Lecture 16: Transformers

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Electrical Transmission

- Electrical equipment use low voltage
  - 120 V, 240 V, 277 V, 480 V
- Electricity generated at medium voltages
  - Generally between 13 kV to 100 kV
- Electrical transmission at high voltages
  - 100 kV to 765 kV
- Long distance transmission (rural areas)
  - Greater than 765 kV

Electrical Transmission cont.

- Electrical equipment use low voltage
  - Primarily for safety

- Electrical transmission at high voltages
  - Efficient
  - Cost effective

- Transmission Losses
  - Some resistance in cables

$$P = I^2 R$$

Reduce current = less loss

Transformers

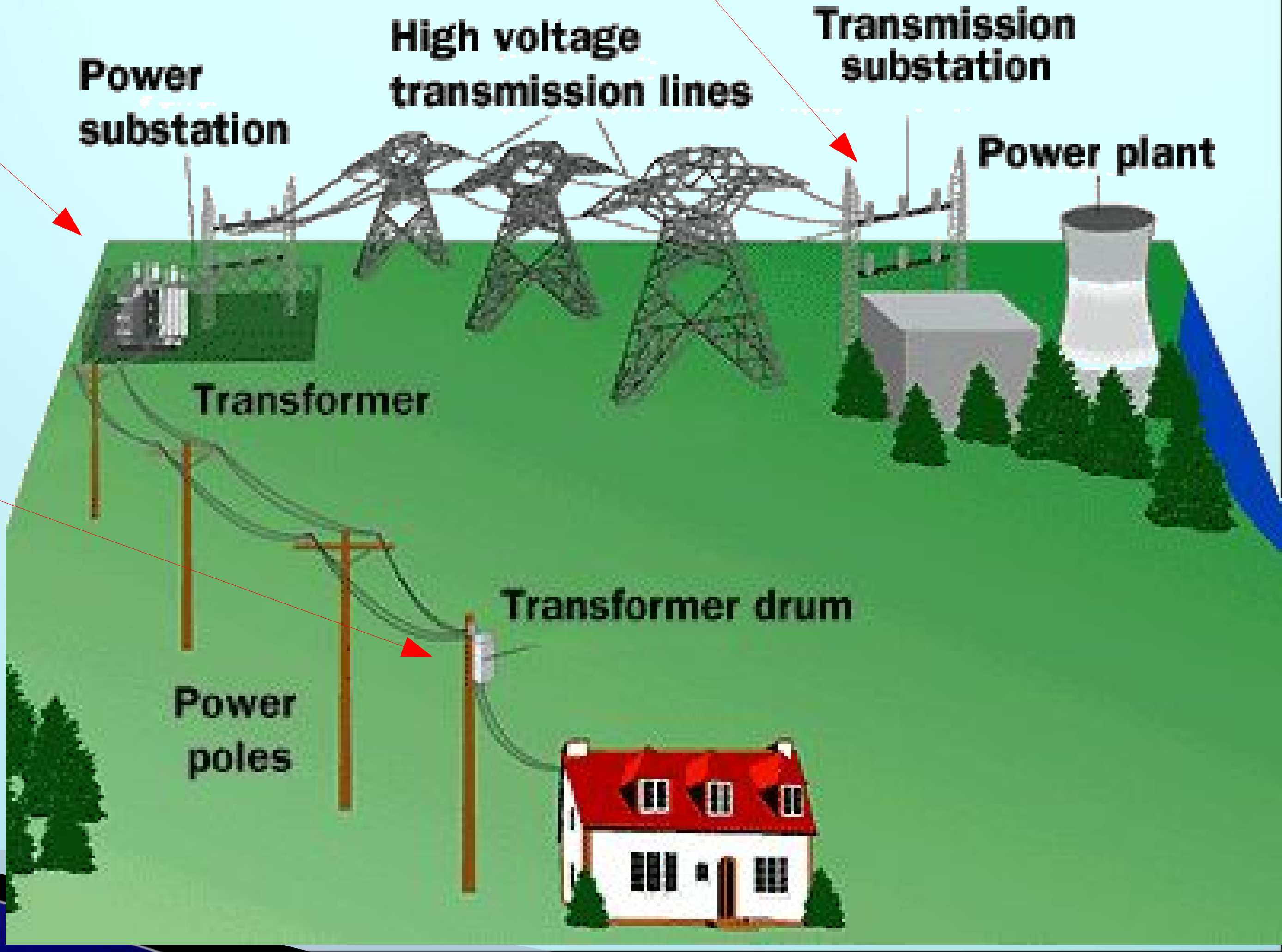
- Used to change the voltage level
  - Step-up transformers increase voltage
  - Step-down transformers decrease voltage
- Power system applications
  - Step-up for transmission
  - Step-down for distribution
  - Maintain voltage levels of distribution
- Other applications
  - Electrical isolation
  - Impedance matching (e.g. audio systems)

