PHYS 1441 – Section 002
Lecture #22

Monday, Nov. 30, 2020

Dr. Jaehoon Yu

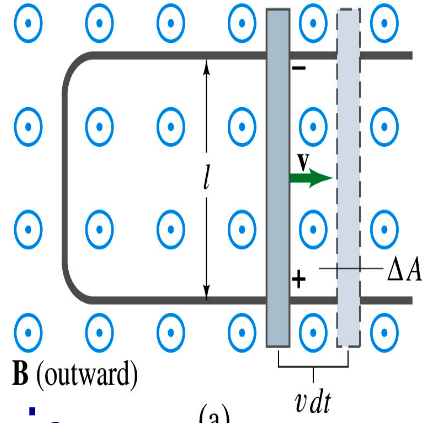
- CH29
  - Generation of Electricity
  - Transformer and Transformer Equation
  - Electric Field due to Changing Magnetic Flux
  - Generalized Faraday's Law
- CH30
  - Inductance
  - Mutual and Self Inductance

Announcements

- Reading assignments: CH29.5, CH29.8
- Final comprehensive exam on Quest
  - 11am – 12:30pm, Wednesday, Dec. 16
    - Roll call begins at 10:45am, Wed. Dec. 16
  - Covers: CH21.1 – what we finish next Monday, Dec. 7
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the exam
  - No derivations, word definitions, setups or solutions of any problems, figures, pictures, diagrams or arrows, etc!
  - No additional formulae or values of constants will be provided!
  - Must send me the photos of front and back of the formula sheet, including the blank, no later than **9:00am the day of the test**
    - Once submitted, you cannot change, unless I ask you to delete some part of the sheet!
- Course feedback survey should be done ASAP!

EMF Induced on a Moving Conductor

- Another way of inducing EMF is using a U-shaped conductor with a movable rod resting on it.
- As the rod moves at a speed ***v***, it travels ***v*dt** in time **dt**, changing the area of the loop by **dA=*lv*dt**.



- Using Faraday's law, the induced EMF for this loop is

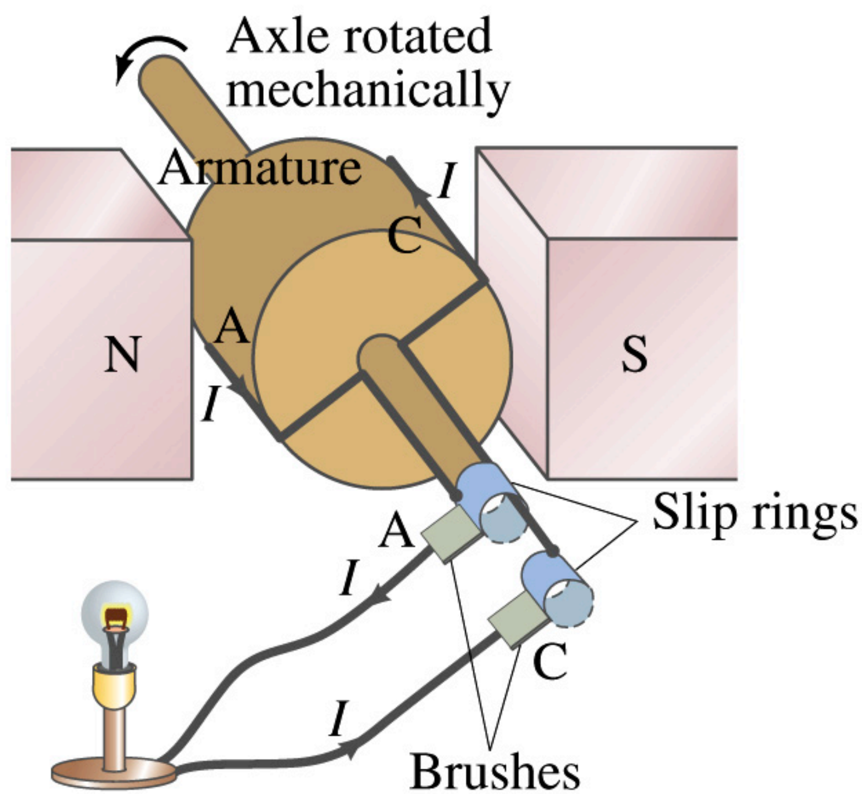
$$|\varepsilon| = \frac{d\Phi_B}{dt} = \frac{BdA}{dt} = \frac{Blvdt}{dt} = Blv$$

