IEEE Fort Worth PES Chapter

High Voltage Substation Design Approach
- For Utility Systems

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Agenda

- What is a Substation?
- Substation Equipment
- Substation Configurations
- Protection Philosophies
- Substation Project Life Cycle
- Questions
What is a Substation?

- IEEE 100 – An assemblage of equipment for purposes other than generation or utilization, through which electric energy in bulk is passed for the purpose of switching or modifying its characteristics.
What is a Substation?

Talk About These

Not These

- Generation
  - Typically 4kV - 20kV
- Transmission
  - Typically 100kV - 765kV
- Sub-transmission
  - Typically 69kV - 100kV
- Transmission Substations & Switching Stations
- Distribution Substations
- Distribution to Customers
  - 35kV - 2.4kV
Substation Voltage Levels

- **Ultra High Voltage (UHV)** – >800kV
- **Extra High Voltage (EHV)** - ≥240kV and <800kV
  - Typical: 765kV, 500kV, **345kV**
- **High Voltage (HV)** - ≥100kV and ≤230kV
  - Typical: 230kV, 161kV, **138kV**, 115kV
- **Medium Voltage (MV)** - >1kV and <100kV
  - Typical: **69kV**, 34.5kV, 24.9kV, 13.8kV, 13.2kV, 12.5kV, 4.16kV, 2.3kV
Substation Insulation Types

- Air Insulated (AIS)
- Gas Insulated (GIS)
Power System Network Types

- Radial
- Loop
- Loop w/ Taps or Ties
- Grid or Mesh
Substation Types

★ Generation Substations
  ■ Outside Power Plants and have Step-up Transformers

★ Transmission Substations
  ■ Generally don’t have Distribution and have Autotransformers

★ Switching Substations
  ■ Don’t have Power Transformers

★ Distribution Substations (Collector Substations)
  ■ Have Distribution Feeders (Collector Fdrs.)
Generation Substations
Substation Equipment

- **Modify Power Characteristics**
  - Power Transformers
  - Capacitor Banks (Series or Shunt)
  - Reactors (Series or Shunt)

- **Switching and/or Protection**
  - Power Circuit Breakers, Circuit Switchers
  - Power Fuses
  - Disconnect Switches
  - Surge Arresters

- **Measurement**
  - Instrument Transformers (CTs, PTs, CCVTs, SSVT)

- **Other**
  - Wave Traps
Power Transformers

- 345/138kV Auto
- 161/12.5kV
Capacitor Banks

- 345kV, Series
- 69kV, Shunt
Reactors

- 345kV, Shunt
- 15kV, Shunt
- 15kV, Series
Power Circuit Breakers

- **345kV, PCB**
- **345kV, FIS**
- **138kV, FIS**
- **15kV, PCB**
Power Fuses

- 138kV
- 15kV
Disconnect Switches

- 345kV, Double-End-Break
- 138kV, Vertical-Break
- 138kV, Vee-Center-Break

* There are many other styles & variations
Surge Arresters

- **345kV, Station Class**
- **138kV, Station Class**
- **15kV, Dist. Class**
Instrument Transformers

- 345kV, CCVT / CT
- 138kV, SSVT
- 138kV, CT/PT
- 69kV, PT
Instrument Transformers

- 15kV, CT, Tube Type
- 15kV, CT, Bar Type
- 15kV, PT
Wave Traps

- 345kV Vertical
- 345kV Horizontal
- 138kV Horizontal
Substation Configurations

- **Radial Feed**
- **Single Bus**
- **Sectionalized Bus**

![Diagram of substation configurations]
Substation Configurations

Main & Transfer Bus

Ring Bus
Substation Configurations

- Breaker-and-a-Half Bus
- Double Bus-Double Breaker
# Substation Configurations

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Pros</th>
<th>Cons</th>
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</thead>
<tbody>
<tr>
<td>Single Bus</td>
<td>Lowest Cost, Small Land, Easy to Expand, Simple to Operate</td>
<td>Low Reliability, Low Maintenance Flexibility, Single Point of Failure</td>
</tr>
<tr>
<td>Ring Bus</td>
<td>High Reliability, Low Cost, Flexibility of Operation, Expandable</td>
<td>Complex Protection and Controls, Breaker Failure Trips Additional Circuit</td>
</tr>
<tr>
<td>Breaker-and-a-Half</td>
<td>Very High Reliability, Very Flexible Operation, Very Maintainable, Expandable</td>
<td>Largest Area Required, High Cost, Complex Protection and Controls</td>
</tr>
</tbody>
</table>
Substation Configurations

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Relative Cost Comparison</th>
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</thead>
<tbody>
<tr>
<td>Single Bus</td>
<td>100%</td>
</tr>
<tr>
<td>Sectionalized Bus</td>
<td>122%</td>
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<tr>
<td>Main &amp; Transfer Bus</td>
<td>143%</td>
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<tr>
<td>Ring Bus</td>
<td>114%</td>
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<tr>
<td>Breaker-and-a-Half</td>
<td>158%</td>
</tr>
<tr>
<td>Double Bus-Double Breaker</td>
<td>214%</td>
</tr>
</tbody>
</table>

Reference: “Reliability of Substation Configurations”, Daniel Nack, Iowa State University, 2005
Protection Philosophies

- **Sensitivity** – Ability of protective device to detect faults and operate under minimum expected conditions.
- **Selectivity** – Ability of protective device to operate the minimum number of circuit breakers to isolate the faulty equipment and clear a fault. The protective device must be able to recognize faults within protective zone and ignore faults outside their protective zone.
- **Speed** – Required to obtain the minimum fault clearing time and equipment damage.
- **Reliability** – Measure of the degree of certainty that the protective system will perform correctly.
Protective Relaying
System Design Criteria

- Transformer Protection
  - Current Differential
  - Overcurrent (Overload, Short-circuit, Ground, Directional)
- Bus Protection
  - Overcurrent
  - Current Differential (High-Impedance, Low-Impedance)
  - Trip Blocking Schemes
- Line Protection
  - Distance
  - Current Differential
  - Directional Comparison Blocking (DCB)
  - Directional Comparison Unblocking (DCUB)
  - Permissive Overreaching Transfer Trip (POTT)
Power Line Communication

- Fiber Optic
  - Need Optical Ground Wire (OPGW) along the line
- Power Line Carrier (PLC)
  - Need carrier equipment at remote ends of line
- Microwave
  - Need line of sight
Substation Project Life Cycle

- Study Identifies Project Need
- Project is Funded
- Engineering Resources Secured
- Substation Property Identified/Secured
- Geotechnical and Topographical Surveys Performed
- Conceptual Sub Layout Defined and Approved
- Required Permits identified and processed
- Site Grading Design Performed
- Major Equipment Ordered
- Physical Design Performed
  - Grounding calculations
  - Bus calculations
Substation Project Life Cycle

- Physical Design Performed (cont.)
  - Lightning calculations
  - Lighting calculations
- Relay Protection & Control Design Performed
  - Battery sizing calculations
  - Cable/Conduit/Tray calculations
- Relay Setting Files Prepared
- Construction Packages issued for Bid/Construction
- Construction executed by one or multiple contractors
- Testing & Commissioning
- Field redlines developed and constr. Records issued
Questions and Answers

Thank you!