# INSULATION CO-ORDINATION

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# Overvoltages (Surges)

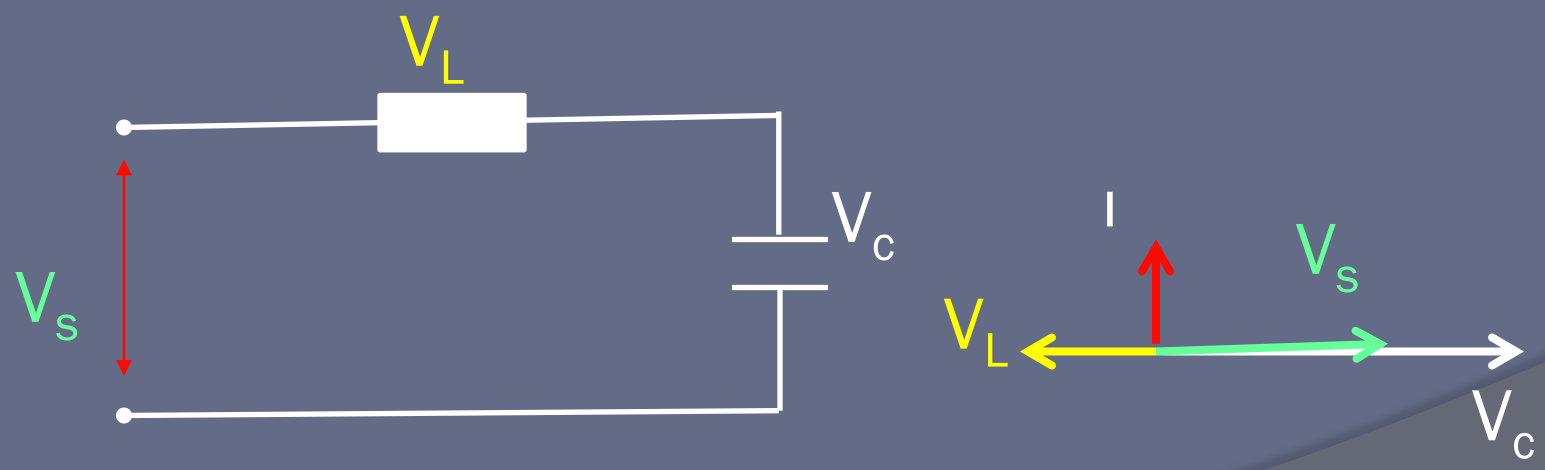
- Overvoltages can be classified into three categories,
  - Power frequency overvoltages (Temporary overvoltages, (TOV),
  - Lightning impulses and
  - Switching surges.

# Power Frequency Overvoltages

- Power frequency overvoltage (POP): are any voltage increases above 20% of the effective nominal value.
- Power frequency overvoltage differ from transient switching overvoltage in that they last for longer durations.
  - Sudden loss of loads,
  - Ferranti effects
  - Single line to ground fault

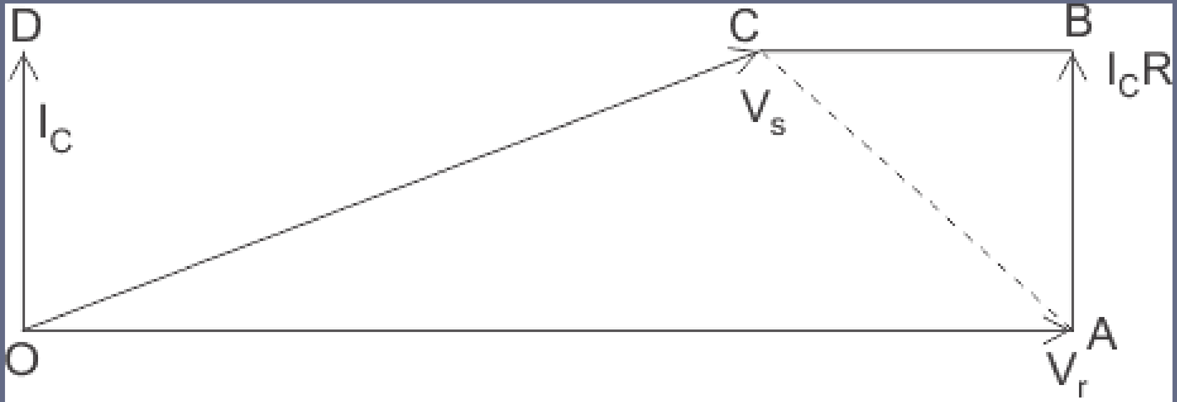
# Power Frequency Overvoltages

- Ferranti effect on a line: the voltage at the open end will rise above nominal for a long line or cable,
- Open end voltage > input voltage ($V_0 > E$)



# Power Frequency Overvoltages

- Ferranti effect on a line:




Ferranti effects in transmission line

$V_s = V_r + I_c(R + jX)$

$I_c = j\omega C V_r$

$V_s = V_r + j\,\omega C V_r\,(R + jX) = V_r + j\omega CR\,V_r - \omega^2 CLV_r$

$X = \omega L$

$V_s$ is represented by the phasor OC.

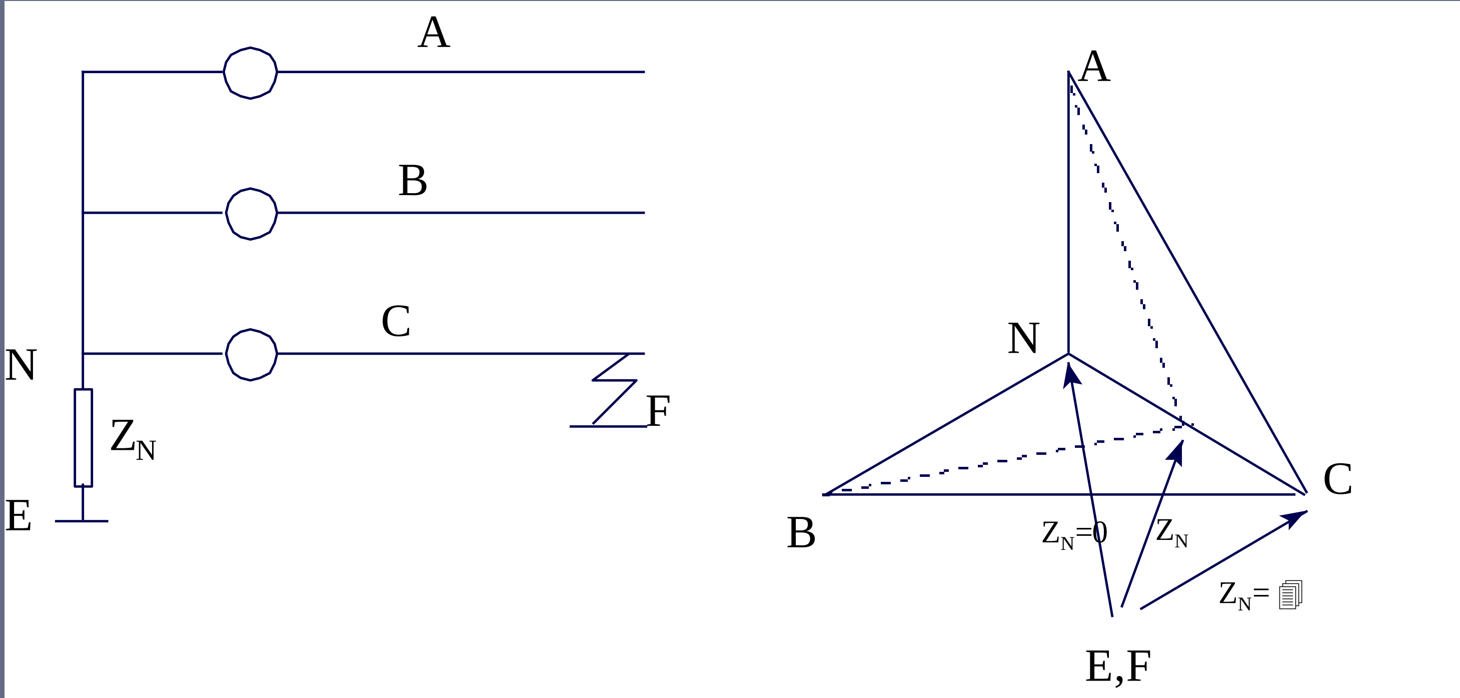
# Power Frequency Overvoltages

- Ferranti effect on a line:

- Assuming R=0 for a transmission line of length l with $C=c_o l$ and $L=l_o l$, $c_o$ and $l_o$ are per unit capacitive and inductive reactances.
- Since, in case of a long transmission line, the capacitance is distributed throughout its length, the average current flowing is, $I_c=\frac{V_r}{2Xc}=\frac{V_r}{2}\omega c_o l$
- The inductive reactance of the line is $X=\omega l_o l$
- Thus the rise in voltage due to line inductor is given by, $I_c X=\frac{V_r}{2}\omega^2 l_o c_o l^2$, is proportional to the length of transmission lines

# Power Frequency Overvoltage

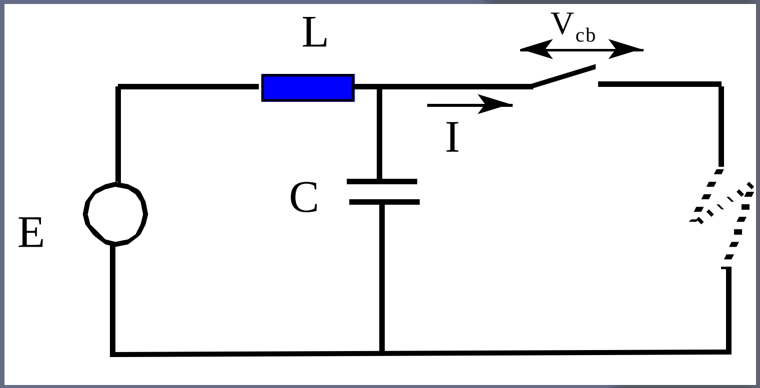
- Earth faults: effect of neutral earthing
- Sound phase voltages to earth depend on neutral earthing impedance, $Z_N$

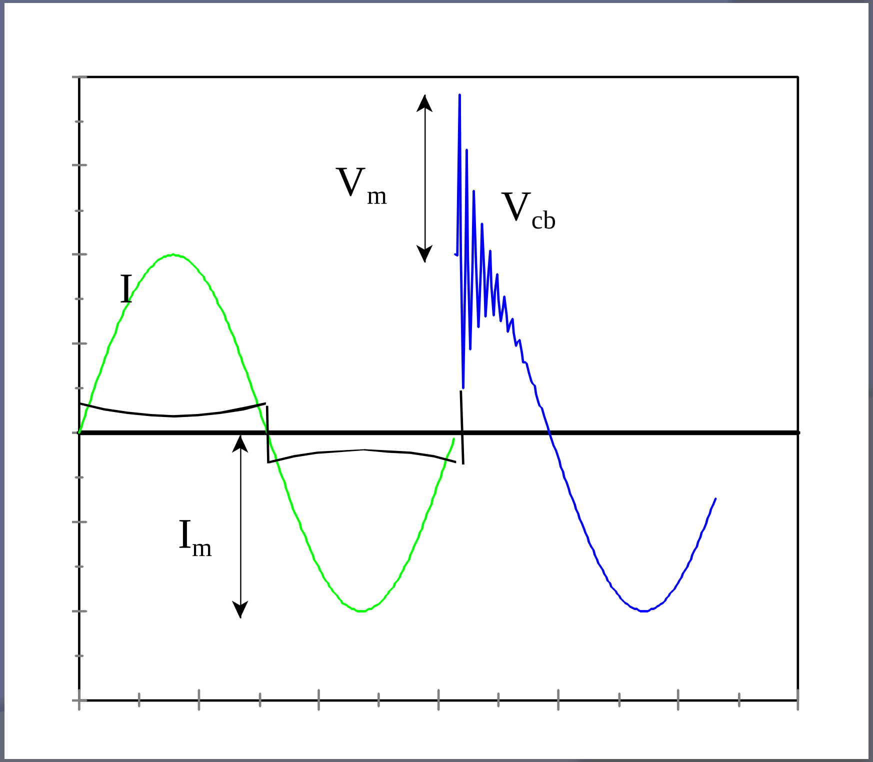



Earth Fault on Phase C

# Switching Overvoltage: Fault Clearing

- When current ceases at current zero, a high frequency transient voltage occurs ($2V_m$)
- Solution: Tripping resistors



# Lightning

- The Nature of Lightning
  - Charge separation in clouds
  - Downward leader develops from cloud
  - Final discharge, 20 - 100 kA