  – This equation is valid as long as **B**, *l* and **v** are perpendicular to each other. What do we do if not?
    - Use the scalar product of vector quantities

- An emf induced on a conductor moving in a magnetic field is called a **motional EMF**

Electric Generators

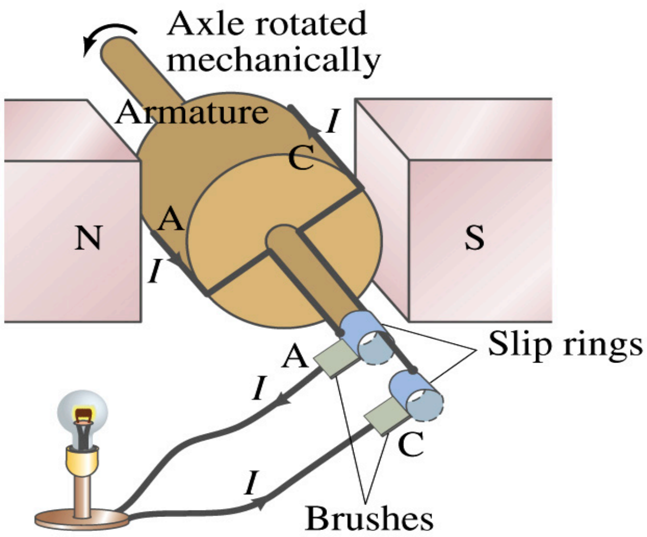
- What does a generator do?
  - Transforms mechanical energy into the electrical energy
  - What does this look like?
    - An inverse of an electric motor which transforms electrical energy to mechanical energy
  - An electric generator is also called a dynamo



- Whose law does the generator based on? (poll 17)
  - Faraday's law of induction

How does an Electric Generator work?

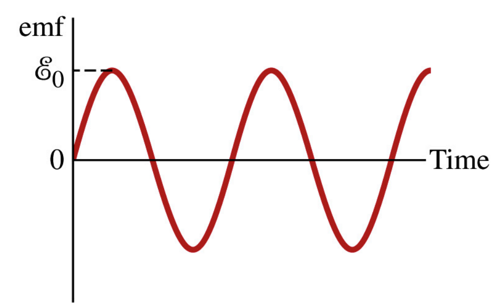
- An electric generator consists of
  - Many coils of wires wound on an armature that can rotate by mechanical means in a magnetic field
- An emf is induced in the rotating coil
- Electric current is the output of a generator



- Which direction does the output current flow when the armature rotates counterclockwise?
  - The conventional current flows outward on wire A toward the brush
  - After half the revolution the wire A will be where the wire C is and the current flow on A is reversed
- Thus the current produced is alternating its direction

How does an Electric Generator work?

- Let's assume the loop is rotating in a uniform B field w/ a constant angular velocity **ω**. The induced emf is
- $$\varepsilon = -\frac{d\Phi_B}{dt} = -\frac{d}{dt}\int \vec{B}\cdot d\vec{A} = -\frac{d}{dt}\left[BA\cos\theta\right]$$
- What is the variable that changes above?
  - The angle **θ**. What is **dθ/dt**?
    - The angular speed **ω**.
  - So we can express **$\theta=\theta_0+\omega t$**
  - If we choose **$\theta_0=0$**, we obtain
  - $$\varepsilon = -BA\frac{d}{dt}\left[\cos\varpi t\right] = BA\varpi\sin\varpi t$$
  - If the coil contains **N** loops: $$\varepsilon = -N\frac{d\Phi_B}{dt} = NBA\varpi\sin\varpi t = \varepsilon_0\sin\varpi t$$
  - What is the shape of the output?
    - Sinusoidal w/ the amplitude **ε_0=NBAω**



- USA frequency is 60Hz. Europe is at 50Hz
  - Most the U.S. power is generated at steam plants

Example 29 – 9

An AC generator. The armature of a 60-Hz AC generator rotates in a 0.15-T magnetic field. If the area of the coil is $2.0\times10^{-2}m^2$, how many loops must the coil contain if the peak output is to be ε_0=170V?

