Electrical Theory

Transformer Theory

PJM State & Member Training Dept.

Objectives

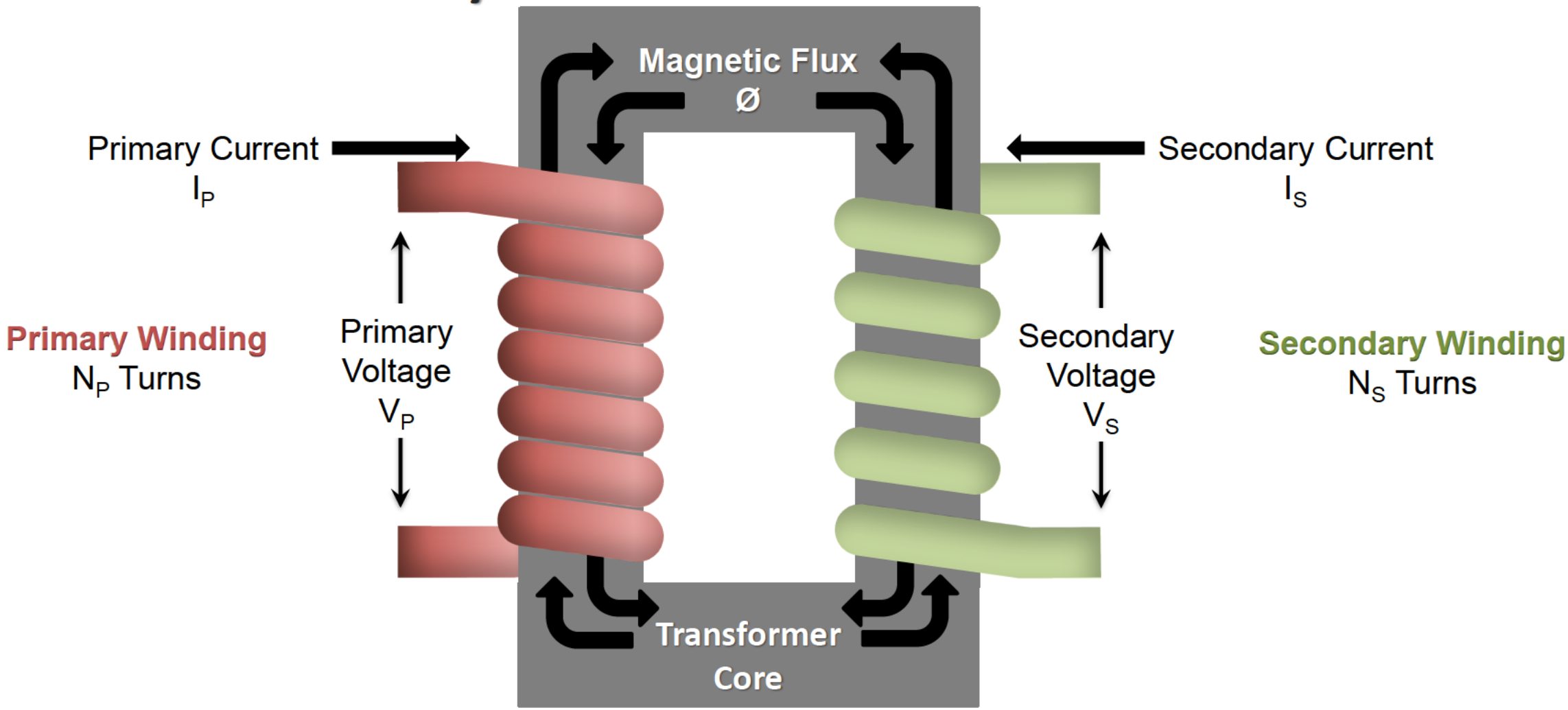
By the end of this presentation the Learner should be able to:

- Describe the basic operational theory of transformers
- Interpret the formula for turns ratio
- Describe transformer efficiency and losses
- Describe transformer tap changers
- Classify the different types of transformers

Transformer Theory

- **Transformer**
  - Static device
  - Used to convert high-voltage power to low-voltage power and vice versa
  - Consists of two or more windings wound around a single magnetic core
    - Windings are insulated from each other and from ground
    - Primary winding - power source
    - Secondary winding - load side
    - Tertiary winding - provides power to auxiliary equipment
  - Energy transfer is done via electromagnetic induction, or mutual induction