# Overvoltages and Insulation Levels

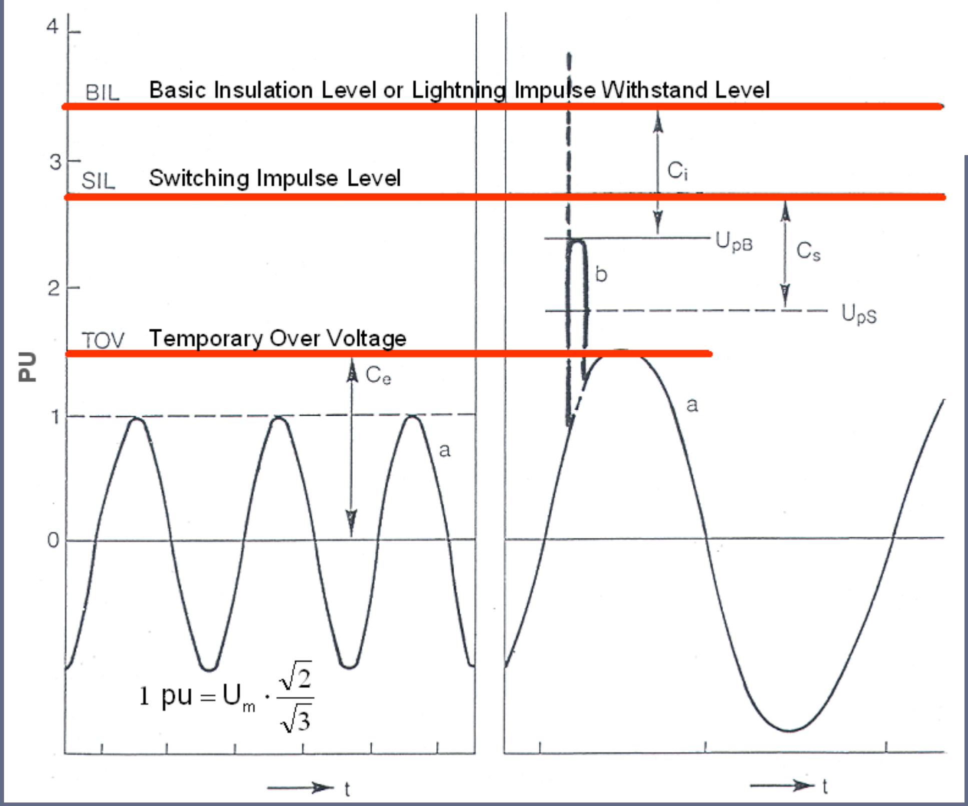
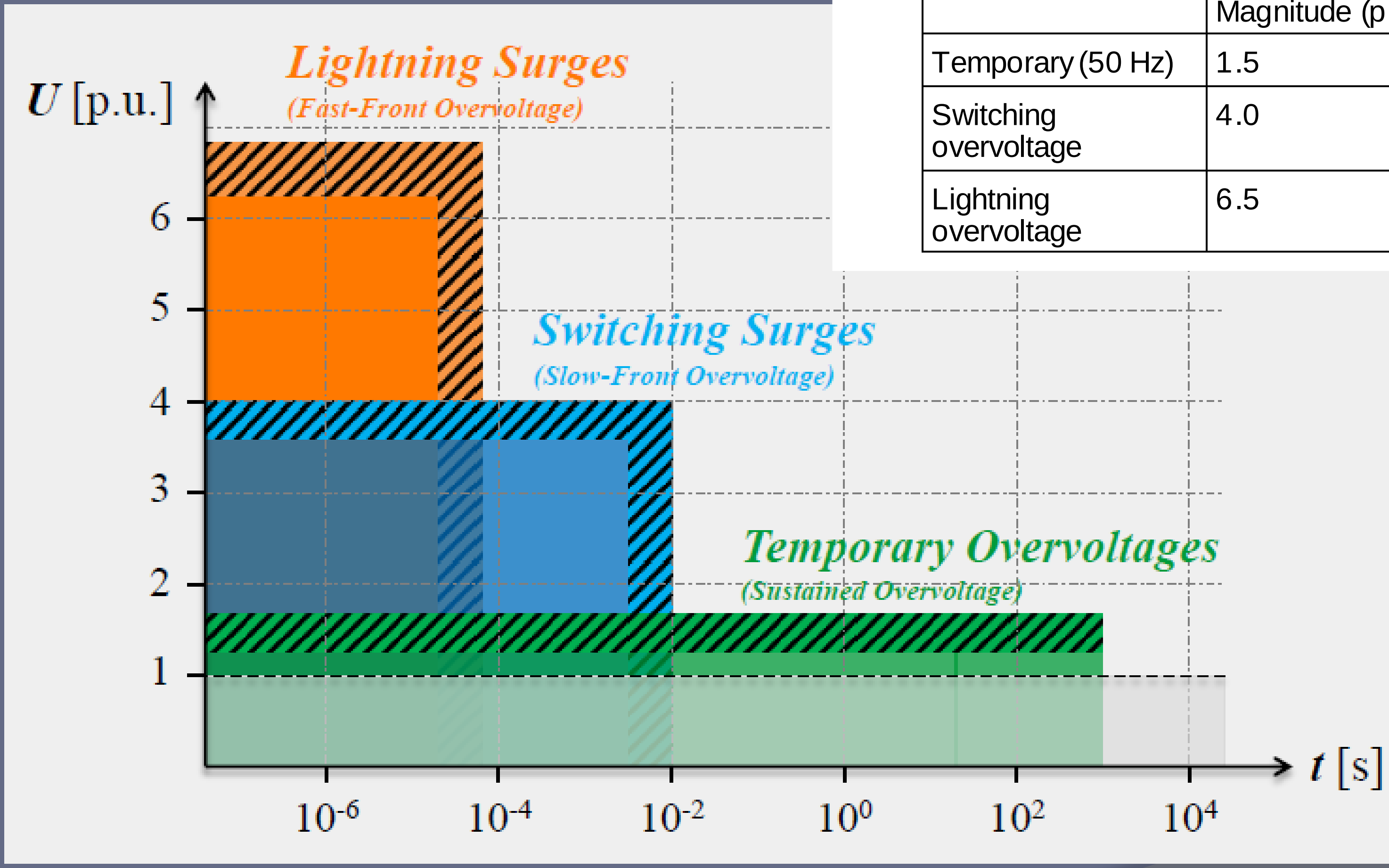



**Table 6.1: Typical magnitudes and durations of overvoltages**

| | Magnitude (p.u.) | Duration |
|---|---|---|
| Temporary (50 Hz) | 1.5 | 50 s |
| Switching overvoltage | 4.0 | 10 ms |
| Lightning overvoltage | 6.5 | 100 µs |

# Overvoltages and Insulation Levels

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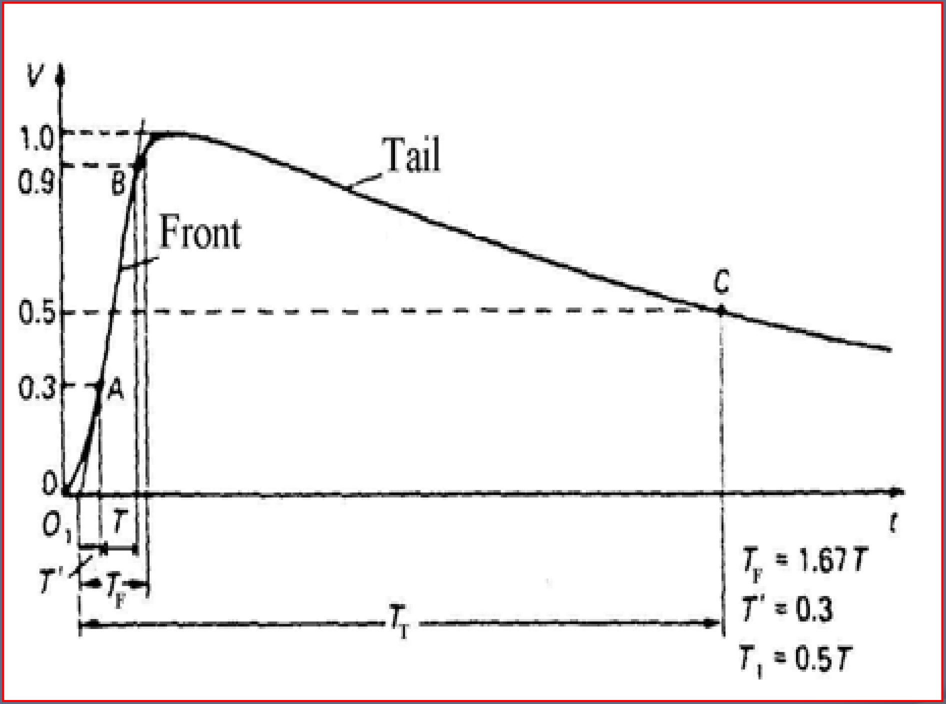
# System Overvoltages