Transformers in the Electrical Power System

Step-up transformer

Step-down transformer

Step-down transformer



Transformer Operation

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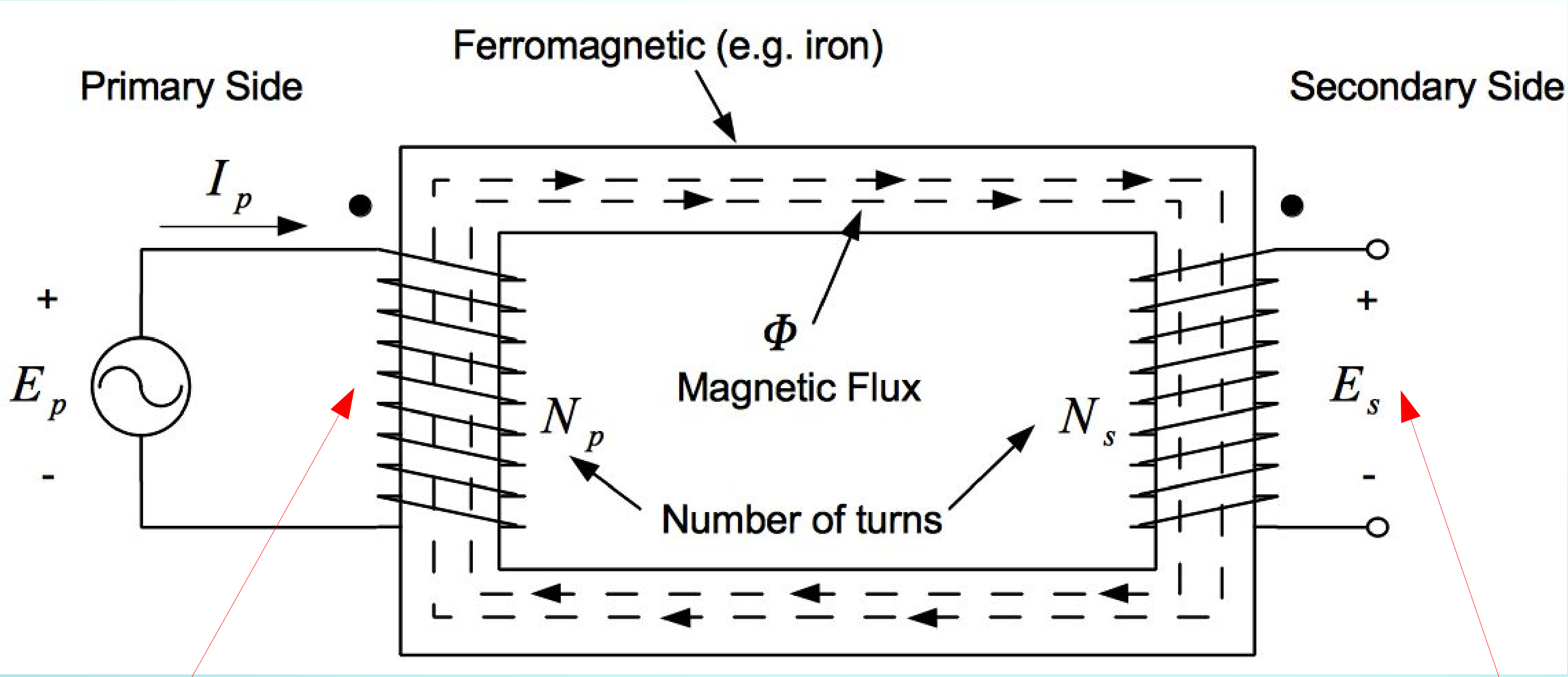
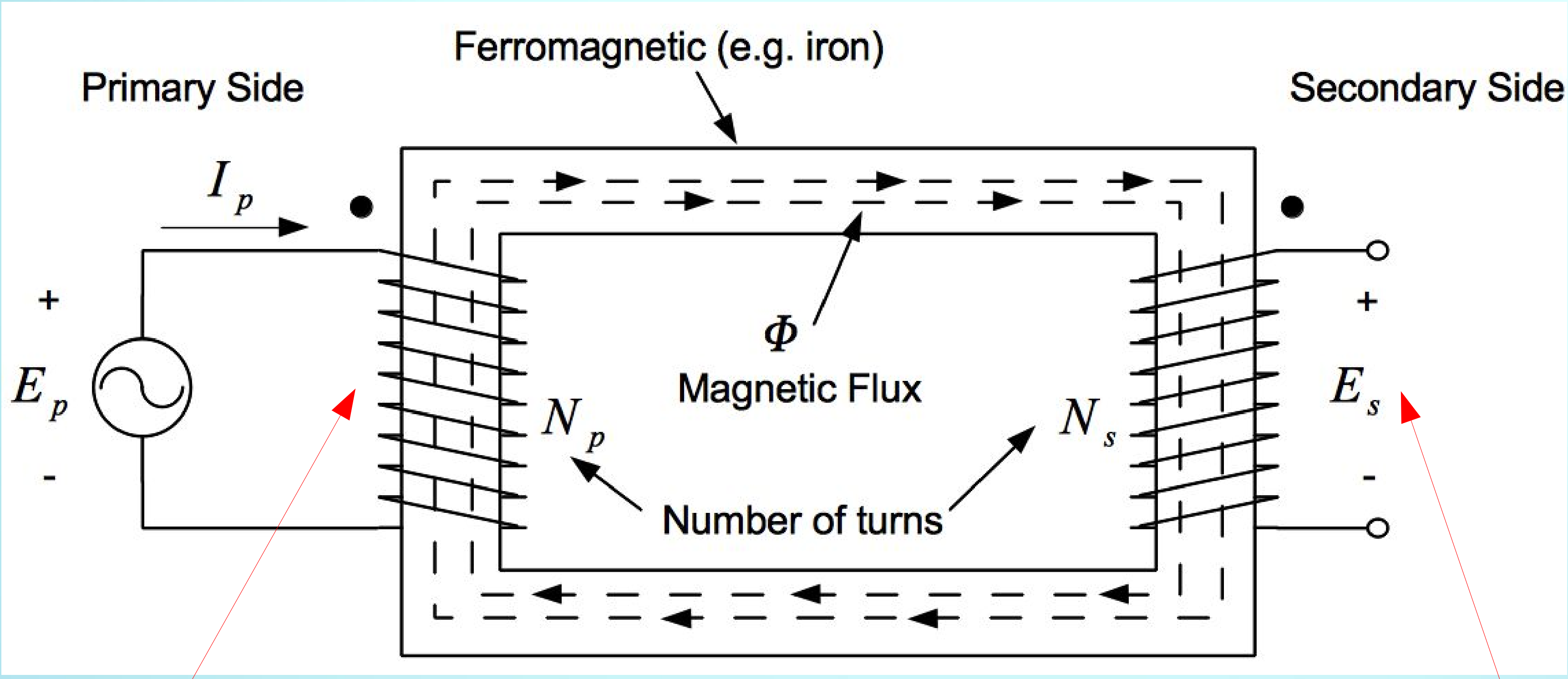


