenario 2 – Total request handling time

scenario 1 where we had only 1 socket). As it can be seen in Table 1, there is a clear gain in request throughput against scenario 1, while also sustaining a clear increase in response time (as shown Figure 4). The gain in throughput is a consequence of the use of multiple sockets, and thus multiple threads, resulting in the requests being handled in parallel. So, instead of one request being handled (scenario 1), ten requests are handled at the same time (scenario 2).

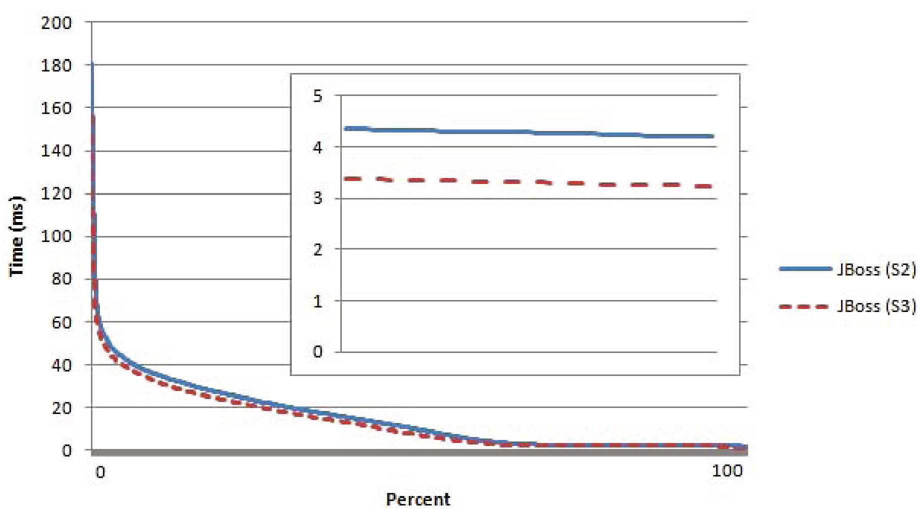

Fig. 5. Scenario 2 vs. Scenario 3 load duration curve

Figure 5 shows a comparison of the load duration curves for scenario 2 and scenario 3. As expected, the difference in insignificant, since the overall load is similar; the only difference is that in scenario 3 the composite load comes from two different workstations. However, as we can see, a higher throughput was achieved in scenario 3, most probably due to variable network conditions or JBoss AS internal management.

5 Discussion and Future Directions

We have seen that in the prototyped smart metering platform, a large portion of time is spent on internal processing happening at the Application Server itself. As shown in Figure 3, the total request/response time for one socket connection was approximately four times longer than the DB INSERT operation. This difference was possibly the first sign that the application server load should be balanced over multiple application servers. Therefore, further possible performance enhancements should be explored in order to reduce that time, for example via the usage of multiple application platforms running as front-end. However, more aggressive performance-related strategies might provide better results, such as usage of in-memory DBs or strategic (on-demand or periodic) committing to the DB.

As already noted and also depicted in Table 1, the indicative performance depends on many factors. With the current configuration, our scenarios would accommodate in a per-15-minute measurement window approximately 692k (scenario 3) measurements. This gave some early indication on the infrastructure that needed to be in place to accommodate millions of meters in this time interval. However, we have to point out here that these end-metering points could also be concentrators that then would further increase the total number of last-mile end-points (smart meters results are grouped at concentrator level) whose data could be collectively reported.

Our test generates (on client side) and pushes (to server side) a high amount of generated data; as such, the communication throughput is limited by the

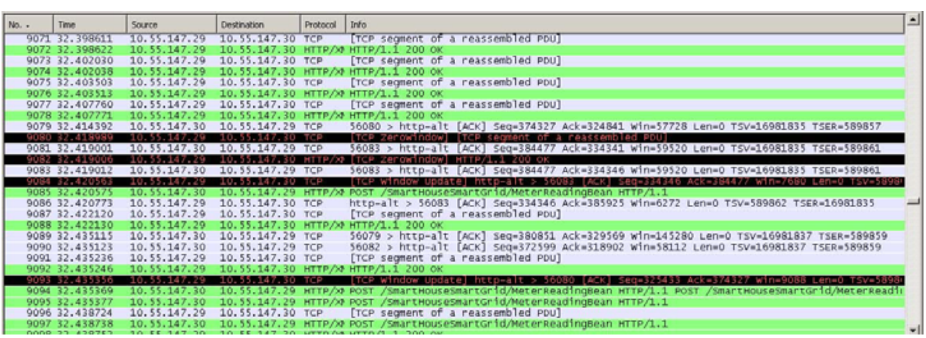

Fig. 6. Communication analysis: TCP Window scaling

TCP receive window (server side). If we take a closer look into the transport layer (Figure 6), it can be seen that the server side reaches its input buffer limits (TCP window size). Thus, TCP window scaling (RFC 1323), that is, to increase the TCP receive window size above its current value (Windows default is 65535 bytes), is an option. The increase of the TCP window on the server side helps to not exceed the capacity of the receiver to retrieve data (flow control). As we can see in Figure 6, TCP window updates were very common, and also TCP ZeroWindow occurred during our tests. This was due to the fact that our client generates (many) more requests than those the server can handle. Thus, the client will continue generating data, but it will be kept in output buffer until the server updates its window size to equal (or greater) value of the message size to be sent. These steps will be repeated over and over again until all data is transmitted.

Apart from the initial performance evaluation presented here, several directions can still be assessed both in the laboratory environment and in real world conditions. With respect to metering data exchange, the time penalties in submitting single vs. multiple metering values from one or multiple locations needs to be further evaluated. The reliability needs to be investigated, especially over unreliable or congested channels. The metering payload and its correlation to processing and transmission time need to be further evaluated. Furthermore, we mostly assume best-effort network, therefore we wanted to take a closer look at network performance aspects, such as possible optimizations on the communication strategy: create connections per message, per client, strategy to manage connection time, such as one connection open for multiple measurement submissions, etc. The usage of approaches that provide some guarantees, such as WS-ReliableMessaging, or security, such as exchange of signed/encrypted measurements, would also be of interest.

For the metering platform, we want to further investigate issues related to throughput, that is, performance measurements related to number of measurement messages processed, resource consumption e.g. CPU, memory, etc, message processing time (from acceptance to storage), as well as storage performance (for storing and retrieving). Scalability of the platform (clustering, etc.) and/or its components is also an issue, especially considering the heavy load that near real-time metering might pose. End-to-end service performance (for example, from metering of data up to end-user display) would also enable us to see if and how real-time services can be provided.

6 Conclusions

We have presented our experiences in prototyping an online smart metering platform that can communicate via web services with the metering points and collect the measurements. Initial evaluation shows that the concept and technology approach are sound and that we can achieve a high number of measurements, even with COTS hardware and software, and with no significant performance tweaking. Although there are many aspects to be evaluated, here we focus on a service-enabled infrastructure and evaluate the performance of a simple prototype platform for acquiring and storing high numbers of metering measurements.

Nowadays, many commonly refer to high-resolution metering, which is considered in a "15-minute" period. However, in the near future we will move not only towards real-time metering but also expand on the notion of "meters", since any of the billion Internet of Things envisioned devices could be acting as a "meter". This trend will pose some significant requirements to metering platforms in order to be able to accommodate all measurements in a timely manner. We have shown that simple prototype solutions as ours can achieve considerable performance. However, requirements for more reliability and scalability will increase in the future.

Acknowledgment

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A Review of Customer Management Tools: The Energy Industry

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Abstract. In a deregulated electricity market, as the one formed by the current developments in the regulatory framework, where the electricity customers are able to choose their supplier freely, energy companies are expected to be more and more competitive, while changing the focal point of their activities from the traditional production-centered to a customer-centered. As part of this customer-centric evolution, energy companies are focusing their attention on software platforms that support closer customer relationships, enhance customer service, and reduce costs. Customer Relationship Management (CRM) constitutes a very attractive solution for addressing their customer management requirements. The present paper describes the tools incorporated in such a system and additional tools necessary for tackling future challenges.

Keywords: Electricity retail companies, customer management, Customer Relationship Management (CRM) systems.

1 Introduction

Current developments in the regulatory framework of the electricity market driven by Directive 72/2009/EC, lead to the creation of a new energy trading environment, in which electricity customers are able to choose their supplier freely. As a result, energy companies begin to realize that their most valuable "asset" is the consumer, while knowledge (not just merely data) is their only sustainable advantage, leading to a change in their focal point of their activities from the traditional production-centered to a customer-centered.

Especially with the recent developments in the field of smart metering, energy providers/companies will be expected to cope with a vast amount of data (such as hourly consumption per meter), which can be considered more of a problem – the company is data rich but information poor – than bless, if properly employed. The need for efficiently managing massive amounts of customer data along with the ever increasing competition in the retail market combined with the need to retain and attract customers inescapably results in investing in systems that support closer customer relationships, enhance customer service, and reduce costs through effective knowledge mining from vast amounts of data, providing effective support for decision making – summarized under the label Customer Relationship Management (CRM) systems.

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At the heart of any CRM system lies a central database containing information about each customer (contractual data, energy consumption etc.). Moreover a CRM system is comprised by a number of tools such as:

- Risk management
- Load modeling/Customer profiling
- Billing/Tariff design
- Meter data management

These tools facilitate the handling of a large volume of data, the extraction of useful information regarding the electricity consumer behavior as well as the operation of the company in general.

The rest of the paper is organized as follows: in paragraph 2 the current situation regarding the above mentioned tools is described. In paragraph 3 the developments in the same tools as well as additional tools necessary for the retail company of the future are described. Paragraph 4 concludes the paper.

2 Current Situation

2.1 Risk Management

Energy companies in general and electricity retailers in particular, who buy electricity in bulk from the wholesale market at constantly changing prices only to sell it to retail customers at a fixed price, are inevitably exposed to price and volume risks. In order to reduce their exposure to price risks, retailers hedge their positions using a combination of various contracts such as: forwards, options and contracts for differences [1].

Forward contract for physical delivery is an agreement to buy/sell a specified volume of electricity at a specified future time at a price agreed today [2]. This is in contrast to a spot contract, which is an agreement to buy or sell an asset today. The price agreed upon is called the delivery price, which is equal to the forward price at the time the contract is entered into.

Options are contracts with a conditional delivery, which means that they are exercised only if the holder of the contract decides that it is in its interest to do so. They come in two varieties: calls and puts. A call option gives its holder the right to buy a given amount of a commodity at a price called the exercise price. A put option gives its holder the right to sell a given amount of a commodity at the exercise price.

In case the market participants are not allowed to enter into bilateral agreements (such as forwards or options), they resort to *contracts for differences*. In a contract for difference, the parties agree on a 'strike price' and an amount of the commodity. Once trading on the centralized market is complete, the contract for difference is settled as follows: In case the strike price is higher than the wholesale electricity market price (spot price), the retailer pays the generator the difference between these two prices times the amount agreed in the contract. If the strike price is lower than the market price, the generator pays the retailer the difference between these two prices times the amount agreed in the contract.

2.2 Billing/Tariff Design

As the electricity systems become more and more stressed by high volumes of energy during peak load hours that occur only a few hours per year leading to price spikes, it becomes clear that grid reinforcements and expansions and new peak generation capacity cannot be the most efficient answer [3].

The answer lies on the other side of the scale. Load is today seen as a resource for achieving better utilization of the existing power production and transfer capacity. The flat rates however at which the electricity consumers pay their consumption – it being the norm for many years in the electricity market – begin now gradually to be considered old-fashioned and obsolete. In contrast, multiple tariffs or time-of-day tariffs are in the order of the day. By this way price-responsive demand is achieved, while providing an –up to now missing– link between wholesale and retail power markets.

Figure 1 [4] illustrates the effect of price sensitive demand on the market prices. Retail customers, who modify their usage in response to price volatility, help lower the size of price spikes. For this case, consumer response to price induces demand by 5% and cuts the price by 55%.

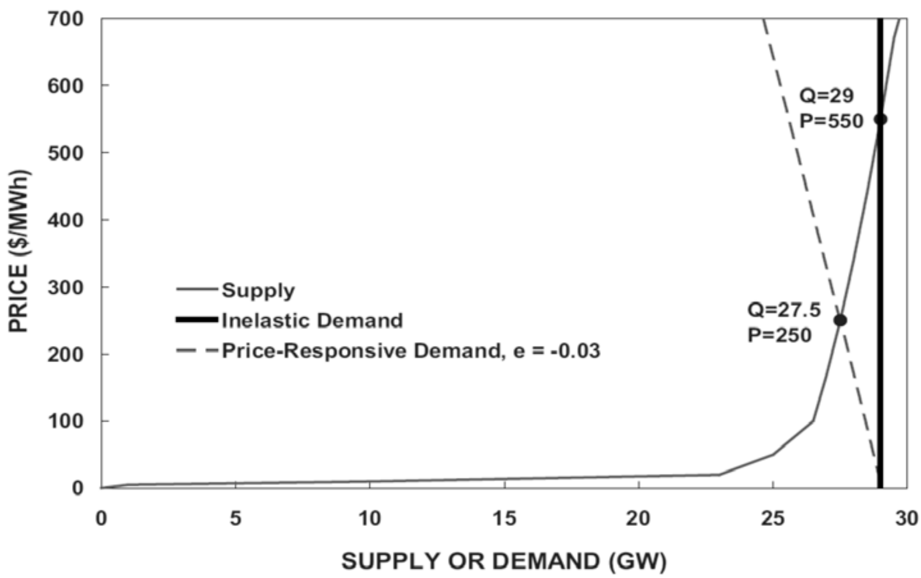

Fig. 1. Hypothetical wholesale supply and demand curves. The solid vertical line represents demand that is insensitive to price; the dashed line represents demand that varies with price.

Two mechanisms for achieving load flexibility can be identified [5]:

1. Sending price signals in the form of demand response programs, in which consumers bid load reductions at specified prices and receive payments for reducing load relative to a calculated baseline level of consumption if the bid is accepted or in the form of time-sensitive pricing (time-of-use or TOU rates) [3].
2. Sending volume signals through traditional direct load control or interruptible service program.

Sending price signals is, of course, advantageous for the electricity consumers, since they are provided with the opportunity to choose whether or not they will reduce their consumption during periods of high prices, thus saving money. Volume signals on the other hand provide power system operators with the advantage of greater control over the load but would be more difficult to be adopted from the consumers.

Today price signals are considered the most appropriate lever in order to induce the desirable consumer behavior. As a result, the traditional flat rate has been gradually replaced by two-part tariffs especially for domestic consumers. However, its economic justification has frequently been disputed [6].

3 Future Developments

Future developments that the electricity retailers will be called upon to act are mainly driven by the new metering technology. Smart metering and smart grid solutions will bring about radical changes in the interaction between the electricity retailer and the consumers. Loads will no longer be considered as passive entities, while real time pricing programs will create price-responsive consumers. What is more, retail companies will be expected to be able to cope with a vast amount of data acquired by the new real time meters.

Furthermore, changes in the regulatory framework with the introduction of competition in the retail electricity markets appear as new challenges for companies that participate in such markets. As more and more retail companies strive to gain more customers, they are expected to become more competitive. In order for them to be able to retain their customers, a number of tools are expected to be used: load modeling, consumer profiling, and behavior prediction.

3.1 Risk Management

Up to this date the electricity load has been considered more or less as constant with only minor changes over the years directly driven by changes in population, weather or living conditions. Consequently, load posed no risk to the electricity retailers.

Electricity prices, on the other hand, posed no risk for the electricity consumers, since consumers were price-insulated through the flat rates. However, as new metering concepts, such as real-time pricing, gain day-by-day in popularity, and with the application of real-time pricing, part of the price risk previously faced only by the retailers will be transferred to the price-sensitive consumer. This risk reduction, however, comes with a price for the electricity retailer, who is exposed to a volume risk due to the uncertainly over the load. Management of that risk is achieved by load modeling and consumer behavior prediction as described in the following paragraphs.

3.2 Load Modeling/Customer Profiling

Load modeling is expected to be greatly facilitated by the utilization of the real time consumption readings provided by the new metering equipment. The discovery of common consumption patterns between different customers will contribute to a better understanding of the consumer behavior and will serve as a tool for a personalized and, thus, more effective interaction with the customers.

Several modeling algorithms can be used based on real time load curves. The wide variety of clustering and segmentation algorithms, as well as, the fact that they fall into the category of unsupervised learning renders them the most appropriate tool for the task at hand. Figure 2 presents a general division of classical clustering algorithms.

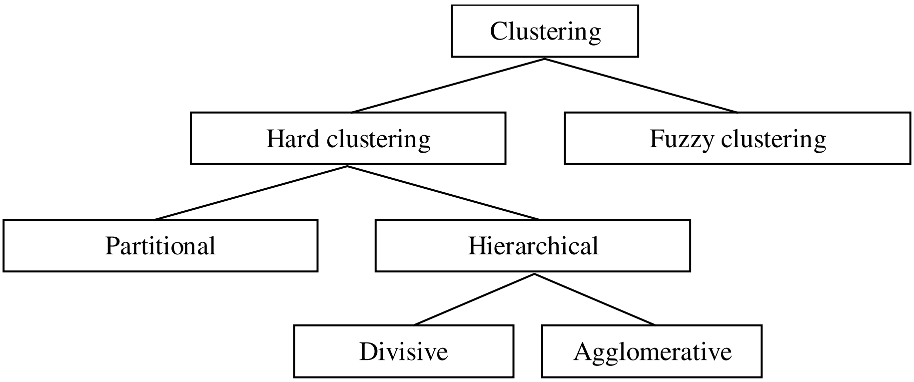

Fig. 2. Categorization of classical classification methods

Partitional algorithms (e.g. k-means) divide the data set into a single partition while the number of desired output clusters is predefined. On the other hand, *hierarchical algorithms* (e.g. single link, complete link) divide the data set into a sequence of nested partitions. Hierarchical algorithms are further subdivided into divisive and agglomerative. Divisive hierarchical clustering starts with all objects in one cluster and repeats splitting large clusters into smaller pieces, while agglomerative hierarchical clustering starts with every single object in a single cluster. Then it repeats merging the closest pair of clusters according to some similarity criteria until all of the data are in one cluster [7]. Partitional and hierarchical algorithms generate partitions; in a partition each pattern belongs *to one and only one* cluster (*hard clustering*). By contrast, *fuzzy clustering* associates each pattern with *every* cluster using a membership function. The output of such algorithms is a clustering but not a partition.

Apart from the classical methods developed solely for the purpose of clustering, as those mentioned previously, during the last decades several other methods are used for classification and clustering. *Artificial Neural Networks* (e.g. Kohonen's learning vector quantization (LVQ), self-organizing map (SOM), adaptive resonance theory models) are often used to cluster input data by representing each pattern by a single unit (neuron) [8], [9], while evolutionary approaches (e.g. genetic algorithms (GAs), evolution strategies (ESs), and evolutionary programming (EP)) solve the clustering problem by viewing it as a minimization of the squared error criterion of the clustering [8]. Finally, during the last years *Support Vector Clustering* (SVC) is used as a complementary method to the aforementioned for detection of the outliers exhibiting anomalous behavior [10].

Additionally, data reduction algorithms such as *Principal Component Analysis* (PCA) work in synergy with the previously mentioned classification and clustering algorithms [11]. PCA is a widely used statistical technique for unsupervised dimension reduction and is closely related to k-means clustering.

3.3 Billing/Tariff Design and Consumer Behavior Prediction

Flat rates and two-part tariffs can be considered today outdated. Instead, time-of-use (TOU) rates, in which electricity prices vary across time periods within a day and even seasonally are a significant improvement. TOU rates provide consumers with an economic incentive to reduce usage during high-priced periods and to shift load from high-priced to lower-priced periods. However, they do not give consumers the opportunity to mitigate price risk on the customer side of the meter, or to avoid potentially higher costs of traditional risk mitigation methods. Only dynamic pricing creates this opportunity for consumers [12].

Traditional time-sensitive pricing varies rates across time periods within a day and even seasonally and comes in three forms:

1. Prices are set ahead of time, but the timing when these prices are in effect is unknown e.g. critical peak pricing
2. Both price levels and timing are unknown, but the time blocks within a day when prices change from one level to another are known
3. Price levels, time periods, and timing are all variable: real-time pricing

Flexibility in pricing is facilitated by the advancements in the metering systems. New technology in metering systems summarized under the term Advanced Metering Infrastructure (AMI) offers new capabilities for two way communication between the energy provider and the consumer that can be exploited for implementing demand response programs or, in more advanced environments, for real time pricing.

By this way the consumers respond to incentives specifically designed for encouraging a certain behavior (e.g. load shift during peak hours in order to relieve the electricity system) or to real time electricity prices. More specifically, in case the energy prices are announced in advance, the usage and operation of various household appliances are properly adjusted – when feasible (for example refrigerators consist a type of load that is difficult if not impossible to control, while water heating loads or the use of the oven are much more easily controlled) – by the homeowner. In case real-time prices are available, the adjustments take place in real-time. In the first case the consumer chooses a certain scheduling for the usage of the appliances beforehand, while the procedure in the second case is fully automated by means of the appropriate software embedded in the intelligent meter.

The real-time market price and control system turns home electricity customers into active participants in managing the power grid (use of load for congestion management or for achieving a higher accommodation ceiling of distributed generation through the right price incentives) and their monthly utility bills [13].

The aforementioned developments create a new environment, in which the electricity consumer behavior is no longer determined only by weather conditions and the personal preferences that aim at maximizing the comfort level. The –previously price-insulated– electricity consumers will be constantly informed about price fluctuations. As a result, price signals will play a far more decisive role in the choices made by electricity consumers that determine the load curve, making load forecasting not only difficult to perform but also imprecise. Thus, the old-fashioned forecasting will be replaced by more complex methods appropriate for behavior modeling. Methods such as game theory will undoubtedly prove to be a valuable ally in the effort of simulating the expected load response to price signals taking into account a new parameter as independent variable – electricity prices.

3.4 Meter Data Management

Automatic Meter Reading (AMR) provides a much higher frequency of data as meter reading moves from monthly to daily or even hourly. As a result future electricity retailers will be expected to cope with a vast amount of data, while problems regarding volume, scalability, and processing power of existing systems will arise [14].

Meter data management (MDM) solutions provide data storage and management and act as an intermediate between the metering system and various business applications such as the company billing platform, executive forecasting, customer service, customer relations, operation and support.

The definition of a meter data management solution can vary widely. At a minimum, MDM provides a database repository and utility-specific business logic to:

- Automate and streamline the complex process of collecting meter data from multiple meter data collection technologies
- Evaluate the quality of that data and generate estimates where errors and gaps exist
- Deliver that data in the appropriate format to utility billing systems

Some of the validation and estimation functions that the MDM system should enable are the following:

- Estimate interval data based on meter readings
- Replace all values with a constant
- Multiply or divide by a constant
- Add or subtract a constant
- Slide a range of interval data ahead or back in time
- Perform linear interpolation
- Split or combine intervals
- Restore a previous version

Additionally, utilities should be able to edit values using a host of standard editing functions:

- Add or replace values manually
- Modify read status
- Display or edit multiple reads
- Copy or cut/paste a string of values from one meter to another
- Copy or cut/paste values from a spreadsheet

The most important service that a MDM system provides is the pre-processing of interval meter data at large volumes very quickly, while in the future an MDM system should be able to:

- Accommodate two-way communications between Customer Information Systems (responsible for commercial integration of data acquired by the metering system) and AMI systems and
- Provide a platform to enable other AMI applications and business processes thus simplifying the integration of new AMI technologies.

Furthermore, MDM systems simplify the billing processes of a utility by supporting complex load calculations and aggregations that are essential for time-of-use and critical peak pricing programs [15].

4 Conclusion

As the retail industry gradually shapes into the form of a competitive market, electricity retail companies will face a number of challenges in order to retain and even increase their customer base. Their previous activities (such as risk management and tariff design) will need to be adjusted to the new challenges as well as enriched with new ones while the consumer will be at the center of their strategies. These activities will include – amongst others – load modeling, consumer behavior prediction and meter data management.

In this consumer-centric environment software platforms summarized under the label Customer Relationship Management (CRM) systems provide multi-dimensional support for decision making, thus constituting a very attractive solution for addressing customer management requirements and developing business strategies in a highly competitive environment.

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High Level Requirements for Smart Meters that Will Enable the Efficient Deployment of Electric Vehicles

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Abstract. In case the electrification of transportation, i.e. electric vehicles (EV), occurs in an uncontrollable way, electric grids may come up with various potential problems, in terms of overloaded lines, increased losses, voltage quality issues, generation adequacy etc. There is a need for a middleware between EV and grid, on the top of which the different involved parties (DNO, ESCOs and aggregators) will be able to implement their EV control and management concept. Smart meters are the key technology that will enable the efficient adaptation of EV in the electric grids. However, the lack of common requirements on functionality and open interfaces fractionalize their massive implementation and increase their cost. This paper presents the high level requirements for future smart meters that will enable the efficient EV deployment.

Keywords: electric vehicles (EV), smart meters, interoperability.

1 Introduction

The massive adaptation of electric vehicles (EV) in an uncontrolled way may create a negative impact on the operation of electricity grids (overloaded lines and transformers, voltage drops, increased network losses, generation adequacy and frequency regulation, higher energy market prices etc.), necessitating new investment in the distribution, transmission and generation system [1],[2]. In order to overcome such difficulties, a middleware between the EV and the electric grid should be implemented, on the top of which the different energy/grid parties (DNO, ESCOs and aggregators) will be able to deploy their EV control and management concept. Smart meters can be effectively implemented as the middleware that will enable the control of EV.

Smart meters offer to the responsible energy/grid parties real time monitoring of the energy transaction between the EV and the grid. This energy exchange is bidirectional: grid to vehicle when EV are charging their batteries and vehicle to grid (V2G) when the EV support the grid, behaving as distributed generators [3],[4]. Smart meters allow the control of energy flow, in terms of amount and direction, in a direct or indirect way. With the direct control, the party controlling the EV defines the

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set- points of the batteries and this order is transmitted to the EV battery management system through the smart meter. With the indirect control, the responsible party gives incentives through tariffication (dynamic prices, multiple tariff zones etc) to the EV owners who finally take the decisions.

Utility metering is undergoing a revolution as long established mechanical and electromechanical meters are replaced by electronic meters. This has the potential to bring hundreds of millions of new meters into use across Europe. Smart metering technology has shown general evidence of product evolution. However, the great technological diversity should not generate new obstacles. The lack of adequate common requirements on functionality and open interfaces (interoperability) fractionalizes the market and increases costs both for smart meters and for the applications and services that use metered data. Section 2 presents the high level requirements for smart meters that will enable the efficient control of EV.

2 High Level Requirements for Smart Meters

The high level requirements, which should be adopted by smart meters for the efficient deployment of EV in the electric grid, are described in this section. Each one is presented and analyzed in detail below.

2.1 Interoperability and Public Communication Standards

Large, integrated, complex metering systems require different layers of interoperability, from a plug or wireless connection to compatible processes and procedures for participating in distributed business transactions. Very simple functionality—such as the physical equipment layer and software for encoding and transmitting data—might be confined to the lowest layers. Communication protocols and applications reside on higher levels with the top levels reserved for business functionality. As functions and capabilities increase in complexity and sophistication, more layers are required to interoperate to achieve the desired results. Each layer typically depends upon—and is enabled by—the layers below it. Establishing interoperability at one layer can enable flexibility at other layers.

Compatibility and interoperability must be ensured so that the functions of the meters can be effectively used by various parties without any unnecessary technical ramifications. From the end users' scope, it is important to have the freedom to contract with different energy supplier companies (ESCOs), without the need to change the metering infrastructure, and take services from different market parties. For energy retailers competing for final customers, the key issues regarding interoperability is that the smart meter fitted at the property can be adopted by any new energy retailer and connected seamlessly with the new energy retailer's billing system. This would imply that energy retailers will have to find common approaches and agree a minimum level of functionalities related to final customer feedback that all energy retailers provide or risk implementing incompatible schemes with consequent high costs of final customer switching.

The issue of interoperability can be identified more as an issue of standards rather than technology. Standards are critical to enabling interoperable systems and components [5]. Mature, robust standards are the foundation of mass markets for millions of components i.e. smart meters. Standards enable innovation where components may be constructed by a multitude of companies. They also enable consistency in systems management and maintenance over the life cycles of the components. Such standards enable diverse systems and their components to work together and to securely exchange meaningful, actionable information.

There are a number of different physical communication media and associated protocols. It is possible that no single approach will meet all requirements, for instance, wireless based systems may fail to work in circumstances where heavy screening to the signals is required. Thus it is likely that a number of different options will be required even within a single smart metering system. Smart meters will introduce new functions such as local and wide area communications between the meters, local displays, other utility meters and the remote data collector. Smart meters may also introduce new data items, data flows and new business processes, such as dynamic tariffs and multi utility data flows. Smart metering systems will also interface with customers, smart homes applications and smart grids. The meters, display devices, communications and other devices will be produced by many manufacturers to be used by many utilities working under a wide range of market conditions. There will be multiple software applications from those embedded on the meters through to the back office. All of these components must work together correctly and reliably in parallel and series as appropriate. To achieve this, it is essential to develop a comprehensive interoperable environment for smart meters. Thus, it is important to use common standards approach as to facilitate connection to the meters.

There is a danger that the development of incompatible national schemes will lock final customers into their existing energy retailer or restrict market access to local companies that have the necessary knowledge to operate the schemes. The costs for new entrant companies will be lower if they could replicate a common approach in different countries. Such a common approach would have a number of benefits. By avoiding the need for each member state and national metering stakeholder to investigate and develop their own approach, less regulatory, industry and government cost would be required. Meter and associated equipment would be manufactured in larger volumes resulting in lower costs. Larger markets would also encourage more innovation from hardware and software developers. A common approach would also support European Commission objectives for free market in services.

2.2 Communication Architecture

A conceptual model of the communication architecture of smart metering is presented in figure 1. Two layers of smart meter communication can be identified, one with the upstream network and another with the end-user. In the upstream network, the parties that require communication with the smart meters are the energy suppliers, the distribution network operator and the service companies (i.e metering service companies). Bidirectional information flow and data exchange between the upstream network and the smart meter is mandatory, whereas it is optional for the local communication between smart meter and the customers. In the latter case, the decision depends on the cost of the required communication infrastructure which should be evaluated depending on the added value of the customers' feedback.

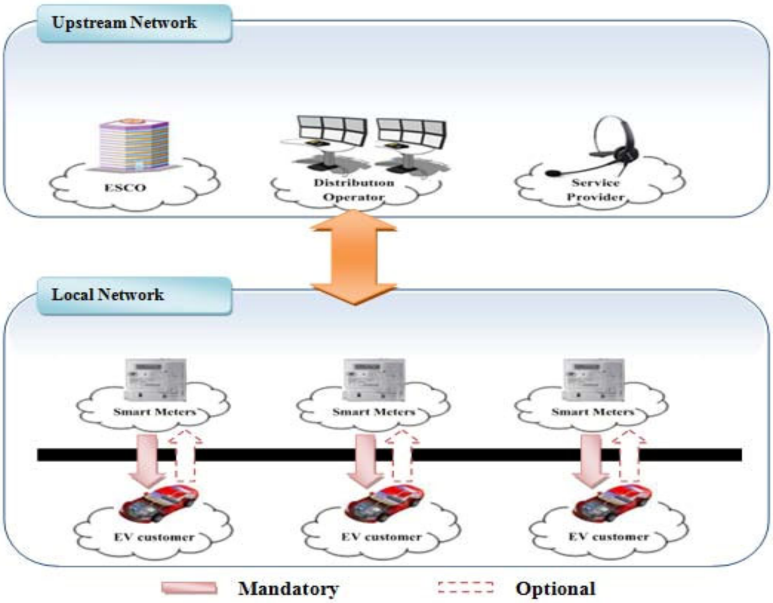

Fig. 1. Conceptual model of the communication architecture

Data exchange between smart meters and the upstream network enables various tasks like readings, connection and disconnection, tariff programming, alarms management, clock synchronization and/or firmware update, which can be done remotely.

Smart meters provide useful information to distribution network operators providing increased levels of monitoring of the distribution system. This information can be further evaluated to manage networks more efficiently, minimizing the risk of congestions and reducing the network technical or non-technical losses. Furthermore, the real-time information enables faster identification of the location of a fault and restoration time, as with smart meters the DSO automatically knows where the power is out and can dispatch crews to restore it without having to wait for customer notification.

Smart meters allow the energy supplier a better knowledge of the consumption pattern of individual customers, giving the opportunity to target them with different price options. Remote collection of meter data reduces the cost of data collection and billing inaccuracies, while the energy supplier is capable of remotely interrupting and reconnecting the customer supply. Smart meters might also be used to reduce the curtail final customer load (load management) when network or generation capacity is approached, reducing the cost of energy supply and improving efficiency.

Smart meters provide consumers historical and present information about energy consumption, power quality and the different tariff schemes. Thus customers are able to manage their energy consumption more efficiently resulting in savings on energy bills. Such information is important for the owner of an electric vehicle, since he should have knowledge of the state of charge of the batteries, the estimated time of battery charging and the remaining time of charging.

Energy and other utilities are supplied using independent distribution networks. In most cases, metering of energy as electricity, gas and heat, as well as water, is based on individual, independent meters. The principle of multi-utility smart metering is to combine all utility measurements into one device or system. In many circumstances, a smart metering system for more than one utility, for example electricity and gas, could be more effective in influencing energy savings as well as optimizing the metering installation costs and maintenance. There are a number of different models for multi-utility metering; the system can be operated by a single energy retailer offering multi-utility services, metering services can be provided by an external independent data acquisition company, or a single utility can offer access to their smart metering system to other utilities. Generally, multi-utility metering offer a significant opportunity for reduction of operational reading costs, especially with regard to shared communications systems and customer displays. Instead of many subsystems only one reliable system is used.

The design of the communication architecture should ensure the communication performance requirements in terms of availability, reliability and speed of response. For some services communication availability and response time are much more critical than high data transfer rates and the impact of these on the final customer experience should be considered at the design stage. For example, dynamic tariffs and demand response might need instantaneous communication in order to deal with an imminent peak demand rather than settlement and billing. Reliability is very important as far as the billing process is concerned. Most modern meters store metered values for several weeks or months (depending on memory specified) thus reducing the risk of billing data loss due to WAN reliability issues.

Security of the communication is another major issue that should be addressed. Smart meter systems are vulnerable to hacking attempts as they are widely accessible for extended periods and control large financial values. The security of the system must be managed appropriately to ensure that only approved parties can access the meter data and that final customers and others cannot access data within the meter that they are not approved to view. As the computing power of home computers can be expected to rise considerably over the lifetime of the smart metering system, the meters should be able to remotely accept improved security algorithms during their service lives.

2.3 Service Lifecycle Management

Service lifecycle management deals with the administration of functionalities and services during their entire lifecycle. Service lifecycle management (SLM) is a holistic approach which helps service organizations better understand the revenue potential by looking at service opportunities proactively as a lifecycle rather than a single event or series of discrete events. Almost all the different types of smart meters provide customers the same functionalities. What will drive the purchase decision of the customer besides price is the service.

The service lifecycle management should enable the deployment of new services, the update of existing services, the starting and stopping of services and the configuration and parameterization of running services. A sophisticated lifecycle management has the potential to increase the availability of enterprise systems as it extends the possibilities of changing grid operation processes without considerably influencing the efficiency of the entire system.

2.4 Eventing Support and Alarm Handling System

Either in the local network or in the grid, the events that can be generated are numerous even during normal operation. Some of these events can provide an overview of the current status of the network while others can indicate unexpected problems. The event reports may not be only electrical but functional as well. The list below presents examples of event reporting:

- Confirming successful initialization of the smart meter installed in the field
- Confirming data linkages between a smart meter identification number, serial number and customer account
- Confirming that the meter management data has successfully received notification of any changes to customer account information
- Confirming that the metering service operator has successfully made changes to customer account information
- Confirming the successful collection and transmission of meter data or logging all unsuccessful attempts to collect and transmit meter data, identifying the cause, and indicating the status of the unsuccessful attempt(s)
- Confirming whether the meter reads acquired within the daily read period are in compliance with the time accuracy levels
- Confirming time synchronization
- Addressing the functionality of the smart meter communication link
- Identifying suspected instances of tampering, interference and unauthorized access
- Identifying any other instances that impact or could potentially impact the smart meter's ability to collect and transmit meter reads to the responsible parties.

Apart from the eventing support, smart meters should be equipped with an alerting system in case critical events are generated. Critical events are defined to include any operational issue that could adversely impact the collection and transmission of meter information during any daily read period.

- ✓ Smart meter operational failure
- ✓ Issues related to the storage capacity
- ✓ Communication links failures
- ✓ Network failures
- ✓ Loss of power and restoration of power
- ✓ Unauthorized access

Filtering (to select the messages that are of real interest), local processing and evaluation are additional mechanisms that can enhance the performance and scalability of the eventing support. In a critical situation, messages have to be treated with high priority. Furthermore, the smart meter should get only the necessary decision, critical information and not get overwhelmed with all alerting data from the network. Therefore, support for the exchange of emergency data and a common alerting protocol have to be in place.

2.5 Ability to Combine Different Business Cases and Participate in Different Market Services

The power market environment is quite complicated since there are several different market sectors where a market player can participate. The fact that electric vehicles can behave either as distributed generators or as controllable loads complicates the situation even more since they are able to directly sale energy or provide ancillary services. Smart meters are the mean to the market participation. Thus, they should enable the participation of EVs in different business cases, such as those described in SmartHouse/SmartGrid project [6] and the selection should be made according to the price offered by the responsible parties (aggregator, ESCO).

Smart meters should enable the market participation of electric vehicles as either individual units or aggregated sets [7]. In the latter case a commercial aggregator should exercise the task of jointly coordinating the energy use of electric vehicles that have contracted with them. The joint management of a collection of electric vehicles can be done in two ways. The aggregator might directly control several electric vehicles, however this would require the end-users to allow direct access to the control of the vehicles. Another way is that an aggregator can only provide incentives to the participating vehicles, so that they will behave in the desired way with a high probability, but not with certainty. The second option leaves the power of control to the end-user.

The aggregated sets of electric vehicles can provide real-time imbalance reduction of a retail portfolio by utilizing the real time flexibility of the end customers. An actor that is responsible for a balanced energy volume position is called Balance Responsible Party (BRP). The BRP is obliged to make a plan by forecasting the production and consumption of the responsible grid area (control area) and notify this plan to the TSO. The risk of this predictability may cause deviations from this plan and consequently generate imbalance costs due to the use of reserve and emergency capacity. In order to manage imbalance risk, market participants undertake balancing activities before gate closure occurs in the power exchanges, as well as in the settlement period itself. In the latter case, the key idea is the utilization of real-time flexibility of their dynamic approach, behaving either as flexible distributed generators or as responsive loads/storages. Market parties aggregate these flexible distributed generation and responsive loads in a virtual power plant (VPP).

Another business case is the distribution system congestion management. Non- coordinated control of a large fleet of electric vehicles may lead to a sharp rise in needed capacity on lines and transformers. By coordination of these devices they can be allocated time slots for operation, that are spread over time ensuring the stability of the grid. The distribution network operator detects overflow situations based on the congestion management system and relies on customer site response programs to tackle this. The end user (electric vehicle owner) should be able to deliver flexibility services to the network operator. Therefore, in case that a substation controller measures the load flow and is critical, it creates a market signal that encourages the electric vehicles to react accordingly by adjusting their operating point based on the prices.

Variable tariff-based load and generation shifting is the business case where a variable profile is given to the customer one day before the day of delivery by a retailer. The profile is considered fixed after transmission to the customer, so the customer can rely on it and send feedback of their automatically planned/predicted load/generation profile. It would be possible that in exchange for an additional financial incentive, customers might be willing to accept adaptations of the price profile during the day of delivery reflecting changes in the retailer's portfolio that come up during the day and also to reduce imbalance in his portfolio. Another option could be a "maximum average cost per kWh" guarantee given by the retailer, protecting the customer from an increase in his energy cost by errors in the automated management systems or by his personal behavior.

Distribution grid cell islanding in case of upstream system events is another important business case. The key idea of this business case is to allow the operation of a grid cell in island mode in case of upstream system disturbances in a market environment. This business cases considers that the islanding procedure is performed automatically. The scenario has two main steps: the first step takes place before the event that may occur and the second step is the steady islanded operation. During the first step the customers declare their availability and forecast the consumption as well the available power and energy in the next hours. A load shedding schedule should be created according to the criticality of the consumers, as well as the amount of money they are willing to pay during the island mode. In the first minutes after the event the DSO allows operation according to the criticality. If there is enough power within the islanded part, no load shedding will take place. When balance and stability has been ensured, the Aggregator decides how to manage the energy within the network.

3 Conclusions

Smart meters are the key technology that allows the actors involved to control the bi- directional energy flow between EV and grid. The massive implementation of smart meters presupposes the definition of common requirements. This paper presented a discussion on common high level requirements for smart meters, that will allow the controlled deployment to mitigate potential negative impacts of a massive EV penetration to the grid.

Smart meters are the middleware that enables market participation of EVs. Smart meters allow either direct control of the EV by defining set-points for the exchange of power between batteries and the grid or indirect control by providing the EV battery management system with price signals, depending on the type of market they participate.

Interoperability and high communication standards are the two major forces that will boost the massive implementation of smart meters. The common architecture defines all interactions between smart meters and the different entities or devices in the overall electric grid.

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Technical Session 3: Implementation of Smart Grid and Smart Home Technology

Suppressing Peak Load at Simultaneous Demand of Electric Heating in Residential Areas

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Abstract. High peak loads at distribution stations in domestic residences are expected where heating is provided merely by heat pumps with additional electric heating. Two scenarios are studied: the event of a black start and high electricity demand on a day with a very low outdoor temperature. The simulation is done with agents representing up to 100 dwellings based on PowerMatcher technology. The results demonstrate significant peak load reduction can be achieved at the expense of only a small decrease of comfort. This allows the usage of smaller load transformer units, reduces grid losses and benefits the lifetime of medium and low voltage transmission cables.

Keywords: Multi-agent, simulation, electric, heating, residential, distribution station, peak shaving.

1 Introduction

Currently in The Netherlands residential areas are built, aimed to reduce the energy consumption of households by using heat pumps for heating and cooling of all dwellings. Uncommonly for the Netherlands, in newly built areas there is no opportunity for a gas infrastructure. Several heat pumps are connected to an aquifer of which a few are present in the surrounding. Electric power is served by a local distribution station which serves about 150 houses equipped with heat pumps.

Although the houses are well insulated, it is expected that, on cold days, which may occur on the average only once or twice a year during a limited period of a few weeks, the power of the heat pump is insufficient to keep the temperature in the dwelling sufficiently high for user comfort. This is the reason why additional heating devices are present in the form of a simple electric resistance heating. As the power of the heat pump is typically 2.2 kW and the power of the auxiliary electric heating is 6 kW, the total power is much larger than the typical power of 1-1.5 kVA, available at the distribution level for a Dutch household. So the local distribution station, which serves about 150 similarly accomplished houses, and the transmission cables need to be designed for a much larger peak load, thereby raising costs and negatively influencing lifetime expectancy of the components.

Network companies facing these problems have wondered whether smart grid solutions can attribute to their design and maintenance problems by decreasing peak loads. During a field test with micro-CHP's, coordination of micro-CHPs using the PowerMatcher has shown this ability [1].

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They described two scenarios which would challenge a possible solution. One is the situation of a very cold day where heat pumps alone wouldn't be able to satisfy the habitants overall need for heat. The other is the situation where a blackout has occurred on a cold day, all the houses are cooled down and where at the blackstart all the houses demand a large amount of heat.

This is why software agents were designed and built for this case and used in a simulation to investigate the overall electric behavior and explore the possibilities of smart grid solutions based on the market algorithms the PowerMatcher employs [2].

According to the expected increase of the share of distributed energy resources in the electricity network, a proper integration operation of renewable devices into the network is necessary.

This study is performed as part of the Dutch project "SmartProofs", which aims at the development of a smart power system. This provides a proof-of-principle of successful integration of renewable energy sources in the electricity network with preservation of the guarantee of the delivery service. At the initialization of the project the focus was on the introduction of micro-CHP. During the course of the project the network companies involved in the project recognized that the introduction of heat pumps leads to the above mentioned scenarios with high peak loads. This has leaded to a shift of at least a part of the effort in the project to investigate heat pump related issues.

