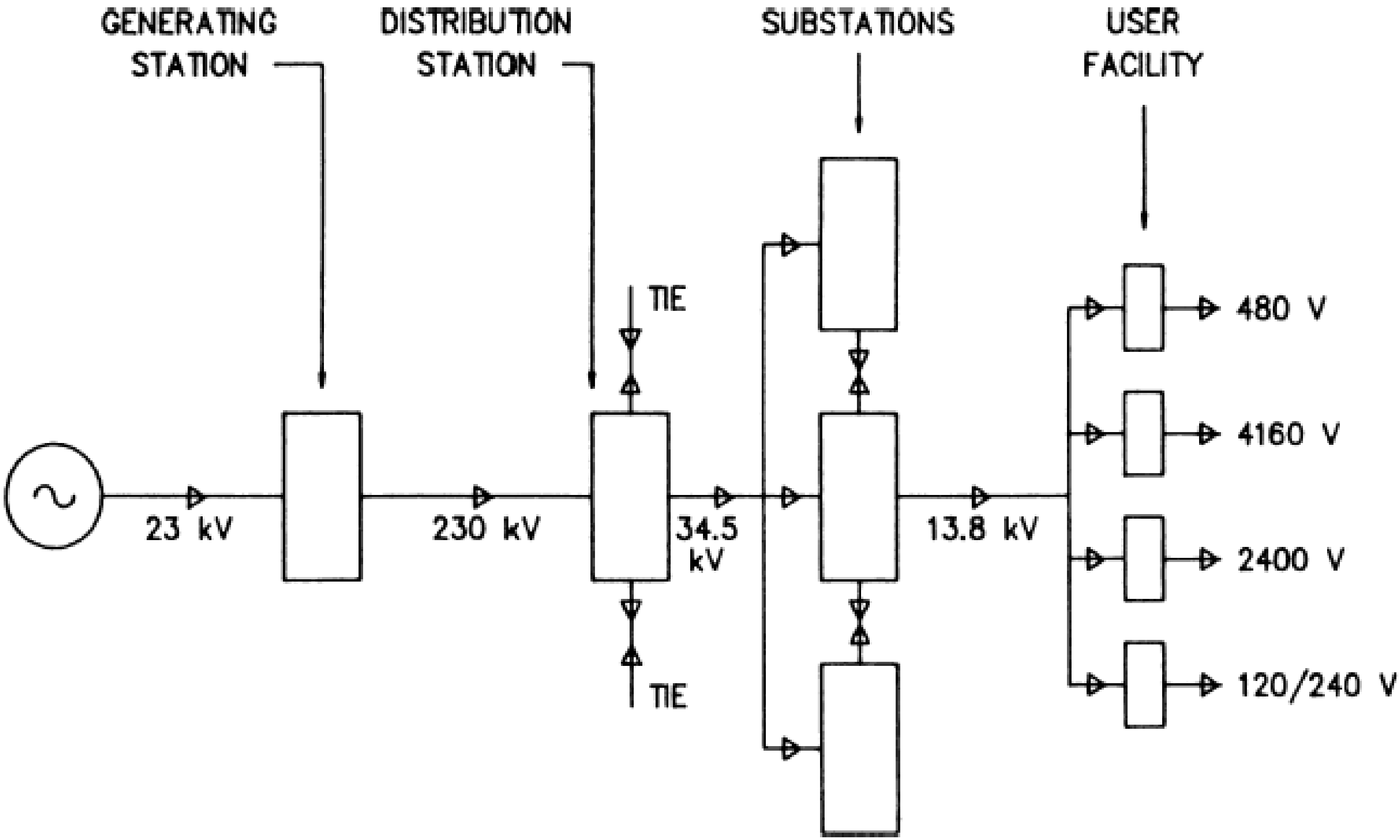
ELG4125

Distribution and Utilization Power System

Largely Based on: Power System Analysis and Design

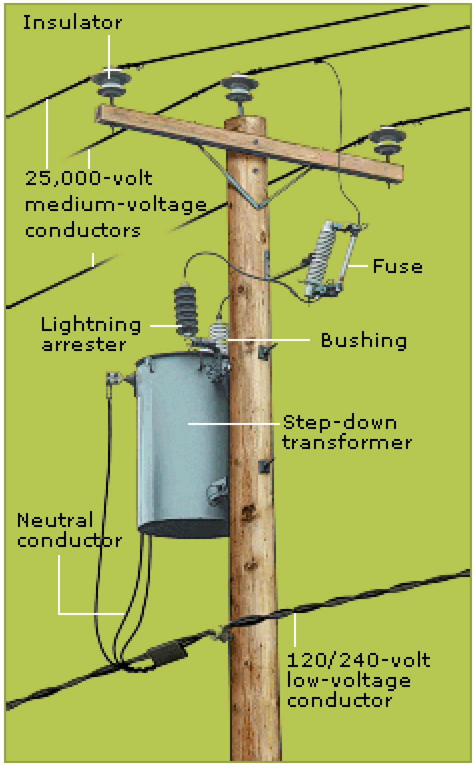
Hydro Quebec Website

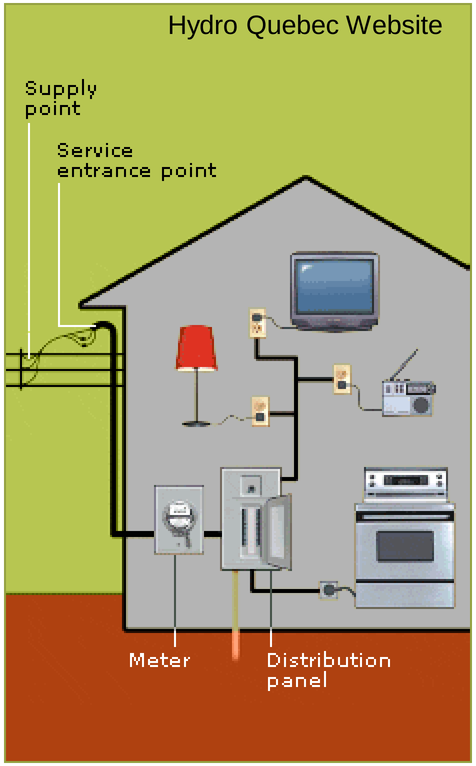
Single Line Diagram of the Entire Power System



High Voltage Network

- High-voltage networks, consist of transmission lines, connects the power plants and high-voltage substations in parallel.
- This network permits load sharing among power plants.
- The typical voltage of the network is between 240 kV and 700 kV.
- The high-voltage substations are located near the load centers.



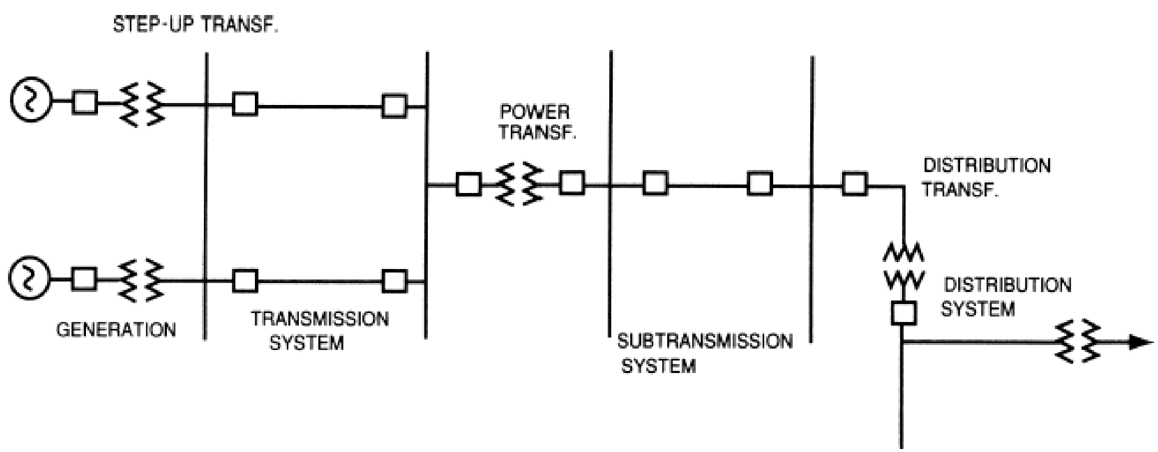


Subtransmission Network

- The subtransmission system connects the high-voltage substations to the distribution substations.
- The typical voltage of the subtransmission system is between 138 and 69 kV.
- In high load density areas, the subtransmission system uses a network configuration that is similar to the high voltage network.
- In medium and low load density areas, the loop or radial connection is used.

Distribution and Utilization Network

- The distribution system has two parts, primary and secondary.
- The primary distribution system consists of overhead lines or underground cables, which are called **feeders**.
- The feeders supply the distribution transformers that step the voltage down to the secondary level.
- The secondary distribution system contains overhead lines or underground cables supplying the consumers directly by single- or three-phase power.