Transformer Theory



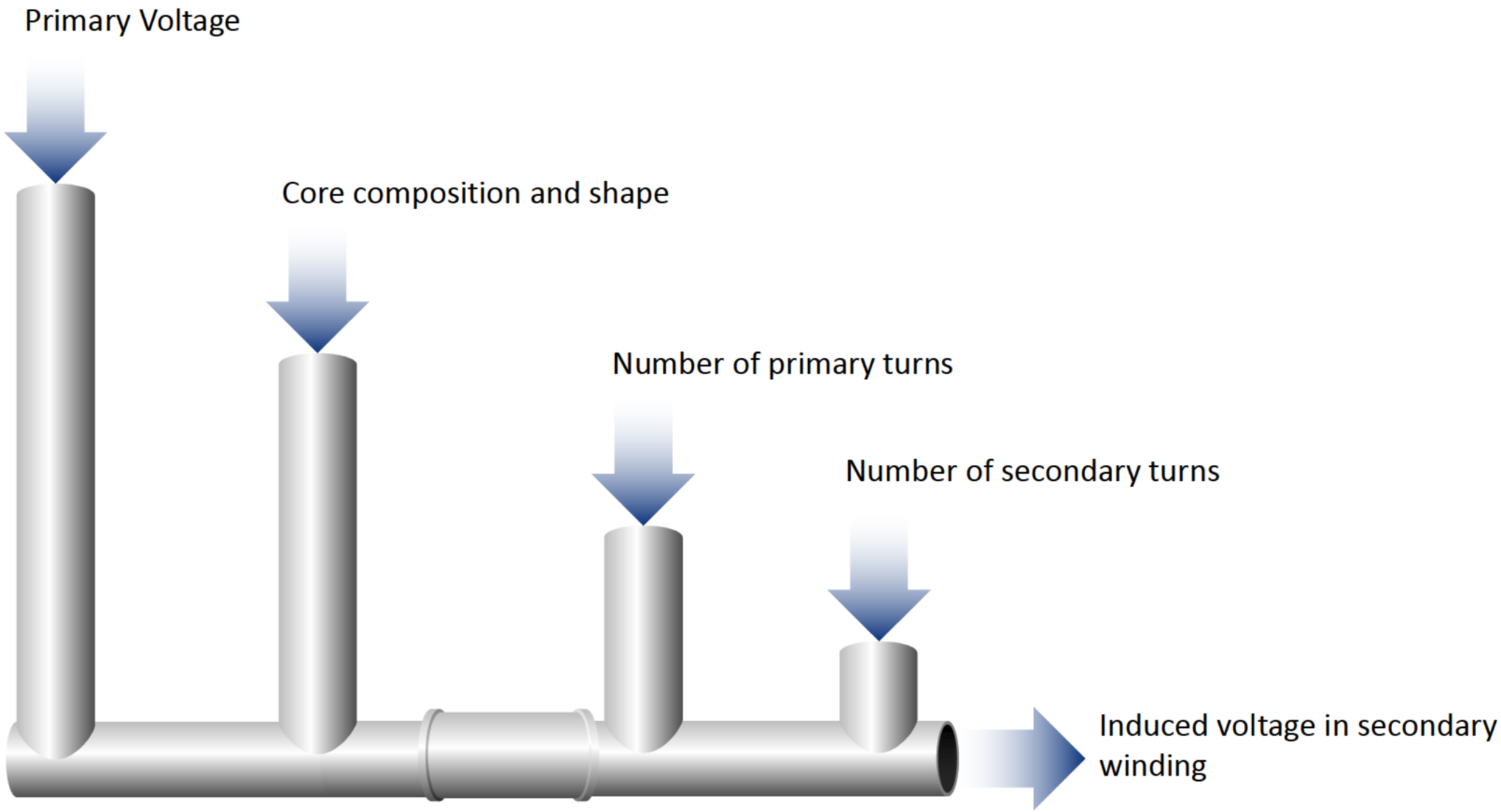
Transformer Theory

"How'd they do that?"

