Power System Operation

Power system operation

- With the importance of the electricity industry for the functioning of the entire society such as it is, the reliability of supply, and thus power systems security, has become a serious issue.
- Interconnection of the power systems spanning large geographic areas has offered a number of benefits, such as sharing the reserves both for a normal operation and emergency conditions, dividing the responsibility for the frequency regulation among all generators and a possibility to generate the power in the economically optimum areas, thus providing a good basis for the power trade.
- Although this has brought about many operational benefits, it has also introduced new problems - such as the risk of a disturbance spreading over large distances and thus paralyzing vast service areas.

Quality, reliability and security concepts

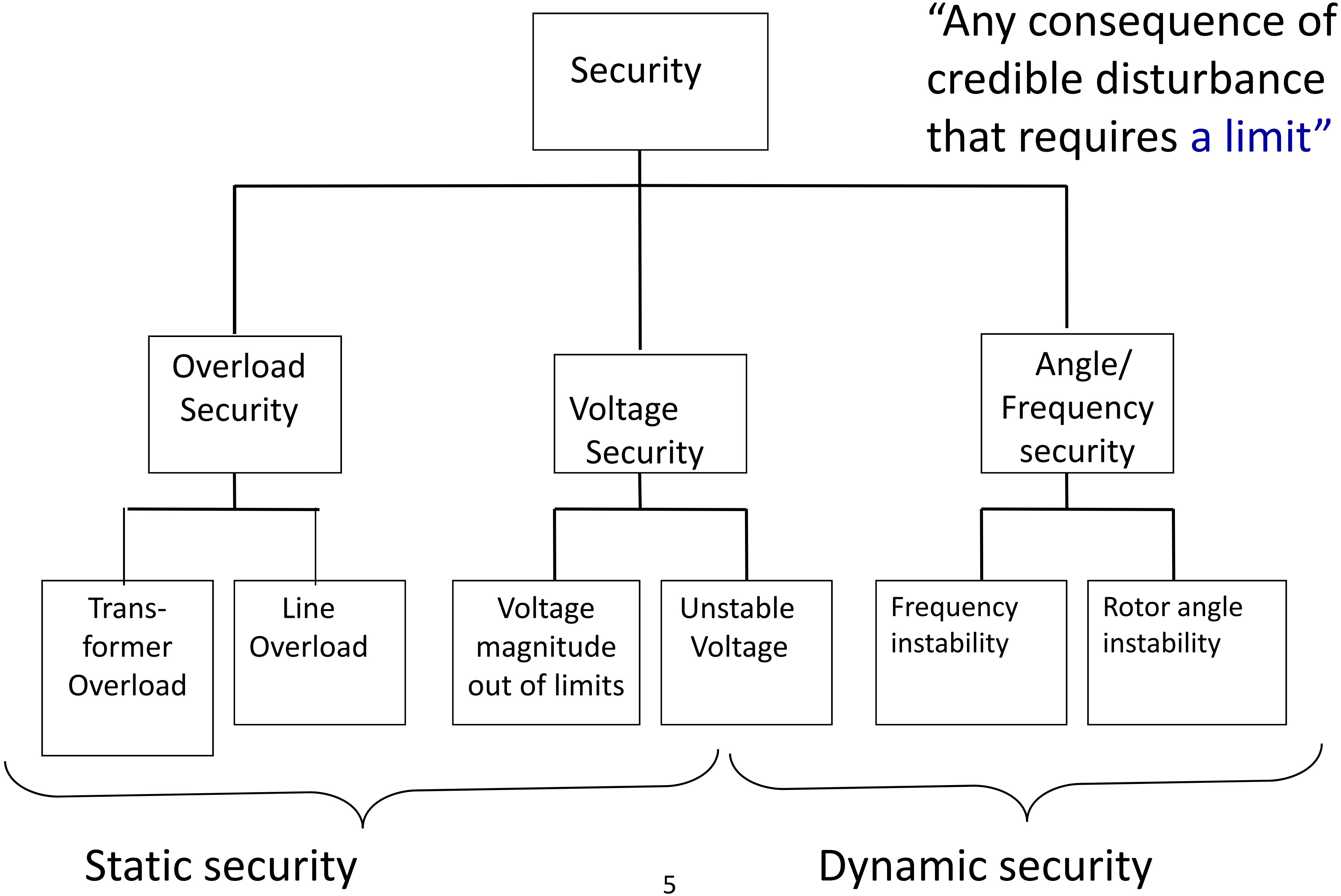
- **Power quality** expresses how the supplied energy in form of current and voltage waveform differs from the normal sinusoidal wave form. Typical examples of power quality problems are distortions of the voltage waveform by power electronics equipment, significant short-term voltage dips, etc. Power quality problems are usually local in nature.
- **Reliability** is defined as the probability of the power system's satisfactory operation over the long run. It denotes the ability to supply adequate electric service on a nearly continuous basis, with few interruptions over an extended time period.
- **Security** of a power system refers to the degree of risk in its ability to survive disturbances (contingencies) without interruption of customer service. It relates to robustness of the system to possible disturbances and, hence, depends on the system operating condition as well as the contingent probability of disturbances.