Services, Wires, and Scheme of Connection for Distribution System

Type Of Service:

- General Lighting & Power
- Industrial Power
- Railway
- Streetlight etc

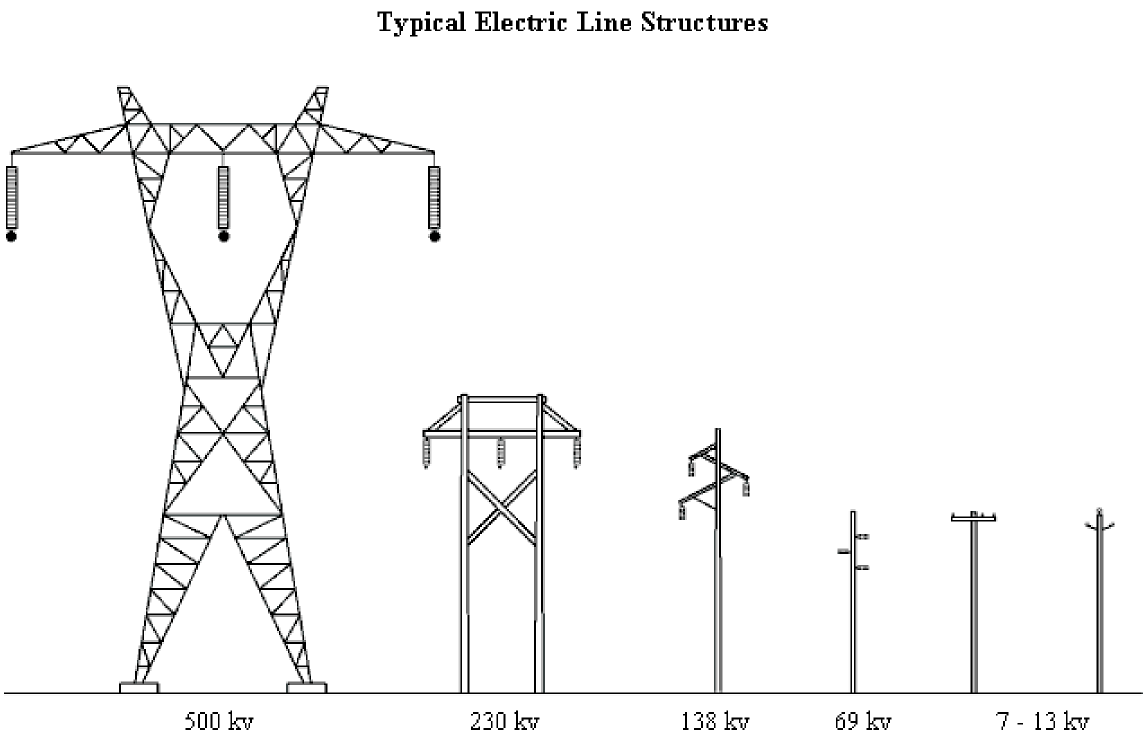
Number Of Wires:

- Two Wire
- Three Wire
- Four Wire

Scheme Of Connection:

- Radial Distribution System
- Ring or Loop Distribution System
- Interconnected Distribution System

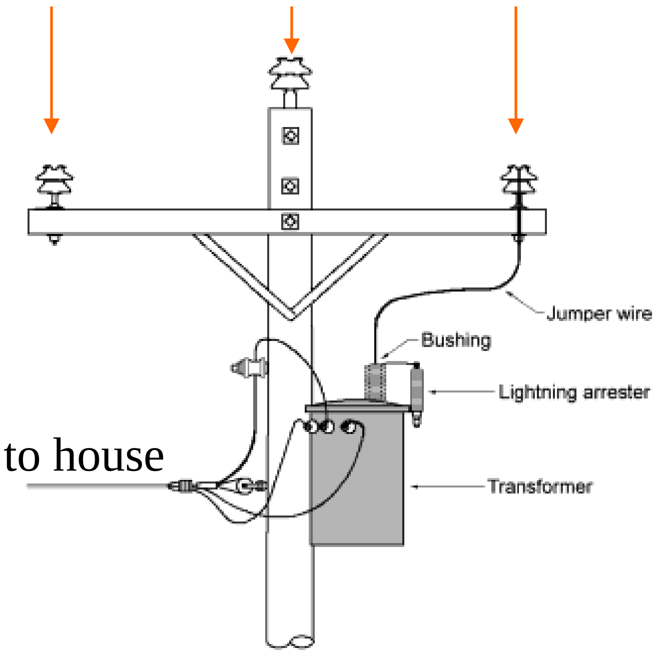
Transmission and Distribution Tower Structure



