EH27401
Communication and Control in Electric Power Systems
Lecture 2

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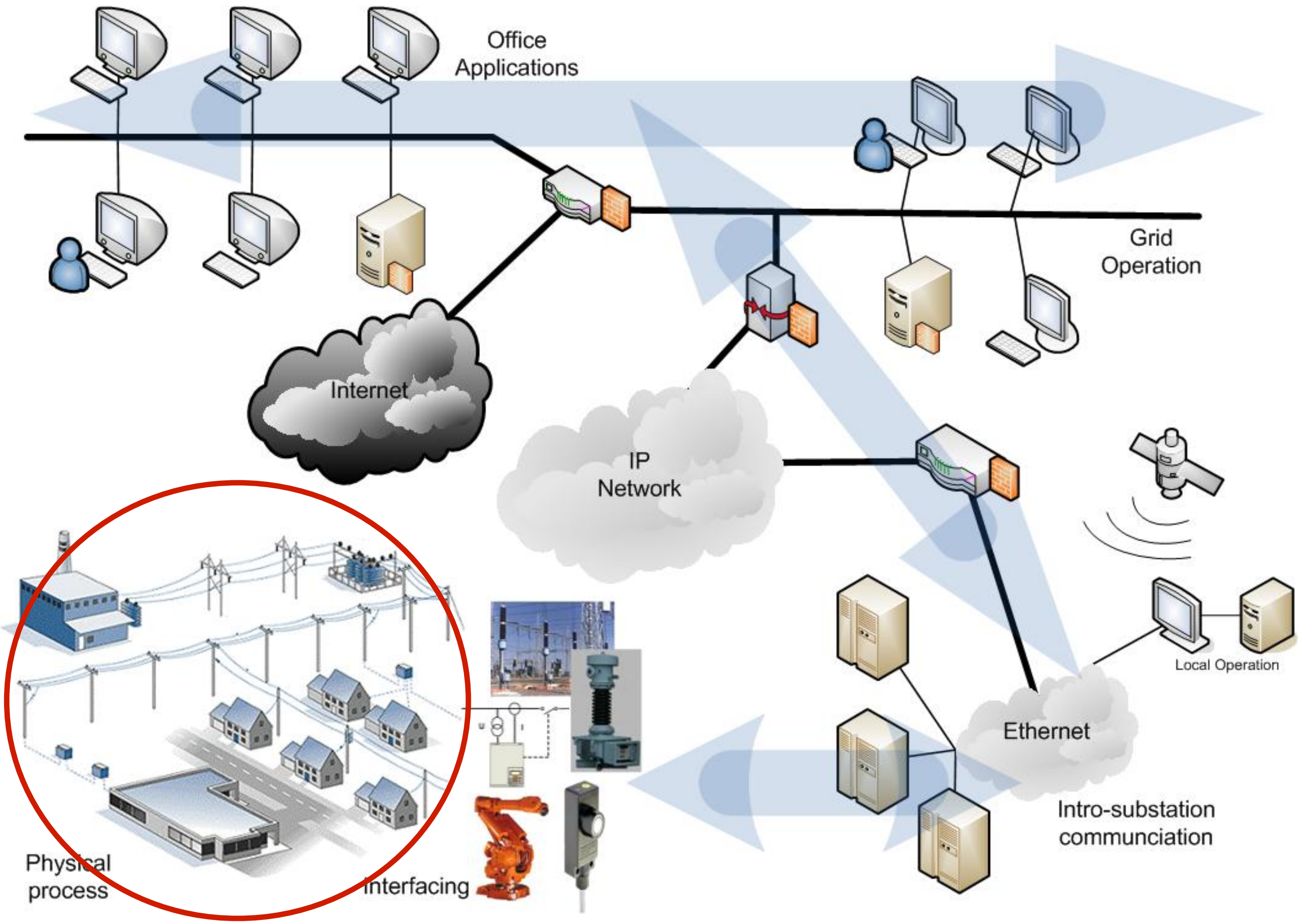
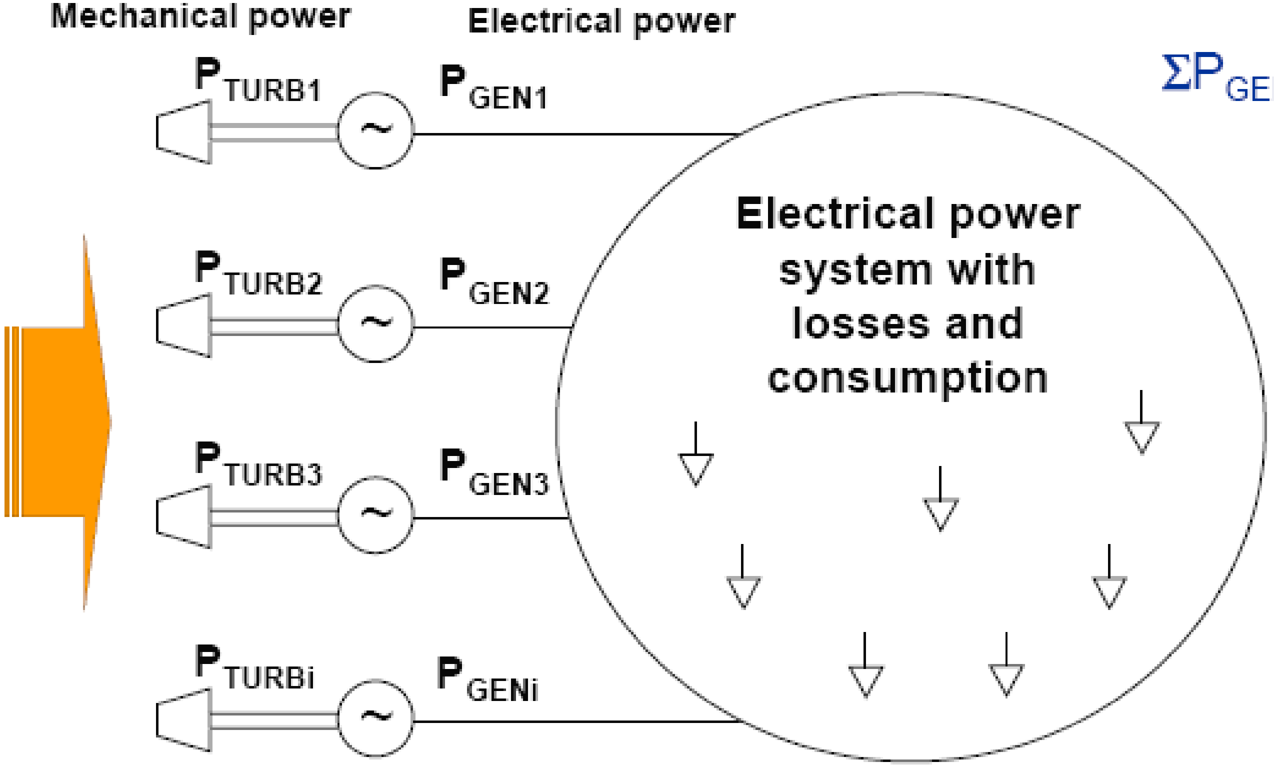
Course map


Office
Applications
Grid
Operation
Internet
IP
Network
Local Operation
Ethernet
Intro-substation
communciation
Physical
process
Interfacing

Outline

1. Power System Topologies
   – Transmission Grids vs Distribution grids
   – Radial grids vs Meshed grids
   – Low Voltage feeders
2. Power System Apparatus & Models
   – Line & Switchyard equipment
   – Compensators
3. Substation Configurations
   – Reliable switching configurations

Frequency Control



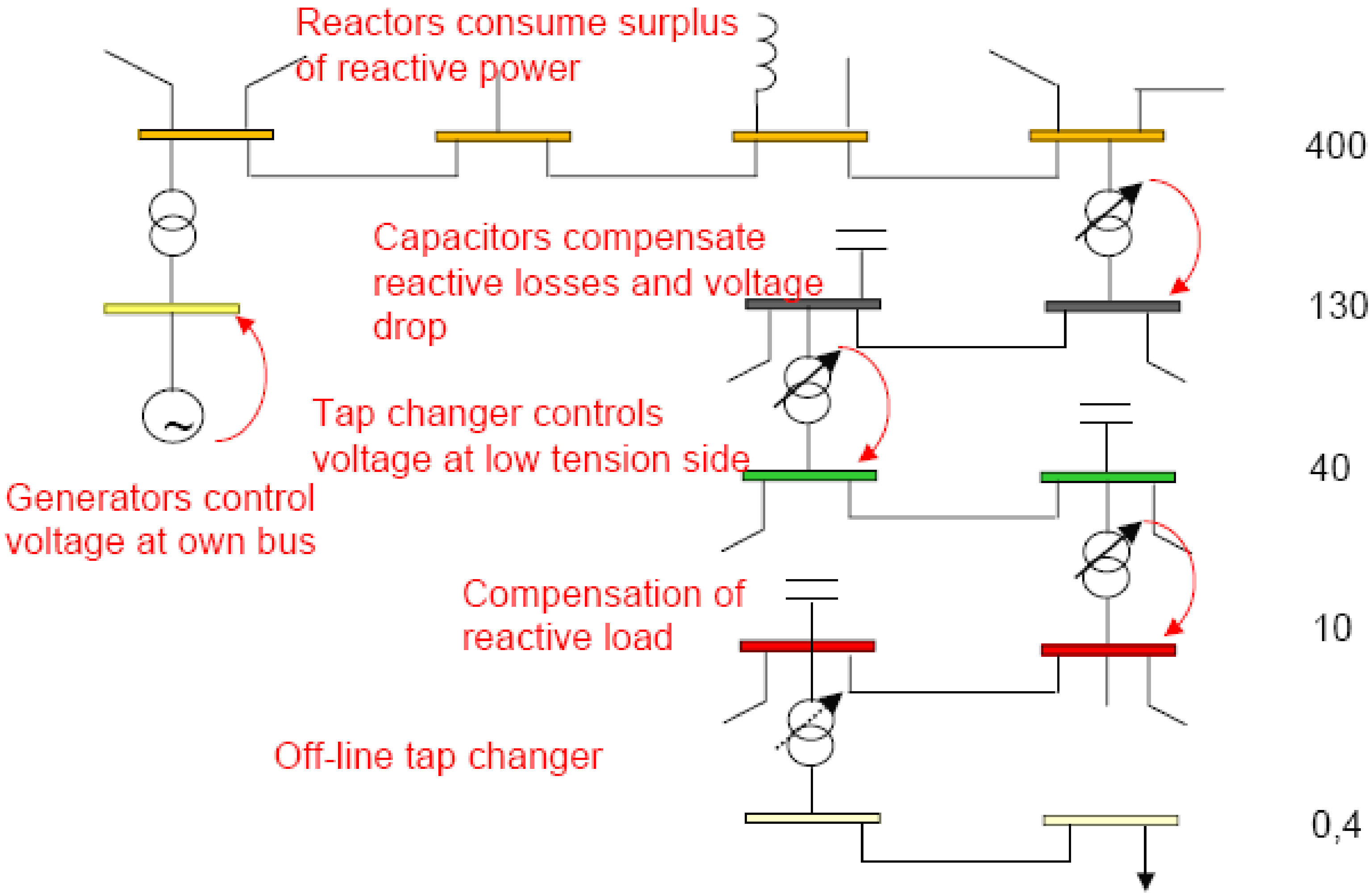
Always balance in the electrical system:

