Power Grid Operation

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Outline

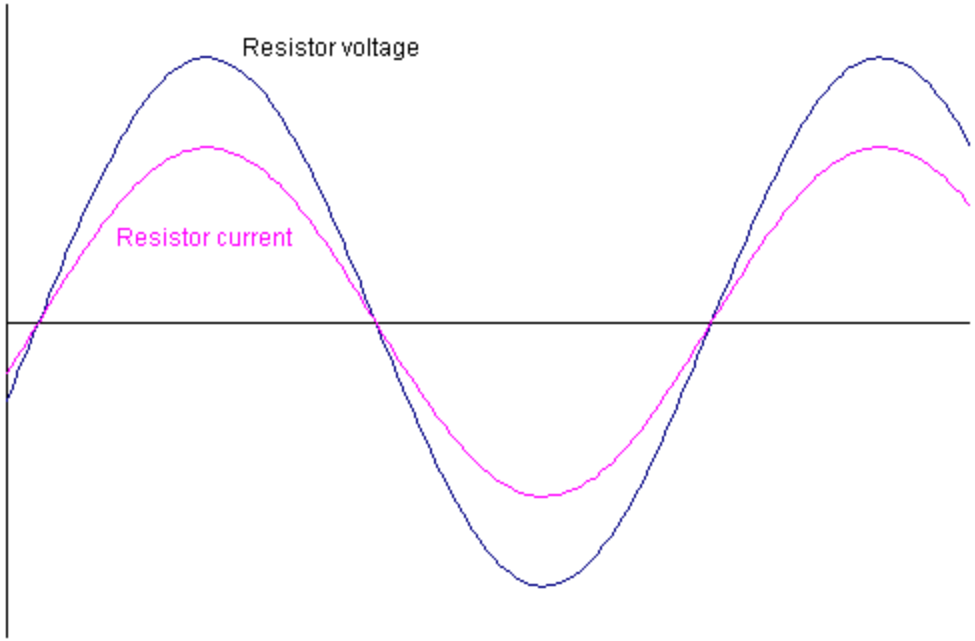
- Review from last week
- Power generation
  - Why 3 phase
  - How generators work
- Power transmission
  - Benefits and limitations of high voltage transmission
  - Grid behavior during solar flares and lightning

Types of loads

- Resistive loads: toasters, light bulbs
  - Emits light or heats up
- Inductive loads: fans, blenders
  - Require magnetic field to operate
  - Loads that have a coil of wire to produce magnetic field (motorized)
- Capacitive loads

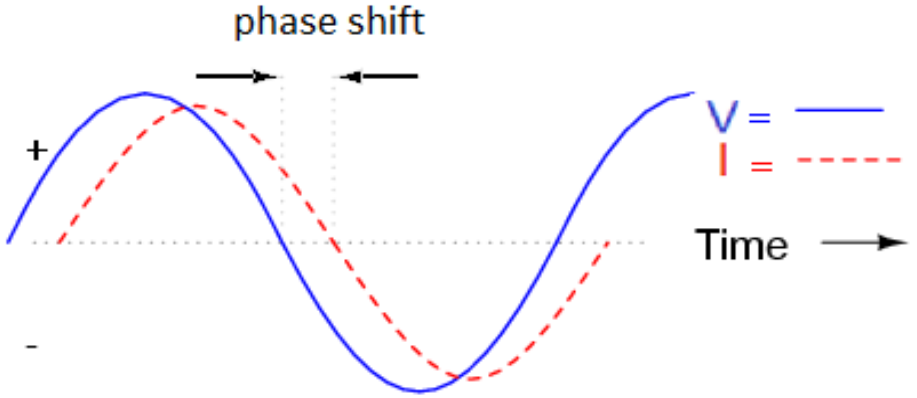
Resistive loads

- Emit light or heat up
- E.g.: toasters, light bulbs
- Voltage and current are in phase