500,000 230,000 138,000 69,000 7–13,000

long-distance → neighborhood

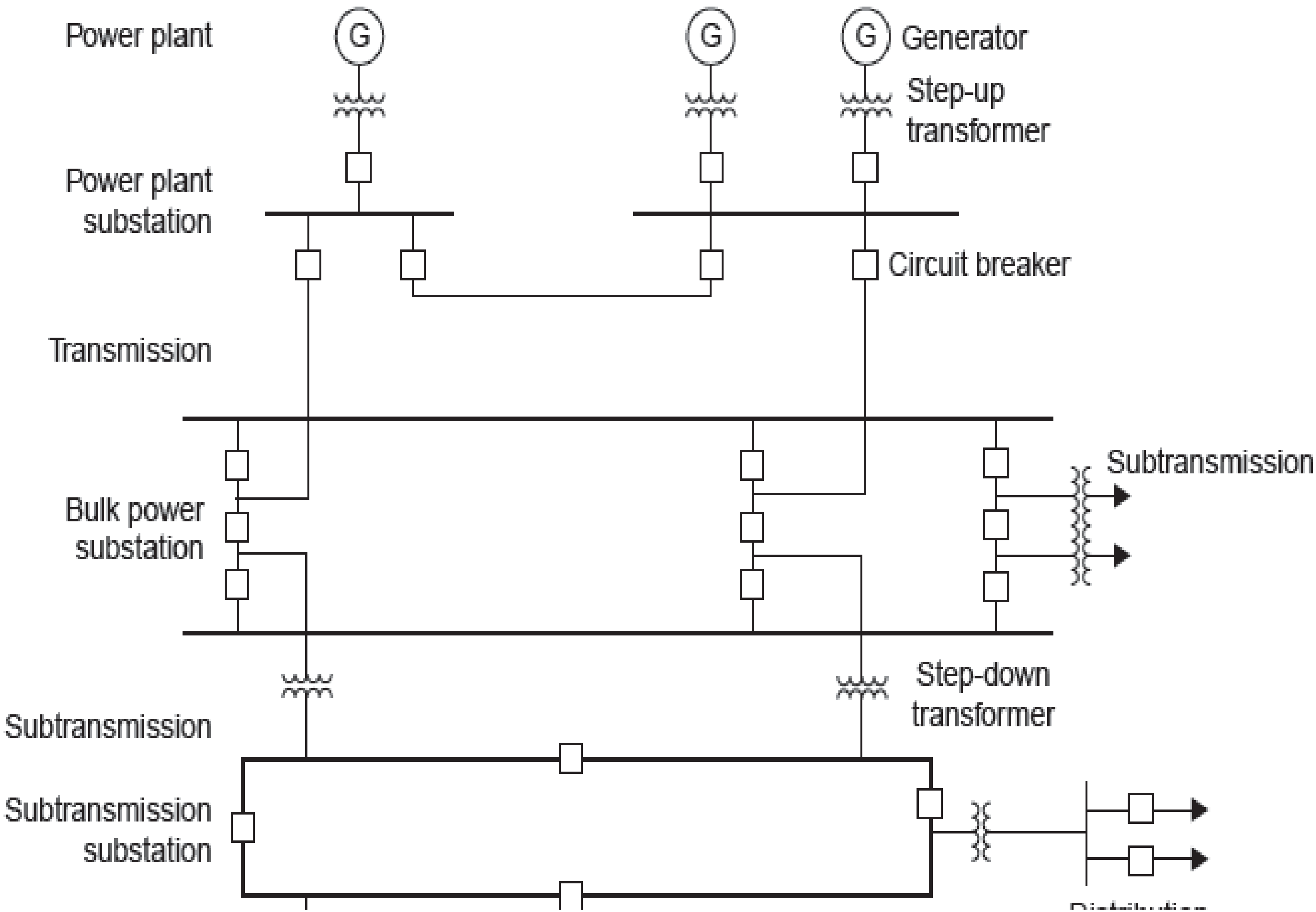
three-phase “live” wires



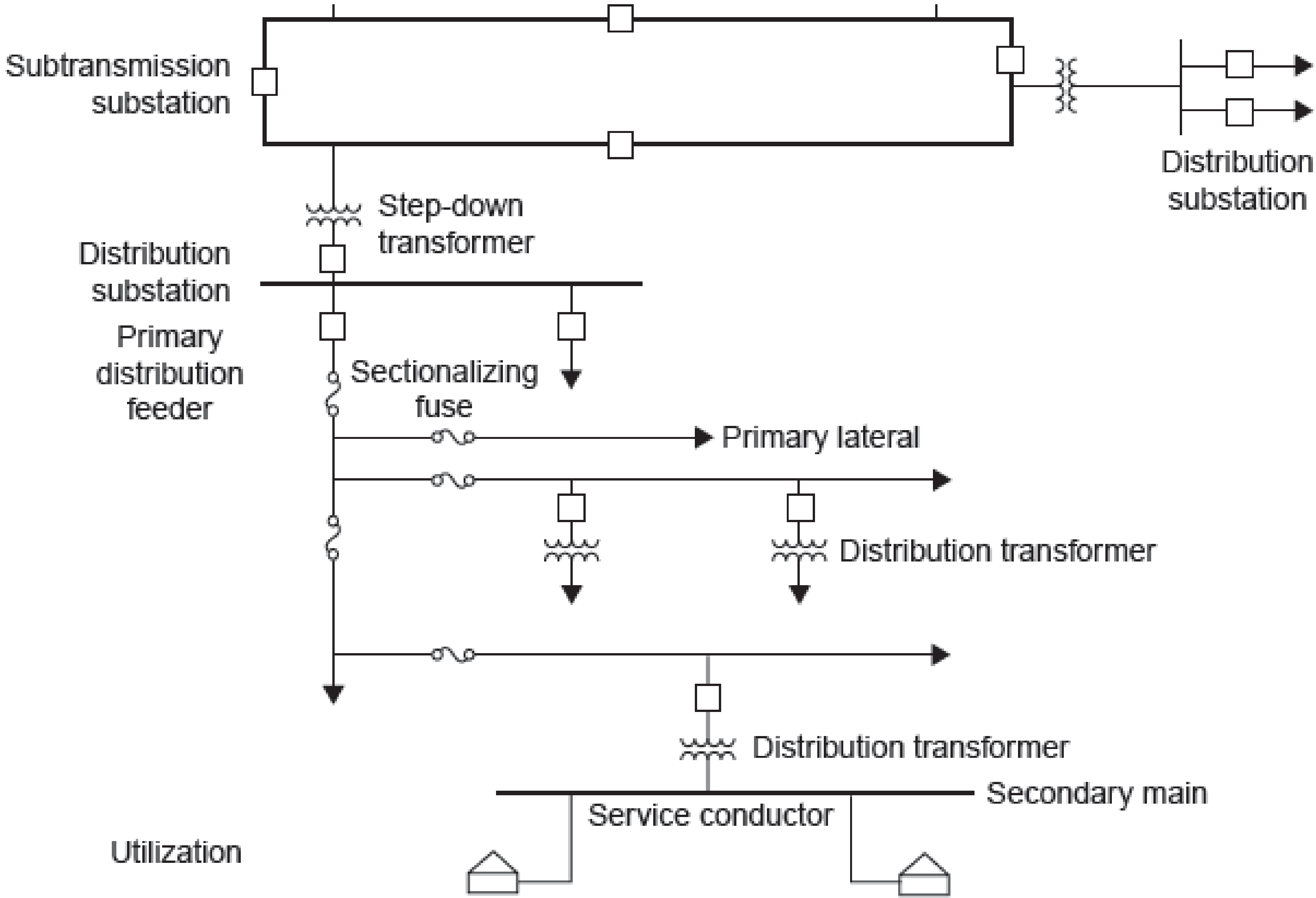
to house

From: UCSD: Physics 8; 2006

Electricity Delivery



Electricity Delivery



Factors Affecting Distribution-System Losses

- Inadequate Size of Conductor.
- Feeder Length.
- Location of Distribution Transformers.
- Low Voltage.
- Use of Over-Rated Distribution Transformers.
- Low Power Factor.

Primary Distribution

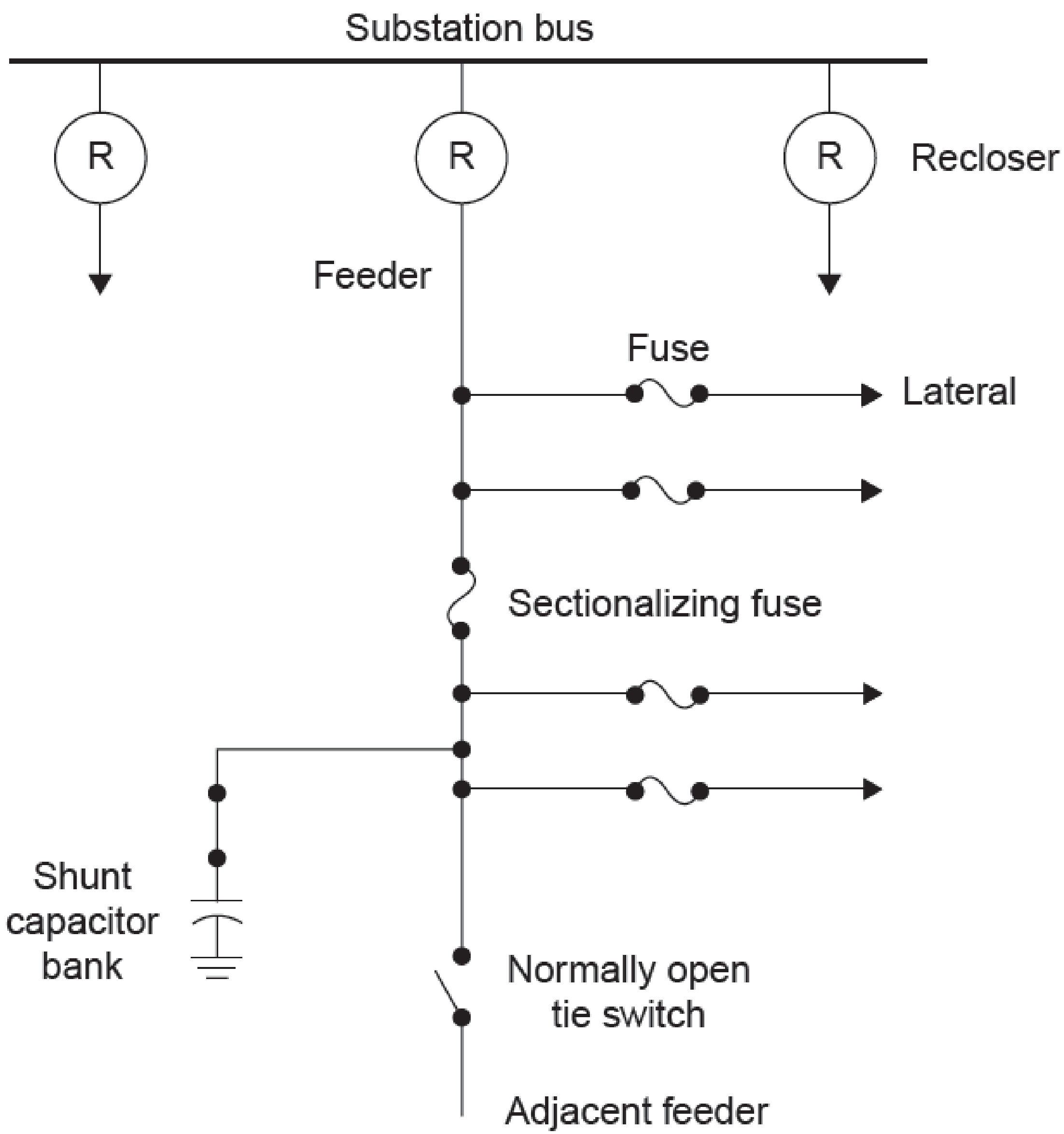
Class, kV	Voltage, kV
2.5	2.4
5	4.16
8.66	7.2
15	12.47
	13.2
	13.8
25	22.9
	24.94
34.5	34.5
50	46

- 15kV class, 4 wire multigrounded is most common

Primary Distribution

- Includes everything from the distribution substation to the distribution transformers
- Rural areas served by overhead lines
- Urban areas served by underground systems
- Three common topologies:
    1. Radial
    2. Loop
    3. Network

Primary Radial Systems



Primary Radial Systems

- Three phase feeder mains of length 1 to 30 miles.
- Single phase laterals branch off main feeder.
- Try to balance the load on the 3 phases.
- Economical and widely used in low load density areas.
- Re-closers are used on overhead lines to minimize loss of load; Typically have 3 shots before lockout.
- Sectionalizing fuses also reduce downtime.