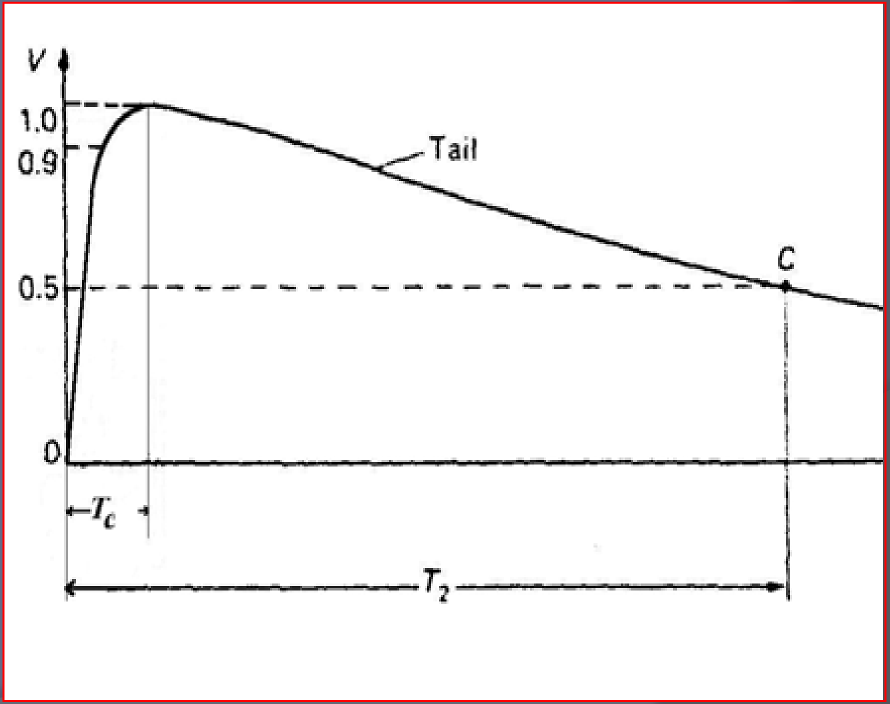
**Impulse Overvoltages**

1.2/50μs impulse having a front time of 1.2 μs and a tail time of 50 μs

**Switching Overvoltages**

250/2500μs impulse having a front time of 250μs and a tail time of 2500μs



# SPECIFYING SYSTEM OVERVOLTAGES

- Standard Wave Shapes

  - Important Parameters (for both waves):

    -Time to crest (called simply "front")

    -Time to half value (called simply "tail")
  - However :

    -Time to crest for Lightning starts from a virtual zero (intersection of line passing 30% & 90% with time axis)

    - $$t_f = 1.67\,(t_{90} - t_{30})$$

# What is Insulation Coordination?

## Definition in IEC 60071-1

**3.1**
**insulation co-ordination**
selection of the dielectric strength of equipment in relation to the operating voltages and overvoltages which can appear on the system for which the equipment is intended and taking into account the service environment and the characteristics of the available preventing and protective devices

[IEC 604-03-08:1987, modified]

Definition in IEEE 1313.1

**3.14 insulation coordination:** The selection of insulation strength consistent with expected overvoltages to obtain an acceptable risk of failure.

**"strength vs. stress"**

# What is Insulation Coordination?

Definition of Insulation Coordination

- ***"Selection of Insulation Strength consistent with expected Risk of Failure"***

**or**

- *"Process of Bringing Insulation Strengths of Elec. Equip. into proper relationship with expected OVs and characteristics of Surge Protective Devices so as to reduce to an economically & operationally acceptable level of risk of failure"*

# Definitions

- **Nominal System Voltage:** It is the r.m.s. phase-to-phase voltage by which a system is designated.
- **Maximum System Voltage**: It is the maximum rise of the r.m.s. phase-to-phase system voltage.

| Nominal System Voltage (kV) | 11 | 33 | 66 | 132 | 220 |
|---|---|---|---|---|---|
| Maximum System Voltage (kV) | 12 | 36 | 72.5 | 145 | 245 |

# Definition

- Insulation Level: For equipment rated at less than 300 kV, it is a statement of the Lightning impulse withstand voltage.
- For equipment rated at greater than 300 kV, it is a statement of the Switching impulse withstand voltage.

# Definition

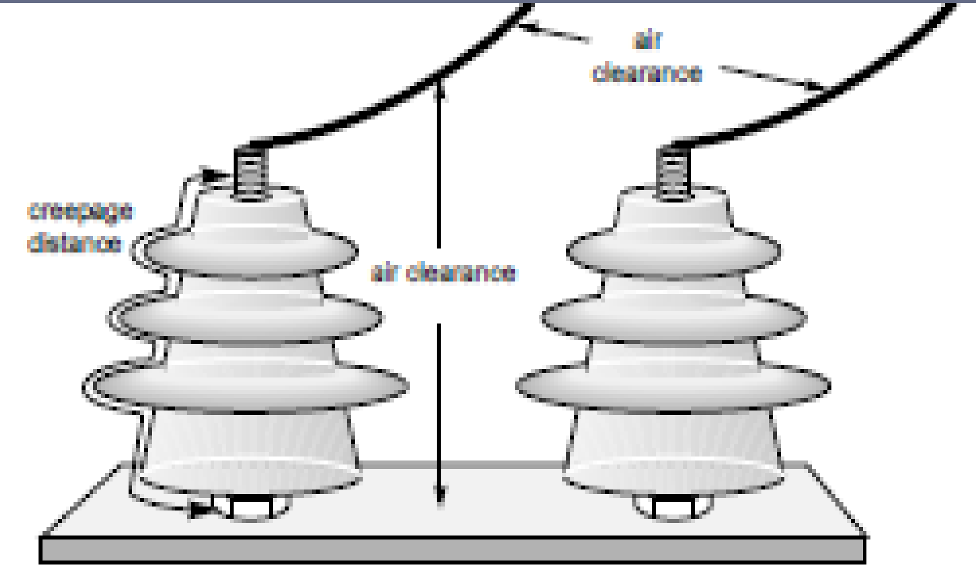
- **Basic lightning impulse insulation level (BIL):** The electrical strength of insulation expressed in terms of the crest value of a standard lightning impulse under standard atmospheric conditions.
- **Basic switching impulse insulation level (BSL):** The electrical strength of insulation expressed in terms of the crest value of a standard switching impulse.

# Definition

- **Protective Level of Protective Device:** These are the highest peak voltage value which should not be exceeded at the terminals of a protective device when switching impulses and lightning impulses of standard shape and rate values are applied under specific conditions.

# Overvoltages (Surges)

- Definitions
  - Creepage Distance: It is the shortest distance on the contour of the external surface of the insulator unit or between two metal fittings on the insulator.