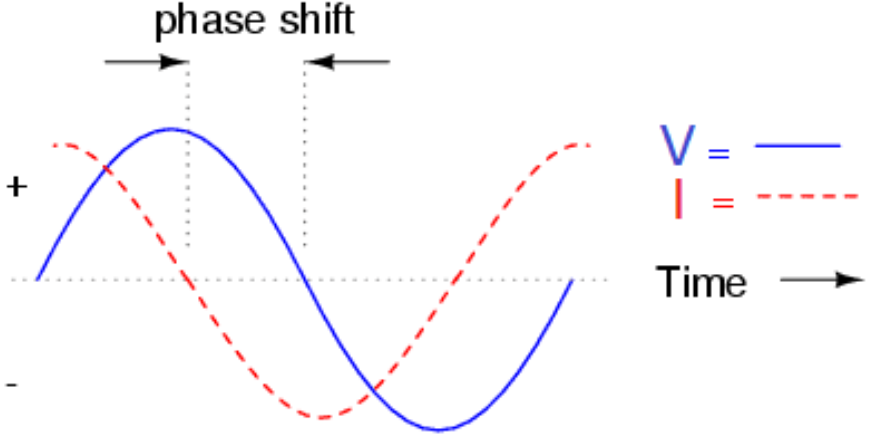


Inductive loads

- Anything with a motor is an inductive load
- Motor has coils of wires inside
  - Coils give rise to a magnetic field
  - The magnetic field energy stored in the coils draws VARs (reactive power) from the grid
- Buy a lot of these -> many inductive loads
- Voltage leads current



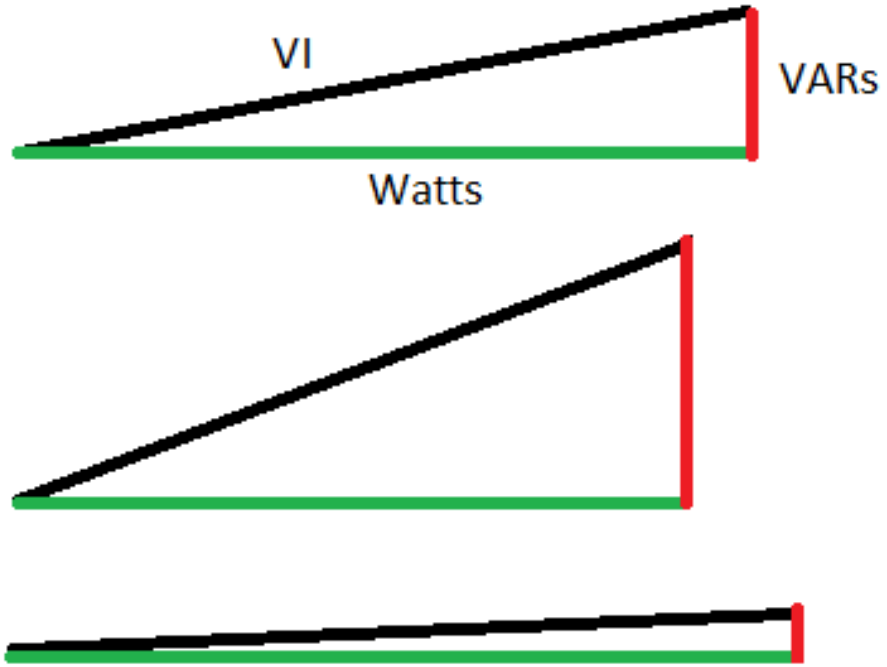
Capacitive loads



- Current leads voltage
- Capacitors supply the grid with VARs (reactive power)
- capacitive loads are not items that people buy so power companies must install capacitor banks to maintain reactive power balance—reduces current in the wires

