IEEE Fort Worth PES Chapter

High Voltage Substation Design Approach - For Utility Systems

By: Gustavo A. Rodriguez, PE

August 19, 2014

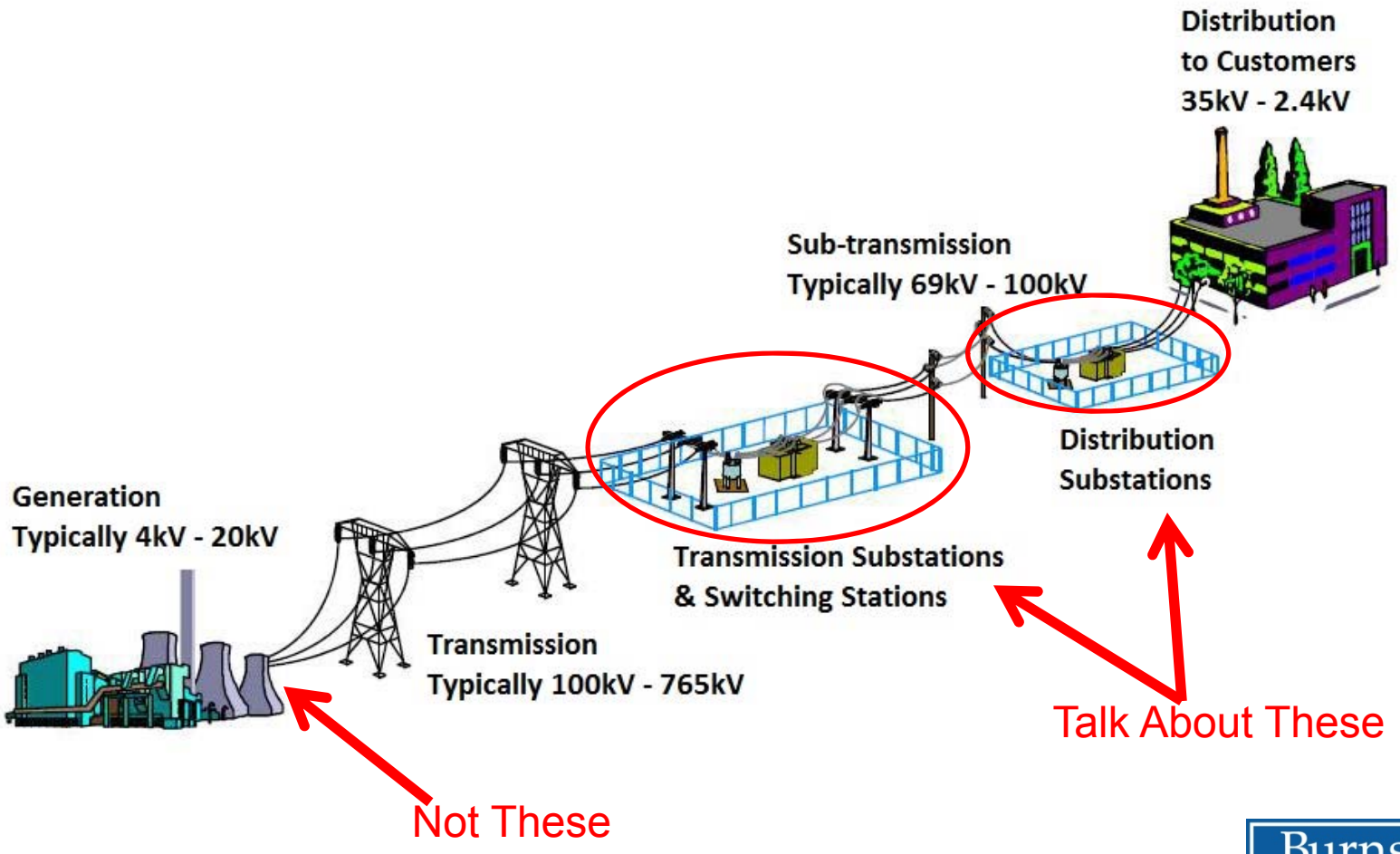
Agenda

- 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?

