CG1111: Engineering Principles and Practice I

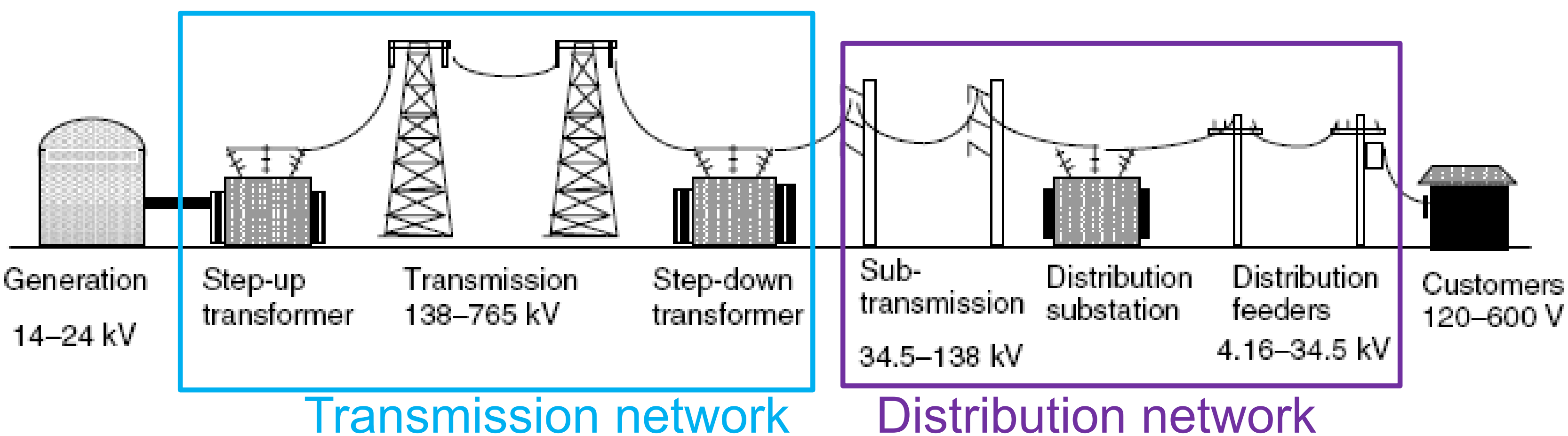
Preparation for Week 7, Studio 1

Principles of Transformers

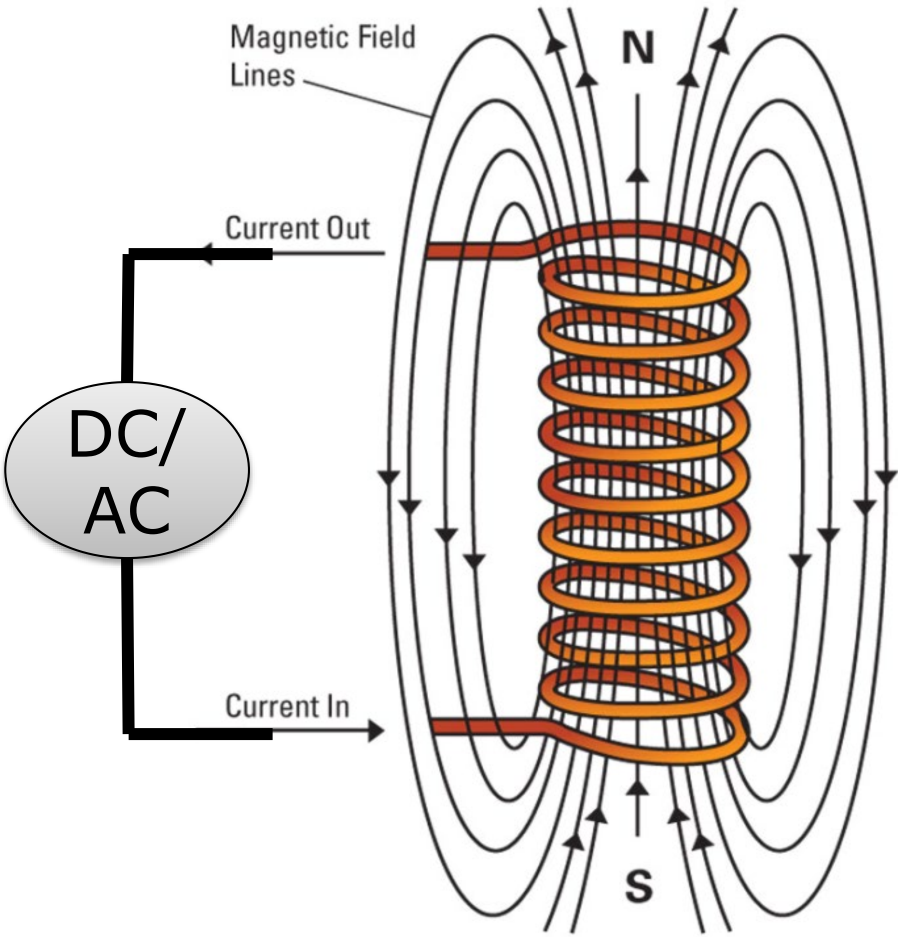
National University of Singapore

Why Transformers???

- Transformers are used to step up voltages from generation units to transmission-line and to step down voltage from transmission to end users.
- Transformers are important in electrical energy systems. With transformers, the overall efficiency can be improved.