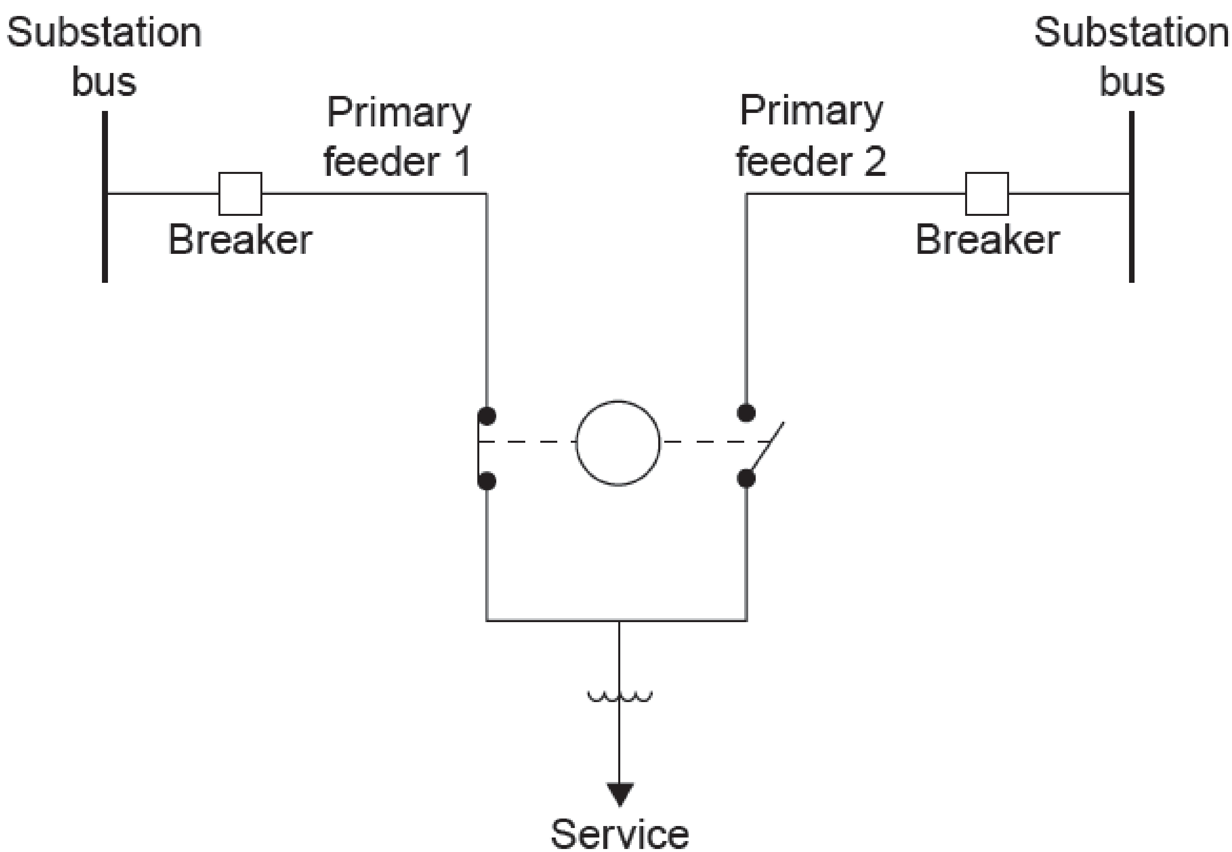
Primary Radial Systems

- Capacitor banks:
  - Reduce voltage drop
  - Reduce losses
  - Improve power factor
- Are often switched off at night!

Source: http://www.powercap.in/pole_mounted_capacitor.htm

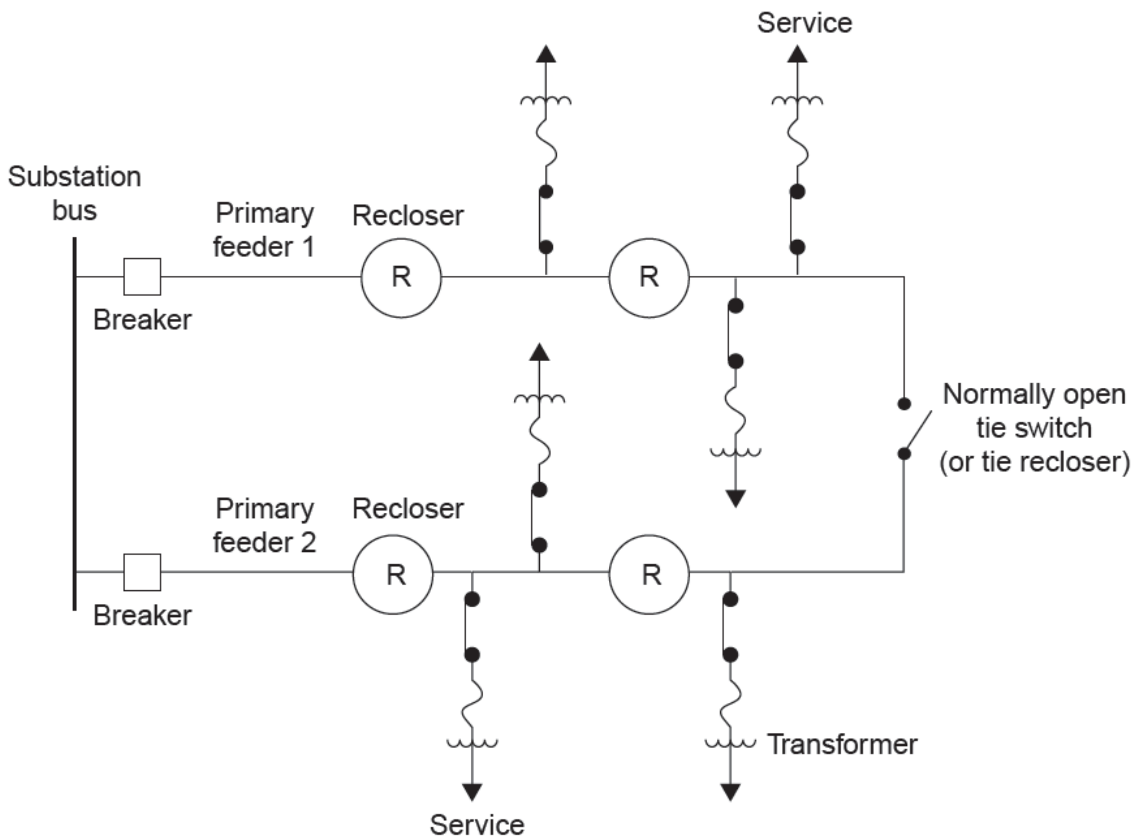
Primary Radial Systems

Primary selective systems can be used as backup for critical loads such as hospitals

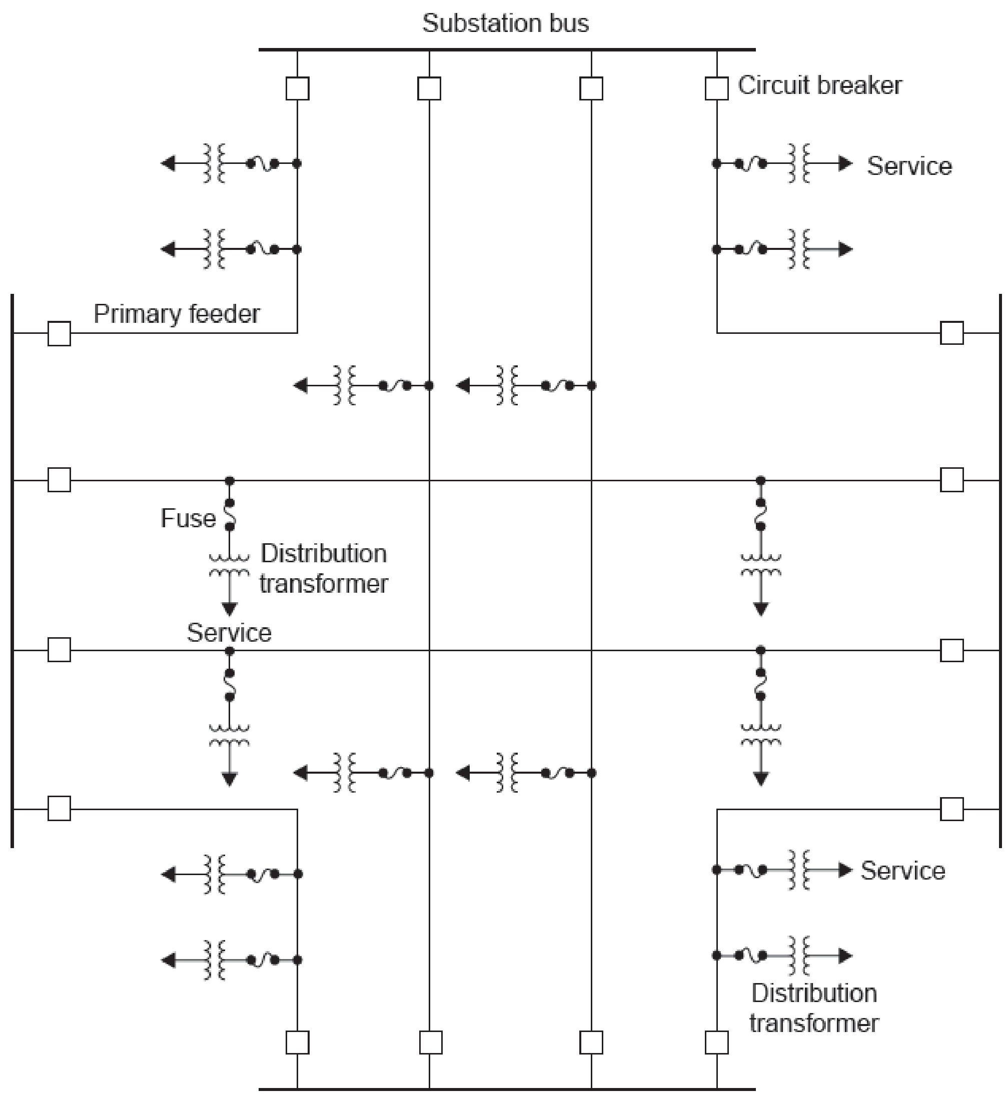


Primary Loop Systems

- Used where higher service reliability is required.
- Generally more expensive than radial systems.
- Feeder conductors are sized to feed entire loop.
- Loop systems can be used in underground residential distribution (URD), where faults are infrequent but are usually permanent.