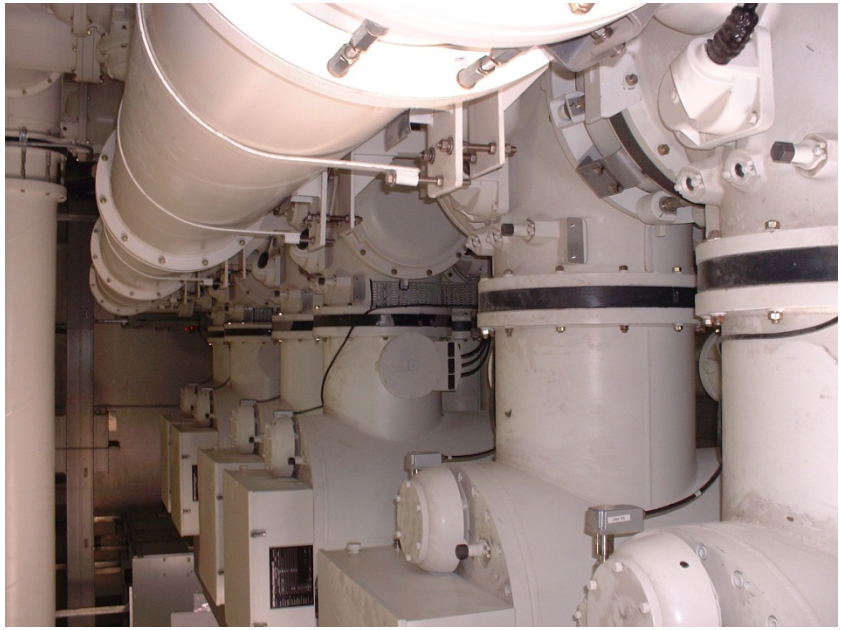


Substation Voltage Levels

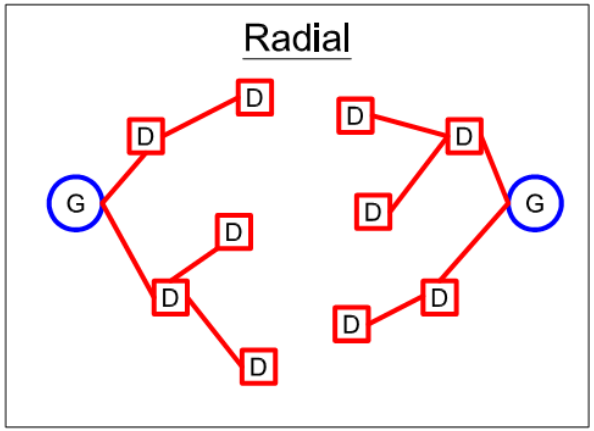
- Ultra High Voltage (UHV) – >800kV
- Extra High Voltage (EHV) - ≥240kV and <800kV
  - Typical: 765kV, 500kV, **345kV**
- High Voltage (HV) - ≥100kV and ≤230kV
  - Typical: 230kV, 161kV, **138kV**, 115kV
- Medium Voltage (MV) - >1kV and <100kV
  - Typical: **69kV**, 34.5kV, 24.9kV, 13.8kV, 13.2kV, 12.5kV,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