Magnetic Flux



- DC source → Constant magnetic flux
- AC source → Varying magnetic flux

What will happen if we have another coil to link the varying magnetic flux?

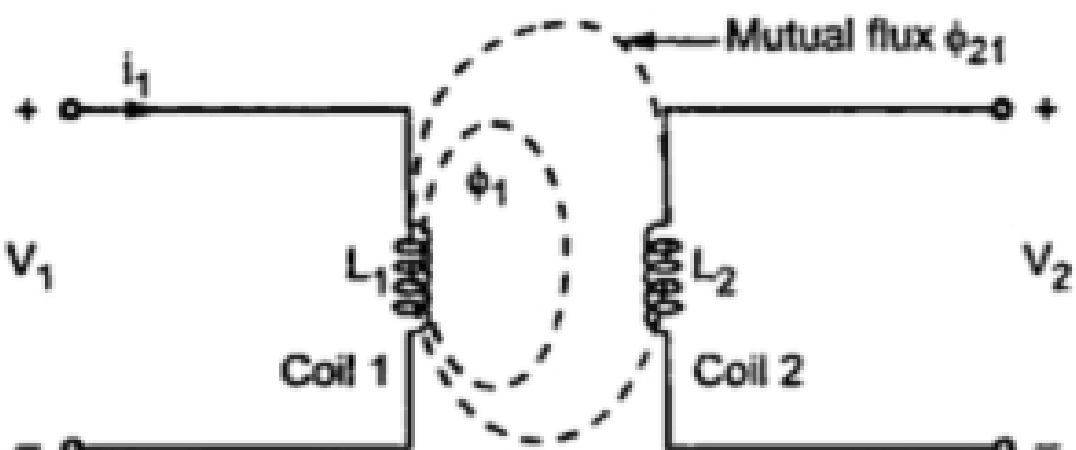
Source: http://www.lanl.gov/news/index.php/fuseaction/1663.article/d/20085/id/13276

Electromagnetic Induction

- Recall Faraday's law:

$$e = N\frac{d\phi}{dt}$$

- When we link Coil 2 to the magnetic flux generated by coil 1, if the flux is varying, there will be induced electromotive force (EMF) V_2, at Coil 2.