Air clearance and Creepage Distance

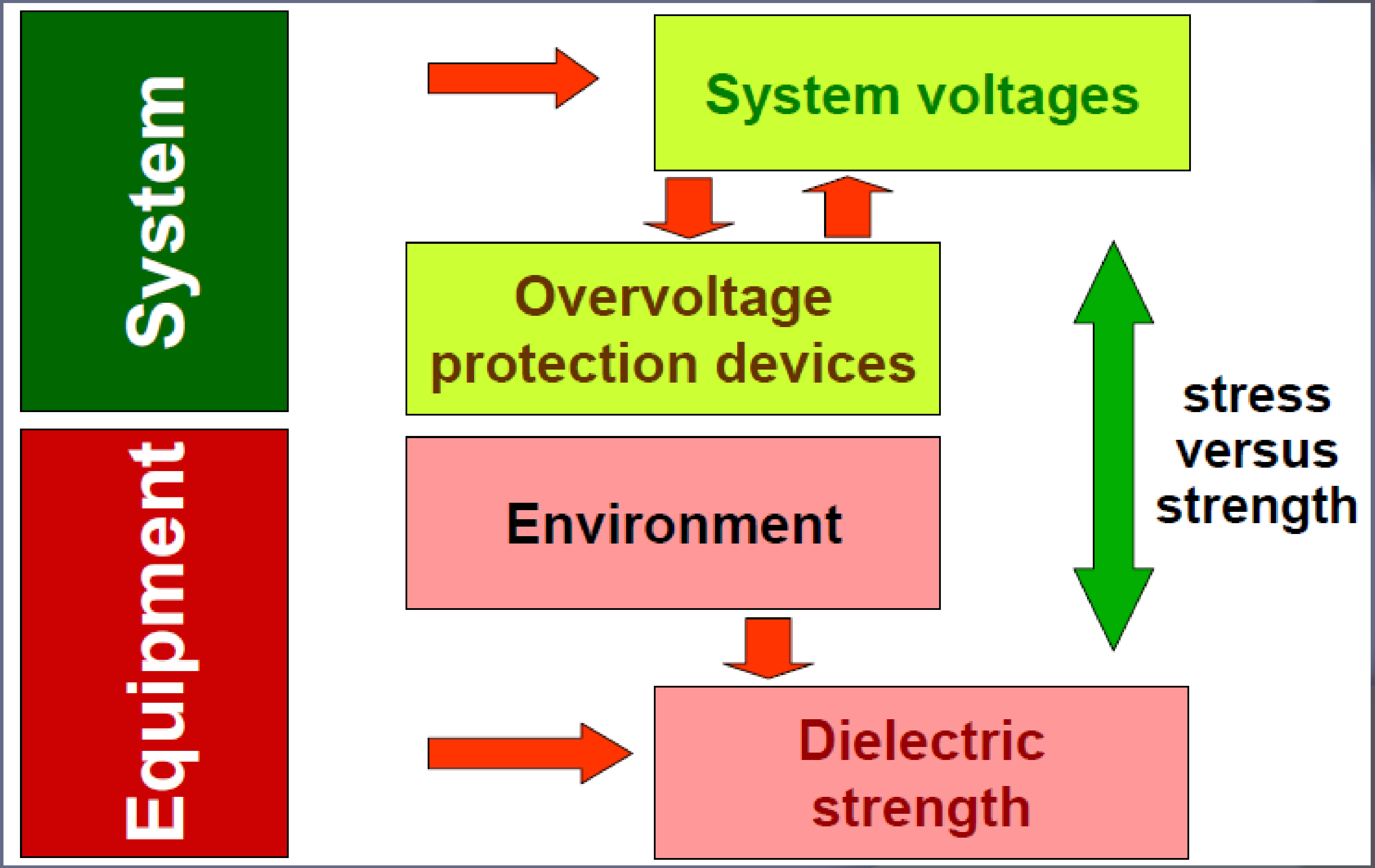
# Fundamentals of Insulation Coordination

## Procedure of insulation coordination:

Two elements are involved in the insulation coordination discipline, namely:

- The study of the "stresses", both electrical and environmental, acting on the equipment insulation.
- The study of the "strength" (dielectric withstand characteristics) of the insulation when submitted to such stresses, taking into account, the effect of the environmental stresses (pollution, rain, snow, ice, atmospheric conditions), using "test and measurement techniques“.

# Insulation Coordination - Principles



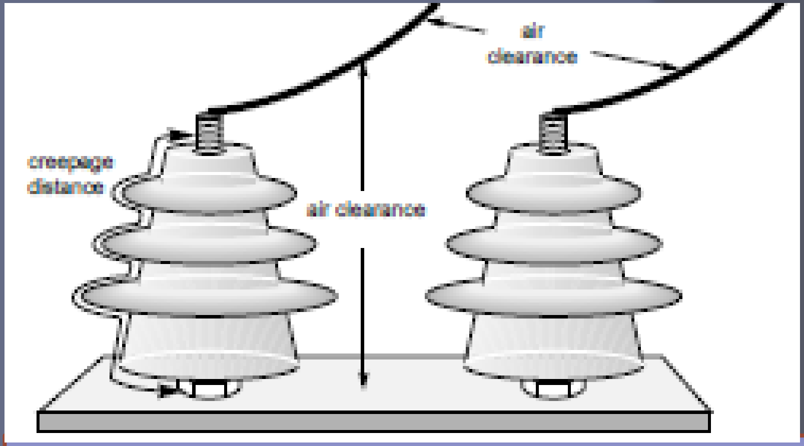
# SPECIFYING INSULATION STRENGTH

- TYPES of INSULATION
  according to ANSI C92.1 (IEEE 1313.1)
  1- classified as :
  INTERNAL or EXTERNAL
  2- classified as:
  SELF-RESTORING &
  NON-SELF-RESTORING

# SPECIFYING INSULATION STRENGTH

## EXTERNAL INSULATION:

- examples:
  - porcelain shell bushing
  - bus support insulators




Air clearance and Creepage Distance

# SPECIFYING INSULATION STRENGTH

- INTERNAL INSULATION

  \- internal solid, liquid, or gaseous parts of equipment insulation, protected by equipment enclosures

  \- Ex: transformer insulation

  Note: equipment may have a combination of internal & external insulation, such as in C.B.

# SPECIFYING INSULATION STRENGTH

## SELFRESTORING (SR) INSULATION

- Insulation completely recovers after a disruptive discharge .

## NON-SELF-RESTORING (NSR) INSULATION

- Opposite of (SR) insulators
- Insulation loses insulating properties or doesn’t recover after a disruptive discharge

# Conventional Method in Insulation Design

- According to the conventional approach to insulation design, the "maximum overvoltage" to which the insulation may be subjected must firstly be determined.
- The insulation is selected in such a way as to have its conventional strength larger than the conventional maximum overvoltage by a "sufficient margin".

# Statistical Methods in Insulation Design

- The aim of statistical methods is to quantify the risk of failure of insulation through numerical analysis of the statistical nature of the overvoltage magnitudes and of electrical withstand strength of insulation.

# Statistical Methods in Insulation Design

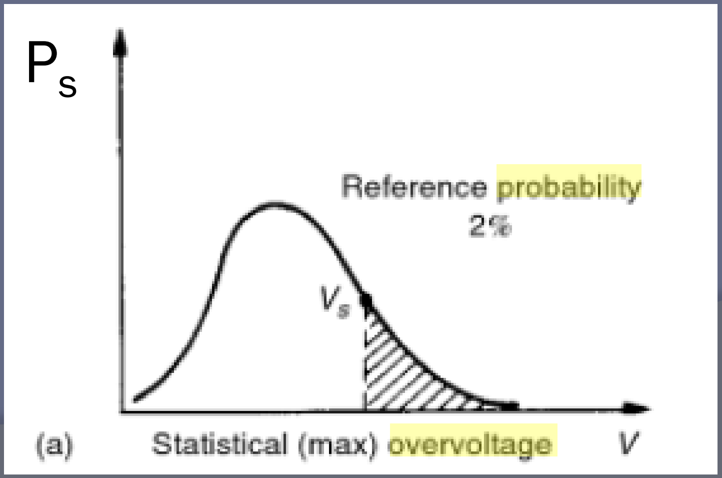
## Statistical Fluctuations in Insulation strength

- The phenomenon of random fluctuation in the strength of insulation was first observed in the breakdown of gaseous dielectrics under impulse voltages.

# Statistical Methods in Insulation Design

## Frequency of Distribution of Overvoltages

- The first requirement for the statistical assessment of insulation behavior is the determination of the frequencies of occurrence of the different types of overvoltage to which the insulation may be subjected.



# Statistical Methods in Insulation Design

Statistical Fluctuations in Insulation strength

- The probability of flashover is simply the ratio of the number of disruptive discharges to the total number of impulse applications.
- This, if plotted against the magnitude of the applied voltage, will yield a breakdown probability distribution curve P(V).