- Transformers work by combining two physical laws:
  - Current flowing in a wire produces a magnetic field
  - Voltage is produced in any conductor in a changing magnetic field
- Current flowing in the coil on one side of the transformer induces a voltage in the coil on the other side
  - Coils are coupled by the magnetic field (mutual induction)

Transformer Theory

Bismarck Demo



Transformer Turns Ratio

- The amount voltage and current changes in a transformer is determined by the: $$\boldsymbol{Turns\ Ratio} = \frac{N_P}{N_S}$$

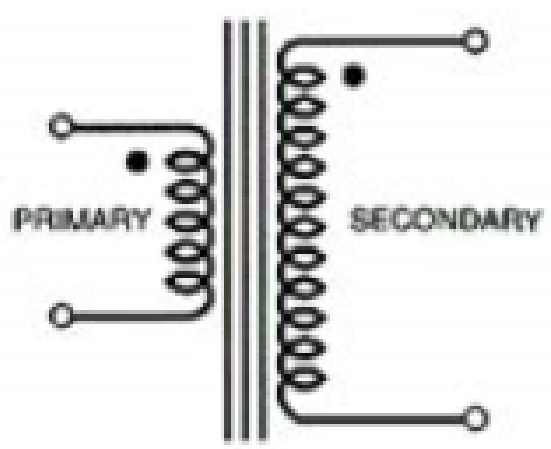
- Transformer Equation: $$\frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P}$$

  where,

  - N_P and N_S = number of turns in the primary and secondary windings
  - V_P and V_S = primary and secondary no-load voltages
  - I_P and I_S = primary and secondary amps

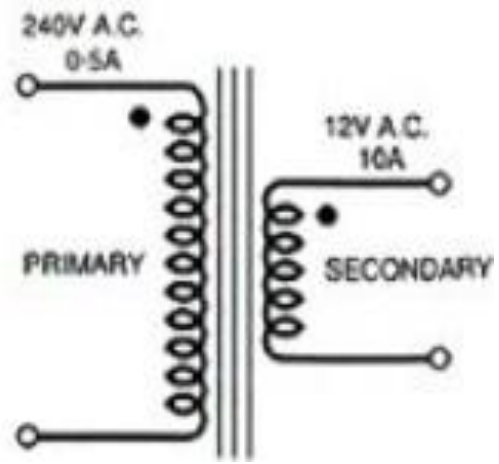
Transformer Turns Ratio

- **Step-Up Transformer**
  - Transfers energy from a low-voltage to a high-voltage circuit ($N_S > N_P$)
  - A turns ratio of 1/8 (1:8) implies that the secondary coil has eight times more turns as the primary coil



Transformer Turns Ratio

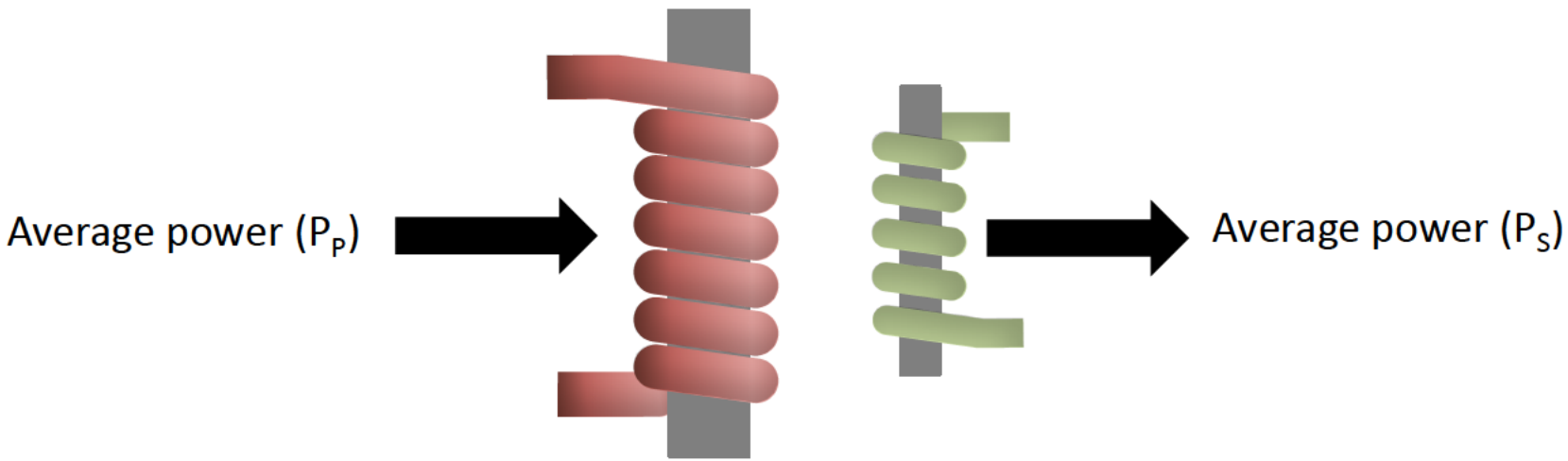
- **Step-Down Transformer**
  - Transfers energy from a high-voltage to a low-voltage circuit ($N_P > N_S$)
  - A turns ratio of 8/1 (8:1) means that the primary coil has eight times more turns than the secondary coil