$\Sigma P_{GEN} = \Sigma P_{LOAD} + \Sigma P_{LOSS}$

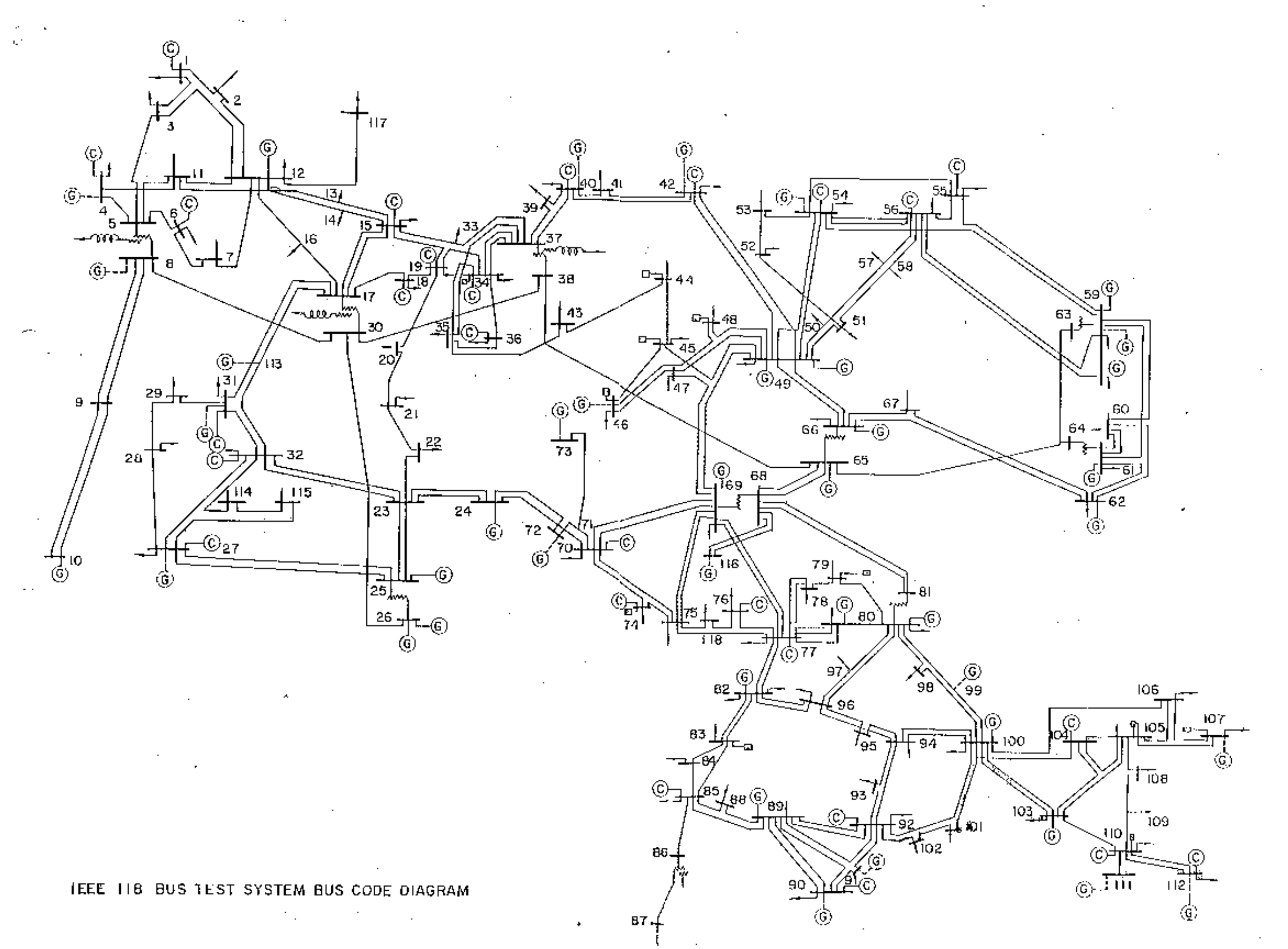
Tools for Voltage Control

- Main goal is to keep an even voltage profile.
- Generators with automatic voltage regulator (AVR) control voltage at generator bus
- Transformers with tapchanger. Step-wise control of voltage at one side
- Shunt reactors consume reactive power, which decreases the voltage
- Shunt capacitors produce reactive power, which increases the voltage
- Shunt compensation can be controlled
  - manually (from the control room)
  - with voltage automatic control
  - with time control
  - by a centralised logic

