Lecture 7: Electrical Transmission

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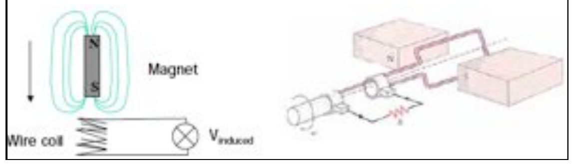
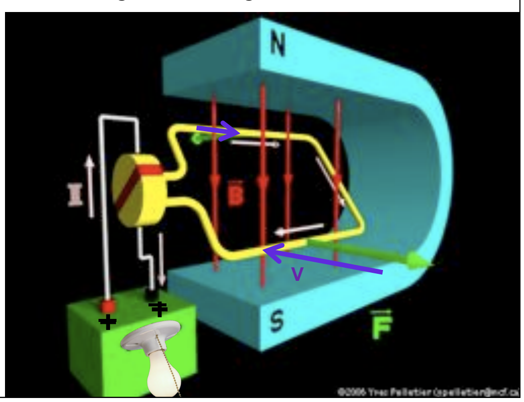
How do Transformers Work?
Why do we need high voltage?
Why do we need transformers and
why do (DID) we need AC at all?
Tesla would cry,
Edison would be (more) arrogant

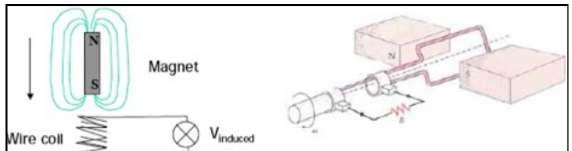
Faraday's Law

- Changing the magnetic field around a conductor will induce an electromotive force (emf, measured in volts).
- Possible sources of change: move the conductor, move the magnet, rotate a coil of wire in a magnetic field
- Faraday's Law – an emf will be created by a coil of wire with N turns when the magnetic field, Φ, that it encloses changes, $e = N \times d\Phi/dt$

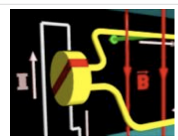


Magnets used to generate voltage and current

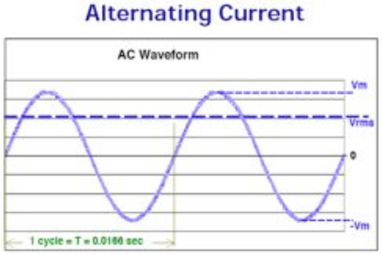




AC: Alternating Current
DC Direct Current



Alternating Current



Why AC?
- High Voltage Reduces Power Loss in Transmission
- Transformers are necessary to change Voltage
- Transformers only work with AC

What is the transmission system?

Electricity is the highest quality energy (conversion efficiency)
Electric Heaters: Electricity => Thermal Energy, $\xi \sim 100\%$???
Electric Motors: Electricity => Kinetic Energy, $\xi \sim 95\%$
Only disadvantage is that it cannot (easily) be stored.
We have to use it when we generate it.

The USA Grid is about 93% efficient: 7% of energy is lost.

At the Generator – 3 Peace Canyon Dam

Major Power System Components

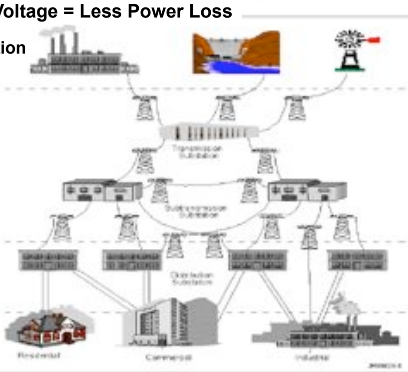
Higher Voltage = Less Power Loss

Power Generation
2 kV – 24 kV

Transmission
69 kV – 765 kV

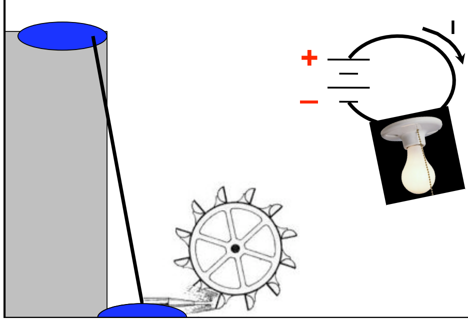
Distribution
23 kV

Load
240 V – 600V



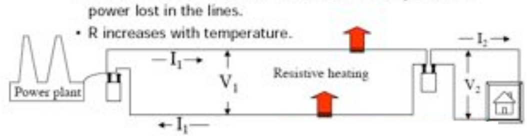
V=IR: Voltage = Current * Resistance

P = I*V = Current * Voltage….. Like Flow Rate * Pressure
= $V^2/R = I^2R$



Why does voltage matter?

- For safety, we use low voltages at end use.
- However, we need high voltages to minimize line losses.
  - $P = I^2 \cdot R = V^2/R$, no matter if the P is delivered power, or power lost in the lines.
  - R increases with temperature.



Power Transmitted = IV
Resistive loss in the lines = I^2R
So if V => HIGH voltage, Increase voltage by a factor of 10,
Current can be divided by 10,
and the power loss will decrease by 100!

Suppose you deliver 1 MW_e to another town: 10,000 V lines run with 100 A (P = IV) in a transmission line that has a resistance of 10 Ω. The drop in voltage across the lines (from one end of the transmission line) will be V = IR = 1000 V, and the power lost will be $P = V_{drop}\ I$ = 1000 V * 100 A = I^2R = 100,000 W, each way, or 10% each way, 20% total.

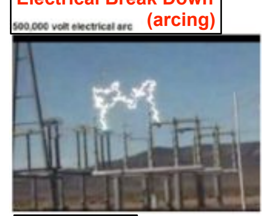
However, if first we boost the voltage to 100,000 V, we can transmit the 1 MW_e with only 10 A of current! The drop across the lines will be 100V, and the lost power will be only 1000W, or 0.1% of the transmitted power, an increase of efficiency by a factor of 100!!

Voltage is like pressure of water. So, if we increase the voltage (pressure) in the cable (hose), we can transport the same amount of power with less current flow, less resistive losses. The cables (hoses) can be of smaller diameter, we save money. So we increase voltage (pressure) until….

Corona Discharge

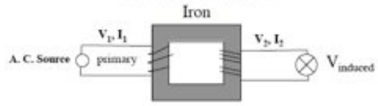
Water Leaks

Electrical Break Down (arcing)



Hose Bursts

Transformers



- The magnetic field is created in the iron 'core' by the alternating primary voltage, V_1. This change provides the necessary motion.
- From Faraday's law: $V_1 = N_1 \times d\Phi/dt$, $V_2 = N_2 \times d\Phi/dt$
- Set up an equality, $V_1/N_1 = V_2/N_2$, or $V_2 = V_1(N_2/N_1)$
- Now, we can change voltage *in an AC system* with step-up and step-down xfmrs.
- Conservation of energy allows calculation of current, $V_1I_1 = V_2I_2$, $I_2=I_1(V_1/V_2)$, $I_2=I_1(N_1/N_2)$

Why do we have Alternating Current?

Implications for system design

- 20th century
  - Safe, efficient, socially acceptable, and profitable electricity systems required large generators and long-distance transmission
  - Long-distance transmission requires high voltages, which imply the need for AC power, given available technologies
- 21st century
  - Power electronics allow for long-distance DC transmission
  - Interest in using waste heat, renewables, low-impact technologies may reduce the need for transmission (or it may not)

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