Source http://yourelectrichome.blogspot.com/2011/07/introduction-to-coupled-circuit.html

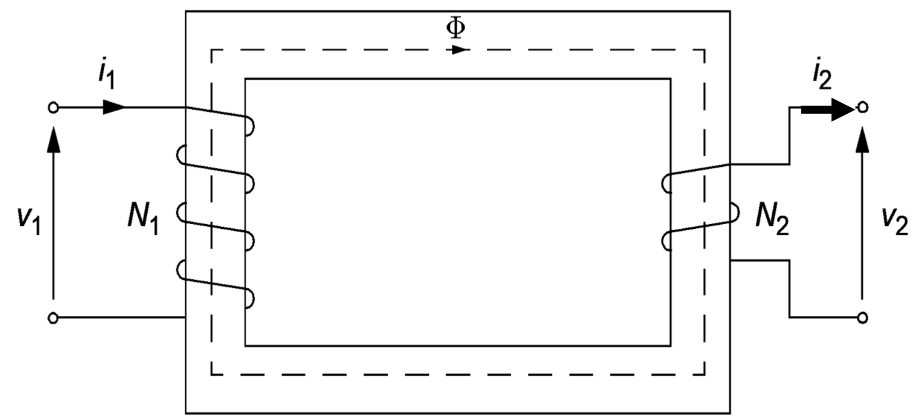
Transformer: Voltage Ratio

- For **ideal** transformer, we assume that the flux linkage at coil 1 and coil 2 is the same i.e. there is <u>no flux linkage loss</u>.
- We can now find a relationship between the voltages at two sides of the transformer as follows.

$$V_1 = N_1 (j\omega)\Phi = N_1 (j\omega) BA$$

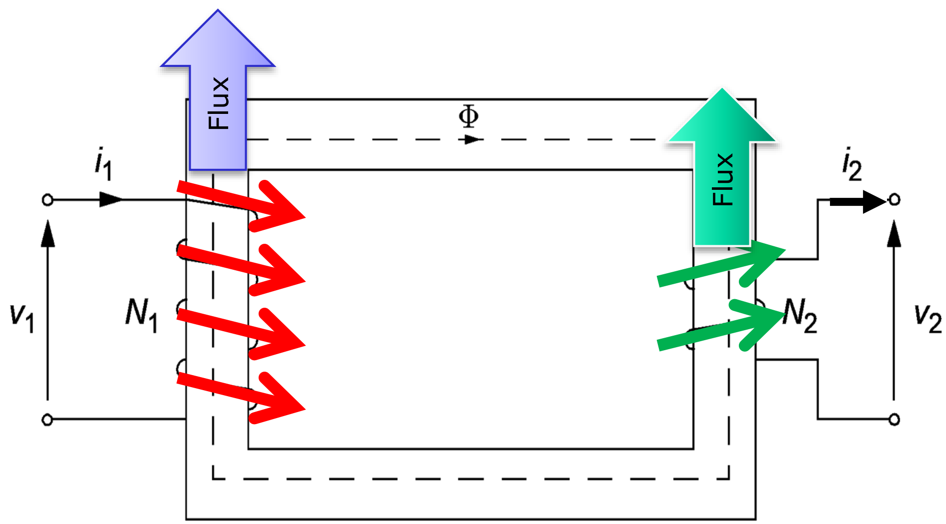
$$V_2 = N_2 (j\omega)\Phi = N_2 (j\omega) BA$$

$$\Rightarrow \boxed{\frac{V_1}{V_2} = \frac{N_1}{N_2}}$$



Ampere's Law Applied to Transformers

- "Magnetic flux along the path equals the net current enclosed by the path"
  - H – Magnetic Field Intensity
  - B = μ H = Magnetic Field Density