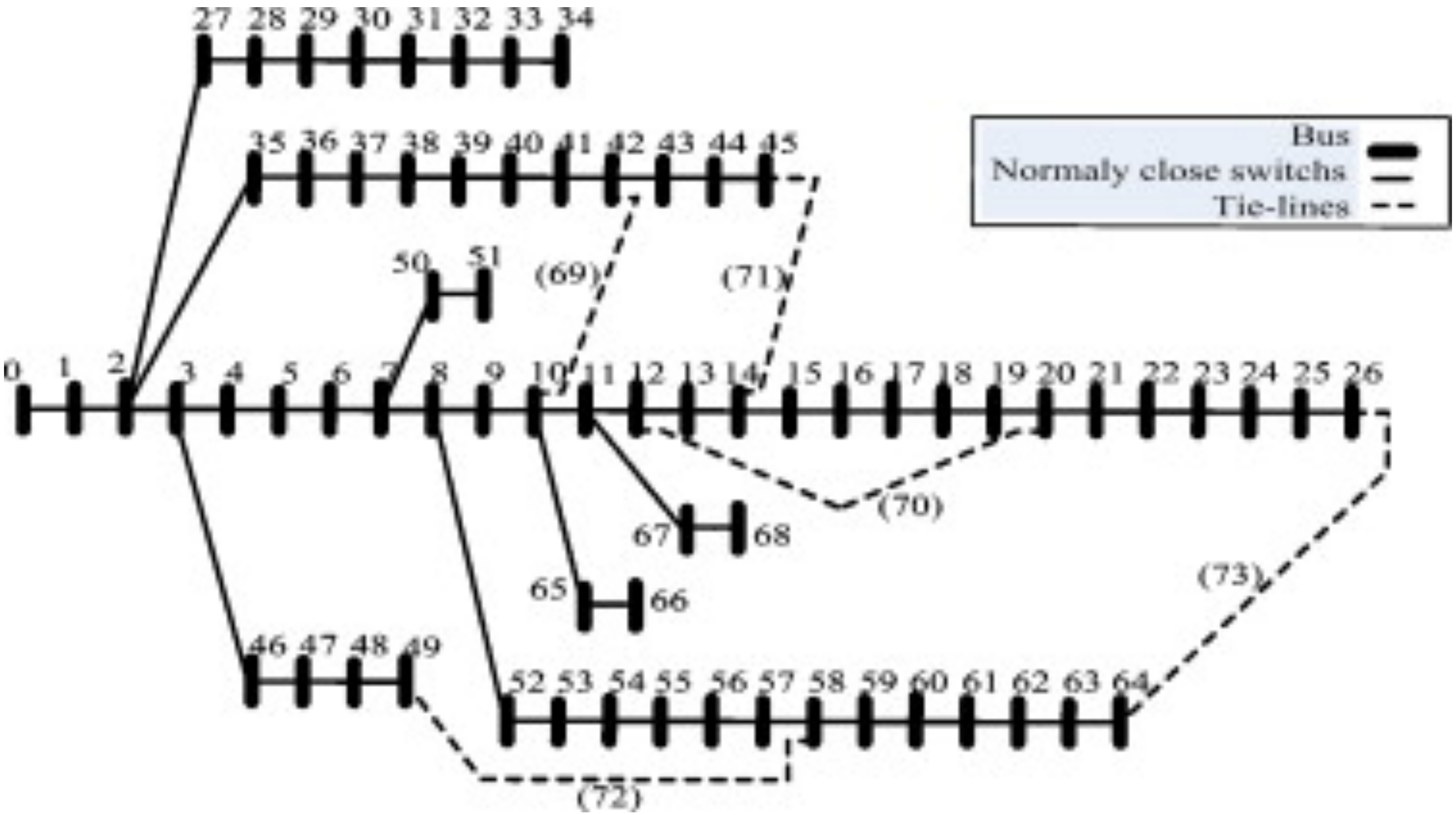
Voltage Control Hierarchy



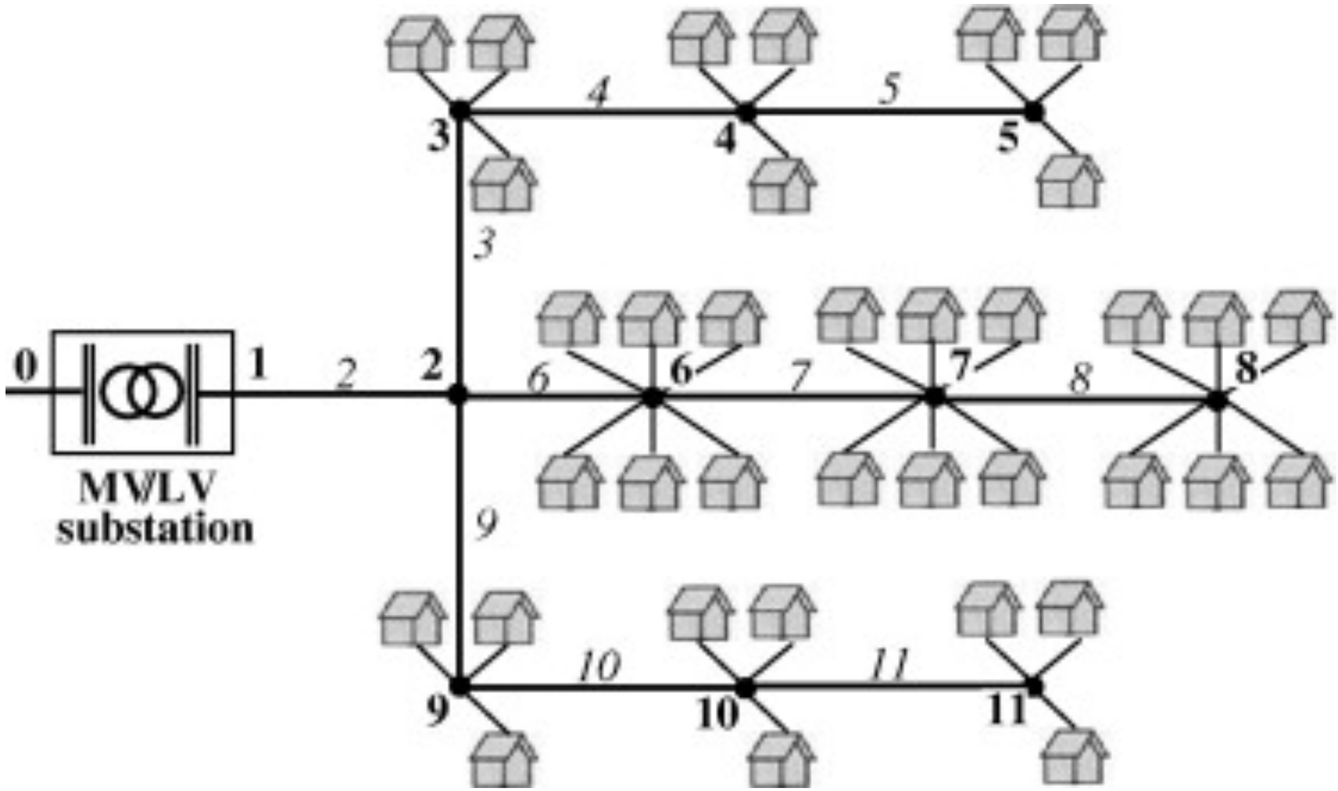
Transmission Grids



Meshed MV Grid



LV Feeders



Distribution Networks

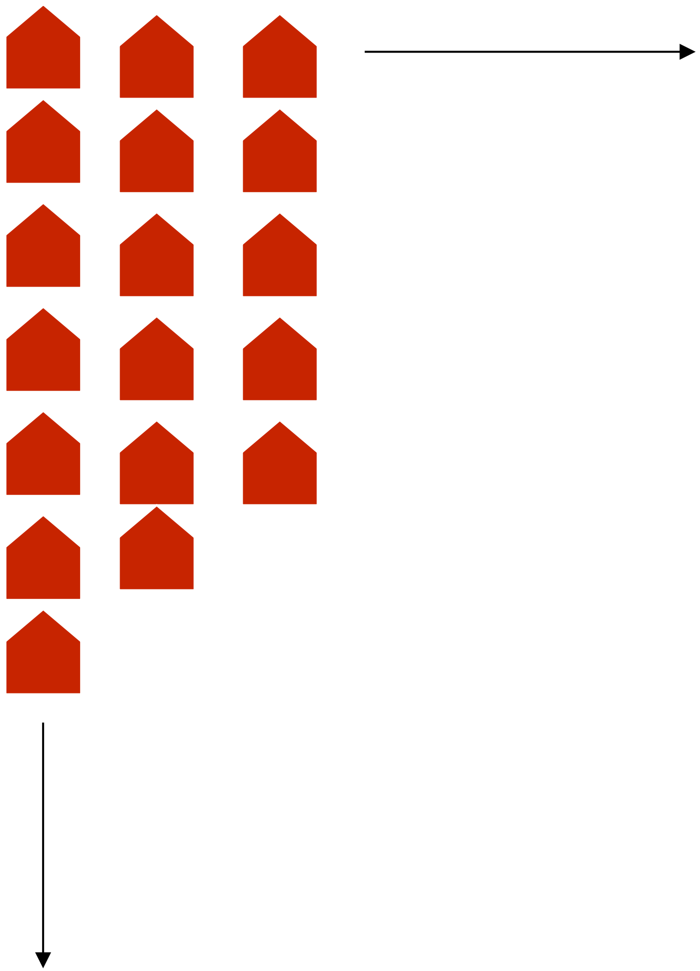
- Design of Distribution Network varies significantly depending on:
  - Type of area(s) served
  - Voltage levels
  - Type of overlying network
  - Overhead or underground networks
  - Sizing of Distribution substations
  - Required performance of the network
  - Projected load growth
  - Losses
  - Historical/Cultural factors
  - Cost of installation
  - Cost of ownership

Selection of Voltage level

- What are the determining factors?
  - High voltage
    - Low losses
  - Low voltage
    - Less insulation problems, smaller equipment
- Other factors
  - Already installed equipment
  - Availability of spare parts, price,…
  - Overlying network
  - Distances

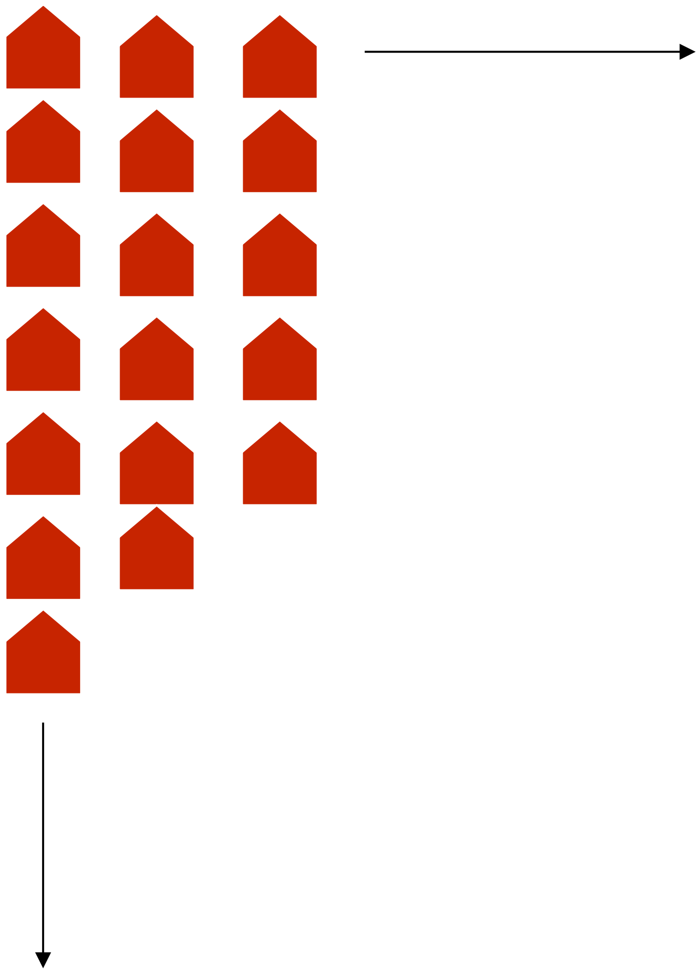
0,4
1
3,3
6
10
11
20
25
33

Simple design example



Assume 1600 loads
Located 40*40
Each at S = 5 kVA
Equidistant 25 m

Small Distribution transformer



Assume 25 kVA trafo

5 Loads per transformer

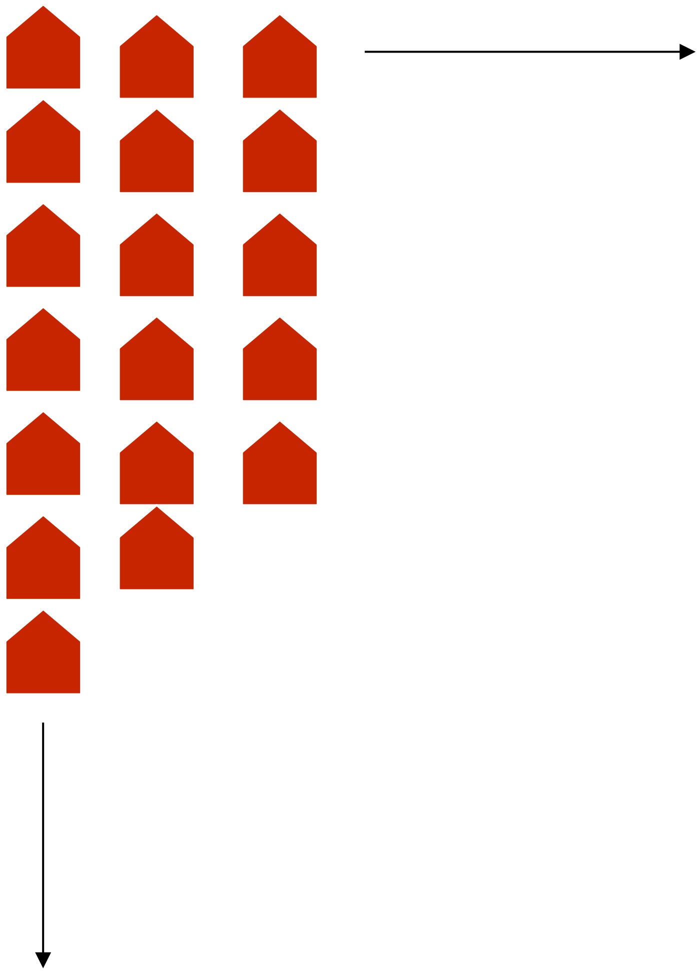
320 substations

MV substation in center

2 MVA per feeder

80 substations per feeder

Larger Distribution transformer



Assume 125 kVA trafo

25 Loads per transformer

64 substations

MV substation in center

2 MVA per feeder

16 substations per feeder

Etc..

Adding some economic data

Trafo Rating (kvA)	Number	LV length (km)	MV length (km)	OH $/kVA	Cable $/kVA
25	320	32	9,7	128	670
125	64	38,4	8,9	80	338
250	32	39,2	5,1	**68**	275
500	16	39,6	4,5	77	**248**
1000	8	52	3,5	79	294

Assuming some typical budget figures for
- MV & LV cables
- MV & LV OH lines
- Distribution Transformers

Example courtesy of "Control & Automation of Electric Power Distribution Networks" J Northcote-Green.

Additional concerns

- In addition to cost of building and operating the distribution network, the reliability of the network is essential.

- A number of indices are used to determine the quality of service delivered.

- Additionally, regulators specify levels of quality and or cost caps that the distribution company must follow or be fined.