Applied AC current induces magnetic flux

AC magnetic flux induces voltage on output

Transformer Operation



Relationship: $E_p = N_p \frac{d\Phi}{dt}$

Relationship: $E_s = N_s \frac{d\Phi}{dt}$

Combined: $\frac{E_p}{E_s} = \frac{N_p}{N_s}$

Transformer Operation

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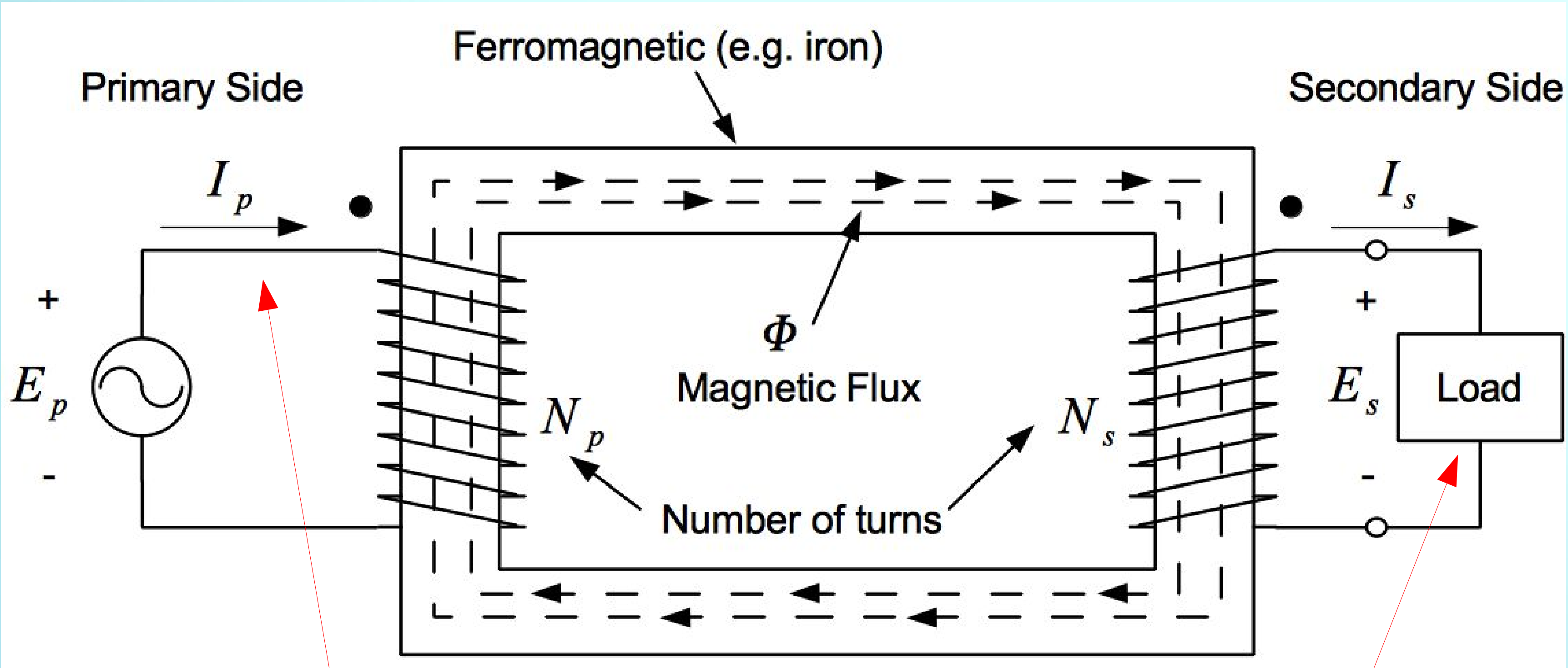
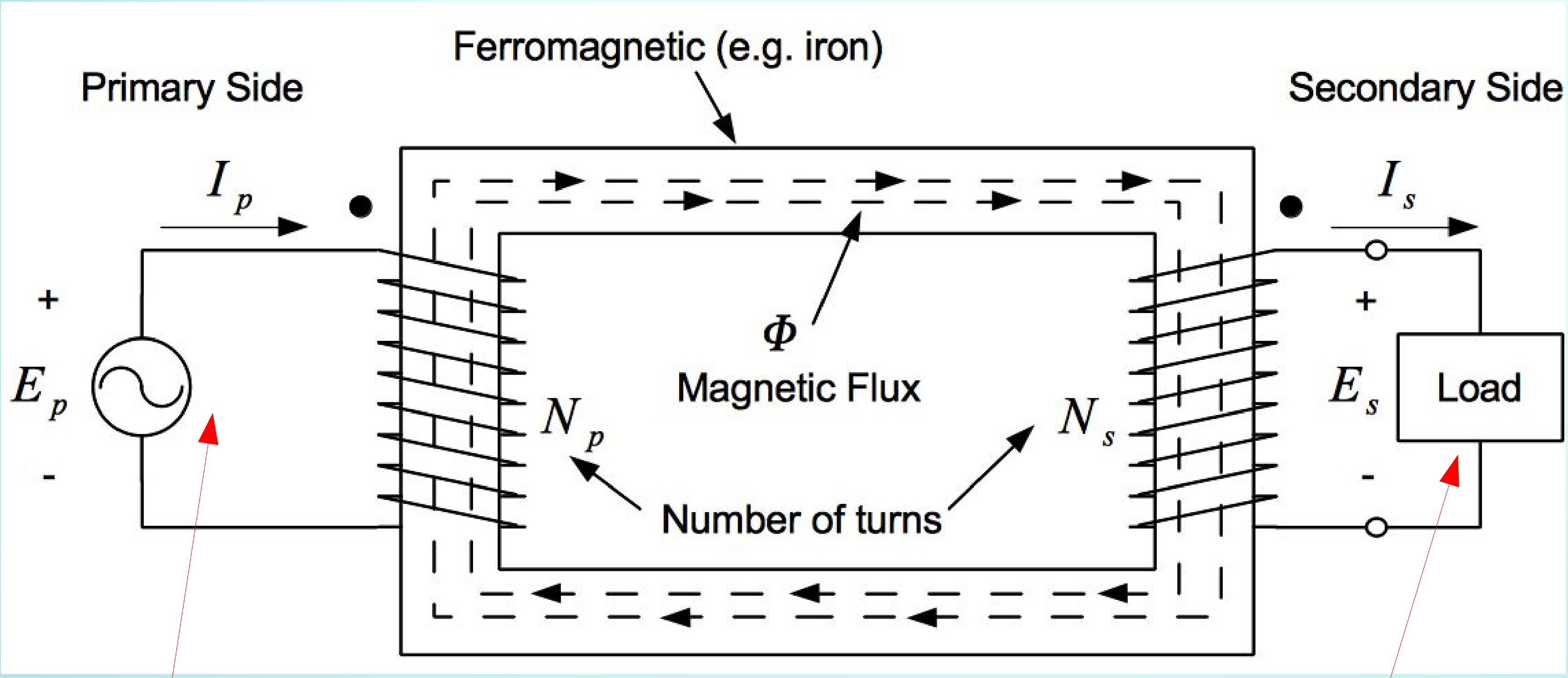


For ideal transformer (100% efficient), power in equals power out

Load draws current and thus, power

Current draw at output Causes current draw at input

Transformer Operation



Power in: $P_p = I_p E_p$

Power out: $P_s = I_s E_s$

From before: $\frac{E_p}{E_s} = \frac{N_p}{N_s}$

and $P_p = P_s$ (if 100% efficient)

So combined $\frac{I_s}{I_p} = \frac{N_p}{N_s}$

Example

A transformer for a house is designed to decrease the line distribution voltage from 7800 V to 120 V. Assuming an ideal transformer, what should the turns ratio be?