2 Multi-agent Systems and Electronic Markets

The multi-agent approach localizes and confines data, processing and controlling in a bottom-up fashion, without an omniscient top-level. In comfort control this has several benefits, such as 1) the generic description of installations 2) plug and play behaviour of appliances 3) adaptation to the circumstances instead of predefined behaviour and 4) no need for complex flow diagrams. For coordination of devices to match supply and demand in an electricity network, there has already been developed and tested a successful technology, 'the PowerMatcher'.

The PowerMatcher is a general purpose coordination mechanism for balancing supply and demand in electricity network [3]. This technique implements supply and demand matching (SDM) using a multi-agent systems and market-based control approach. SDM is concerned with optimally using the possibilities of electricity producing and consuming devices in order to alter their operation in order to increase the over-all match between electricity production and consumption. Within a PowerMatcher cluster, the agents are organized into a logical tree. In this study the leaves of this tree are a number of agents representing a device. This agent tries to operate the process it is associated with in an economical optimal way.

The interactions of individual agents in multi-agent systems can be made more efficient by using electronic markets, which provide a framework for distributed decision making based on microeconomics. Microeconomics is a branch of economics that studies how economic agents make decisions to allocate limited resources, typically in markets where goods and services are being sold or bought. Whereas economists use microeconomic theory to model phenomena observed in the real world, computer scientists use the same theory to let distributed software systems behave in a desired way. Market mechanisms provide a way to incentivize parties (in this case software agents), that are not under control of a central authority, to behave in a certain way [4, 5]. A microeconomic theory commonly used in MAS is that of general equilibrium.

In general equilibrium markets all agents respond to the same price that is determined by searching for a price that balances all demand and supply in the system. An agent on such a market coordinates its actions with all other agents by buying or selling a commodity, here electricity. In order to do so, the agent communicates its latest bid (see below) to a so-called auctioneer and receives price updates from the auctioneer. The bids express to what extent an agent is willing to pay for or receive a certain amount of power; a request is converted to an adaptive price signal. As bids are constructed in a process of weighing the profits versus the costs, thus they represent the utility function of the agent. The bids are ordinary demand functions $d(p)$, stating the amount of electricity the agents wishes to consume (or produce) at a price p. After collecting all bids, the auctioneer searches for the equilibrium price p^*, i.e., the price that clears the market:

$$\sum_{a=1}^{N} d_a\left(p^*\right) = 0 \tag{1}$$

where N is the number of participating agents and $d_a(p)$, the demand function of agent a. The price is broadcast to all agents. Individual agents can determine their allocated production or consumption from this price and their own bid.

Figure 1 is a schematically example of how the electricity market will try to balance demand and supply, taking into account the bids of all agents. he communication between device agents and an auctioneer is very limited. The only information that is exchanged between the agents and the auctioneer are the bids and the price. The auctioneer communicates the price back whenever there is a significant change. The PowerMatcher system thus optimally uses the possibilities of power producing and consuming devices to alter their operation in order to increase the over-all match between supply and demand real-time. It has been shown that a PowerMatcher cluster acts very well as a virtual power plant control [1].

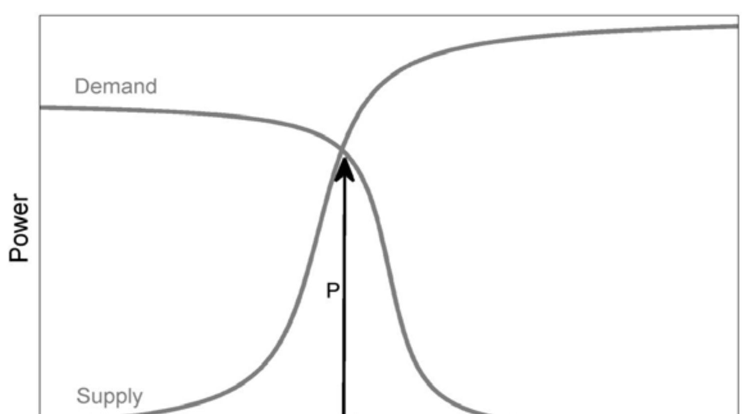

Fig. 1. Matching supply by representation of the bidding curves (P is the exchanged power)

3 Agent Design

For this specific case two software agents were developed i.e. a heat pump agent and a load agent.

3.1 Heat Pump Dwelling Agent

The heat pump dwelling agent represents a dwelling with a heat pump and auxiliary electric heating. A building model is incorporated in the agent, enabling the calculation of the indoor temperature. With the knowledge of the temperature and the set point temperature, certain strategies can be followed to calculate the amount of power demanded over the current price range. Knowing the price, the power can be determined that is allocated for both devices and the corresponding heat can be calculated which is released to the house, as well as the heat loss through windows, walls etc., depending on the outdoor temperature. The resulting room temperature is calculated after a certain time period, in a simulation typically 2 minutes.

The agent accounts for the preferred operation of a heat pump to be turned on for a longer time span T_{span}, e.g. 30 minutes, in order to obtain a good coefficient of operation (COP). This occurs once power is allocated above 2.2 kW. A power larger than this is allocated to the electric heating wire resistance. When this time span is passed and a power is allocated less than 2.2 kW, the power is allocated to the electric resistance heating. The set point value of the temperature depends on the presence and preferences of the habitant, which are resolved based on random parameters. A certain bandwidth around the temperature is employed, preventing the device from switching on and off too often.

In market based agent software like the PowerMatcher flexibility to a certain degree is needed [3]. As, besides peak load reduction, comfort for the inhabitant is the other major objective; it is chosen to incorporate in the bidding strategy a preference to supply more heat to those houses, which are the coldest. So the bid of the agent, which expresses the willingness to pay for heat, will depend on the indoor temperature. Thus implemented, it should be inferred from the results that the coldest houses are heated first.

Next to this, it proved to be beneficial for the heating of the houses, i.e. circumvention of overshoot of temperature, to implement a different bidding strategy when the difference between the indoor temperature and the setpoint value is below a certain value, $T_{Threshold}$, of about 2 °C. Under these circumstances heat from the heat pump is offered as usual, but the maximum amount of heat offered from the auxiliary electric resistance heating and hence the slope of the bidding curve is smaller and depends on the ratio of the actual temperature difference and $T_{Threshold}$.

3.2 Load Agent

The objective of the load agent is to prevent the supply of electricity from becoming so large, i.e. increasing above a certain maximum load, above which the likelihood of melting of the transformer is too large. In practice this means that the current or a certain representative voltage within the distribution station or even a certain temperature is surveyed and once this exceeds a certain cut-off value L_{cutoff}, which is smaller but close to the maximum $L_{maximum}$, a signal is send, preventing the demand agents from getting their full allocation. This translates for the PowerMatcher to a certain price increase of electricity, so that less electricity is supplied, but still within a region between L_{cutoff} and $L_{maximum}$.

In a simulation no current, voltage or temperature can be determined. However it is possible to derive the total power that is allocated by all heat pump dwelling agents. This is accomplished through the possibility of an agent in the PowermMatcher system to ask the auctioneer to send the aggregated bid and given the price, determine the load.

Opposed to practice, in simulations the size of the transformer unit can be varied to any extent. In this study $L_{maximum}$ is always chosen to be proportional to the number of houses and to be lower than the highest possible overall demand.

The heat pump dwelling agents are designed that no power can be consumed at the maximum price $P_{maximum}$. When the load becomes equal to $L_{maximum}$, the load agent is designed in such a way that the price will become $P_{maximum}$. The bid curve of the load agent is then almost zero at all prices. At loads below L_{cutoff} the price is allowed to become $P_{minimum}$, the bid curve of the load agent in this case has a high value at all prices. In the region between L_{cutoff} and $L_{maximum}$ the bid curve is near zero for low prices and has a high value above a certain load price, which is a parameter that is calculated by the load agent.

4 Results

The simulations reported here were performed with an amount of dwellings varying from 4 till 100 and an according maximum load $L_{maximum}$ for the transformer unit. The range of $L_{maximum}$ varied from 70% to 24% of the sum of the powers of the devices in all households.

Outdoor temperatures used in the simulation are actual recorded temperatures in 2000. Fig. 2 shows the result of a simulation with 4 dwellings at black start when outdoor temperatures are as low as 0 °C. As can be seen the total load does not exceed the $L_{maximum}$ and remains above L_{cutoff}.

The scenario of a cold winter morning was studied as well. Fig. 3 shows the result of a simulation with 20 dwellings. Indeed in this scenario the load does not exceed the maximum peak load.

Next the simulation was extended to comprise 100 dwellings represented by as much agents. Fig. 4 shows the total load on a substation on a cold winter's morning with and without PowerMatcher control. In the uncontrolled situation a very high peak demand occurs after a black start. At about 6:30h another peak demand occurs due to households demanding heat for the comfort of their inhabitants as they wake up. Notice this peak is not as elevated as after the black start as people tend to wake up at different times, so the demand is a little outstretched in time. With the PowerMatcher control for 100 dwellings the load never exceeds the maximum permitted load which is 30% of the maximum load.

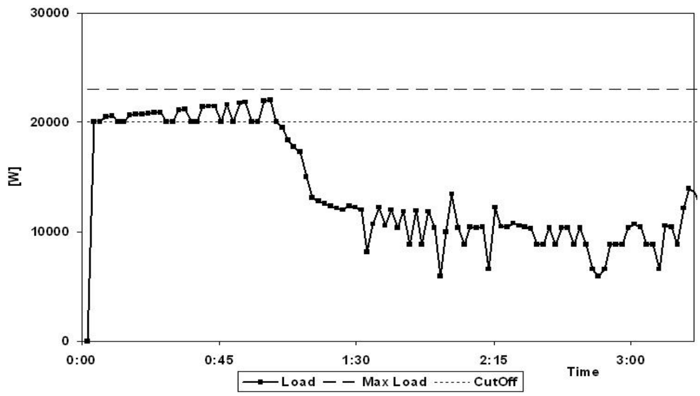

Fig. 2. Peak load reduction after a black start. The simulation comprises 4 dwellings and a distribution station operating at a maximum permitted load which is 70% of maximum load without control.

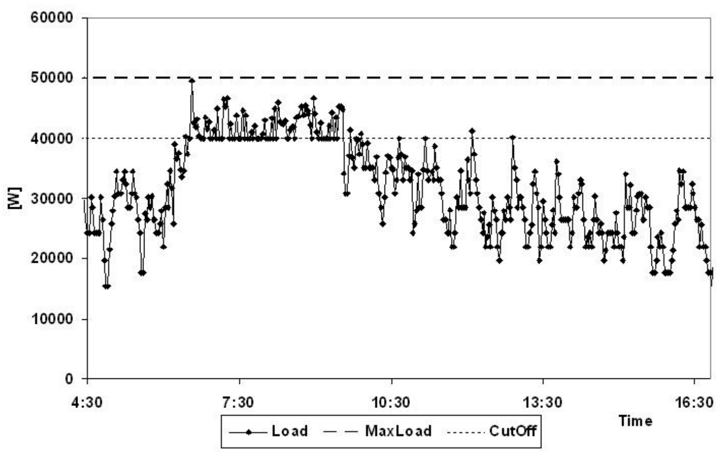

Fig. 3. Peak load reduction achieved at a substation on a cold morning for 20 dwellings. The distribution station operates at a maximum permitted load which is 30% of maximum load without control.

Since after a black start and at a cold morning in a PowerMatcher controlled situation less electricity is allocated for the heating devices of the household this means that less energy is available for heating the dwelling. This may result in decline of user comfort. To assess the extent of infringement with respect to user comfort the ascent of temperatures in a dwelling with and without PowerMatcher control were compared, which are shown in Fig. 5.

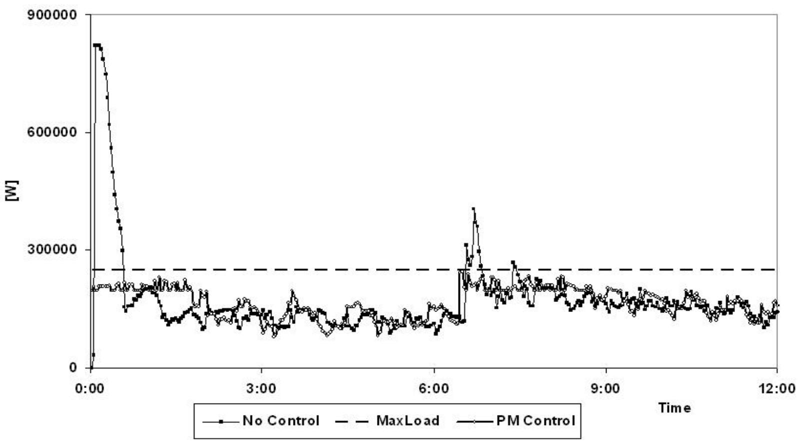

Fig. 4. Load at a substation for 100 dwellings after a black start and on a cold morning with and without PowerMatcher control. Maximum permitted load is 30% of maximum load without control.

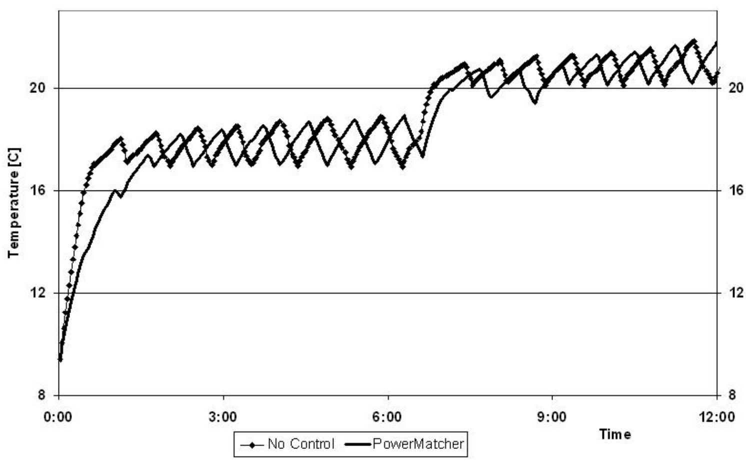

Fig. 5. Temperature in a dwelling with and without PowerMatcher control in a simulation of 100 dwellings. The initial temperature is 9 °C, the set point temperature at night is 17.5 °C and during the day 21 °C.

As can be seen from Fig. 5 the time it takes to reach the set point temperature in the controlled situation is delayed with respect to the uncontrolled situation, as is expected. However, the degree of delay may be quite acceptable.

The data of Fig. 4 can be transformed into a load duration curve, which is shown in Fig. 6. The large peak at the left of the diagram without control has disappeared in the controlled situation. Note that the surface below both curves are comparable, meaning that control did not affect the amount of energy (electricity) supplied to the dwellings.

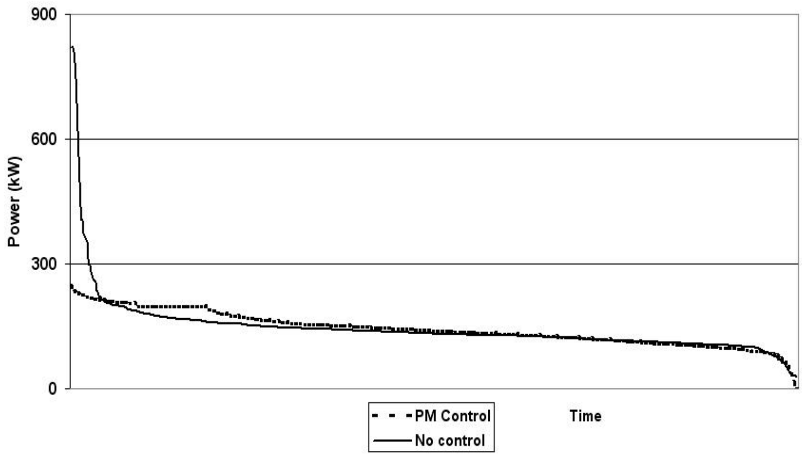

Fig. 6. Load duration curve for substation with 100 dwellings with and without PowerMatcher control. Maximum permitted load is 30% of maximum load without control.

5 Discussion

The simulation results indicate that, after a black start, reduction of peak load is possible. Fig. 2 shows that after a black start the load at a distribution station stays well below a certain maximum load and most of the time remains above a certain cut-off load. So the transformer can be protected against high loads exceeding the transformer limits, thus preventing it from melting. As also the longevity of the transmission cables will increase, PowerMatcher control offers potential benefit to the distribution system operator (DSO). This accounts for the low-voltage network as well as the medium voltage network which does not have to deliver high currents to the distribution station.

The power remains above a certain cut-off peak load. This means that after the black start the energy network hardly looses any capacity in delivering power and hence profit for the energy supplier as well. The equal ratio of surfaces below the load duration curves of fig. 6 further confirms this assumption.

Fig. 5 shows that all the houses can be heated immediately, meaning that, within the limits of the network, comfort returns to the habitants as soon as possible. With respect to the heat pump, it can also account for good operational circumstances, as the power is turned on for at least 30 minutes. It is not considered to be a problem if this time period needs to be a little longer in practice.

The rather steep rise of indoor temperature after change of set point value may be surprising considering the employment of heat pumps in combination with floor heating. Floor heating is associated with a slow process and it should take more time before reaching the set point value. The cause is due to a simplification in the building model heat pump agent. It is assumed that the heat generated by the heat pump is transferred directly to the dwelling rooms in stead of first to the floor. Although subject to improvement, with respect to peak reduction the essence of matter presented here is not affected by this simplification.

During a black out period some houses might become much colder than others. From a human physiology point of view, one might argue that those homes should be heated first as comfort sharply decreases with decreasing temperature [7]. The algorithm employed by the heat pump agents ensures that the coldest houses are heated first and the temperature difference between the houses is leveled out quite soon.

In this study the maximum number of dwellings is 100. This number can further be increased as there is no limit due to a maximum allowable number of agents running in a simulation or any other software or hardware limitation[1]. As the simulations were performed with 100 households this result favorably suggests that the algorithm is scaleable, as claimed by the real-time price based algorithm the PowerMatcher employs [3].

6 Conclusions

The simulation results suggest that using PowerMatcher control peak load reduction in a dwelling resort of up to 100 households is possible without hardly any infringement of user comfort. In the scenarios of a black start and in the morning of a cold winter day peak loads can be avoided.

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The Powermatcher is developed by a large number of people. The Power Matcher team currently consists of: Rene Kamphuis, Koen Kok, Pamela MacDougall, Olaf van Pruissen, Bart Roossien, Gerben Venekamp and Cor Warmer, with support from Sjaak Kaandorp and Arie de Waard.

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Review of IEC/EN Standards for Data Exchange between Smart Meters and Devices

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Abstract. With energy monitoring and control playing an increasingly important role in home energy management, Smart Meters are the key technology for the smart house deployment. Smart Meters collect data from devices to databases for analysis and billing purposes, do data logging, power quality and real time monitoring, offering the knowledge of energy consumption in order to control the flow of energy inside a house. However, the lack of common standard architectures for telecommunications to ensure interoperability between equipment and systems from different manufacturers makes a common Smart Meter adaptation more difficult. Working toward a common standard this paper presents the IEC/EN standards for data exchange between Smart Meters and devices.

Keywords: Smart Meters, standards, data exchange, communication.

1 Introduction

In the ideal world a consumer would purchase a new Smart Meter and when it is plugged into the home for the first time it would automatically identify itself and register with the home network. There are currently a number of barriers to this vision, most significantly the lack of a global standard for meter networking.

Without a single standard, meter manufacturers would be required to offer a number of different solutions incurring additional development expense. The other barrier is that security concerns mean that only trusted appliances can share information with the Smart Meter.

Automatic Meter Reading (AMR) is a technology which automatically collects data from metering devices like water, gas, heat, electricity and transfers these data to a central database for analysis and billing purposes. Many AMR devices can also do data logging. The logged data can be used for water or energy use profiling, time of use billing, demand forecasting, demand side management (DSM), rate of flow recording, leak detection, flow monitoring, etc. [2]

Smart Meter goes a step further than simple AMR. They offer additional functionality including a real-time or near real-time indications and power quality monitoring. Standards for Smart Metering include requirements and test methods to cover data models and protocols for Meter data exchange.

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2 IEC/EN Standards for Data Exchange between Smart Meters and Devices

A schematic diagram of a Smart Meter is shown in Figure 3.1 [1]. The Smart Meter Infrastructure as an Advanced Metering Infrastructure (AMI) can be divided into three segments [2]:

- The local network segment
- The access network segment
- The back-haul network segment

The local network connects Smart Meters belonging to the same entity (home, building, facility) as well as end-user applications (Home Area Network (HAN)) to a node acting as a local data collector and gateway between access and local network.

The access network comprises the networks between house gateway and a hub/data concentrator or the data management center in case there is no data concentrator.

The backhaul network is the final segment between hub/data concentrator and the data & management center for utility services and customer-related services.

In case that there is no hub/data concentrator, the data are sent directly to data & management center.

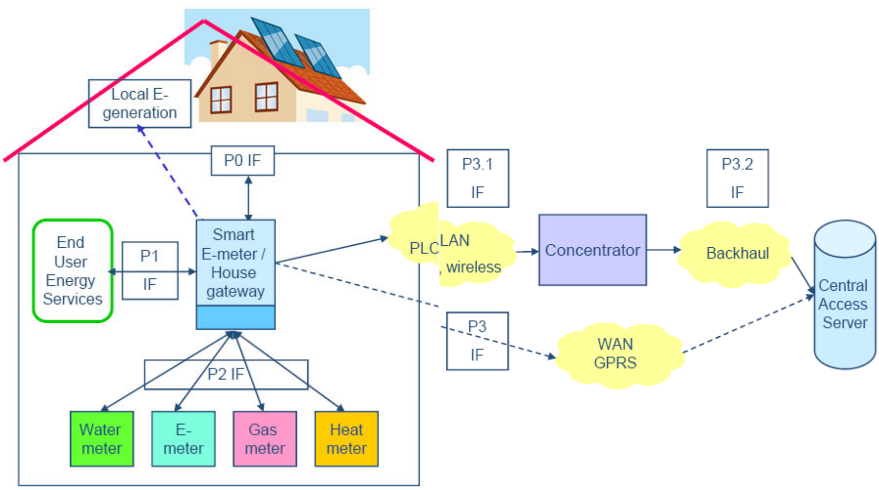

Fig. 1. Schematic diagram of a Smart Meter Infrastructure [1]

2.1 Interfaces

There are five interfaces (Ports) that designate the connection of the Smart Meter with other devices, plus an interface between the Concentrator and the Central Access Server.

Port 0. Communication with external devices (e.g. hand-held terminal) during installation and on-site maintenance of the metering installation.

Port 1. Communication between the metering installation and ISP module or auxiliary equipment.

Port 2. Communication between the metering system and one or more metering instruments and/or grid company equipments.

Port 3. Communication between the metering installation and the Central Access Server (CAS).

Port 3.1. Communication between the metering installation and the Data Concentrator (DC).

Port 3.2. Communication between the Data Concentrator (DC) and the Central Access Server (CAS)

2.1.1 Port 0: Local Port

Table 1. Local port standards [1]

Standard	Description
IEC 62056-21	Electricity metering - Data exchange for meter reading, tariff and load control - Part 21: Direct local data exchange
EN 13757-6	Communication Systems for meters and remote reading of meters. The physical layer for local bus

IEC 62056-21 "Flag"

IEC 62056-21 is also known as the "Flag protocol". This protocol was the first standard protocol for meter data exchange and is globally used. Today, its main use is for local data exchange. The current loop is a local bus supporting up to eight meters. PSTN and GSM are supported with appropriate modems [2]. It specifies three local physical interfaces [3], an *Optical interface, an Electrical current loop interface and* an *Electrical V.24/V.28 interface.*

Table 2. Applications

Applications	
Local AMR	Supported, by using a hand held or a permanently connected device
Remote AMR	Supported via PSTN or GSM modems. Several devices can be connected on a current loop.
AMI	Supported when used in Mode E with DLMS/COSEM and remote two-way communication.
Home Automation	Not supported

EN 13757-6

This standard specifies the physical layer parameters of a local meter readout system ("Local Bus") for the communication with and the readout of a single meter or a small cluster of maximum 5 meters via a single battery powered readout device ("master") which can be connected for the communication directly to a meter (i.e. local readout) or via a fixed wiring or a small bus (total cable length max. 50 m, i.e. local remote readout). The Local Bus is an alternative to the M-Bus. The bus has to be switched on before data exchange. [4]

2.2 Port 1: Home Area Network

The Home Area Network (HAN) is contained within a user's premises and interconnects home IT and entertainment devices and their peripherals as well as home security systems, and "smart" appliances such as lighting, heating, cooling, etc.

A number of technologies might be used for this interface. According to the Open meter Deliverable, the only way to succeed in this interface is to specify an interoperable technology, using standard profiles, while the technology must be already available in consumer gadgets such as mobile phones, PDAs or laptops.

Taking everything into account the candidate technologies are, Wi-Fi, ZigBee, Bluetooth, IEEE802.11, IEEE802.15.4 and 6lowPAN. The potential protocols are, IEC 62056-21 Mode D (DLMS/COSEM on local port), *IEC 62056-21 Mode A, B or C should be considered, in order to have two way communication between the HAN and the Smart Meter,* SML, ZigBee SEP and KNX.

The communications between the HAN and the Smart Meter must be secure so that customers' data are not sent to other customers. In practice this will mean that once the customer buying a HAN, would have to agree the identity of the HAN with the utility and then the utility should program the Smart Meter.

One way of approaching this, is to have a 'USB port' on the Smart Meter. The customer plugs their transmitter into this port and the customers' transmitter then talks to the Customers HAN using whatever communication protocols is available. At this stage only the 'USB Style Port' would have to be standardized.

2.3 Port 2: In-House Wired/Wireless

2.3.1 In-House, Wired

Table 3. In- house wired standards [1]

Standard	Description
IEC 62056-31	Electricity metering - Data exchange for meter reading, tariff and load control - Part 31: Use of local area networks on twisted pair with carrier signaling
EN 13757-2	Communication Systems for meters and remote reading of meters. Physical and link layer

IEC 62056-31 "Euridis"

Euridis is a pragmatic and reliable solution for remote meter reading. Nowadays, Euridis is the only standardized interface for the remote reading of electricity meters with a twisted-pair cable, using carrier signaling. [2]. The baud rate is 1200 Baud, 3 minutes to read 100 meters and up to 500 meters local bus.

Table 4. Applications [1]

Applications	
Local AMR	Supported, by using a hand held or a permanently connected device, via a magnetic plug. Gateways to other protocols are possible
Remote AMR	Euridis is a pragmatic and reliable solution for remote meter reading
AMI	Not supported
Home Automation	Not supported

2.3.2 In-House, Wireless

Table 5. In-house wireless standards [1]

Standard	Description
EN 13757-4	Communication Systems for meters and remote reading of meters. Wireless meter readout
EN 13757-5	Communication Systems for meters and remote reading of meters. Wireless relaying

EN 13757-4

The physical and the data link layers for wireless data exchange are specified in EN 13757-4. Three modes of operation are available:

"Stationary mode", *mode S*, intended for unidirectional or bi-directional communications between stationary or mobile devices.

"Frequent transmit mode", *mode T*. In this mode, the meter transmits a very short frame (typically 2 ms to 5 ms) every few seconds thus allowing walk-by and/or drive by readout.

"Frequent receive mode", *mode R2*. In this mode, the meter listens every few seconds for the reception of a wakeup message from a mobile transceiver. After receiving such a wakeup, the device will prepare for a few seconds of communication dialog with the initiating transceiver. In this mode a "multi-channel receive mode" allows simultaneous readout of several meters, each one operating on a different frequency channel.

The available baud rate for the T mode is 67/16 kBaud, for the S mode is 16/16 kBaud and for the R mode is 2.4 / 2.4 kBaud.

An M-Bus device may support one, several or all modes. The M-Bus wireless protocol is optimised for power consumption and low cost, [2].

EN 13757-5

This standard specifies relaying for wireless networks, to extend the action radius of the radio signal. The following modes are specified:

The specified modes are, Mode P using routers, Mode R2 protocol using gateways and Mode Q protocol supporting precision timing. This mode allows using DLMS/COSEM [2].

2.4 Port 3.1: PLC/Wireless LAN

2.4.1 PLC LAN

Table 6. PLC LAN standards [1]

Standard	Description
IEC 62056-53 *S-FSK specified by DLMS UA, to be added*	Electricity metering - Data exchange for meter reading, tariff and load control - Part 53: COSEM application layer

Communication with electricity metering equipment using the COSEM interface object model is based on the client/server paradigm where metering equipment plays the server role. In this environment, communication takes place always between a client and a server. These services are provided via exchanging messages between the client and the server. In general, the client and the server APs are located in separate devices; exchanging messages is done with the help of the communication protocol.

Table 7. Applications [2]

Applications	
Local AMR	Supported via an optical port, current loop interface or RS-232. The physical interfaces are specified in IEC 62056-21. Most meters on the market support both Mode C using ASCII data transfer and Mode E using DLMS/COSEM
Remote AMR	DLMS/COSEM is widely used for AMR with two-way remote data exchange over various media.
AMI	The functions modelled with the COSEM data model support all AMI functionality. Combined with bi-directional data exchange, DLMS/COSEM supports AMI.
Home Automation	Not supported However, DLMS/COSEM devices may serve as a gateway towards HA systems. The principles of the COSEM model also make it suitable to model HA functionality.

2.4.2 Wireless LAN

Although PLC seems to be the dominant technology, Wireless LAN technologies could be used in cases where PLC is not an option. The WLAN communication technologies are specified by the European Telecommunications Standards Institute.

2.5 Port 3.2: Backhaul Network

Table 8. Backhaul network standards [1]

Standard	Description
IEC 62056-21	Electricity metering - Data exchange for meter reading, tariff and load control - Part 21: Direct local data exchange
EN 13757-6	Communication Systems for meters and remote reading of meters. The physical layer for local bus
ETSI	Relevant European Telecommunications Standards Institute standards

This interface is for communication between the Data Concentrator (DC) and the Central Access Server (CAS). The used standards are the same as Port's 0 (Local Port).

2.6 Port 3: PTSN/GSM or Internet/GPRS WAN

2.6.1 PTSN/GSM WAN

Table 9. PTSN/GSM standards [1]

Standard	Description
IEC 62056-42	Electricity metering - Data exchange for meter reading, tariff and load control. Physical layer services and procedures for connection-oriented asynchronous data exchange
IEC 62056-46	Electricity metering - Data exchange for meter reading, tariff and load control - Part 46: Data link layer using HDLC protocol

IEC 62056-42

This standard specifies the physical layer services and protocols within the COSEM three-layer connection oriented profile for asynchronous data communication. (PSTN) To allow using a wide variety of media, the following assumptions are made: The communication is point – to – point or point to multipoint, both half-duplex and full-duplex connections are possible, asynchronous transmission with 1 start bit, 8 data bits, no parity and 1 stop bit, [9].

IEC 62056-46

This part of IEC 62056 specifies the data link layer for connection-oriented, HDLC-based, asynchronous communication profile, including a number of enhancements compared to the original HDLC, for example in the areas of addressing, error protection and segmentation. The communication environments might be point-to-point and point-to-multipoint configurations, dedicated and switched data transmission facilities, half-duplex and full-duplex connections, asynchronous start/stop transmission, with 1 start bit, 8 data bits, no parity, 1 stop bit. Furthermore multicasting and broadcasting are possible using UI frames. In the present environment, this is allowed only for the clients – servers are not allowed to send frames with broadcast or multicast address in the Destination Address field, [10].

2.6.2 Internet/GPRS WAN

Table 10. Internet/GPRS standards [1]

Standard	Description
IEC 62056-47	Electricity metering - Data exchange for meter reading, tariff and load control - Part 47: COSEM transport layers for IPv4 networks

This part of IEC 62056 specifies the transport layers for COSEM communication profiles for use on IPv4 networks. These communication profiles contain a connection-less and a connection-oriented transport layer, providing OSI-style services to the service user COSEM application layer. The connection-less transport layer is based on the Internet standard User Datagram Protocol (UDP). The connection-oriented transport layer is based on the Internet standard Transmission Control Protocol (TCP).[11]

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4. EN 13757-6: Communication Systems for meters and remote reading of meters. The physical layer for local bus
5. IEC 62056-31: Electricity metering - Data exchange for meter reading, tariff and load control - Part 31 Use of local area networks on twisted pair with carrier signaling
6. EN 13757-2: Communication Systems for meters and remote reading of meters. Physical and link layer
7. EN 13757-4: Communication Systems for meters and remote reading of meters. Wireless meter readout

8. EN 13757-5: Communication Systems for meters and remote reading of meters. Wireless relaying
9. IEC 62056-42: Electricity metering - Data exchange for meter reading, tariff and load control. Physical layer services and procedures for connection-oriented asynchronous data exchange
10. IEC 62056-46: Electricity metering - Data exchange for meter reading, tariff and load control - Part 46 Data link layer using HDLC protocol
11. IEC 62056-47: Electricity metering - Data exchange for meter reading, tariff and load control - Part 47 COSEM transport layers for IPv4 networks

Design and Implementation of a Practical Smart Home System Based on DECT Technology

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Abstract. Energy management is important not only for the homes, but also for the energy providers. With the ever-increasing broadband penetration it becomes possible the information exchange between the energy provider and customer, and a smart home management system. In this paper, we present a practical smart home system that serves as platform for efficient metering and communication within the household. The interconnection of the home appliances and the home network is realized by light-weight, feature-rich and cost-effective DECT technology (Digital Enhanced Cordless Tele-communications). Furthermore, we provide a concept of integration of the smart home system within the smart energy grid. A model is presented which served as the basis of the design and prototype realization of components of the system including an energy management device (EMD), DECT communication interfaces based on state-of-the-art technology. Finally, we present our prototype system for the concept.

Keywords: Energy Management, Power metering, Smart Grids.

1 Introduction

Energy management is a new forming issue throughout the world. Power production facilities have to produce energy continuously prepared for heavy fluctuations in consumption, especially when alternative sources are used, or in case of a sudden breakdown. They have to prepare peaks, but in periods when there is less consumption they can lead remaining energy into storage. There are many kinds of techniques to store energy: batteries, large supercapacitors, or large mechanical systems. All of these methods are very expensive in such large scale. Running plants below full capacity is inefficient at the same time; the cost of the same amount of power is more expensive than running on full capacity. In storing and retrieving energy there is always a certain loss. Responding to immediate fluctuations is however impossible, therefore energy production utilities always produce more energy that expected to be needed.

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The Energy Provider (called Utility from now on) places meters to customer's household to measure the overall power consumption at all time. These meters are read periodically by the Utility. The energy bill is calculated based on the read consumption. The main idea behind smart grids is that the utility should be able to balance the load by getting customers to shift their load to off-peak periods. The simplest method would be to charge energy on different prices at off- and on-peak periods. Other aspect of smart grids is the ability to feed power to the grid, which is necessary in case of alternative power production. The former consumer may become a provider by investing into energy production technologies using alternative forms of energy. In order to feed energy back to the grid smart power meters are needed.

To summarize the introduced facts in order to increase efficiency of energy production more intelligence has to be put in the system beginning with the consumer side. While there is significant emphasis on home intelligence and network integration the price of achieving it is not to be neglected. The additional energy, cost, and effort of installing and maintaining such a system determine its competitiveness on the market. We are going to present a novel energy saving approach developed within the AIM project which serves as a platform for smart home integration leaving the interconnection technology freely chosen. During the design of the system scalability and low-power requirements were also taken under consideration. Built on that platform we prove that DECT is candidate technology.

2 Background and Related Work

Several standardization bodies are preparing network standards to be fit in the smart home and smart grid concept. The leading standardization body is CENELEC (European Committee for Electrotechnical Standardization) with the EN 50090 standards about Home and Building Electronic Systems (HBES). The European Commission has also launched several projects dealing with efficient energy-management.

The SmartHouse/SmartGrid FP7 European project (http://www.smarthouse-smartgrid.eu) specifically focuses on connecting smart houses and smart grids and solving load balancing by dynamic electricity pricing. For connection between the utility and the smart meter it targets to define high level (web services based) interfaces. In [2] they present their developed service-based system based on smart houses and smart grids. Other decentralized approaches include decentralized decision based on information from a central control station [8] and agent based control for the electricity infrastructure is presented in [7]. It provides market-based control concept for supply and demand matching (SDM) in electricity networks. In [6] a business model is presented for dynamic service oriented energy network and its security and business aspects are discussed.

Contrary to other solutions our system targets not just smart metering and control, but also energy profiling of appliances and the intercommunication with the energy provider for the benefit of both the customers reducing energy consumption and advanced pricing, and for the provider making possible better energy management and use of renewable power resources.

The general architecture of the smart home used in our research is presented in Section 3. In Section 4 we describe our smart home system realization. The communication protocol we have developed is introduced in Section5. The provided services of our system are described in Section 6. Finally in Section 7 we conclude our paper.

3 The Smart Home System

The AIM project's [12] primary focus is to foster a massively used technology for profiling and optimizing the energy consumption patterns of home appliances. The purpose of the project is to create an end-to-end system where virtualised household appliance functions and utility services are deployed under a common logic on the future's home gateway. AIM targets creating an embedded Energy Management Device (EMD) which can provide basic energy management functions for existing home appliances. Based on the EMD the target is to achieve energy-saving by recognizing pre-defined energy-patterns of home appliances. The project also aims to create a SOA (Service Oriented Architecture) based logic on the home gateway which can integrate the EMD managed home appliances into the home network. Contrary to existing power meters, an EMD is designed to be cheap with most data processed on the gateway. Although complete logic layer structure is being defined for interworking of components of the system, the physical layer communication interfaces are not strictly bound allowing the manufacturers to use their preferred technology.

We are going to present a concept developed in the AIM project which will serve as the basis of our research. The energy management model we are going to present aims for the individual appliances in the household to achieve a smart home system. The system targets the following goals:

- Provide a device which can integrate the home appliances into the home network
- Define energy profiles for home appliances with which energy states can be assigned to the appliances without constant metering
- Provide guidance for manufacturers how to submit state information for energy profiling
- Record energy profiles for ordinary appliances
- Switch off appliances which indicate they are in stand-by mode
- By accessing utility services, real-time price calculation according to selected appliance profile

The model with the key components is presented on Fig. 1. The EMD serves as a communication interface between the energy management functions of the attached appliance and the home network.

With the energy patterns of AIM compliant devices the consumption of an appliance can easily be determined by requesting the state of the appliance thereby excluding the need for constant monitoring. Additionally by physically switching off devices which indicate being in stand-by mode further energy can be saved. The energy provider (Utility) plays a great role in the AIM system. By requesting energy prices from the service of the utility, and based on the appliance profiles, the system ca precalculate the price of operating an appliance with a certain program or for a set time. Cost saving can be achieved with the system by shifting the appliance operation for a time when energy prices are lower (e.g. at off-peak periods). The smart logic residing on the home gateway runs the service which manages the appliances and provides a control point for remote management.

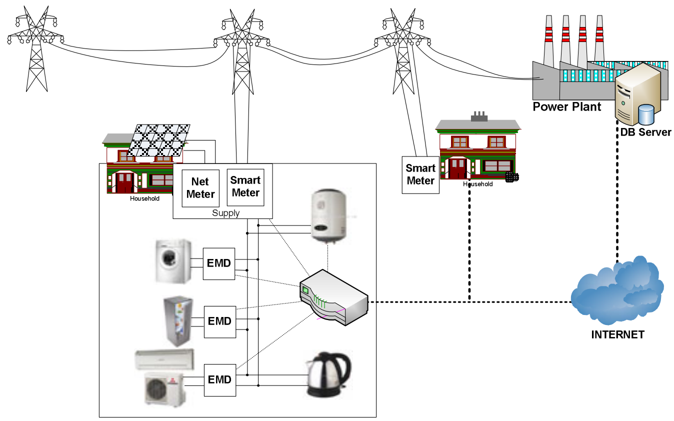

Fig. 1. Model of a smart energy management system. Conventional appliances are equipped with an EMD which serves as a middleware between the home network and the appliance.

4 Composition of Our Smart Home System

Based on the concepts described above in this chapter we present our developed solution. We aimed on developing a system by which home appliances can be connected to a networked, remotely accessible system. The middleware (hardware and software components) which makes it possible is called the Energy Management Device, i.e. it is the building block for smart appliance integration.

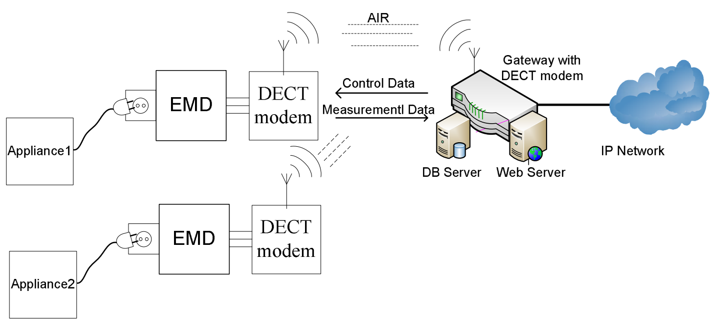

Fig. 2. General architecture of the achieved system presenting components, interfaces and data flow

The system is able to virtualize each appliance on the Home Gateway for the home and external network for management purposes. We have implemented the following functions inside the EMD: consumption monitoring, basic power control, device profile programming, device profile identification.

The general architecture on the modular level of the achieved system is presented on Fig. 2. The Home Gateway communicates the Energy Management Devices through a standard interface (in our implementation via DECT). The appliance gets its power through the EMD which can measure its consumption. According the programmed device profile the EMD can assign power state to the appliance without the need to constantly monitor its consumption.

4.1 The Energy Management Device

The main idea behind the energy management device is to place the household appliances under common management logic in the home. These devices are designed to be cheap and simple, but not to replace the smart meters which are very expensive and very robust equipment. The actual consumption is monitored by the utility installed smart meter, and the production with the net meter and used for billing by the utility. The EMDs are to be used by appliances to monitor consumption and provide remote control through the management logic hosted on the home gateway.

There are two basic functions that the EMD should be capable to fulfil: power consumption metering and power control. It should possess one communication interface towards the home gateway to be able to access its functions. The device has to be cheap in order to be competitive on the market and has to operate with low-power. Additionally the EMD connected to an appliance could measure energy efficiency, to signal any unusual behaviour of the appliance, and even to apply safety precautions immediately to prevent damage, or injuries.

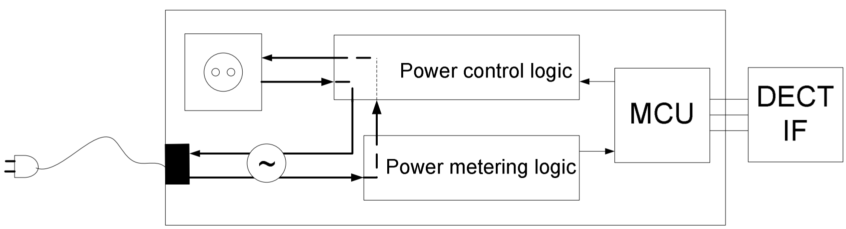

Fig. 3. Block diagram of the Energy Management Device

The EMD we have realized comprises a power metering logic and a power control logic. The power line goes through the power metering logic and the power control logic in that order as presented on the above figure. Therefore the measurements will not be altered by the power control logic. The power metering and power control logics are controlled by a microcontroller which needs negligible power for operation. Low-power requirements are met by the using the low-power sleep mode of the microcontroller. The DECT interface wakes up only before the assigned timeslots to receive and send, otherwise goes to low-power state.

The power metering logic has to measure the real power of the load real-time and performs constant integration to calculate and store consumption. Through the power control logic it has to be capable to switch off the load. For power measurement two circuits are needed, one for voltage measurement and one for current measurement. For current measurement Hall sensors can be used which measure magnetic field of the conductor that is proportional of the current. With this solution no physical contact has to be made with the load to measure current.

For the power control logic the easiest solution is to use a relay which can be driven with a low-voltage output of the microcontroller. Contrary to the large form-factor of the relay a TRIAC can also be used, but this requires zero crossing detection. The latter has an additional advantage that is adjustable power control e.g. for light dimming.

4.2 Communication between EMD and Gateway

We have considered many wired and wireless technologies for the communication interface. Our first candidate was a powerline based interface, however a KNX based EMD realization has already been achieved in the project [1].