Example

- V*I is the same but more real power (watt) available after adding a capacitor



Power Grid

Generation and Transmission

Energy

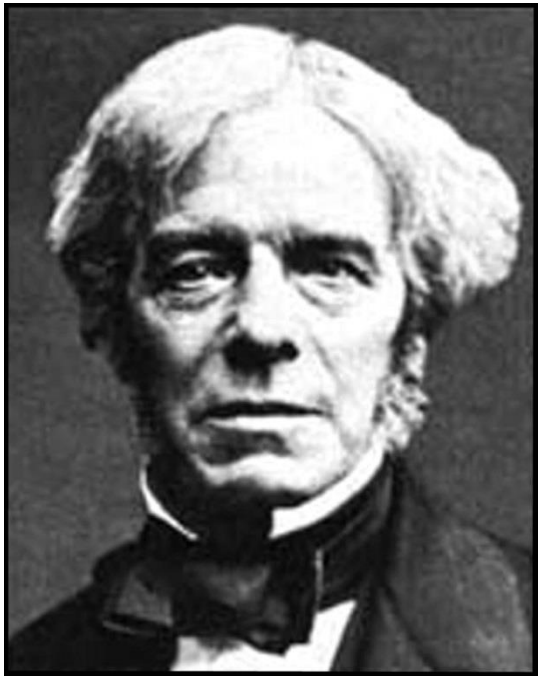
- Electrical energy is the integration of power over time
  - Joule = 1 Watt-second (J)
  - kWh = Kilowatthour (3.6×10^6 J)
- I pay 4 cents/ kWh

Why 3 phase?

- 3 phase provides constant torque when powering electric machines
- Phase current cancel each other in a balanced load system
- Cheaper to transmit compared to 1 or 2 phases
- Each phase is 120 degrees apart from the other two

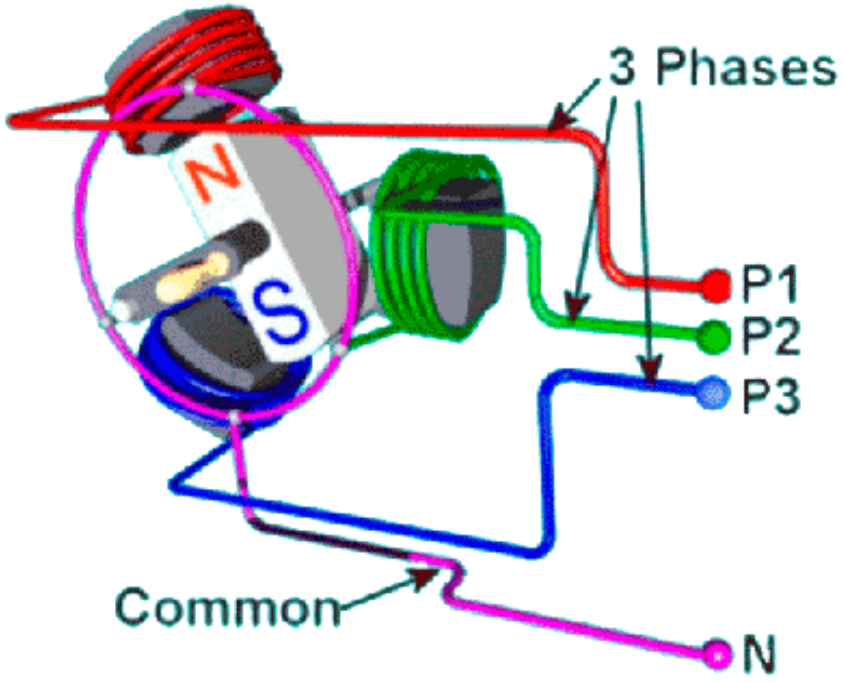
Faraday's Law

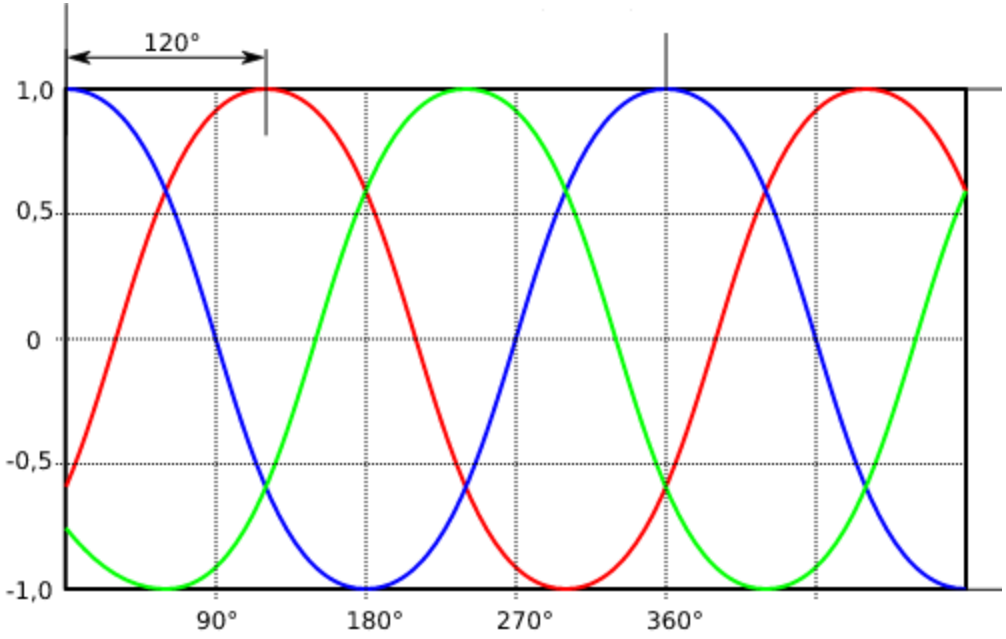
- Faraday's Law: "A voltage is produced on any conductor placed in a changing magnetic field"
- How to obtain a changing magnetic field?