Transformer Turns Ratio

- As voltage ↑, current ↓ by the same ratio
- As voltage ↓, current ↑ by the same ratio

Energy is neither created nor destroyed by a transformer



Transformer Efficiency/Losses

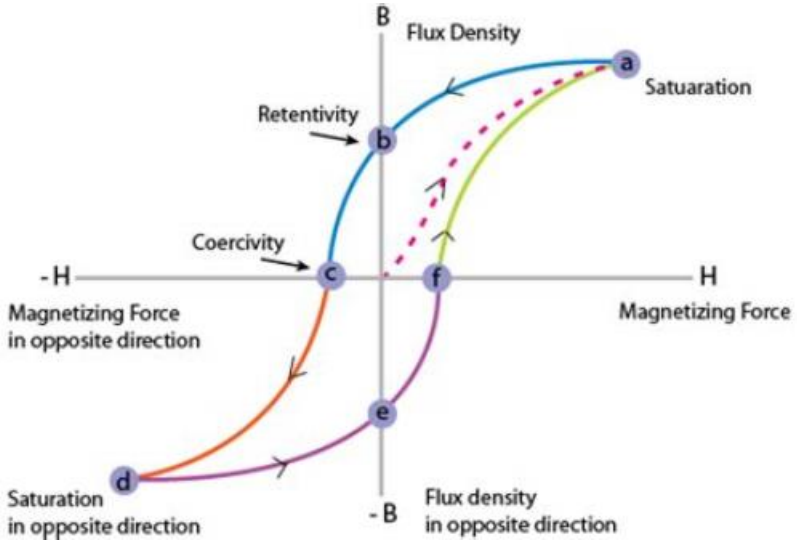
- Transformer efficiency is the ratio of the output power to the input power:

$$Efficiency = \frac{Output\ Power}{Input\ Power} = \times 100$$

- Most transformers have an efficiency of 97% to 99%
- Power consumed by a transformer is caused by:
  - Hysteresis losses (core)
  - Eddy current losses (core)
  - Copper losses (winding)

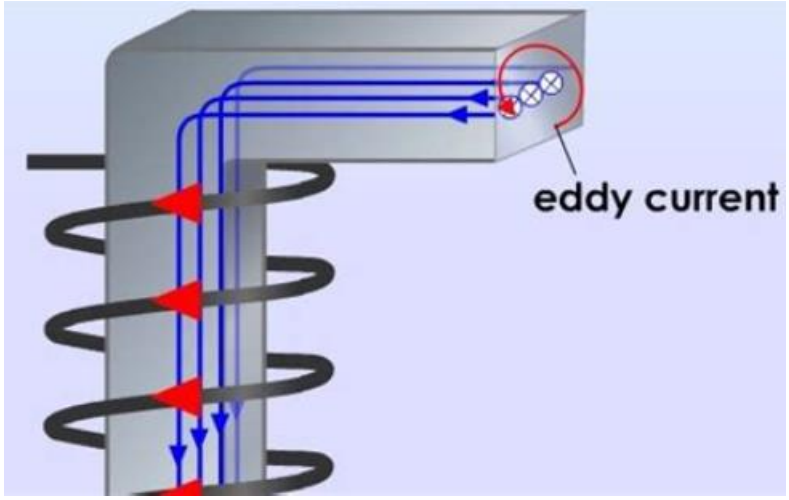
Transformer Efficiency/Losses

- **Hysteresis loss**
  - Due to residual magnetism which remains after the magnetizing force is removed
  - Occurring every half-cycle, hysteresis loss is the energy required to reduce the residual magnetism to zero