Turns ratio: $\frac{N_p}{N_s}$

Example

A transformer for a house is designed to decrease the line distribution voltage from 1200 V to 120 V. Assuming an ideal transformer, what should the turns ratio be?

Turns ratio: $\frac{N_p}{N_s}$

$$\frac{N_p}{N_s} = \frac{E_p}{E_s} = \frac{1200}{120} = 10$$

Thus, there should be 10 turns on the secondary for every single turn on the primary.

Another Example

If the transformer is connected to a load drawing 50 A of current, how much current is being drawn on the primary? Assume an ideal transformer.

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If the transformer is connected to a load drawing 50 A of current, how much current is being drawn on the primary? Assume an ideal transformer.

$$\frac{I_s}{I_p} = \frac{N_p}{N_s} \quad \rightarrow \quad I_p = \frac{N_s}{N_p} I_s$$

$$\frac{N_p}{N_s} = 10$$

$$I_s = 50\ A$$

$$I_p = \frac{N_s}{N_p} I_s = \frac{1}{10} 50 = 5\ A$$

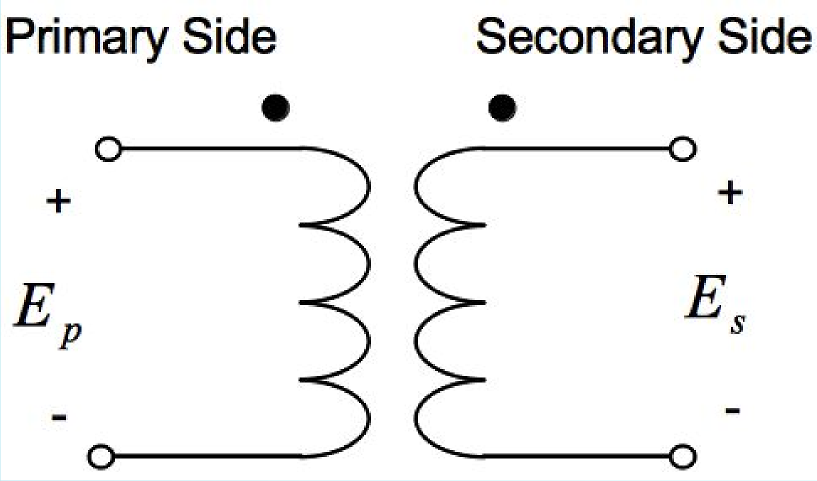
Non-idealities

- Of course, no transformer is ideal
  - Power transformers generally 85% to 99% efficient
  - Small transformers less so
  - Efficiency depends on materials, construction, and load

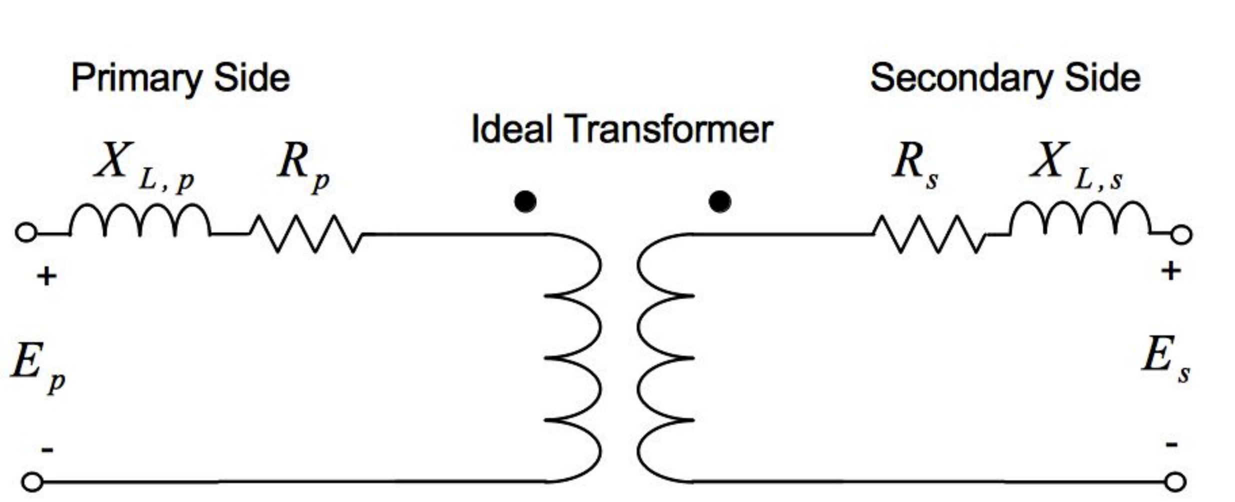
- Power Losses
  - Copper losses
    - Resistance in windings ($I^2 R$)
  - Magnetic losses
    - Primary current required for magnetic flux excitation
    - Magnetic flux leakage
    - Magnetic hysteresis
    - Eddy current losses