Our choice, the DECT technology has many advantages making it a competitor against other wireless technologies, even against powerline. Compared to IEEE 802.11 WLAN [10] it is less resource demanding and considerably cheaper. Contrary to ZigBee [11] it operates in a protected frequency range. Z-Wave [14] could be a good alternative, however it is proprietary technology. The most significant benefit is nevertheless the existing infrastructure which is already available in numerous households, and by the recommendation of the Home Gateway Initiative it will be included in every home gateway in the future [5]. DECT is a widespread technology, DECT phones are widely used for wireless extension of the PSTN service because they are cheap and reliable.

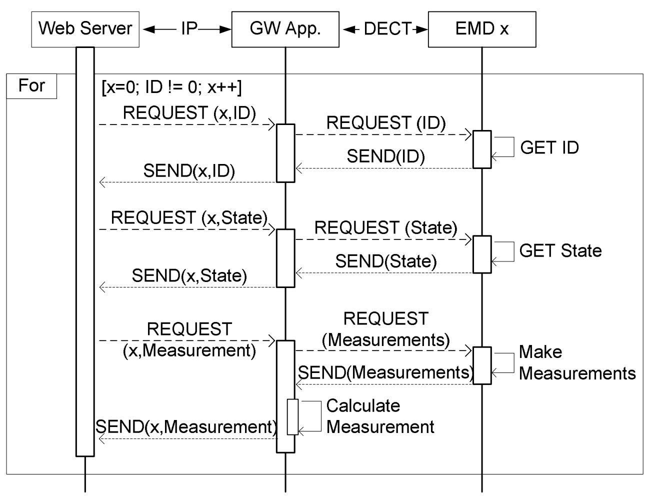

Fig. 4. Sequence diagram of the communication

By request on the gateway (either from the web server or the UPnP server) towards the EMDs a data call is used, which provides a packet switched connection. We have defined a simple request-response based protocol over this connection (Fig. 4), which is presented in section 5.

4.3 The Home Gateway

The integration of different technologies in the Home is also pursued by the Home Gateway Initiative (HGI) defines requirements, and use cases for the Home Gateway, which is to be the central service provider in the home. In connection to the home gateway concept Lantiq (a leading company in access and home networking) will be releasing the first CAT-iq compliant Home Gateway and handset products.

Our goal was to find a gateway platform which supports DECT base station functionality and supports new generation DECT functions. We have selected Lantiq's ARX based reference solution with voice support. The operating system running on this chip is the popular OpenWRT (http://www.openwrt.org/), which is a modular operating system allowing easy development and cross compilation to many types of devices. For the basis of the operating system Linux kernel is used.

Low-power consumption is a very important issue on the gateway as well. The Linux ACPI power management can be used for resource management. The power management features of the ARX platform can be reached using a specific ACPI driver. The Linux resource management provides an API to control the power states of the gateway [13].

5 Using DECT/CAT-iq for EMD-Gateway Communication

Digital **E**nhanced **C**ordless **T**elecommunications was originally a wireless telephony standard. During the call, the portable part (PP, handset) and the fixed part send (FP, base station) uplink and downlink data accordingly in their allotted timeslot. The original DECT standard has defined the possibility to create DECT cellular networks. Distribution of base stations in an area increases the coverage of DECT, and also the number of usable devices.

Currently DECT is undergoing a major transformation. The upcoming CAT-iq (http://www.cat-iq.org) set of standards which are to replace DECT have many interesting features [3]. The main goal is to grow out from the former 'wireless telephony only' scenario and to become a general wireless technology supporting QoS and using above IP communication. CAT-iq has a generic goal to offer internet connectivity to home appliances, which require low data-rate, but quality of service. Other application profiles, like sensor network integration, and home control are under definition.

We have implemented our solution above the standard DECT operation using the data call feature defined in the Dect Packet Radio Service (DPRS) standard [9]. Accordingly the call is initiated by the portable part (which is attached to the EMD) by request of the gateway. The length of a standard DECT frame is 40 bytes, so the maximum length of the Data field (data length) is 35 bytes therefore no message has to be fragmented.

The simple messages needed for the basic functionality is shown in the tables below. The gateway can send turn on or off messages and waits for a response. There is a request state message to get the state of the EMD. The EMD sends messages only if requested to do so by a request state, a request measurement or a request ID message.

Table 1. System messages

FP messages	
Message ID	Data
Turn on	-
Turn off	-
Request state	-
Request measurement	-
Request ID num.	-

PP messages	
Message ID	Data
State indication	on or off
Measurement	measurement
ID number	number

Since the system has to support multiple appliances it is necessary to distinguish these from one another. For this purpose each EMD has an identification number (ID number) which is either a serial number (unique, unchangeable, and set by the manufacturer), or a number entered by the user.

In addition to the EMD messages the gateway can request the number of connected EMDs. Throughout the DECT connection on the gateway the connected EMD's are distinguished by the frequency and timeslot on which the communication is taking place. When the list of EMDs is requested from the gateway the gateway collects the frequency-timeslot pairs where it communicated with an EMD.

According to the standard, a DECT system can support 24 devices on each of the 10 frequencies, altogether 240 and 120 in full duplex mode. Therefore in theory 120 hand phones, called Portable Parts (PP) can be used in a system with a base station called Fixed Part (FP) operating on different frequencies. The communication is robust, retransmission is handled by the DECT protocol, latency is very low, around 10ms.

6 Service Access and Management

The smart home system provides interfaces for remote access on IP in a form of a website hosted on the gateway itself and a UPnP service for general remote interaction. On the gateway we developed an application which implements an UPnP Controller for each EMD discovered in the system. The control point to our management system is a webpage hosted on the gateway itself.

There is a web server established on the gateway which hosts the website for our energy management system. There is a login page performing authentication, after successful login the management page is displayed. This page consists of the listing of discovered appliances, showing the status of the appliances (on/off) and showing momentary consumption of the appliances. There are controls to change the status of the appliances. After login each of the appliances having an EMD is listed with their state, and momentary consumption. We have also implemented UPnP server functionality on the gateway to remain consistent with the management interfaces used in the project. The high-level smart home logic implemented in the project separately accesses all the devices via UPnP.

Our implementation is based on libupnp which is an open-source UPnP development kit. This application is the one which performs the DECT-UPnP bridging by accessing the driver of the DECT module. Our EMDs are hosted as UPnP devices with the following services: appliance name request, status request, momentary energy request, and integrated consumption request for a time interval. The overview of components and offered interfaces are presented in Fig. 5. With the DECT infrastructure we plan to implement a user interface on the handsets, which can host a subset of the system's functions.

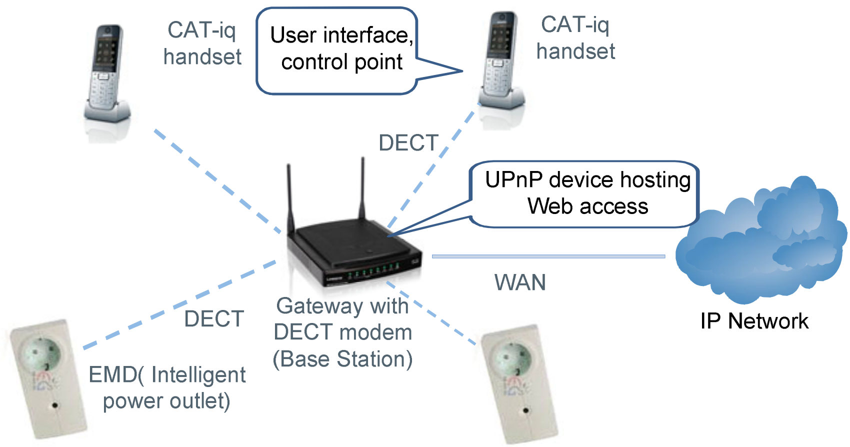

Fig. 5. Services and interfaces in our system

7 Conclusions

An interactive energy management system is very beneficial for the consumer, the provider, and indirectly for the environment, therefore it is demanded in the future.

We have introduced a model for a future smart gird, where smart homes are the key actors. The smart home is built up from smart appliances which provide energy management functions. To integrate existing appliances to the smart home we have created an energy management device (EMD). The EMDs are connected to the home gateway through a DECT wireless interface which is already present on existing gateway platforms. This solution does not require additional expensive hardware. The website on the gateway provides remote user access, while the UPnP server eases the smart home integration to a smart grid. From the basic functions a complex logic can be developed in the future in the Home Gateway achieving automated control of appliances using the interface provided by the Utility for its management functions.

We have designed a simple, robust communication protocol between the EMD and gateway, based on the possibilities provided by the DECT system especially considering the upcoming CAT-iq standard.

Our goal with this system was to provide a cheap solution for the household to turn their home smart. Intelligent energy management is needed in the future smart grids.

Acknowledgment

The presented architecture has been elaborated in the frame of the 224621 project "A Novel Architecture for Modeling and Virtualising Energy Consumption of Household

Appliances-AIM" [12], co-funded by the European Commission. The research leading to these results has also received funding from the ARTEMIS Joint Undertaking under grant agreement n° 100029 and from the Hungarian National Office for Research and Technology (NKTH).

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Field Trials towards Integrating Smart Houses with the Smart Grid

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Abstract. Treating homes, offices and commercial buildings as intelligently networked collaborations can contribute to enhancing the efficient use of energy. When smart houses are able to communicate, interact and negotiate with both customers and energy devices in the local grid, the energy consumption can be better adapted to the available energy supply, especially when the proportion of variable renewable generation is high. Several efforts focus on integrating the smart houses and the emerging smart grids. We consider that a highly heterogeneous infrastructure will be in place and no one-size-fits-all solution will prevail. Therefore, we present here our efforts focusing not only on designing a framework that will enable the gluing of various approaches via a service-enabled architecture, but also discuss on the trials of these.

Keywords: smart grid, web service, smart metering.

1 Motivation

In order to achieve next-generation energy efficiency and sustainability, a novel smart grid Information and Communication (ICT) architecture based on Smart Houses interacting with Smart Grids is needed. This architecture enables the aggregation of houses as intelligent networked collaborations, instead of seeing them as isolated passive units in the energy grid.

The research project SmartHouse/SmartGrid takes a fundamentally different and innovative approach where the ICT architecture under development by the consortium introduces a holistic concept and technology for smart houses as they are situated and intelligently managed within their broader environment [3]. This concept (as depicted in Figure 1) seriously considers smart homes and buildings as proactive customers (prosumers) that negotiate and collaborate as an intelligent network in close interaction with their external environment [4]. The context is key here: the smart home and building environment includes a diverse number of units: neighboring local energy consumers (other smart houses), the local energy grid, associated available

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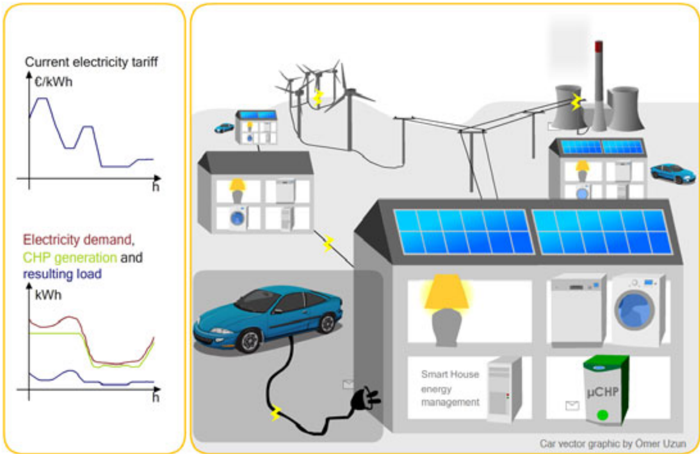

Fig. 1. The SmartHouse/SmartGrid vision

power and service trading markets, as well as local generators, e.g. environmentally friendly energy resources such as solar and (micro) common heat and power (CHP) plants etc. The SmartHouse/SmartGrid approach is based on a carefully selected mixture of innovations from recent R&D projects in the forefront of European smart grid research. These innovations include:

- In-house energy management based on user feedback, real-time tariffs, intelligent control of appliances and provision of (technical and commercial) services to grid operators and energy suppliers.
- Aggregation software architecture based on agent technology for service delivery by clusters of smart houses to wholesale market parties and grid operators.
- Usage of Service Oriented Architecture (SOA) [5] and strong bidirectional coupling with the enterprise systems for system-level coordination goals and handling of real-time tariff metering data.

The main technical measures on which the functionalities of the ICT architecture are based include:

- End User Feedback: Aims at an interface to the end user in order to give feedback on his/her energy behavior and on the availability of (local) clean electricity.
- Automated Decentralized Control of Distributed Generation and Demand Response: Aims at a better local match between demand and supply, at customer acceptance of management strategies, and at a more effective reaction to near-real time changes at the electricity market level (e.g. due to fluctuations in large-scale wind energy production) and grid operations (e.g. for congestion management and reserve capacity operations).

– Control for Grid Stability and Islanding Operation: Aims at the delivery of services by smart houses to be used by network operators to maintain or restore stability in (distribution) networks in an active manner. Here, the particular focus is on: (i) the capability to run local power networks in islanded mode and (ii) reaction of end-user systems to critical situations in the grid.

2 Field Trials

Several trials will be under realization in the course of 2010 and beginning of 2011. We consider them to represent possible constellations in the future smart grid infrastructure. In the ideal case, there would be three single instances of a common SmartHouse/SmartGrid framework. In reality, however, each field trial is bound to several – also architectural – restrictions that arise from the context in which the experiments are carried out. These restrictions result from existing partnerships and parallel related trials that the SmartHouse/SmartGrid members are engaged in. In those cases where different technological solutions have been chosen for realizing similar functionality, a comparative analysis of the technologies will be conducted at the end of the SmartHouse/SmartGrid project, with the aim of identifying the best solution for a given set of framework conditions.

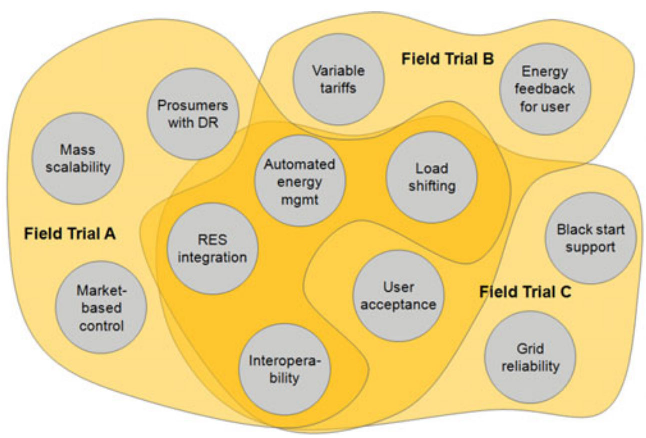

Fig. 2. Complimentary foci of the SmartHouse/SmartGrid trials

2.1 Field Trial A

The cluster of smart houses is located in Hoogkerk, a city in the Netherlands. The end-user systems integrated in the test installation consist of (any combination of) micro-CHPs, heat pumps for domestic heating and electricity intense domestic appliances. To all systems, an intelligent software agent will be associated, running for instance on a programmable intelligent meter. The agent communicates operating preferences to the aggregating level.

The main idea is to integrate existing real households and devices, but also to simulate them in order to make a large-scale test of SmartHouse/SmartGrid concepts with respect to the enterprise integration. We have to make sure that future business solutions will be able to adapt to high-volume data and still be able to deliver high-quality reliable services and near real time processing and views on the acquired information. As such, simulators will be built for several layers and will mimic their behavior by e.g. amplifying in a non-deterministic way the data acquainted from real-field i.e. the real households. A main challenge will be to integrate the infrastructure for near real-time control, requiring frequent and time-constrained communication via low bandwidth, with an infrastructure for variable tariff metering, information handling and billing, based on collection of large volumes of data on a non time-constrained base, e.g. once per month. Both application areas require a reliable and robust infrastructure that connects smart houses with enterprise systems, the so called smart grid.

The problem statement for field trial A can be described as follows: How can we connect and utilize mass scale aggregations of smart houses for support of business operation, such that the interests of different stakeholders are respected as much as possible and as fair as possible? Connection of aggregations of smart houses will focus on the smart grid infrastructure needed for communication and information exchange between the smart houses and the enterprise system(s). The main concepts that will be used are multi-agent i.e. the PowerMatcher [2] systems and web services to communicate information. The infrastructure has to support mass scale participation of 100,000 to 1,000,000 households in an enterprise business application that focuses on near real-time control of household appliances based on variable tariffs. Qualification and quantification of the interests of different stakeholders has to be made, based on energy efficiency enhancement and cost/benefit improvement.

2.2 Field Trial B

The main technical goal of field trial B is to demonstrate how private customers can be motivated to adjust their consumption by load-shifting when they are offered variable electricity tariffs on a day-ahead basis, and how to organize such a system to be applicable for a larger number of customers. The load shifting of non user-controllable loads (e.g. freezers) will be carried out automatically by a system situated at the customers premise, the ISET-BEMI+ [3]. This system comprises a computing core, switching elements for automated load switching and for load supervision (switch boxes), and a visualization functionality. The latter allows the customer to view the variable tariff and thus to manually optimize the operation of user-controlled loads (e.g. cooking appliances) in addition to the automatic optimization. Customers also receive up-to-date information on their energy consumption and cost based on at least hourly values (total) and high-resolution data based on single-device-measurement from loads connected to switch boxes. This is expected to additionally raise customers awareness on the topic of energy efficiency.

The BEMI-equipped customers are given a variable tariff by an energy supplier which operates a Pool-BEMI. The details of the variable tariffs given to the customer are currently under discussion but will be based on day-ahead hourly power prices. By operating devices in times where these prices are low, the customer gets the opportunity to optimize his energy cost. The ISET-BEMI+ automatically carries out this optimization. This shall cause an overall load shift into times where prices from energy markets are low, thus demonstrating that the cost for energy procurement carried out by the energy supplier is lowered as well. It has to be considered that energy costs per kWh generated is low in times of high infeed from generators with zero fuel cost, e.g. wind turbines. Thus, variable tariffs allow the customer to profit from price fluctuations while allowing the energy provider to shift loads such that energy from renewable sources, or in more general at times of a surplus of electricity generation, is preferably and efficiently used. Also, it is expected that this also will reduce balancing energy for deviation of customer consumption from the predicted demand and to reduce peak power in the distribution grid area considered, which again yields economical benefit for grid operator and energy supplier.

Finally a more balanced grid with reduced peak consumption will reduce "stress" in the grid, and allowing for a reduced assumption for maximum power needed in a grid. Hence, there are physical limits for load shifting which stem from restrictions of the loads parameters on one side and the willingness of customers to cooperate on the other. It is yet to learn more about such limits for load shifting given a system of ISET-BEMI+ operating in an urban grid area. The field trial is designed to provide data in order to be able to research these questions. Furthermore, the field trial will provide information and experience in order to identify architecture and technological, economic and regulatory needs for a mass roll-out of energy management systems in the future.

However, it should be noted that the proper implementation of such a field trial will also show the problems and limits that need to be considered if dealing with real customers. Not only does the acceptance of such systems by customers need to be explored, but also their degree of understanding and willingness to study and use any data provided. Not all data available is appropriate to present to an average customer without over-stressing his cooperation possibilities and willingness. Finally, through un-bundling and many competing energy and service providers in Germany, there are many stakeholders to be included in the process.

2.3 Field Trial C

In field trial C the several business cases are combined. We focus on (i) distribution grid cell islanding in case of higher-system instability, (ii) black-start support from smart houses, (iii) integration of forecasting techniques and tools for convenient participation in a common energy market platform, (iv) aggregation of houses as intelligently networked collaborations, and (v) distribution system congestion management.

The problem statement for field trial C is to identify how can the smart house support the grid in case of emergency in an energy market environment. The smart house should include some functionalities in order to deal with emergency and critical situations. This operation includes two phases: the first phase is before the unexpected event and during that phase the team of houses, to which all the customers equipped with the load controller belong to, should make some preparation actions.

The second phase is during the event where the system should decide the actions for fast restoration. This scenario suggests that the aggregator and the distribution network operator (DNO) interact with the smart houses. They should provide to the system the proper information in order to react correctly during the emergency case. However the critical part is that the network of smart houses should have a level of autonomy and decide by itself the overall system management. Furthermore since the system assumes the existence of an energy market it is obvious that the energy consumed/shed during any operation should be monitored. Here again a multi-agent system will be used i.e. the Magic system [1].

3 Discussion

Several aspects of the future SmartHouse/SmartGrid vision are analyzed in all three field trials. Other aspects are specifically tackled in one or two trials only. The most important technological goals of the SmartHouse/SmartGrid solutions, which will be similar across trials, are the following: (i) Automated energy management, (ii) Variable tariffs, (iii) Integration of renewable energy sources and (iv) Interoperability. Other aspects, such as user acceptance, the impact of energy feedback on user behavior or variable tariffs, are also relevant in all three trials, but are only investigated in a structured way in one or two trials. Besides, the analysis of some aspects are deliberately allocated to one specific trial, such as mass-scalability and market-based control (trial A) or black start support and islanding (trial C).

In the SmartHouse/SmartGrid projects, three different technologies for managing demand and supply in a way to realize the goals of an energy efficient, flexible and sustainable smart grid are developed. In this document, the commonalities and differences between the three technologies are reviewed, and conclusions for a common architecture are drawn. Table 1 summarizes the main characteristics of the three technologies PowerMatcher, BEMI and Magic while Table 2 provides an overview of the different methodologies.

Table 1. Concept comparison of technologies

	Trial A: PowerMatcher	**Trial B: BEMI**	**Trial C: Magic**
Local control	Decentralized decisions about consumption and production	Decentralized decisions about consumption and production	Decentralized decisions about consumption and production
Basis for decision-making	Centralized market equilibrium of all bids	Centralized tariff decision	Centralized negotiation of requests
Control objective	Real-time mapping of demand and supply	Shifting demand to times of low-cost supply	Mapping of demand and supply in critical grid situations
Trial specifics	Scalable architecture	User-information for manual control of consumption behavior	

As depicted in Table 1 and Table 2, it can be recognized that the common idea of the SmartHouse/SmartGrid implementation follows a unified approach: Power

Matcher, ISET-BEMI+ as well as Magic manage demand and supply on the basis of a centralized optimization tool that works with decentralized decision making. This is highly important for the acceptability of these technologies each participant keeps full control over his devices, but has incentives to align the device operation with the global status of the overall system. Several challenges have already been identified and will be investigated also during the trials, as depicted in Table 3.

Table 2. Methodology comparison of technologies

Trial A: PowerMatcher	Trial B: BEMI	Trial C: Magic
– Market-based concept for demand and supply management – General equilibrium theory – Market is distributed in a tree structure – Participants: devices, concentrators, objective agents, auctioneer – Device agents submit bids / demand and supply functions	– BEMI enables decentralized decisions based on tariff information – Decision based on local information about devices and central information about variable prices – Pool-BEMI sends price profiles – Avalanching can be avoided by giving different price profiles to different customer groups – Day-ahead announcement of price profiles	– MAS-based using JADE (negotiation-based) – Grid announces SP/BP – MG tries to agree on better prices – Maximum of internal benefit – Based on symmetric assignment problem

Table 3. Challenges per Technology

Trial A: PowerMatcher	Trial B: BEMI	Trial C: Magic
Definition of demand functions	Definition of price profiles	Fixed negotiation periods
Triggering of new rounds problem was solved using an event based market concept	High-quality forecast of customer reactions to price profiles	Scalability
Effectiveness if real-time price is not binding for the customer?	Congestion management might be limited due to lower price limit	

Each of the three technologies is based on the concept to map the consumption demand to the producible or produced energy. On the one hand, the consumed energy amount needs to be adjusted in an appropriate way. This adjustment of the energy amount to be consumed is possible by deploying several features like automatically switching on and off consuming devices or manually influencing the consumers behavior. These features are part of all the three architectures especially the automated switching of the controllable devices in the households. The control of the shiftable production of energy is in a similar way possible by means of automated on and off switching features for e.g. CHP producers.

Each of the concepts includes a central negotiation or calculation mechanism that tries to map the producible energy to the consumable energy for all sources (smart houses and production sites) within the enclosed smart grid. External production sites producing and providing a certain amount of energy can be included in the negotiation process as a fixed and non-controllable amount of energy. Therefore, the architecture of all three set-ups contains a negotiation tool or balancing tool as depicted in Figure 3.

The way how the three used negotiation or balancing tools are designed is similar from a high-level perspective, but different in the details. Each tool either collects information or forecasts the desired amounts of energy to be consumed or produced from all participating smart houses and production sites. Each tool is able to understand besides the desired energy amounts some indicators that state under which conditions the energy will be consumed or produced. One condition is used for all of the three tools: It is a piece of information about the desired price, if energy is shiftable. After having collected all offers and requests, the tool analyzes how the equilibrium can be reached under the given conditions.

One major difference between the negotiation procedures is the time interval for the repetition of the negotiations and therefore for the consideration of unforeseeable changes. The PowerMatcher and also the Magic system can work in (near) real-time. The advantage is that for unforeseeable demand or production requests a short reaction time can be expected to map the complementary production or demand requests. The BEMI technology, in contrast, works on a time scale of a day, where dayahead considerations of production and consumption patterns are done in order to define the price levels that act as decision guiding signals. Intraday redistribution of price profiles is possible, but not done on a regular basis.

Finally, the field trials will demonstrate if a lower repetition of equilibrium calculations is sufficient. The near real-time negotiation causes a high degree of scalability and performance requirements. The PowerMatcher tool does the real-time negotiation using a multi-level approach realized by the use of agents clustering several smart houses or concentrator levels stepwise. For a lower number of smart houses, the concept of real-time could scale easily, but for a higher number of smart houses the concept has to be proved.

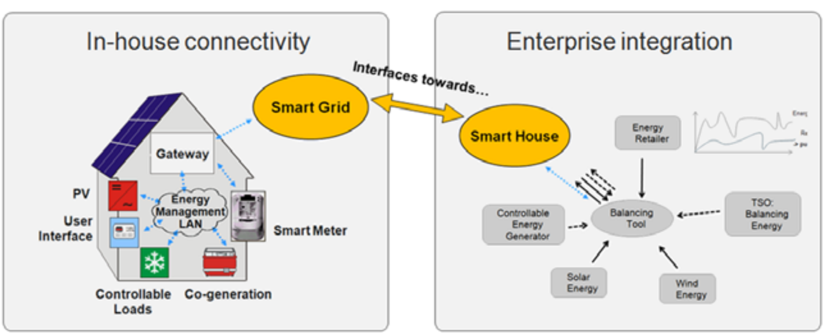

Fig. 3. Connection between the in-house architecture and its integration within enterprise processes

Decentralized decisions about consumption and production are made by all of the three field trials. This fact is the main common part of the three architectures. The control of switching on or off of a certain producing or consuming device is always done within the smart house itself. Even when for the smart house a central control is established, the decision remains within the house. Of course the decision is guided by a centralized determined and provided signal (e.g. virtual price signal or a real-time tariff/price structure or direct control signals).

Historical information about the consumed energy and/or the produced energy within the smart houses and the historical price and cost information are all provided and displayed within the smart houses(i.e. per metering point). This allows the customer to adapt his behavior to the current situation in the power grid.

It is still unresolved whether all energy-consuming appliances should be integrated into the local energy management within the smart house. A quite realistic vision is that only some appropriate appliances are connected to the BEMI, PowerMatcher or Magic system. Amongst those, there can be identified devices that run a user-prepared program (i.e. washing machine), devices with thermal storage(i.e. cooler, CHP plant) or dimmable devices. Those appliances that the customer will always want to consume instantly (like, e.g., entertainment, lighting or cooking) will probably be controlled solely by the customer, just like today. An energy information portal which delivers all price and consumption data to the end customer can then give the information necessary for deciding about the operation of devices that are not integrated into the energy management. The customer is made aware of the current price, so that he can manually optimize the timing of his energy consuming activities.

4 Conclusions

Innovative technologies and concepts will emerge as we move towards a more dynamic, service-based, market-driven infrastructure, where energy efficiency and savings can be facilitated by interactive distribution networks. A new generation of fully interactive Information and Communication Technologies (ICT) infrastructure has to be developed to support the optimal exploitation of the changing, complex business processes and to enable the efficient functioning of the deregulated energy market for the benefit of citizens and businesses.

We do not expect that an one-size-fits all technology will prevail in the market; we rather consider that several of them will coexist and the real challenge would be to integrate them in a global ecosystem that will deliver the envisioned smart grid benefits. To this end the SmartHouse/SmartGrid project has designed and will realize in real world three field trials, each of them testing several aspects vital towards making the smart grid vision a reality. We have shown here in detail the motivation behind them, the considerations but also the challenges that may lie ahead. On the basis of the results and experiences from these field experiments, we will define a roadmap focused toward a mass- market application.

Acknowledgment

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E-ENERGY 2010

Technical Session 4: Microgrids and Energy Management

Demand Side Management in Smart Buildings Using KNX/EIB

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Abstract. This paper aims to present the development, design and analysis of a control scheme named Thermal Model Predictive Control for Demand Side Management Cooling Strategies. The control is implemented on a building in Athens whose thermal model is derived using the Finite Difference Calculation Method. The development and testing of the thermal model is implemented on-line while the predictive controller for cooling strategies is analysed through simulation results. The advantages of the scheme are described, including the ability of the predictive controller to consult the users for energy and cost savings during the peak demand, in an acceptable way by them regarding the thermal comfort issue. Smart Grids and Smart Microgrids can communicate with this controller for increasing their efficiency.

Keywords: Demand Side Management, SCADA, Smart Buildings, KNX/EIB.

1 Introduction

Demand Side Management (DSM) is a measure taken by electric utilities to influence the amount or timing of customers' energy demand, in order to utilize scarce electric supply resources more efficiently. According to IEA Demand Side Management working group, the term “demand response” refers to a set of strategies which can be used in competitive electricity markets to increase the participation of the demand side in setting prices and clearing the market [1]. The net effect of the demand response is to ease system constraints and to generate security and economic benefits for the market as a whole. As far as the thermal comfort is concerned in order to reach the desired indoor temperature and humidity, the heating/cooling demand should be regulated thus satisfying a DSM strategy. In the framework of this paper “Thermal Model Predictive Controller” is developed implementing super cooling strategies, through which a building or a building part is pre-cooled during low peak periods achieving peak shaving in an acceptable way by the users regarding the thermal comfort issue during summer.

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2 Buildings Description

DSM strategies have been considered in several buildings in Athens and in Kassel. A building in Athens, Greece, has been chosen for implementing the Thermal Model Predictive Controller for DSM actions. It is called Georgiadis building, it is named after its owner, it is located in Gerakas city and the KNX/EIB technology has been installed in it, where EIB stands for European Installation Bus. A DVD Club is situated at the basement of the building. Furthermore, a bookshop and a shop which sells desalination plants are situated in the ground floor. Finally, an apartment with an attic is in the first floor. The bookshop has been chosen as the place to accommodate the experiments of this paper due to the owner‟s special interest to save energy in this building part. The Georgiadis building is depicted in the following Figure 1, where the DSM strategies have been considered.

Fig. 1. Georgiadis Building in Gerakas of Athens in Greece

The Thermal Model Predictive Controller is developed on a PC at the first stage. This development requires a communication system in order to acquire all the needed data and measurements from the building and to process them in on-line mode. The controller should be economically attractive and for this reason the following requirements have to be defined:

- Only existing on the market system components are applied; no special designs and developments.
- Basis for the design is a „normal‟ building part (bookshop) and no any „super installation . Research results should be able to be transferred economically into a product.

These requirements are achieved by concatenation of different networks that exist in modern buildings (Figure 2) [2]. However, today they exist in parallel without any concatenation among each other.

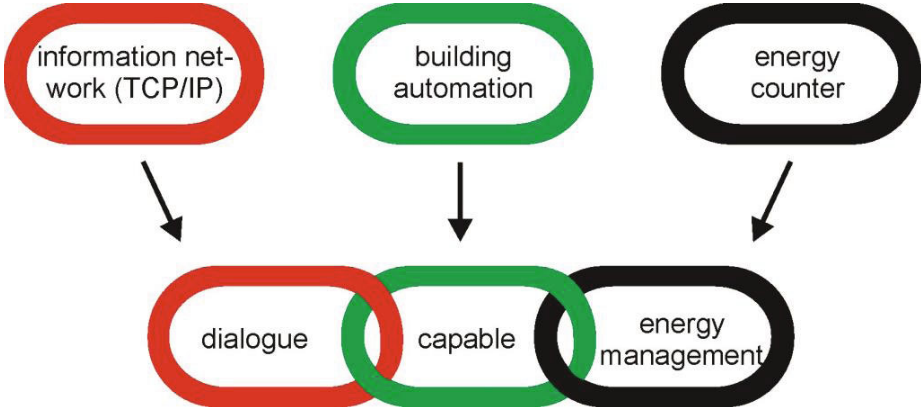

Fig. 2. Chain of different networks to obtain Thermal Model Predictive Controller

The realization of the communication process between the Thermal Model Predictive Controller, the building and the user are very important for the acceptance on behalf of the latter and the function of the system. Especially, the remote monitoring and control through Intranet even more via Internet is one of the goals of this thesis. At this point, we should take into consideration the fact that almost all building users have access to a PC that is linked to an Intranet or the Internet which consists of an ideal communication interface for building automation, as well. Therefore, building automation is linked to the information network TCP/IP. Here the building automation is based on KNX/EIB technology, where EIB stands for European Installation Bus.

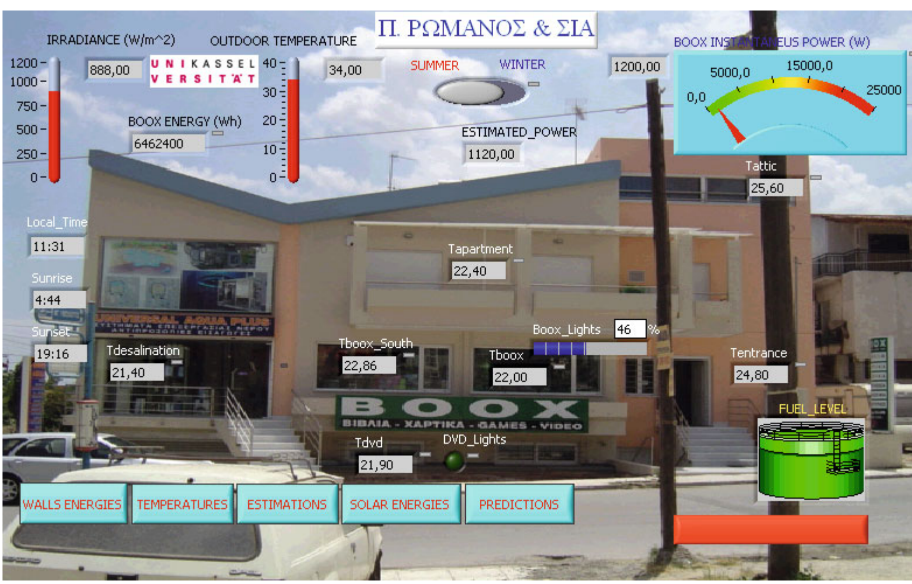

Fig. 3. The SCADA main window page

The following Figure 3 depicts the main window of the SCADA, where all indoor and ambient temperatures are monitored as well as the energy consumption and the power of the bookshop. The local time and the solar irradiance on a horizontal surface are also presented on it. With the option "WALLS ENERGIES", Inflow, Outflow and Stored Energies of the bookshop are viewed, while the predicted indoor temperature and the measured temperature of the bookshop are shown when the "PREDICTIONS" key is chosen.

The absorbed solar radiation by the surface of the outer north wall and the windows, which are also located to the north and by the roof part made of glass are depicted when the tab "SOLAR ENERGIES" is pressed, while the estimated instantaneous power and the measured one are shown by choosing "ESTIMATIONS". Finally, a graphical view of all temperatures is presented by pressing "TEMPERATURES".

3 Concept

The aim of a DSM strategy is the reduction of the peak demand. Taking into account the fact that the peak demand is mainly caused by the operation of air-conditioning units during summer, the DSM cooling strategy intends to reduce the consumption of these units during the peak periods. However, this reduction should not be against the thermal comfort. This means that the indoor temperature and the humidity should not be increased more than a specified limit, so that the users still feel comfortable in it. The Thermal Model Predictive Controller is based on the Thermal Model, which is used for the prediction of the indoor temperature during pre-cooling and DSM phases. In addition, it calculates the heat fluxes of the walls and the Inflow, Outflow and Stored energies of the examined room. The Thermal Model plays a significant role in order to define the duration of the pre-cooling phase. The pre-cooling period is independent from the indoor temperature reduction [2].

The TMPC-DSM controller operates in three phases every day. The period in which the TMPC-DSM controller pre-cools a room is called Pre-cooling period or Pre- cooling phase, while the period in which the TMPC-DSM controller acts to air- conditioning units during the peak demand is called DSM phase. Moreover, the period in which the TMPC-DSM controller does not operate or act to air-conditioning units and only receives information from the Power Predictor is called Inactive phase. The TMPC-DSM controller can communicate with the operator of a Smart Grid or a Smart Microgrid for maximizing end-use efficiency.

4 Absorbed Solar Radiation

An Anisotropic Solar Radiation diffuse model based on the Hay-Davies-Klucher- Riendl (HDKR) model is applied to the bookshop of the examined building [3]. The HDKR model estimates the absorbed beam, diffuse and ground reflected solar radiation by the surface of the outer wall, the windows and a part of the roof of the bookshop, which is made by glass. The following Figure 4 depicts the measured Solar Incident Radiation on a horizontal surface by the ISET-Sensor–monocrystalline pyranometer and the absorbed radiation by the surface of the northern wall, the windows and the roof glazing in the bookshop from 18/9/2005 until 25/9/2005.

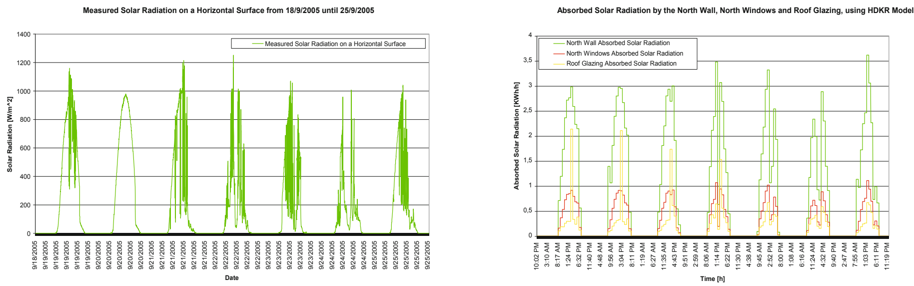

Fig. 4. Measured Solar Radiation on a Horizontal Surface (left) and the absorbed radiation by the surface of the northern wall, the windows and the roof glazing in the bookshop (right) from 18/9/2005 until 25/9/2005

5 Thermal Model

The Dynamic Thermal Model of the Bookshop is developed based on the Finite Difference Calculation (FDC) Method [4]. Inflow Energy is considered to be the energy resulting from the heat flux due to the difference between the indoor temperature and the surface temperature of the inner wall. The internal heat sources with the rates of heat transfer from the air-conditioning units leave the shop, interact to the indoor and inner surfaces temperatures and are therefore assumed as Inflow Energies.

Respectively, Outflow Energy is the thermal energy due to the difference between the surface temperature of the outer wall and the ambient temperature. The solar radiation is applied onto the surface of the outer northern wall part and is also considered as Outflow Energy.

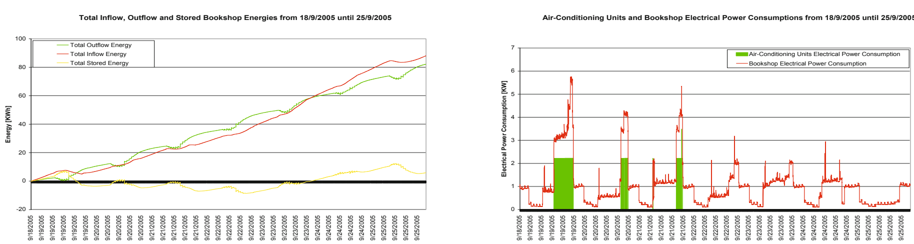

Fig. 5. Total Inflow, Outflow and Stored Energies of the Bookshop (left) with the electrical power consumption of the air-conditioning units in comparison with the bookshop electrical power consumption (right) from 18/9/2005 until 25/9/2005

The Total Inflow, Outflow and Stored Energies of the Bookshop with the electrical power consumption of the air-conditioning units in comparison with the bookshop electrical power consumption are depicted in Figure 5. Figure 5 verifies the fact that the thermal model is based on the energy balance equation. Obviously, the peak demand is mainly caused by the operation of the air-conditioning units during summer, it occurs at 19:00 and its duration is 2 hours, which is the prediction horizon of the DSM phase.

6 Analysis

The pre-cooling period is 26 minutes at maximum [2]. Therefore, the prediction horizon of the pre-cooling phase is also 26 minutes and is reduced by 47 seconds at every sample. The maximum desired predicted indoor temperature is defined to Tin_max = 27°C. Figure 6 depicts the predicted indoor temperatures, using the TMPC-DSM controller, during the Pre-cooling and DSM phases in comparison with the predicted and measured indoor temperatures on 19th, 20th and 21st September 2005. Three different cases are investigated respectively these days, when the bookshop is opened during afternoon. The predicted indoor temperatures are obtained by using the Finite Difference Calculation Method.

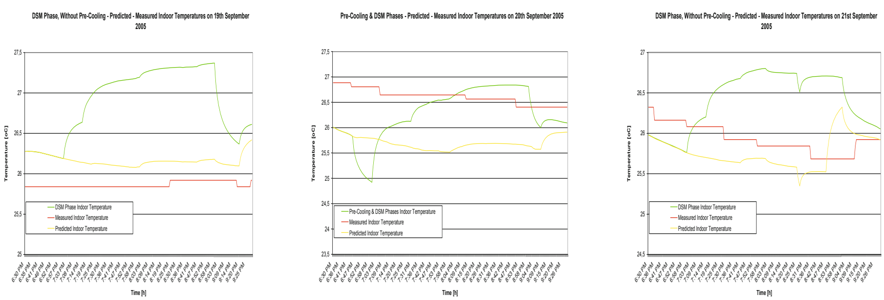

Fig. 6. Predicted indoor temperature during the Pre-cooling and DSM phases in comparison with the predicted and measured indoor temperatures on 19th (left), 20th (center) and 21st (right) September 2005

More specifically, Figure 6 (left) illustrates that the SCADA suggests the user to accept the indoor temperature which reaches 27,5°C on 19th September. The SCADA informs the user that if the indoor temperature is decreased to 27°C during the peak demand for that day, then an additional electric energy consumption of 1,67 KWh will occur. That will cost him €0,12 due to the increased operation of the air- conditioning units during the Pre-cooling and DSM phases. It is assumed that the user accepts this increase of the indoor temperature in our simulation results. If he does not accept it, the Thermal Model Predictive Controller

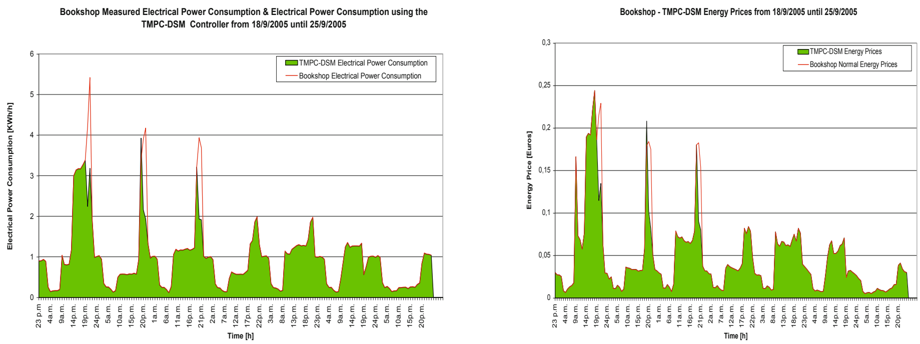

Fig. 7. Measured and prices of electrical power consumption of the bookshop in comparison with that from applying the DSM cooling strategy

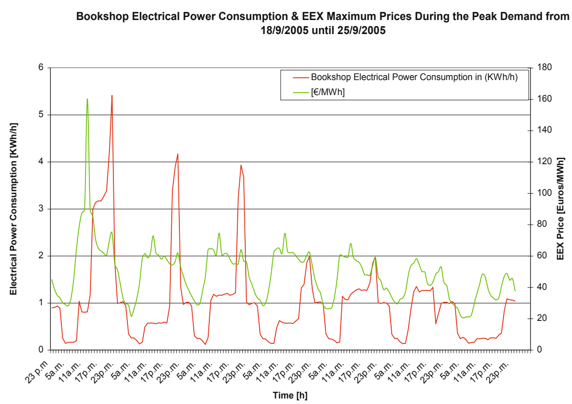

Fig. 8. Measured electrical power consumption of the bookshop and EEX prices where the maximum ones occur during the peak demand

will be deactivated and the indoor temperature will be regulated by the KNX/EIB thermostat. In this case, the SCADA will inform him about the economic benefits from applying the DSM cooling strategy.