System Performance Indices

- SAIDI
  - System Average Interruption Duration Index

$$\frac{\textit{Sum of all customer interruption durations}}{\textit{Total number of customers}}$$

- SAIFI
  - System Average Frequency of Interruption Index

$$\frac{\textit{Total number of customer interruptions}}{\textit{Total number of customers}}$$

Customer Performance Indices

- CAIDI
  - Customer Average Duration of Interruption Index

$$\frac{\text{Sum of all customer interruption durations}}{\text{Total number of interruptions}}$$

- CAIFI
  - Customer Average Interruption Frequency Index

$$\frac{\text{Total number of interruptions}}{\text{Number of customers that have experienced an interruption}}$$

- CTAIDI
  - Customer Total Average Interruption Duration Index

$$\frac{\text{Sum of all customer interruption durations}}{\text{Number of customer that have experienced an interruption}}$$

Some typical data (US)

Overall Averages of Sustained Reliability Indices from January 1st – December 31st 2002				
SAIFI (Interruptions Per year)	SAIDI (Minutes per year)	CAIDI (Minutes)	CTAIDI (Minutes)	CAIFI (# of Sustained Interruptions)
3.25	64.58	66.32	23.15	2.10

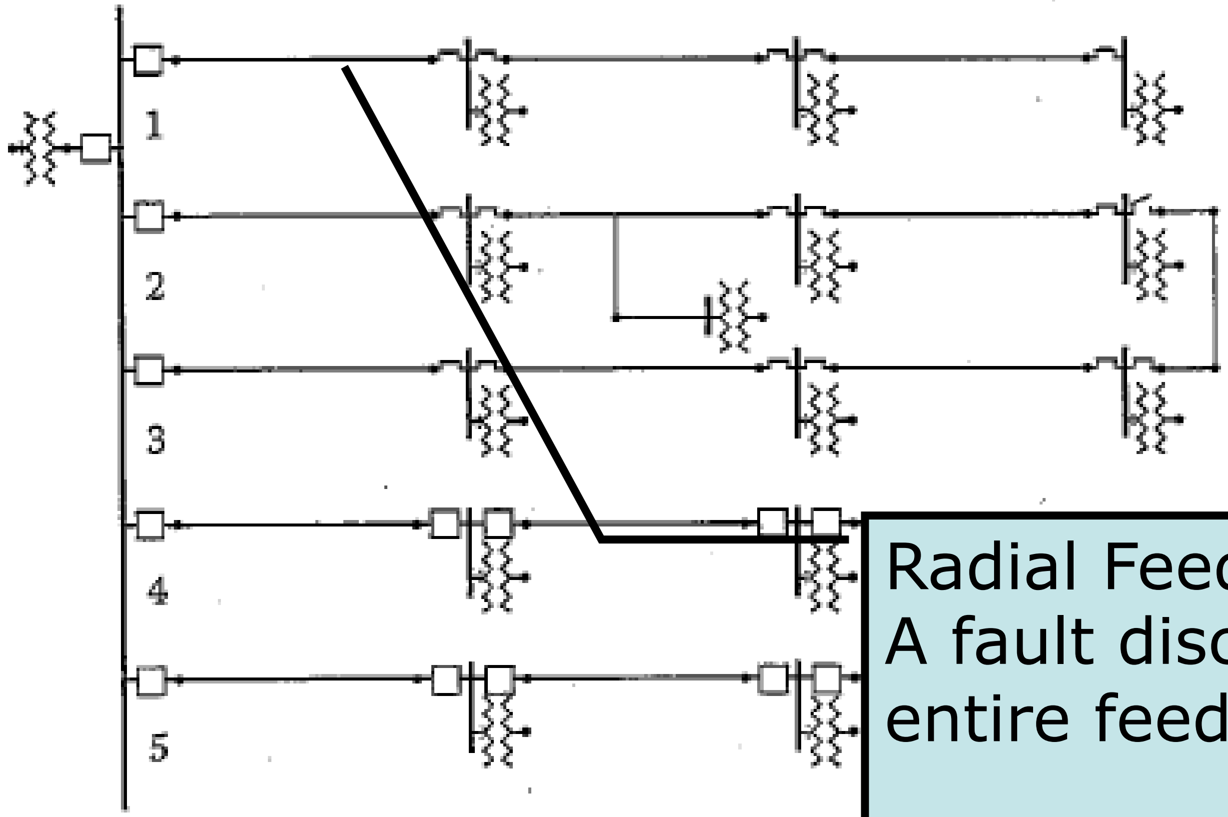
Overall Averages of Sustained Reliability Indices from January 1st – December 31st 2000				
SAIFI (Interruptions Per year)	SAIDI (Minutes per year)	CAIDI (Minutes)	CTAIDI (Minutes)	CAIFI (# of Sustained Interruptions)
4.68	55.88	91.03	17.81	10.67

Source: APPA 2003: Distribution System Reliability & Operations Survey
http://www.appanet.org/files/PDFs/Strange2004.pdf

Main challenge for DSOs

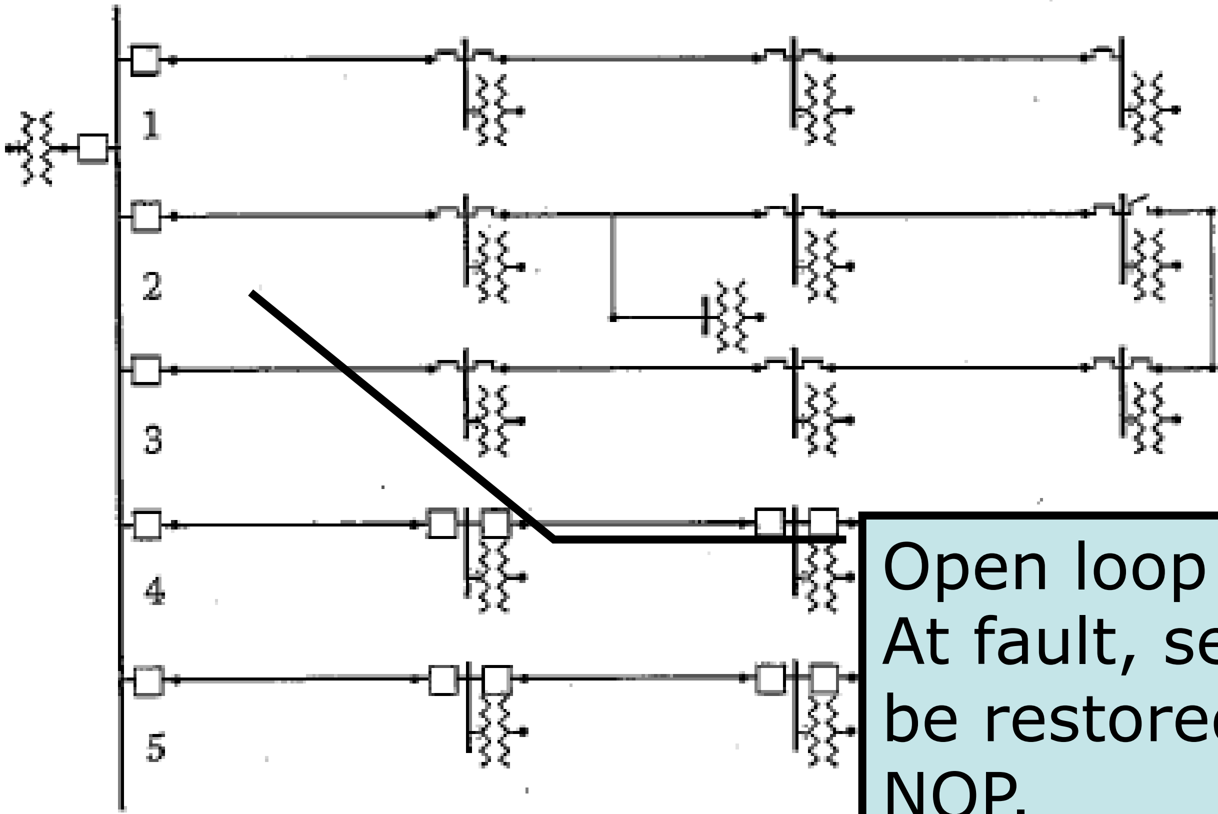
- Designing and operating a distribution network at low cost while maintaining high level of reliability

Underground distribution net



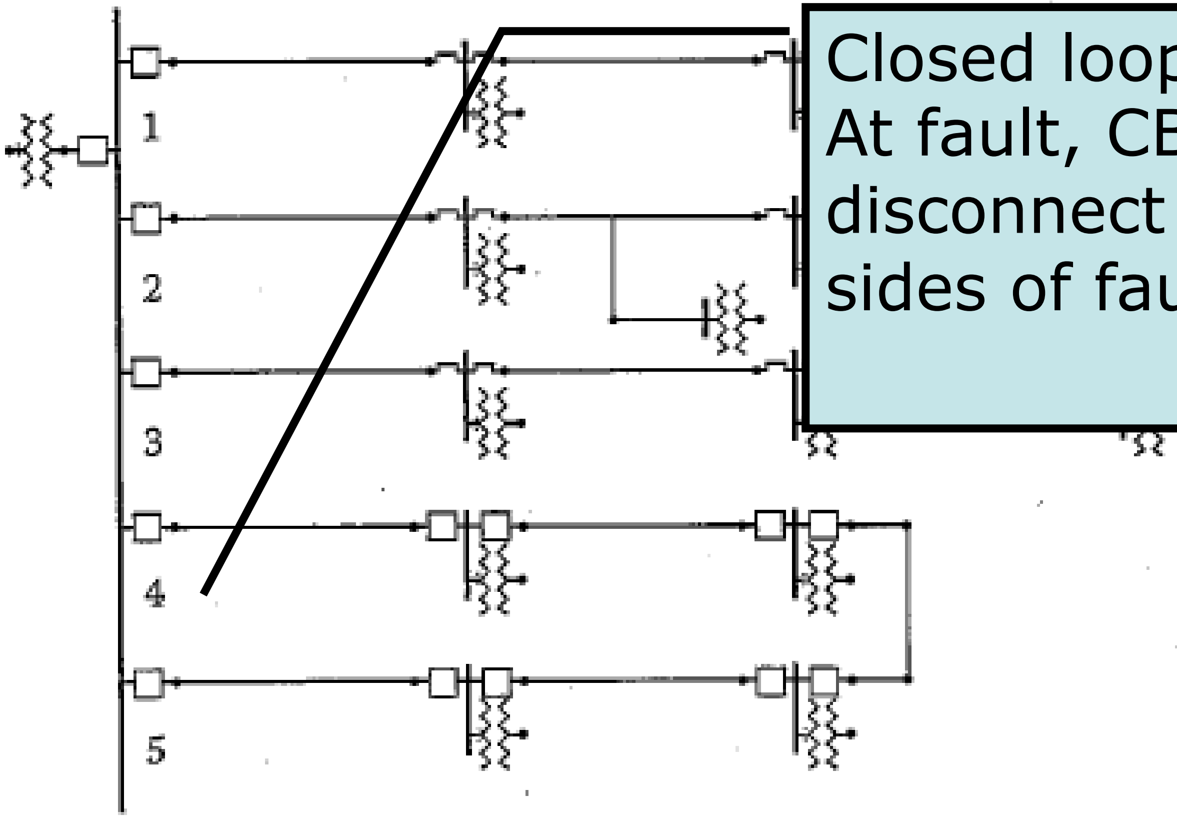
Radial Feeder
A fault disconnects entire feeder at CB