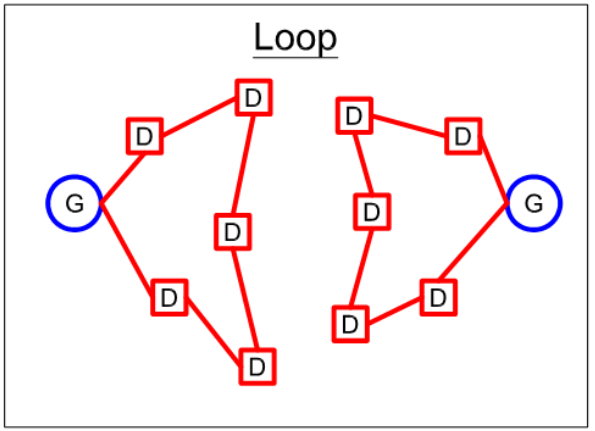
Substation Insulation Types

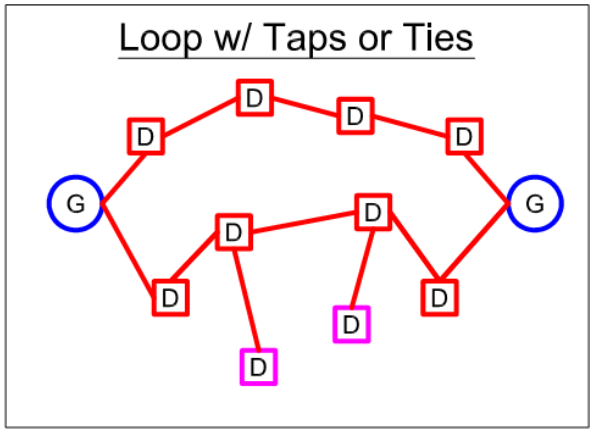
- Air Insulated (AIS)
- Gas Insulated (GIS)