Furthermore, according to the indoor temperature prediction during the peak period, the Pre-cooling Phase is needed only on 20th September as it is shown in Figure 6 (center). Both, the Pre-cooling and DSM optimization algorithms are applied for that day. Finally, Figure 6 (right) depicts that the predicted indoor temperature reaches 27^{o}C on 21st September during the DSM phase and without the use of the Pre-cooling phase. Only the DSM optimization algorithm is applied for this day.

The analysis of Figure 7 shows that the electric energy consumption of the bookshop is 93.180 Wh with €4,94 cost from 18/9/2005 until 25/9/2005. By applying the DSM Cooling Strategy, the energy consumption is reduced to 81.810 Wh with €4,43 cost for the same period. Therefore, energy savings of 12,21% with cost savings of

10,28% are achieved by applying the DSM cooling strategy using the TMPC-DSM controller. In the case where the maximum EEX prices occur during the peak demand as it is shown in Figure 8, the following Figure 9 depicts the cost profile of the energy consumption of the bookshop with the maximum prices duri ng the electric peak demand and the prices which will be derived if the DSM cooling strategy is applied from 18/9/2005 until 25/9/2005 [5]. In this case the energy savings are the same as in Figure 7; however, the cost of energy is reduced from €5,67 to €4,93 by using the TMPC-DSM controller; attaining cost savings of 13,03%.

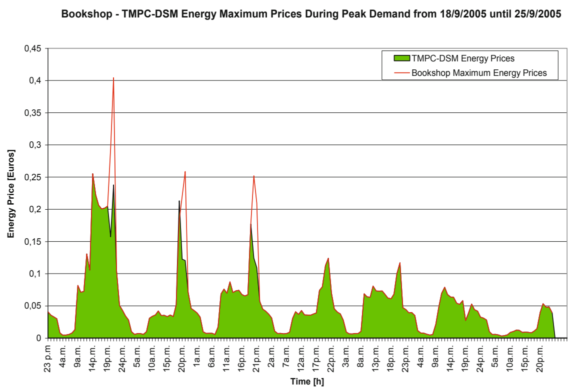

Fig. 9. Cost profile of the measured electric energy consumption of the bookshop with the maximum prices during the peak demand and the prices which will be derived if the DSM cooling strategy is applied from 18/9/2005 until 25/9/2005

Table1 illustrates the total with the daily energy and cost savings, by the application of the TMPC-DSM controller.

Table 1. Total and daily energy and cost savings using the TMPC-DSM controller

Date	Without TMPC-DSM (KWh)	TMPC-DSM (KWh)	Energy Savings (%)	Without TMPC-DSM (€)	TMPC-DSM (€)	Cost Savings (%)
19/9/2005	40,2	36	10,44	2,75	2,45	11,05
20/9/2005	24,14	20,73	14,14	1,29	1,09	15,96
21/9/2005	28,84	25,08	13,05	1,63	1,4	14,05
Total	93,18	81,81	12,21	5,67	4,93	13,03

7 Conclusions

A simplified thermal model based on FDC, assuming that there is one-dimensional conduction in x, can describe adequately the dynamics of the system. The application of Thermal Model Predictive Control for Demand Side Management Cooling Strategies proves that energy saving of 12% is feasible. The cost savings by using the TMPC-DSM controller depend on the prices of the energy during the peak periods. It is concluded that cost savings about 13% can be achieved. Smart Grids and Microgrids can communicate with the controller for increasing their efficiency.

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Smart Grids: Importance of Power Quality

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Abstract. The transformation from a centralized electrical grid system to a distributed electrical system via smart grids has drawn tremendous attention. Smart grids introduce new technological concepts that require interconnection between sensitive electrical and electronics components. It is important to maintain electromagnetic compatibility between these components to assure uninterrupted and high quality supply of electricity in future under deregulated grid set-up. Realization of smart grids requires balance between two main trade-offs: efficiency and reliability. Often reliability is given priority however it is not always guaranteed. Power quality is one of the important aspects responsible for smart grids reliability and should not be neglected. An adequate power quality guarantees the necessary compatibility between all equipments connected to grids. Henceforth, in this paper presents a review on smart grids structure, significance and requirement of power quality, and different levels of power quality issues in smart grids.

Keywords: smart grids, power quality, levels of power quality, pricing, and energy internet.

1 Smart Grid: Opportunities and Vision

The review and research effort on smart grids and its aspect of power quality is based on current developments and well over 10 years of experience with CIMGE [1]. The Consortium for the Intelligent Management of the Electric Power Grid (CIMEG) was responsible for developing intelligent approaches to defend power systems against potential threats. CIMEG was led by Purdue University and included partners from The University of Tennessee, Fisk University, Tennessee Valley Authority, and ComEd (now Exelon) [1].

The importance of energy and its delivery infrastructure for humanity can never by overstated. The availability of resources (especially fossil fuels), determines that massive generation of energy, such as electricity, has been centralized. This has been the feature of the traditional electrical grid system and relies on important central power stations; thereby making difficult to integrate distributed energy sources and microgrid [2]. They most often only support one-way power flow and communication, i.e., from the utility to consumers. Further, utilities can barely track how energy is consumed across the grid and, as a consequence, have no possibility to provide any pricing incentive to balance power consumption over time. As utilities can only accommodate increases in demand up to a certain level, they are forced to rely on additional peak load

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power plants to cope with unexpected demand increases [3]. This is highly expensive and potentially polluting, particularly if plants use fossil fuels [4].

The above mentioned characteristics of a traditional electrical grid are its shortcomings. As a result, transformation from a centralized, producer controlled network to the one that is less centralized and more consumer-active has become imperative. The transformation that will promise [5]:

1. The change of industrys entire business model and
2. Its relationship with all stakeholders involving and affecting utilities, regulators, energy service providers, technology and automation vendor, and all consumer of electric power.

The vision of smart grids promises to make transformation in transmission, distribution, and conservation of energy possible by bringing philosophies and technological concepts that enabled internet to the utility and the electric grid. It employs digital technologies to improve transparency and to increase reliability as well as efficiency of electrical network. Tsoukalas et al. [6] showed that the progress made on smart grids has enabled novel and meaningful discussion on a full scale energy internet. The assumptions, the architecture, and the technical requirements essential for realization from smart grids to energy Internet is presented in [6]. Smart grids also provides/enables customers to react dynamically to changes in electricity prices. The implementation of such programs may reduce energy costs and increase reliability as shown in [7].

It is extremely difficult to present a unique definition of smart grids as the concept involve various components and concepts. Table 1 gives some of the selected definitions of smart grids. From Table 1, we realize that smart grid can be defined in two different ways: it is either defined from a solution prespective ("What are the main advantages of the grid?") or from a components' prespective ("Which components constiture the grid?").

From a solution perspective, the smart grid is characterised by:

- **Intelligence** – capable of sensing overloads and rerouting power to prevent or minimize a potential outrage.
- **Efficient** – capable of meeting increased consumer demand without adding infrastructure.
- **Accommodating** – accepting energy from virtually any fuel source including solar and wind as easily and transparently as coal and natural gas; capable of integrating all better ideas and technologies - energy storage technologies.
- **Motivating** – enabling real-time communication between the consumer and utility so consumers can tailor their energy consumption based on individual preference like price.
- **Opportunistic** – creating new opportunities and markets by means of its ability to capitalize on plug and play innovation wherever and whenever appropriate.
- **Quality-focussed** – capable of delivering the power quality necessary - free of sags, spikes, disturbances, and interruption.
- **Resilient** – increasingly resistant to attack and natural disaster as it becomes decentralized and reinforced with smart grids security protocols.

Table 1. Selected Smart Grid Definitions

Organization/ Author	Grid / Concept	Definition
Climate Group [3]	Smart Grid	A "smart grid" is a set of software and hardware tools that enable generators to route power more efficiently, reducing the need for excess capacity and allowing two-way, real time information exchange with their customers for real time demand side management (DSM). It improves efficiency, energy monitoring and data capture across the power generation and Transmission & Distribution network.
Adam and Wintersteller [4]	Smart Grid	A smart grid would employ digital technology to optimize energy usage, better incorporate intermittent "green" sources of energy, and involve customers through smart metering.
Miller [8]	Smart Grid	The Smart Grid will: (i) Enable active participation by consumers; (ii) Accommodate all generation and storage options; (iii) Enable new products; services and markets; (iv) Provide power quality for the digital economy; (v) Optimize asset utilization and operate efficiently; (vi) Anticipate and respond to system disturbances (self-heal); (vii) Operate resiliently against attack and natural disaster.
Franz et al. [9]	eEnergy	Convergence of the electricity system with ICT technologies.
EPRI [10]	Intelli- Grid / Concept	The Intelli-Grid vision links electricity with communications and computer control to create a highly automated, responsive and resilient power delivery system.
DOE [11]	Grid 2030	Grid 2030 is a fully automated power delivery network that monitors and controls every customer and node, ensuring a two-way flow of electricity and information between the power plant and the appliance, and all points in between. Its distributed intelligence, coupled with broadband communications and automated control systems, enables real-time market transactions and seamless interfaces among people, buildings, industrial plants, generation facilities, and the electric networks.

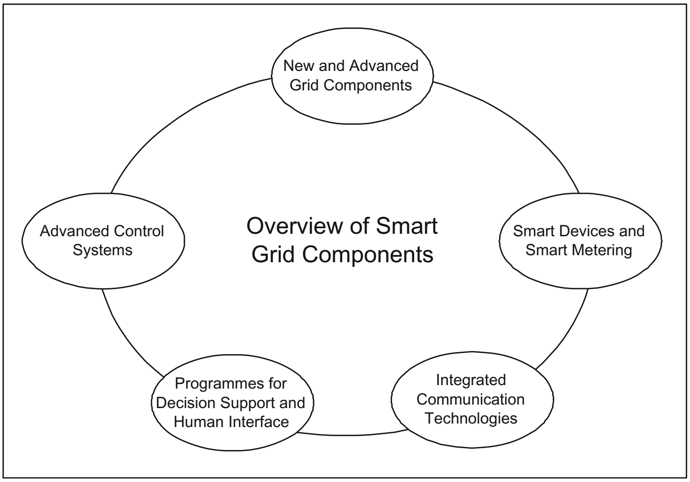

Fig. 1. Main component of a smart grid. Source: DOE, 2003, EPRI, 2006

From a technical components perspective, the smart grid is a highly complex combination and integration of multiple digital and non-digital technologies and systems. Figure 1 provides an overview of the main component of a smart grid: i) new and advanced grid components; ii) smart devices and smart metering; iii) integrated communication technologies; iv) programmes for decision support and human interfaces; and v) advanced control systems. These individual grid components do not need to be centralized, but can have more control stations and be more highly integrated.

In the ongoing discussion on smart grids, we observe that a complete realization of the smart grid presents several challenges. One of the several challenges that cannot be ignored is the need to ensure highest level of power quality. It is desirable to consider power quality not only from the electronic components usage in electrical network but also for the design of regulatory system for electrical networks. Therefore, this paper focuses on the satisfactory function of equipments for smart grid with respect to electromagnetic disturbances, i.e. power quality and types of power quality in the following sections.

2 Power Quality

Smart Grids results in drastic increase in the use of electronics in the power system. This requires satisfactory function of electrical and electronic equipments vital for realization of a robust smart grid structure. It opens up the opportunity for an evermore sophisticated electrical system containing lots of electronic devices both controlling the power flow itself, so called power electronics, and electronics controlling the power electronics and other devices.

Power quality is one of the important aspects of smart grid and should not be neglected. An adequate power quality guarantees the necessary compatibility between all equipment connected to the grid. It is therefore an important issue for the successful and efficient operation of existing as well as future grids. The "smart" properties of future grids poses challenges for new approaches to achieve efficient management of power quality. Especially the advanced communication technologies can establish new ways for selective power quality management. Power quality covers two groups of disturbances: variations and events [24]. While variations are continuously measured and evaluated, events occur in general unpredictable manner and require a trigger action to be measured. Important variations are: slow voltage changes, harmonics, flicker, and unbalance. Important events are rapid voltage changes, dips, swells and interruptions. The actual power quality (i.e. the disturbance levels) results from the interaction between the network and the connected equipments.

3 Power Quality Issues

Bollen et al. [13] discussed different types of power quality issues in smart grids which includes: (i) emission by new device; (ii) interference between devices and power-line communication; (iii) allocation of emission limits; (iv) improving voltage quality; (v) immunity of devices; and (vi) weakening of the transmission grid.

3.1 Emission by New Device

Smart grids introduces growth both in production at lower voltage levels (distributed generation) and in new types of consumption (for example, charging stations for electric vehicles, expanded high-speed railways, etc.). Some of these new types of consumption will emit power-quality disturbances [14, 15, 16, 17], for example harmonic emission of the lower odd integer harmonics (3, 5, 7, 9 etc).

3.2 Interference between Devices and Power Line Communication

Communication between devices, customers, distributed generators, and the grid operator is a salient feature of smart grid. Many types of communication channels are possible. Power-line communication might seem an obvious choice due to its easy availability, but choosing power-line communication could introduce new disturbances in the power system, resulting in a further reduction in power quality. Depending on the frequency chosen for power line communication, it may also result in radiated disturbances, possibly interfering with radio broadcasting and communication. It is also true that modern devices can interfere with power-line-communication, either by creating a high disturbance level at the frequency chosen for power-line communication, or by creating a low-impedance path, effectively shorting out the power-line communication signal [18].

3.3 Allocation of Emission Limits

In traditional grids, the number of existing customers and expected future customers to be connected to the grid is generally known. Thus, the total amount of acceptable voltage distortion is divided over all existing and future customers. As a result, for each new customer a so-called emission limit is allocated [19]. With smart grids, the amount of consumption will have no limit. This continued growth in both production and consumption could lead to the harmonic voltage distortion becoming unacceptably high. Also the number of switching actions will keep on increasing and might reach unacceptable values. As a result, the system strength is no longer determined by the maximum amount of consumption and/or production connected downstream, but by the total amount of harmonic emission coming from downstream equipment.

3.4 Improving Voltage Quality

One of the aims of smart grids is to improve the performance of the power system (or to prevent deterioration) without the need for large investments in lines, cables, transformers, etc. From a customer viewpoint, the improvements can be in terms of reliability, voltage quality or price. The only voltage-quality improvement expected to be made by smart grids in the near future would be a reduction in longer-term voltage-magnitude variations. In theory, both under-voltages and over-voltages might be mitigated by keeping the correct local balance between production and consumption [20, 21]. The same balance between "production" and "consumption" can in theory also be used for the control of harmonic voltages. Smart grid communication and control techniques, similar to those used to balance consumption and production (including market rules), could be set up to reduce harmonic emissions. This could solve the growing harmonic emission issue with growing amounts of production and consumption.

3.5 Immunity of Device

Simultaneous tripping of many distributed generators due to a voltage-quality disturbance (like a voltage dip) is the subject of active discussion [22, 23]. As smart grids attempts to maintain a balance between production and consumption, mass tripping of consumption could have similar adverse consequences.

3.6 Weakening of the Transmission Grid

The increased use of distributed generation and of large wind parks will result in a reduction of the amount of conventional generation connected to the transmission system. The fault level will consequently be reduced, and power-quality disturbances will spread further. This will worsen voltage dips, fast voltage fluctuations (flicker) and harmonics. The severity of this has been studied for voltage dips. The conclusion from the study is that even with 20% wind power there is no significant increase in the number of voltage dips due to faults in the transmission system [24].

4 Conclusion and Future Work

Smart grids can enable more renewable and efficient use of electricity. It is expected to boost an increased use of electronically based equipment in the electrical power system. Most of these electronic components are highly sensitive to electromagnetic disturbance. Replacement and maintenance of such components is an expensive affair. Hence it is important to maintain power quality level both in current and future grids. The issue of power quality at different levels and the challenges associated with each level were discussed. Thus new development requires new approaches and perspectives to address the issue of power quality in smart grids.

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Development of a Simulation Tool for Evaluating the Performance of the Pilot Microgrid at Gaidouromantra-Kythnos

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Abstract. The concept of "Microgrid" is one of the most promising architectures expected to support the transition from present to future Electricity Grids by integrating large amounts of Renewable Energy Sources. The numerous benefits of microgrids have attracted attention and during the last decade several projects and researches have focused on this field. Within different European projects the pilot microgrid located at Gaidouromantra, in Kythnos island was constructed in order to electrify a number of vacation houses. In this paper, a simulation model for this microgrid together with some simple guidelines for modeling such systems are presented. The model was developed for testing the system performance under different operating conditions as a subtask of the FP6 EU project More-Microgrids. Specifically, the selected mathematical models and assumptions are presented. In addition, simulation results and discussion of them are given compared also with real data measurements which validate the model accuracy.

Keywords: Microgrids, Simulation, Renewable Energy Sources, Distributed generation, Photovoltaics.

1 Introduction

The need for increased penetration from RES (Renewable Energy Sources) as well as the transition from the current to the future Electricity Systems has led to research of alternative technologies and architectures which will support and allow a smooth change into the future power systems by exploiting at the maximum possible degree the benefits from RES and DER (Distributed Energy Resources), reducing also the related problems [1]. One of the most interesting and promising architectures, expected to play critical role in the next years is the 'microgrid'. By definition, microgrids are parts of the LV (Low Voltage) distribution grid with some specific features as mentioned in [2-4]:

- Incorporation of different types of small power sources such as micro-turbines, fuel cells, PVs (PhotoVoltaics), etc. called MicroSources, together with storage devices, (i.e. flywheels, energy capacitors and batteries), and controllable loads.

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- They are interconnected to the MV (Medium Voltage) distribution grid through transformers and static switches and due to this they can also operate in isolated mode, in case of faults in the upstream network.
- From the customer's point of view, microgrids can provide both thermal and electricity needs, and in addition enhance local reliability, reduce gas emissions, improve power quality by supporting voltage and reducing voltage dips, and potentially minimize costs of energy supply.

A pilot microgrid system, which is used to electrify a cluster of houses, is located in Gaidouromantra-Kythnos [5]. Specifically, it electrifies 12 vacation houses and one control room in a small valley in Kythnos, an island in the cluster of Cyclades situated in the middle of the Aegean Sea. The installation of the system began in 2001, as part of the projects PV-MODE, JOR3-CT98-0244 and MORE, JOR3CT98-0215. Some of the most important features of the system are the following:

- The system is permanently islanded because there is no physical connection with the public utility.
- The main energy producers are PVs.
- The consumption profile deviates from normal household profiles because the houses are used only in holidays and equipped with high efficiency loads.

In the framework of the project More-Microgrids the system was upgraded and used as test field for investigation of different control strategies. In addition, one of the project subtasks included the development of a simulation model for testing the operation of the microgrid. This tool provides capability of investigating the operation under different production or consumption scenarios offering versatility regarding the system configuration. In addition this model can be used for testing alternative technologies before used in the real system (e.g. control strategies, connection of extra sources and loads, configuration changes etc.). Due to this, the model can be used not only for power flow analysis but potentially for dynamic tests. In this paper, the selected mathematical models with all necessary assumption are described. The presented assumptions can be used as guidelines for designing such tools. Moreover, some key results from 24-hour simulation tests are given, and also compared with real data in order to deduce the model accuracy.

2 System Configuration, Model Characteristics and Assumptions

2.1 System Configuration

The power system of Gaidouromantra covers the needs of totally 13 houses. The main parts of the microgrid are briefly described below:

- PV generators: The system includes 7 PV panels with 11kWp total installed power.
- Two Lead-Acid (FLA) Battery banks, with 1000Ah/48V (main), and 480Ah/60V (secondary). The main system is managed through three single phase battery inverters (SMA-SI5048) while the secondary through one single phase inverter (SMA-SI4500). During the day, the two storages are connected together at the AC side. During the night, the two banks are disconnected and the secondary system

covers the control and monitoring equipment needs. The 3-phase configuration and the interconnection between the main and the back-up system are changeable according to each project requirements.

- Three-phase, 9kVA diesel back-up generator which is controlled by the Battery Management System (BMS) when State Of Charge (SOC) <30%.
- Loads (refrigerators, lamps and dwelling pumps) represented as ohmic and inductive constant and programmable loads.
- The microgrid includes Load Controllers for protection against overloading or extreme battery discharge. These devices are triggered from the frequency and shed loads when frequency goes under 49,14Hz. The load reconnection takes place at least two minutes after the frequency restore, in a random order to prevent instant reconnection of all the consumers. It is worth mentioning that in the frame of More-Microgrids a new generation of Intelligent Load Controller was installed in conjunction with the already existing equipment. These devices offer a number of capabilities regarding load and source management but their operation was not modeled in the specific study.

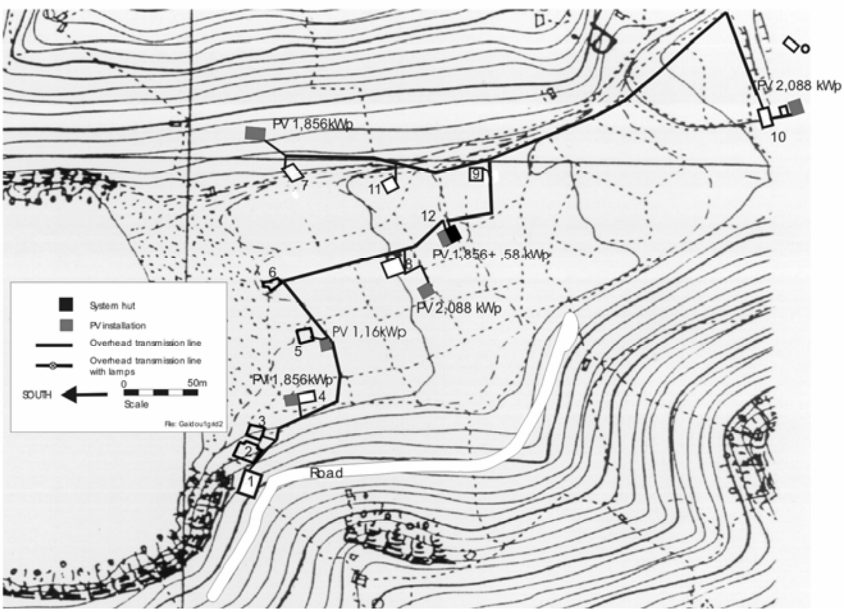

Fig. 1. The pilot microgrid located at Gaidouromantra, Kythnos

2.2 Main Features of the Developed Simulation Model

As it is evident the studied system presents a complexity due to the number and variety of parts and due to this, during modeling a set of parameters and features should be considered as more critical. This study focuses on some specific characteristics which were finally integrated in this model. Namely:

- The microgrid was modeled in 3-phase configuration but it can be changed to single phase with minor modifications.
- Each PV panel together with its inverter was modeled as taking into account the effects of irradiance and temperature. Every PV system includes MPPT (Maximum Power Point Tracking) algorithm based on the open-circuit voltage calculation. In addition, the ability of power derating versus frequency was modeled. This feature is used in order so as to prevent battery overcharge.
- Regarding batteries the selected model includes calculation of the terminal voltage, remaining Ampere-hours and maximum available capacity.
- The battery inverters were modeled as separate blocks into account their ability for grid-forming or grid-tied operation, battery SOC calculation and battery management. The latter is divided into frequency regulation according to the battery SOC and selection of the appropriate battery charging phase.
- The diesel genset was modeled as a simplified linear source with load-depended variable frequency.

2.3 Basic Assumptions

The model development requires some assumptions, which are necessary in order to reduce as much as possible model complexity, simulation time and burden of calculations. In order to obtain results for some days of operation a number of crucial simplifications were regarded:

- Use of continuous linear sources (current or voltage) instead of detailed Switch Mode Power Converter models because the switching behavior in software simulation tools increases dramatically the simulation time and it was considered out of the scopes of our study.
- Calculations by using phasors instead of instant values. This approach increases considerably the simulation speed because the electric quantities are treated as DC instead of AC values.

3 Model Development

Based on the aforementioned assumptions separate models for each part of the microgrid were developed. Each subsystem is described in the next lines.

3.1 PV System Model

The selected PV model for our study is the interpolation model [6] which is advantageous compared with the parametric one, because it involves parameters given by the manufacturers' data sheet while it involves the irradiation and temperature effects. The basic equation set describing the I-V characteristic is:

$$I = I_{SC}\left[1 - C_1\left(\exp\left(\frac{V_R}{C_2 V_{oc}}\right) - 1\right)\right] + D_I \tag{1}$$

$$C_1 = \left(1 - \frac{I_{mp}}{I_{sc}}\right)\exp\left(-\frac{V_{mp}}{C_2 V_{oc}}\right) \text{ and } C_2 = \left(\frac{V_{mp}}{V_{oc}} - 1\right)\Big/\ln\left(1 - \frac{I_{mp}}{I_{sc}}\right) \tag{2}$$

$$V_R = V + C_{TV}\left(T - T_{ref}\right) + R_s D_I \text{ and } D_I = C_{TI} G\left(T - T_{ref}\right) + I_{sc}\left(G - 1\right) \tag{3}$$

where: V_{mp}=MPP Voltage, I_{mp}=MPP Current, V_{oc}=Open Circuit Voltage, I_{sc}=Short Circuit Current, G=Solar Irradiance, T=Cell Temperature, T_{ref}=Reference Temperature(25°C), C_{TI} and C_{TV}=Coefficients of Isc and Voc variation depending on temperature, R_s=Series Resistance.

In addition to the PV modules a model for the PV inverters was developed. The main feature taken into account in the model is the MPPT in order to always obtain the maximum power from the PVs. Specifically; the selected algorithm calculates the maximum power point as proportional to the open circuit voltage [7] multiplied by 0,79. The coefficient selection was done so as to match the behavior of the specific modules. In a real system V_{oc} can be determined through sensing during instant open circuit condition. Although this technique was initially used in the model, finally, the selected V_{oc} estimation was based on the interpolation model given by:

$$V_{oc}^{*} = C_2 V_{oc} \ln\left(\frac{\left(1 - \left(I - D_I\right)/I_{sc}\right)}{C_1} + 1\right) - \beta\left(T - T_{ref}\right) - R_S D_I \tag{4}$$

if I=0. Moreover, two worth mentioning features of this model is its operation as current source, and the power versus frequency linear derating in order to prevent battery overcharging.

3.2 Battery Model

The battery storage units were simulated by using the KBM (Kinetic Battery Model) [8]. According to this, each battery can be described by a Thevenin equivalent circuit. In our study, two major components of the battery were calculated. These are the remaining charge q and the battery terminal voltage V. The battery capacity is calculated from the following equations set:

$$q = q_1 + q_2,\ \frac{dq_1}{dt} = -I - k\left(1 - c\right)q_1 + kcq_2,\ \frac{dq_2}{dt} = k\left(1 - c\right)q_1 - kcq_2 \tag{5}$$

where q=remaining charge, q_1=readily available charge, q_2=bound charge, I=battery current, k=rate constant, c=ratio of available charge capacity to total capacity. In addition to the above, the following equation set for the terminal voltage was adopted:

$$V = E - IR_{bat},\ E = E_o + AX + CX/\left(D - X\right) \tag{6}$$

$$X = \begin{cases} q/q_{max}\left(I\right), & \text{charging} \\ \left(q_{max} - q\right)/q_{max}\left(I\right), & \text{discharging} \end{cases} \tag{7}$$

$$q_{max}(I) = \frac{q_{max} kc \left(q_{max}(I)/I\right)}{1 - e^{-k\left(q_{max}(I)/I\right)} + c\left(k\left(q_{max}(I)/I\right) - 1 + e^{-k\left(q_{max}(I)/I\right)}\right)} \tag{8}$$

where E_o=fully charged/discharged internal battery voltage, A=Parameter reflecting the initial linear variation of internal battery voltage with state of charge, C & D=Parameters reflecting the decrease/increase of battery voltage during charging discharging.

3.3 Battery Inverters

Battery inverters play the most critical role in the system operation because they perform the energy management by regulating frequency either for load shedding or PV power derating. In addition they manage the diesel generator start-up. In our study the same model was used for both battery systems with minor differences. It includes: a) SOC calculation, b) Frequency regulation according to the battery SOC, c) Diesel genset start-up (only for the main system), d) Charging phases including temperature compensation and e) Grid forming or charging through the diesel genset. Below, a brief description of each feature is given.

SOC: The accurate calculation of the battery SOC is critical for an effective battery management. Among different calculation methods, the one selected in our study was the Ah-balancing. This method takes into account the charging/discharging current over time. The accuracy of the method increases if losses due to gassing [8] are considered. The equation set describing the method is:

$$SOC = \frac{1}{C_{10}} \int \left(I_{bat} - \frac{I_{go}}{100Ah} \exp\left[C_V \left(V_{cell} - 2.23V\right) + C_T \left(T - 20^o C\right)\right]\right) dt \tag{9}$$

where C_{10}=Battery capacity for 10-hour discharging, I_{go}=Normalized gassing current, C_V=Voltage coefficient, V_{cell}=Battery cell voltage, C_T=Temperature coefficient, T=Cell temperature.

Frequency regulation: In the specific system the frequency is used as communication signal between the power units in order to manage the generated/consumed energy and hence to extend the battery lifetime. For this scope the battery inverters were modeled to keep constant frequency at 50Hz under normal conditions. This value changes in three cases: a) when SOC falls under 30%, the diesel generator is set in operation and charges the batteries. In this case the battery inverter follows the generator frequency. b) When SOC falls under 15% the frequency becomes 47Hz in order to trigger the load controllers. c) If the battery voltage becomes high, the frequency changes from 50 to a value between 51 and 52 Hz in order to cause PV power derating.

Charging phases and temperature compensation: The charging phases as well as the temperature compensation where also modeled. Specifically, from the four possible charging phases the two most important of them were regarded: Boost charging which has maximum duration 90min, which is followed by float charging until SOC becomes 70% or more than 30% of the nominal capacity has been used. The voltage/cell for each of the previous phases is: 2,55V for boost and 2,23V for float

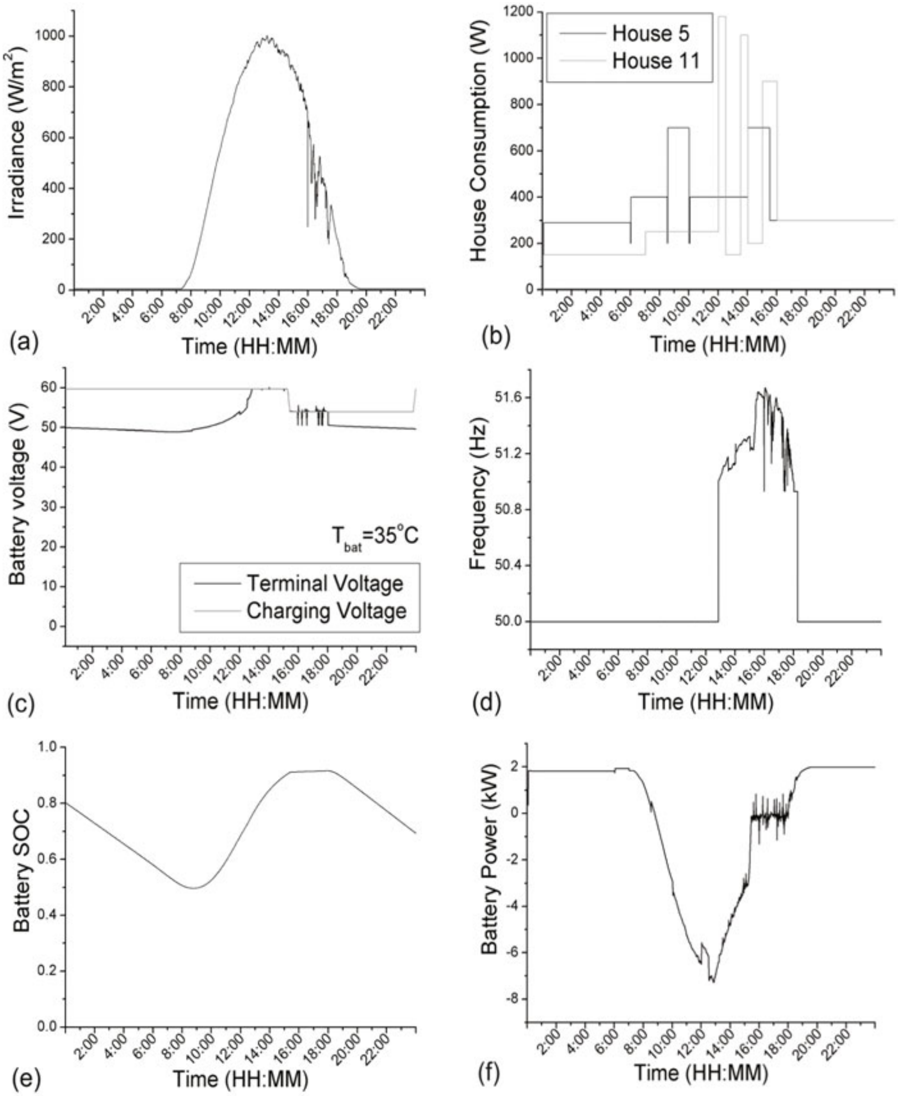

Fig. 2. 24-hour simulation test: a) insolation profile, b) two houses consumption, c) battery voltage, d) microgrid frequency, e) battery SOC, and f) battery power

charging. These values in the real system as well as in the developed model change according to the battery temperature with a coefficient of -0,4%/°C for each cell.

3.4 Loads and Load Controllers

The consumers of the microgrid are modeled as programmable resistive and inductive loads enabling the user to implement input data files for simulating the consumption.

More specifically, each house was modeled as a combination of static and dynamic load. Also, each house is equipped with a load controller, which sheds specific loads when the frequency falls under 49,14Hz. The controller remains in this state until we have frequency restore and a minimum 2-min interval elapses before the load is reconnected. Then the reconnection is done randomly within a 2-min time frame.

4 Simulation Tests-Results

The simulation tests were divided into different parts covering the model validation and system performance evaluation. During the model validation, each part was separately tested while simulation tests related to the total system operation were done for different operating conditions and time intervals. More analytically, in figure 2 the results for a 24-hour test while in figure 3 the comparison between simulation results and real measurements are illustrated.

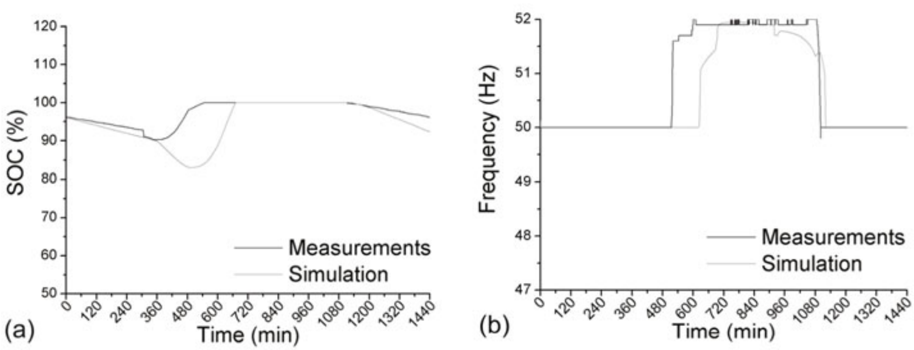

Fig. 3. Comparison between real data and simulation results: a) battery SOC and b) frequency

The examination of figure 2 reveals that the battery voltage initially decreases slowly (between 0:00 and 9:00) due to the fact that there is no generation from PVs. As the irradiance increases, there is an energy surplus and thebattery voltage increases up to the value defined from the boost charging phase (around 13:00). It is evident that at that point the frequency increases and a PV power derating begins. The frequency changes from 51 to 52 Hz so as to keep the battery voltage at 60V (a 35^{O}C battery temperature was regarded). In the voltages' diagram the reference value changes to 53V after the boost-charge phase time elapses. The frequency is kept above 51Hz until the battery voltage becomes lower than the reference value.

In figure 3, the comparison of the developed model with real measurements is shown. The most important points which worth some discussion are:

- In both cases the system behaviour is very similar proving so that the developed model has the desired effectiveness.
- There are some deviations between real and simulated values in both SOC and frequency and in addition there is a time shift in the simulation results due to the

fact that the input data used in our simulation test were not measured on-site. Specifically, due to absence of irradiance and temperature sensors on each PV plane an estimation of these quantities was used based on measurements performed in another site and date. This means that the real irradiance does not exactly coincide with the used data file. A second drawback was the absence of direct data representing analytical consumption profile for each house separately. Instead of this, the houses' consumption was estimated through the total power from the battery inverters. The above assumptions lead to the deviation in the resulted values and the synchronization of the curves.

5 Conclusion

In this paper, a simulation modeling of the pilot microgrid located at Gaidouromantra-Kythnos is presented. This work was realized in the frame of the European project More-Microgrids. For the needs of the project, a simulation model of the microgrid was developed in order to study the operation of the system under short or long term intervals and as a tool for tests before real implementation of desired experiments and modifications. Because of this the model was developed so as to be used not only for power flow analysis but also for potential dynamic tests (e.g. short circuit tests). The model development was based on some critical assumptions and mathematical models for the different parts. A number of simulation tests and comparison with real data reveal the accuracy of the used models and microgrid operation under different operating conditions and time intervals.

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Cutting-Edge Information and Telecommunication Technologies Meet Energy: Energy Management Systems and Smart Web Platforms

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Abstract. Green consciousness is a prerequisite for environmental protection. Renewable Energy Sources and Energy Efficiency seem to be the only way to reduce harmful greenhouse gases like CO_2. Cutting-edge technologies could be a driving force in the energy sector, covering issues that are vital for energy production, consumption and management. With rising energy costs and the move toward more sustainable buildings, increasing energy use in buildings has both financial and environmental consequences. So it is critical for building owners and facility executives to determine if their buildings are operating as efficiently as they can and if not, having the ability and control to do so. Aiming at a new era of energy, Build-IT provides energy monitoring solutions and innovative applications for energy data analysis.

Keywords: Automated Metering Infrastructure, smart meters, energy Monitoring & Targeting, energy saving, energy analysis.

1 Introduction

The vast majority of energy management activities are based on the financial impact they will have on the company. Today's rapidly evolving energy markets are forcing organizations to consider new ways to centrally manage the energy portfolio of the company. These two real-world conditions are causing building owners and energy managers to search for solutions to integrate and coexist with the rest of the enterprise building information network [1]. Energy managers are looking for an Internet friendly, smart platform that manages the "X" factor of energy.

Build-IT, having the technological know-how resulting from a 3-year Research and Development program, provides modern, reliable solutions in the field of energy Monitoring and Targeting (M&T). Incorporating the global energy trends, Build-IT creates innovative systems for M&T, smart homes, focusing on the energy management of large buildings and industries.

The cost of energy has to be incorporated in the operating cost of any company and should not be assumed as a fixed cost. This is especially critical in times of economic instability, where reduced energy costs can be considered as a profitable investment.

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With adoption of energy efficiency practices, total energy consumption increases with lower rates or even remains the same. As a result, energy efficiency and saving come hand in hand with a plethora of benefits (environmental, commercial, financial), becoming a really vital process. The following figure presents the integrated solutions of Build-IT. This paper focuses on Smart Metering Systems and Energy Monitoring & Targeting [2].

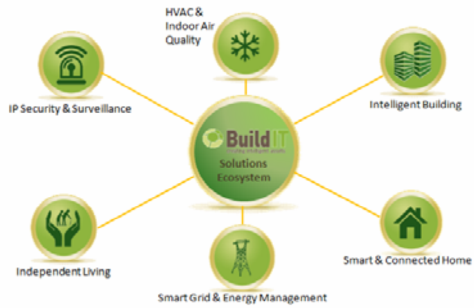

Fig. 1. Integrated solutions of Build-IT

2 Advanced Metering Infrastructure (AMI)

In partnership with E-sight Energy (UK), Build-IT provides the AMIplus solution, a fully integrated solution for energy metering, monitoring, targeting and management. As a real-time integration platform and automation infrastructure, it enables users to deploy optimal energy and environmental management strategies, allowing notification of events before they occur.

The technology also enables users to collect information and benchmark buildings so as to expose operational inefficiencies. From a green building perspective, AMIplus allows users to capitalize on accurate and concise intelligence relating to the energy performance of a building in order to achieve lower energy consumption and enhanced efficiencies.

The whole AMI system, as shown in figure 2, combines telecommunication technologies, data base principles, web based programmable logic controllers (Tridium), smart meters and sensors. The users are able to login the system from anywhere, just by using an internet connection.

Fig. 2. AMIplus system architecture

2.1 System Architecture

Focusing on the system's architecture, the metering system consists of smart meters, autonomous sensors (temperature, lux meters, humidity sensors, occupancy sensors etc) and programmable controllers – data collectors. The following figure presents the energy management installation for a typical large building [3] [4].

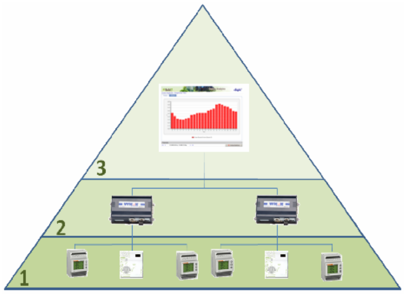

Fig. 3. Build-IT AMI system

The **first level** on the above figure consists of smart meters and sensors. It is crucial to collect plenty of values which constitute the input data that will be considered in further energy analysis. Smart meters are divided into two categories. The first category includes the energy meters, whereas the second one the power analyzers. Energy meters record only energy values (kWh) but they are considerable in special load metering and sub-metering. Power analyzers are complicated and have the ability to record power quality values such as Power, Current, Voltage, Total Harmonic Distortion (THD), Harmonics, Frequency, Energy (Real, Apparent) and Power Factor (cosφ). They are usually applied in the main installation to depict the whole energy profile.

The **second level** consists of the data collector. These powerful controllers, with a web based communication philosophy, are the most important components of the whole automated procedure. They use the internet as a gateway for data transport, using a new, secure, fully automated protocol oBiX (Open Building Information eXchange). oBix leads the new era of Machine to Machine (M2M) communications in buildings.

The **third level** of the above figure is the tool of energy monitoring and analysis. It is a software platform which is developed with sources of E-sight Energy (UK) and Build-IT. The use and benefits of this software are analyzed in paragraph 3.

2.2 Open Building Information eXchange (OBIX)

Standards in the device network industry have attempted to define "models" for every potential type of known device. This exercise continues to produce brittle models which do not capture the reality of smart devices. As a result, devices have an extremely variability between manufacturers. oBIX embraces this reality by using a model based on a simple, flexible type system backed by real computer science. First of all, oBIX defines a "kernel" model based on a few key primitive types such as integers, strings, etc. Secondly, defines an open ended type system for both standards organizations and individual vendors or integrators to build up their own custom models. This is not much different from how a programming language like Java allows people to build up their own class libraries. Furthermore, oBIX sets a simple, elegant mechanism to combine the models from different organizations into one system based on prototype inheritance. This is the critical missing piece in most alternatives to oBIX. Finally, identifies all information using URIs, making it ideal for developing the Web of Things.

2.3 Networking of Things

Although vertical industries have been networking smart devices for decades; they implement their own solid solutions [5]. The following figure illustrates a small sampling of the solutions in use today:

Residential				Commercial		Lighting	Industrial				Automotive	Metering	Verticals
X10	Zigbee	Z-Wave	Konnex	BACnet	Lonworks	DALI	Modbus	ProfieBus	DeviceNet	ControlNet	CAN-Bus	M-Bus	Proprietary

Fig. 4. The variety of protocols and their usage

Each industry tends to have hundreds of protocols, most of them proprietary to the manufacturers. Despite the fact that many things are networked today, very few of them are IP networked. However, efforts tend to this direction.

