04-Power System Components

Text: Chapter 2

ECEGR 3500

Electrical Energy Systems

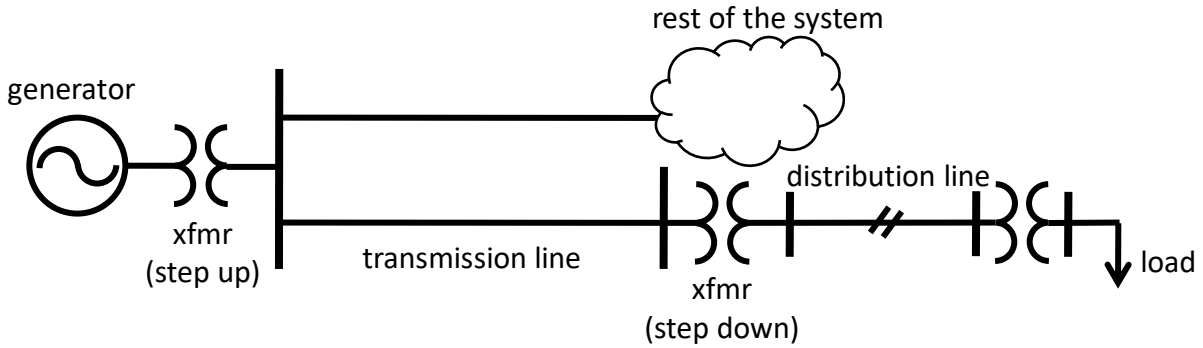
Professor Henry Louie

Overview

- Power System Topology
- Transmission Lines
- Distribution Lines
- Fuses
- Circuit Breakers
- Switches
- Reclosers
- Transformers
- Substations

Introduction

- Power systems can be divided in to three sub-systems
  - generation
  - transmission
  - load
- Transmission is often separated into transmission and distribution



Transmission

- Facilitates flow of power from generators to load
- Several different voltage levels are used
  - Generator terminals: approximately 10kV to 40kV
  - Transmission system: approximately125kV to 1200kV
  - Distribution system: approximately15kV to 25kV
  - Households: 100V to 240V

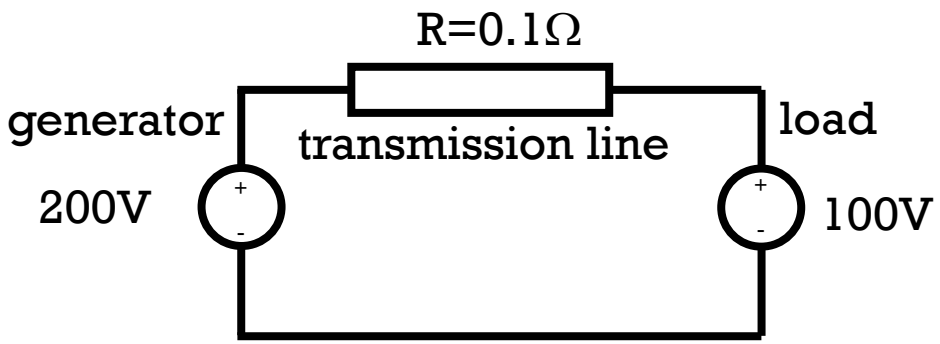
Transformers are used to switch between voltage levels

Transmission Voltages

- Transmitting power at high voltage is more efficient than using low voltage
  - Lower I^2R loss in the conductors
- However, high voltages are hazardous, and require greater insulation and clearances
- Voltage levels are decreased within cities and in homes and buildings for safety

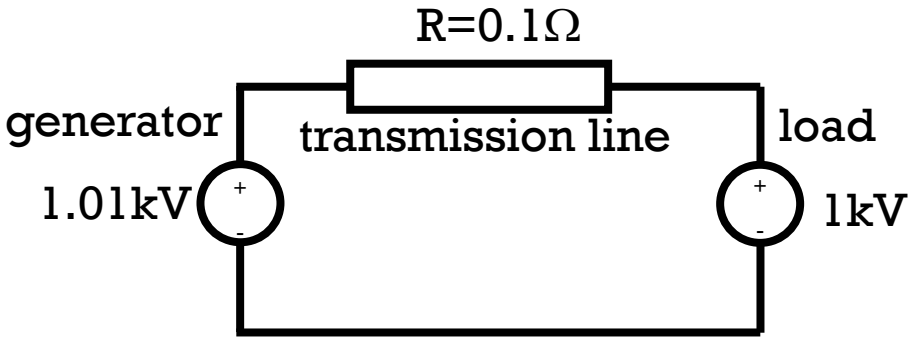
Exercise

- Consider the two options of supplying the load with 100kW of power. Which is more efficient?



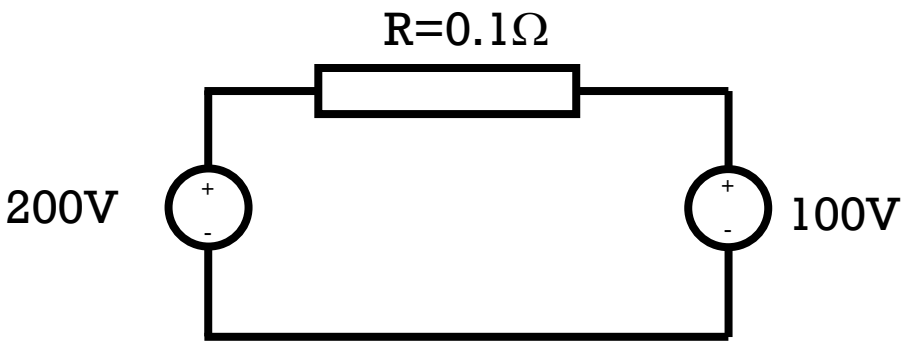
I = (200-100)/0.1 = 1000A

P_{load} = 1000 x 100 = 100kW
P_{gen} = 1000 x 200 = 200kW
P_{loss} = 100kW



P_{load} = ?
P_{gen} = ?
P_{loss} = ?