# Statistical Methods in Insulation Design

- Breakdown probability distribution curve P(V)

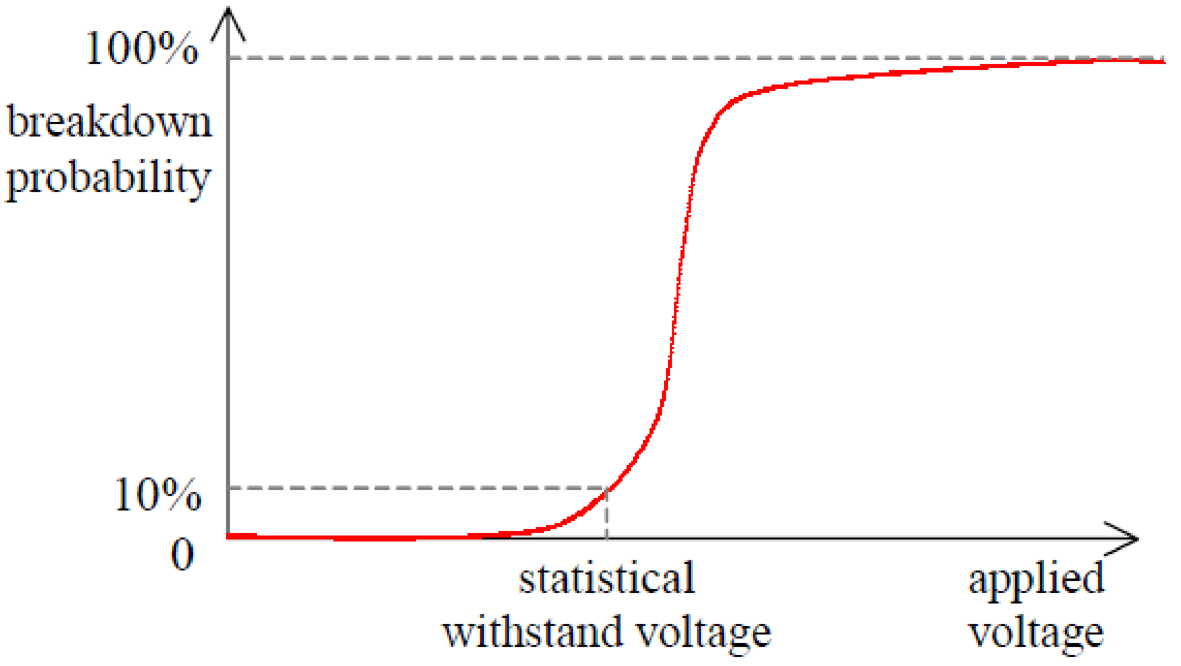



Figure 10.1 - Statistical Impulse Withstand Voltage

# Statistical Methods in Insulation Design

- The flashover probability distribution P(V), i.e. the flashover probability as a function of the applied voltage V
- A cumulative Gaussian (normal) distribution P (V) is used to describe the flashover probability.

$$P(V) = \frac{1}{\sigma_v \sqrt{2\pi}} \int_{-\infty}^{V} e^{-\frac{(v - V_{50\%})^2}{2\sigma_v^2}} dv$$

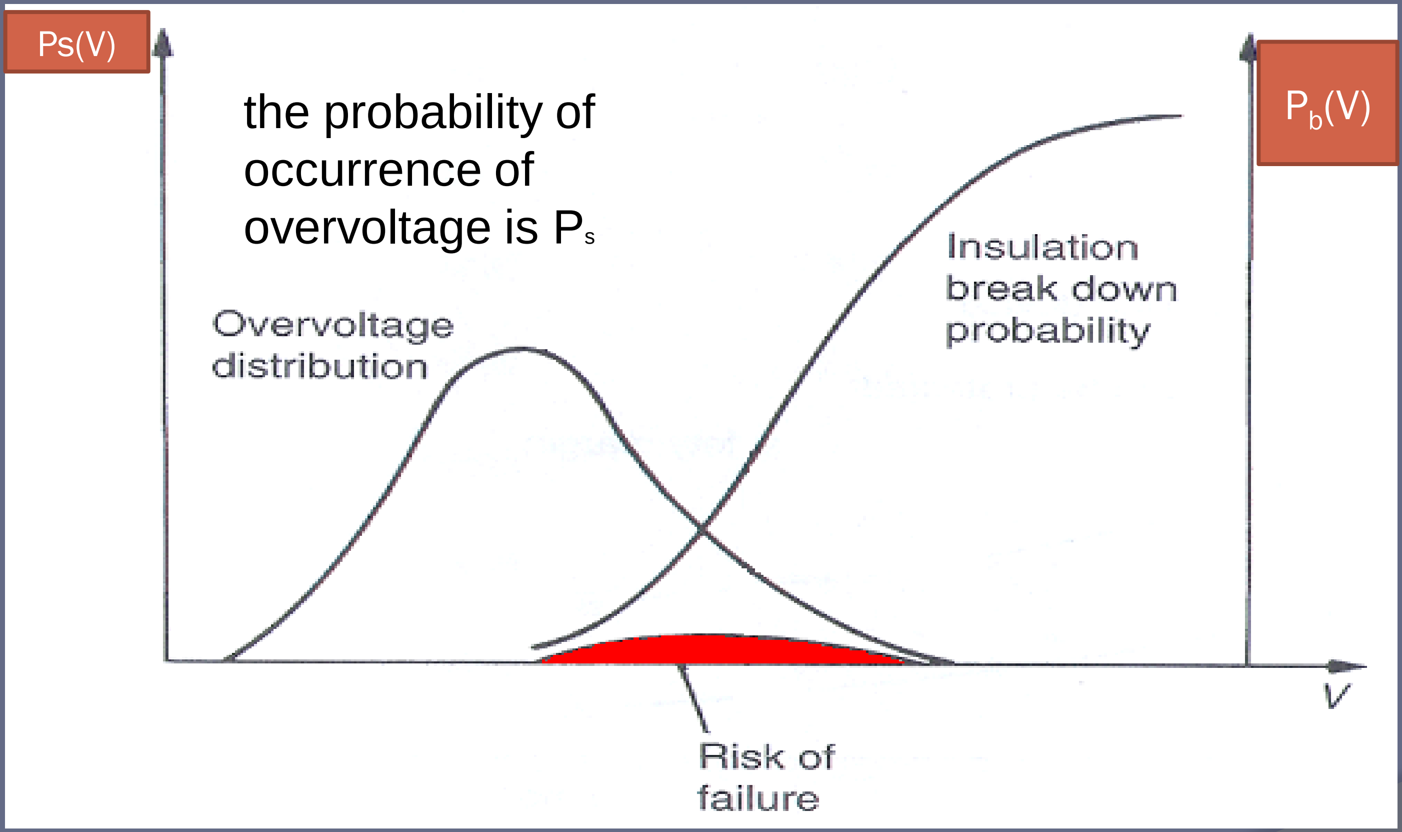
# Statistical Methods in Insulation Design