2.4 Internet of Things

Over the past two decades, there has been an explosion of standardization around the Internet Protocol (IP) [5]. The elegance of IP is that it defines a common interface between application protocols and the heterogeneous networking technologies used to transmit those protocols. As new networking technologies become available such as Wifi, all our old protocols continue to work.

Telemetry applications such as energy management have been using cellular communications for years. The value-chain required to build cellular solutions is quite complicated, but as the industry matures, it is becoming simpler and more cost effective to create cellular enabled devices. This has huge implications for the Internet of Things – manufacturers can sell devices to the field with automatic, built-in connectivity. The cellular enabled device simply finds the network and reports itself when powered up. As new protocols are invented, they can be carried over existing networks. The following figure depicts this procedure.

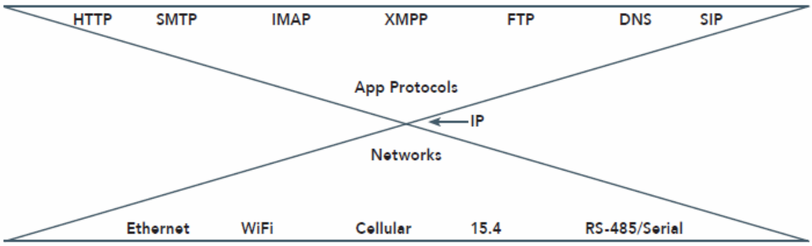

Fig. 5. New protocols are carried over existing networks

The only real problem today for using IP to network devices is lack of a standard for running IP over wired media.

For the foreseeable future, many categories of smart devices will lack an Ethernet port. Wifi will continue to drop in cost and will see its way into more devices. But the explosive growth in the Internet of Things will likely come from IP over cellular, 6LoWPAN, and wired serial communications. The Internet of Things is still in its infancy (today a very small percentage of microprocessors are IP enabled) but in the future, it will become a new communication skin through devices.

3 Energy Monitoring and Targeting

Energy Monitoring & Targeting helps both small and large organizations integrate, measure, manage and reduce their energy consumption [4]. AMIplus solution based on the MAIE methodology (Measure, Analyze, Improve, Evaluate) is a recurring process that should be repeated continually in the company, in order to allow rational use of energy [6]. Figure 6 shows the four interrelated steps of MAIE method:

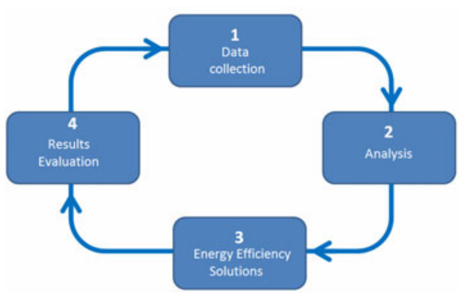

Fig. 6. Energy efficiency methodology

These four steps analyzed in the following paragraphs:

- *Data collection*

The first step of the MAIE method applies to the automated collection of energy data such as energy, temperature, lighting, production etc. Measurements are made from special digital meters and sensors at regular intervals e.g. per half hour or at smaller intervals (if necessary). The data generated from the meters and sensors are collected wirelessly or wired to a central controller which formats and sends them via the Internet to a secure database for further processing. The uninterruptible transfer of large data volumes with accuracy and security is a strong feature of the AMIplus solution.

- *Analysis*

The data analysis starts with the conversion of large data volumes into tangible and useful information for the user. The graphical representation of the energy data is able to display potential problems in the energy function of a building. Such problems may be caused by bad planning and bad energy behavior of the personnel, as well as problems of faulty management and waste of energy.

- *Energy Efficiency Solutions*

When problems arise from the energy profile of the building, improvement solutions for minimizing or avoiding the energy waste are proposed. As a next step, an attainable energy optimization target is applied that should be supported by all employees. In many cases it is not possible to save energy solely by improving energy behavior. In these cases, it is important to apply systems which automate the energy – inefficient procedures like heating, cooling, ventilation, lighting etc. Consumption parameters are carefully analyzed in combination with other factors (e.g. external temperature) and various corrective actions are proposed.

- *Results Evaluation*

The fourth step of the methodology is the most important one, since it is dedicated to the calculation of the level of achievement of the energy saving target.

Energy is a value that lacks visualization and therefore the location and the amount consumed cannot be determined absolutely. The solution is to focus on energy monitoring. The visualization of energy brings the revolution in energy management [7]. The debriefing measurements of the past seem to be an inefficient way of energy monitoring in comparison with the live display of a variety of electrical values. The existence of a system which collects, processes and analyzes energy data is necessary in the era of excessive energy consumption.

The following figures show two important ways of energy analysis and monitoring [2]. Raw values are transformed into useful diagrams to give an accurate sense of the energy consumption for each installation.

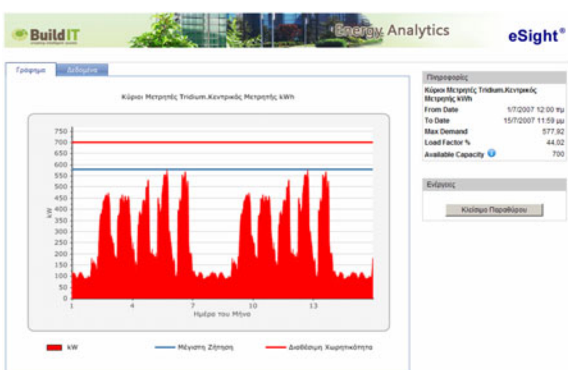

Fig. 7. Load factor analysis

Load data analysis depicts the characteristics of the load. This analysis focuses on the average, minimum and maximum load. It represents the consumption of the building, in any time intervals and finds the peaks and the valleys.

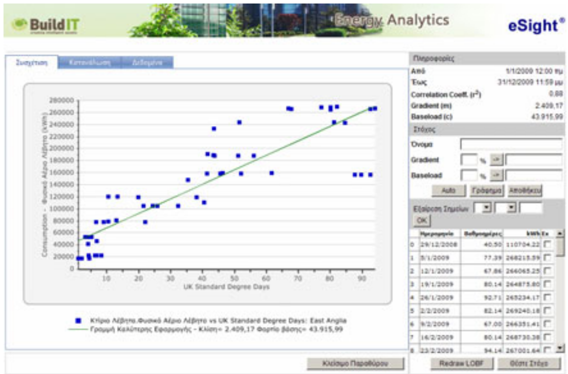

Fig. 8. Regression analysis

Regression analysis constitutes an extremely useful tool for energy managers. It presents the correlation between two values. Regression analysis is known from the diagrams of degree days and energy. Generally, it depicts any value (energy, gas) in regression with a force factor (temperature, degree days).

By managing energy and facilities as investments, companies gain control of energy use and achieve high rates of return in the form of energy savings and better performance of their buildings [8]. Benefits from this investment approach can include double digit energy reductions, as well as improved building performance, lower operating costs and increased environmental responsibility.

4 Energy Benefits from Monitoring and Targeting – Case Studies

With a huge portfolio of companies that have applied an AMI system worldwide, monitoring and targeting procedure becomes a new necessary component of energy efficiency in buildings and utilities. The following case studies emphasize the advantages of AMI systems in two huge European companies.

4.1 CDF Suez

GDF SUEZ possesses a broad portfolio of energy supply customers, from manufacturing companies to service providers. With many clients requesting access to energy data on a regular basis, GDF SUEZ identified the need for an energy management suite [9]. Customers would be able to view energy data thus allowing full autonomy of energy management.

Having identified the need for such a system, GDF SUEZ had a number of specific requirements such as Web-based architecture and allowing access across the internet from any PC, at any location for both GDF SUEZ staff and customers. The second need was a scalable system which can be expanded at any time and finally a comprehensive functionality covering a multitude of analyses.

The Solution

GDF SUEZ selected a 100% web enabled energy management suite for the following reasons:

- Complete web-based architecture: Using any browser, users are able to log on from any PC, to check the status of their energy data.
- Individual profiles can be set up, allowing the personalization of the platform for each independent user regardless of their location.
- Scalability: the platform is a fully expandable system and is ideal for any company dealing with growing numbers of metering channels.
- Functionality: energy M&T platforms include a wide range of energy analysis techniques enabling the user to perform a multitude of functions; from simple energy graphs to complex calculations, simplifying the sometimes difficult task of managing energy.

Customer Benefits

Utility customers can view energy data from any PC at any location, equipping them with a mean to monitor and manage their own energy consumption. By offering this facility, the supplier empowers the consumer to be responsible for their own energy use, thus increasing customer loyalty and retention.

4.2 Carlsberg

Carlsberg UK Leeds is a Brewing and Packaging Site [10]. Some of its annual operational characteristics are shown in the following table.

Table 1. Important operational data of Carlsberg

Name	Value
Employees	150
Production output	2.6 million Hectoliters beer
Gas energy consumption	57 million kWh
EU ETS Phase II allowance	14,254 tones
Water consumption	900,000 m^3
Effluent produced	600,000 m^3
Production CO_2, N_2	8,000 tones

The Solution

For the implementation of an AMI system 6 utilities accounting areas created consisting of Brewery Site KPI centre, Energy Centre plant, Brewing Process plant, Bottling plant, Canning plant, Large Pack Keg and Cask plant.

For purposes of energy monitoring and targeting used 142 meters, 25 calculated meters and 104 energy and performance analysis templates. The energy strategy included:

- Weekly Key Performance Indicators (KPIs) which calculated and compared to targets.
- Weekly meeting is held with user departments reviewing diagrams for previous 7 days, and any exceptions are discussed.
- Hourly dashboards are used at department operator level to monitor usage when the plant is running, stopped, shutdown or during maintenance periods.
- Email alarms range and average are used for alerting high usage of specific meters which can have a major impact on utilities costs, environmental compliance, and production output.

Results

The AMI system reduced site overall energy consumption in 2009 by 10% by understanding consumption loads and matching with production periods. Furthermore, utilized CHP plant and the recovered heat by matching to process demands, improved recovered energy from brewing process which uses 60% of site usage and opened a window into shutdown opportunities when production ends.

The whole process reduced site water consumption by 10% and effluent cost by 16%. It used alongside continuous improvement as a measure in root cause analysis and generated automated email systems to all production allowing early reaction and intervention to process losses.

5 Conclusion – Further Fields

Build-IT merges automation systems and real-time integration into a single, extensible platform that monitors, manages and controls the power consumption, drives energy efficiency and reduces energy costs. The AMI system is a scalable platform that delivers measurable Return On Investment (ROI) enabling users to capture the benefits of integration, automation and energy control of their buildings and maximize the value of information contained within them in real time.

An additional field of practice in which Built-IT focuses on is the development of Building Management Systems (BMS). BMS manage all building systems taking into account all critical areas and subsystems that make a building functional, including lighting, heating, ventilation and air-conditioning (HVAC), security, and energy management. It allows devices to share information with each other and streamlines them into a common system where management can control and monitor the buildings' operations [1].

The new era of technology and energy needs a bridge between systems and devices, simplifying the process of connectivity and integration that makes building and facility management easier. In addition to integrating energy consuming devices and systems within a building and getting them to work together to be managed, controlled and operate at optimum levels, Build-IT includes energy measurement and verification tools that allow users to implement the most efficient and sustainable energy strategies in a building today.

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Routing and G-Networks to Optimise Energy and Quality of Service in Packet Networks

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Abstract. We formulate the problem of joint energy and quality of service (QoS) optimisation in packet networks and show how it can be formalised using the control capabilities inherent in G-network theory, which also includes the overhead due to control traffic. Using known energy consumption characteristics of network routers and of network link driver equipment, this approach leads to a polynomial time complexity gradient optimisation algorithm which seeks a judicious balance between the QoS experienced by the users and the overall energy consumption of the network.

Keywords: Energy Optimisation, Wired Networks, Packet Routing, User QoS, Polynomial Time Complexity Optimisation Algorithm.

1 Introduction

The ever increasing importance of wired packet networks as the transport substrate of most communication technologies creates the need for their greater energy efficiency. How to manage a wired packet network so as to enhance energy efficiency while respecting the users' QoS needs was studied in [1] and also for Cloud Computing in [2]. In this paper we examine the problem via an analytical approach. We first briefly review the literature on power management for wired networks and then we discuss relevant power consumption models. Our main result is a gradientr descent $O(N^3)$ time complexity algorithm that optimises power and QoS for a N-node network.

Energy savings in the Internet [3] can be achieved by routing modifications that aggregate traffic along a few routes and putting some nodes and devices to sleep. A network design problem where components can be powered on/off in combination with the solution of traffic assignment with flow-balance constraints is presented in [4]. An online technique to spread the load through multiple paths, based on the ability of nodes to adjust their operating rate is proposed in [5], and rate-adaptation for individual links is also examined in [6]. In [7] active links and routers are selected to minimize the power consumption via simple heuristics. In [8] a case study based on specific backbone networks is discussed, and

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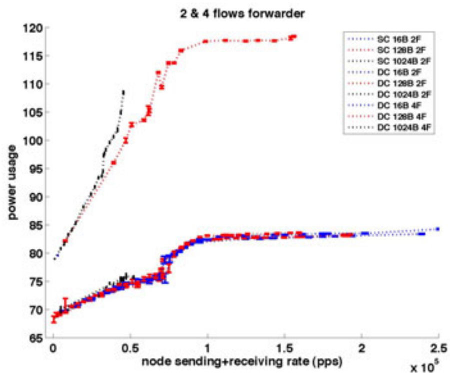

Fig. 1. Router power consumption as a function of packet rate[12]

the potential overall energy savings in the Internet is estimated in [9]. The Cognitive Packet Network (CPN) [10,11] for QoS is also considered in [1]. Another important set of problems that must be addressed when one attempts to design power management schemes for networks concern the proper choice of power consumption models for network components and sub-systems. In [4] a generic model for router power consumption is presented. Two widely used routers are measured in terms of system power demand with different configurations of line cards. Other work [6] focuses on the impact of the hardware processing rate and traffic on the power consumption. The power consumption model in this paper is based on measurements similar to those in Figure 1 [12].

2 Routing for Energy Management

In a network with N queues $\mathbf{N} = \{1, \ldots, N\}$, carrying a set of *user traffic classes*. $N+1$ denotes the "inexistent node" so that a packet that reaches node $N+1$ has simply exited the network or it has been lost. The term node is not restricted to the store and forward nodes of a network: a subset $\mathbf{R}$ is the usual store and forward nodes or routers, while the set $\mathbf{L}$ represents links which connect store and forward nodes, $\mathbf{N} = \mathbf{R} \cup \mathbf{L}$. Thus, to travel from some store and forward router node to another such node, a packet will transit through the "other type of node", i.e. a link. This separation of the N nodes into the set of routers and the set of links has two advantages:

- It allows us to model separately the impact of routers and links (e.g. delay and loss) on QoS and on the *energy consumption*, and
- Secondly it allows us to explicitly represent packet re-routing as the modification of a path that goes (say) from router r via output link l, to a new path from router r via some other output to l'. Thus, re-routing control can then be viewed as taking place by an action on a packet in r that changes the next link that the packet must enter.

Links have a single predecessor node (which is a router) and a single successor node (also a router) and routers typically have multiple predecessor and successor nodes that are links. The two directions of a physical link are viewed as two distinct links, but they may be coupled because they may share the same power supply and the same hardware. Since router hardware will typically use "multi-cores", connections that are being concurrently processed by a router will often be handled by separate threads of execution, and packets within the same connection may be handled in first-come-first served order, while those of distinct connections may be processed in parallel.

Each user traffic class is denoted $k = U(s, d, \sigma)$ where (s, d) is a given source and destination router pair and σ is a QoS level that this traffic class expects to receive from the network. For the time being we will not specify the form that σ takes. We denote by $\lambda(i, k)$ the *external* arrival rate of packets of user class k to router i so that obviously $\lambda(i, k) = 0$ if $k = U(s, d, q)$ and $i \neq s$, while $\Lambda(i, k)$ is the total arrival rate of user traffic of class k at node i. Each class of users will, at any given instant of time, have a single path to its destination so that the probability that a packet of user class k travels from some node i to some node j is denoted by $P(i, k, j)$; if all packets of a given user class only travel over a single path at a time, then this quantity will be either equal to 1 or 0. Note also that if i is a router, the j is a link, while if i is a link, then j must be a router. Since user traffic is assumed to travel on a single path we obviously have that $\Lambda(s, k) = \lambda(s, k)$ when s is source router, and $\Lambda(i, k) = \Lambda(s, k)$ when i is not the source of the connection or user class k but i is a router or link that lies on the path of this traffic class.

We also have *control traffic classes* where each of these classes is in charge of selecting the next hop that a packet of a given user traffic class will take at some router. Since packets are re-routed by changing the selection of the outgoing link in a router, this selection will be signified by control packets. Thus, control traffic classes are denoted (i, k) where i is a router and k is a *user* traffic class since a control class acts on a specific user class at some given router. Control traffic can travel over multiple hops just like any traffic class until it reaches the node where it is supposed to take action. The number of control traffic classes may be small if at a given instant a class of user traffic can only transit through a small number of network nodes.

A control packet of class (i, k) may move from router r to link l with probability $p((i, k), r, l)$ provided $i \neq r$ so that this particular control packet does not act at the router r to redirect traffic. This probability would be just 0 or 1 whenever there are no losses, simply because the output of a link is only connected to a single router. Similarly, the control packet moves from some link l to some router r, with probability $p((i, k), l, r)$.

The *control function* is represented by $Q(i, k, j)$, the probability that a user packet of class k at router i is *directed* by the control packet of type (i, k) to link j. $Q(i, k, j)$ is only defined at a router i for control class (i, k): in other words we need not specify how the control policy acts at a node where this particular control class is not empowered to act. Also, the control packets can only act at routers, so that $Q(i, k, j) = 0$ if $i \in \mathbf{L}$. We also assume that once a control packet has acted at some router, then it is destroyed; in other words, each control packet can only act *once* on a single user packet at some specific router. If a control packet of class (r, k) arrives at router r when that router does not contain *any* user packets of class k, then the control packet is destroyed. For $r \in \mathbf{R}$:

$$\sum_{l \in \mathbf{L}} P(r, k, l) + P(r, k, N+1) = 1, \sum_{l \in \mathbf{L}} Q(r, k, l) = 1 \tag{1}$$

$$\sum_{l \in \mathbf{L}} p((i, k), r, l) + p((i, k), r, N+1) = 1, r \neq i \in \mathbf{R} \tag{2}$$

while if $l \in \mathbf{L}$:

$$\sum_{r \in \mathbf{R}} P(l, k, r) + P(l, k, N+1) = 1, \tag{3}$$

$$\sum_{r \in \mathbf{R}} p((i, k), l, r) + p((i, k), l, N+1) = 1, \ i \in \mathbf{R} \tag{4}$$

Note that there are no control packets classes of the form (l, k) where $l \in \mathbf{L}$. The control traffic classes may be seen in two ways:

- As flows of signaling information sent out from decision nodes, to routers where it may be necessary to re-route traffic, or
- As a mathematical representation of re-routing decisions. The arrival rate of control packets at some router may be used to represent the rate at which control decisions are made.

We assume that all user or control packets that travel *through* a node i have the same service rate μ_i at that node, but control packets act instantaneously when they act as control packets, rather than when they are simply transiting through a node and experience the usual queuing phenomenon. All packets are processed in first-come-first served mode in the nodes and links, so that there is no priority difference between user and control packets. On the other hand, when a control packet arrives at a node where it is supposed to act, it does this instantaneously on its "target" packet class, selecting the target packet of the appropriate class which is first in queue within its own class. If the router where this happens contains no packets of the target class, then the corresponding packet is destroyed. This model is a special case of G-Networks [13,14,15] with triggered customer movement, where control classes embody the triggers of the mathematical model [16], including multiple classes [17,18]. Thus we are able to apply the corresponding theory, and the steady-state probability that the queue of node i contains at least one user packet of class k can be obtained as follows.

In many practical networks, each link has only a single router at its input and output. However, in the notation below we continue to treat links as just another type of node, which is useful when links also represent data concentrators, dispatchers, buses or switching networks for distributed computer architectures and multiprocessors.

Let $\lambda^{-}(j, (i, k))$ be the *external* arrival rate of control traffic class (i, k) to router j, and such arrivals can only occur at routers. The *total arrival rate* of control traffic class (i,k) at router j, which will be computed below, is denoted by $\Lambda^-(j,(i,k))$. This allows us to represent control traffic that may originate at different routers and act at the router where they originate, or they may act at other routers. The steady-state probability that a router or link contains at least one packet of user class k is given by

$$q(r,k) = \frac{\Lambda_R(r,k)}{\mu_r + \Lambda^-(r,(r,k))},\ if\ r \in \mathbf{R}, \tag{5}$$

We are assuming that each of the user classes are handled by separate queues in routers, e.g. when different user class queues within the same router are processed concurrently with a multicore architecture so that the queues are separate entities running in parallel. On the other hand, all packets within a link are handled in first-come-first-served order. The steady-state probability that the link l contains at least one packet of user class k is then

$$q(l,k) = \frac{\Lambda_L(l,k)}{\mu_l},\ if\ l \in \mathbf{L}, \tag{6}$$

and the total arrival rates of user packets of class k to the routers and links are

$$\Lambda_R(r,k) = \lambda(r,k) + \sum_{l \in \mathbf{L}} q(l,k)P(l,k,r)\mu_l,\ if\ r \in \mathbf{R} \tag{7}$$

$$\Lambda_L(l,k) = \sum_{r \in \mathbf{R}} [P(r,k,l)q(r,k)\mu_r + \Lambda^-(r,(r,k))q(r,k)Q(r,k,l)],\ if\ l \in \mathbf{L} \tag{8}$$

while the arrival rate to router or link j of control traffic of class (i,k) is

$$\Lambda^-(j,(i,k)) = \lambda^-(j,(i,k)) + \sum_{l \in \mathbf{L}} p((i,k),l,j)c(l,(i,k))\mu_l,\ if\ i,j \in \mathbf{R} \tag{9}$$

$$= \sum_{r \in \mathbf{R}} p((i,k),r,j)K(r,(i,k))\mu_r,\ if\ i \in \mathbf{R}, j \in \mathbf{L}, i \neq r \tag{10}$$

where the steady-state probability that link l contains at least one control packet of class (i,k) is

$$c(l,(i,k)) = \frac{\sum_{r \in \mathbf{R}} p((i,k),r,l)K(r,(i,k))\mu_r}{\mu_l}, l \in \mathbf{L}, i \in \mathbf{R} \tag{11}$$

and $K(r,(i,k))$ is the steady-state probability that router r contains at least one control packet of class (i,k) for $r,i \in \mathbf{R}$ and $r \neq i$

$$K(r,(i,k)) = \frac{\lambda^-(r,(i,k)) + \sum_{l \in \mathbf{L}} p((i,k),l,r)c(l,(i,k))\mu_l}{\mu_r} \tag{12}$$

Note that the steady-state probability that link l is busy is simply

$$B(l) = \sum_{k \in \mathbf{U}} [q(l,k) + \sum_{i \in \mathbf{R}} c(l,(i,k))] \tag{13}$$

Assuming unbounded queue lengths, the average queue length at link l is

$$N(l) = \frac{B(l)}{1 - B(l)}, l \in \mathbf{L} \tag{14}$$

While consistent with the assumption that each category of packets, whether of user type or of control type, is handled in a separate queue at each router r, the average queue lengths at router r and $k \in \mathbf{U}$ are

$$N(r,k) = \frac{q(r,k)}{1 - q(r,k)} \tag{15}$$

$$N(r,(i,k)) = \frac{K(r,(i,k))}{1 - K(r,(i,k))}, i \neq r \tag{16}$$

We also define the probabilities that a user packet of class k, or a control packet of class (i,k), enters router r or link l

$$\pi(r,k) = \frac{\Lambda_R(r,k)}{\lambda^+(k)}, r \in \mathbf{R}, \pi(l,k) = \frac{\Lambda_L(l,k)}{\lambda^+(k)}, l \in \mathbf{L} \tag{17}$$

$$\pi(j,(i,k)) = \frac{\Lambda^-(j,(i,k))}{\lambda^-(i,k)}, j \in \mathbf{N}, i \in \mathbf{R}, i \neq j \tag{18}$$

where:

$$\lambda^+(k) = \sum_{r \in \mathbf{R}} \lambda(r,k) = \lambda(s,k) \tag{19}$$

is the total user traffic of class k in the network, s being its source router, and

$$\lambda^-(i,k) = \sum_{r \in \mathbf{R}} \lambda^-(r,(i,k)) \tag{20}$$

is the total control traffic of class (i,k). Using Little's formula [19,20] the total average delay through the network for a user packet of class k is

$$T(k) = \sum_{l \in \mathbf{L}} \pi(l,k) \frac{N(l)}{\Lambda_L(l,k)} + \sum_{r \in \mathbf{R}} \pi(r,k) \frac{N(r,k)}{\Lambda_R(r,k)} \tag{21}$$

while the total average delay experienced by a control packet of class (i,k) is

$$T^-(i,k) = \sum_{l \in \mathbf{L}} \pi(l,(i,k)) \frac{N(l)}{\Lambda^-(l,(i,k))} + \sum_{r \in \mathbf{R}, r \neq i} \pi(r,(i,k)) \frac{N(r,(i,k))}{\Lambda^-(r,(i,k))} \tag{22}$$

The separation of nodes into routers **R** and links **L** allows us to model separately their power consumption. As indicated in [4], the power consumption of a router consists of a part that depends on the particular chassis type, and another determined by the line cards. In the router the power consumption includes the amount needed to keep it on, the operating for route changes, and that which is needed for processing individual packets. Let Λ_i^+ be the total traffic of user packets entering node i, while Λ_i^- is the total control transiting that node. They are given by

$$\Lambda_i^+ = \sum_{k \in \mathbf{U}} \Lambda_R(i,k) \ if \ i \in \mathbf{R} \tag{23}$$

$$= \sum_{k \in \mathbf{U}} \Lambda_L(i,k) \ if \ i \in \mathbf{L} \tag{24}$$

$$\Lambda_i^- = \sum_{j \neq i} \sum_{k \in \mathbf{U}} \Lambda^-(i,(j,k)) \tag{25}$$

and the total traffic of packets Λ_i transiting through a node i will be

$$\Lambda_i = \Lambda_i^+ + \Lambda_i^- \tag{26}$$

The measurements reported in Figure 1 [12] for two distinct machines used as routers and different fixed packet lengths, show that for older single core technology (curves above) the power consumption increases monotonically with the rate at which *packets* are processed in the router. The curves below show similar results for a more recent multicore technology with much lower power consumption, and have a distinct step upwards when an additional core kicks in as packet rate increases. In all cases *packet length* has little effect on power consumption. Thus, we use the following power consumption formula for a router

$$P_i = \alpha_i + g_R(\Lambda_i) + c_i \sum_{k \in \mathbf{U}} \Lambda^-(i,(i,k)), i \in \mathbf{R} \tag{27}$$

where α_i corresponds to the router's static power consumption, $c_i > 0$ is a constant, $g_R(.)$ is an increasing function of the packet processing rate, as in Figure 1, while c_i is a proportionality constant related to the amount of processing being carried out in the router for re-routing control. The link power will depend on the traffic rate in bytes or bits per second (rather than packets per second), and includes the needs for operating the interface with the router, and for transmitting data on the line. Additionally, one could include the power consumed for propagating or "repeating" data on the line, but this may be negligible [21]. The link power model that we propose is then:

$$P_i = \beta_i + g_L(\Lambda_i), i \in \mathbf{L} \tag{28}$$

where β_i corresponds to the static power consumption, and $g_L(.)$ is an increasing function. Thus (27) and (28) allow us to examine the impact of routing decisions via changes in traffic rates, and also to evaluate the effect of putting different routers or links "to sleep". Since link interfaces can consume up to 40% of the overall router power, and because they can be put to sleep or woken up much more rapidly than a whole router, one can benefit from just turning links off.

The users' QoS needs are typically expressed in terms of packet delay, probability of loss, jitter etc. that depend on the congestion at routers and links, which depend on the probabilities that the nodes or links are busy. Thus the $q(i,k)$, $c(l,(i,k))$ and $K(r,(i,k))$ are the key quantities we will use to obtain the QoS metrics.

The average overall network packet can be expressed as

$$\overline{T_N} = \sum_k \frac{\lambda^+(k)}{\Lambda_T^+} T(k) \tag{29}$$

where $\lambda^+(k)$ is given by equation 19, $T(k)$ is given by (21) and $\Lambda_T^+ = \sum_k \lambda^+(k)$.

2.1 Gradient Descent Optimisation

Routing optimization can be expressed as the minimization of a function f that includes both the Network Power Consumption and the Average Delay

$$\text{Minimize } f = c\sum_i P_i + \overline{T_N} \text{ by selecting the control parameters } Q(x,m,y) \tag{30}$$

Since we are interested in gradual improvements in the presence of ongoing flows, we compute the partial derivative of f

$$\frac{\partial f}{\partial Q(x,m,y)} = c\sum_{i\in\mathbf{N}} \frac{\partial P_i}{\partial Q(x,m,y)} + \frac{\partial \overline{T_N}}{\partial Q(x,m,y)} \tag{31}$$

where we use (27), (28) and (29). Since $\frac{\partial P(i,k,j)}{\partial Q(x,m,y)} = \frac{\partial p((i,k),j,n)}{\partial Q(x,m,y)} = 0$ we only need to calculate $\frac{\partial q(r,k)}{\partial Q(x,m,y)}$ and $\frac{\partial q(l,k)}{\partial Q(x,m,y)}$. Define $h(i,j) = 1$ if there is a physical connection from node i to j and $h(i,j) = 0$ otherwise. Note that for evaluating $\frac{\partial \mathbf{X}}{\partial Q(x,m,y)}$ we need only consider cases where $h(x,y) = 1$. Define the vector $\mathbf{q}_k = (q(1,k), q(2,k), .., q(N,k))$ and the $N \times N$ matrices

$$\mathbf{A}_k = [A_k(l,r)], A_k(l,r) = \frac{P(l,k,r)}{\mu_r + \Lambda^-(r,(r,k))} \tag{32}$$

$$\mathbf{D}_k = [D_k(r,l)], D_k(r,l) = [P(r,k,l)\mu_r + \Lambda^-(r,(r,k))Q(r,k,l)) \tag{33}$$

$$\mathbf{B}_k = [B_k(l,r)], B_k(l,r) = \mu_l P(l,k,r) \tag{34}$$

$$\mathbf{C}_k = [C_k(r,l)], C_k(r,l) = \frac{[P(r,k,l)\mu_r + \Lambda^-(r,(r,k))Q(r,k,l)}{\mu_l[\mu_r + \Lambda^-(r,(r,k))]} \tag{35}$$

and the $1 \times N$ row vectors

$$\mathbf{N}(l) = 1/\mu_l \tag{36}$$

$$\mathbf{H}_k^{xmy}(l) = \begin{cases} \Lambda^-(x,(x,k))q(x,k) & k = m, l = y \\ -h(x,l)\Lambda^-(x,(x,k))q(x,k) & k = m, l \neq y \\ 0 & \text{otherwise} \end{cases} \tag{37}$$

Then after some calculations we get

$$\frac{\partial \mathbf{q}_k(r)}{\partial Q(x,m,y)} = \frac{\partial \mathbf{q}_k(r)}{\partial Q(x,m,y)} \mathbf{D}_k \mathbf{A}_k + \mathbf{H}_k^{xmy} \mathbf{A}_k \tag{38}$$

$$\frac{\partial \mathbf{q}_k(l)}{\partial Q(x,m,y)} = \frac{\partial \mathbf{q}_k(l)}{\partial Q(x,m,y)} \mathbf{B}_k \mathbf{C}_k + \mathbf{H}_k^{xmy} \mathbf{N} \tag{39}$$

where $r \in \mathbf{R}$ and $l \in \mathbf{L}$. Thus, equations (38) and (39) can be written as

$$\frac{\partial \mathbf{q}_k}{\partial Q(x,y,m)} = \frac{\partial \mathbf{q}_k}{\partial Q(x,y,m)} \mathbf{W}_k + \gamma_k^{xmy} \tag{40}$$

where the matrix $\mathbf{W}_k$ and the vector γ_k^{xmy} are given by

$$W_k(i,j) = \begin{cases} \sum_{l\in\mathbf{L}} D_k(i,l)A_k(l,j) & i,j \in \mathbf{R} \\ \sum_{r\in\mathbf{R}} B_k(i,r)C_k(r,j) & i,j \in \mathbf{L} \end{cases} \tag{41}$$

$$\gamma_k^{xmy}(n) = \begin{cases} \sum_{l\in\mathbf{L}} H_k^{xmy}(l)A_k(l,n) & n \in \mathbf{R} \\ H_k^{xmy}(n)N(n) & n \in \mathbf{L} \end{cases} \tag{42}$$

So,

$$\frac{\partial \mathbf{q}_k}{\partial Q(x,y,m)} = \gamma_k^{xmy}(\mathbf{I} - \mathbf{W}_k)^{-1} \tag{43}$$

where $\mathbf{I}$ is the $N \times N$ identity matrix. Using (43) we can calculate $\partial f/\partial Q(x,m,y)$ from equation (31). Note that the matrix inversion is of time complexity $O(N^3)$.

The gradient descent algorithm to obtain the parameters $Q(i,k,j)$ that reduce the cost function at a given operating point of the network $\underline{X} = [\underline{\lambda}, \underline{\lambda^-}, \underline{\mu}, \underline{P^+}, \underline{p}]$ is determined by its n^{th} computational step:

$$Q_{n+1}(i,k,j) = Q_n(i,k,j) - \eta \frac{\partial f}{\partial Q(i,k,j)}|_{Q(i,k,j)=Q_n(i,k,j)} \tag{44}$$

where $\eta > 0$ is the "rate" of the gradient descent and the partial derivative is computed with the n^{th} values of the weights. The steps of the algorithm are

1. Initialise all the values $Q(i,k,j)$ and set $\eta > 0$.
2. Solve the $U \times N$ equations (5)-(12) to obtain the $q(i,k)$.
3. Solve the $U \times N$ equations (43) using the $q(i,k)$.
4. Using the steps 2 and 3 update $Q(i,k,j)$ (44)

3 Conclusion

Technological means to greater energy efficiency such as the Smart Grid, distance learning and E-work, depend increasingly on computer networks and information technology: while they reduce energy consumption in transportation (for instance), they increase the need for energy to run networks and ICT systems. Thus, we must develop energy efficient ways to run ICT systems. Our work seeks techniques that use routing control in a network as a means to reduce energy consumption while remaining aware of QoS considerations. G-Networks are mathematical models that incorporate both the user traffic and the traffic used to control packet routing. Based on G-networks, we have developped a model that incorporates routers and links as separate queuing servers, and the model is also able to incorporate the overhead of the control traffic as well as the ordinary payload traffic in the network. A gradient based algorithm for progressive traffic re-routing is developped to minimise a cost function which incorporates both the energy consumption and the QoS. The algorithm is shown to be of $O(N^3)$ time complexity in the size of the network. In future work we expect to present an experimental implementation of energy aware routing based on the modelling and analysis techniques developped in this paper.

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Energy Efficiency through Distributed Energy Management in Buildings Workshop

The BeyWatch Conceptual Model for Demand-Side Management

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Abstract. The BeyWatch project designs, develops and evaluates an innovative, energy-aware and user-centric solution, able to provide intelligent energy monitoring/control and power demand balancing at home/building and larger geographical area level. The focus lies in increasing the use of ICT in power systems. We first provide a brief overview of the concepts involved. After that, we highlight one of the crucial problems of demand side management: striving to attain a balance whereby the system meaningfully influences user behavior / electricity consumption while at the same time avoiding the two extremes of either: (a) putting too much strain on consumers by forcing them to second-guess and obsessively optimize the operation of their appliances or (b) taking over control of their household. We present the BeyWatch Conceptual Model that drove the architecture definition of the BeyWatch platform which solves this conundrum. We finish with a presentation of actual architecture deployed for the trials.

Keywords: demand-side management, dynamic tariffs, home automation.

1 Introduction

The scope of the BeyWatch project [1] is quite broad. Targeting environmental sustainability, energy efficiency [2] and new power distribution/production business models, BeyWatch aims to design, develop and evaluate an innovative, energy-aware and user-centric solution, able to provide intelligent energy monitoring/control and power demand balancing at home/building & neighborhood level. The BeyWatch system interconnects legacy professional/ consumer electronic devices with a new generation of energy-aware white-goods, where multilevel hierarchic metering, control, and scheduling will be applied, based on power demand, network conditions and personal preferences. In addition to the above objectives, BeyWatch also targets innovations not directly related to Information and Communications Technologies (ICT) as well as the integration of combined photovoltaic / solar systems in the home power network allowing either peak hour use of locally produced energy or selling it to the external grid.

The system is thus designed to interconnect legacy/consumer electronic devices with a new generation of energy-aware white goods in a common network, where multilevel hierarchic metering, control, and scheduling will be applied, based on

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power demand, network conditions and personal preferences. By scheduling and controlling the electronic devices operation, BeyWatch aims to minimize power distribution peaks, balancing energy load in power distribution networks and ultimately achieving smooth, predictable, large-scale energy consumption profiles [3].

Moreover, BeyWatch optimizes and integrates an innovative Combined Photovoltaic - Solar (CPS) system, which will provide: a) hot water for white goods (such as dishwasher, washing machine) in order to strongly decrease energy consumption and CO_2 emissions at home by reducing/removing some heating cycles and b) generate electrical energy from Renewable Energy Sources (RES), which can be utilized at home, and during peak periods, even fed to the electricity network in a reverse power generation/ distribution business model.

BeyWatch solution combines innovation in a number of areas:

- *Intelligent personalized energy-management/control and small-scale power demand balancing platform*: Different users have different priorities, preferences, needs and consider the energy commodity from different viewpoints. The idea of intelligently controlled appliances has been found in market research studies to be very appealing to the greatest percentage of consumers, with at least 70% of consumers inquired finding the idea "interesting" or "very interesting" [4] yet it is at the same time recognized that the right balance has to be struck between either taking too many unwarranted decisions or requiring intensive user engagement. Both extremes are unwelcomed by home consumers. BeyWatch proposes a solution that is balanced and at the same time goes beyond mere automation by including demand-side management features and delivering electricity bill benefits to the consumer.
- *Modeling and medium-scale control of power distribution*: By providing a detailed analysis of the consumption pattern in a square block, neighborhood or larger geographical areas, BeyWatch allows the energy supplier companies to balance the energy consumption peaks using comprehensive power demand scheduling and reduce the need for out-of-schedule power imports from neighboring countries or other exigency measures.
- *Technologies for very low-cost white goods' power consumption combined with ICT*: According to research performed by CECED [5] domestic appliances in the 15 EU countries in 2001 consumed about 250 TWh of electrical energy in year 2000 - about 30 TWh less than in 1990, due to the improvements of the efficiency of various products. In BeyWatch, new technologies are evaluated and tested to offer significantly reduced power consumption and much more efficient power control in a new generation of energy-aware white goods. What's more important from an architecture perspective is that all home appliances (including white goods) now include ICT enhancements allowing them to be controlled by the home automation software (BeyWatch Agent) over open interfaces.
- *Small scale renewable energy resource integrated with home network*: BeyWatch takes advantage of the opportunity to reduce energy consumption and CO_2 emissions at home level by integrating a CPS panel, which produces energy and hot water [6]. The CPS offers two more levers (local energy production and hot water) for energy management in order to maximize energy and environmental savings at home [7][8].

2 The BeyWatch Business Model

In a deregulated electricity market where multiple electricity companies compete for customers, the need for service / product differentiation to avoid commoditization and price-only-based competition is even more pronounced [9]. We foresee that electricity companies will have an incentive to couple their offerings with additional services typically offered by telecommunication providers. This creates an incentive for both energy utilities and telecom operators to align themselves and perhaps offer synergistic service bundles that combine ICT with electricity distribution:

- Utilities will need to acquire technology and knowledge to help them develop and disseminate end devices for controlling the demand side management and to integrate the final users as an active part of the energy system, giving them the tools and services needed to make a more efficient use of energy.
- Telecom operators also need knowledge on how and why ICT are so important in the energy market and to address more effectively the sustainability challenges posed in Europe and worldwide.

The combination of both is critical in order to involve the users effectively in the energy value chain, providing them with valuable information and the tools to control their energy budget, but without overburdening them with new responsibilities and concerns.

The BeyWatch platform is indeed such a technical enabler of powerful solutions with far-reaching implications and puts in place capabilities that do not presently exist. Although the BeyWatch architecture is, in our opinion, coherently designed from principles derived from all participating disciplines, we cannot claim the prescience to know how independent market participants will best organize themselves around this architecture. On the other hand, architecture and design is driven by use cases, and defining use cases entails identifying actors and roles, and by extension, having some kind of business model framework in mind (in whose context to identify the actors and their roles / interactions). Therefore the aim of this section is to describe a rather abstract BeyWatch "business model" that has allowed us to derive a number of assumptions / functionalities which the architecture will have to implement.

Presently, in the typical case when no demand-side management solution is implemented, the relationship between the electricity company and the electricity consumers is a clean-cut producer-consumer relationship. When demand-side management is introduced the picture gets a bit more complex in that the entity responsible for the demand-side management could be the electricity company itself or another entity (e.g. the grid administrator). In a typical de-regulated electricity environment there can be many electricity producers feeding power into the grid, but the grid as a whole is a shared resource managed by the grid administrator and the stability of the grid is something that affects all market participants.

The BeyWatch business model (or rather the BeyWatch business model framework) is even more complex in that it introduces three additional points:

1. *Demand side management takes place by utilizing a whole array of measures*: not just the KWh price of energy but many different incentives / counterincentives that can influence (with varying degrees of effectiveness) electricity demand. Moreover these measures are modified at real time. Such measures (in addition to the sell

price of energy), can be: a power ceiling, a penalized power ceiling (above which a surcharge is applied to the price), the buy price of energy, and others.
2. *Communications infrastructure*: in contrast to traditional demand-side management solutions which view the user as part of the market-driven response loop, in BeyWatch the communication of the incentives / counterincentives takes place through an ICT infrastructure and it is taken into consideration not by a human user (who would be swamped by all this influx of information) but by a software module (the BeyWatch Agent / Scheduler).
3. *Households as energy producers*: in BeyWatch households are themselves energy producers. The first experimental BeyWatch system put together includes a CPS system which allows the household to generate energy. Incentives propagated from the grid administrator can include time-varying inputs not just for the “sell price” of electricity, but also for the “buy price” meaning the system is not strictly demand-side management but can also influence a (small but potentially critical) component of the supply side (that generated at homes / offices using RES).

Given the above, Table 1 that follows juxtaposes the BeyWatch “Business Model” with traditional demand-side management business models in the electricity retailing business.

Table 1. Juxtaposing traditional demand-side management with the BeyWatch approach

Aspect	Traditional way	BeyWatch way
Means available to influence demand:	electricity cost (mainly)	electricity cost, but also others
Measures influencing demand …	… are announced on traditional media outlets and are received and acted upon by humans	… are published in electronic format (web-services) and are acted upon by software
Decisions in response to these measures …	… are taken by humans (consumers) after they have been announced using traditional means (radio, TV, human-readable web pages) and are effected by manually interacting with the appliances usually locally but perhaps also remotely	… are taken by the BeyWatch Agent software (running on behalf and under the broad outlines / directions set by the consumers) after receiving notification of incentives / counter-incentives through a web services interface
Burden of “optimization” …	… is borne by the home consumer	… is transparent to the home consumer and is borne by software
Updated measures with the goal of influencing demand can be sent …	… not too frequently (usually daily) considering that human users will need to learn about them using traditional media channels	… very frequently considering that the software is always “on” and is always “listening”
Complexity of measures …	… must be low enough (usually price hikes) to allow the users to comprehend the effect their actions will have on their monthly bill and make obvious the kind of behavior expected	… can be arbitrarily complex since an optimizing scheduler will be used to find out the optimal solution

3 The BeyWatch Conceptual Model for Demand-Side Management

With the risk of oversimplifying, the diagram in Fig. 1 that follows depicts the concept used in BeyWatch to achieve demand-side management.