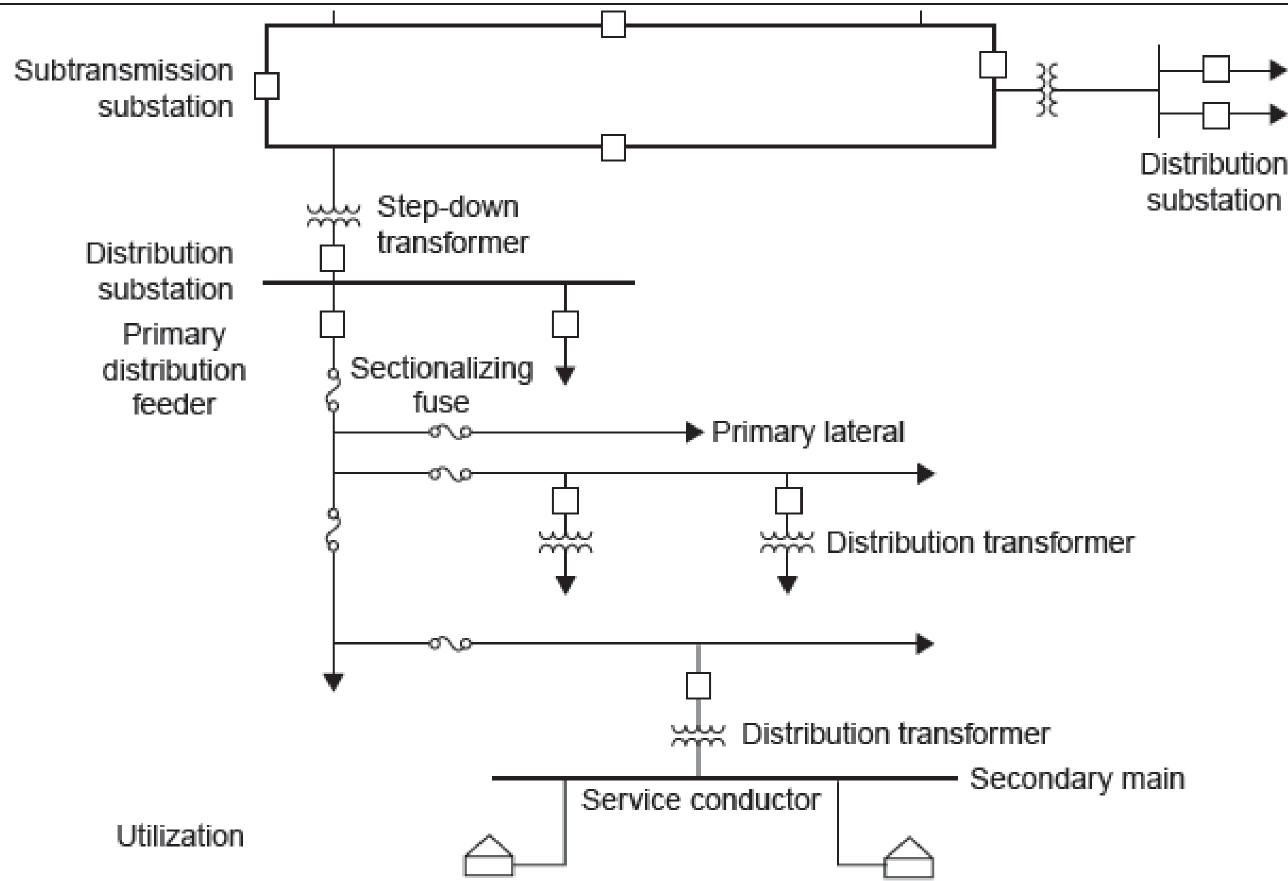
Primary Network Systems



Secondary Distribution

Includes everything from the distribution transformer to the meters

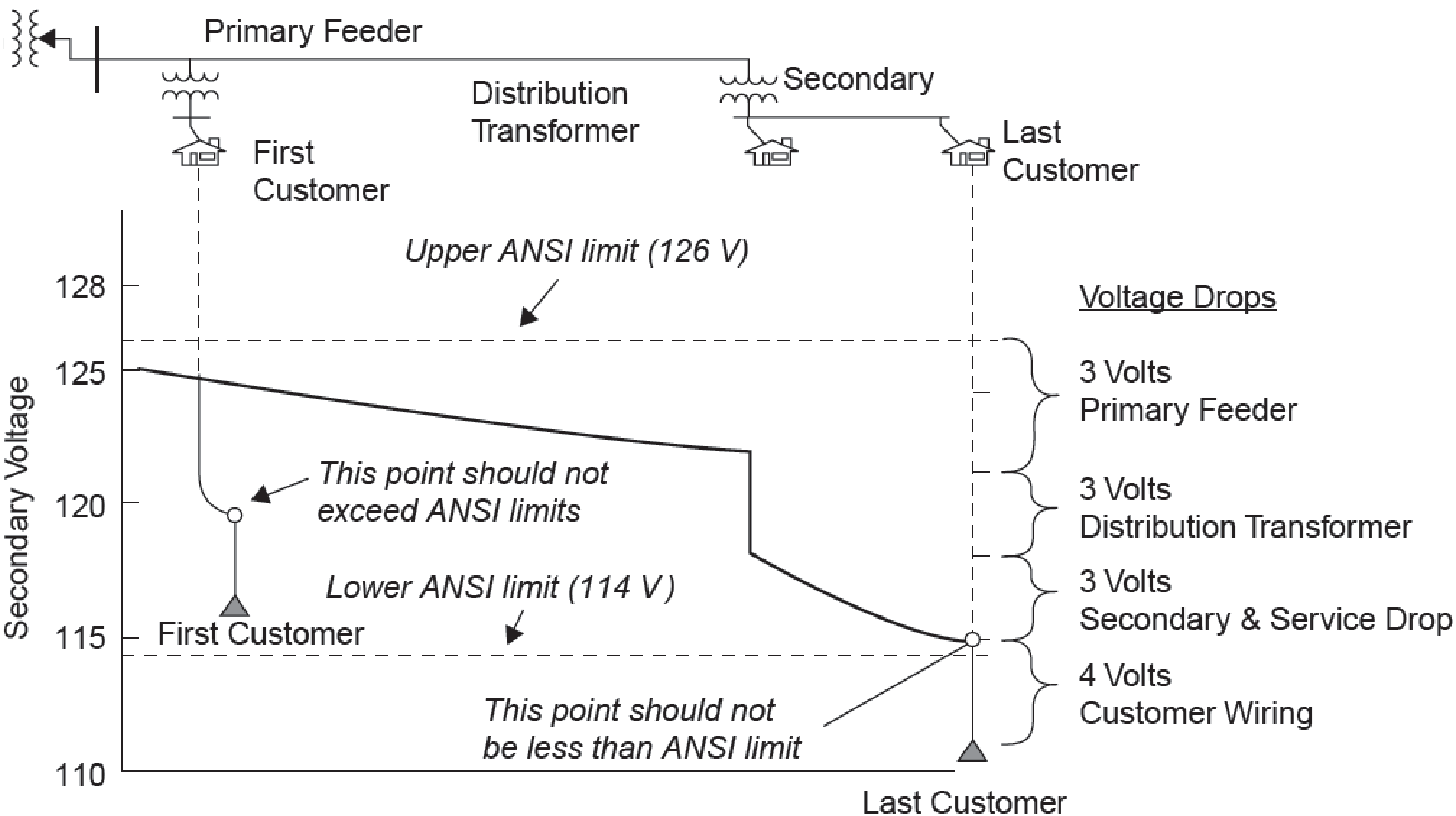
Voltage	# Phases	# Wires	Application
120/240 V	Single-phase	Three	Residential
208Y/120 V	Three-phase	Four	Residential/Commercial
480Y/277 V	Three-phase	Four	Commercial/Industrial/High Rise



