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## Insulation Coordination

*ECE524*

*Lecture 45*

- *We can't prevent transient overvoltages, so we need to protect against them*
- Objective:
  - Design system insulation (for all components) to minimize power interruptions and damage resulting from steady-state, dynamic and transient overvoltages in an economic fashion.

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## Primary Areas of Concern

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- Voltage Stress:
  - Magnitude of Surge
  - Duration of surge
  - Distribution of stress
- Current Stress:
  - Magnitude of surge
  - Length of surge

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## Primary Areas of Concern

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- Dielectric Strength of insulation
- Surge protective devices
  - Device characteristics
  - Device placement
- Cost

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## Types of Voltage Stresses

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- **Temporary Overvoltages:** Power frequency disturbances of relatively long duration
- Possible causes:
  - Faults (unbalanced)
  - Sudden changes in load (usually load rejection)
  - Underloaded long lines
  - Linear resonances
  - Ferroresonance
  - Electromagnetic and electrostatic induction
  - Electromechanical resonances with generators

# *U* *I* Types of Voltage Stresses

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- **Transient Overvoltages:** Switching transients and transients resulting from changes in operating states. High frequency oscillations can result from these transients, lasting from microseconds to several cycles.
- Possible causes:
  - Line energization
  - Reclosing into trapped charge
  - Opening breakers (TRV)
  - Opening breakers in ungrounded 3 phase systems
  - Capacitor switching
  - Breaker restrike
  - Inductor switching (current chopping)

# *U* *I* Analysis of Transient Overvoltages: Solution Issues

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- Analytical solutions
- EMTP-type programs
- Location of transient relative to components is important
- Ground connections
- Parasitic capacitance, inductance and resistance

- Reproducing the event that has occurred (and caused a failure)
- Finding worst case timing and location (statistical study)
- Develop physical understanding

- **Lightning Transients:** Very fast, hundreds of nanoseconds to a few microseconds
  - Direct strike most severe
  - Transmission lines are shielded but do not have adequate insulation for a direct strike
  - Overvoltages not normally from lightning striking phase conductor
    - Secondary effects of shield wire or tower strikes
    - Backflashover (most common)
    - Electromagnetic induction (least severe)

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## Design Issues: Transmission lines

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- Conductor to conductor clearances
- Conductor to tower clearances
- Specify insulator strings
- Placement of shield wires
- Placement of ground conductors
- Tower type
- Tower footing resistance

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## Design Issues: Transformers and Rotating Machines:

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- BIL (basic lightning impulse insulation level),
  - Rise time of  $1.2\mu\text{sec}$  and decay to 50% in  $50\mu\text{sec}$ .
- BSL (basic switching impulse insulation level),
  - Rise time of  $250\mu\text{sec}$  and decay to 50% in  $2500\mu\text{sec}$ .
  - Both are used to measure ability of equipment (and insulation) to withstand overvoltages

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## Characteristics of Self- Restoring Insulation

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- Self-Restoring
  - Insulator string in air (or other path in air)
  - Once the arc clears completely, insulation back at full strength
  - Circuit breakers in this class

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## Characteristics of Non-Self- Restoring Insulation

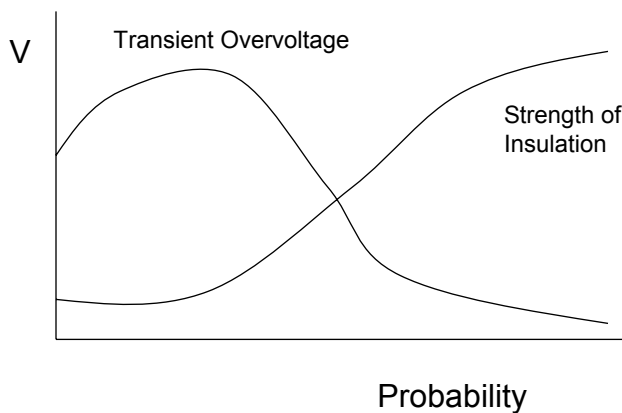
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- Non-Self-Restoring
  - Insulation failure results in damage to insulation
  - Will need to be isolated and repaired
- Underground cable
- Transformers
- Rotating Machines

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- Apply Rules of Thumb to estimate worst case voltages
- Pre-calculated deterministic studies
  - Calculate absolute worst-case overvoltages
  - Over design
- Deterministic and Statistical
- Purely Statistical



- 3 Phase Line Energization with trapped charge 3.5pu
- 3 Phase Line Energization with closing resistor and trapped charge 2.3pu
- Energize Ungrounded Capacitor Bank 2-2.5pu
- Capacitor Bank Restrike 3.0pu

- Transient Recovery Voltage 2-3pu
- Unfaulted phase, SLG fault 1.73pu
- One approach is to assume these will occur and design appropriately.

- Transient network analyzers were very good at doing repeated studies with the same network configuration and different switching times/conditions
  - Long set up time
  - “Real time” run time

- Can also be used for statistical studies
- A bit more effort to vary switch timing
- STATISTICS and SYSTEMATIC switch will allow pseudo-random variation in switching times