Michael Faraday
1791-1867

Generators





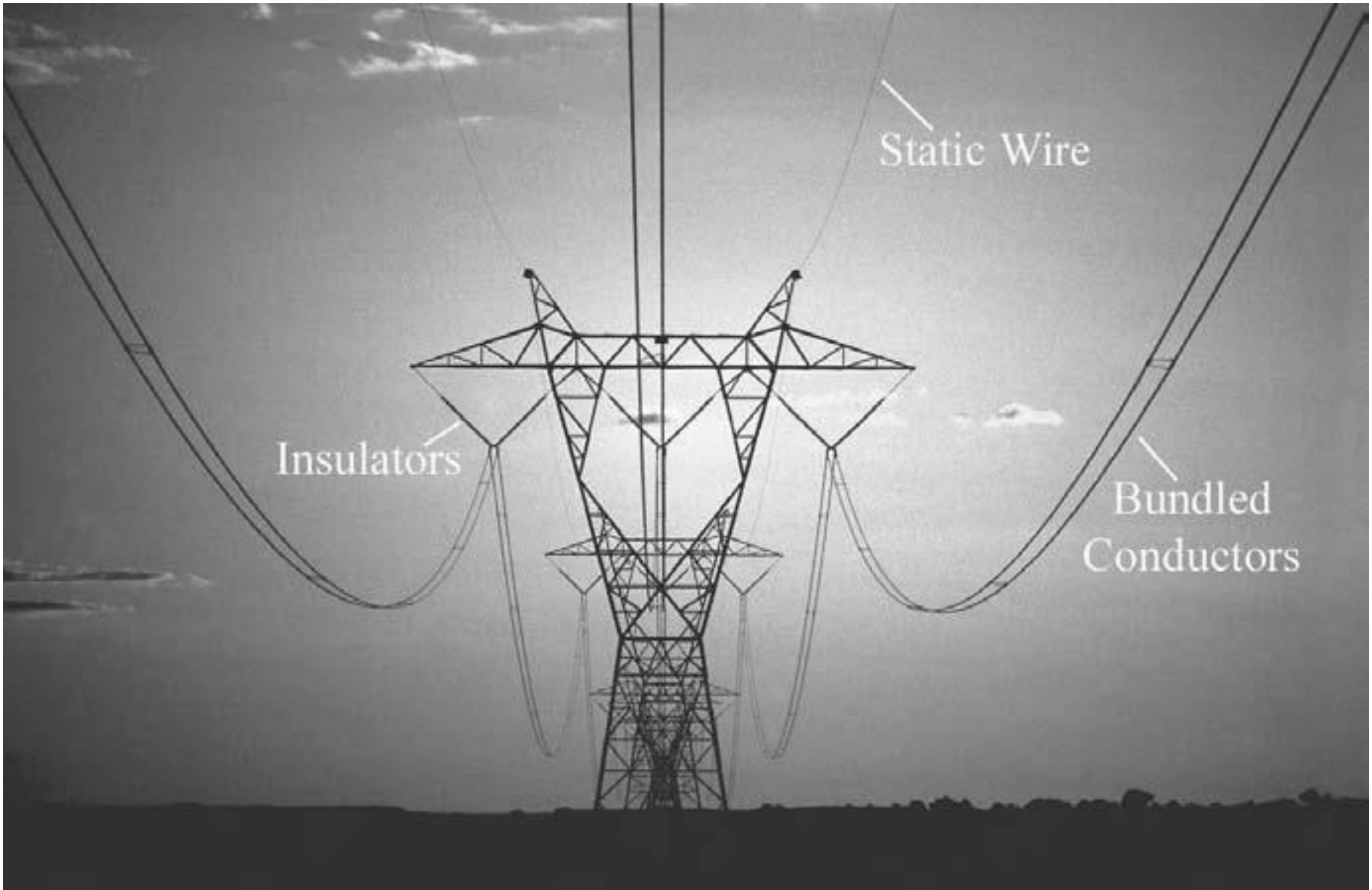
Examples

- Steam turbines
  - Fossil fuels (coal, gas, oil)
  - Nuclear
  - Geothermal
- Hydro turbines
  - Dams and rivers
- Combustion turbines
  - Diesel, natural gas
- Wind turbines

Generation Protection

- Use relays to detect abnormalities within the system
- Relays: devices that compare real time values to preprogrammed values
  - Send a signal to trip circuit breakers