If $P_b(V)$ is the breakdown probability of insulation as a function of the prospective peak voltage of the applied surge, and $P_s(V)$ is the probability distribution of surge voltage V, the overall risk of insulation failure under all possible surge magnitudes *is* given by

$$R = \int_{-\infty}^{\infty} P_s(V) * Pb(V)\,dV$$

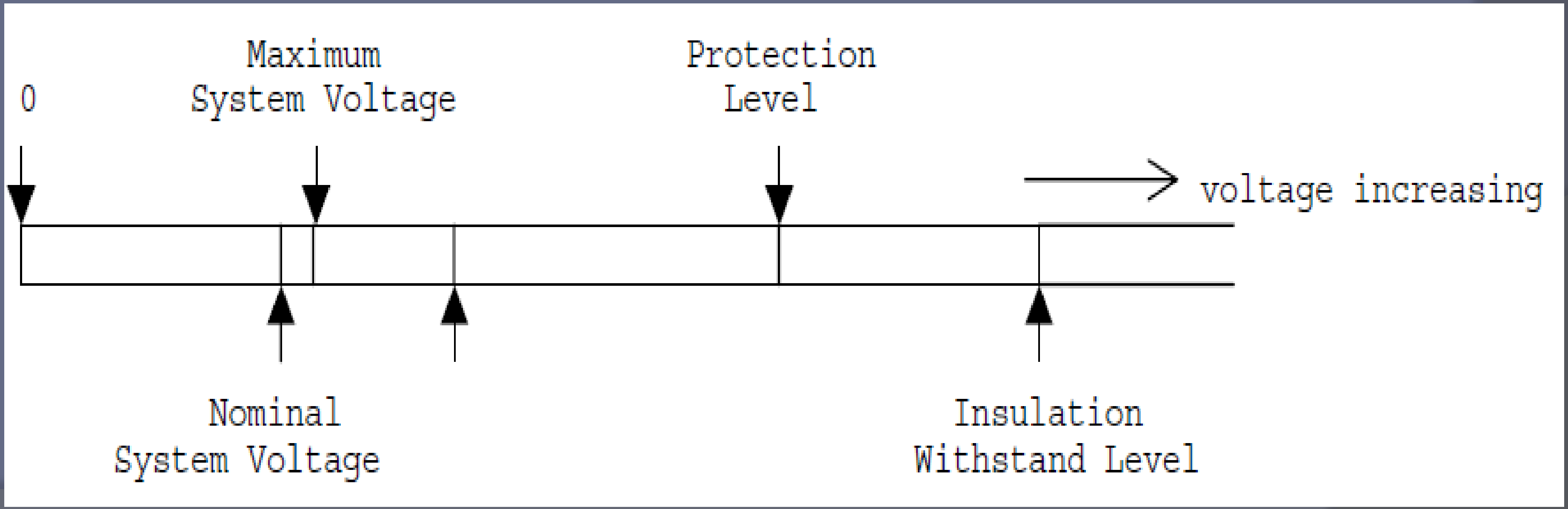
The risk of failure will thus be given by the shaded area under the curve R.

# Statistical Methods in Insulation Design



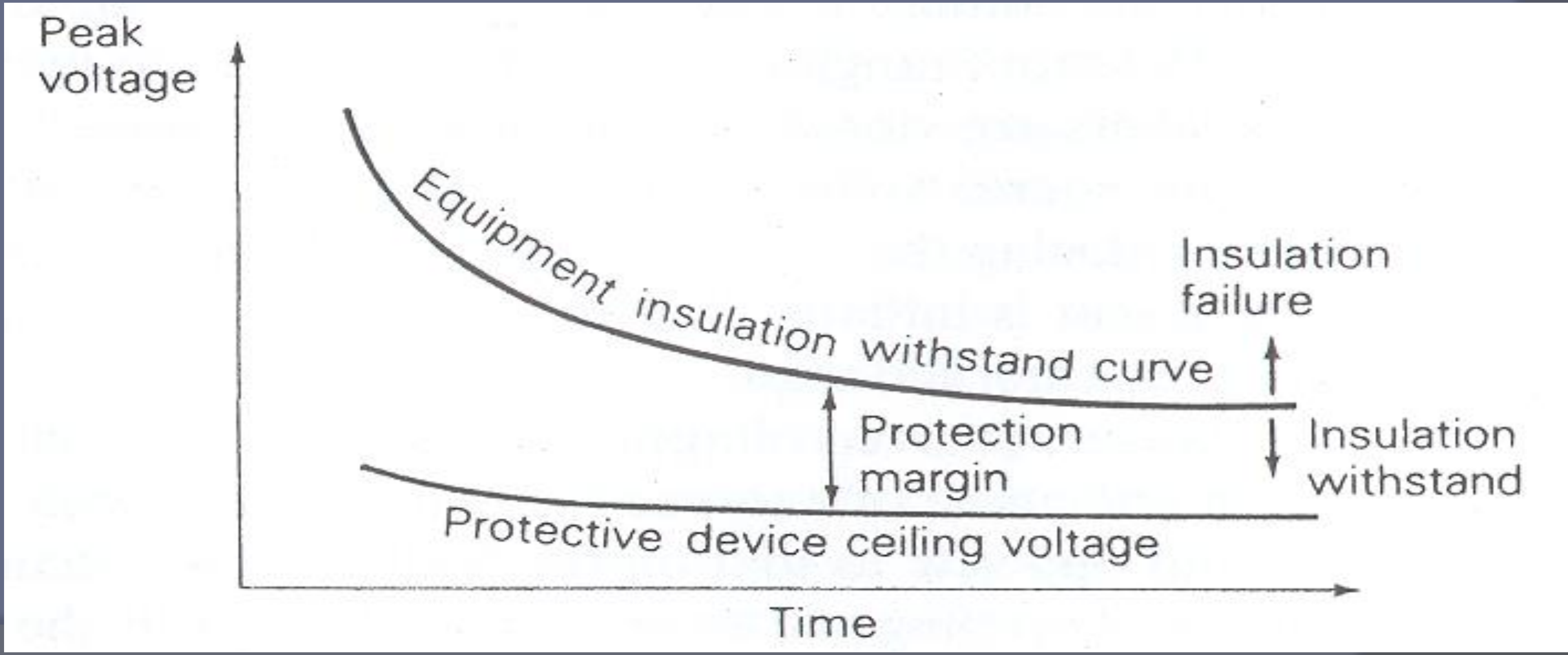
# Fundamentals of Insulation Coordination

- The magnitude of transient over-voltages are usually limited to a protective level by protective devices. Thus the insulation level has to be above the protective level by a safe margin. Normally the impulse insulation level is established at a value 15-25% above the protective level.



# Fundamentals of Insulation Coordination

- In order to avoid insulation failure, the insulation level of different types of equipment connected to the system has to be higher than the magnitude of transient overvoltages that appear on the system. – Conventional (Deterministic) Method



# Fundamentals of Insulation Coordination

- Protective Ratio for *Lightning Surge Withstand* Level is:

$$= \frac{\text{BIL}}{\text{max lightning impulse protection level of protective device}} \geq 1.20$$

(BIL): Basic lightning impulse insulation level.

- Protective Ratio for *Switching Surge Withstand* Level is:

$$= \frac{\text{BSL}}{\text{max switching impulse protection level of protective device}} \geq 1.15$$

(BSL): Basic switching impulse insulation level for 230 kV and 380 kV.