Underground distribution net



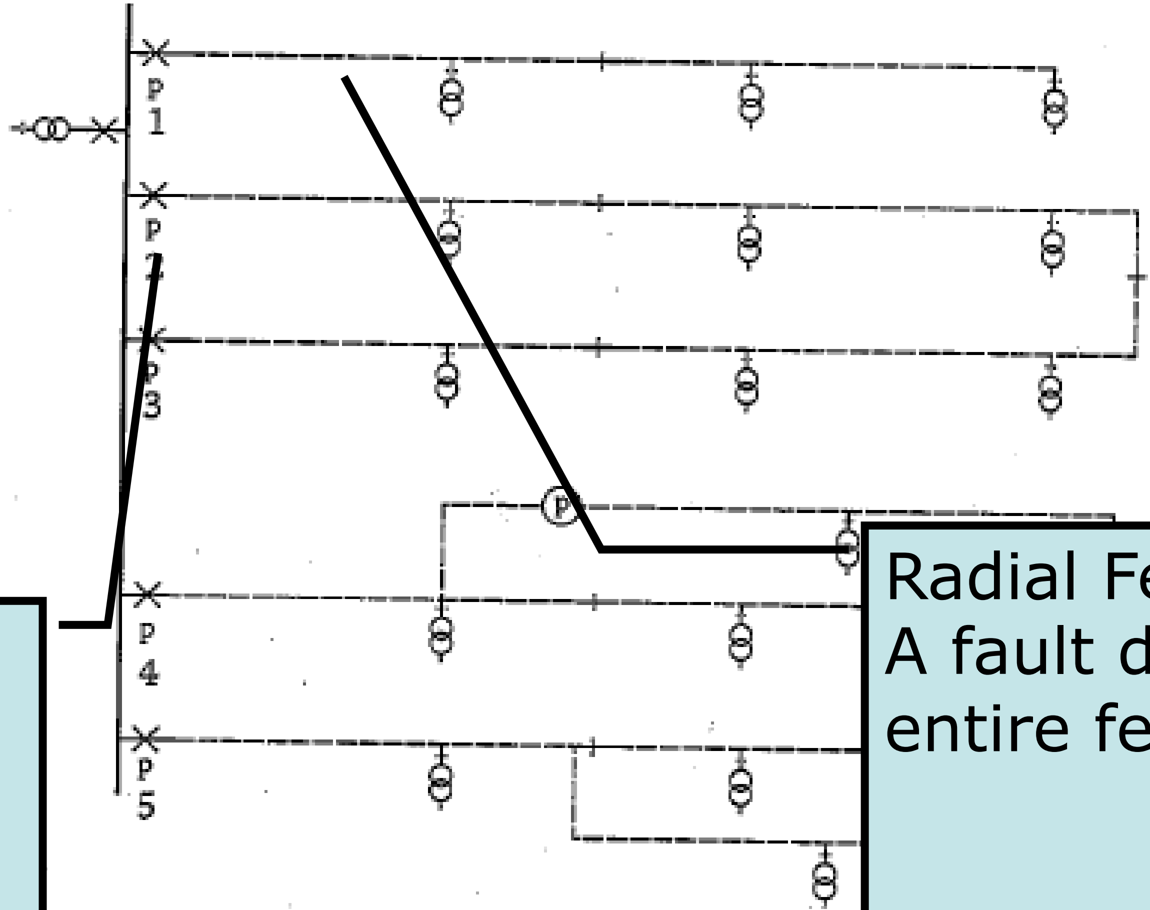
Open loop feeders
At fault, service can be restored by closing NOP.
(Normally open point)

Underground distribution net



Closed loop feeders
At fault, CBs disconnect at both sides of fault.

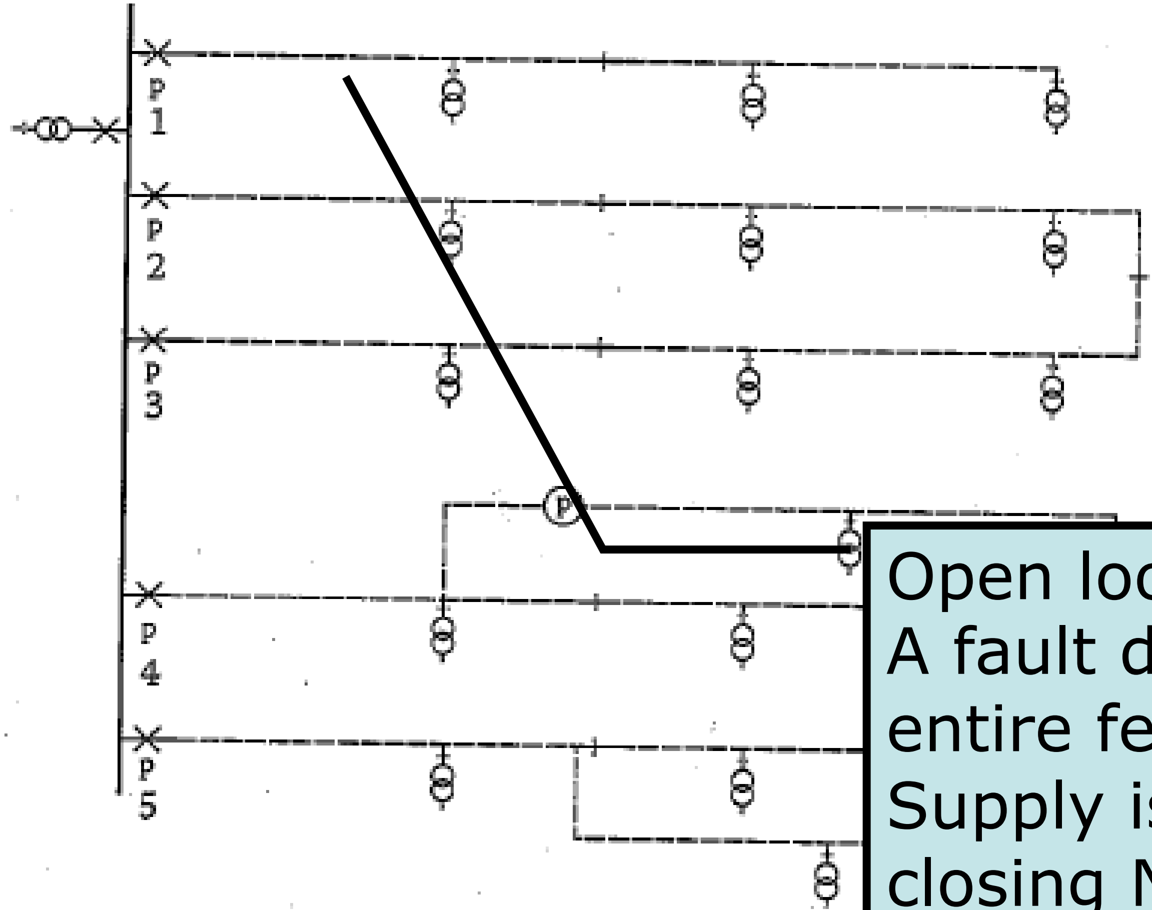
Typical Overhead network



CBs with Auto reclosers

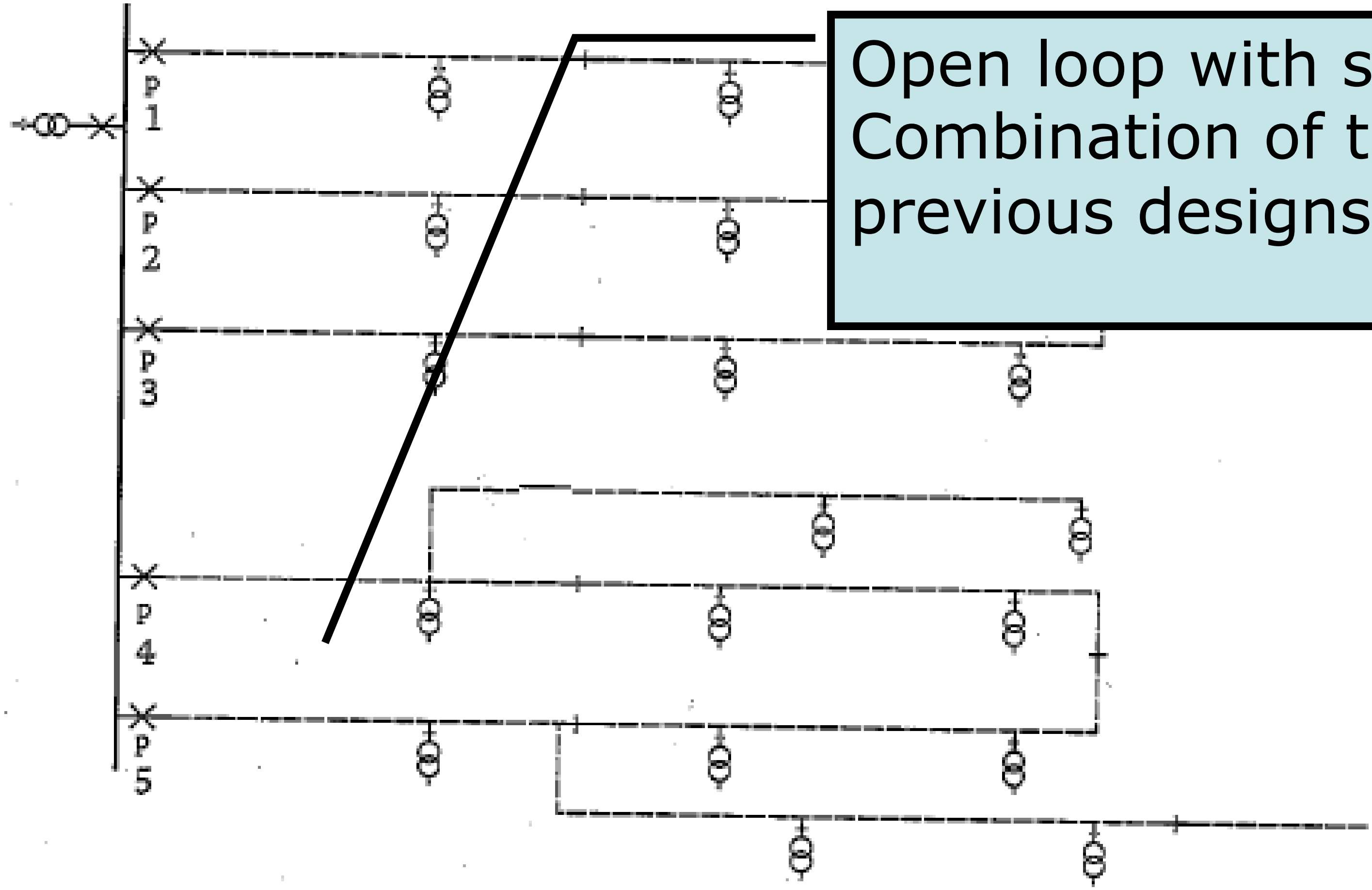
Radial Feeder
A fault disconnects entire feeder at CB

Typical Overhead network



Open loop Feeder
A fault disconnects entire feeder at CB
Supply is restored by closing NOP