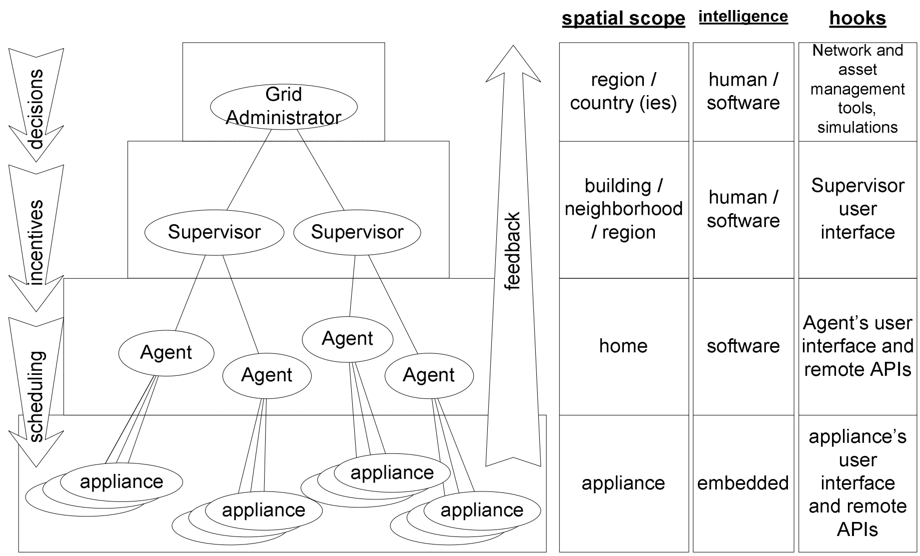

Fig. 1. BeyWatch demand-side management conceptual model

Fig. 1 is an abstract diagram yet it still identifies in a graphical way the key properties underpinning the BeyWatch approach. We refer to Fig. 1 as the BeyWatch Monitoring and Control System Conceptual Model ("BWCM").

Each plane of the BWCM corresponds to a certain scope for control. At the base plane of the hierarchy the entities on which control is exercised are more localized, consisting, usually of single, discrete appliances. As we move up the hierarchy planes, the scope of control becomes broader extending to apartments / homes, buildings, neighborhoods and larger geographical regions. Attendant with the change in the location scope is a change in the kind of control that is possible at each plane. Moreover, different actors are envisaged in each layer.

The key concepts of the BWCM are discussed in the remainder of this section.

Hierarchical Propagation. Propagation of incentives/counterincentives for demand-side management is done in a hierarchical approach. The hierarchy is organized according to spatial scope: from larger geographical regions and agglomerations on the upper layers to neighborhoods, buildings, homes and, eventually, appliances at the lowest level.

Semantic Translation. The incentives / counterincentives measures propagate from the higher planes to the lower planes and undergo several "semantic" translations at each plane so as to be consistent with the spatial scope of that plan. For example, a typical propagation / refinement would be the following:

1. a request to lower the total demand on a geographical area gets translated to …
2. … multiple requests to lower demand in various regions (cities, neighborhoods) that collectively comprise that area, each of which is further translated into …
3. … a set of incentive / counter-incentives, distinct for each home (Agent) which will (hopefully) influence that Agent's automated scheduling decisions and they are …
4. … ultimately effected by scheduling household appliances or otherwise modifying aspects of their operation (through a remote, wireless API)

Feedback then works its way up in much the same way.

Organizational boundaries. Moreover, as a qualification to the previous point, since, in most business models at least, the upper layers correspond to units or processes that lie within the same organization or within organizations that are closely aligned (e.g. grid administrator or grid administrator and electricity company and / or distribution company) the applicable concept is not so much one of incentives / counter-incentives, than one of decisions. Within the same organization or within aligned / cooperating organizations we see a propagation of decisions. These "decisions" are then translated into an incentive / counter-incentive structure when it becomes necessary to deal with external, independent actors (e.g. households) who are better influenced by the price mechanism or, in general, free market forces. These independent actors have their own set of priorities and motivations and operate independently of the grid administrator or the electricity company. As such, they cannot simply be coerced or told what to do but rather have to be induced to behave in a way that ensures the stability of the grid. Therefore the appropriate mechanism to bring about the intended behavior is to try to influence home energy patterns through market forces by providing a system of incentives / counter-incentives which can vary over time or in response to emergencies. These measures could for instance include modifying the energy price, imposing a power cap or other more refined measures and will of course have to be explicitly allowed as part of the contract.

Distribution of Intelligence. The intelligence (both human and software implemented) that is necessary to support this transition of decisions, incentives and scheduling through greatly differing spatial scopes is again distributed in the planes of the hierarchy. The proportion of human / software intelligence in the mix again changes in a consistent way as we move down the hierarchy. In the upper layers, decision making is left to humans with support from tools / simulations, etc. These humans are presumable grid administrator operators or specialized personnel at the electricity company. In the house component the participation of human intelligence in the functioning drops precipitously as the idea is to allow the software to do all optimizing / scheduling and have the user simply set broad guidelines and preferences. Ultimate control however, rests with the user who decides the latitude granted to the BeyWatch Agent so that a HAL-like entity does not emerge.

The BWCM is structured in the form of a multi-layered hierarchy. Obviously, any comprehensive demand-side management system will need to tie together actors and assets in vastly disparate scopes: from the power stations and the transmission and distribution networks to the actual mundane home appliances which collective generate the aggregate load that the infrastructure has to serve. Similarly, the software implementation of the BeyWatch system that implements this hierarchy of control is a complex system that encompasses a multitude of interactions between different actors, components and protocol entities in very diverse scopes. In the case of BeyWatch, it was recognized very early that the scope of the effort necessitated a clear sense of direction and approach philosophy at every level so as to yield a coherent and manageable architecture. In order to ensure that outcome, the abstract conceptual model presented above was articulated quite early in the specification of the system and proved a useful aid in deciding concrete design questions.

4 The BeyWatch Prototype Architecture for the Trials

Based on the conceptual model of Fig. 2, Fig. 3 that follows depicts the concrete technical architecture used for the BeyWatch prototype trials.

It is also easy to see that the architecture of Fig. 2 is consistent with the BWCM presented in Fig. 1.

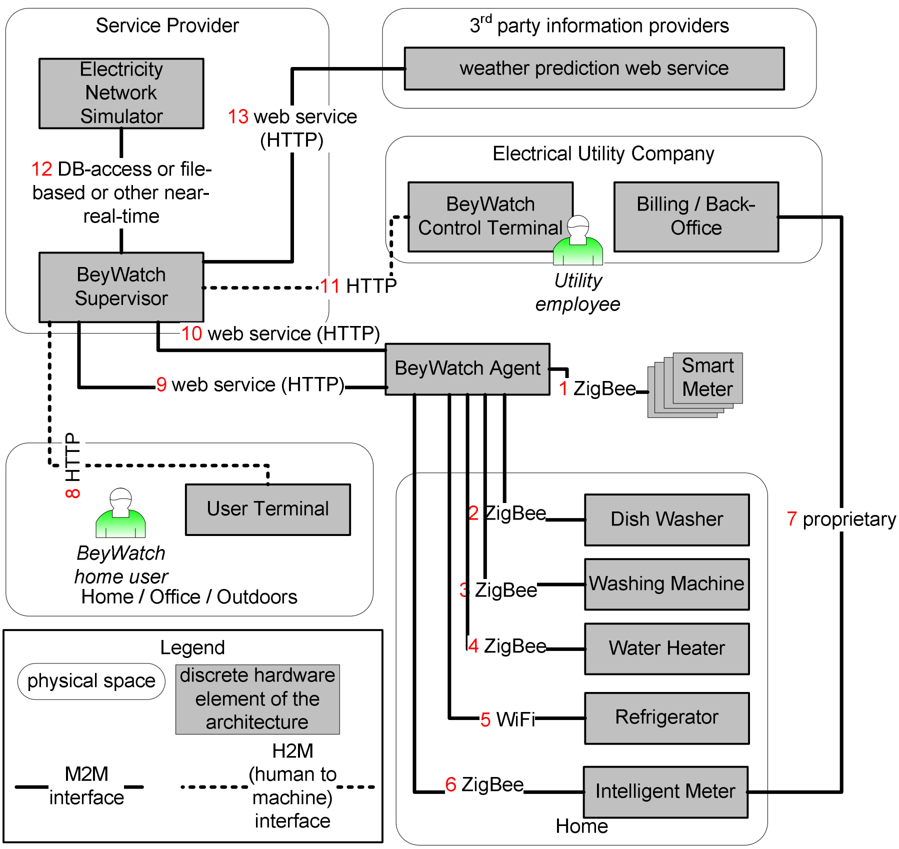

Fig. 2. BeyWatch deployment and software architecture for the trials

Demand-side management in BeyWatch is therefore implemented by infusing "intelligence", understood here to mean ICT-type intelligence in all the levels at which electricity consumption can be meaningfully assessed, monitored, influenced or overtly controlled:

- Appliance level: a home appliance, seen as a single entity, represents the smallest unit at which ICT-related intelligence is injected allowing the appliance to become an actor in the BeyWatch universe. It should be noted that BeyWatch also caters for traditional, "dumb" appliances with no extra ICT-related improvements and manages to include them meaningfully in its demand flexibility planning.
- Home level: the home as an aggregation of household appliances and as the living space of a person or family which is treated as a single "customer" for provisioning, electricity consumption, and ultimately, billing.

The BeyWatch platform can be used to build a closed-loop system that enables real-time demand-side management functions together with real-time feedback on the way individual homes, neighborhoods and larger areas respond to the measures put in place. This is done by relying exclusively on an ICT infrastructure using protocols and applications built on top of the standard Internet TCP/IP stack for both delivering the incentive / counter-incentive measures to the end consumers (actually to the Agent software that is responsible for making the decisions on their behalf) and for collecting and reporting power consumption information and statistics. The technology used consists of HTTP-based web services following the REST pattern [10] and exchanging information in the form of JSON objects [11]. By providing a detailed analysis of the consumption pattern in a square block, neighborhood or larger geographical area, BeyWatch allows the energy supplier companies or the grid administrator to balance the energy consumption peaks. Comprehensive power demand scheduling then reduces the need for out-of-schedule power imports from neighboring countries or other heavy-handed emergency measures that attempt to curb consumption. By allowing real-time demand-side management and real-time feedback the BeyWatch platform can allow a gradual fine-tuning approach. It should be noted that real-time control is possible due to the existence of scheduling / optimizing software at homes (the BeyWatch Agent) that is able to respond swiftly to changing prices and other parameters and assure timely influencing of home energy patterns without requiring the home consumer to be constantly on the alert.

Evaluation of BeyWatch solution will be executed through three main directions:

- Internal evaluation of all project objectives through simulations, laboratory trials, measurements, evaluations, etc.
- Results evaluation through laboratory trials which will be also submitted to the judgment of a number of potential users. This will especially help the consortium to evaluate the degree of acceptability of the BeyWatch system and services (or part of it) in the every-day life.
- Comparison of BeyWatch cost/benefits with other projects/solutions running in Europe. This will help decision makers evaluate and take advantage of some of the most interesting solutions in Europe in order to save energy and reduce CO_2 emissions.

Two trial sites have been selected and equipment is, at the time of this writing, in the process of installation and integration: (a) the Smart Home Demonstrator testbed provided by Telefonica I+D in Madrid and (b) the Électricité de France (EDF) laboratories near Paris which includes a complete house. Both sites are realistically furnished and decorated to create a setting that will allow evaluating the project results from the real user point of view, showing real and expected services and applications. They are both depicted in Fig. 3.

Fig. 3. TID Test-bed Equipment (left) and EDF R&D Les Renardières Multi-energy House Test Facility (right)

The TID test-bed simulates an apartment with a living room, a kitchen, a bedroom, an office and a terrace. It has installed residential gateways, users PCs, PDAs, network cameras, home fixed telephones and a LonWorks network that controls different devices from lights to water stopcock. The EDF multi-energy house is equipped with solar and PV panels, a kitchen equipped with a BeyWatch energy aware dishwasher and fridge and a BeyWatch energy aware washing machine and a solar hot water tank in the garage. In both sites, alongside existing appliances and devices, BeyWatch networking, hardware / software elements are also being installed.

These trial sites will concentrate all of the service concepts developed so far and be enhanced in the context of the BeyWatch project by adding new services (energy monitoring & peaks shaving, white goods control, water management, energy generation/distribution) as provided by the BeyWatch Supervisor and Agent and other elements of the BWCM. Electricity consumption measurements will take place to: (a) test the effects of energy efficiency on individual appliances and as a whole, and (b) gauge the power peak shaving effects of the demand-side management mechanism implemented in BeyWatch.

More specifically the following data will be measured:

- Solar radiation
- External temperature
- Hot water temperature in the storage tank
- Power produced by the Photovoltaic panel
- Power consumed by the house
- Power consumed by the fridge / freezer (both BeyWatch enhanced and not)
- Power consumed by the dishwasher (both BeyWatch enhanced and not)
- Power consumed by the washing machine (both BeyWatch enhanced and not)
- Power consumed by non-Beywatch appliances.

The behavior of the BeyWatch system will be tested according to the weather forecast and to several tariff scenarios: the use of the electricity produced by the Photovoltaic panel (either sent to the home grid or to the national distribution grid) will be determined by comparing the price at which this PV electricity can be sold to the grid against the price of the electricity coming from the grid. Furthermore, the calculation of the BeyWatch starting time for the washing machines will depend on both the weather forecast and the grid electricity tariffs.

The data collected will help to compare a home equipped with a complete BeyWatch system to a regular home. The energy produced and consumed by the trial facilities will be compared to the energy consumed by similar homes, equipped with the same appliances, but not "BeyWatch compliant", i.e. a home in which every appliance is operating independently. For instance, the energy efficiency of a BeyWatch refrigerator will be monitored, in different weather conditions and for different user requirements, and compared to the efficiency of an otherwise identical refrigerator model but without the BeyWatch electronics installed. Apart from establishing energy savings due to increased appliances efficiency or the use of the CPS, BeyWatch will also evaluate the ability of the system to respond to demand-side management measures and thus lead to (assuming a widespread deployment) smoother demand curve without very pronounced spikes. This, in itself, can produce considerable economic and environmental benefits as the peak demand determines the infrastructure requirements and leads to capital outflows and deployment of assets which then have to be maintained and are depreciated whilst idling underutilized for most of their service life time.

More subjective end-user acceptability tests will also be carried out to evaluate ease of use, intuitiveness of the interfaces, impact / disruptions in daily routine, intrusiveness and the overall "disposition" of real users vis-à-vis the system.

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NOBEL – A Neighborhood Oriented Brokerage ELectricity and Monitoring System

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Abstract. Distributed generation of energy coming from various vendors, even private homes, is a big challenge for tomorrows power management systems that, unlike today, will not dispatch energy centrally or under central control. On the contrary, the production, distribution and management of energy will be treated and optimized in a distributed manner using local data. Even today, parts of the power system are highly nonlinear with fast changing dynamics. It is hard to predict disturbances and undertake countermeasures on time. In existing approaches electricity is distributed to the final users according to its expected estimated demand. Such non-dynamic approaches, are difficult to evolve and can not accommodate rapid changes in the system. By having a cross-layer and open information flow among the different actors involved we can make better and more timely predictions, and inject new dynamics in the system that will lead to better energy management and achieve better energy savings. The NOBEL project is building an energy brokerage system with which individual energy prosumers can communicate their energy needs directly to both large-scale and small-scale energy producers, thereby making energy use more efficient.

Keywords: smart grid, smart metering, prosumer, brokerage system, neighborhood management, smart city.

1 Motivation

Europe is striving towards saving of 20% of the European Union's primary energy consumption and greenhouse gas emissions, as well as the inclusion of 20% of renewable energies in energy consumption until 2020 (known as the "20-20-20" target). Energy efficiency is the most cost-effective way of reducing/optimizing energy consumption while maintaining an equivalent level of economic activity. Improving energy efficiency also addresses the key energy challenges of climate

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change, energy security and competitiveness. The main obstacles to energy efficiency improvements are the poor implementation of existing legislation, the lack of consumer awareness and the absence of adequate structures to trigger essential investments in and market uptake of energy efficient buildings, products and services.

Distributed generation of energy coming from various vendors, even private homes, is a big challenge and, additionally, a source for new business opportunities for tomorrows power management systems that, unlike today, will not dispatch energy centrally or under central control [2, 5]. On the contrary, the production, distribution and management of energy will be treated and optimized in a distributed manner using local data. Nowadays, 40% of all energy consumption in the world is electrical energy, with 41% of this energy consumed by households and services [1]. This will grow to 60% by 2040. Much of this energy is wasted by inefficient technologies, especially during its transport, but also in the last mile of distribution, where the management and control take place, most of the time, in a centralized way, as opposed to a more local driven monitoring and control. Information and Communication Technologies (ICT) are the key to enhance the monitoring and control of electrical energy from the source to the load, especially in cases where we have large scale distributed energy production [3].

In existing approaches electricity is distributed to the final users according to their expected estimated demand, usually precomputed yearly. Such non-dynamic approaches, are difficult to evolve and cannot accommodate rapid or unpredictable changes in the system e.g. on production side, on consumer side etc. By having a cross-layer and open information flow among the different actors involved we can make better and more timely estimations, and inject new dynamics in the system (e.g. locality of energy production, direct interaction of business processes with the energy management systems etc) that can eventually lead to better energy management and achieve better energy savings.

2 The NOBEL Approach

The NOBEL approach targets to develop, integrate and validate ICT enabling a reduction of the currently spent energy, by providing a more efficient distributed monitoring and control system for local network operators and prosumers (as depicted in Figure 1). NOBEL will focus its efforts in designing a new Neighborhood Oriented Energy Monitoring and Control System. This solution will help network operators to improve last mile energy distribution efficiency by integrating operators requirements and by enabling bidirectional interaction between them.

Two different prosumer (producer and consumer) profiles are considered for the proof of concept:

– A standard prosumer, represented via a Brokerage Agent. This Agent will be developed within the project to dynamically monitor the amount of energy that he has produced, and the amount that is not yet consumed. This energy

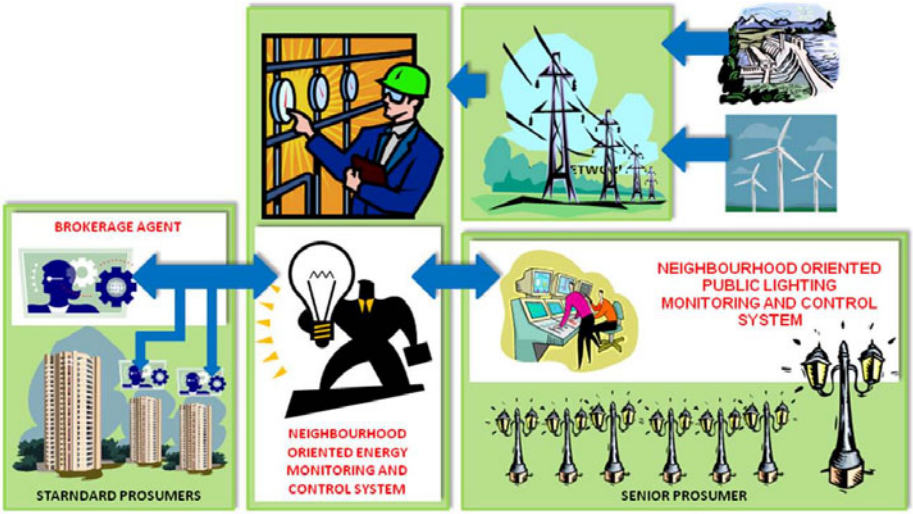

Fig. 1. NOBEL overview: Energy Efficiency for the Neighborhood

can be traded and therefore made available to other users, improving in this way the overall efficiency of the system.

– A senior prosumer, that extends the previous concept in the sense that that it requires additional internal processes to not only dynamically monitor but additionally control the energy produced or consumed in a largely distributed local area. Examples of senior prosumers are sport centers, industrial parks, shopping centers, etc. NOBEL will use a real-world testbed i.e. the Neighborhood Public Light System to validate and assess its concepts.

By improving monitoring efficiency, the NOBEL approach aims at reducing the required production of energy. In the short term, it is more important to improve the efficiency than trying to dramatically reduce the production, which would require a major social agreement and a major adjustment in the behavior of citizens. The key to NOBELs efficiency improvement is that prosumers become sources of both energy and information. The information allows the energy system to better adapt the amount of electricity in the network to the real time demand. The performance of the entire system is enhanced by exploiting the locality of the processes in monitoring and control that normally do not consider the detailed behavior of the actual consumers.

The ultimate objective is to achieve higher energy efficiency and optimize its usage. This will be achieved by analyzing and continuously monitoring the components in the distribution network, gathering the appropriate data and, finally, identifying on-the-fly situations where energy can be saved. This will allow NOBEL to create a highly dynamic system where the amount of electricity in the network follows the current demand. Excess energy already bought or created is monitored and managed to make the energy available in other parts of the network (see Figure 2) or to intelligently make use of it via demand side

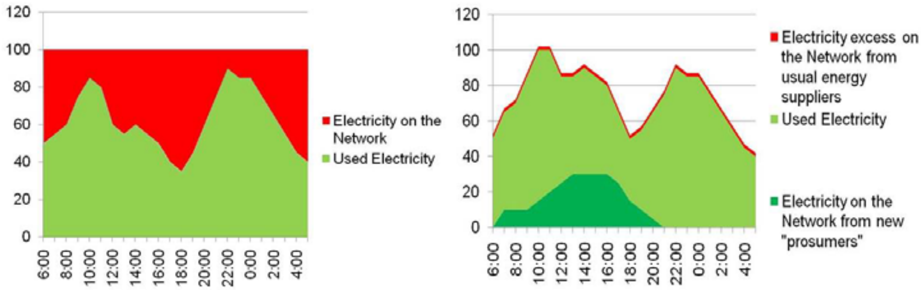

Fig. 2. NOBEL approach: demand-driven production/energy-purchase

controlling. To achieve this goal, the energy that comes from the local network operator as well as the prosumers will have to be monitored in a fine-grained way, analyzed, and decisions will need to be made in a timely manner.

In summary, the NOBEL project has set the following scientific and technical objectives:

– *Information retrieval:* NOBEL uses state of the art technologies to dynamically obtain and process information from current available installed equipment. This will be achieved by implementing bidirectional communication with all involved entities, process the information with respect to consumption and production and automate decisions to be made network-wide.
– *Information distribution:* NOBEL develops a service oriented framework that will allow easy flow of information among the prosumers and the enterprise systems in order to foster more energy efficient processes. This implies the development/extension of a middleware and a set of application independent services that enable the distributed capturing, filtering and processing of the energy related data. The same services will ease enterprise wide inclusion and allow for better cross-layer collaboration which will lead to holistic optimization strategies.
– *A cooperative system:* NOBEL develops cooperation approaches for all entities involved. This assumes cooperating objects at device level, at the energy brokerage system, at service level etc. Interoperability in heterogeneous environments will need to be tackled, while we focus on the use of the Internet Protocol for communication e.g. at smart meters, etc. The system includes a core platform to assist local network operators in the monitoring and control of energy, and a brokerage system and usage of brokerage agents that act on behalf of a prosumer, to distribute fine-grained knowledge and gather information through the network.
– *End-user applications:* A Neighborhood Oriented Energy Monitoring and Control System, a Brokerage Agent front-end, a Neighborhood Oriented Public Lighting Monitoring and Control System, and Applications are expected to be strongly integrated with the Enterprise Services and provide mash-up customized services to the users.

– *Real-world evaluation:* NOBEL validates and assesses the NOBEL approach in a real world Pilot Site, where customers reside and use it in their daily lives.

3 Challenges and Research Directions

Apart from the energy efficiency, the NOBEL project focuses on the technology side as well, including IP communication for low power networks, data capturing and on-device / in-network cooperative processing, enterprise integration and timely user interaction also with the usage of mobile devices.

3.1 IP Communication for Low-Power Networks

To support the large number of devices and communication patters in NOBEL, the underlying networking technology must be inherently scalable, interoperable, and have a solid standardization base to support future innovation as the application space grows. IP provides standardized, lightweight, and platform-independent network access embedded networked devices. The use of IP makes devices accessible from anywhere and from anything; general-purpose PC computers, cell phones, PDAs as well as database servers and other automated equipment such as a temperature sensor or a light bulb. NOBEL addresses three key issues in low-power IP networking:

– *Power-saving MAC protocols:* To provide a long lifetime of the power-constrained nodes, power-saving MAC protocols are crucial. Although IP packet transmission on Layer 3 has been standardized, there is a remaining need to develop low-power solutions for Layer 2. Several power-saving MAC protocols exist in the sensor network research community, but they are not developed with the traffic patterns of IP-based communication in mind. We will develop and evaluate low-power MAC protocols for IP-based sensor networks and embedded networked devices.
– *Application Programming Interface (API)*: General-purpose operating systems provide the so-called socket API to application programs, but the socket API was no designed to capture the specific requirements for multi-node communication patterns of sensor networks.
– *Routing-independent packet forwarding*: To support future innovation in routing protocols for cooperating objects, we provide a packet forwarding mechanism that is independent of the routing protocol running on top of the communication system. This allows for empirical evaluation of different routing protocols running in the same system, which is crucial for performance evaluation of future routing protocols for low-power networks.

3.2 Data Capturing and Cooperative Processing

The use of Cooperating Objects technologies [4] for the purpose pursued in NOBEL is a novel approach that involves the following challenges:

- The definition of relevant data to the application and its efficient capture within the network.
- The appropriate routing of this information to the critical parts of the system that requires it.
- The filtering of non-relevant information in order to minimize resource usage such as bandwidth and reduce the latency.
- The support of quality of service-type characteristics such as scalability with respect to the number of prosumer devices in the system and the timeliness of information to the appropriate devices.
- The cooperation of devices within the network to enable the emergence of large-scale properties that implement the application.

It is worth mentioning that the devices used for the metering and monitoring of the network are to be small and non-intrusive. Therefore, if there are no components in the network that are interested in the type of information a device is able to provide, the system should be able to recognize this and increase the level of efficiency in the data gathering. The transfer of relevant information to the appropriate devices includes not only the selection of the end-points for the routing of data, but also each intermediate node(s) that might be involved in the forwarding procedure. The use of an asynchronous event-based system using a publish/subscribe paradigm for this purpose seems to be the appropriate choice to disseminate information at the interested parties only. Routing is then selected based on the number and location of the subscribers in the network.

As with any kind of technology that makes use of small devices (such as sensor networks, ubiquitous devices or cooperating objects), the appropriate filtering of information plays a crucial role for the efficiency of the system. Even if data is produced by a device, if no other device in the system is interested in knowing what this information is all about, it does not need to be forwarded within the network. Similarly, if a piece of information is relevant to all of the devices, a flooding-like approach should be used. A publish/subscribe system is able to cope with the flexibility required by the system and hides the complexity of finding the appropriate routes and using the right techniques for data forwarding from the application.

An energy distribution network is very complex and contains many different elements. Depending on the state of the system and whether or not some of the components (nodes in the network) are able to produce and/or consume energy, their role in terms of the forwarding and data processing technology changes. Therefore, a publish/subscribe system that is able to adapt to these changes by the definition of additional subscribers and publishers can help in coping with the high application complexity. The challenge that still remains is the definition of the appropriate structures to cope with the requirements of timeliness and scalability.

3.3 Enterprise Integration and Energy Management

The aim is to effectively tackle the challenges of Enterprise Integration and Energy Management. To do this we will make the Enterprise systems and their services at first stage energy-aware, and then move towards optimization based on energy Key Performance Indicators (KPI).

To achieve this we need fine-grained energy monitoring (for the awareness) and subsequently management/control in order to close the loop and allow the system to optimize itself. To achieve the energy optimization, our system must be able to integrate and interact with a number of players. This includes the producers, the consumers as well as various service providers. The core of the approach is in the cooperative energy services that almost in real-time integrate the business and the real world, allowing bidirectional information flow and computation at device, network and enterprise level using the middleware developed within the project. The use of a publish/subscribe paradigm allows for the definition of data channels that can be used for the distribution of data gathered in all layers of the application. These need to be correlated and commonly evaluated in order to lead to energy efficient strategies by taking a holistic view on how energy efficiency can be achieved. This should include also cross-enterprise issues and in cooperation with external entities such as smart electricity grid and the increasing integration of alternative energy resources.

To ease cross-layer cooperation we need to tackle heterogeneity and allow interaction via open technologies. As such open cooperative services that can be used as basic blocks for creating more complex distributed energy-related applications should be designed and realized. Following the "software as a service" paradigm, dynamically scalable and often visualized resources are provided as a service over the Internet, including manifold auxiliary services for accessing, managing and using the infrastructure. As it can be expected, the advanced metering infrastructure (AMI) will pose new challenges to enterprise systems due to the high rate of communication with the metering devices and other interacting entities [3]. Also the way we design and implement enterprise applications will change, as now cooperation capabilities, direct end-to-end interactions with energy as KPI need to be built-in. Finally algorithms taking into consideration locality as well as global system dynamic requirements need to be investigated and applied.

4 Real-World Validation

Two real-world validation scenarios are envisioned and will be prototyped i.e. an electricity monitoring and management and a public lighting system management. The goal is to significantly raise energy efficiency.

4.1 Electricity Monitoring and Management System

The future energy monitoring and management systems are in close cooperation with the enterprise systems. As it is depicted in Figure 3, data available on enterprise systems is combined with data on the network (e.g. via personalized services), and both of them are mashed-up to create new user applications. NOBEL aims at creating dynamically applications that use the "software as a service" paradigm to create dynamically customized applications at the end user

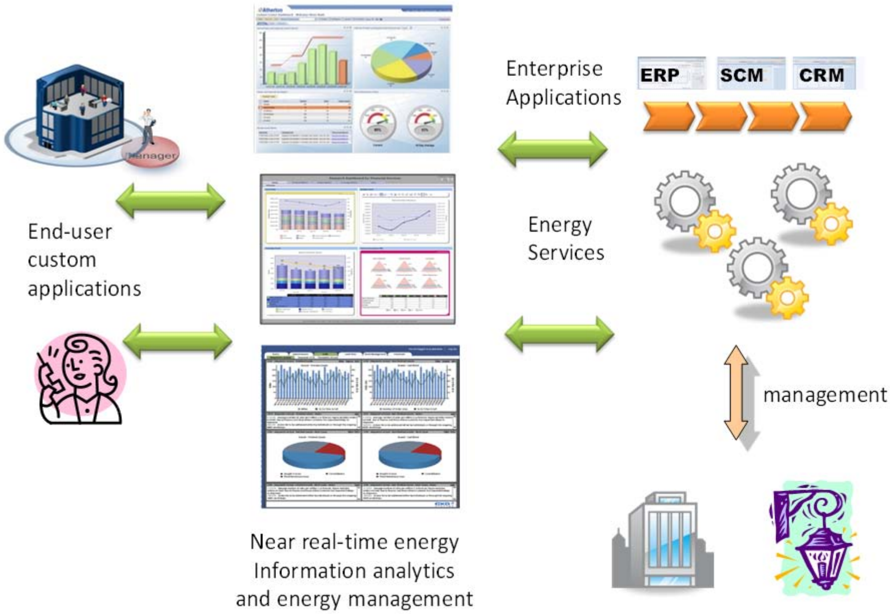

Fig. 3. End-user customized applications

side, whether this is a simple user, a standard prosumer or a senior prosumer (as defined in the project context). This is a significant change for the energy domain, as we move away from heavyweight monolithic applications towards much more dynamic, mobile, up-to-date and interactive ones.

To that extent close collaboration is needed. Applications for electricity monitoring and management are expected to be composed of services that are distributed and are brought dynamically together to realize a specific application (in the NOBEL case these will be service mash-ups). The envisioned applications will offer close coupling to existing energy monitoring infrastructure, to the information residing on enterprise systems, and the customized profiles of the users. Data will be mixed, processed and analyzed and near real-time analytics will be available.

The users will have access to their existing energy consumption, analysis of the situations and possible identification of energy wasting. They will be able to have a historical overview as well as a projection of their future energy and costs depending on their current consumption behavior. Further customized services will be available for them, and will be provided by wired and wireless means in order to achieve access to the energy data anywhere, anytime, in any form easily and effectively. Based on their capabilities the users will be able to not only have monitoring information but also manage their personal plans and their infrastructure. By increasing visibility via near real-time assessment of the energy information, providing analytics on it and allowing selective management, NOBEL will provide a new generation of customized energy efficiency services.

A real world trial will be realized in the town of Alginet, which is located 25 Km from Valencia, Spain. Alginet has 15000 inhabitants, the majority of whose lives in homes equipped with smart meters that can make fine-grained measurements. The Electrical Cooperative of Alginet is the local electricity provider with an approx. 6000 customer base where the neighborhood concepts of NOBEL can be tested. Additionally the coverage of the area via WiMax will enable us to test mobile applications.

4.2 Public Lighting Control System

Public lighting in urban areas represents a high cost to the municipalities in all Europe. Current modern public lighting control systems are based on the management of points of light which are controlled by a segment controller managed from a control center. We intent to demonstrate how the technologies realized in NOBEL, can provide better monitoring and managing of the electricity, and how better energy efficiency in public sector can be achieved. Therefore NOBEL will extend the capabilities of the control center to realize better visibility and increased performance.

In detail we will work towards providing:

– A higher level of granularity with respect to the control of lamps, thanks to the new developments in data capturing and processing.
– A real time capability to react to different situations implementing different policies (natural light conditions, meteorological conditions, different calendars, lamp conditions, effect of urban traffic on public lighting, etc).
– Real time monitoring of the amount of energy consumed, identifying geographically the different level of consumption in a neighborhood.

The energy efficiency can be improved by means of policies, adapting the light intensity to different situations. For instance, it is proposed to adapt the intensity of light, or even if necessary increase the number of lamps switched on, by taking into account the proximity of vehicles or pedestrians. This increases the life expectancy of lamps and equipment, generating significant economic and energy savings. Moreover, the powerline transmission of data to a GIS-database containing information on every single fixture enables the operator to easily identify lamps that have or soon will burn out therefore realizing better asset management.

5 Conclusion

NOBEL presents a new approach that focuses on the small and medium-sized communities, with the goal to better enable them to manage their resources and additionally achieve better energy efficiency. Towards this quest we will investigate and advance state of the art technologies by taking full advantage of the Internet technologies, the capabilities of modern networked embedded systems and the collaboration of different actors to achieve the common goals.

As we have presented there are several challenges that lie ahead, however the benefits for communities will be significant. We aim at validating our prototypes in real-world trials in the city of Alginet in Spain.

Acknowledgment

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Monitoring and Control for Energy Efficiency in the Smart House

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Abstract. The high heterogeneity in smart house infrastructures as well as in the smart grid poses several challenges when it comes into developing approaches for energy efficiency. Consequently, several monitoring and control approaches are underway, and although they share the common goal of optimizing energy usage, they are fundamentally different at design and operational level. Therefore, we consider of high importance to investigate if they can be integrated and, more importantly, we provide common services to emerging enterprise applications that seek to hide the existing heterogeneity. We present here our motivation and efforts in bringing together the PowerMatcher, BEMI and the Magic system.

Keywords: smart house, smart grid, web services, PowerMatcher, BEMI, Magic, software agents.

1 Motivation

The existing electricity infrastructure is still primarily organized under the centralized approach where a few large power plants broadcast energy to the different consumers. However, in compliance with social and economic demands of our times, ongoing developments in the energy sector tend towards an increasing usage of alternative energy resources which are usually smaller and regionally dispersed. This leads to a very dynamic future energy network, where electricity will be produced in a distributed way, and customers are not only consumers, but also producers of energy (e.g. *prosumers*), and where bidirectional interaction between generators, consumers and other entities will be possible.

The research project SmartHouse/smart grid[1] takes a fundamentally different and innovative approach where the ICT architecture under development by

[1] http://www.smarthouse-smartgrid.eu/

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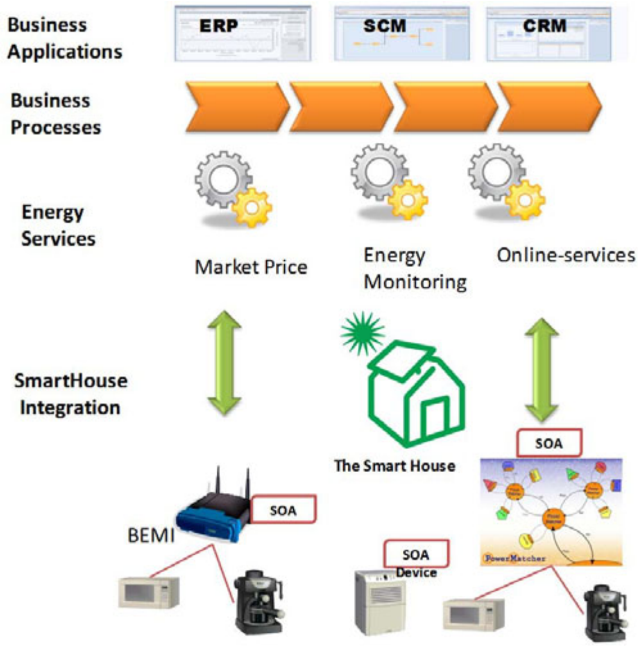

Fig. 1. Enterprise Integration of Smart Houses

the consortium introduces a holistic concept and technology for smart houses as they are situated and intelligently managed within their broader environment [3]. This concept seriously considers smart homes and buildings as proactive customers (prosumers) that negotiate and collaborate as an intelligent network in close interaction with their external environment [5]. The context is key here – the smart home and building environment includes a diverse number of units: neighboring local energy consumers (other smart houses), the local energy grid, associated available power and service trading markets, as well as local generators, e.g. environmentally friendly energy resources such as solar or small combined heat and power (CHP) plants.

As depicted in Figure 1, enterprise integration is expected to be the key issue for harvesting the benefits of the smart grid and making the concepts pursued by the SmartHouse/smart grid viable. This is expected to empower new businesses and strategies, and enable market-driven approaches to flourish. Our approach is based on the following elements:

- In-house energy management based on user feedback, real-time tariffs, intelligent control of appliances and provision of (technical and commercial) services to grid operators and energy suppliers.
- Aggregation software architecture based on agent technology for service delivery by clusters of smart houses to wholesale market parties and grid operators.

– Usage of Service Oriented Architecture (SOA) [6] and strong bidirectional coupling with the enterprise systems for system-level coordination goals and handling of real-time tariff metering data.

Within the household, appliances and devices are integrated via some form of gateway or concentrator that has connectin to the smart grid. More specifically, in the SmartHouse/smart grid project we use three kinds of integration concepts, i.e. the *bi-directional energy management interface* (BEMI), the PowerMatcher and Magic system. These concepts will be described in more detail in this paper. What is also needed for realizing viable business cases with smart houses as part of the smart grid is the integration of in-house services with enterprise-level services. The last included typical business-to-customer services such as billing, but also other business-to-business services such as the interaction among different players such as the TSO, distributed generation (DG) operator, energy retailer, wholesale market and others.

2 In-House Architecture Overview

The main goals for the design of the in-house architecture are listed in the following:

– To provide a framework for applications in the area of energy management and energy efficiency at customers' sites in smart distribution grids. This framework will typically run as software on an in-house gateway computer.
– To allow for access to devices and other hardware functionalities that are connected to the gateway via standardized data models or device service models.
– To allow for automated registration of new devices based on standardized data models and device services.
– To make the data provided from outside the in-house gateway that might be relevant to various applications (such as the price of electricity) accessible based on standardized data models.
– To define standardized framework services for using these data models and device services.
– To also provide standardized services for functionality that will be needed for many applications: the user web interface, persistent storage of certain types of data and logging.

From these goals, several architectural elements of the framework have been identified and defined (depicted in Figure 2):

Application: An application is a piece of software that is able to run in the environment of the in-house framework. In contrast to a communication system driver, it is not used to enable the physical connection to hardware. Applications represent certain use cases and should be specific to a use case.

Resource: A resource is a representation of states, parameters or other data generated outside the framework. So a resource can either represent a physical

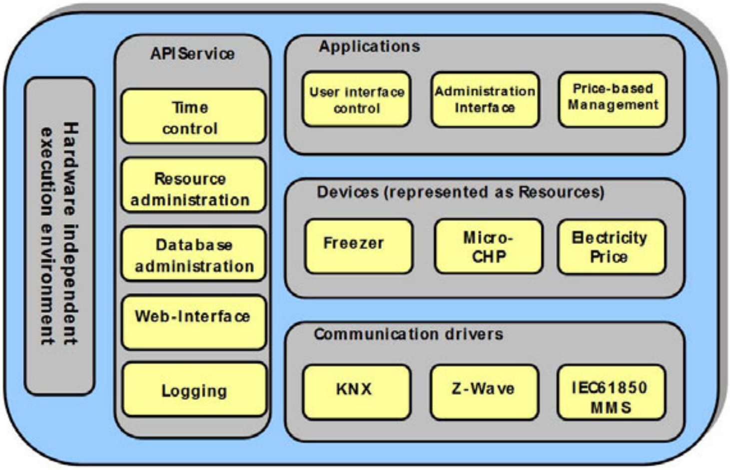

Fig. 2. Example: In-house framework

device, the parameters/state of a communication system or data transmitted to the system from a control station, such as a price profile.

Resource Type: A resource type is a model definition for resources. In order to enable automated device identification and plug&play, standardized resource types have to be used on all framework implementations. However, it shall be possible to add new resource types to a framework when standardized types are available. In an object oriented perspective, this is the class description of which the resources are instances.

Communication System: A communication system is able to connect the data representation of a resource with the actual physical device it represents or with the external data source (e.g. the control station delivering the price profile). In this way, the information of the physical connection of each resource is made transparent to the rest of the framework as it is processed solely by the communication system. Each connection links one data element of a resource to an address of a communication system. The addressing scheme of each communication system is specific to each communication system, of course.

API Service: The framework needs to offer several functionalities to the applications and communication systems. These services can be grouped into the administration of resources (Resource Administration), the administration of applications, the system time they are using and the way they are executed (Time Control), services for persistent storage of preferences data of applications and of data structures that are commonly needed by applications in the area of energy management and efficiency (Persistent Storage), access to a user interface and services for logging and evaluation of text log messages as well as of measurement data series. The API Service bundles all modules of services of the framework. Further services available to applications and communication systems can be provided by applications, but the services of the API Service can be expected on every framework implementation, thus being a base set for interoperability. The

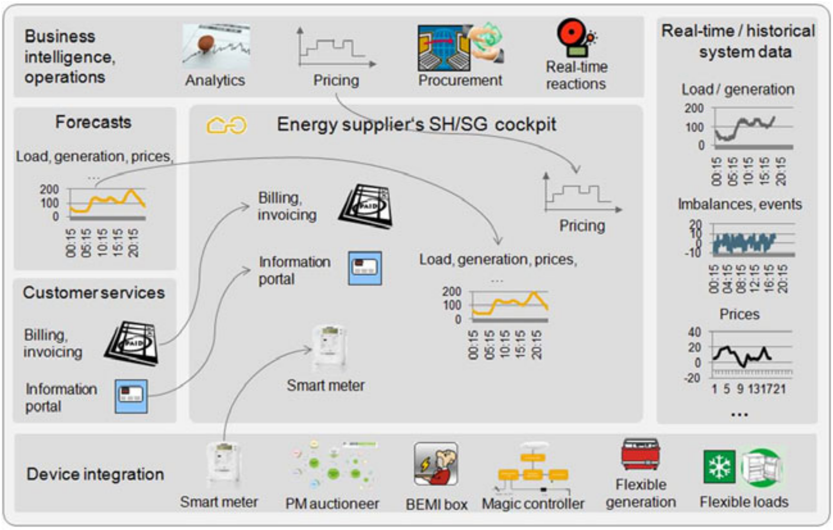

Fig. 3. Enterprise Cockpit for SmartHouse/smart grid Services

framework specification, thus, developed was not only described theoretically, but is also put into a reference implementation which will be tested in real field. Furthermore, in order to define and develop a standard for the in-house services described above, the Open Gateway for Energy Management Alliance (OGEMA)[2] was kickstarted in September 2009. The scope of this alliance is to provide an open standard for a software framework for energy management in the building sector, including private buildings and households. This framework is to be run on a central building gateway which serves as interface between the smart house and the smart grid, integrating as many applications in the area of energy management and energy efficiency as possible. Standard and reference implementation will be made available for public download at the alliance's website.

The smart house will need to interact with numerous external entities, let it be alternative energy resources, marketplaces, enterprises, energy providers etc. In order to rapidly realize business processes, as well as efficiently take decisions, enterprise cockpits (Figure 3) are envisioned that will offer customized functionality depending on near real time data coming from a variety of sources including the smart houses.