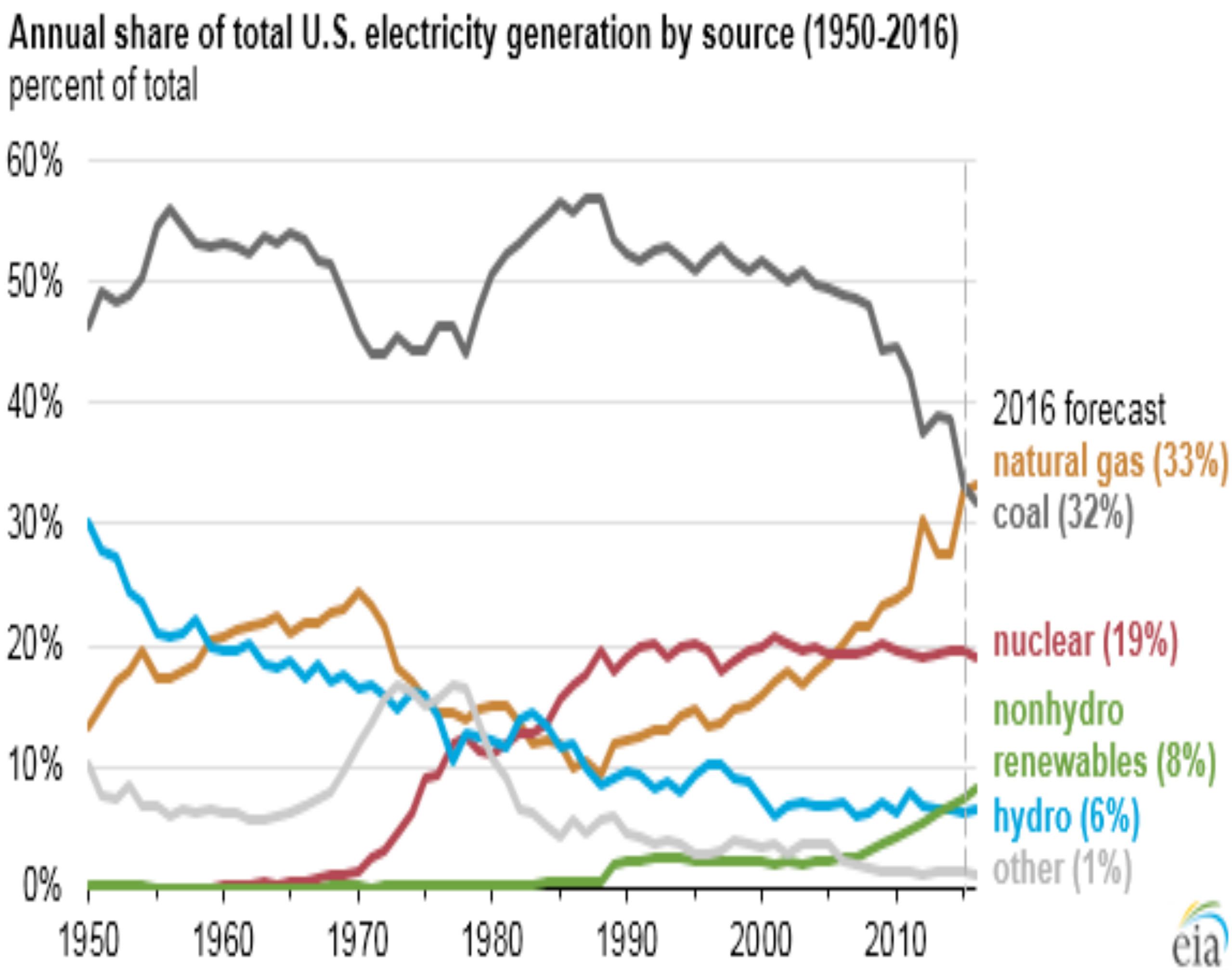
The maximum emf of a generator is $\varepsilon_0 = NBA\varpi$