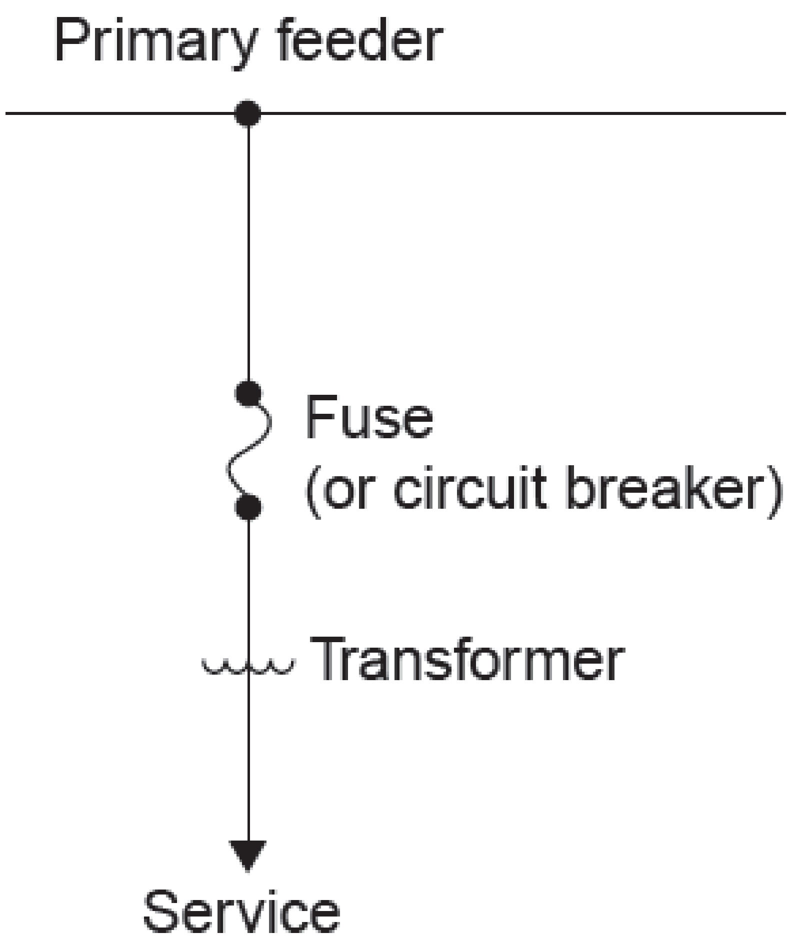
Secondary Distribution

- Distribution system must ensure customer voltage is within ANSI standards +/-5% (114-126V).
- Most problematic:
  - Voltage of first customer under light load.
  - Voltage of last customer under peak load.
- Load tap changers, voltage regulators, and shunt capacitors are used.
- Four types of secondary systems:
  - Individual distribution transformer per customer.
  - Common secondary main.
  - Secondary network.
  - Spot network.

Secondary Distribution

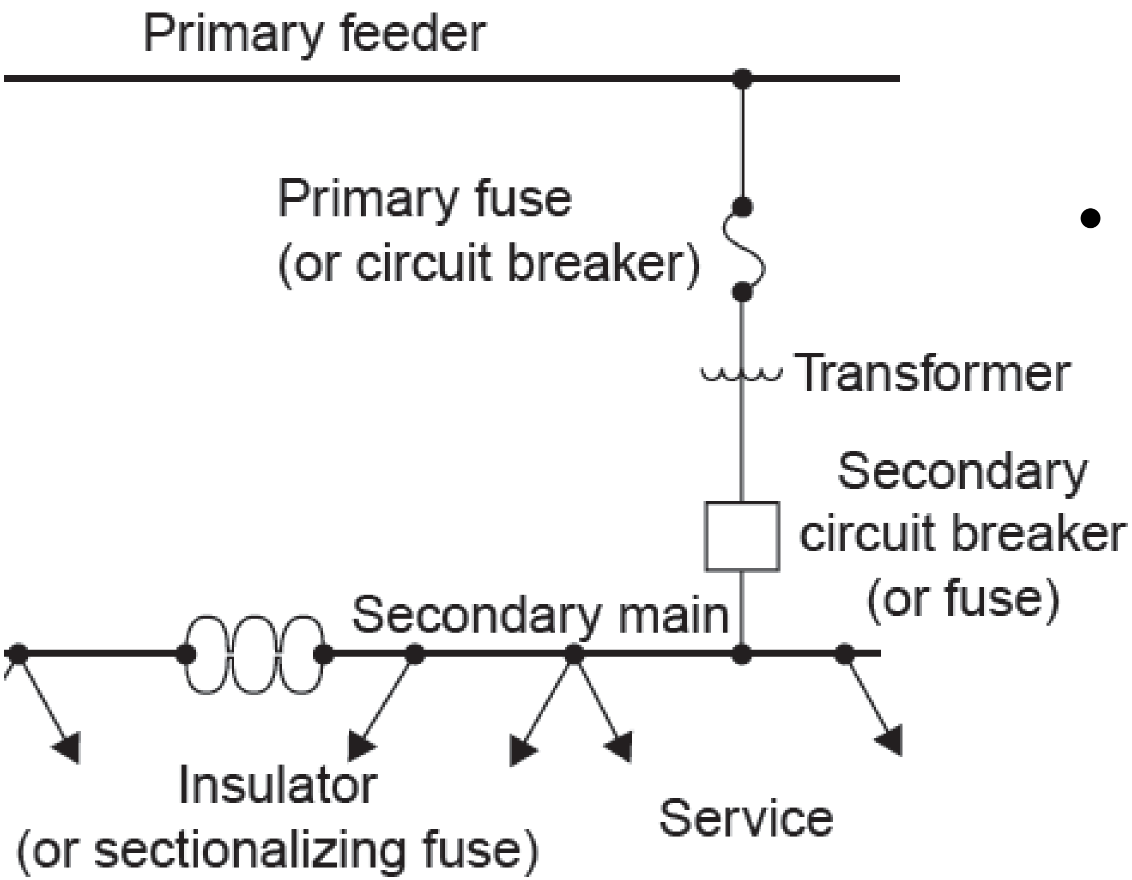


Individual Distribution Transformer



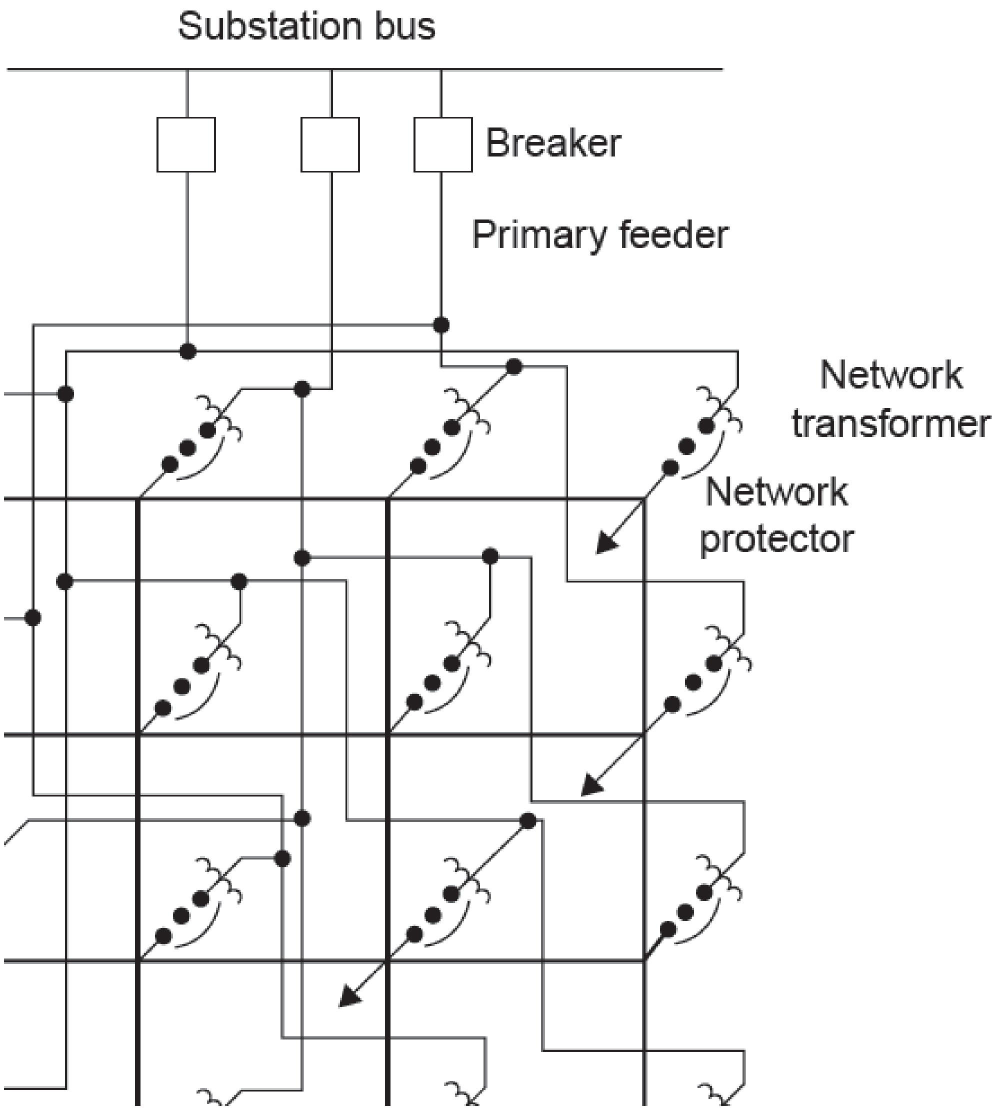
- The customer is directly connected to the primary feeder through a distribution transformer
- Commonly used for:
  - Rural areas
  - Large single customers
  - Voltage problems with common secondary main