Exercise



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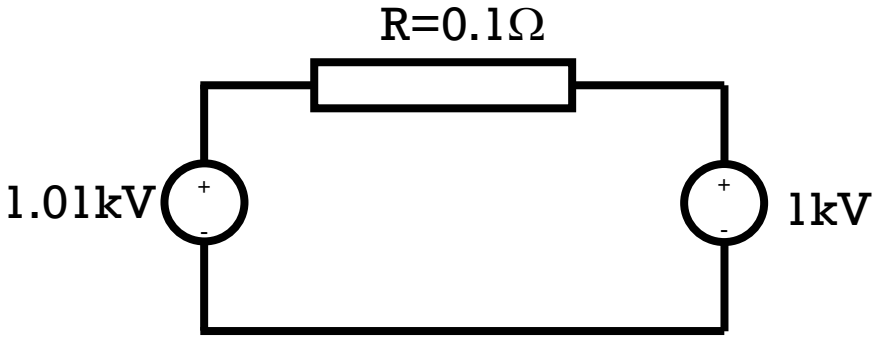


I = (1010-1000)/0.1 = 100A

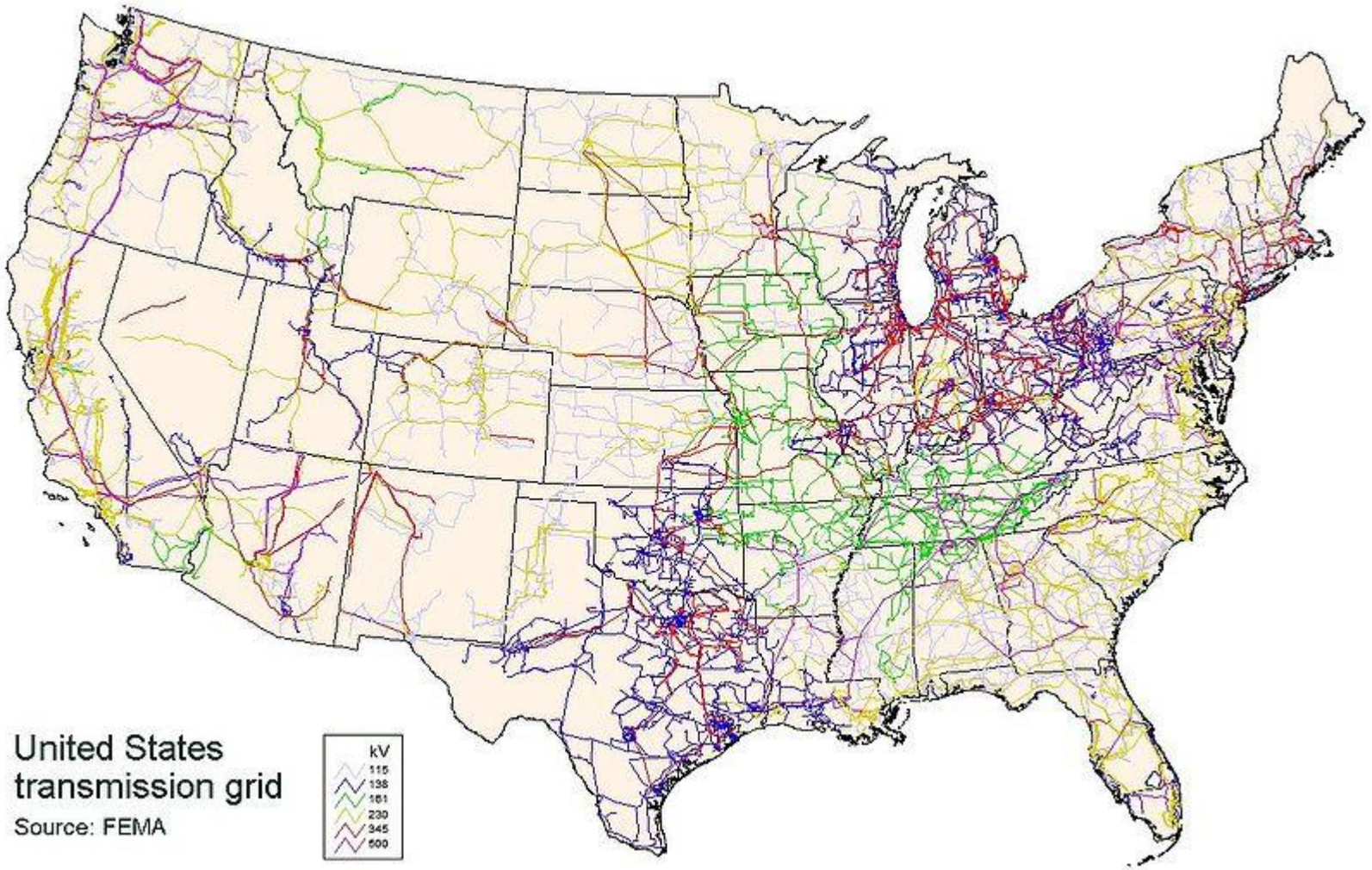
P_{load} = 100kW
P_{gen} = 101kW
P_{loss} = 1kW