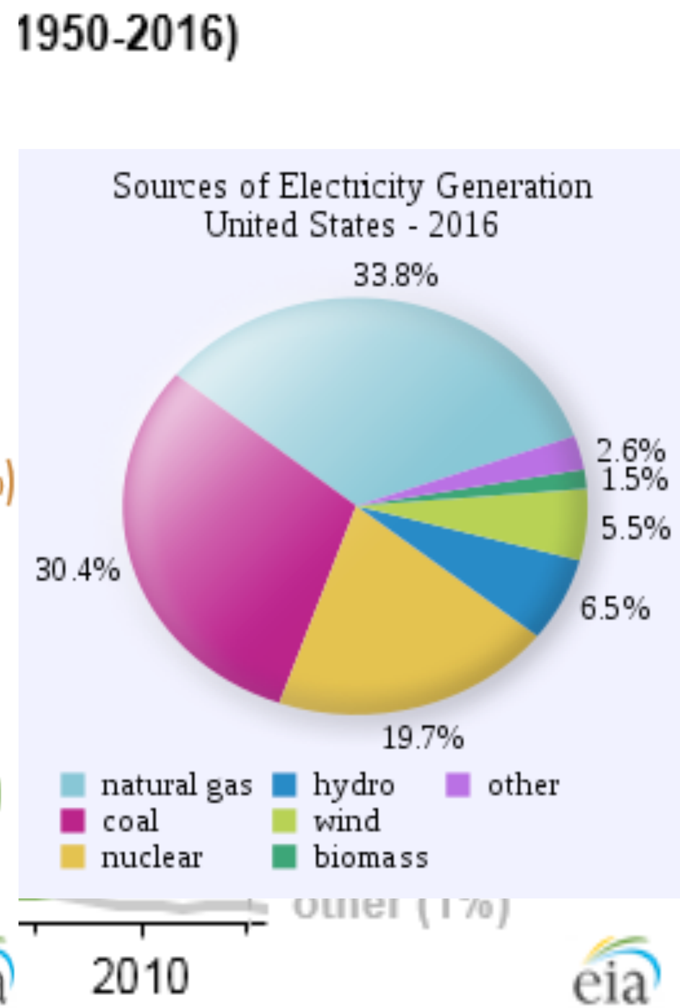
Solving for N $N = \dfrac{\varepsilon_0}{BA\varpi}$