Quality, reliability and security concepts

- Security is a time-varying attribute which can be judged by studying the performance of the power system under a particular set of conditions.
- Reliability, on the other hand, is a function of the time-average performance of the power system; it can only be judged by considering the systems behavior over a long period of time.
  - ***Reliability is the overall objective in power system design and operation.***
  - ***To be reliable, the power system must be secure most of the time.***
- Finding an appropriate balance and compromise between:
  - reliability and security on the one hand and reducing running and installation cost of a power system on the other is generally a challenging task in power system design

An operator's view of "security"

"Any consequence of a credible disturbance that requires a limit"



Factors affecting reliability and security

- Frequency Instability
- The inability of a power system to maintain steady frequency within the operational limits.
  - Keeping frequency within the nominal operating range (ideally at nominal constant value) is essential for a proper operation of a power system.
  - The maximum acceptable frequency deviation (up to ca. 2 Hz) is dictated by the optimal setting of control circuits of thermal power plants. When this boundary is reached, unit protection disconnects the power plant.
  - This makes the situation even worse - frequency further decreases and it may finally lead to the total collapse of the whole system.
  - Frequency instability is in its nature rather a tracking than truly a stability problem.

Factors affecting reliability and security

- *Voltage Instability*
  - The inability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance.
  - A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system conditions causes a progressive and uncontrollable drop in voltage.

Factors affecting reliability and security

- *Transient Angular Instability*

- The inability of the power system to maintain synchronism between the synchronous generators when subjected to a severe transient disturbance. The resulting system response involves large excursions of generator angles and is influenced by the nonlinear power vs. power angle relationship.
  - A severe disturbance blocks a generator from delivering its output electrical power to the network (typically a tripping of a line connecting the generator with the rest of the network to clear a short circuit, for example).
- This power is then absorbed by the rotating masses of the generator in form of increased kinetic energy, which results in the sudden acceleration of the rotor above the acceptable rotational speed.

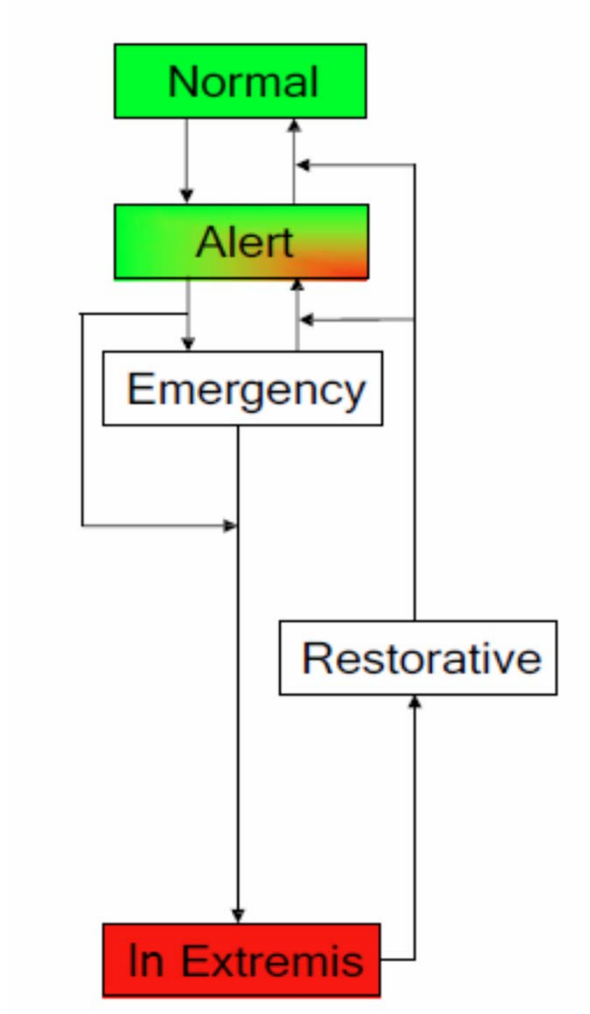
Factors affecting reliability and security

- *Small-signal Angular Instability*
- The inability of the power system to maintain synchronism under small disturbances. Such disturbances occur continually because of small variations in loads and generation.
    - The disturbances are considered sufficiently small for the linearization of system equations to be permissible for purposes of analysis.
    - Local modes or machine-system modes are associated with the swinging of units at a generating station with respect to the rest of the power system. The term local is used because the oscillations are localized at one station or small part of the power system
    - Inter-area modes are associated with the swinging of many machines in one part of the system against machines in other parts. They are caused by two or more groups of closely coupled machines being interconnected by weak ties.