Typical Overhead network



Open loop with spurs
Combination of the previous designs

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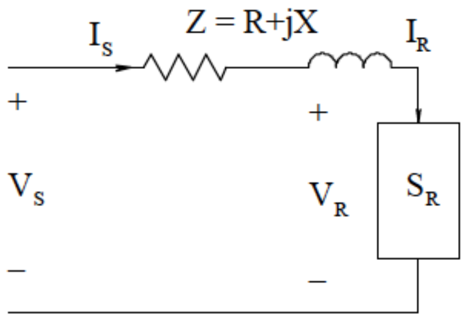
AC Power line

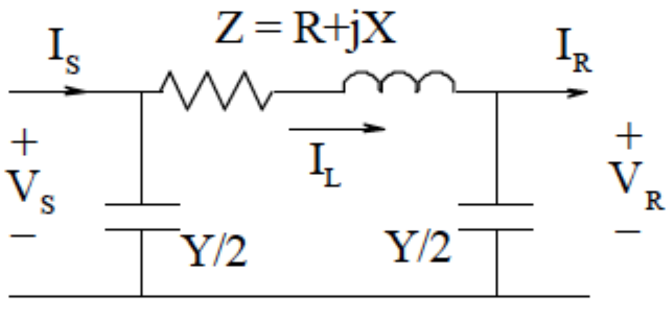
- Three phase AC
- Transfers energy with low losses
- Voltage levels from 0,4kV to 400 kV(+)

PI model of Lines

- Short line models
- Medium line models
- Long line models

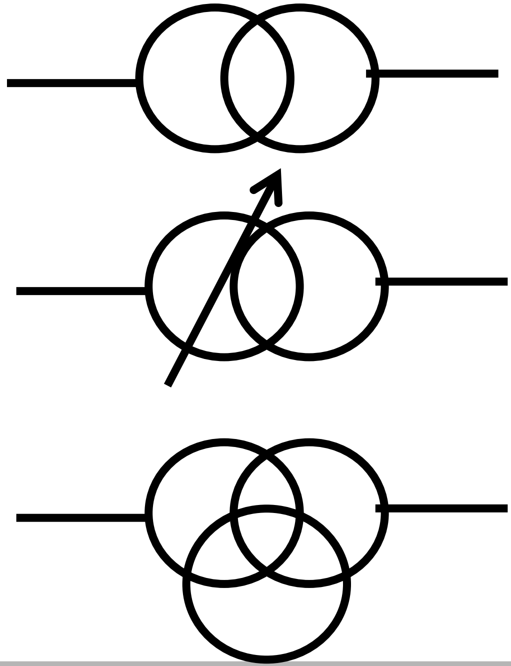
- Line parameters (Y,R,X) vary with line type



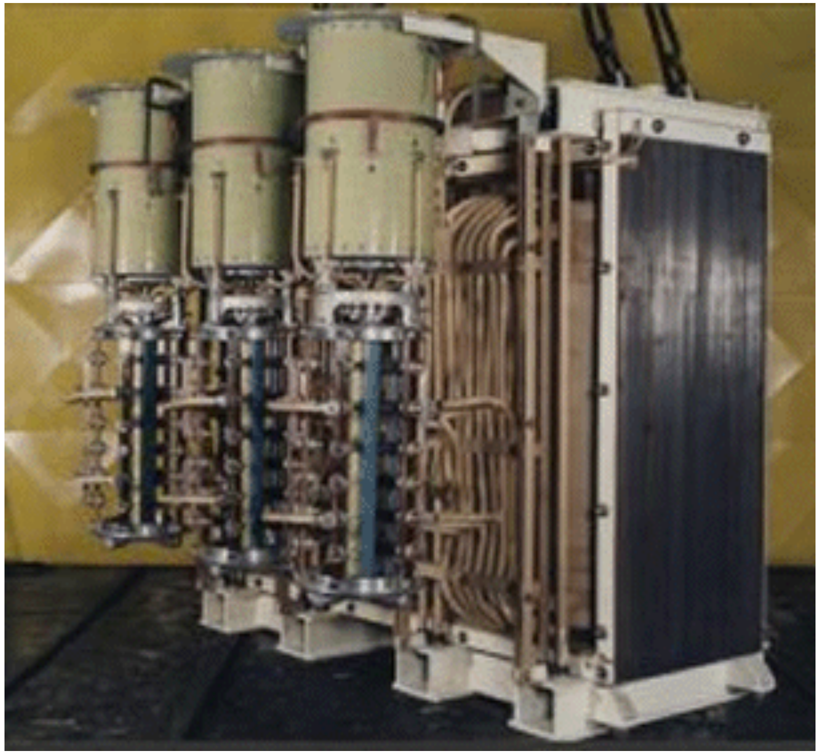


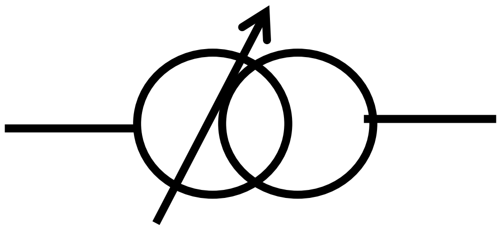
Power Transformer

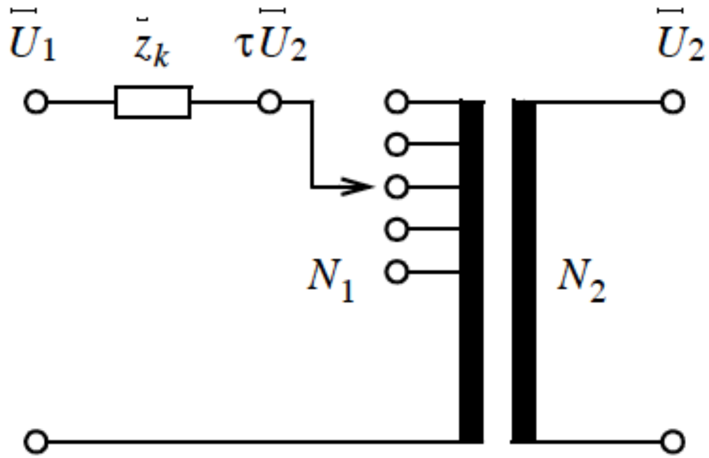
- Transfers energy between different voltage level
- Higher voltages are single pole
- Can shift phase angles



Tap changer



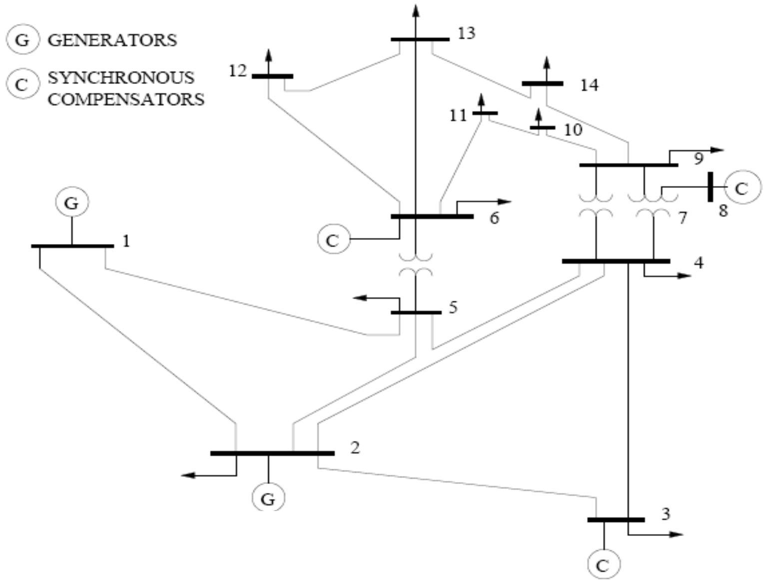




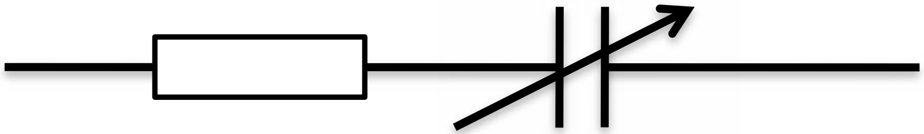
Power System models

$$0 = -P_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik})$$

$$0 = -Q_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik})$$

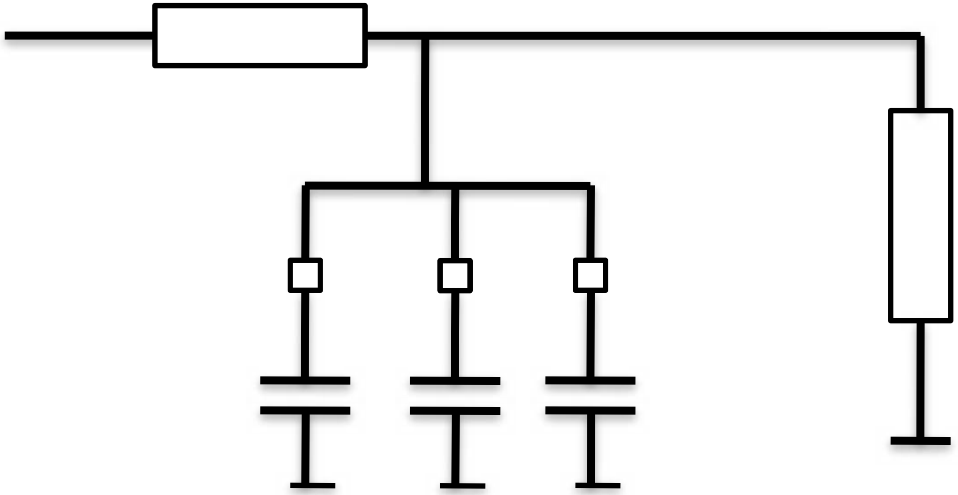


Series capacitor



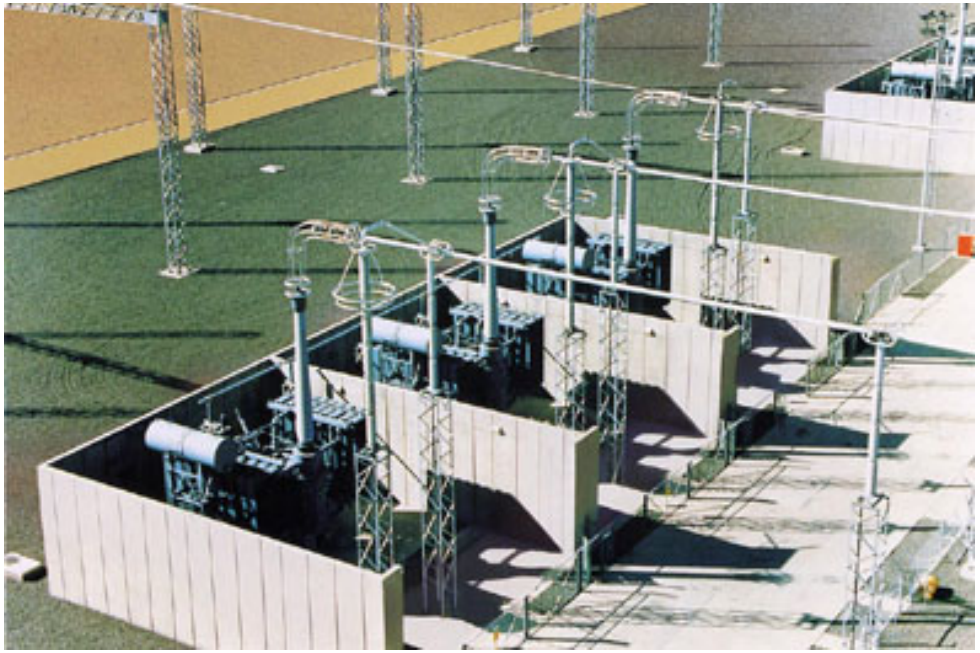
- Compensates for inductance in long power lines
- Connected manually/mechanically