Since $\varpi = 2\pi f$ We obtain

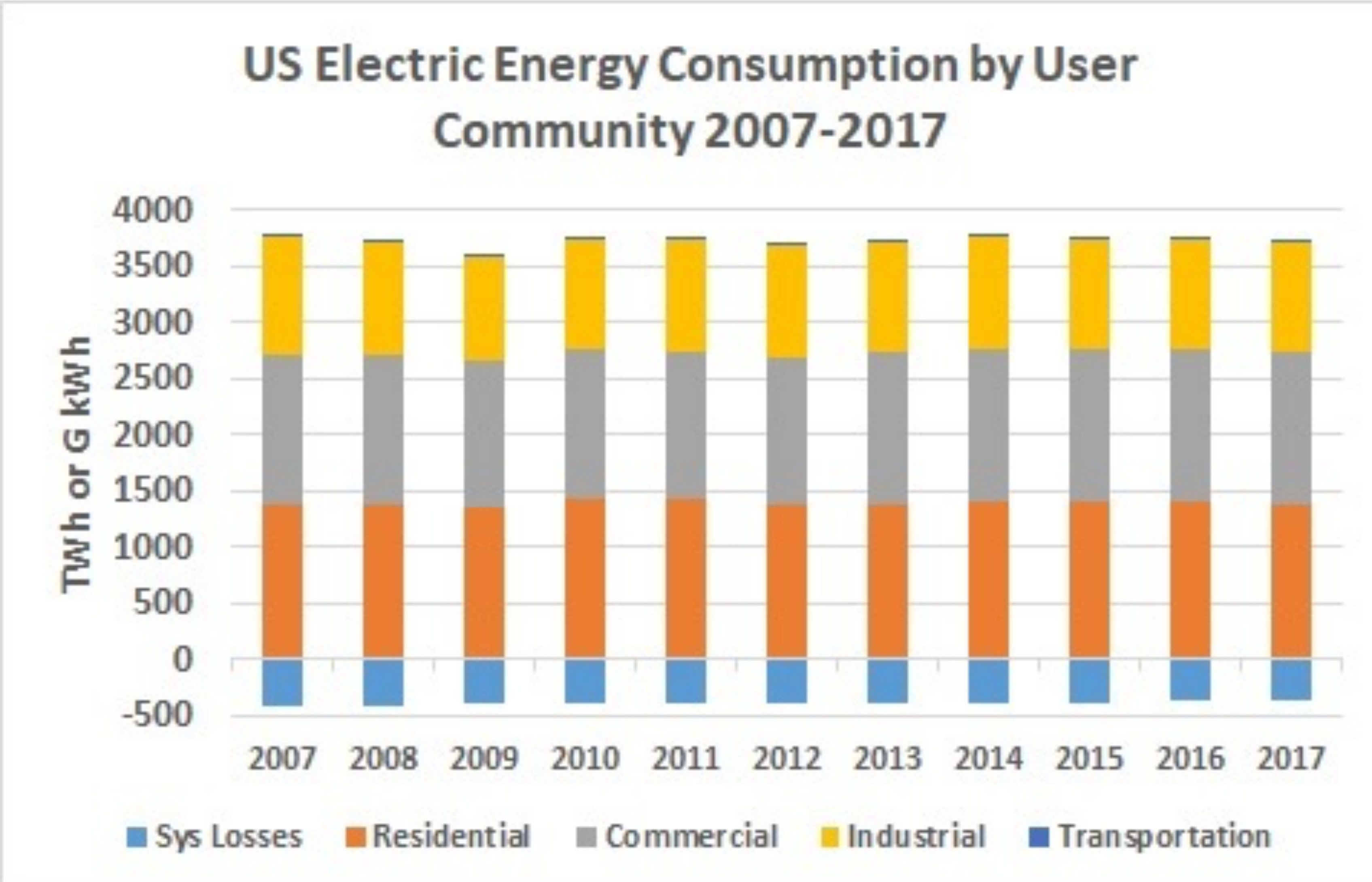
$$N = \frac{\varepsilon_0}{2\pi BAf} = \frac{170V}{2\pi\cdot(0.15T)\cdot\left(2.0\times10^{-2}m^2\right)\cdot\left(60s^{-1}\right)} = 150 turns$$

US Electricity Sources





US Electric E Consumption by Users



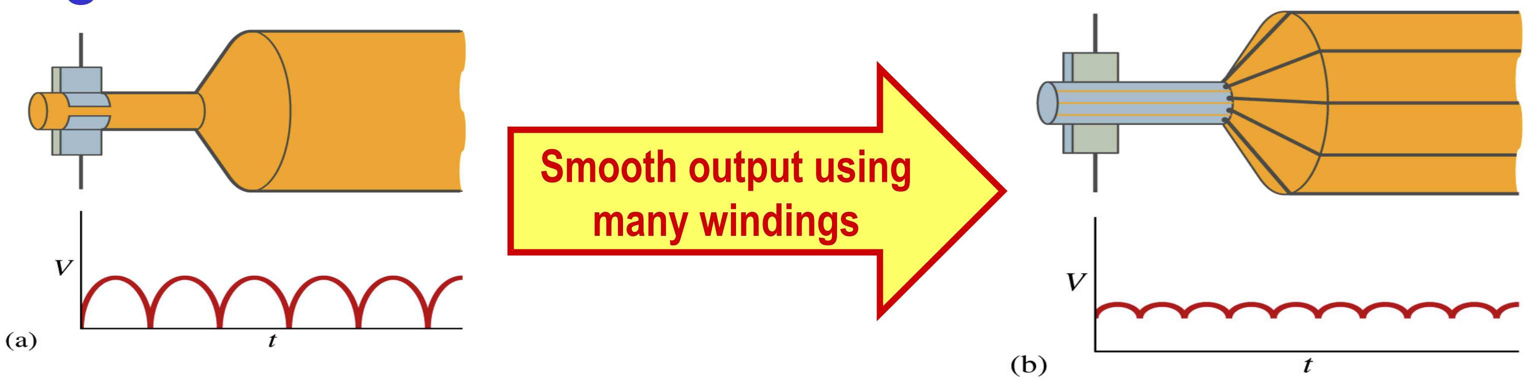
US Energy Information Administration http://www.eia.gov/electricity/