Operation planning

- Counteracting (mitigating) the above listed phenomena in order to keep a secure system operation form the basis for four major activities forming control philosophy of power systems:
  - Operation
  - Day-ahead Operation Planning
  - Short-term Planning
  - Long-term Planning

Classification of operational states



Quality, reliability and security concepts

- Normal
  - All system variables are within the normal range and no equipment is being overloaded. The system operates in a secure manner and is capable of withstanding a contingency without violating any of constraints.
  - Here all equality (E) and inequality constraints (I) are satisfied. In this state, generation is adequate to supply the existing load demand and no equipment is overloaded. Also in this state, reserve margins (for transmission as well as generation) are sufficient to provide an adequate level of security with respect to the stresses to which the system may be subjected. The latter maybe treated as the satisfaction of security constraints.

Quality, reliability and security concepts

- Alert
  - All system variables are still within the acceptable range and all constraints are satisfied. However, the system has been weakened to a level where a contingency may cause an overloading of equipment that can place the system in an emergency state.
  - The difference between this and the previous state is that in this state, the security level is below some threshold of adequacy. This implies that there is a danger of violating some of the inequality (I) constraints when subjected to disturbances (stresses). It can also be said that security constraints are not met.
    - → Preventive control enables the transition from an alert state to a secure state.

Quality, reliability and security concepts

- Emergency
  - Some system variables are outside of acceptable range (e.g. voltages too low, lines overloaded). If no control changes are introduced, system progresses into In Extremis.
  - Due to a severe disturbance, the system can enter emergency state. Here (I) constraints are violated. The system, can still be intact, and emergency control action (heroic measures) could be initiated to restore the system to an alert state. If these measures are not taken in time or are ineffective, and if the initiating disturbance or a subsequent one is severe enough to overstress the system, the system will breakdown and reach "In Extremis" state.

Quality, reliability and security concepts

- In Extremis
  - Cascading spread of system component outages resulting in partial or system-wide blackout
  - Here, both (E) and (I) constraints are violated; the violation of equality constraints implies that parts of the system load are lost. Emergency control action should be directed at avoiding total collapse.

Quality, reliability and security concepts

- Restoration
   - Energizing the system or its parts and reconnection and resynchronization of system parts.
   - This is a transitional state in which (I) constraints are met from emergency control actions taken but the (E) constraints are yet to be satisfied. From this state, the system can transition to either the alert or the normal state depending on the circumstances.

Classification of control measures

- Normal and preventive control
  - This control is applied in the normal and alert state, and its objective is either to stay in or return to normal state.
- Emergency control
  - This control is applied in emergency or in extremis state to stop further progress of the failure and to bring back the system into normal or alert state.

Normal and Preventive Control

Hierarchical frequency control is the only fully automated closed loop control in Normal and Alert state. In all other cases, the human factor is involved in form of operator intervention.

The control scheme/loop basically involves:

- Data Acquisition and monitoring
  - This stage is usually handled by Supervisory Control and Data Acquisition (SCADA) system and State Estimation
- Operator’s decision
  - Operator based on the knowledge about the present state of the system, coming from SCADA system, decides whether to intervene by modifying actual values of controls. Operator can base his intervention decision either on his experience and judgment or on decision support tools.
- Control execution
  - This stage materializes either via link SCADA - Substation Automation, or communication with the personnel executing the control manually in substations or/and power plants.

Normal and Preventive Control

- The main objective is to keep the power system in a secure state,
  - compliance with N-1 criterion (outage of any single component shall not create an unacceptable stress on other component(s) or instability problem)
- Security Assessment is (usually implemented as a program belonging to the Energy Management System (EMS) processing) present state information given by State Estimator
- Security Assessment is then done in a continuous cycle, typically every 5 or 15 minutes, or it is initiated by operator.
- The consequences of possible component outages are examined

Normal and Preventive Control

Typical representatives of normal and preventive control are:

- Hierarchical automatic control:
  - Frequency control
  - Voltage control
- Centralized manual control based on:
  - Contingency screening
  - Operator judgment
- Control measures usually include:
  - Change of active power generation set-points, i.e. re-dispatch.
  - Change of reference points of flow controlling (FACTS) devices.
  - Start-up of generation units.
  - Change of voltage set-points of generators and Static VAR Compensators (SVC).
  - Switching of shunts elements (reactors, capacitors).
  - Change of substation configuration (e.g. splitting of busbars).