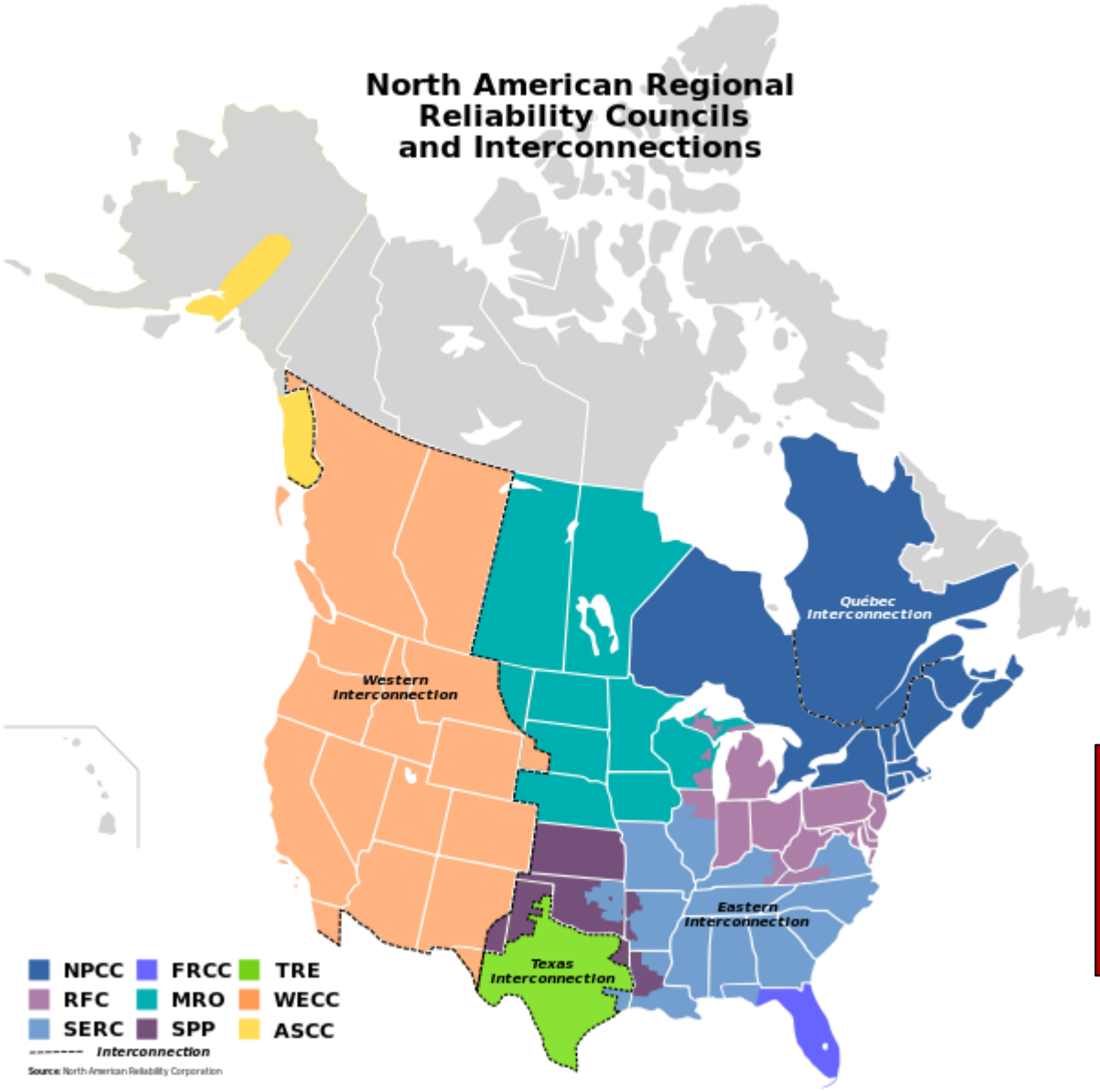
Raising the load voltage by a factor of 10 reduced the losses by a factor of 100.

Transmission Voltages

- For a constant power load, there are fewer transmission losses when a higher voltage level is used
- Previous example used DC elements, but the result is true for AC systems as well

Transmission

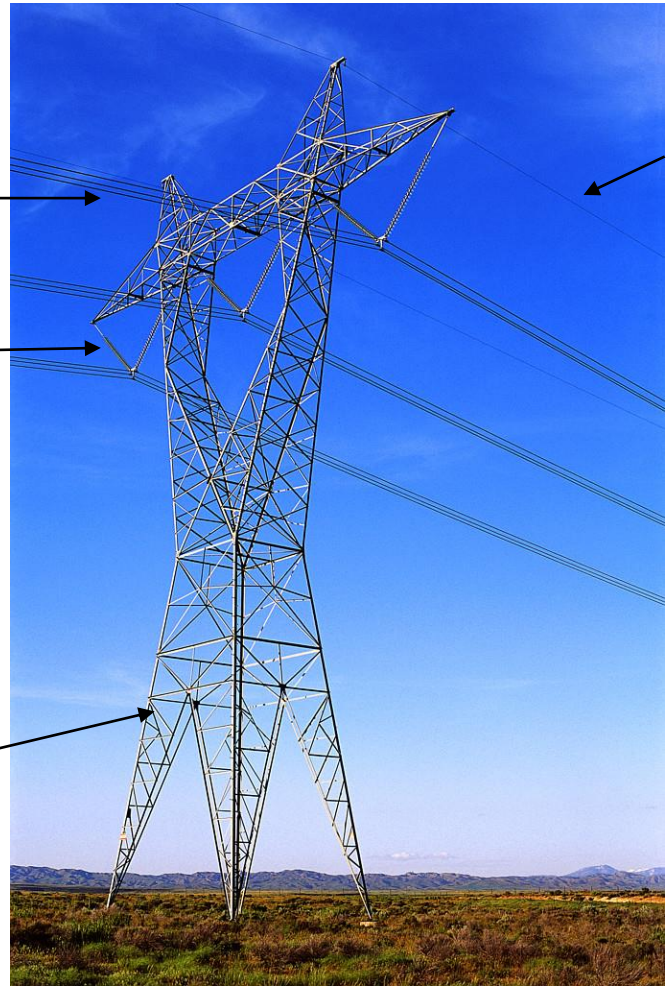




There are three grids in the U.S.
(Western, Eastern and Texas).
They are asynchronously connected using back-to-back AC/DC converters