The World Energy Consumption

- In 2016, total worldwide energy consumption was 567 EJ (567×10^{18} J=157 PWh)➔ expected >1000EJ by 2050
  - Equivalent to an average energy consumption rate of 18 terawatts (1.8×10^{13} W)
  - U.S. uses 39.1 PWh (~25% of total, 1.38kWh/person, as of 2014)
- The potential for renewable energy
  - solar energy 1600 EJ (444,000 TWh)
  - wind power 600 EJ (167,000 TWh)
  - geothermal energy 500 EJ (139,000 TWh),
  - biomass 250 EJ (70,000 TWh)
  - hydropower 50 EJ (14,000 TWh) an
  - ocean energy 1 EJ (280 TWh)
  - Read this paper if you want to learn more

A DC Generator

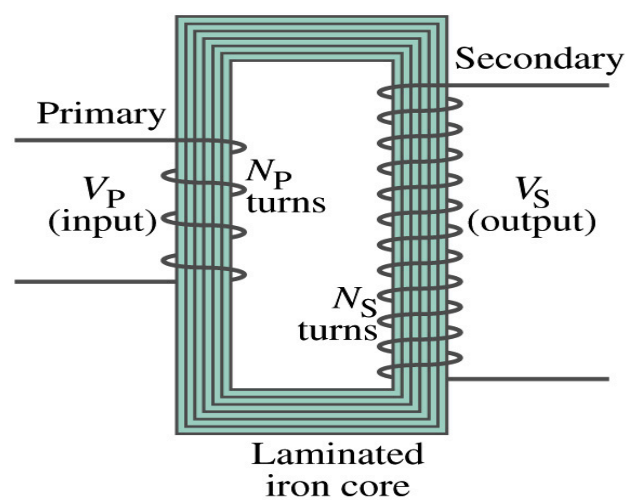
- A DC generator is almost the same as an AC generator except the slip rings are replaced by split-ring commutators



- Output can be smoothed out by placing a capacitor in parallel to the output
  – More commonly done using many armature windings

Transformer

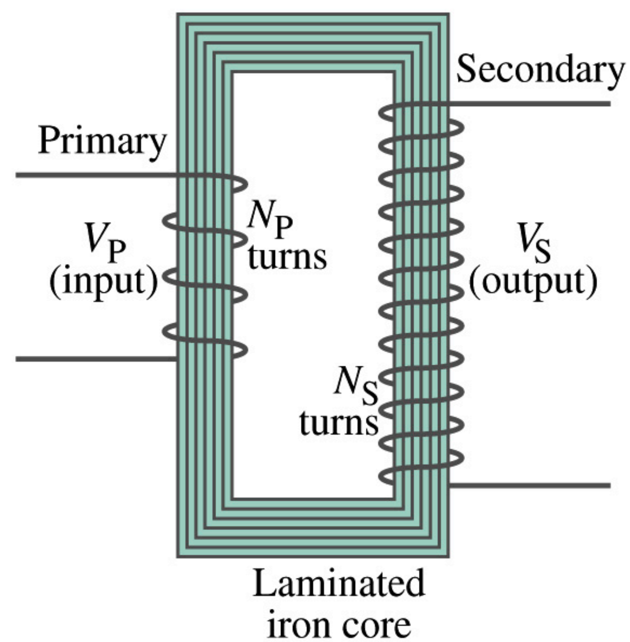
- What is a transformer?
  - A device for increasing or decreasing an AC voltage
  - A few examples?
    - TV sets to provide the high voltage to picture tubes, portable electronic device converters, transformers on the pole, etc
- A transformer consists of two coils of wires known as the primary and the secondary
  - The two coils can be interwoven or linked by a laminated soft iron core to reduce losses due to Eddy current
- Transformers are designed so that all magnetic flux produced by the primary coil pass through the secondary