Transformer Model

Symbol in a circuit diagram:

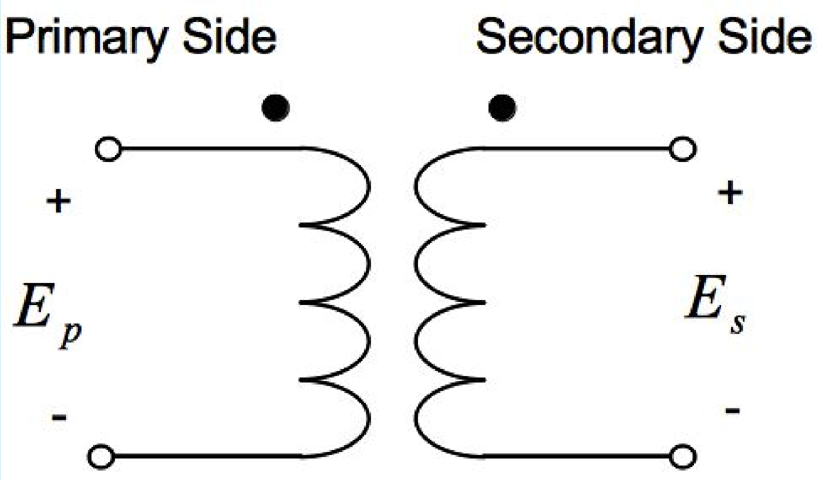


When considering losses and reactance:

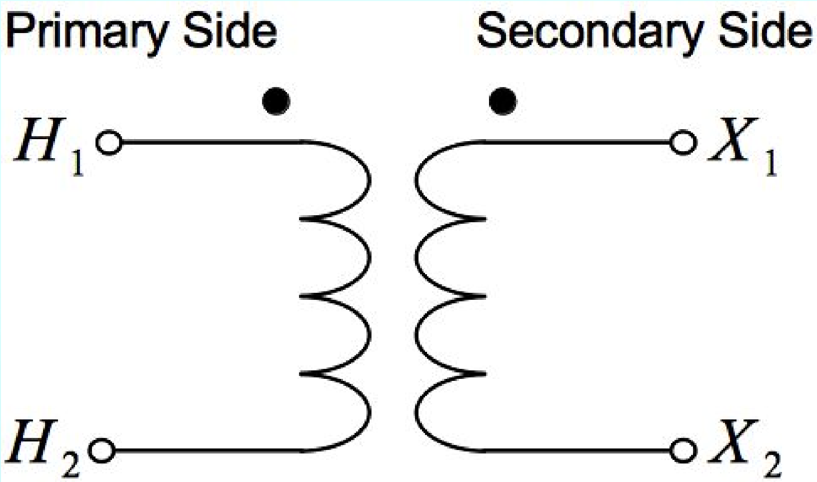


Transformer Model

Symbol in a circuit diagram:



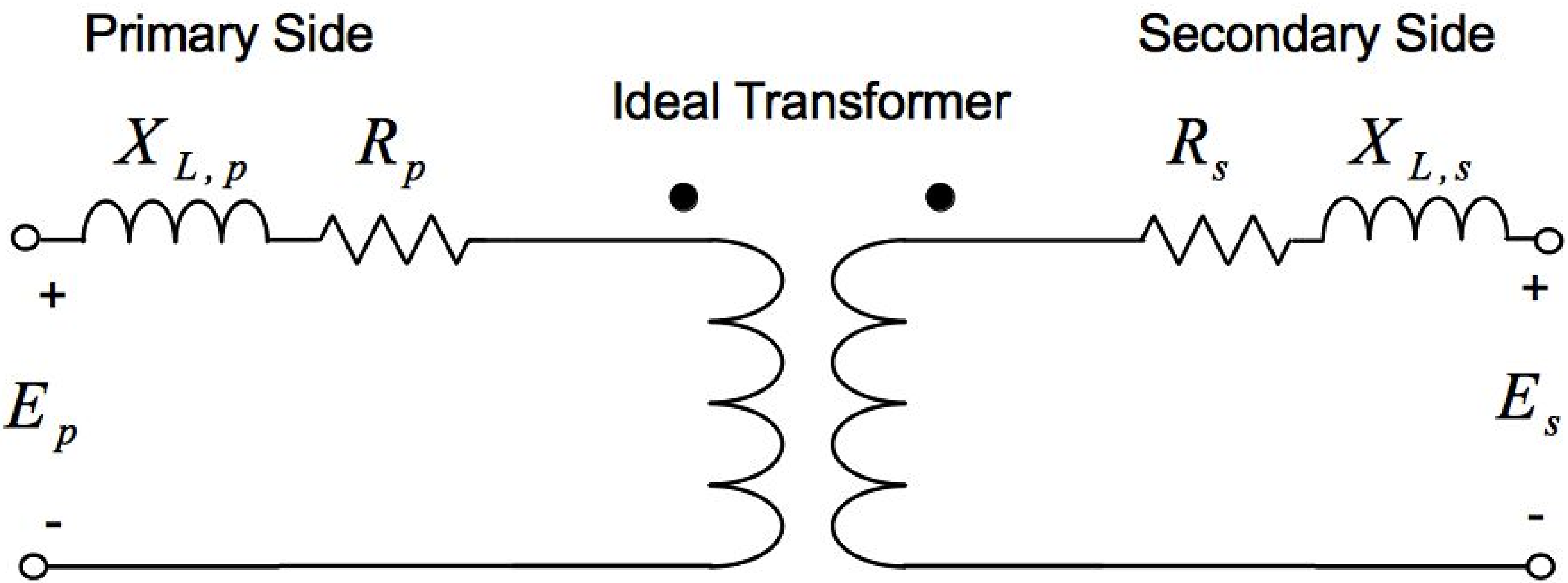
Polarity in Diagram:



Two general methods to indicate same relative polarity:

- Dots
- Letter markings (usually H for primary, X for secondary)

Transformer Losses Modeled

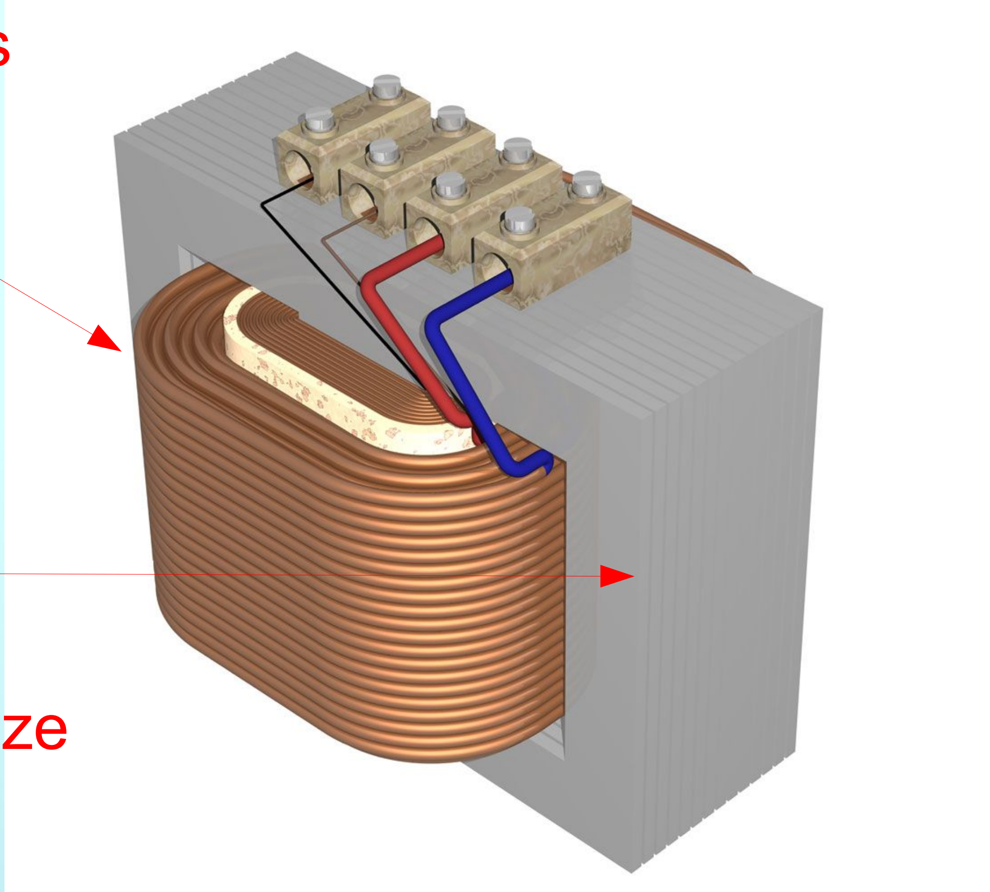


Resistances used to model various losses

Inductors used to model self-inductance

Transformer Construction

Primary and secondary windings usually wound together
- minimize leakage



Transformer core
- Typically iron or steel
- Laminated sheets to minimize eddy current losses

Methods for Cooling Transformers

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- Losses result in heat
-
- Small transformers generally air cooled (5 kVA or less)
- Small to medium distribution transformers cooled by oil
- Large transformers – require external radiators