- Chance of failure is small because of materials, technology and design of generators

Transmission



Transmission Voltages

Voltage class	Voltage category	System voltage
69,000		Subtransmission
115,000		
138,000		
161,000		Transmission
230,000	Extra high voltage (EHV)	
345,000		
500,000		
765,000		
Above 1,000,000	Ultra high voltage (UHV)	

Why Use High Voltage Transmission Lines?

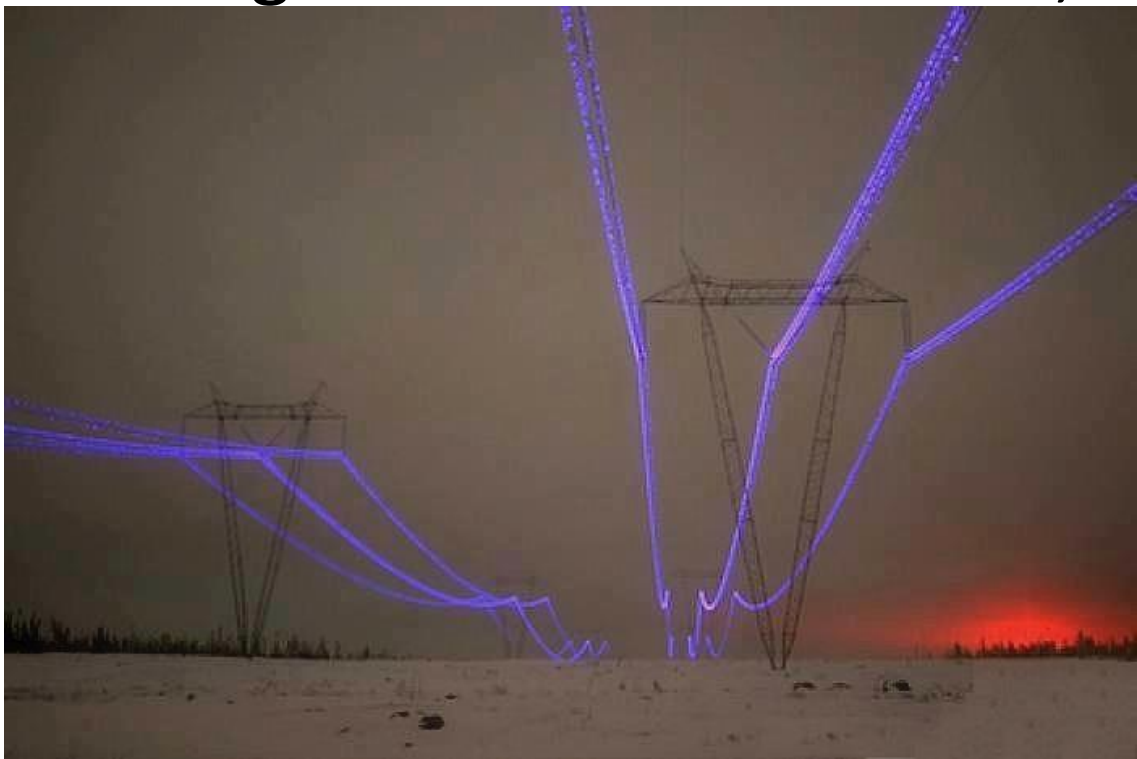
- $P = V*I$
- Losses = $I^2 * R$
- High voltage -> low current -> reduced losses