Common Secondary Main



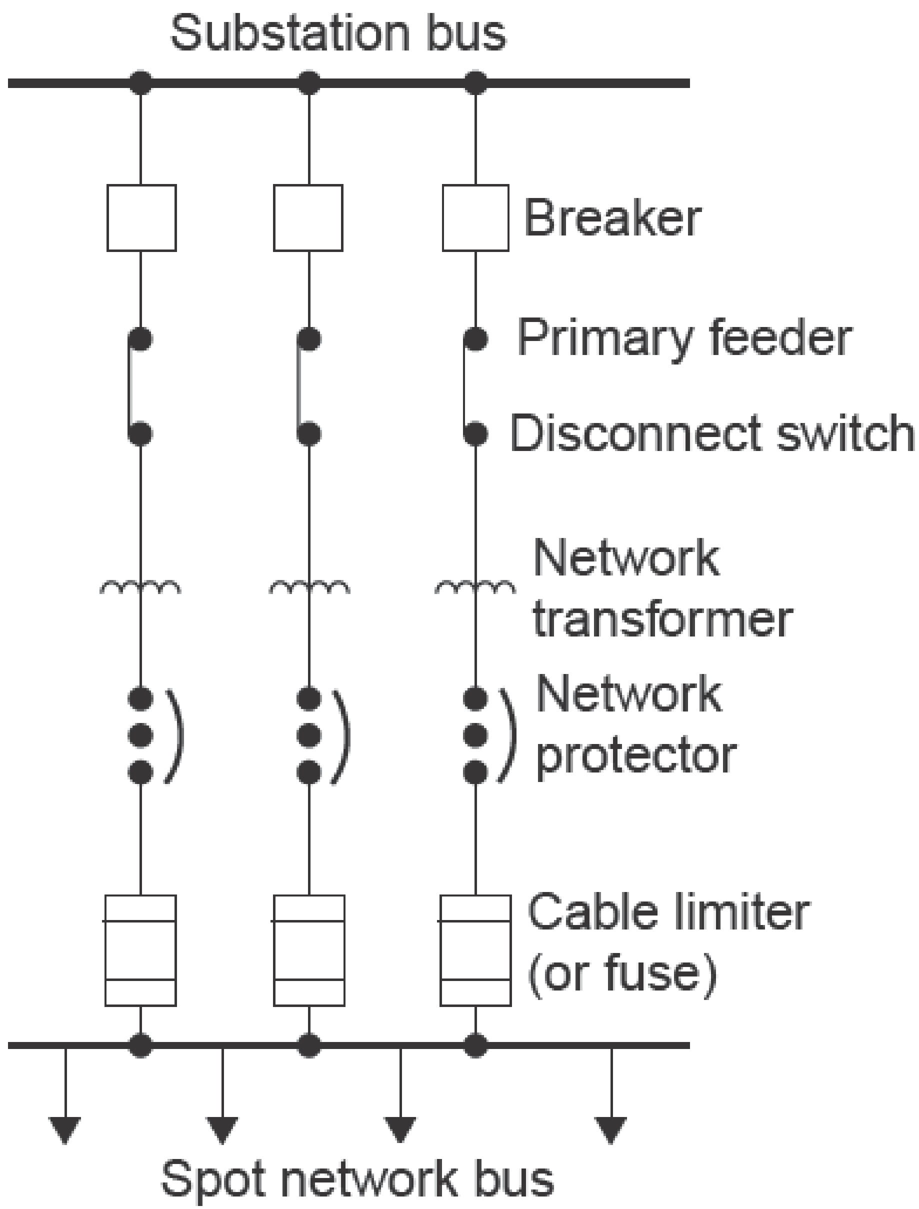
- Several customers share a secondary main
- Takes advantage of the diversity of loads:
  - A smaller transformer is required
  - Sudden load changes (eg a large motor starting) will have less effect on voltage

Secondary Network



- High reliability
- Multiple primary feeders, each over-sized
- More than 260 cities in USA have secondary networks
- Requires comprehensive protection using relays, fuses, network protectors
- 208Y/120 or 480Y/277V

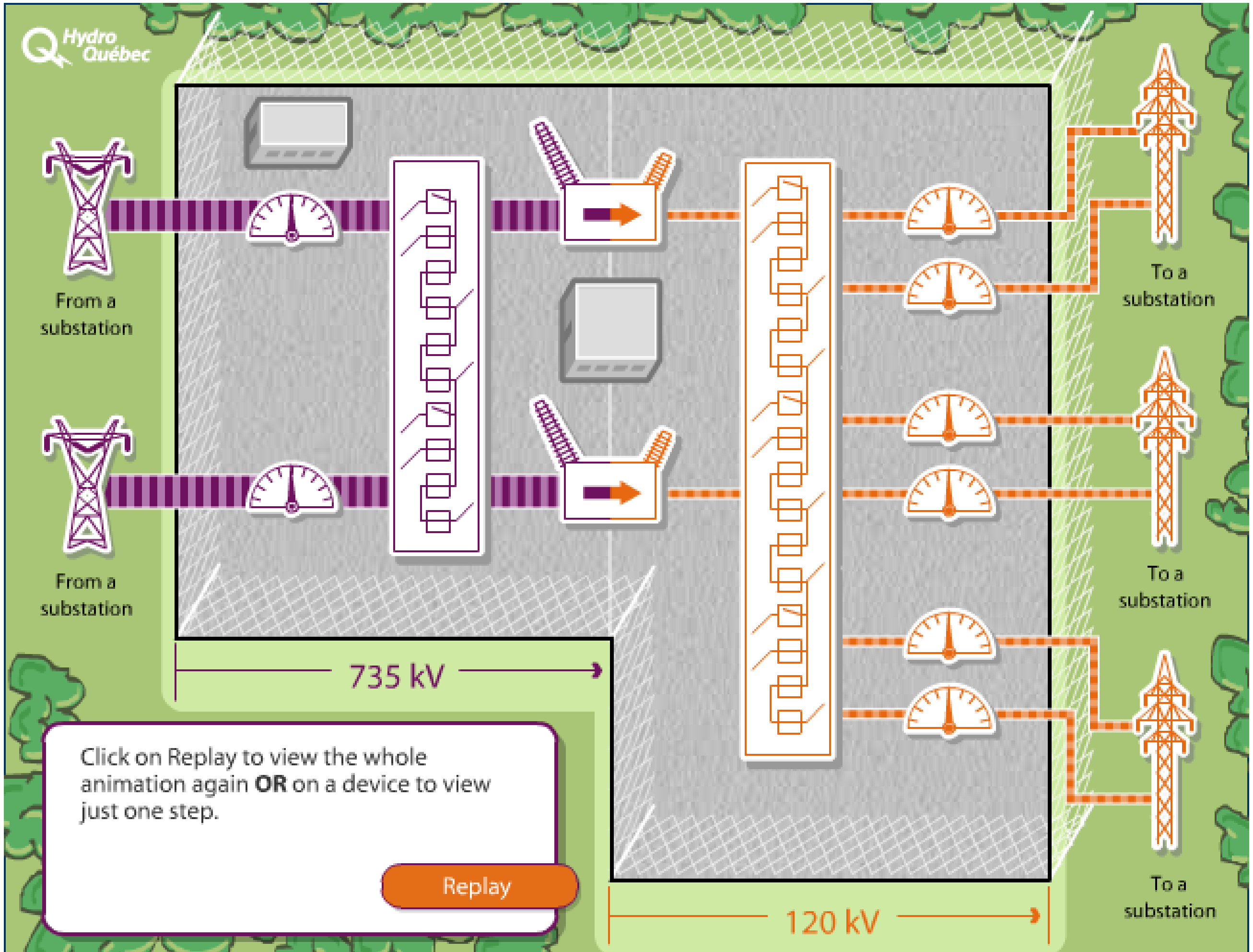
Spot Network



- Used for single, concentrated load (eg., high rise, mall)
- Usually 480Y/277V
- High reliability

How a Substation Works?

http://www.hydroquebec.com/learning/transport/construction-poste/index.html



Distribution Substation Transformers

Rating of High Voltage Winding	34.5 to 230 kV
Rating of Low Voltage Winding	2.4 to 46 kV
MVA Rating (OA)	2.5 to 75 MVA
Transformer Impedance	5 to 12 %
Number of Transformers in Substation	1 to 4
Loading	OA, OA/FA, OA/FA/FOA, OA/FA/FA
High Side Protection	Circuit Switches, Circuit Breakers, Fuses
Relay Protection	Overcurrent, Differential, Under-Frequency
Feeder Protection	Circuit Breakers, Reclosers

Distribution Substation Transformers

- Emergency loading:
  - 2 hour emergency rating (eg 170%) which gives time to perform switching to alleviate loading
  - 10 or 30 day emergency rating (eg 155%) which gives time to perform maintenance
- Construction:
  Contain mineral oil for insulation and cooling
  Sealed and internal pressure is monitored
- Can have LTC and voltage regulator
- Ratings:
  OA: passive cooling
  FA: active cooling with fans only
  FOA: active cooling with fans and oil circulation pump
- Nameplate transformer impedance usually given in % using OA rating as the MVA base

Distribution Substation Transformers

Three phase 22.9kV Δ / 4.16kV Y, 12MVA OA, 16MVA FA1, 20MVA FA2, LTC on LV side

Example 14.2

- A distribution substation is served by two transmission lines, each connected to a 40MVA (FOA) transformer. The utility that owns the substation uses the following loading criteria:
  - 128% for normal loading
  - 170% for 2 hour emergency
  - 155% for 30 day emergency

1. What is the normal rating of substation
2. What is the 2 hour emergency rating under single-contingency loss of a transformer (n-1)
3. What is the 30 day emergency rating for n-1

Example 14.2

1. What is the normal rating of substation
   1.28 * (40+40) = 102.4MVA
2. What is the 2 hour emergency rating under single-contingency loss of a transformer (n-1)
   1.7 * 40 = 68MVA
3. What is the 30-day emergency rating for n-1
   1.55 * 40 = 62MVA

Distribution Transformers

- Convert the primary distribution voltage (2.4 to 46kV) to secondary distribution voltage (<480V)
- Location: pole mounted, pad mounted, inside buildings, or underground

Pole Mounted Transformers

- Liquid filled, 1 or 3 phase
- Small (eg., 25kVA)
- Different levels of protection, as required (eg., fuse cutout, surge arrester, circuit breakers).
- Typically the protection is attached to the outside of the transformer.