i_1N_1 $\quad$ $-i_2N_2$

$$Hl_{path} = I_{enclosed}$$

$$Hl_{path} = i_1N_1 - i_2N_2$$

$$\frac{Bl_{path}}{\boxed{\mu}} = i_1N_1 - i_2N_2$$

Magnetic permeability

Transformer: Current Ratio

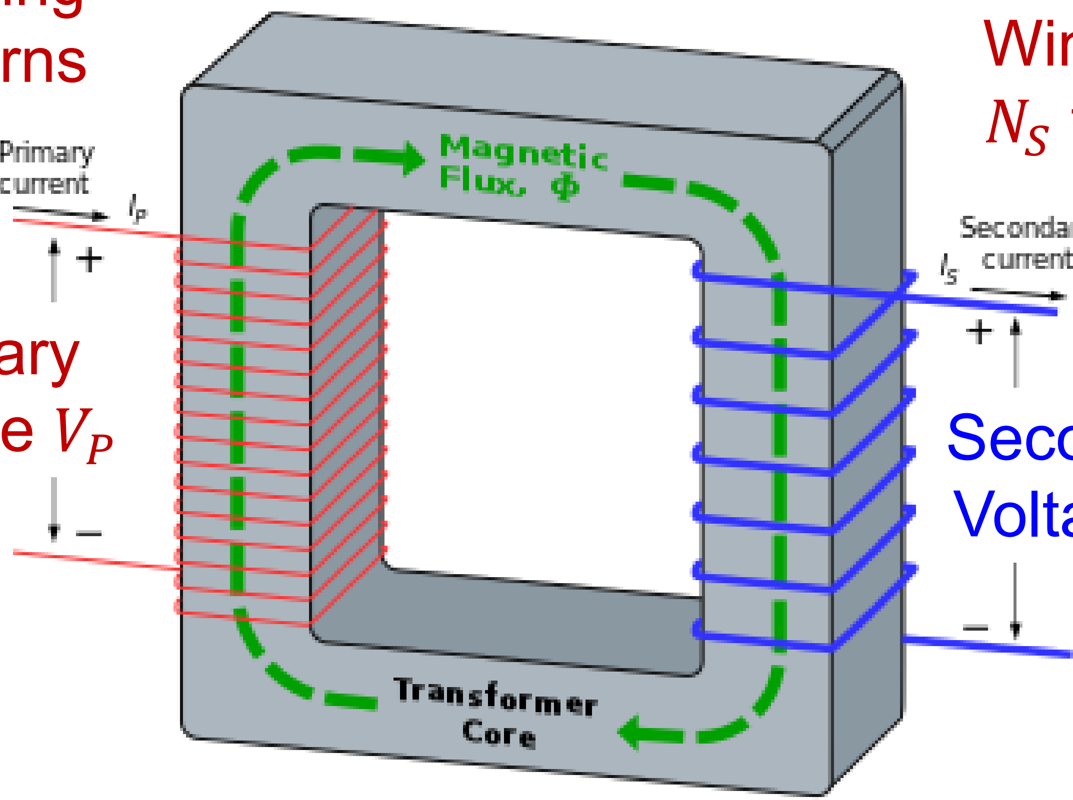
- Note that magnetic core permeability (μ) represents the degree of magnetization that the magnetic core will allow the magnetomotive force to pass through.
- For **ideal transformer**, the value of the permeability is infinity.
- We can now see the relationship of the current from both sides of the transformers.

$$\frac{Bl_{path}}{\mu} = i_1 N_1 - i_2 N_2 \quad \Rightarrow \quad \boxed{i_1 N_1 = i_2 N_2}$$

Step-Up/Down Transformer

Primary Winding N_P turns

Secondary Winding N_S turns



Primary Voltage V_P

Secondary Voltage V_S

$$\boxed{\frac{V_S}{V_P} = \frac{N_S}{N_P}}$$

$$\boxed{\frac{I_S}{I_P} = \frac{N_P}{N_S}}$$

Transformer: Complex Power

- Complex power *at* *primary* *side*,

$$S_1 = V_1 I_1^* = aV_2\left(\frac{I_2}{a}\right)^* = V_2 I_2^* = S_2$$

- **is the same as** the complex power *at secondary side*.
- This means that ideal transformer has **no real/reactive power losses**.

THANK YOU