How does a transformer work?

- When an AC voltage is applied to the primary, the changing B it produces will induce voltage of the same frequency in the secondary wire
- So how would we make the voltage different?
  - By varying the number of loops in each coil
  - From Faraday's law, the induced emf in the secondary is
  - $V_S = N_S \frac{d\Phi_B}{dt}$
  - The input primary voltage is
  - $V_P = N_P \frac{d\Phi_B}{dt}$
  - Since **$d\Phi_B/dt$** is the same, we obtain
  - $\boxed{\frac{V_S}{V_P} = \frac{N_S}{N_P}}$

Transformer Equation



Transformer Equation

- The transformer equation does not work for DC current
  - Since there is no change of magnetic flux!!
- If **$N_S > N_P$**, the output voltage is greater than the input so it is called a **step-up transformer** while **$N_S < N_P$** is called **step-down transformer**
- Now, it looks like energy conservation is violated since we can get more emf from smaller ones, right?
  - Wrong! Wrong! Wrong! Energy is always conserved!
  - A well-designed transformer can be more than 99% efficient
  - The power output is the same as the input:
  - $V_P I_P = V_S I_S$
  - $\boxed{\dfrac{I_S}{I_P} = \dfrac{V_P}{V_S} = \dfrac{N_P}{N_S}}$

The output current for a step-up transformer will be lower than the input, while it is larger for a step-down x-former than the input.

Example for A Transformer

Portable radio transformer. A transformer for home use of a portable radio reduces 120-V AC to 9.0V AC. The secondary contains 30 turns, and the radio draws 400mA. Calculate (a) the number of turns in the primary (b) the current in the primary and (c) the power transformed.

(a) What kind of a transformer is this? A step-down x-former

Since $\frac{V_P}{V_S} = \frac{N_P}{N_S}$ We obtain $N_P = N_S \frac{V_P}{V_S} = 30 \frac{120V}{9V} = 400 turns$

(b) Also from the transformer equation $\frac{I_S}{I_P} = \frac{V_P}{V_S}$ We obtain

$$I_P = I_S \frac{V_S}{V_P} = 0.4A \frac{9V}{120V} = 0.03A$$

(c) Thus the power transformed is

$$P = I_S V_S = (0.4A) \cdot (9V) = 3.6W$$

How about the input power? The same assuming 100% efficiency.

Ex. 29 – 13 Power Transmission – Why HV?

Transmission lines. An average of 120kW of electric power is sent to a small town from a power plant 10km away. The transmission lines have a total resistance of 0.4Ω. Calculate the power loss if the power is transmitted at (a) 240V and (b) 24,000V.

We cannot use $P=V^2/R$ since we do not know the voltage along the transmission line. We, however, can use $P=I^2R$.

(a) If 120kW is sent at 240V, the total current is

$$I=\frac{P}{V}=\frac{120\times10^3}{240}=500A.$$

Thus the power loss due to transmission line is

$$P=I^2R=(500A)^2\cdot(0.4\Omega)=100kW$$

(b) If 120kW is sent at 24,000V, the total current is

$$I=\frac{P}{V}=\frac{120\times10^3}{24\times10^3}=5.0A.$$

Thus the power loss due to transmission line is

$$P=I^2R=(5A)^2\cdot(0.4\Omega)=10W$$

The higher the transmission voltage, the smaller the current, causing less loss of energy. This is why power is transmitted w/ HV, as high as 170kV.