Any smart retailer or new energy service provider that wants to use the functionality of one or even more than one of the energy management technologies developed within SmartHouse/smart grid should be able to chose from existing services that are needed at the enterprise level. Through a service repository, the new enterprise should be able to drag all functionality into its system in order to realize its business case(s) which should be interoperable and functioning together.

[2] http://www.ogema-alliance.org/

The de-facto standard for high-level communication today is via web services, which allows for flexible functionality integration without revealing details for the implementation. Therefore, the heterogeneity is hidden, while a common service-based interaction is empowering the creation of sophisticated applications. The SmartHouse/smart grid project is deeply investigating the possibility of using web services at least for the interaction of the smart house with other smart houses, and with entities in a smart grid.

Within the smart house, we have numerous protocols and even different technologies at the hardware communication layer. It is, however, a common belief that all of this heterogeneity will be hidden behind gateways and mediators, which will eventually allow the device to tap into an IP-based infrastructure, using Internet standards. Already today, the IP protocol is developed further to run in tiny and resource constrained devices (6lowpan)[3], while with the IPv6 – and 6lowpan – any device will have its own IP address and be directly addressable.

Due to IP penetration down to discrete device level, it is expected that devices will not only provide their information for monitoring to controlling entities, but will be able to dynamically discover nearby devices and collaborate with them. In this way, peer-to-peer interactions will emerge, which can be exploited by locally running applications that execute monitoring or controlling tasks.

Devices in the smart house are and will remain highly heterogeneous, both in hardware and in software. As such, we need to find a way that this heterogeneity is abstracted, and yet communication (and collaboration) among them can be achieved. The development of middleware systems that act as the "glue" for device-to-business connectivity (and later also for device-to-device connectivity) is a viable approach.

3 Amalgamation of Monitoring and Control Approaches

SmartHouse/smart grid does not have a common architecture in the classical notion, but rather advocates an amalgamation of heterogeneous approaches that are "glued" together with SOA. This is a key part for enabling the future smart grid vision as we do not expect that a single architecture will prevail; rather several heterogeneous approaches will be applied but all of them will exchange information at higher level via common standardized approaches such as those enabled by web services (WS-* standards).

We do not expect that a one-size-fits all technology will prevail in the market; we rather consider that several of them will coexist and the real challenge would be to integrate them in a global ecosystem that will deliver the envisioned smart grid benefits. To this end the SmartHouse/smart grid project follows three different architectures driven by common goals but fundamentally different in the way they approach the energy monitoring and management. Real world trials as depicted in Figure 4 will validate our efforts.

[3] 6lowpan is an acronym of IPv6 over Low power Wireless Personal Area Networks, or IPv6 over LoW Power wireless Area Networks; `http://6lowpan.net/`

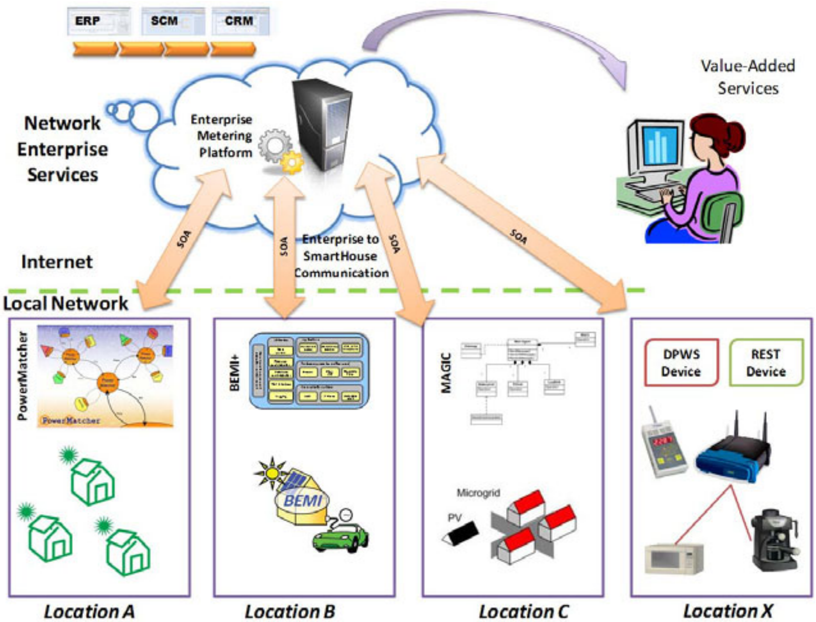

Fig. 4. Enterprise Integration in Trials: PowerMatcher, BEMI and Magic

The first architecture is the PowerMatcher. In this concept, a large number of agents are competitively negotiating and trading on an electronic market with the purpose to optimally achieve their local control action goals. In the market-based optimization, the optimal solution is found by running an electronic equilibrium market and communicating the resulting market price back to the local control agents.

The second architecture is the BEMI. It uses an energy management approach that is organized in a decentralized way and avoids a central control of the individual loads and distributed energy resources (DER). In this approach, every decentralized market participant operates a BEMI interface which optimizes the local power consumption and generation automatically, depending on local as well as central information like e.g. variable tariffs. In field test location B, this approach will be implemented as application using the OGEMA framework as a software basis.

The third architecture is the Magic system which is based on a multi-agent system that enables the coordination of the actors. The system provides an architecture that supports complex interactions between the agents based on agent communication language (ACL). The system is implemented upon the Java Agent Development Framework (JADE) which is a FIPA[4] compliant platform. Finally, the description also provides part of the system organization, since the concept of coordination between the agents imports significant complexity to the system.

[4] FIPA stands for Foundation for Intelligent Physical Agents; `http://www.fipa.org/`

3.1 PowerMatcher

The PowerMatcher [2] concept uses agent technology that allows software agents, representing real-world entities, to interact with each other to perform a task or reach a certain goal. The agents are organized into a logical tree. The root of this tree is formed by the auctioneer agent that handles the price forming process. This price is based on the demand and supply functions that are issued by the leafs of the tree, the local device agents and, occasionally, by an objective agent. Concentrator agents can be added to the structure as tree nodes.

The PowerMatcher concept is developed as a market based concept for coordination of supply and demand of electricity in networks with a high share of distributed generation. In this concept, a large number of agents are competitively negotiating and trading on an electronic market with the purpose to optimally achieve their local control action goals.

PowerMatcher is concerned with optimally using the possibilities of electricity producing and consuming devices to alter their operation in order to increase the over-all match between electricity generation and consumption. In the PowerMatcher concept, each device is represented by an agent which tries to operate the process associated with the device in an economically optimal way. The agents mediate the electricity consumed or produced by the devices by using an electronic exchange market.

The electronic market is implemented in a distributed manner via a hyperlinked structure of so-called PowerMatchers. A PowerMatcher concentrator aggregates the demand and supply of the components directly connected to it and passes it on to its higher level controlling component, either another concentrator or an auctioneer. Different types of devices can act as related consumers and producers. The PowerMatcher auctioneer receives the aggregated demand and supply for the whole and determines from it the equilibrium price, which is communicated back to the concentrators and from there on to the agents. From the market price and their own bid function, each agent can determine the power allocated to its device. An auctioneer or concentrator cannot tell whether the devices connected to it are agents or other concentrators, since the communication interfaces of these components are equal. This makes the concept less privacy sensitive, while it is greatly scalable to include large numbers of device nodes.

The PowerMatcher concept can be applied in several business cases. A business case can be implemented at a higher level in the network by an objective agent that order to achieve a predefined goal. This goal is reached without intrusion at the agent level, since each agent is free to express its own supply or demand curve based on local needs.

3.2 BEMI

The BEMI [4] uses an energy management approach that is organized in a decentralized way and avoids a central control of the individual distributed energy resources (DER) like electric loads, generators and storage devices. Instead of this, local optimization decisions will be made through the customers themselves (or automatically by appropriate devices acting on the customer's behalf), who can act as consumers and/or producers of electric energy. In this approach, every decentralized market participant operates a BEMI, which optimizes the local power consumption and generation automatically, depending on local as well as central information like e.g. variable tariffs.

The optimization is carried out on the basis of locally available information, which differs from the approach of typical virtual power plant (VPP) implementations. Thus, the customer has access to all optimization relevant data by means of a man-machine interface and, if desired, can also influence the optimization himself. In this way, an active integration of the customer with a high level of transparency is possible. Furthermore, the BEMI implements measurement devices for low-voltage grid supervision, which is a prerequisite for increasing the share of fluctuating distributed generators (DG) we are facing in today's distribution network. Herewith, the BEMI can supply measurement data, e.g. of voltage, grid impedance and frequency.

Generally, the BEMI coordination algorithms can be divided into two domains: Algorithms that are executed at the customer site by the customer grid interface (BEMI) and algorithms executed at the aggregation level usually in the domain of an energy provider or the DSO. The algorithms at the customer's site must react on the price profile given by a higher-order element named Pool-BEMI, typically situated at the energy provider. However, these algorithms also must take into account the processes and the parameters of the devices installed as well as customer preferences. The algorithms on the customer site shall be designed in a way that the energy cost for the customer gets minimized under the constraints defined by the customer.

Energy provider and DSO thus need their own algorithms to ensure that they are also able to benefit from the management. The energy provider needs to fulfill the balancing schedule registered for a certain day, which means that the customers shall ideally consume or generate exactly as much energy per balancing interval as acquired from/sold to various sources. When calculating prices for customers also the customer contracts have to be fulfilled. The DSO has to make sure voltage level and line loads are maintained and might have to react to emergency situations. Whereas the energy provider usually defines the price profiles day-ahead like the existing energy exchange markets, the DSO has to react much more quickly. In order to enable this, using adaptations to the prices previously announced to the customers can be applied. Since this but influences the energy provider's business, DSO and energy provider have to agree on mechanisms how to use this possibility. A very straight forward and liberalized market oriented approach to this is the introduction of new distribution grid services offered by the energy provider to the DSO.

3.3 Magic

The Magic [1] is a multi-agent system (MAS) and its control approach supports several aspects of DG and controllable loads operation. This control approach also focuses on a concept called Microgrid. This is a new type of power system which consists of small modular DG in the low-voltage (LV) grid. This control scheme introduces the idea that all the main decisions should be taken locally, being though in coordination with the other actors. The ability of coordination implies the usage of a high level language from the actors and consists of two main parts. The first part is that although the decision is local, it has to take into account the conversation or the negotiation between the actors. The second part is that a certain degree of high level coordination or monitoring is inevitable.

In a microgrid, each agent controls one unit of the system, for example a battery bank, a wind turbine or a controllable load. In the first step, the MAS, after negotiating with the energy supply companies (ESCo), should receive a schedule for power production and power consumption that also includes prices. The negotiation and the decisions regarding the participation of the Microgrid in the market belong to the higher level of control which constitutes the team behavior.

Afterwards, the agents should decide how to realize the schedule. Two schedules are created, one for production and one for consumption. In this way, it is obvious that there are now two sub problems that do not include all the agents. The production schedule includes only the DG units and the consumption schedule only the controllable loads. Focusing on the production schedule, the DG units should decide on how to share fairly the requested production. After the negotiation, each DG has a separate schedule and the control process moves to the lowest level, i.e. is the local level. In the local level, every DG unit should accomplish its schedule taking into account its special characteristics and status. It is obvious that the special characteristics as well as the status information were taken into account in the previous negotiation. For example, a battery unit would not make any bid if it has no sufficient kWh stored.

4 Conclusions

The infrastructure that will exist on the future smart house is expected to be heterogeneous. However, it seems that at some level all devices – either by themselves or via gateways – will be able to communicate over the Internet protocol and participate in bidirectional communication with other devices and enterprise services. Similarly, multiple concepts for monitoring and controlling the smart houses and the smart grid will emerge, with different optimization and control algorithms. It is therefore imperative not to focus on a single one-size-fits all approach, but rather also prove that an amalgamation of existing approaches can be done. The SmartHouse/smart grid project can be seen as first step on developing mechanisms for "glueing" different monitoring and control approaches as well as empowering the next generation enterprise services and applications. This is done by using web services and open standards and is applied to the PowerMatcher, BEMI and Magic systems.

Acknowledgment

The authors would like to thank for their support the European Commission and the partners of the EU FP7 project SmartHouse/smart grid (www.smarthouse-smartgrid.eu) for the fruitful discussions.

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Market Optimization of a Cluster of DG-RES, Micro-CHP, Heat Pumps and Energy Storage within Network Constraints: The PowerMatching City Field Test

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Abstract. The share of renewable energy resources for electricity production, in a distributed setting (DG-RES), increases. The amount of energy transported via the electricity grid by substitution of fossil fuels for mobility applications (electric vehicles) and domestic heating (heat pumps) increases as well. Apart from the volume of electricity also the simultaneity factor increases at all grid levels. This poses unprecedented challenges to capacity management of the electricity infrastructure. A solution for tackling this challenge is using more active distribution networks, intelligent coordination of supply and demand using ICT and using the gas distribution network to mitigate electricity distribution bottlenecks.

In the EU FP6 Energy Program Integral[1] project, a large scale heterogeneous field test has been designed for application of the software agent based PowerMatcher technology. The test is conducted in a suburb of Groningen, Hoogkerk, and entails approximately 30 homes with either a 'dual fuel' heating system (electrical heat pump with gas-fired peak-burners) or a micro-CHP. Homes also may have PV. Furthermore, a wind production facility and nodes with electricity chargers for EVs and electricity storage are part of the Virtual Power Plant cluster, constructed in this way.

Domestic heating systems have intrinsic operational flexibility in comfort management through the thermal mass of the dwellings. Furthermore, the field test comfort systems are equipped with possibilities for hot water storage for central heating as well as for tap-water. Finally, having additional gas-fired heating capacity for electrical heat-pumps adds to increasing flexibility by switching the energy source dependent on the status of the electricity grid.

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[1] Integral is financially supported in part by the EU 6th energy research framework (see http://integral-eu.com/)

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Purpose of the field test is using this flexibility to react to phenomena in the electricity system.

- From a commercial perspective, the aggregated cluster reacts on small-time scale events like real-time portfolio imbalance, compensation of ramp-up and ramp-down induced phenomena of large generators and compensating for variable output of renewables like PV and Wind. Aim for the latter is to reduce the margin between realization and forecast of a portfolio containing these resources.
- From a distribution perspective, the total load on the transformer is monitored and coordination also involves diminishing this load during peak periods to improve the utilization of grid components and increase their lifetime.

An extensive socio-economic study is performed on user perception of the control of these new types of installations. In this paper, the component configuration and set-up of the field-test and the architecture of the ICT-network for coordination are discussed. The test has commenced in December 2009.

1 Introduction

In the EU there are strict targets for 2020 in terms of energy efficiency increase (20%), carbon dioxide reduction (20%) and energy produced from renewable energy sources (RES) (20%). In certain countries, plans exist to set these targets even higher for individual nations as for instance the Netherlands. However, the introduction of renewable embedded generation, in a dispersed setting, at a large scale and spread over a large area reaches the limits of central control. Central coordination concepts, influencing prosumers at low levels in the grid, lead to an increase in complexity, system management and cost. Dispersed generation with distributed ICT and bottom-up coordination mechanisms isolates responsibilities and allows decision-making and coordination based on the local primary process connected to the supplier or demander of electricity. It also allows DER units to connect and disconnect at will and pre-empts for all (future) DER types. Also, multi-actor interaction requires local and global balancing of stakes and local and global coordination exceeding ownership boundaries, facilitating decision making locally on local issues and alignment to liberalized energy markets.

In the market design of traditional electricity grids, end-users having shift-able energy or capacity are treated in a similar way as end-users demanding energy at peak prices. All end-user consumption is averaged in profiles, according to which cost are attributed following the mix in the development of commodity prices, bilateral contracts and so on in the markets forming the portfolio. Therefore, the full potential of flexibility on the demand side is not unveiled. Indeed, the way small customers are accounted for in current markets even acts against utilizing flexibility. A similar story can be told for integration of variable output DG-RES resources, which sometimes lead to more carbon emission because of the required extra generation capacity needed to compensate for intermittent fluctuations.

Not only the energy price picture does not map the system costs to the real world; indeed, a similar mechanism also holds for mapping the distribution cost to the real world. As an example, consider having a large HVAC-related domestic load at peak commodity price periods in moderate climate zones. Effects on the system are accounted for via the profiling of the household and the fixed capacity tariff limits.

Fixed capacity tariffs are no problem if they are time-dependent. Ideally, with a perfect mapping of cost on environmental impact, operating the electricity system using commercial markets would be optimal. However in reality there are a lot of market imperfections and there is no level playing field between different countries.

In the market view in this experiment an abstracted, more or less optimal mapping is assumed to pick up the optimal operation perspective for each device. Stakeholders in the experiment are the energy delivery related parties like retailers, traders and prosumers and the capacity related parties like transmission, distribution operators and – again - prosumers. Benefits for them using the technology developed are different per stakeholder. For retailers and prosumers, the overall energy bill will be lower due to sharing the revenues of the coordination mechanism. For the program responsible parties and the balancing responsible parties the benefits will come from much more accurate knowledge of their actual market position in real-time as well as the opportunity to foster the benefits of helping to diminish the overall system imbalance (both actively and passively). The INTEGRAL project aims to build and demonstrate an industry-quality reference solution for DER aggregation-level control and coordination, based on commonly available ICT components, standards and platforms. In one of the experiments of this project, the PowerMatcher technology [IEEE-PES, 2008, IEEE-NGI, 2008] is used for bottom-up coordination of a heterogeneous cluster of energy supply, demand and storage with a large number of smart IT-nodes in a communication network, each presented by a software agent.

2 ICT in Automated Grids, Smartgrids and Intelligent Grids

Discrimination has to be made between Automated Grids, Intelligent Grids and Smart Grids once looking at the integration of ICT-technology with electricity grids. In automated grids, which have been around for quite some time now, functions operated manually by an operator, are substituted with automated functions. Intelligent grids are grids equipped with distributed ICT to achieve a common optimization goal via an ICT enabled application. Intelligent in this sense means operating grids using extended context information from the capillary level (at the level of individual devices) to the highest HVDC connection level. Intelligent also means application of results of ICT research like knowledge base systems and advanced computational techniques like neural networks. 'Smart' grids, according to the SmartGrids platform strategic deployment document [SmartGridsSDD, 2008] have to be defined as follows:

> *''A SmartGrid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies. ''*

SmartGrids, thus integrate all intelligence for optimization for all actors in the value chain, including traditional stakeholders, but also new actors.

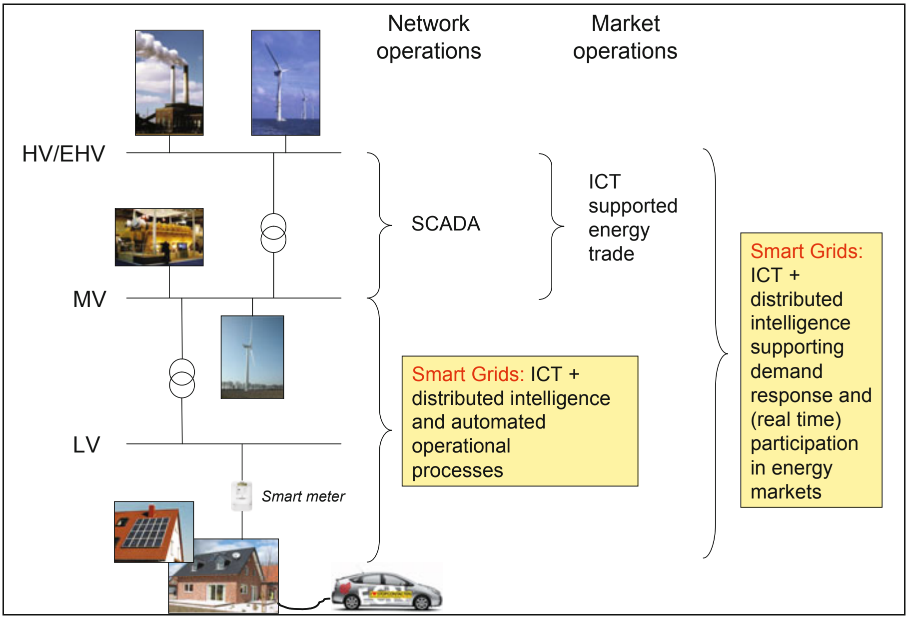

Fig. 1. Loosely and tightly coupled ICT in electricity networks

In using ICT in Power Systems, one can use tightly bound layers parallel to the physical infrastructure or loosely coupled layers built using existing mainstream ICT-technology and infrastructures. Tightly coupled layers will be used for direct, fast control (e.g. deterministic switching in real-time); loose coupling for coordination purposes (supply-demand matching). The art of architecture design of ICT in Power Grids lies in attributing a limited number of low-level functions directly coupled to the physical infrastructure and designing functionally rich applications using the loosely coupled networks.

3 Thermal Flexibility as a Means for Electrical Flexibility

As already mentioned, having flexible electricity generation or production, especially once aggregated, leads to economic value increase. In the comfort system of the homes in the field-test buffering of heat can be achieved through a hot water storage tank. A flexible coupling to electricity production/consumption in the case of the heat pump and the micro-CHP is possible in this way. The heat-pump can produce hot water by electricity or by an additional gas-fired peak burner in a common storage tank. The hot water can be used for heating and to produce tap-water. The micro-CHP, when used for heating, produces electricity and heat, which can either be directly used in the house or can be buffered in the tank. The upper level of the tank is primarily used for tapwater;

the bottom part for space heating. The bottom capacity is used in the home heating season buffering on expected electricity price changes. The upper part above the 'comfort level' is used for providing additional flexibility, especially in the summer season.

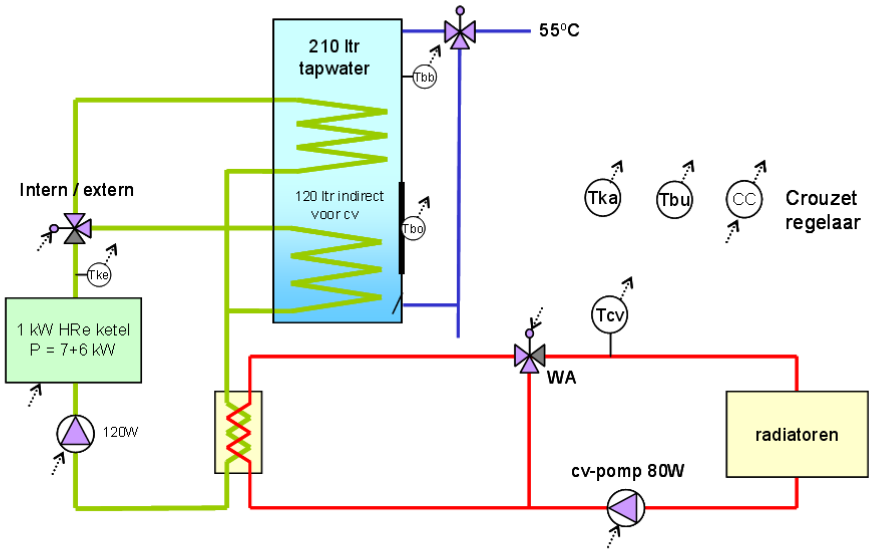

Fig. 2. Hydraulic scheme of a heating system with storage capability

4 Configuration and Use Cases in the Powermatching Fieldtest

The field test is currently taking place in a residential area in Hoogkerk near Groningen in the Northern part of the Netherlands (http://www.powermatchingcity.nl). The 'PowerMatching City' (see Figure 3 upper part) field-test A has three hierarchic levels. At the first hierarchic level, a cluster of residential houses is configured, in which generation and load flexibility is delivered by the heating systems in the houses as discussed. In this sub-cluster setting, PV is a must-run generator and must-run loads are lighting loads. A power distribution agent monitors constraints on the LV-distribution network. Finally the lowest level for coordination is the home context level, operation of devices behind-the-meter.

A further node is located at the ECN facilities and includes electricity storage and an electric vehicle charging unit near a test dwelling. The ECN node further has the wind-park Kreileroord connected, for which day-ahead forecasts of power output from the high-resolution HIRLAM meteorological model, covering Western Europe, are determined as in the CRISP-field-test [AAMAS, 2005]. At the Groningen Gasunie research lab and at the RenQi educational facility a variety of devices (PV, urban wind, scooter chargers) is installed to form the third sub-cluster.

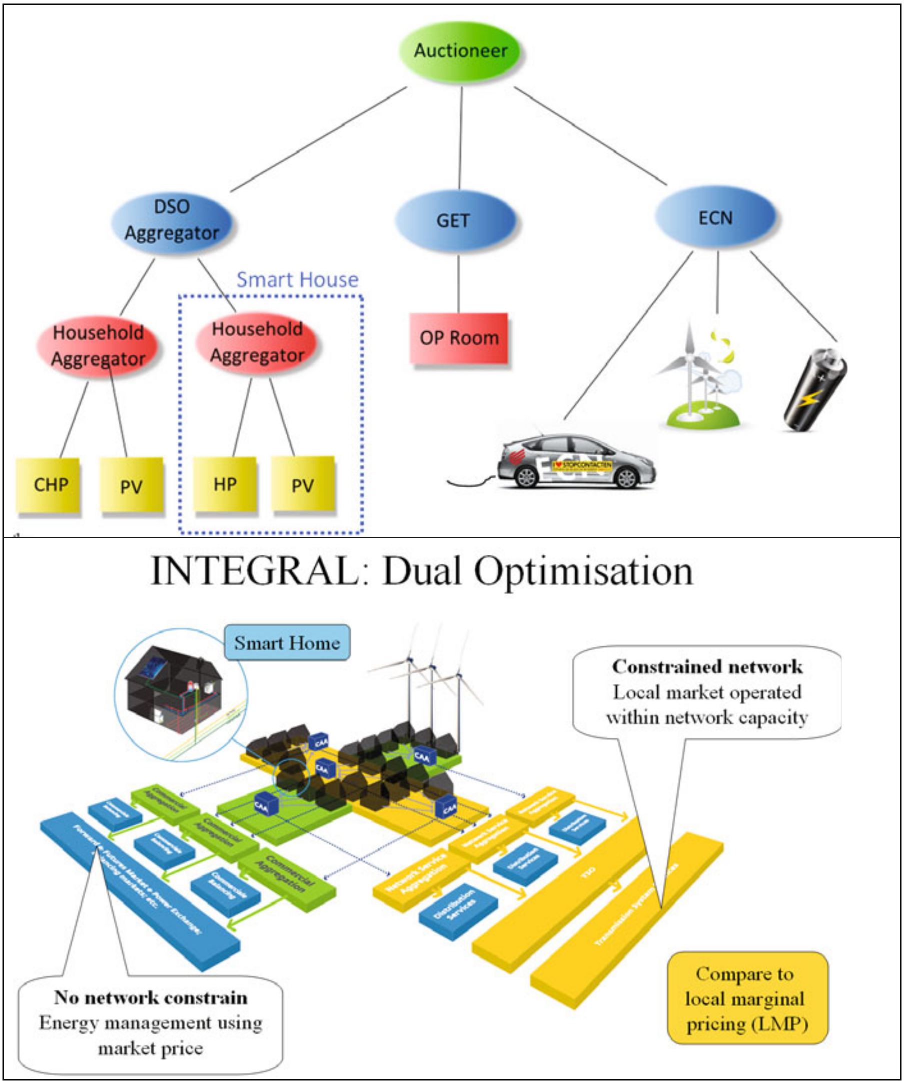

Fig. 3. The PowerMatching city /experiment A field-test configuration and optimisation

The renewable integration and cost optimization use cases at the residential level include:

- **Reduce transformer losses** in high import/export situations. Verification of the result of the coordination action will be done by setting up load the duration curve of the transformer with and without coordination using the PowerMatcher. The effects of conflicting scenarios, like all heat-pumps operating simultaneously, will be determined and the way the coordination algorithm resolves the conflict using the PowerMatcher algorithm.

- **Commercial imbalance reduction** with all loads and generators part of a commercial portfolio. The flexibility of the total cluster will be determined in the form of the total amount of control and reserve power that can be liberated as a function of time and of time-of-year. The achievable ramp-up/ramp-down speed of the Virtual Power Plant will be determined.
- **Valorisation** of renewable electricity. The mechanism pre-emptively lowering pre-production peak consumption, if a forecast of high local production of PV around 12 o'clock in summer with minimal local demand will be shown and, in the same way, lowering flexible generation during the PV-peak.
- **Household monitoring and optimization** behind the meter. Use PowerMatcher technology to optimize 'behind the meter' in a flat or a two-price import and export tariff scheme and maximum capacity constrained operation.
- **Cost-effective use** of energy. Show cost reduction effects in a semi-artificial real-time pricing environment.
- **Provide for customer feedback.** Extensive usability and participatory design is used to provide feedback to the inhabitants of the homes in the field-test. Participation retribution fees have a fixed component, but also variable components linked to 'grid-friendliness' and contribution to the results of the cluster.

Finally, in the field test, the combined effect of having commercial incentives combined with network constraints is modelled. Especially in the winter period, if there is a large heat demand, μ-CHPs, may have incentives to deliver electricity at high market prices, exposing the local distribution grid with overload on transformers (Figure 3; lower part). In this case, an additional PowerMatcher agent counteracts by applying a additional local distribution tariff for a limited period of time. Because operation of the devices strongly depends on the heat demand and the production of renewable resources like solar energy and wind, the field-test is conducted to cover summer and winter as well as autumn and spring.

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INTEGRAL: ICT-Platform Based Distributed Control in Electricity Grids with a Large Share of Distributed Energy Resources and Renewable Energy Sources

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Abstract. The European project INTEGRAL aims to build and demonstrate an industry-quality reference solution for DER aggregation-level control and coordination, based on commonly available ICT components, standards, and platforms. To achieve this, the *Integrated ICT-platform based Distributed Control (IIDC)* is introduced. The project includes also three field test site installations in the Netherlands, Spain and France, covering normal, critical and emergency grid conditions.

Keywords: Smart Grids, DER/RES integration, Distributed Control, ICT, multi-agent systems.

1 Introduction

With large shares of Distributed Energy Resources (DER) and Renewable Energy Sources (RES) that are expected in coming decades as a consequence of reaching EU policy targets, important challenges will have to be met with regard to controllability and optimal integration in Electric Power Systems of the EU and its Member States.

The EU project INTEGRAL (http://www.integral-eu.com) aims to build and demonstrate an industry-quality reference solution for DER aggregation-level control and coordination, based on commonly available ICT components, standards, and platforms.

To achieve this *Integrated ICT-platform based Distributed Control (IIDC)* solution (see Sec. 2), the INTEGRAL project is taking the following steps:

N. Hatziargyriou et al. (Eds.): E-Energy 2010, LNICST 54, pp. 215–224, 2011.

- Define *Integrated Distributed Control* as a unified and overarching concept for coordination and control, not just of individual DER devices, but at the level of large-scale DER/RES aggregation.
- Show how this can be realized by common industrial, cost-effective and standardized, *state-of-the-art ICT platform solutions*.
- Demonstrate its practical validity via three *field demonstrations* covering the full range of different operating conditions including:
  - *normal* operating conditions of DER/RES aggregations, showing their potential to reduce grid power imbalances, optimize local power and energy management, minimize cost etc. (see Sec. 3.1).
  - *critical* operating conditions of DER/RES aggregations, showing stability when grid-integrated (see Sec. 3.2).
  - *emergency* operating conditions, showing *self-healing capabilities* of DER/RES aggregations (see Sec. 3.3).

The project will summarize its IIDC reference solution by wrapping up the lessons learned from the demonstrators, and providing resulting practical how-to-build industrial guidelines. Figure 1 depicts the positioning of the INTEGRAL project.

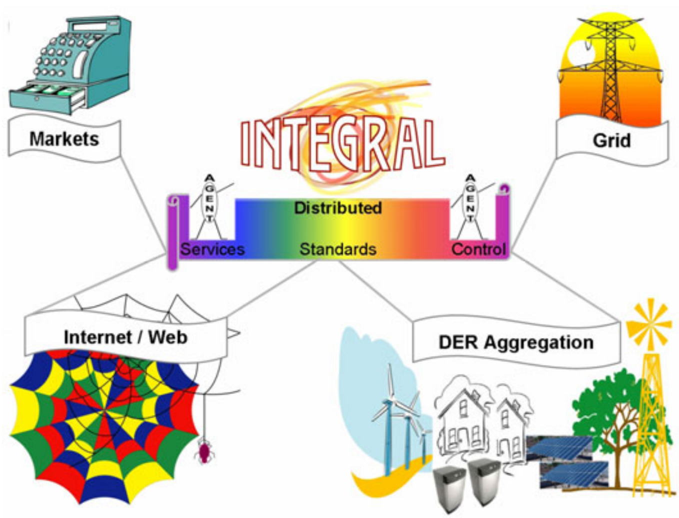

Fig. 1. Positioning of the INTEGRAL project

2 Integrated ICT Platform for Distributed Control: Design Issues

A wide range of projects in [1-4] and outside [5-7] Europe investigate the many issues that come with Smart Grids. Smart grids are grids equipped with distributed ICT to achieve a common optimization goal via an ICT enabled application. Smart or intelligent in this sense means operating grids using extended context information from the level of individual devices to the highest HVDC connection level. Intelligent also means application of results of ICT research like knowledge and agent systems and advanced computational techniques like neural networks. Compared to other approaches for making power grid applications interoperable, INTEGRAL's IIDC solution focuses on a granular, dispersed lower grid level for facilitating intelligence.

The focus of the INTEGRAL project is to provide a set of three solutions for Active Distribution Grids enabling DER/RES integration:

- *Aggregation*
  - Dynamic real-time context
  - Cells, micro-grids
  - Virtual power plants
- *Integration of these DER aggregations into*
  - Local distribution grid operations
  - Higher-level grid operations
  - Power trading
- *Availability of*
  - Practical aggregation mechanisms
  - Low-cost and industry-quality standard solutions

These Active Distribution Networks should support the following *operational stages*:

- *Normal operations*
  - Trading optimization (supplier)
  - Grid optimization (DSO)
- *Critical operations*
  - Support stability higher level grid
- *Emergency/black start behaviour*
  - Self-healing reaction to local faults
  - Micro-grid mode

In addition, general *requirements regarding ICT Systems* in Smart Grids apply:

- *Scalability*
  - Large numbers of DER/RES components
  - Spread over large area
  - Centralized control reaches complexity limits
- *Openness*
  - DER/RES units connect and disconnect without any central control involved
  - All (future) DER/RES types must be able to connect
- *Multi-actor interaction*
  - Balancing of stakes: locally and globally
  - Coordination exceeding ownership boundaries
  - Decide locally on local issues (autonomy)
- *Alignment with Liberalized Energy Markets*
  - Support different types of regional markets
  - New market designs, especially facilitating mechanisms for better valorisations of DER/RES should be configurable
  - Clustering of interests should be possible at several levels

The INTEGRAL technology consists of software and a hardware shell with applications coupled to the grid to ICT networks and business systems in a tighter or looser way depending upon the type of application. In using ICT in Power Systems, one can use tightly bound layers parallel to the physical infrastructure or loosely coupled layers built using existing mainstream ICT technology and infrastructures. Tightly coupled layers will be used for direct, fast control (e.g. deterministic switching in real-time); loose coupling for coordination purposes (supply-demand matching). The art of architecture design of ICT in Smart Power Grids lies in attributing a limited number of low-level functions directly coupled to the physical infrastructure and designing functionally rich applications using the loosely coupled networks. To take the INTEGRAL project as an example, for the normal operation case the link to business optimization objectives is strong as is the aggregation diversity in the cluster; the link to the physical grid is loose. On the other hand, for emergency operations the ICT grid connections should be tight and secure and the business objectives are loosely coupled as is the aggregation diversity. The critical case is inbetween these two.

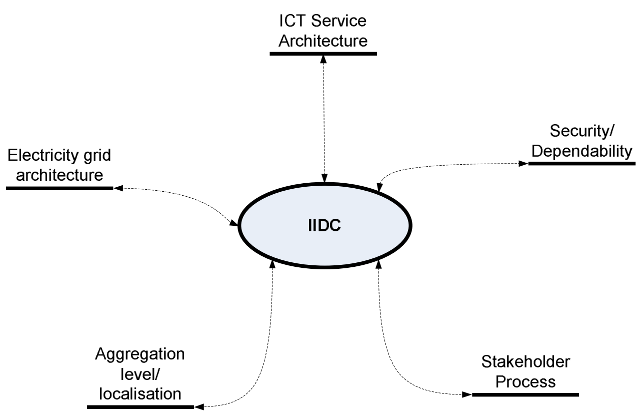

Fig. 2. Five views context of ICT enabled electricity grid applications

A first context scheme for the INTEGRAL IIDC framework is shown in Figure 2. Smart Grid applications combine different architectural views in one IIDC platform:

a) **The physical electricity grid architecture.** This architecture includes additional ICT tightly coupled to the grid to exert direct grid control functions like real-time balancing, frequency and voltage control.
b) **The ICT service architecture** is loosely coupled to the grid functions. The grid is one of the context items for the ICT applications, but the operational aspects of the grid do not have to be the main issue in designing these functions.
c) **The aggregation/localization level.** The hierarchical division (HV/MV/LV) of the power grid is an example of aggregation on the physical level; on the application level, software enabled transparency enables variable aggregation schemes. This is one of the strong points of applying ICT in the electricity field [8]. E.g. operating a nationwide spread cluster of μ-CHP might enable profitable

operation on the electricity market. The nano-level refers to the individual households, the micro-level to a LV-grid comparable Microgrid, the meso-level to the MV-comparable level of a region and the macro-level to the nationwide HV-grid level issues.

The following additional aggregation levels are possible:

- Logical aggregation: connected to certain device logics (type of apparatus)
- Functional aggregation: connected to a certain service or function in the grid. Energy and capacity based applications may lead to this type of aggregation.
- Business aggregation: linked to business objectives in a business model [2].
- Stakeholder aggregation.

A more grid oriented classification uses levels 0, 1 and 2 [1, D2.1], where 0 corresponds to the above-mentioned macro level, 1 to the MV-level and 2 to the micro-grid level.

d) **The stakeholder process.** The process involving the stakeholder is another context boundary. Stakeholders include commercial parties optimizing portfolios for cost, installation owners, distribution system operators, home owners etc. Aggregation levels may exist. For instance, an individual housing corporation may aggregate a heat pump cluster of residents and coordinate operation. A market party may aggregate a number of Housing Corporations.

e) **Security and dependability.** These issues in the power system play an important role from the electrical as well as the ICT point of view.

3 Demo Site Descriptions

3.1 Demo Site A – Netherlands (Normal Operation)

The normal operation 'PowerMatching City' [9,10] (Hoogkerk, NL, see Figure 3) field-test A has three hierarchic levels. At the first level, a cluster of residential houses is configured, in which generation and load flexibility is delivered by the heating systems in the houses. Through a storage tank, these are able to buffer hot water and thus heat. A flexible coupling to electricity production/consumption in the case of the heat pump and the micro-CHP is possible in this way. The heat pump can produce hot water by electricity or by an additional gas-fired peak burner in a common storage tank. The hot water can be used for heating and to produce tap water. The micro-CHP, when used for heating, produces electricity and heat, which can either be directly used in the house or can be buffered in the tank. In this sub-cluster setting, PV is a must-run generator and must-run loads are lighting loads. A power distributor agent monitors constraints on the LV distribution network. Finally the lowest level for coordination is the home context level, operation of devices behind-the-meter.

The communication network infrastructure of experiment A is depicted in Figure 4. Standard TCP/IP technology is used with the public Internet protected by VPN. At the household level, a dedicated ADSL connection provides for broadband connectivity. This connectivity is also used for operation of the database, that is extensively used as a medium for information exchange in the experiment A system. Through the choice of a loosely coupled database as the cornerstone of the information system, it is possible to refine the control algorithms using already measured data from the

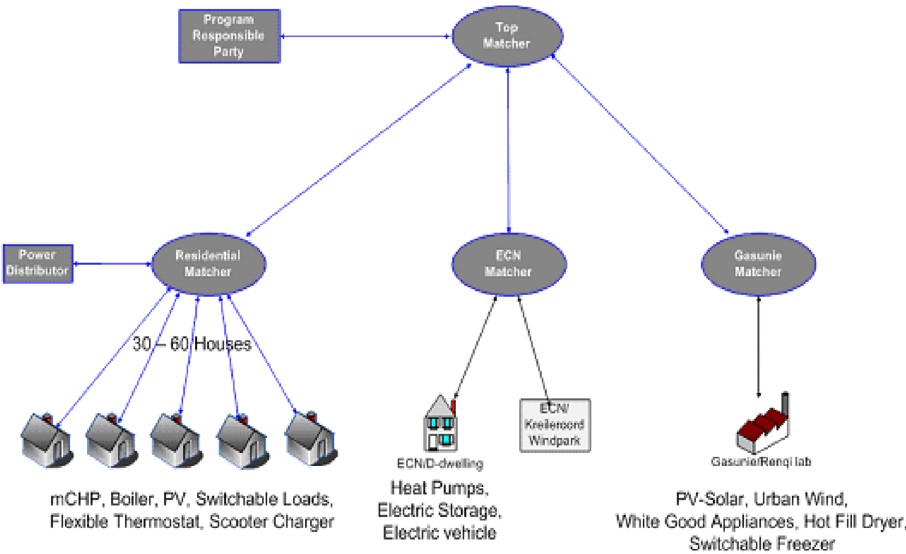

Fig. 3. The PowerMatching city: Experiment A field-test configuration (normal operations)

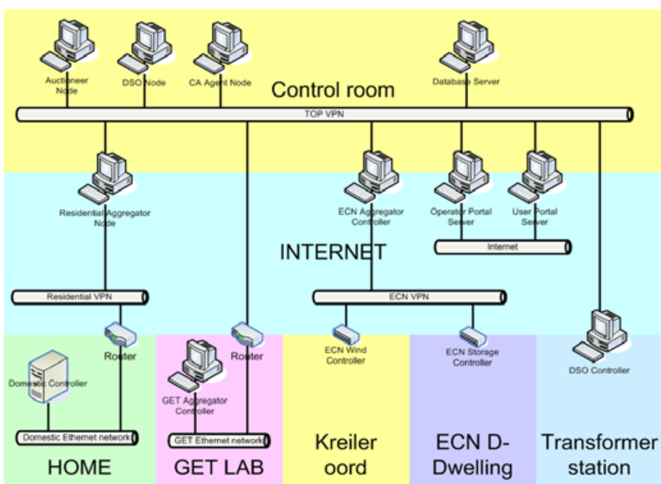

Fig. 4. Experiment A communication network

experimental configurations. A two-level data-collection scheme is used with local fast data acquisition and processing and storage of averaged and derived data. The database used is standard SQL Server technology from Microsoft, which also has functionality for distributed processing. The data exchanged and stored include:

- Network set-up definitions
- Site set-up definitions

- Values of measurement and control signals
- PowerMatcher messages
- Configuration
- Logging (Log4Net)

User interaction, interfacing hardware and inter-process communication in field-test A is realized in the C# environment utilizing the Microsoft .NET framework supported by an SQL based relational database system. It is foreseen that implementations with Web Services using SOAP and XML will be used for interfacing the components.

3.2 Demo Site B – Spain (Critical Conditions)

The experiment B critical operation field-test configuration is depicted in Figure 5. There is a Microgrid, consisting of a number of RES generators (PV, Wind turbine), a backup power diesel unit and a number of shiftable loads related to domestic consumption like heating/cooling and lighting. There is a 220 V local grid, connected to two types of inverters including SMA-inverters, that are able to exert control actively in response to voltage and frequency deviations. As a secondary response a UPS-storage unit is available; this also contributes to produce variations on physical characteristics of the general grid in order to emulate external events. Within the Microgrid, not connected to the main grid, a separate place is reserved for additional equipment, which emulates external events (due to legislation in Spain, the Microgrid is not allowed to be physically connected to the main grid).