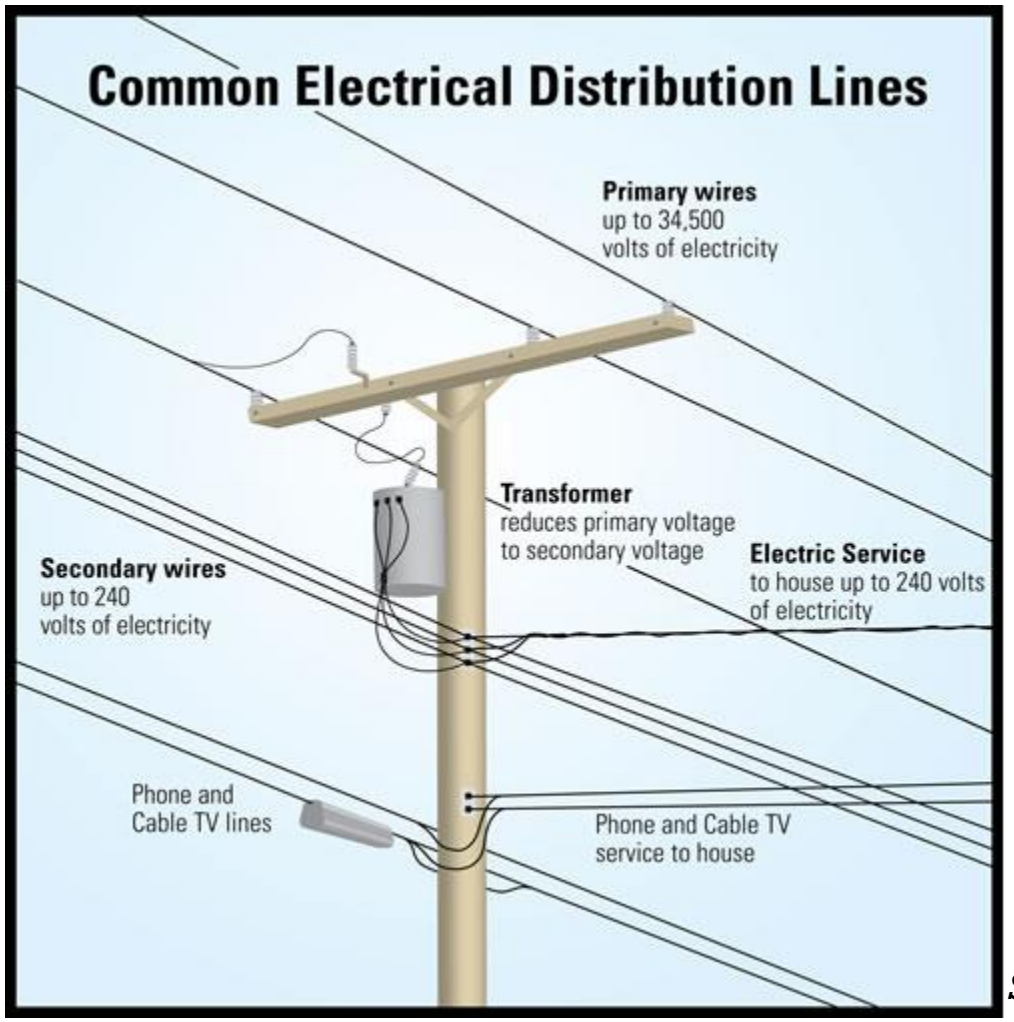
Transmission Line Anatomy

Conductors are often bundled to reduce corona.



Conductors are given code names of birds, flowers and cities.

Distribution Lines



Source: www.we-energies.com

Question

Are overhead distribution lines insulated?

Question

Are overhead distribution lines insulated?

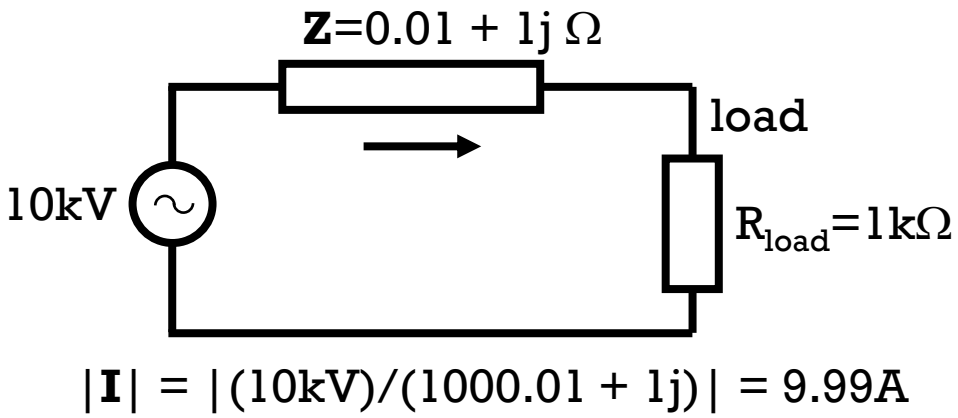
Answer: No, although the secondary wires run into a house are insulated.

Discussion

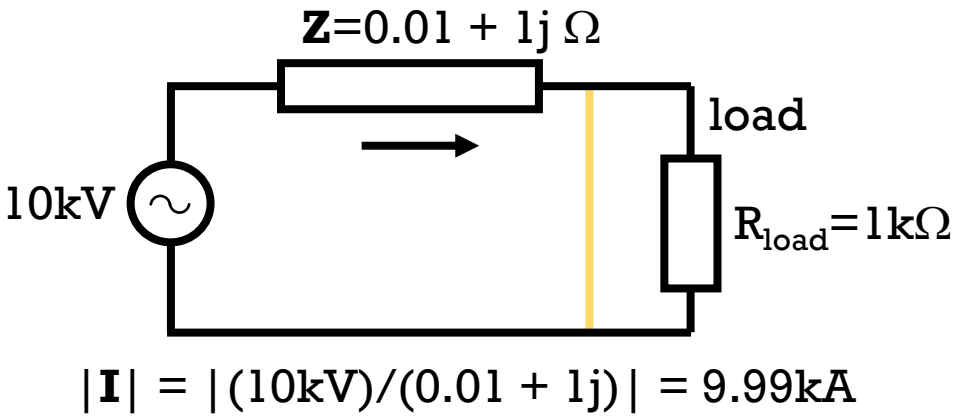
In many parts of the world, the distribution lines are buried underground using insulated cables. Where is this done in the U.S. and why is it not a universal practice?