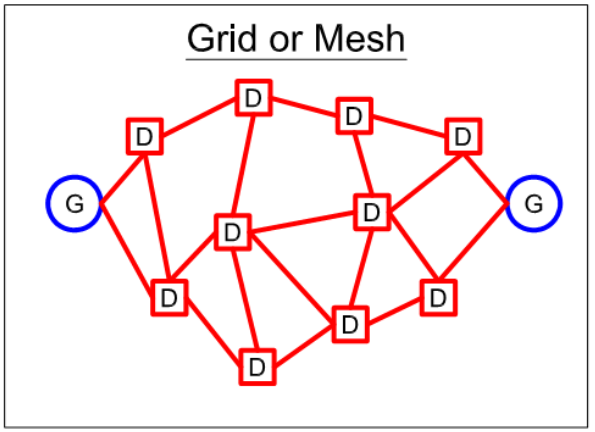


Power System Network Types





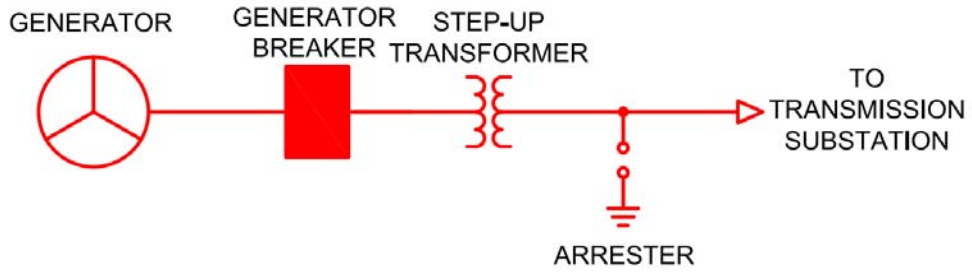




Substation Types

- 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

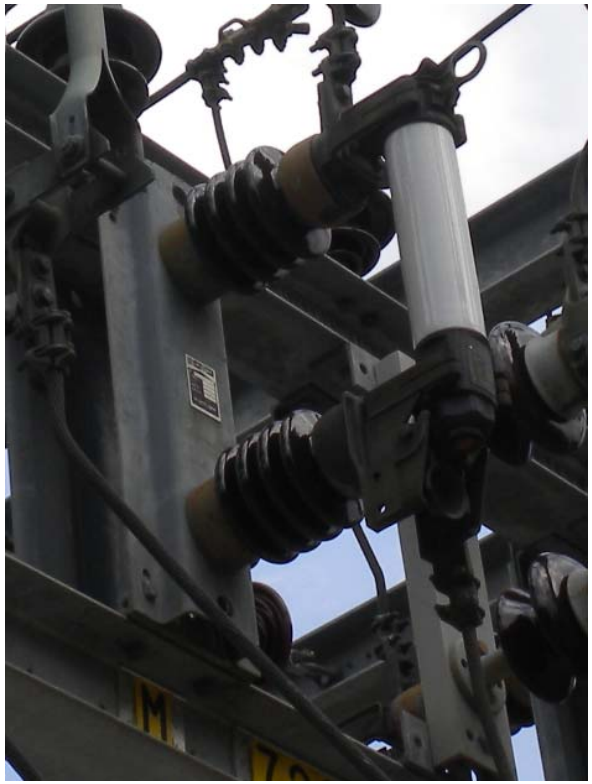
- 138kV, FIS

- 15kV, PCB

Power Fuses

★ 138kV

★ 15kV

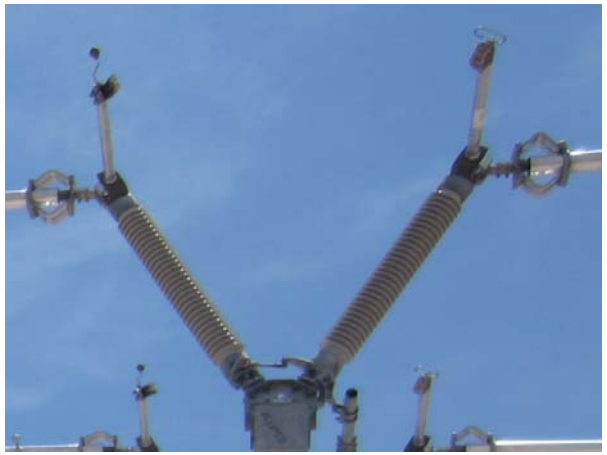


Disconnect Switches

- 345kV, Double-End-Break

- 138kV, Vertical-Break

- 138kV, Vee-Center-Break



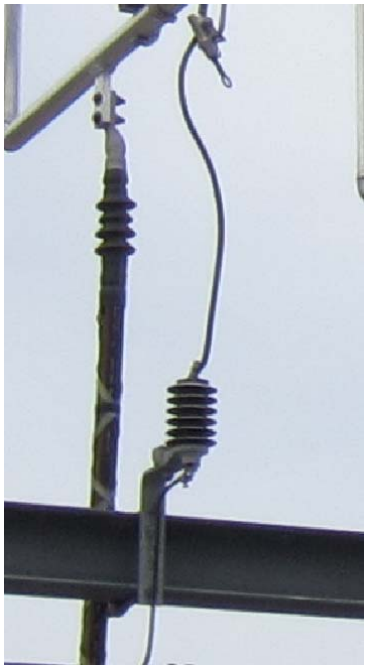
- There are many other styles & variations