Emergency Control

Typical representatives of emergency control are:

- Protection based systems:
  - Under frequency load shedding (UFLS) schemes

    Local devices used for UFLS schemes are UFLS relays. They are usually triggered when frequency drops to a predefined level and/or with a predefined rate of frequency change. Their action is disconnection of the load in several steps (5 - 20 % each) from the feeders they supervise. However, their effectiveness is strongly dependent on their careful tuning based on prior studies, since there is no on-line coordination between them.
  - Under voltage load shedding (UVLS) schemes

    Under voltage load shed- ding relays are a conventional local solution to prevent voltage instability The criterion triggering the load shedding action is a predefined voltage level in the supervised node (For example 88 % and 86 % of the nominal voltage in one particular isolated network.).

Emergency Control

- Special Protection Schemes (SPS)

  Definition of SPS:

  a protection scheme that is designed to detect a particular **system condition** that is known to cause unusual stress to the power system and to take some type of predetermined action to counteract the observed condition in a controlled manner.

- SPS differ from UFLS and UVLS schemes and relays essentially in two aspects:
  - SPS use in addition to (or instead of) measurements also a particular topology change (i.e. contingency) information to detect a dangerous system state.
  - SPS consist of several relays, which often use an information from a remote location (e.g. measurement taken by one relay is sent to other relay, which processes it and executes a control action).
  - The action required may be opening of one/more lines/tripping of generators/ramping of HVDC power transfers, load shedding or other measures that will alleviate the problem of concern..

Emergency Control

- Damping control

  Some power systems lack a ”natural” damping of oscillations, and they would be unstable when subjected to any minor disturbance and sometimes even under normal operation conditions if no measures increasing the damping were introduced.

  A traditional way of introducing an additional damping in the system is using Power System Stabilizer (PSS), which modulates the output voltage of the generator.

- Other emergency control measures may include:
  - Tripping of generators
  - Fast generation reduction through fast-valving / water diversion
  - Fast HVDC power transfer control
  - Load shedding
  - Controlled opening of interconnection to neighboring systems to prevent spreading of frequency problems
  - Controlled islanding of local system into separate areas with matching generation and load
  - Blocking of tap changer of transformers
- Insertion of a braking resistor

Day-ahead Operation Planning

- The objective of day-ahead operation planning is to prepare a plan for a secure and economical operation of the system for the next day

Short-term Planning

- The main focuses of short-term planning are activities having time constants in order of several days to several weeks. Typical example:
  - approval of maintenance of generators and transmission components in a coordinated way, guaranteeing that there will be sufficient resources and system capability to execute a secure operation on D day.

Long-term Planning

- Long-term planning activities can be divided into:
  - Computation and Analysis
  - Preparation of Operation Procedures
  - Preparation of Operation Rules
  - System Extensions
  - System Maintenance
  - Experimental Tasks

Computation and Analysis

- Long-term load forecast focuses mainly on a **peak annual consumption** values and its location within the network, not a **particular load profile**.
- Load forecast, together with expected new generation additions are used for a procedure called adequacy assessment.
  - Adequacy assessment measures capability of power system to supply load in all steady state conditions under all normal conditions and situations that may occur.
  - Adequacy assessment can be seen as a forecast employing statistical tools and methodology.

Computation and Analysis

- Generation adequacy assessment aims at quantifying generation capability to meet the peak load demand, considering possible generation units' outages.
- Standard quantification indices are:
  - LOLP (Loss of Load Probability) is number of hours in a period when there is not enough capacity to supply the load. LOLP is usually expressed in hours/year or % of the period.
  - UE (Unserved Energy) is the amount of energy that cannot be delivered depending on deficit of capacity. UE is expressed in MWh/year or % of load.
- In pure generation adequacy assessment, only ratio between load and generation, as well as generation reliability is considered, transmission and distribution systems are assumed to be 100 % reliable.