Fuses

- In power systems, accidental short circuits can occur



$|\mathbf{I}| = |(10\text{kV})/(1000.01 + 1\text{j})| = 9.99\text{A}$

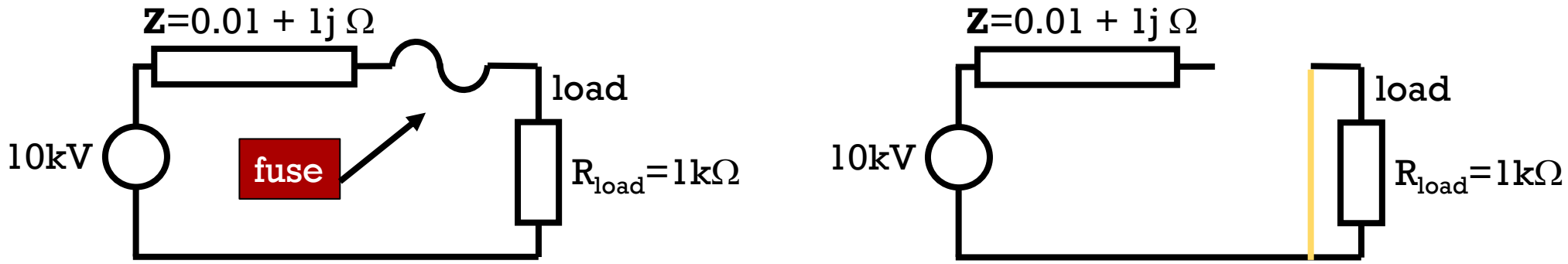


$|\mathbf{I}| = |(10\text{kV})/(0.01 + 1\text{j})| = 9.99\text{kA}$

Far greater current flows during a low impedance short circuit. This current can overhead the distribution line and/or damage the generator.

Fuses

- Insert a fuse in series (before) the load
- Fuse will "blow" when excess current passes through it



Fuse protects against overloads at the end of the distribution line.
How can a fault in the middle of the distribution line be protected against?

Fuses

- Designed to have low resistance (series element, and losses should be minimized)
- Conductor melts and open circuits due to I^2R losses

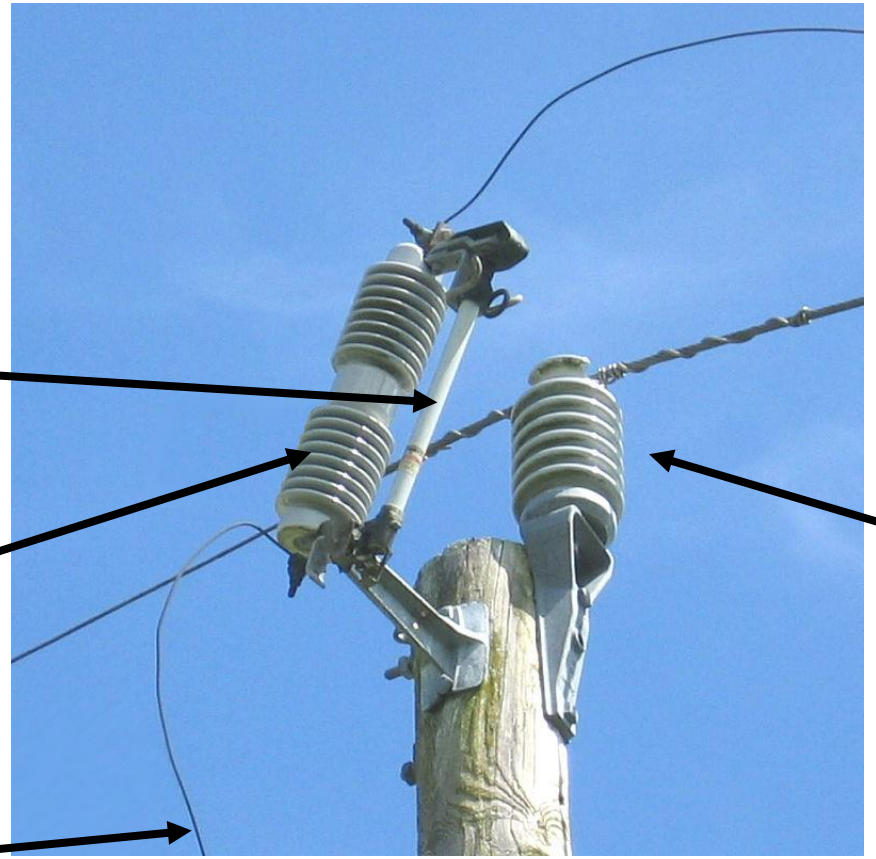
Fuse Ratings

- Current Rating: Ampere value at which a fuse begins to operate
- Interrupting Rating: Ampere value the device can safely interrupt
- Voltage Rating: Maximum voltage level of the system the fuse can safely be applied to

Fuse Applications

- Fuses "blow" based on current level and time (i.e. they activate based on energy)
- If the full load of a circuit is 100A, what size fuse should be used?
  - Generally, a fuse is sized to be125% of the full load at a minimum or so that the current does not exceed the rating of the wires downstream of it
- Fuse selection also requires coordination
  - Minimize customers affected by fuses being blown while protecting equipment