Special Transformers

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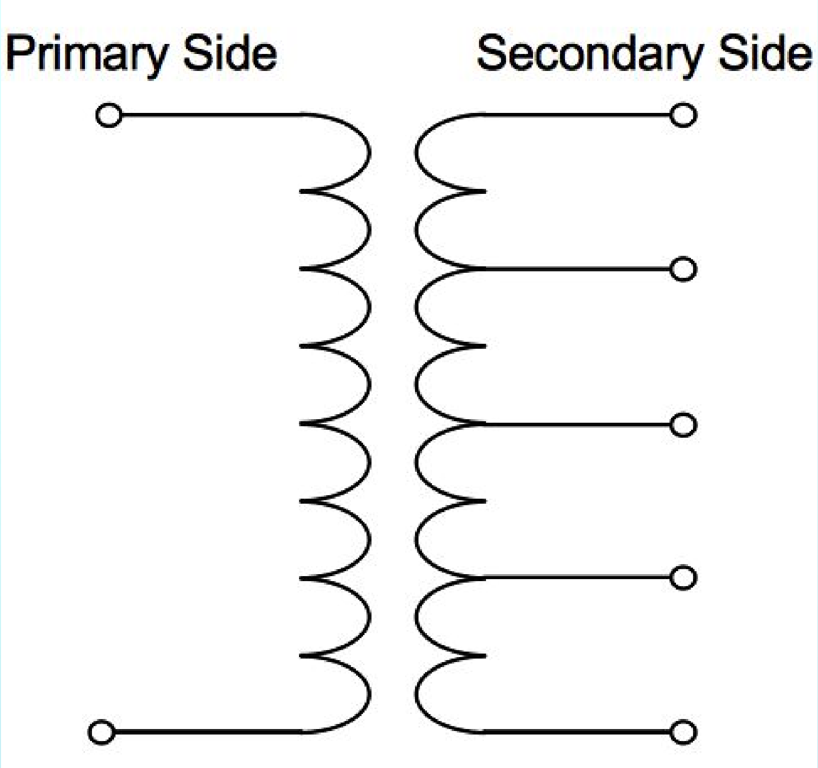
Tapped Transformers

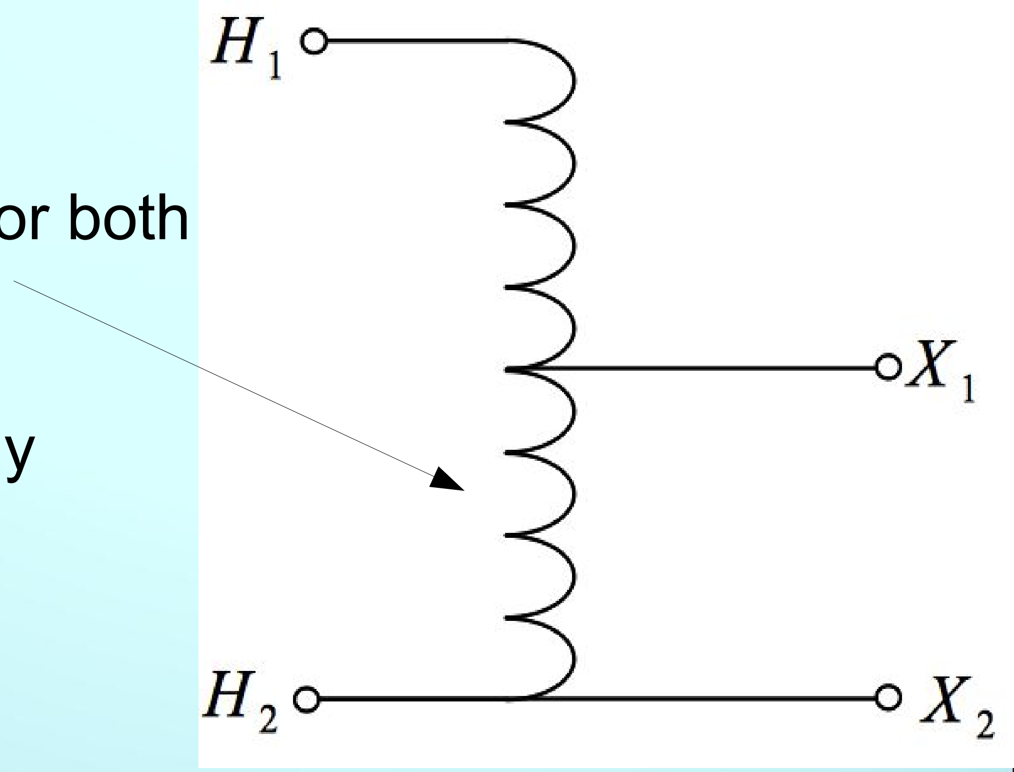
- Multiple connection points on one side of transformer
  - Mechanically removes turns from transformer
  - Used to regulate voltages in power system



Autotransformers

Autotransformers

- Only has one winding
  - One portion of winding for both primary and secondary
- Standard equations still apply
- Require less copper
  - Cheaper
  - Smaller
- Disadvantage is more hazardous



Upcoming in class

3-phase systems

- Circuits
  - Delta and Wye connections
- Transformers
- New homework on D2L
  - Due Wednesday 11/06
- CHANGE TO SYLLABUS
  - There IS lab next week
  - We will do project later (probably week before Thanksgiving)