Shunt capacitors



- Compensates for inductive loads by drawing leading current

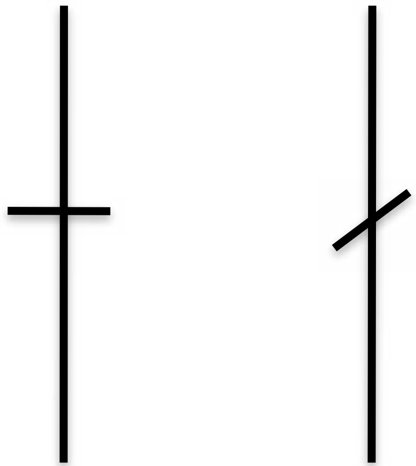
Shunt Reactance



- Consumes reactive power
- Compensates for shunt capacitances in long power lines

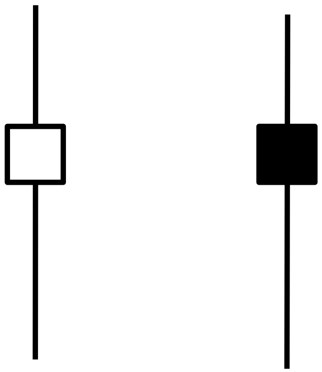
Disconnectors

- Disconnects equipment
- Cannot break load currents

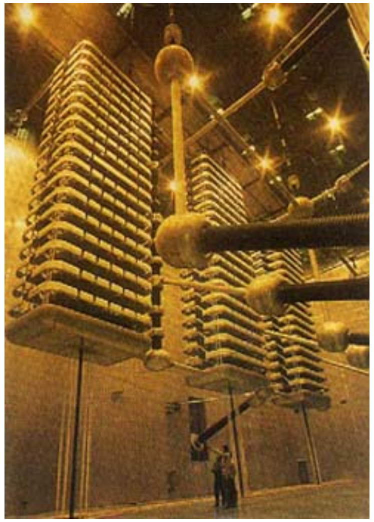


Circuit Breakers

- Basic types divided according to how the arc is extinguished
  - Vaccum insulated
  - Gas insulated (SF6)
  - Oil insulated
  - Air insulated



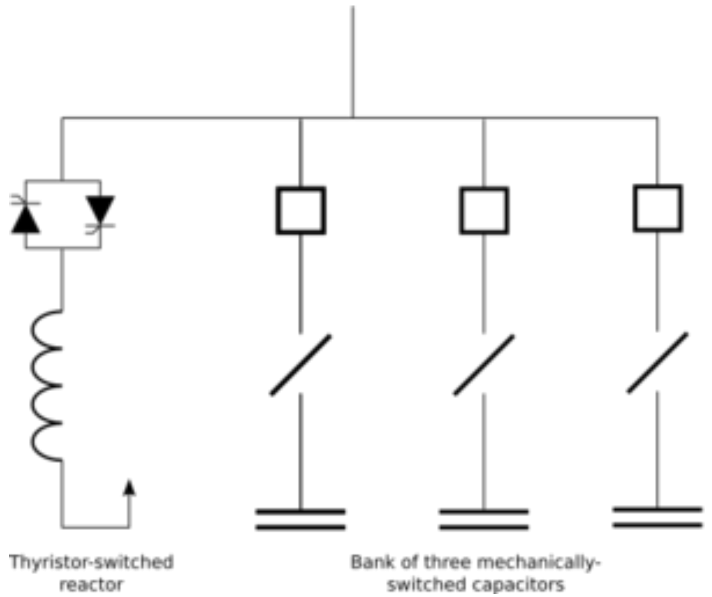
HVDC link



- Direct Current
- Rectifier stations convert to/from AC
- Controllable energy transfer with low losses
- No reactive components

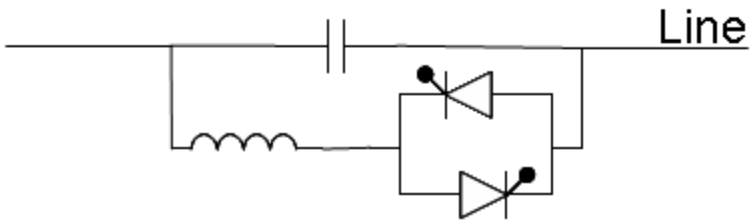
SVC

- Shunt capacitor with greater controlability
- Capacitor banks in parallell with tyristor controlled inductance
- Part of the FACTS concept



TCSC – Thyristor controlled series capacitor

- Series capacitor with greater controllability
- Series capacitor in parallel with inductance
- Part of the FACTS concept



TCSC / TSSC

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   – Generating equipment
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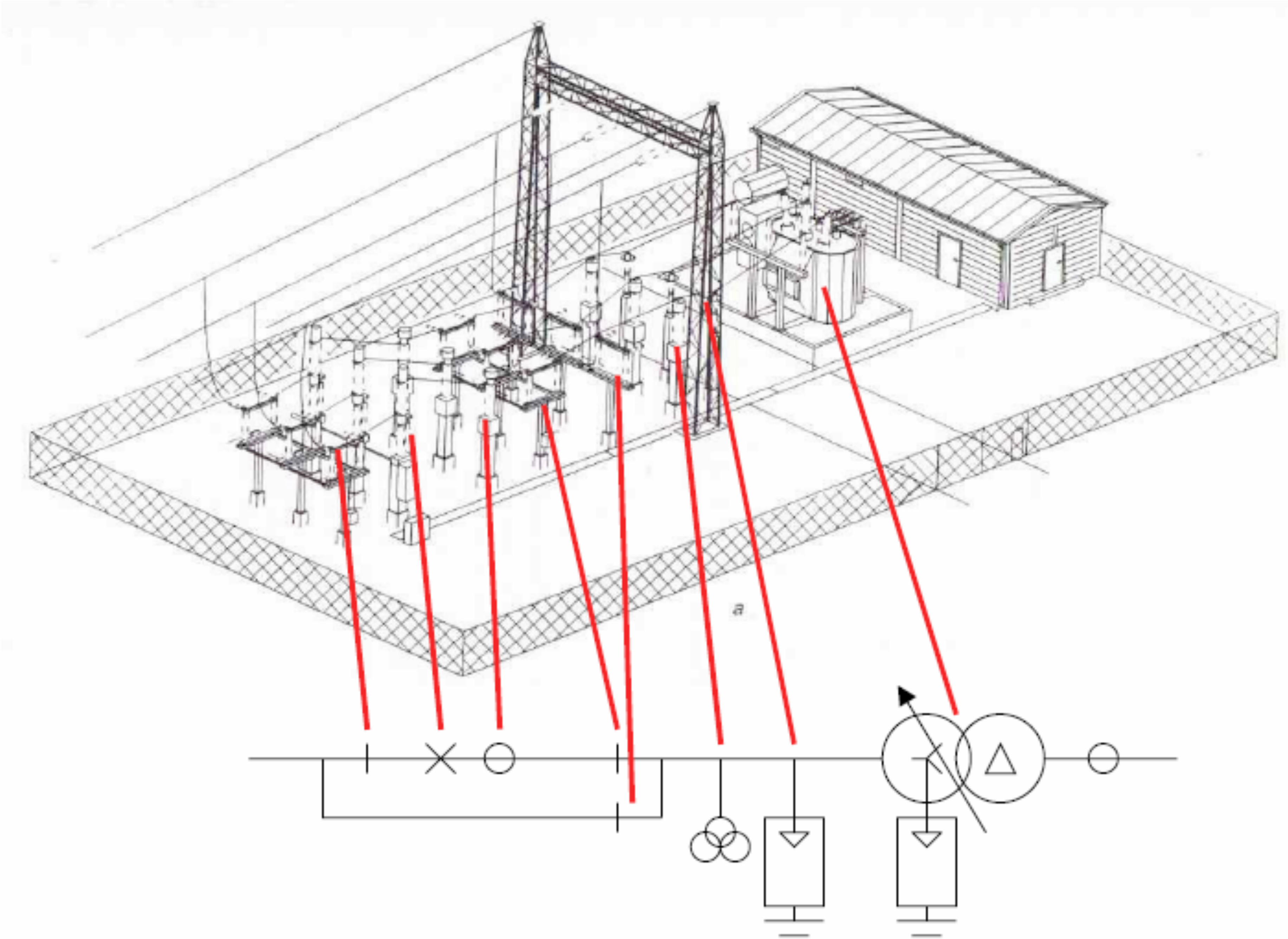
Transmission Substation

Open air, vaccum insultated

- Gas Insulated

Distribution Substation

- 10 - 25 kV range
- Equipment housed in compartments
- Separate compartments for
  - –Disconnector
  - –Breaker
  - –Feeder
  - –Measurement