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

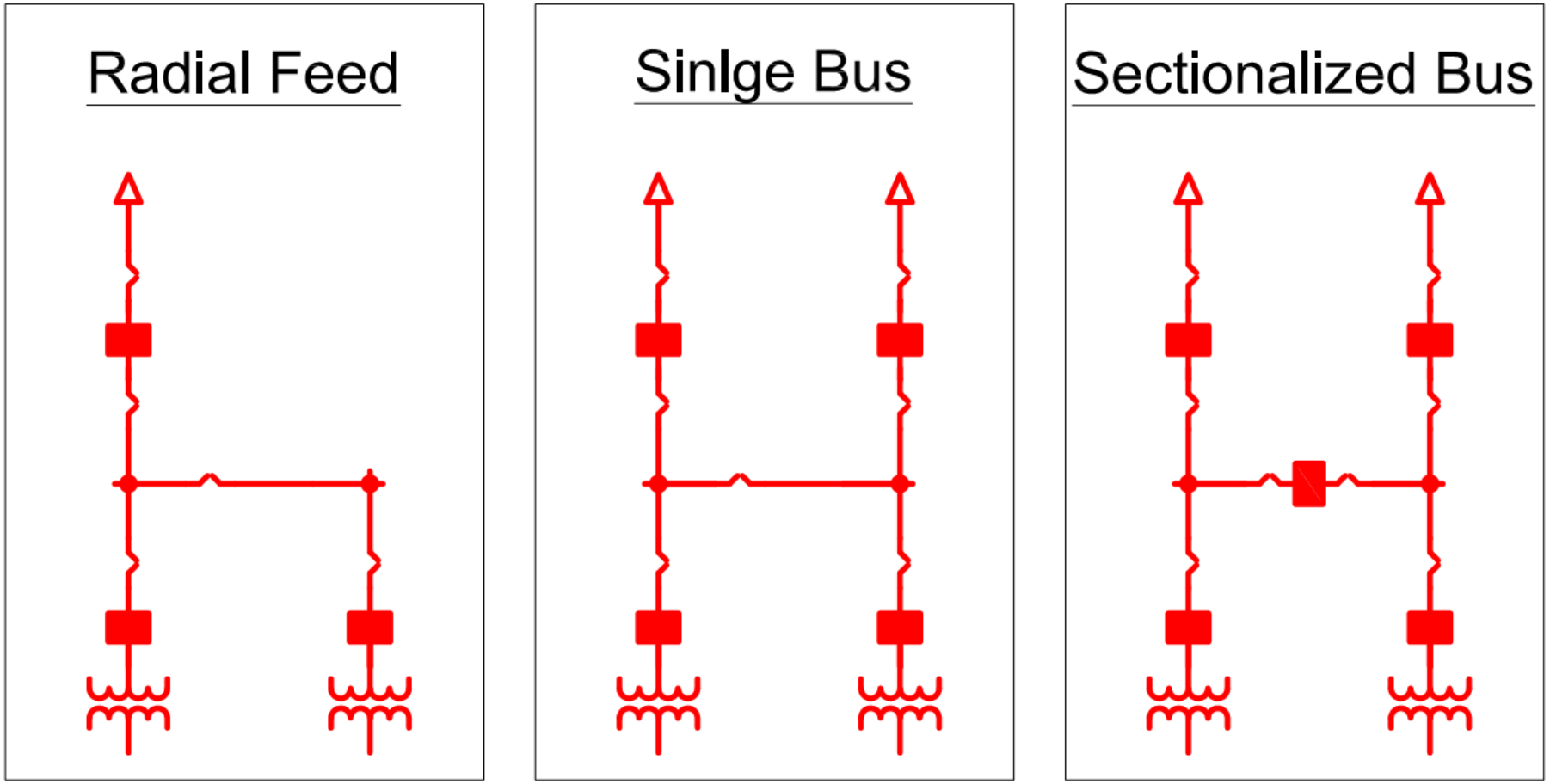
Wave Traps

- 345kV Vertical

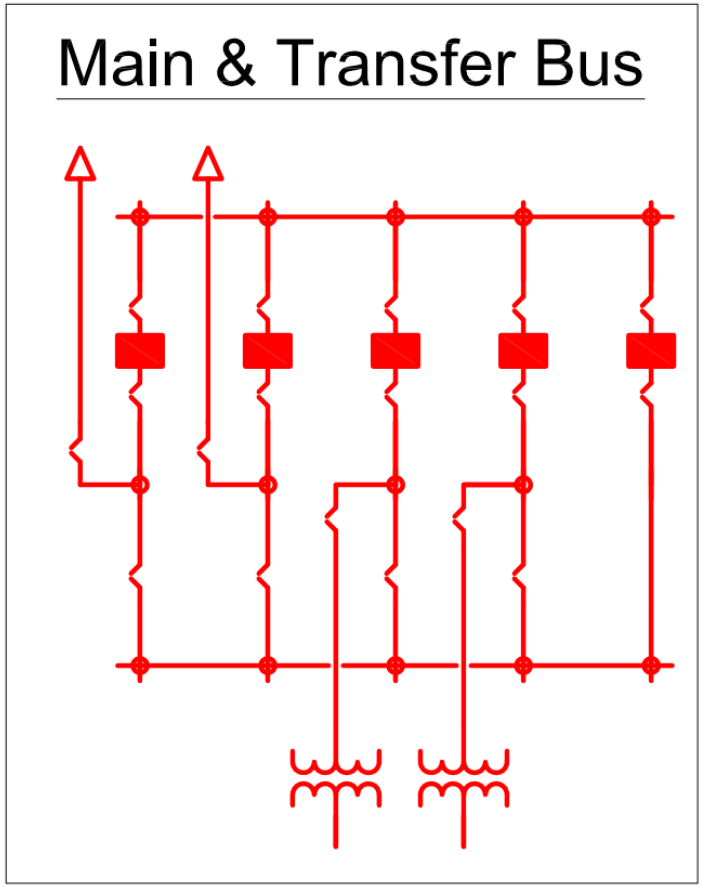
- 345kV Horizontal

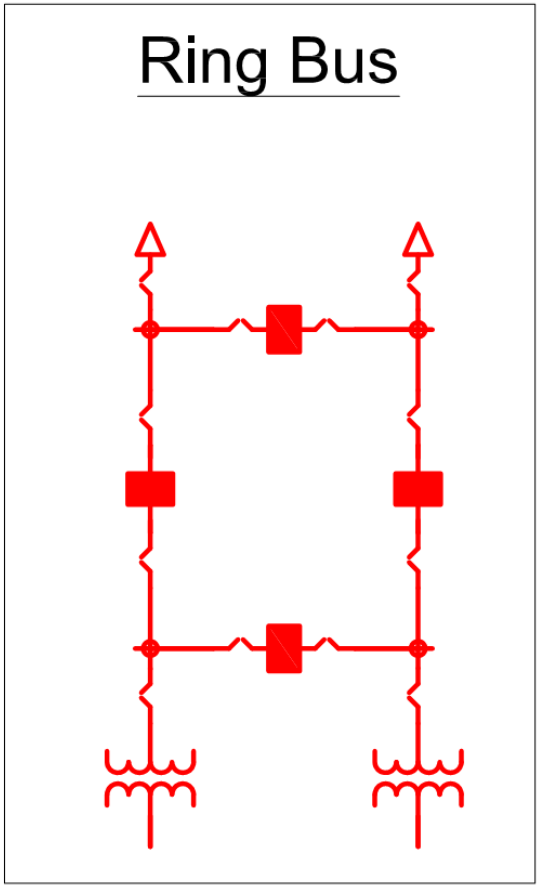
- 138kV Horizontal

Substation Configurations



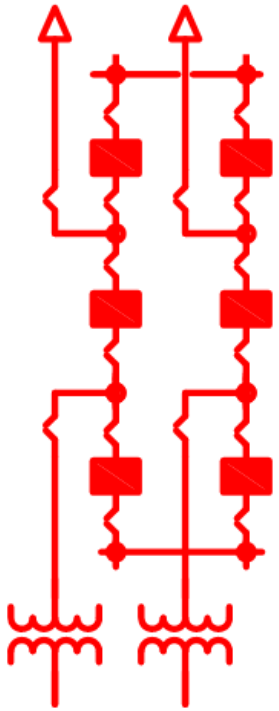
Substation Configurations



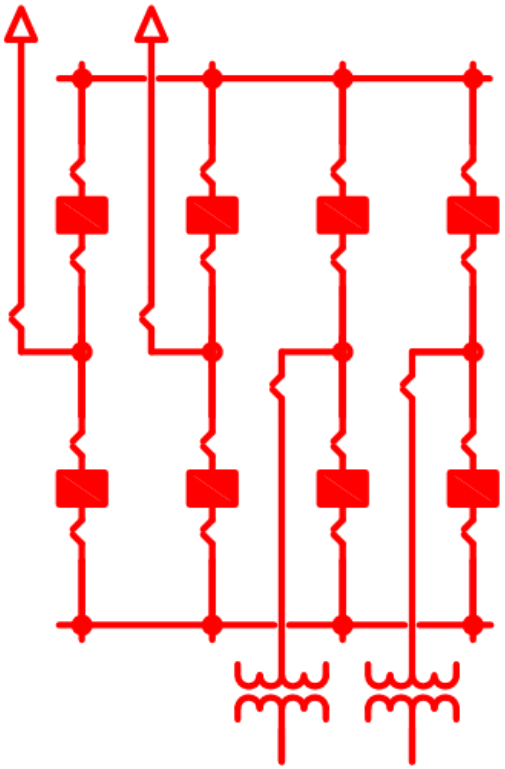


Substation Configurations

Breaker-and-a-Half Bus



Double Bus-Double Breaker



Substation Configurations

Configuration	Pros	Cons
Single Bus	Lowest Cost, Small Land, Easy to Expand, Simple to Operate	Low Reliability, Low Maintenance Flexibility, Single Point of Failure
Ring Bus	High Reliability, Low Cost, Flexibility of Operation, Expandable	Complex Protection and Controls, Breaker Failure Trips Additional Circuit
Breaker-and-a-Half	Very High Reliability, Very Flexible Operation, Very Maintainable, Expandable	Largest Area Required, High Cost, Complex Protection and Controls

Substation Configurations

Configuration	Relative Cost Comparison
Single Bus	100%
Sectionalized Bus	122%
Main & Transfer Bus	143%
Ring Bus	114%
Breaker-and-a-Half	158%
Double Bus-Double Breaker	214%

- 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 !