Fuse cutout


Connection not shown
Fuse (connected)
insulator
insulator
to a transformer

Non-energized

Fuses are disconnected

Energized

Circuit Breakers

- Switches that are designed to interrupt current
- Similar function as fuses, but circuit breakers can be reset

Source: Electric Energy: An Introduction, M. El-Sharkawi

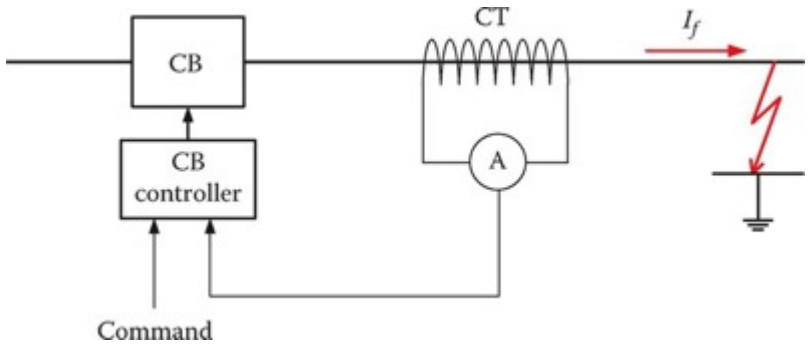
High-voltage circuit breaker

Household circuit breaker

A "switch" and a "circuit breaker" are different components. Switches are not designed to interrupt load.

Circuit Breakers

- Circuit breakers often use external measuring (current transformers) and decision making devices (relays) to determine when to "trip" (open)



Source: Electric Energy: An Introduction, M. El-Sharkawi

Lower voltage CBs operate based on heat from the fault current and/or its magnetic field

Circuit Breakers

- A red indicator means the circuit breaker is closed
- A green indicator means the circuit breaker is open

Circuit Breakers

- Inductance in a system can make it difficult to open a circuit (why?)
- Arcs must be extinguished quickly and safely
- Circuit breakers use the following mediums to interrupt arcs
  - Air (low voltage)
  - Air blast
  - Vacuum (be careful of x-rays!)
  - Oil (not commonly used in modern CBs)
  - SF_6 (sulfur hexafluoride) (higher voltages)

Exercise

Is it “easier” to interrupt an AC circuit or a DC circuit (all other things being equal)? Why?

Exercise

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Answer. An AC circuit. AC circuits have natural zero crossings in which the voltage across the circuit breakers contacts are zero.

Recloser

- Designed to interrupt current, wait and then close again (process can repeat several times before the recloser locks itself out in the open position)
  - Most faults are temporary (self-clearing)
- Used in medium voltage applications
- Installed in substations and even on pole-tops

Source: www.sandc.com

Disconnect Switch

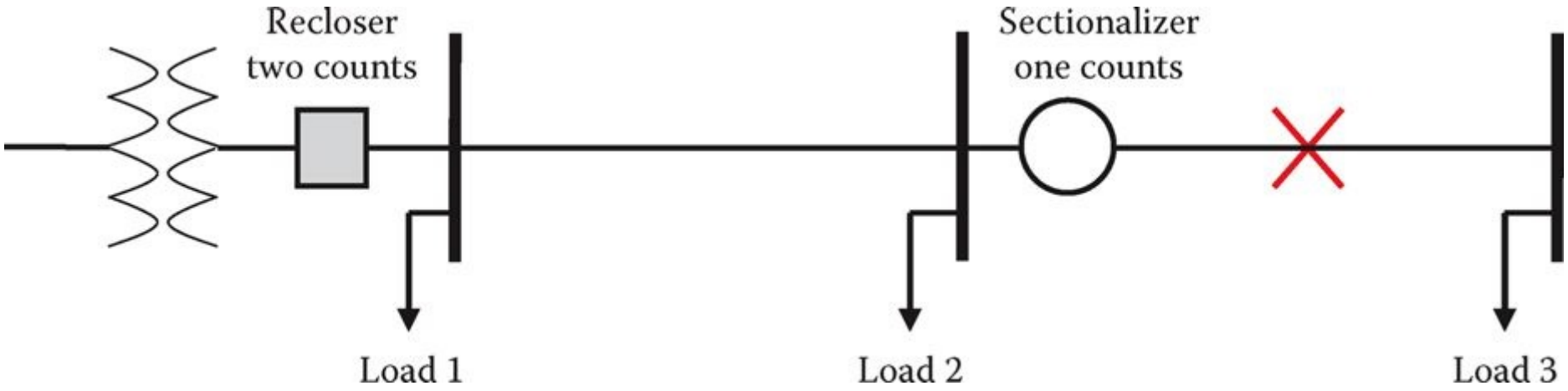
- Normally used to isolate components
  AFTER a CB has operated
- Minimal amount of current is interrupted, but arcing may occur
- Manually or automatically operated

Source: Electric Energy: An Introduction, M. El-Sharkawi

See: https://www.youtube.com/watch?v=hIkNY5xjy5k for what is NOT supposed to happen when a switch operates.