Computation and Analysis

- Studies and simulations of dangerous scenarios, possibly having an impact on the system stability and security, are conducted.
  - This procedure is called security assessment.
  - Dangerous scenarios are usually simulated for peak load conditions and all single and chosen multiple contingencies.
- When unsatisfactory system performance is revealed, mitigation measures have to take place.
  - In a short-term perspective, operation rules are modified, in a long-term outlook, corresponding system extensions are stimulated.

Computation and Analysis

- Short-circuit analysis processes forecast load and generation patterns and system topology, in order to determine short-circuit capacity throughout the network and subsequently, potentially highest short-circuit currents.
  - After that it is investigated if they can be cleared (if installed circuit breakers have sufficient rating) and how fast (if angular instability of nearby generators can be encountered).
- Operation limits are determined if some operation scenarios are identified to endanger the system.
  - Only a short term solution, until the limitation is removed or minimized by investment in new primary or secondary equipment.

Preparation of Operation Procedures

- Network operators are trained to handle various types of situations and which procedures they shall apply.
- Emphasis is placed on alert and emergency states.
  - First on recognition signs of a dangerous situation and then
  - on identification of effective employment of necessary controls.
  - Results of security assessment studies is utilized, often in form of look-up tables and instruction manuals.
- A separate category is system restoration after a major part of the system has suffered a blackout.
  - In each utility there are plans and procedures prepared, starting from small power plants, having a black start capability (usually small hydro power plants, having an autonomous excitation system based on batteries, and no auxiliary connection of the main grid is required) and good controllability and then
  - connecting loads in appropriate amounts to avoid large frequency excursions and over-voltages. This is done gradually feeder by feeder.

Preparation of Operational Rules

- Rules for external entities for access to the facilities of the transmission operation company.
- In particular, what are conditions for a usage of the transmission network.
  - Ancillary services pricing
  - Transmission pricing
  - Transmission capacity allocation rules
- Ancillary services usually refer to control functionalities to be supplied by generators not for a particular customer but for the benefit of overall system security. These include:
  - secondary frequency control, voltage control, emergency reserves etc.
- In liberalized markets, there are various pricing schemes to provide an incentive to generators to participate in ancillary services.

System maintenance

- A maintenance of both primary and secondary assets is conducted on regular basis.
  - Equipment aging is checked and performance tests are carried out (e.g. if transformer isolation and losses are still adequate etc.).
  - An important aspect in case of secondary equipment is software maintenance, e.g. update of databases containing models of power system components used for system studies etc. (Databases updates are caused by adding new components in the network, new composition of loads, new flow patterns, updates of models after new measurements are available etc.).
- It is necessary to make detailed preparations considering:
  - Secure conditions to perform maintenance (e.g. light loading)
  - Coordination with all involved parties (neighboring TSOs)
  - Announcing sufficiently in advance
  - Modification of operation rules (e.g. Net Transfer Capacity NTC reduction, etc.)

System extensions

- If system performance (from technical or economical perspective) could be improved by an installation of an additional equipment, system operating company carries out feasibility studies, design, and implementation activities.
- An expression, which describes the whole set of activities related to it, is Asset Management, defined as process for acquisition and use of an operation component for a maximum economical profit and management of risks and cost during the entire component lifetime.

Experimental tasks

- New technologies, tools and procedures are first thoroughly tested and examined before being deployed in system operation.

What is Energy Management System (EMS)?

An **energy management system** (EMS) is a system of computer-aided tools used by operators of electric utility grids to **monitor**, **control**, and **optimize** the performance of the generation and/or transmission system.

Why Power EMS?

Critical Loads
Limited In-plant Generation
Insufficient reliability of Public Grid

} Load Shedding

Several Generators
Contracted Power Importation

} Power Control

Different Electrical Operational
Configurations possible

} Mode Control

Complex Distribution Networks
“Local only” Control facilities

} SCADA

Functionality Power EMS

- Load Shedding
- Active and Reactive Power Control
- Supervision, Control and Data Acquisition (SCADA)
- Mode Control
- Re-Acceleration / Re-Starting
- Synchronisation

Load Shedding: The types

- Fast Load Shedding on Loss of Power Resources
- Load Shedding on Frequency Drop
- Slow Load Shedding on Overload
- Slow Load Shedding for Peak Shaving
- Manual Load Shedding

Power EMS Load Shedding: Keywords

- Fast
- Exact
- Flexible
- Co-ordinated
- Deterministic
- Security and Reliability
- Accurate Event Logging
- Operator Guidance
- Independent Back-up System

Integration with supervisory systems

- Plant Information Systems - MIS
- Regional Dispatch Centres
- Power Generation Co-ordination Centres
- Energy Trading
- Utility Management Systems