Source: http://www.freefoto.com/preview/13-20-72/Electricity-Transformer-mounted-on-a-Utility-Pole

Pad Mounted Transformers

- Used for underground distribution
- Liquid filled or dry-type, 1 or 3 phase
- Medium sized (eg., 225kVA)

Source: http://www.zeppaenterprises.com/electric/2000amptrans.jpg

Network Transformers

- Located in vaults, supplies power to secondary networks or spot networks
- Liquid filled, 3 phase
- Large (300-2500kVA)

Source: http://www.howard-ind.com/howardtransformers/Images/Network%20Transformer%20%28Vault%20Type%20Crop%.jpg

Distribution Transformers

- Like distribution substation transformers, distribution transformers can also be overloaded

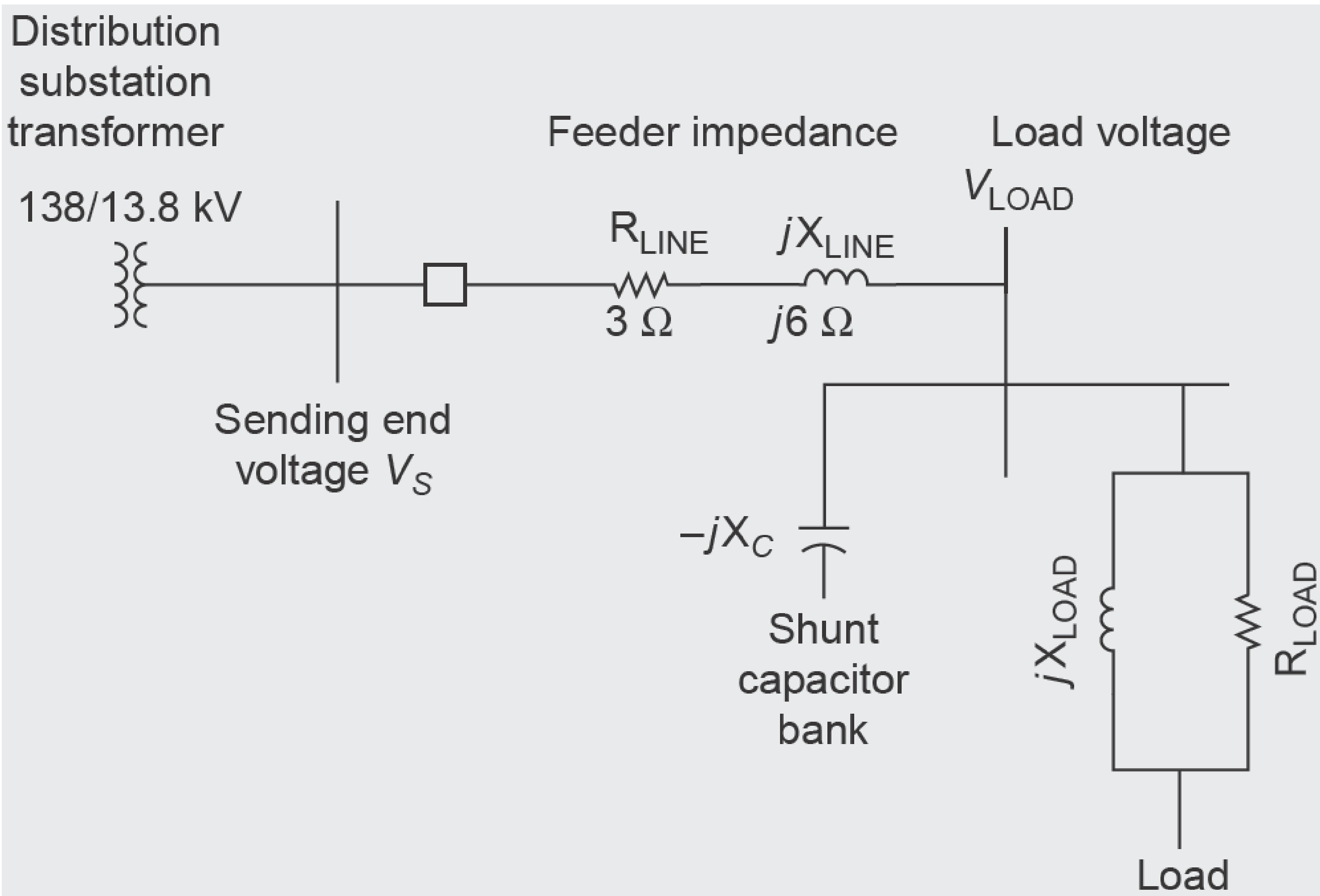
Period of Increased Loading, Hours	Average Initial Load in Per Unit 0.9	0.7	0.5
	Maximum Load in Per Unit		
0.5	1.59	1.77	1.89
1.0	1.40	1.54	1.60
2.0	1.24	1.33	1.37
4.0	1.12	1.17	1.19
8.0	1.06	1.08	1.08

Shunt Capacitors in Distribution

- Supply reactive power to inductive loads, thus reducing line losses and improving voltage
- Placement is important:
  - If only 1 load, place cap bank at load
  - Cap banks placed at distribution substations only reduce I^2R losses and voltage drops in transmission, not distribution
  - Common to use 2/3 rule: place 2/3 of the required reactive power 2/3 down the feeder
- A combination of fixed and switched cap banks are used

Example 14.3

X_{LOAD}=40Ω, R_{LOAD}=20Ω, X_C=40Ω



Example 14.3

- Impedance seen by source without cap bank

$$Z_{\text{TOTAL}} = 3 + j6 + \frac{1}{\frac{1}{20} + \frac{1}{j40}}$$

$$= 23.60\underline{/36.38^\circ}\ \Omega/\text{phase}$$

- Impedance seen by source with cap bank

$$Z_{\text{TOTAL}} = 3 + j6 + \frac{1}{\frac{1}{20} + \frac{1}{j40} - \frac{1}{j40}}$$

$$23.77\underline{/14.62^\circ}\ \Omega/\text{phase}$$

Distribution Software

- Functions:
  - Analysis: faults, contingencies, reliability, harmonics, losses
  - Optimization of cap placement, conductor size, switching, transformer size, voltage
  - Operations (DSM, PF correction, voltage, relay coordination)
  - Visualization
  - Outage management

Distribution Reliability

- Goal: 1 interruption, max 2 hours in 1 year
- Reliability indices:

System Average Interruption Frequency Index (SAIFI):

$$\mathrm{SAIFI} = \frac{\Sigma \text{ Total Number of Customers Interrupted}}{\text{Total Number of Customers Served}}$$

System Average Interruption Duration Index (SAIDI):

$$\mathrm{SAIDI} = \frac{\Sigma \text{ Customer Interruption Duration}}{\text{Total Number of Customers Served}}$$

Customer Average Interruption Duration Index (CAIDI):

$$\mathrm{CAIDI} = \frac{\Sigma \text{ Customer Interruption Duration}}{\text{Total Number of Customers Interrupted}} = \frac{\mathrm{SAIDI}}{\mathrm{SAIFI}}$$

Distribution Reliability

Average Service Availability Index (ASAI):

$$\text{ASAI} = \frac{\text{Customer Hours Service Availability}}{\text{Customer Hours Service Demands}}$$

- Momentary interruptions not included
- Prolonged interruptions (eg storm) treated differently
- Typical values
  - SAIFI: 1.1 interruptions/year
  - SAIDI: 90 minutes/year
  - CAIDI: 76 minutes/year
  - ASAI: 99.982%
- Utilities may be obligated to or may voluntarily report indices to state commissions
- Reports help identify weakest links, trends

Finally to Your Home: The AC Receptacle

- Receptacles have three holes each
- Lower (rounded) hole is earth ground
  - connected to pipes, usu.
  - **green wire**
- Larger slot is "neutral"
  - for current "return"
  - never far from ground
  - white wire
- Smaller slot is "hot"
  - swings to +170 and –170
  - black wire
  - **Dangerous!**