Sectionalizer

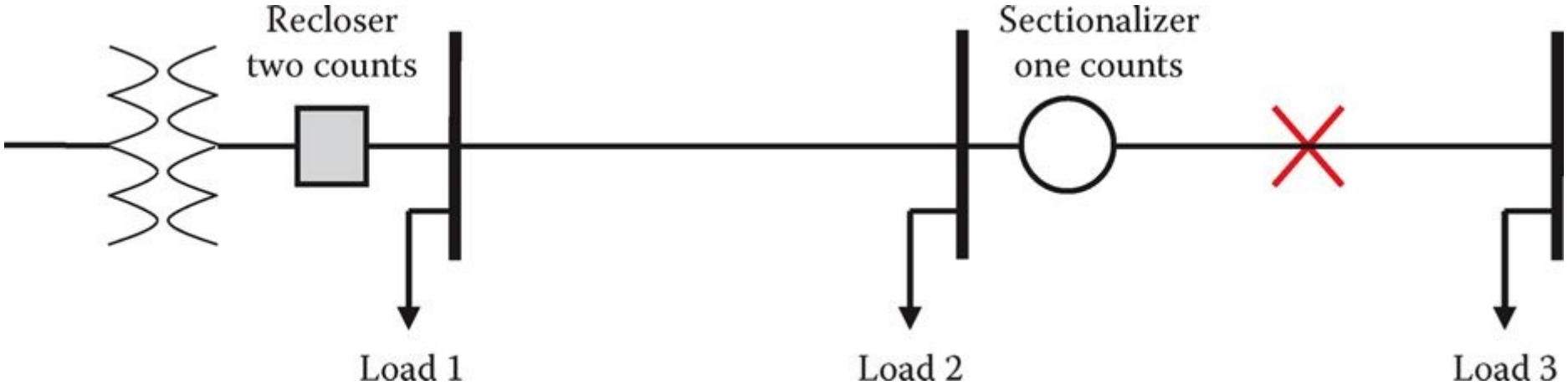
- Works in concert with a recloser
- Used to minimize loads affected by fault
- Not intended to interrupt fault current



Source: Electric Energy: An Introduction, M. El-Sharkawi

Sectionalizer

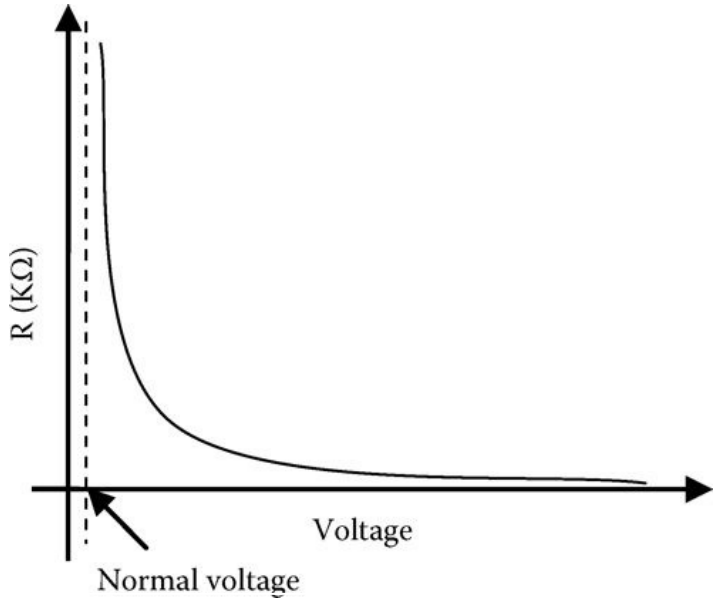
- A fault occurs between Load 2 and Load 3
- Recloser opens (hopefully clearing the fault)
- Sectionalizer "sees" the recloser open and reclose
- If the fault is not cleared, the recloser will open a second time
- Sectionalizer sees this second opening, and then itself opens to isolate the fault
- Recloser will try closing a third time and should remain closed because the fault is now isolated



Source: Electric Energy: An Introduction, M. El-Sharkawi

Surge Arrestor

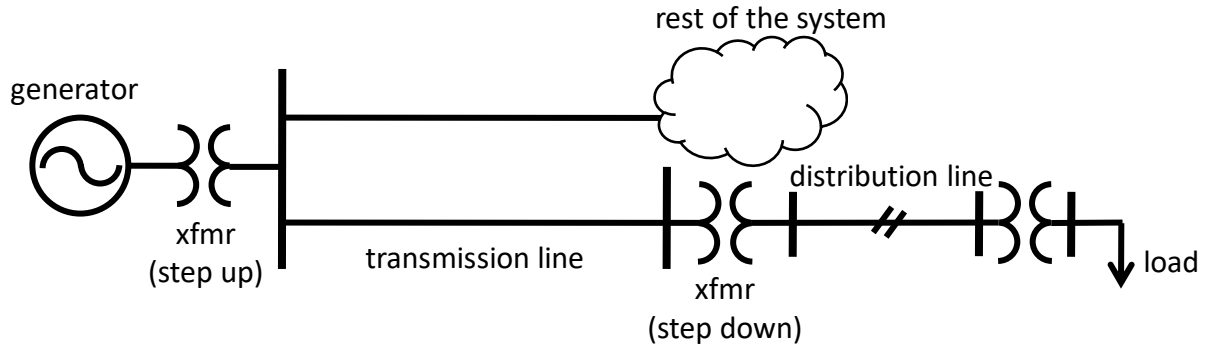
- Provides protection of equipment against overvoltages, primarily lightning strikes
- Connected between energized line and ground
- Uses metal-oxide varistor (MOV)
- High resistance at nominal line voltage, but the voltage quickly decreases during over-voltage conditions and the current flows to ground



Source: Electric Energy: An Introduction, M. El-Sharkawi

Transformers

- Generate power at a voltage suitable for energy conversion
- Step-up voltage for efficient transmission
- Step-down voltage for consumption at safe levels
- Also used for voltage regulation



Transformers

- In ideal transformers real power is conserved
- Power into the transformer

  $P_1 = \mathrm{Re}\{\boldsymbol{V}_1\boldsymbol{I}_1^*\}$
- Power out of the transformer

  $P_2 = \mathrm{Re}\{\boldsymbol{V}_2\boldsymbol{I}_2^*\} = P_1$

We will discuss the physics of transformers later.