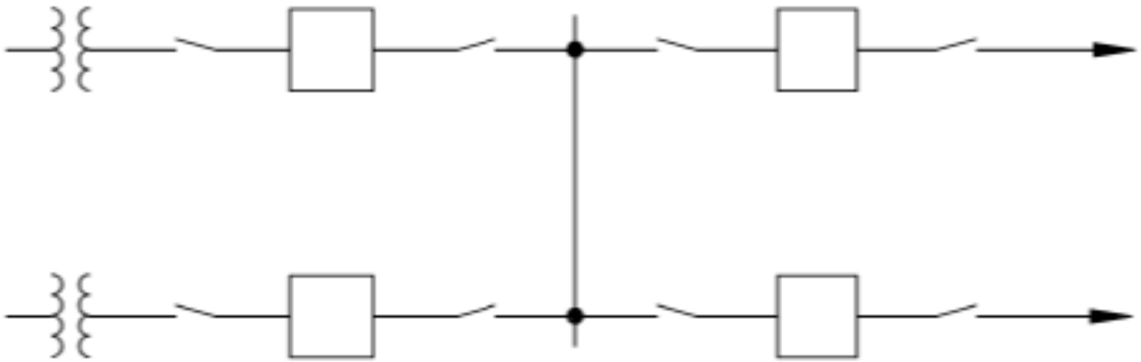


Source: Lakervi & Holmes

Evaluation Criteria

- Reliability
- Operation Flexibility
- Maintenance Flexibility
- Costs

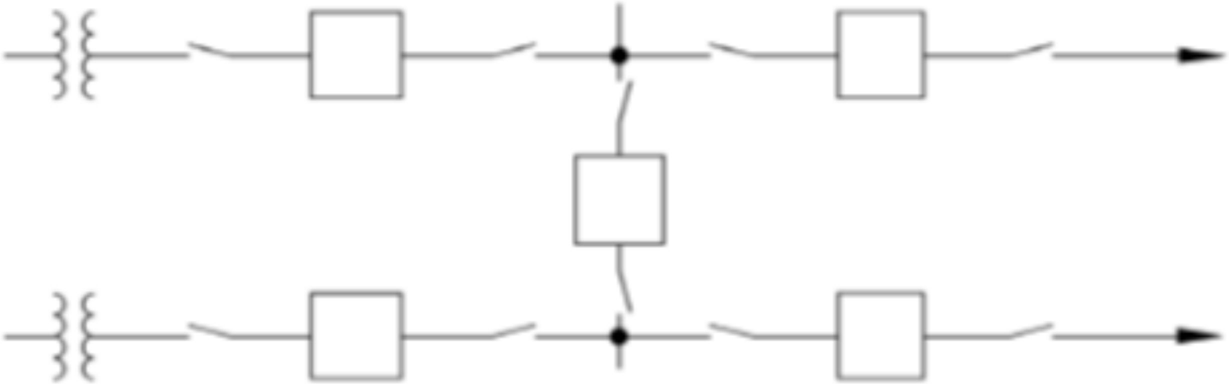
Single Bus Configuration



Advantages:
• Lowest cost
• Small land area
• Easily expandable
• Simple in concept and operation

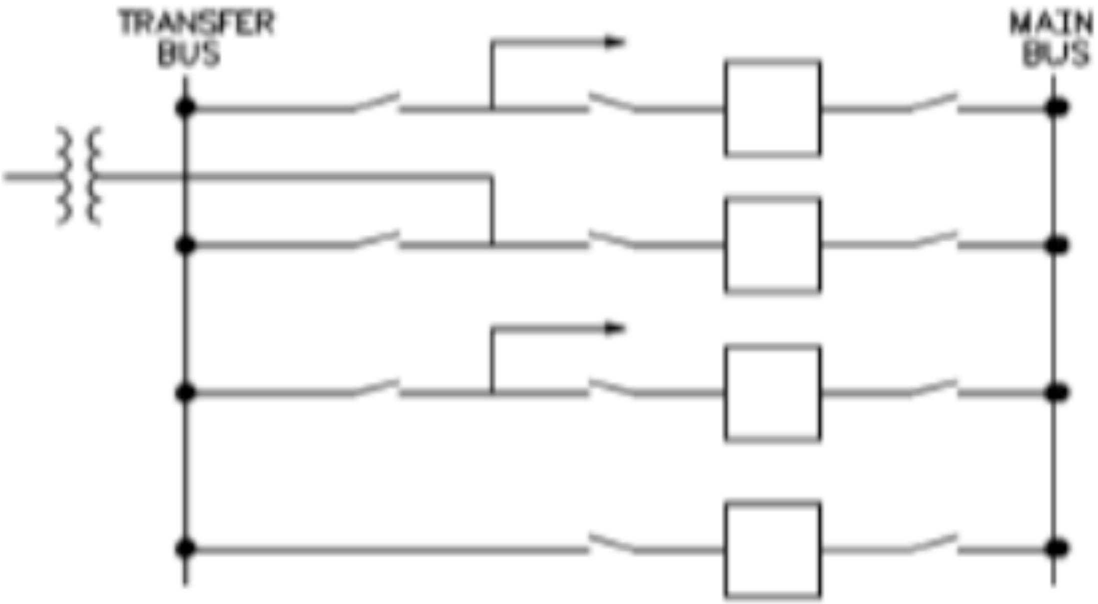
Disadvantages:
• Single bus arrangement has the lowest reliability
• Failure of a bus fault causes loss of entire substation
• Maintenance switching can complicate

Sectionalised Bus



Advantages:
• Flexible operation
• Isolation of bus sections for maintenance
• Loss of only part of the substation for a breaker failure or bus fault
Disadvantages:
• Additional circuit breakers needed for sectionalizing, thus higher cost
• Sectionalizing may cause interruption of non-faulted circuits

Main & Transfer Bus



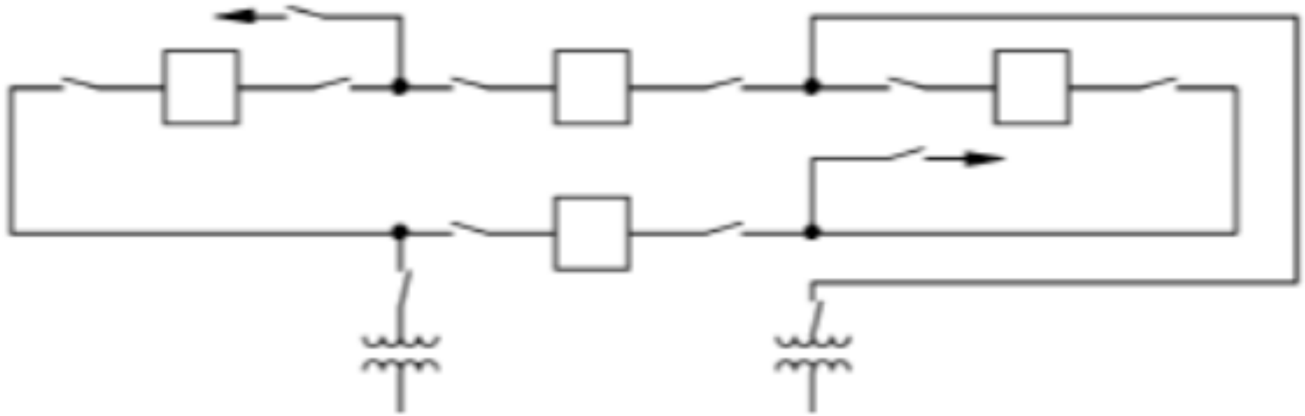
Advantages:

- Maintain service and protection during circuit breaker maintenance
- Reasonable in cost
- Fairly small land area
- Easily expandable

Disadvantages:

- Additional circuit breaker needed for bus tie
- Protection and relaying may become complicated
- Bus fault causes loss of the entire substation

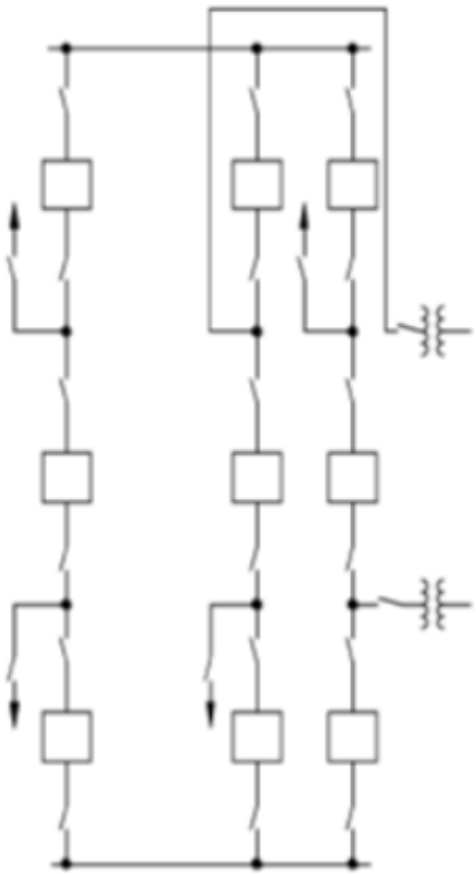
Ring bus configuration



- Advantages:
  - Flexible operation
  - High reliability
  - Double feed to each circuit
  - No main buses
  - Expandable to breaker-and-a-half configuration
  - Isolation of bus sections and circuit breakers for maintenance without circuit disruption

- Ring Bus Disadvantages:
  - During fault, splitting of the ring may leave undesirable circuit combinations
  - Each circuit has to have its own potential source for relaying
  - Usually limited to 4 circuit positions, although larger sizes up to 10 are in service. 6 is usually the maximum terminals for a ring bus

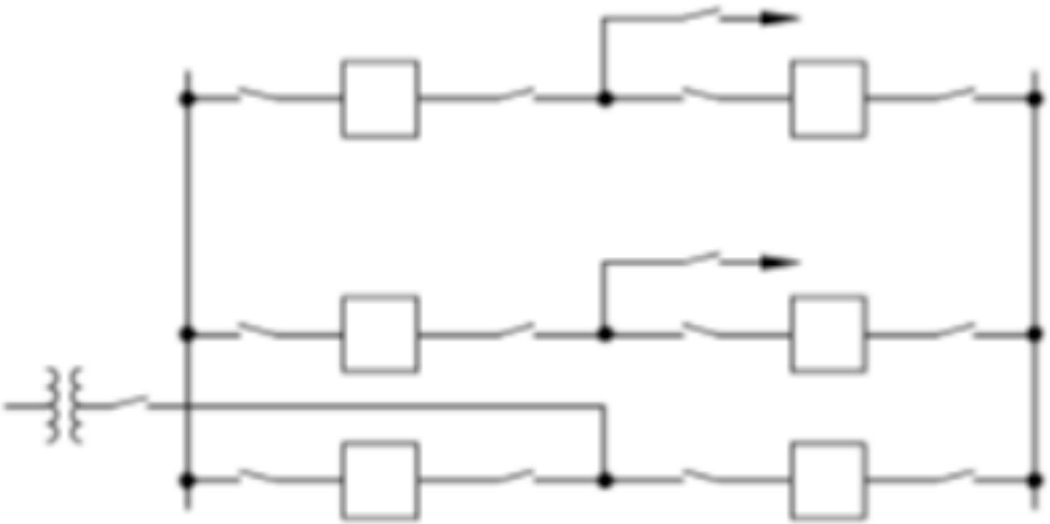
Breaker & a half configuration



Advantages:
• Flexible operation and high reliability
• Isolation of either bus without service disruption
• Isolation of any breaker for maintenance without service disruption
• Double feed to each circuit
• Bus fault does not interrupt service to any circuits
• All switching is done with circuit breakers

Disadvantages:
• One-and-a-half breakers needed for each circuit
• More complicated relaying as the center breaker has to act on faults for either of the 2 circuits it is associated with
• Each circuit should have its own potential source for relaying

Double breaker



Advantages:

• Flexible operation and very high reliability

• Isolation of either bus, or any breaker without disrupting service

• Double feed to each circuit

• No interruption of service to any circuit from a bus fault

Disadvantages:

• Very high cost – 2 breakers per circuit

Questions or comments?