# Typical Standard Insulation Levels

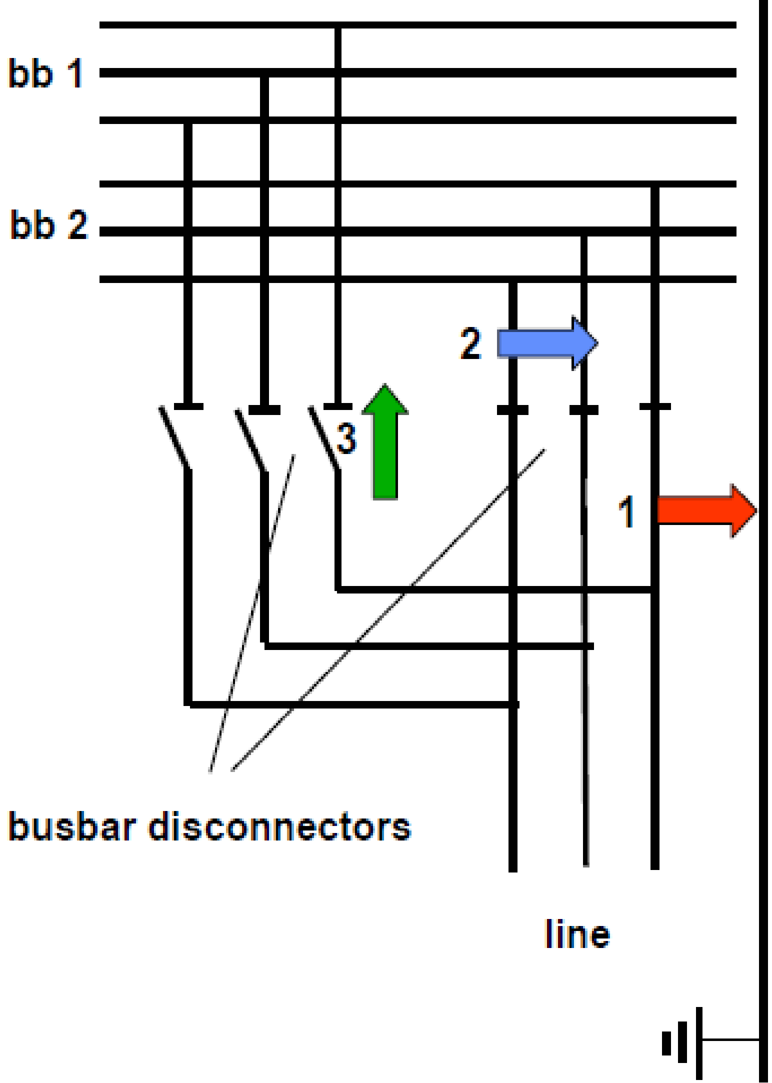
| Nominal and highest (in brackets) system voltage, $U_m$, $kV_{rms}$, line to line | Standard power frequency short-duration withstand voltage $kV_{rms}$ | Standard lightning impulse withstand voltage $kV_{peak}$ | Standard switching impulse withstand voltage $KV_{peak}$ |
|---|---|---|---|
| 6.6 (7.2) | 22 | 75 | _ |
| 11 (12) | 28 | 95 | _ |
| 22 (24) | 50 | 150 | _ |
| 66 (72.5) | 140 | 350 | _ |
| 132 (145) | 275 | 650 | _ |
| 275 (300) | 460 | 1050 | 850 |
| 400 (420) | 630 | 1425 | 1050 |

# Fundamentals of Insulation Coordination

The following insulation configurations are identified:

- Phase-to-ground: An insulation configuration between an energized part and the neutral or ground.
- Phase-to-phase: An insulation configuration between two phases of energized conductors or parts.
- Longitudinal: An insulation configuration between energized conductors or parts belonging to the same phase, which are temporarily separated into two independently energized parts (e.g., open switching device).

# Fundamentals of Insulation Coordination




### Insulation phase - ground

stressed by voltages between one phase and ground

1

### Insulation phase - phase

stressed by voltages between two phases

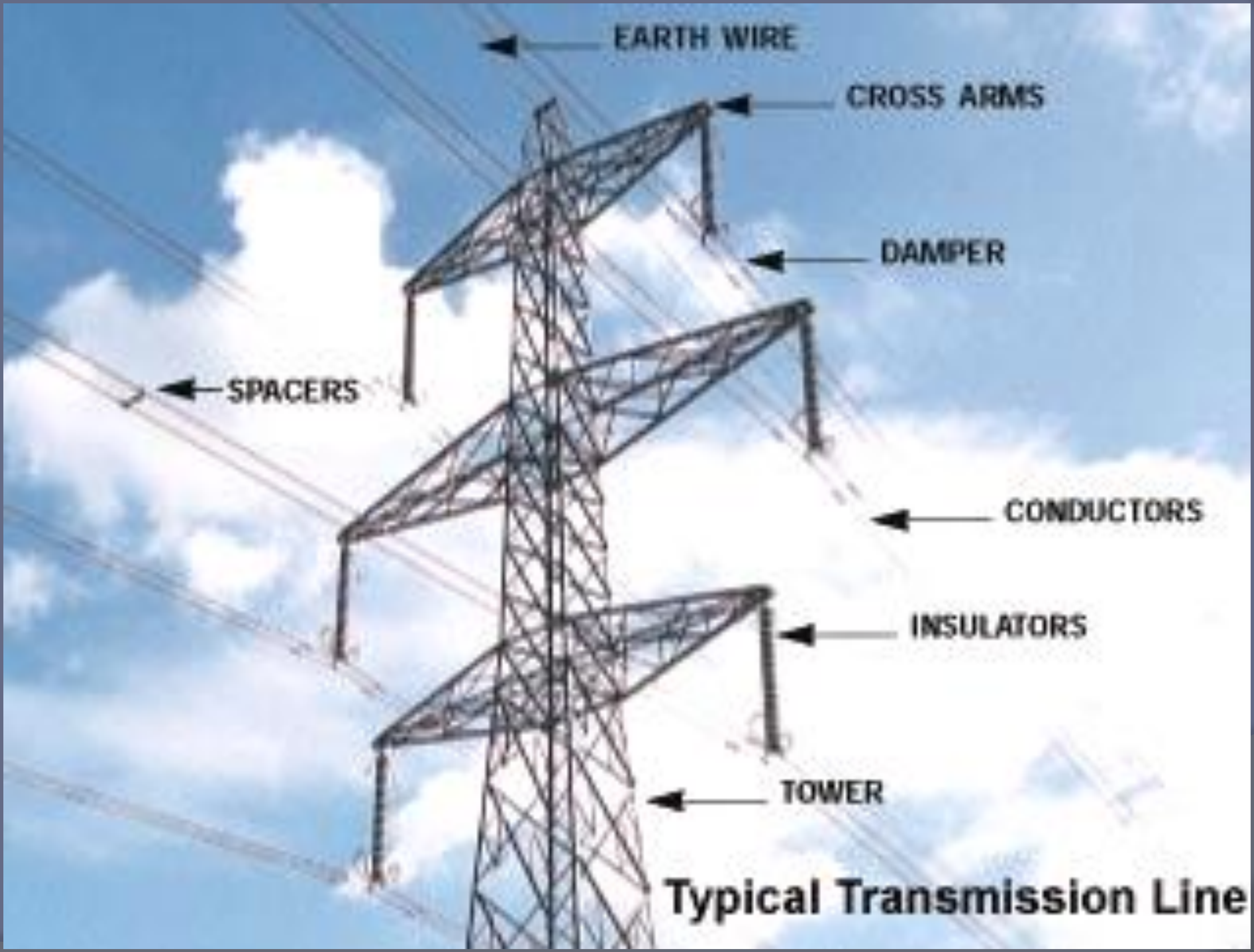
2

### Longitudinal insulation

stressed by voltages between same phases of two different systems

3

# TYPICAL Transmission Line



# Fundamentals of Insulation Coordination

Keep in mind

- It's impossible to design a system that is 100% protected
- Insulation coordination is often an economic decision