High Voltage Considerations

- Arcing occurs at high voltages
  - Rule of thumb 1 foot of air for every 100 kV for 60 Hz frequency
- Higher structures, bigger gaps between phases

Limitations for Ultra High Voltage (UHV)

- UHV -> 1 MV or higher; in Russia and China
- Towers become expensive to build
- Ionization of air -> air begins to conduct current; lose power
- Power lines start glowing due to ionization



Controversy over UHV

- Health issues from magnetic field???
- Dependency on UHV is not good
  - Lose a lot of power if line goes out

Conductors

- Copper
  - Durable and not much affected by weather
- Aluminum
  - Not as good of conductor as copper
  - Costs and weighs less, rust resistant
- Steel
  - Poor conductor compared to copper and aluminum
  - Very strong
  - Used as core of aluminum conductors

Solar Flares

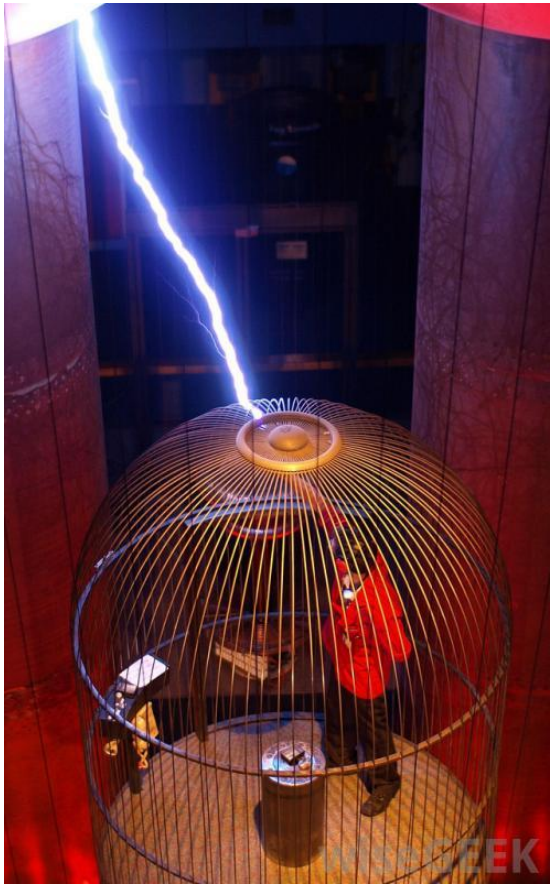
- Disturb Earth's magnetic field
- Faraday's Law -> change in magnetic field produces currents
  - Extra currents might overload lines

Lightning Strikes

1. Current spikes in the line
2. Relay detects abnormality
3. Signals circuit breakers to open the line
4. Customers lose power
5. Closes the lines after a couple of seconds
6. Customers regain power

- Relays are used for both generation and transmission protection—important to be secure

Faraday's Cage



Live Line Technique

- 100s of amps on high voltage lines
- Birds don’t get shocked because they are at the same potential

Underground Transmission

- 3 to 10 times more costly due to materials and obstacles
- Used in urban areas or near airports where overhead transmission is not an option

Key ideas to remember

- Capacitor banks balance inductive loads
- Power is transmitted in 3 phases
- Higher voltage transmission means less losses
- Relays are important protective devices
- Michael Faraday helped us better understand electricity

References

- http://faculty.ccri.edu/jbernardini/JB-Website/ETUT1160/M01/0-ETUT1160-02-WP-ElectricPowerBasics.pdf
- http://www.theamazingpics.com/wp-content/uploads/2013/01/Corona-Effect-on-750KV-Transmission-Line.jpg