In field-test B supply-demand matching coordination is performed to react to critical situations in the grid. The supply-demand matching is done using software agents operating in an agent development and execution environment. In this environment, JADE, device behaviour and energy usage optimization are also at

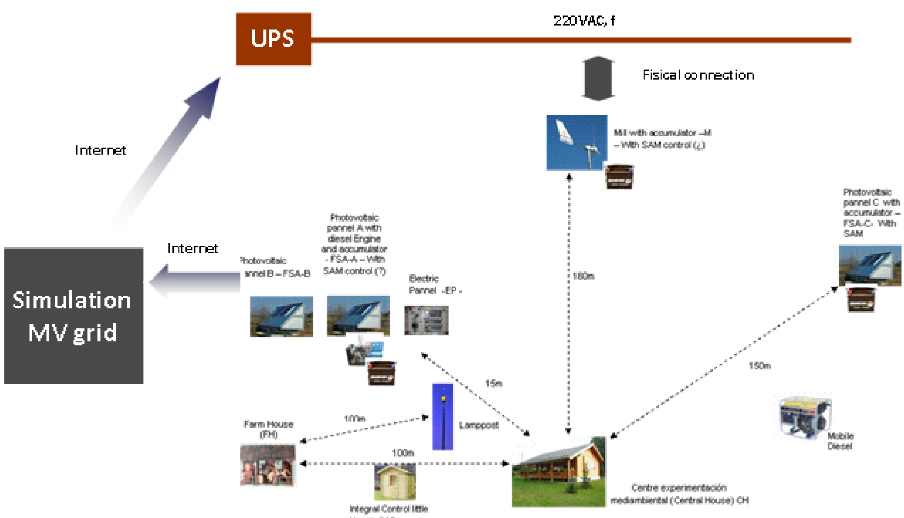

Fig. 5. Experiment B – the Mas Rog configuration (critical conditions)

stake. Embedded controllers in the field (ZigBee nodes) are linked to a central PC in which the agents are operating as separate software processes. Therefore, having a JADE<>WCF/.NET interface would enable flexible interchange of agent logics and data. A DataBase Agent (DBA) provides the functionality on the use of the general database, a User Agent (UA) provides the communication with the User, and finally the Local Controller (LC) is the agent assigned to the specific element in the field with its particular logic for the device.

The software interconnectivity in field-test B is realized by ZigBee technology for real field communication and basic reactive control in the hardware part, and by using primitives from the JADE environment in the software part for complex control. Each device has physically associated a unique ZigBee node which is communicated to the central system. Into the central system, each device in the real field has an associated agent which is part of the multi agent system (MAS). Thus, the interconnectivity in field-test B is realized using primitives from the JADE environment.

The ZigBee to agent connection (the MAS system) is established using the serial RS-485 protocol via a ZigBee mesh network by means of the central ZigBee node connected to the multi agent system. Communication is via the Microgrid Central Controller (MGCC). The Micro Grid Central Controller (MGCC) provides the coordination of the system. This Microgrid Central controller has communication with the Internet by means of standard TCP/IP protocol, cf. Figure 6.

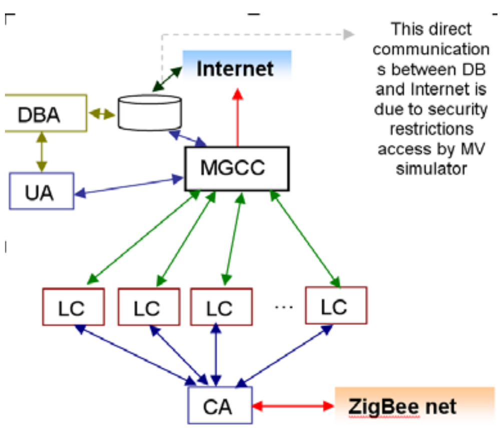

Fig. 6. Communication network of experiment B

3.3 Demo Site C – France (Emergency Case)

The emergency case field-test C configuration is depicted in Figure 7. Use cases are the following:

Fast fault detection and isolation (location robustness, fault type). On the demonstration network, different fault locations and short circuits will be tested (three phases, two phases, single phase with or without grounding). The DSO will use the high level functionality associated with the ADA devices (Fault Passage Indicator, remote control switches…) in order to quickly detect and isolate the faulty section.

Fast service restoration processes (communication performance). Short circuit and self healing functions will be tested. The performance of the communication, bandwidth and latency will be studied between the RTUs and the agents.
Fast fault detection and isolation (grounding of the substation). Short circuits (of a different nature) and self healing functions will be tested as function of grounding type. The DSO will then be able to quickly detect and isolate the faulty section even in various grounding conditions.
Fast fault detection and isolation (load and generation conditions). On the demonstration network, different short circuits will be tested with various loading and sourcing conditions.

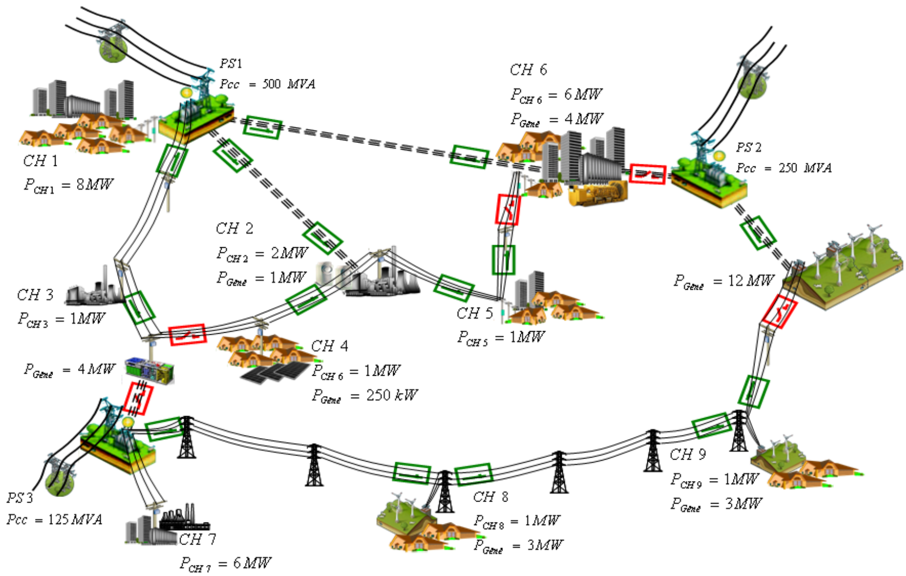

Fig. 7. Experiment C configuration (emergency operations)

The field-test C communication configuration is shown in Figure 8. Equipment and tools used are based on standard open protocols with interfaces to proprietary protocols. OLE for Process Control (OPC™) via Ethernet is used as the standard protocol for communication between the SCADA OPC server and the RTUs (OPC clients). Equipment and tools used are:

- The electrical measurement devices: current transducer (4..20mA), voltage transducer (4..20mA) linked with the automated components and the RTUs will be installed to have the real situation of the experimental network.
- The communication requirements of the different elements will be analyzed.
- The Intelligent Ethernet Switches from BTH will be installed and validated.
- Communicating RTUs based on the PLC/PC104 standard will be analyzed and chosen in term of required data acquisition and computerization abilities.
- OPC servers need to be installed in the ICT platform of G2ELab laboratory.
- A link between OPC servers and OPC MATLAB toolbox.
- A link between the MATLAB toolbox and advanced functions for self healing is established.

Closed loop control between MATLAB advanced functions and SCADA system are being designed to operate the remotely controlled switches. The agent logics is coupled through the OPC server.

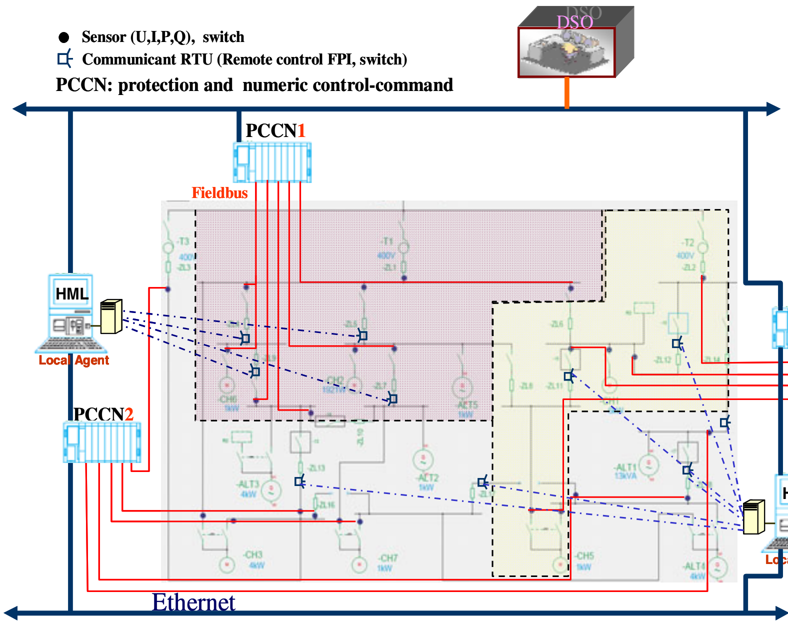

Fig. 8. Communication network of Experiment C

4 Further Information

Further information on the EU project INTEGRAL, including the IIDC common architecture and results of the field experiments, will be made available on the project website at http://www.integral-eu.com.

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Cellular System Model for Smart Grids Combining Active Distribution Networks and Smart Buildings

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Abstract. With the European Union's political 20-20-20 targets, the structure and control of the overall electricity grid is changing towards a smart grid.

In order to optimizing future grid management, end-users will be integrated into the energy system through incentives and several new energy services. Indeed, end-consumers will become active and independent participants in the energy market by either shifting or lowering their electricity usage as a function of both availability of certain energy sources and energy costs, thereby contributing to the development of environment- friendly energy and improvement of energy efficiency.

Smart grids are also a response to the expected increase in complexity in the control of the low-voltage level, which results from amplified fluctuation of current flows due to the high proportion of decentralized energy generation. As such, smart grids will serve to maintain or even increase supply security in this energy landscape.

At present, energy feed can still be handled by conventional means. However, with the rapid growth of decentralized generation and especially weather-dependent generation, measures must be taken to secure a reliable power supply.

In 2007 the German government initiated the E- Energy programme in order to demonstrate the smart energy supply system of the future – the smart grid[1] - in specific model regions. As one of the six selected model regions, the Model City Mannheim project is currently developing a new ICT infrastructure to boost energy efficiency and receptivity for renewable energy as well as to strengthen grid users' personal responsibility for their energy consumption.

This paper presents the required core elements of a future smart grid.

Keywords: energymanagement, E-Energy, distributed generation, renewable energy, smart grid, active distribution system, ICT, swarm intelligence, distributed automation, agent, system architecture.

1 Objectives of the German E-Energy Funding Programme

The following figure summarizes the objectives described below.

Environmental compatibility

The fundamental aim is carbon dioxide emissions reduction and a more conscious use of the limited supply of fossil fuels. A global consensus exists for the pursuit of these overarching goals and has led to the formulation of climate

N. Hatziargyriou et al. (Eds.): E-Energy 2010, LNICST 54, pp. 225–242, 2011.

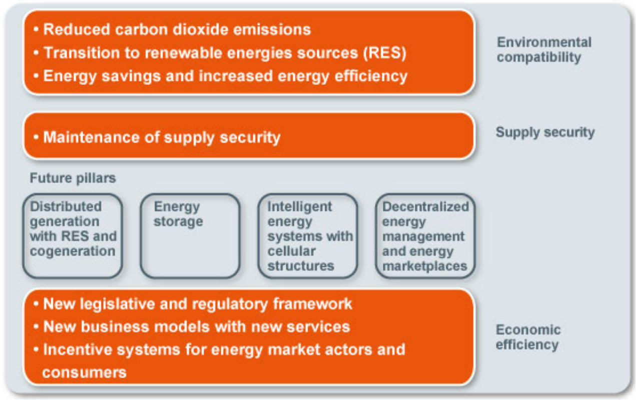

Fig. 1. Objectives and pillars of the future energy system

change-focused policy framework. **The resulting objective is thus the accelerated implementation of energy conversion facilities that make use of renewable energy sources, within the new energy portfolio.** The ERGEG's Position Paper on smart grid and the sources cited there [1, 3-8] provide a summary of these objectives.

The first pillar of future energy management is then, energy conversion through, first, **centralized large- scale generation** in the high-voltage range of the **transmission system**, secondly **distributed generation** in the medium-voltage range of the **distribution system**, and finally **micro-conversion** from local energy sources on areas and buildings on **grid user sites** in the low- voltage range. With regards to distribution grids, the aim is to **augment the ability to integrate the conversion of renewable energy sources and the cogeneration of heat and power**.

The increasing use of renewable energy sources results in **an increased fluctuation in the available energy**. It then becomes necessary to resort to energy storage facilities – in particular **thermal storage** – and develop corresponding business models, in order to integrate both heat and power into the energy system.

Fuel switching away from refined fossil fuel products in the transportation and heat sectors will be a major contributor to the increase in electricity demand, specifically in developed countries. The anticipated widespread introduction of electrically powered vehicles and heat pump technology is expected to increase Germany's annual electricity consumption by about 30 percent (by when?). In the field of **environmental compatibility**, a further target, therefore, is **to conserve energy and to increase energy efficiency across the entire value chain including all participants in the energy market, right down to the grid user.** The planned measures aim to bring about, on one hand, changes in grid user behaviour and, on the other, a reduction of losses during energy transport. The reduction of transport losses can be achieved with incentives for erecting decentralized generation facilities close to the point of consumption and with price incentives for sourcing locally generated heat and electrical energy. A further pillar of future energy management, therefore, is the **decentralized energy management with virtual, local balancing areas**. In decentralized energy management the prosumer is incorporated into the energy market, together with the traditional energy market participants. The aim is to reduce energy consumption through new energy services which disclose **product charateristics including the type of energy conversion and transport distances**. Possibilities for establishing a closer relationship between energy supply and energy service provision will be created, paving the way for many new energy services. In combination with smart grid and smart buildings, the new services induce a holistic approach to building–energy management and facilitate a link with other areas of life. The **grid user is promoted to an active, independently acting participant** in the energy market. The development of the smart grid offers the opportunity of increasing energy efficiency across multiple media (such as electricity, heat and refrigeration/air conditioning).

Supply security
Under these new conditions, the **supply security** must absolutely be maintained. A bidirectional energy flow between transmission system, distribution system and consumer site grids with variable load flows will develop to deal with higher penetration of medium to micro-scale decentralized renewable energy systems in the distribution grid. The inclusion of decentralized installations and consumers' active participation in the control scheme of the low-voltage grid, results in a significantly increased complexity. An excessive level of complexity can lead to loss of controllability in central control stations and centrally controlled balancing areas. This **complexity can be reduced** with individual, intelligently and synergistically behaving structures that are self-organizing but remain connected to the overall system. The current uncontrolled feeding into the decentralized area, therefore, must be overcome through even more decentralized energy management with control loops in cellular structures that supplement the central control measures. The result is a **smart grid with a cellular structure** – an additional pillar of future energy management.

To this end, structures that act independently of each other electrically and in their communication will be created through meshed distribution systems and agents capable of acting autonomously within the **grid cells** (grid moderators) and in **virtual balancing areas** and market areas (market moderators). These structures will act synergistically with other cells, forming an energy organism based on a **distributed and decentralized automation solution**. Smart grids are a response to the increasingly complex control of the low-voltage level resulting from the fluctuating current flows that will occur due to a high proportion of decentralized energy generation Because a cellular approach and decentralized, distributed automation solutions allows the operation of grid sections to be maintained when adjacent sections have failed, they also ensure, or even increase, supply security. The smart grid concept also promote supply security by lowering the dependence on a small number of centralized energy systems and allowing to rely rather on many smaller energy systems in the distribution grid as described above.

Cost-effectiveness
The modernization of the energy system can succeed only if politically and commercially successful market scenarios can be created and implemented. Thus we come to the third of the three energy policy objectives – **cost-effectiveness**. We describe here the specific means to reach cost-effectiveness. Firstly, the necessary **legislative and regulatory** changes must be defined to facilitate the inclusion of the consumer in the smart grid's function with a bidirectional communication between partners in the energy market.

New market scenarios with new business models must be defined **from market roles in the energy sector value chain,** under the conditions of a new kind of energy network with decentralized generation, storage and energy management. This will result in new **products and use cases** as functional components. **Roles and responsibilities** must be defined for this purpose.

A communication between the use cases across the non- discriminating marketplace and between the energy system components within the grid and consumer appliances and installations in the grid user's property, increases the demands on standardized communication. Accordingly, the **standardization** of use case service interfaces, site models and site relationships form a focal point in the development of the smart grid.

The transition to the new energy system requires the participation of all market partners and can not be achieved through a change in one link of the value chain alone. The grid user as well must be motivated to participate in the energy system in a new and unfamiliar way. The objective, then, is to define **incentive systems for grid users**. Especially in the distribution system this may be associated with a change in the regulatory framework.

While the required legislative and regulatory changes are defined mainly from a perspective of environmental compatibility and supply security, the subject of cost-effectiveness focuses rather on business models and **consumer-centric perspective in an atmosphere of increased individual responsibility and personal treatment, especially through incentives, with regards to the provision of energy services**. These two elements are the motivation for the participation in the **energy marketplace**, communication over the **energy Internet** and development of new **energy services** in combination with other areas of life.

2 Business Modelling

We have described so far the objectives pursued through the implementation of the smart grid concept and the essential conditions to allow its development. However, people will invest in a smart grid only if:

1) we succeed in developing future market scenarios with politically and commercially successful business concepts as well as concrete incentive systems to integrate grid users in decentralized energy management;

2) the legislative and regulatory environment required to achieve the objectives and to develop commercially successful business concepts is created, which role is also to fairly allocate the initially very high investment costs across all stakeholders and establish sufficient investment incentives;

3) the standardization process required for a non- discriminating, open electronic market communication between all participants in the future E-Energy market's more complex value network is advanced, whereby standardization of communications affects not only the technical system but also business process communications between the market partners (interconnection of equipment, pants and operating resources in the energy Internet through the virtual energy marketplace with all market partners).

On this basis the mirror committee of the German electrotechnical commission (DKE) for IEC SMB/SG3 Smart Grid [9] defined the term “smart grid” as follows.

*“The term “**smart grid**” covers the networking and control of smart generators, stores, consumers and grid operating resources in energy transmission and distribution systems with the aid of information and communication technology (ICT).”*

The term has also been adopted in the German standardization roadmap [10] as represented in Fig. 2.

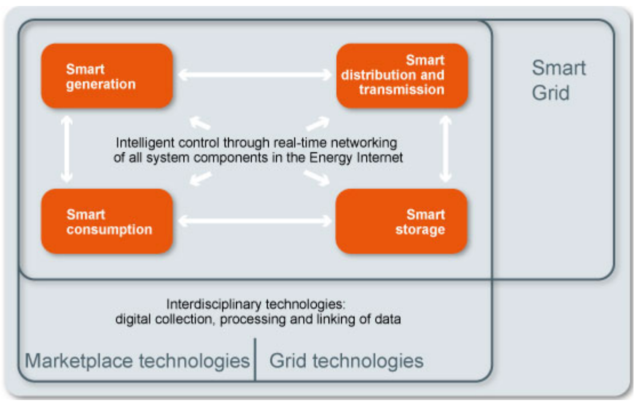

Fig. 2. Smart grid as total intelligent energy system

On this basis, key factors for the ability to describe new market scenarios and business concepts are the use of standardized terminology and definition of unified core models. The following section provides an introduction to standard terminology and Fig. 3 illustrates the defined concepts.

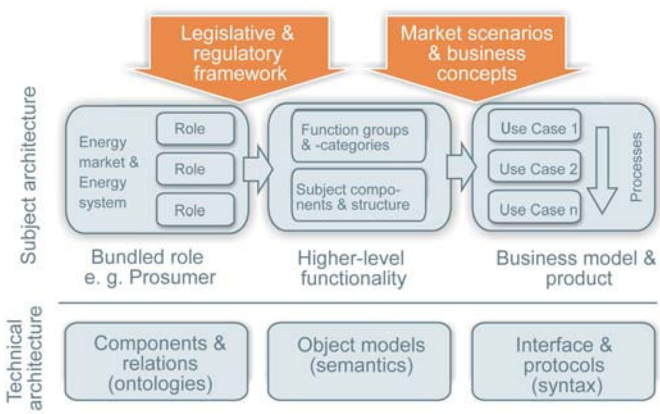

Fig. 3. Modelling of the E-Energy market

➢ Roles

Market roles are assigned to all activities in the smart grid. The roles represent fine-grained instances in the value network, capable of legal transaction.

Roles are, to some extent, nationally or regionally defined by various laws and regulations. With as detailed a classification of theoretical granular roles as possible, an attempt can be made to define solutions, functions, modules and interface descriptions such that basic results remain transferrable on an international or European level. In practice this means that some market roles will be grouped into so-called **bundled roles** (for example prosumer as producer and consumer) or market participants will perform several market roles (for example utility companies).

The following market roles exist already or have been identified in the smart grid with newly arising responsibilities:

- Producer
- Consumer
- Transmission system operator (TSO)
- Distribution system operator (DSO)
- Communications network provider
- Energy supplier (electricity, heat, gas)
- Balance responsible party (BRP)
- Balancing grid coordinator
- Control zone responsible party
- Energy trader
- Energy exchange
- Measuring point operator
- Measuring service provider
- Energy marketplace operator
- Billing and settlement service provider (accounting between unbundled mar ket participants)
- Energy service provider (energy advisor, contractor)

To these market roles that participate directly in the processes, other stakeholders must be added, such as

- manufacturers of smart grid-capable electrical apparatus, plants and operating resources,
- suppliers of information and communication technology incl. software for energy services,
- regulatory institutions,
- political entities.

➢ Actors

An actor is an acting element within a domain. It is sender for a use case or recipient of a reaction from a use case and has an assigned role, for example a natural or a legal entity, a physical device, or a logical device as abstraction of a category of physical devices.

➢ Domains

Domains are system areas with defined boundaries, in which the activities of use cases take place and in which the overall energy system can be coarsely classified by the physical current flow, as, for example, laid out in the NIST or IEC roadmap. To allow a meaningful bundling of use cases, a further breakdown of the overall system may make sense.

The following illustration shows a proposal forwarded by Transmission & Distribution Europe that has been expanded into a more comprehensive domain proposal:

- Power Generation domain with the three subdomains, namely Central Power Generation in large-scale power stations, Distributed Power Generation in the distribution systems, and micro generation on grid user sites (such as photovoltaics or cogeneration units)
- Transmission System domain with the two subdomains Decentralized Transmission System Infrastructure and Central Transmission System Infrastructure
- Distribution System domain with the two subdomains Decentralized Distribution System Infrastructure and Central Distribution System Infrastructure
- Grid User Property domain with the four subdomains Residential Sites, Commercial Sites, Industrial Sites and Vehicles
- Site Devices and Installations domain
- Markets domain with subdomains Energy Wholesale Market, Central Balancing Power Market, Energy Services Marketplace and Decentralized Markets

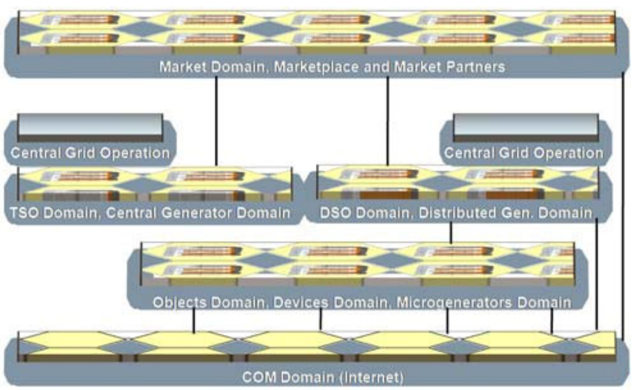

Fig. 4. Domains in the energy system

➢ Use cases

A use case is a structure for bundling activities on a lower classification level from an external viewpoint. The use case is used to represent detailed functional descriptions within a domain independently of the business model or the system architecture. The description of use cases with site models and service interfaces is regarded as the basis for standardization in the smart grid.

➢ **Use case activity**

A use case activity is an activity within a domain in the energy market with definition of an input through an actor (the sender) and an output through another actor (the recipient).

➢ **Site semantics, interface syntax and site relationships (ontologies)**

As process function blocks, the use cases communicate through interfaces. To ensure a trouble-free information flow through interfaces, communication models and market roles require unified site semantics, defined relationships between sites (ontologies) and a defined syntax.

➢ **High-level functions**

High level functions bundle use cases with various actors in order to describe complex sequences across roles and systems and to systemize the many use cases.

➢ **Processes and products**

Use cases are connected to processes by market roles and are associated with products.

➢ **Business cases**

Business cases as commercial services arise through the connection of processes with their component parts – the use cases – and the products of a role or bundled role.

3 System Modelling

3.1 Basic Cellular Concept

With the advancing utilization of decentralized renewable energies in the distribution system, a bidirectional energy flow between transmission system, distribution system and grid user properties is developing. Cases of load reversal can already be witnessed today and will, in future, necessitate an active management of decentralized plants. The currently uncontrolled decentralized infeed must be overcome with decentralized energy management. Initial initiatives to this end have been taken with the bundling of distributed generation capacities into virtual power plants. The grid, however, continues to be controlled by central operations from grid control rooms, with the consequence of a significant increase in the complexity of the control system due to the growing number of decentralized components that need to be considered. This also impacts the complexity of the existing balancing area management through supraregional balancing grids on the transmission system level. The developments in E- Energy project *moma* therefore focus especially on new methods of decentralized and automated grid management within the distribution system and on virtual balancing areas that can handle both the local situations and the creation of new product groups related to generation or aimed at specific consumers.

The concept of complexity, the associated approach in moma, the network topology that is based on it and the cell model have been described in [11] and in the associated sources [12,13] and will not be dealt with again here.

3.2 Site-Related Energy Management

An approach is proposed for developing a smart grid in the domains of the transmission system, the distribution system and the site grids in the grid user domain in the form of a cellular grid system. The cells are each fully equipped with smart grid components (generators, consumers, energy storage and grid operating resources), so that they can act as agents with self-optimizing energy balance as a system expanded with ICT interfaces and as core of the local intelligence.

Through local measurements, status information about other cells and external parameters from central distribution grid control systems allow the agents to operate as a part of an overall energy system. This results in an information and energy exchange between the cells. A swarm intelligence pattern emerges at this point, carrying the patterns of self- optimizing and self-healing.

In the moma project, a solution is being developed to link energy system components and site agents within the site domain via the system structure of the bidirectional energy management interface (BEMI) and the Energy Butler's local intelligence, combined with the local intelligence in the grid and market agents of the distribution system cell in which the site is integrated. The developments for the Energy Butler are based on the Fraunhofer IWES papers on the BEMI [14,15,16,17]. The following illustration shows the implementation model within the scope of moma.

The domains described above contain the grid user's site domain, which can be in one of the four categories residential, commercial or industrial sites and vehicles. In the cellular core model of the energy system, it is proposed to include the grid user's site domain in a site grid cell that is part of the system architecture and has an independent flow of both energy and information. As an electrically independent unit, a site grid cell features each of the four energy system components categories: loads, generators, accumulators and grid operating resources. These, in turn, are linked to system services and to communication equipment through an ICT interface with its own information-processing equipment (sensors, switchgear, control equipment). The site grid cell is defined as the smallest electrically independent unit in the sense of its down-regulation and startup capability and therefore has its own network structure.

Because a single site may contain several consumers with different energy management interests and requirements, it is further proposed that the system architecture be further broken down within the site domain viewed as connection site with sub-site cells. In an electrical sense, sub-site cells are non-independent structures in terms of the definition as site cells and distribution grid cells, but are independent structures in an information technology sense because they are equipped with sensor and actuator circuits as well as agent structures for energy management in the sub-site cell. Sub-site cells can correspond, for example, with apartments in apartment buildings and with offices and shops on commercial sites. Site grid cells and sub-site cells contain energy system components and an ICT interface in the form of a bidirectional energy management interface (BEMI).

In Model City Mannheim this approach is being implemented through

- consumer metering equipment in the site grid cell with field communication between the metering devices of all supply partners;
- a meter gateway for communication with the metering equipment, with the sub-site cell and with the distribution system cell

- a BEMI computer (Energy Butler) acting as central ICT interface component, which maps the site's agent structure;
- devices and installations as energy system components of all four categories
- ICT interfaces at the consumers and generators (appliance and power plants) with information- processing modules (sensors, actuators, control devices) as so-called sub-BEMIs
- a user control and display unit
- site-integrated communications between these components in the form of a private network, an automation network or an energy management LAN
- communication between the grid user's private network and the Internet and a protected, IP-based broadband communication with the DSO's communication network, whereby broadband power line is used for IP communications in moma.

To ensure data privacy, the communication between the meter gateway and the Energy Butler with the distribution system cell containing the site ensures the interaction of these two gateways in site grid cell and sub-site cell, so that data from consumer metering devices that is supplied only for on-site services is not sent to other market partners. If a suitable safety bridge is set up between Energy Butler and meter gateway, direct on-site communications can also be set up. To this end, approaches to defining a common smart meter gateway with common hardware for both cell areas also exist. A clear security and role concept for the smart meter gateway is crucial especially in buildings with several apartments and offices.

To introduce decentralized energy management as a widely accepted solution, a standardized communication method is needed for interfacing automation and consumer metering devices in grid user property with devices and plants from many different manufacturers. Energy system components (devices and plants) of all four categories are therefore regarded as domains in their own right within the energy system.

This section briefly outlines the remaining cell types in Figure 5. The site grid cell is integrated in a distribution system cell, which contains agent structures for grid and market support. The distribution system cells, in turn, are components of a system cell, which contains an integration platform that connects the grid cells to the overall grid control room – including the grid control station – and to the transmission system. Through the energy marketplace it also connects the system cells' local market mechanisms with the partners on the energy market (suppliers, traders, wholesale and balancing power market, energy and metering service providers). Communications of the overall system is IP-based. The result of this interconnection of energy system components in the grid cells with the energy market partners is the so-called Energy Internet.

In the German standardization roadmap document, the two focus groups Inhouse Automation and Distribution System Automation have been set up with the aim of advancing the standardization process for the function principle of the site domain, the devices and plants domain and the distribution system domain. Under the umbrella of E-Energy and moma, initial standardizable solution approaches have been presented for the definition of a hardware-independent site agent execution layer for site agents (for example BEMI computers), for controlling the energy system components with OGEMA [18], and for communications between the energy system

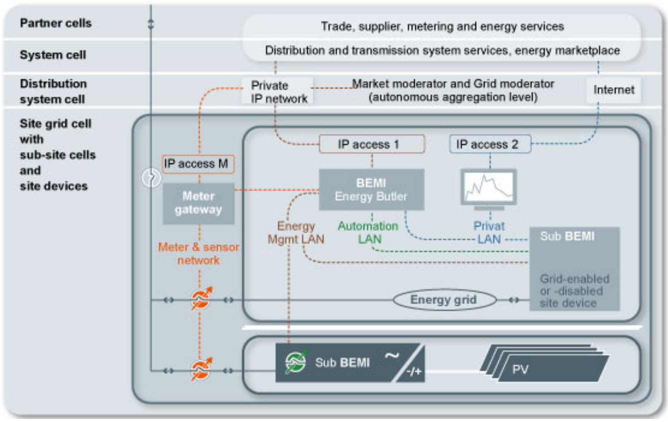

Fig. 5. Arrangement of the site domain within the cellular model

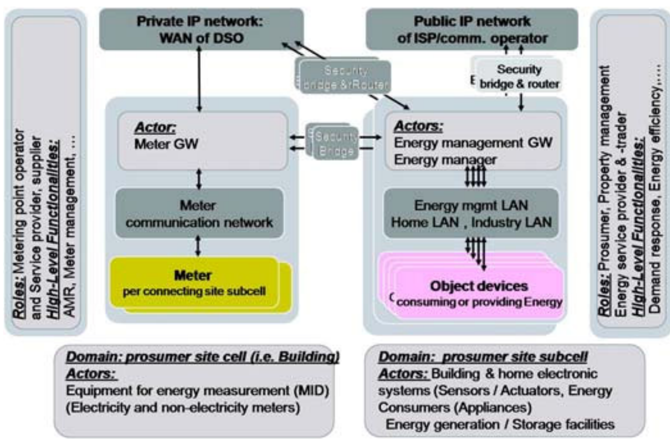

Fig. 6. Object domain of the grid user in the cellular model

components for the object's energy management LAN shown in Figure 5. To facilitate a description of these approaches, generalized terms are to be introduced. Figure 6 illustrates their assignment to the activity domains, market roles and function examples.

Figure 6 illustrates the relationships between the following:

- the consumer metering devices and associated communication paths to the metering equipment
- the meter gateway as communication component between the consumer meters in the site grid cell and the distribution system cell and the energy management gateway
- the energy management gateway (EMG) as generalization of the BEMI computer platform
- the energy manager, which performs the energy functions and generalizes the services of the BEMI computer

- the energy management LAN in the sub-site cells, which connects the energy management with several site devices
- the energy system components (site devices) to be controlled across the site's entire control loop.

Between the meter gateway and several EMGs in the sub-site cell the issue of data protection and data security is visualized by means of the security bridge and by the IP-based communication with the public Internet and the distribution system's private, protected communications network. The illustration further shows the domains, in which the components are listed as actors in the energy system. Market roles and use cases or function groups acting in the domains are shown here only by way of example.

The EMG is defined as a physical device consisting of computer system hardware, an operating system, a virtual runtime machine, a hardware-independent programming platform and an application and communication framework for mapping communication stacks, resource description and basic functions. For the Energy Butler, the EMG is a hardware and firmware system platform, bundled with an application and communication framework that facilitates operation of an energy manager software application.

The energy manager is implemented as a software solution consisting of device-specific energy services that access the EMG's application and communication framework. It further consists of energy automation services, which use the device-specific services and device resources for in-house communication and which act as interface to the active distribution system. It represents a smart agent structure as grid user agent in the site grid cell or in the sub-site cell. Its functions are to automate energy management, maximize energy efficiency, reduce energy costs and determine price, source, type and use of the consumed energy.

The described solution is illustrated in the form of an implementation stack in the figure below.

The OSGi programming framework and the OGEMA application framework run on the underlying hardware of an embedded system. This allows the execution of

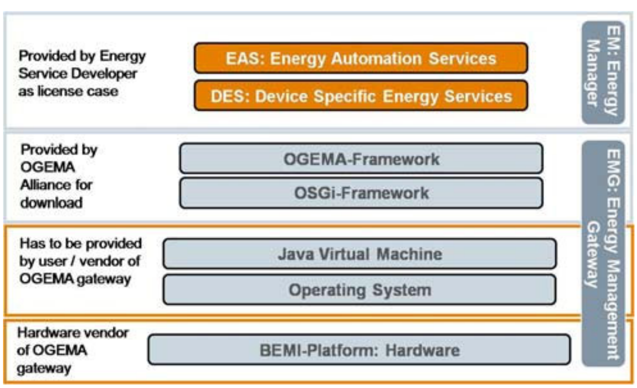

Fig. 7. Energy Butler, implemented as a BEMI computer, generalized as sum of energy management gateway (EMG) and energy manager (EM)

energy functions for delivery products, energy and energy metering services, and interface services to other areas of life on various hardware platforms (smart meter gateways, heater controls, building services automation systems, network routers, Energy Butlers, etc.) As application platform for the OGEMA framework, a technology-specific stack consisting of operating system, Java Virtual Machine and OSGi is currently being proposed, although this approach could also be implemented with other technologies.

3.3 Energy Management in the Distribution System with Decentralized Decision-Making and Site Guidance

As part of a dissertation, the grid user site-centred approachto energy management in Model City Mannheim using the BEMI model has been extended with regional energy management, which operates on a higher level but still uses decentralized decision-making. This is implemented with a component that forms part of the distribution system [19].

Especially in the context of the liberalized market and the unbundling of grid and supplier, the role of energy management has been investigated with various market operating models. Included in this consideration of a combined system of decentralized energy management withdecentralized decision-making but associated, higher-level incentive management through a BEMI pool is the operation of a virtual power station. A simulation program has been developed to investigate the operation of a system consisting of many BEMIs and a higher-level BEMI pool, including its repercussions on grid management. A lab test was also performed to investigate incentive-based voltage-maintenance through influence of the active power in combination with a virtual power station.

The BEMIs are controlled from a higher-level system by means of price forecasts, from which variable price curves for consumption and generation management are plotted. These curves, in turn, form the basis for new load and generation forecasts that yield new energy quantity forecasts for balancing. The operation of a BEMI pool is proposed for a market actor, which is referred to as *energy service provider* in the paper. Through the market processes proposed as influencing factors for active power, the grid's influence on prices therefore becomes a second reference variable. The pool BEMI, then, is the interface between market and grid operator on one hand and the sites' energy system components, which the BEMI system controls, on the other. In the distribution system, the BEMI rules, then, do not develop as a swarm but through a controlled model.

With the system model for connecting energy management in the grid user property through a higher- level instance in the distribution system – which can unite market and grid interests in the BEMI pool – a foundation has been created on which virtual power stations can be included in the market mechanisms of Model City Mannheim. Integration of virtual power stations is realised through virtual balancing areas and products for energy supply in combination with variable pricing to influence consumer behaviour based on generation. This also paves the way for local market mechanisms.

The paper furthermore concludes that the complexity in virtual power stations and in higher-level decentralized energy management systems in large distribution system areas will, in future, increase significantly as the number of energy system components incorporated in market and grid management rises. A central control loop in the distribution system with the described mechanisms will no longer be controllable once a certain degree of complexity is exceeded. As mentioned above for the core model, complexity can be reduced again through the creation of cells with their own control loops and a much lower number of energy system components. A market controlled only through the swarm intelligence of the BEMIs in the site grid cells is not proposed as alternative. Indeed, the energy volumes that can be handled with this approach are still too small. An additional barrier to deployment of the swarm intelligence concept is that the fine-grained grid management's dynamic behaviour can not yet be easily simulated numerically.

The described paper identifies the connection between decentralized energy management and central distribution system operation through the grid control system as a further research requirement. The moma project therefore proposes a connection of central and decentralized grid management in distribution system cells. The number of all four categories of energy system components in each of these distribution system cells is large enough to allow the meaningful operation of a closed control loop. On the other hand, the number of components is small enough to keep the complexity of the decentralized control loop in the distribution system cell at a manageable level. In each of these distribution system cells the link-in mechanism for a virtual power station can be utilized in the sites (BEMIs) through decentralized energy management controlled by a higher-level instance (BEMI pool).

In an extended approach, virtual balancing areas and a new actor, the market agent, facilitate regional market mechanisms. Through the grid agent, metrology, regional reserve generation plants and regional system services facilitate a grid management that is split into regional grid cells. In order to join the overall system consisting of several grid cells to an overall distribution system, an exchange of information and energy between grid cells and a control with outline conditions by the central grid management is implemented. This cellular structure of autonomous but interconnected systems results in a self-optimizing, self-healing network of independent cell agents, which collectively exhibit swarm intelligence. Since only a select few cells can be equipped in this ways in the scope of this project, practical trials are supplemented with comprehensive, in-depth numerical grid simulations of larger grid areas.

The following section describes the initially outlined approach in detail as a possible solution.

3.4 Decentralized but Connected Grid Management in Grid Cells with Grid Agents and the Interaction with Market Agents

The challenge consists in achieving:

- site-related energy management with BEMI systems in the grid user sites;
- energy management with decentralized decision- making in regional energy market structures (market agents for virtual power station functions for generation aggregation and virtual balancing areas) with site guidance through communication of market situations to BEMI pool functions;
- energy management with decentralized decision- making in the distribution system (grid agents in controllable grid cells, whose regional expansion is determined by manageability of complexity) and with site guidance through communication of grid situations to BEMI pool functions;

- connected grid management of all cells of a grid compound as self-optimizing control loops, such that the cells form an overall compound system with self- optimizing control on one hand and guidance through boundary conditions of higher-level market- and grid management structures on the other.

The overall system of grid cells, in which market and grid agents operate, is to be modelled as a swarm of agents that form the overall system of grid cells into a unified energy organism.

In order to facilitate widespread penetration of an energy system with agents acting as smart, decentralized grid and market instances, modelling and simulation work will be necessary to investigate the overall system's behaviour. With this new concept, decisions are made decentrally on the basis of complete control loops in the grid cells with decentralized information about market, grid and environment, and on the basis of external outline conditions in the other grid cells and higher-level management instances. The aim is to achieve self- organizing, smart consumer and generator behaviour in cellular grid structures while minimizing the level of central control. Regarding site-related energy management with control through BEMI pool structures, the Energy Butler, as core of the BEMI systems, receives the listed information for local control of the sites' loads and generators via (i) direct load and generator control, (ii) a market partner or (iii) incentive-based control with decentralized decision-making. The control takes place in such a way that a predictable behaviour of the whole body of BEMI systems is achieved. The individual BEMI systems exhibit defined behavioural patterns, which are influenced by the requirements of the consumers and which autonomously make decisions in their name.

The BEMI is the site-specific node in the distribution system cell at which various interests and tasks of several energy market roles come together. The possible actions are limited by the components actually installed and by existing energy potentials.

The many and varied interests of generator, consumer, supplier, grid operator, energy service provider and other market roles must be matched to each other. To this extent, intensive market communication and a balance between various interests through regulated procedures is also necessary in the unbundled market. Especially the interaction between BEMI pool, in which market and grid roles interact, and the site BEMI systems, which represent the grid users, reflect these conflicting interests. While the system actors with these roles represent their owners' interests, they also consider the interests of other market users through external parameters and incentives.

In a social context, this would be termed social behaviour, although, to technical systems, this term can be applied only in a figurative sense. Nevertheless, the rules by which the actors act must be implemented in such a way that the system becomes self-stabilizing. It would therefore seem to make sense to **allow market and network agents to develop a swarm-intelligence**.

The market roles' various interests come to play in an environment that is formed through a virtual energy market and the physical, electrical energy grid. The actors' freedom of action therefore is defined by the energy exchange market mechanisms and by the technical limitations imposed by the grid. The initial situation is one of large control time constants between forecasting and balancing that form a present-day perspective, reaches a long way into the future to determine target values and the control based on actual values in predominantly central structures. In an effort to obtain better forecasts and reduce deviations in the context of an ever more decentralized and varying generation, control time constants with decentralized control structures would tend to be smaller. The long-term objective is to achieve a real-time capability for this control process and thereby, through ICT networking, to create a system that can, independently and at any time move energy to where it is needed.

As long as the BEMI systems on the grid user sites are being controlled by the BEMI pool in regional structures, it is proposed that the overall grid structure be split into regional, independent control loops, which, equipped with agents, exhibit local intelligence. The overall system of cells should, however, exhibit swarm intelligence through its agents and within the constraints of external and higher-level limitations. Building upon the individual behavioural patterns, a need therefore exists to model and simulate the swarm behaviour of an overall energy system consisting of cells that each contain all required energy system components.

Swarm intelligence is a specific field of artificial intelligence (AI) based on agent technology. It is also referred to as distributed artificial intelligence. G. Beni and J. Wang coined the term in 1989 in the context of robotics research.

Distributed artificial intelligence works on the premise that artificial agents, through cooperation, are capable of higher cognitive activity. Marvin Minsky terms this ‘The Society of mind’. Sunil Nakrani of Oxford University and Craig Tovey of the Georgia Institute of Technology presented an application example at a conference on mathematical models of social insects in 2004. They modelled the calculation of optimum load distribution in a cluster of Internet servers based on bee’s behaviour when gathering nectar.

Communication and specific actions of individuals can result in a social community developing collective intelligence, which is also referred to as group or swarm intelligence. System-theoretical and sociological explanations of this phenomenon have been given.

An organism of this kind does not have a central instance that controls the behaviour of each individual. Instead, the swarm as a whole simply reacts to information in the form of higher-level outline conditions. This presupposes a communication between swarm members (market and grid agents) with each other and an exchange of information with the system environment, i.e. the energy marketplace with associated market partners and the central grid management instances.

There are several reasons why individuals strive to act as part of a swarm. One is that the space within a swarm offers both protection and a greater range of possibilities. Applied to the energy system this means a higher degree of supply security in the overall grid and a greater scope of performance possibilities compared to energy structures consisting only of discrete, autonomous sites. The aim of self-determination can therefore be associated with the aspect of supply security.

The agent swarm identifies overall states within the system but can furthermore ensure regional optimization, since the complexity of regional control structures remains manageable. It also becomes easier to maintain operation of sub-grid areas in the event of a failure of other grid areas, which contributes to supply security.

With this objective in mind, a model is being created as part of the moma project, within which a swarm of market and grid agents can exhibit meaningful behaviour.

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