Transformers

- Transformers scale the voltage as

  $\boldsymbol{V}_1 = a\boldsymbol{V}_2$

- For power to be conserved, the current is scaled by the inverse

  $\boldsymbol{I}_1 = (1/a)\boldsymbol{I}_2$

- Therefore:

$$P_2 = \mathrm{Re}\{\boldsymbol{V}_2\boldsymbol{I}_2^*\} = \mathrm{Re}\{\frac{1}{a}\boldsymbol{V}_1\boldsymbol{I}_2^*\} = \mathrm{Re}\{\frac{1}{a}\boldsymbol{V}_1 a\boldsymbol{I}_1^*\} = P_1$$

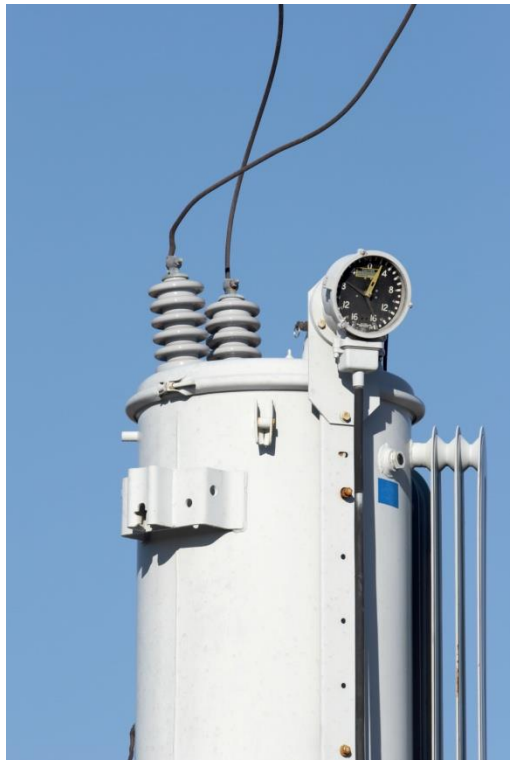
Exercise

An ideal transformer increases the voltage from 22kV to 125kV. If the current into the 22kV side has a magnitude of 10 A, what is the magnitude of the current out of the 125kV side?

Exercise

An ideal transformer increases the voltage from 22kV to 125kV. If the current into the 22kV side has a magnitude of 10 A, what is the magnitude of the current out of the 125kV side?

Answer: the ratio "a" is 22/125 = 0.176. Therefore the current is stepped down to 1.76 A.



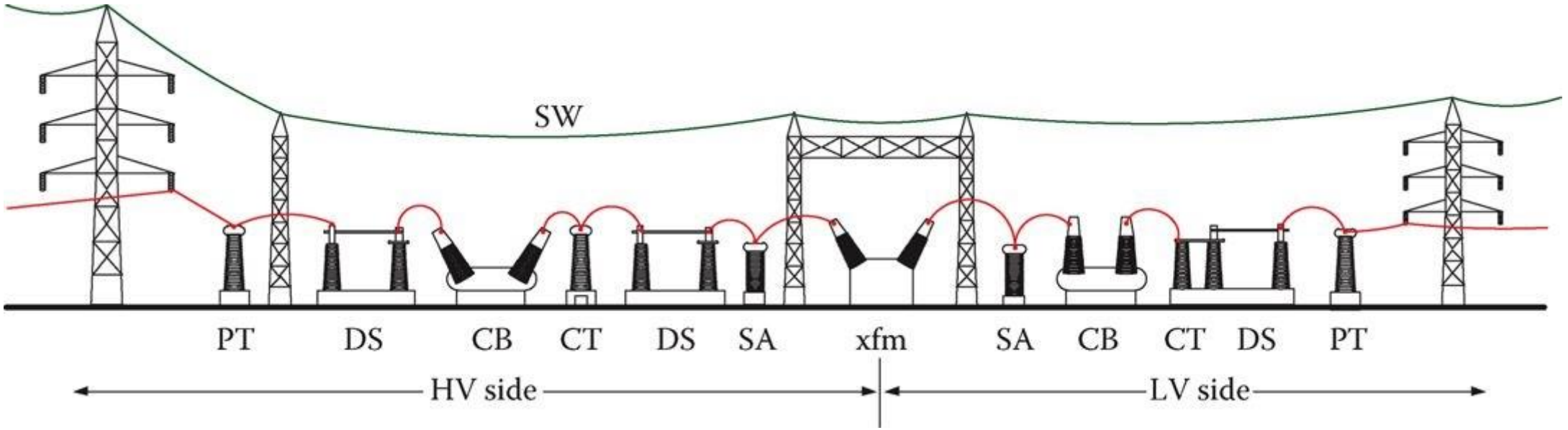
Instrument Transformers

- Some transformers are used to step-down voltage and current so they can be measured easily
- Designed to consume minimal amounts of power
- Potential Transformers (PTs or VTs)
  - Step down voltage level
  - High impedance secondary
- Current Transformers (CTs)
  - Step down current level (e.g. 100:5 ratio)
  - Very low impedance secondary

Substations

- Typical functions
  - transform the voltage level (up or down)
  - connect/disconnect (switch) transmission and distribution lines
  - measure/monitor the system
  - control voltage
  - protect equipment

Substations



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Voltage Frequency and Level Standards

- Large scale electric power systems are primarily AC
  - Several high-voltage, long distance DC transmission lines
- Frequency and voltage level differ based on local standards
  - Higher voltage: more dangerous, but less conductor is needed
  - Higher frequency: rotating machines and transformers can be smaller (less iron)
- Frequency of the voltage is proportional to the speed of generators (for mechanical reasons, we generally want generators to rotate fast)

TABLE 2.1 Standards for Voltage and Frequency in Several Nations

Country	Voltage (V)	Frequency (Hz)
Australia	230	50
Brazil	110/220	60
Canada	120	60
China	220	50
Cyprus	240	50
Egypt	220	50
Guyana	240	60
South Korea	220	60
Mexico	127	60
Japan	100	50 and 60
Oman	240	50
Russian Federation	220	50
Spain	230	50
Taiwan	110	60
United Kingdom	230	50
United States	120	60