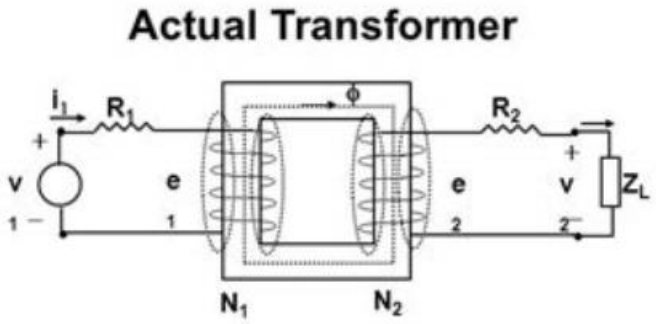
Transformer Efficiency/Losses

- **Eddy current**
  - Flows in the transformer's core caused by the induced voltage from the primary winding (Induced voltage is converted to heat)
  - Eddy current can be reduced by laminating the core with a higher resistance material



Transformer Efficiency/Losses

- **Copper loss**
  - Power dissipated in the transformer windings
  - Copper loss is due to the resistance of the windings
  - Using larger conductors for the transformer windings, which is restricted by the core openings, helps to reduce copper loss



Transformer Taps

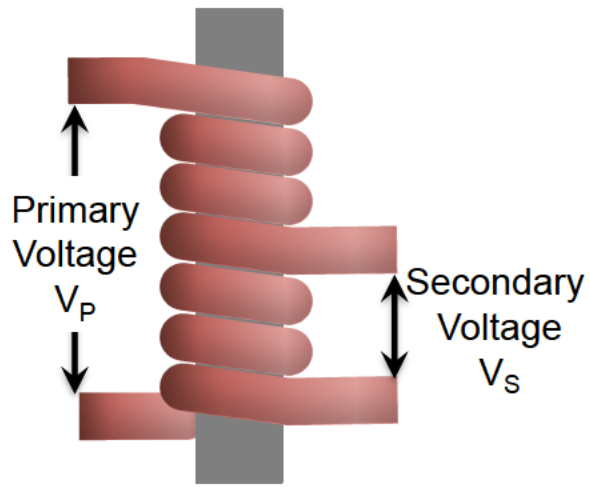
- Connections on a primary or secondary winding
  - Permits changing the turns ratio to alter the primary and/or secondary voltage
  - Two types:
    - No load de-energized tap changers
    - Load tap changers
  - Tap changer is motor-operated in response to a relay setting to hold voltage at a pre-determined level
  - LTC transformers change taps automatically, remote via SCADA, or manually while the transformer is energized

Types of Transformers

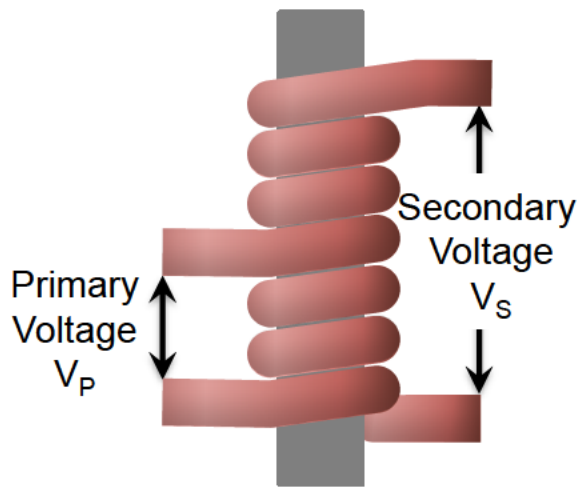
- **Power Transformer**
  - Used to transfer power for voltages usually higher than 69kV
  - Most power transformers are three-phase
  - Power transformers can step-up or step-down the voltage
  - Other capabilities, such as tap changing equipment can be added to a step-up or step-down transformer

Types of Transformers

- **Autotransformer**
  - Single-winding transformer with a terminal dividing the winding into two sections
  - Simply constructed and cost relatively little in comparison



Step Down Autotransfomer

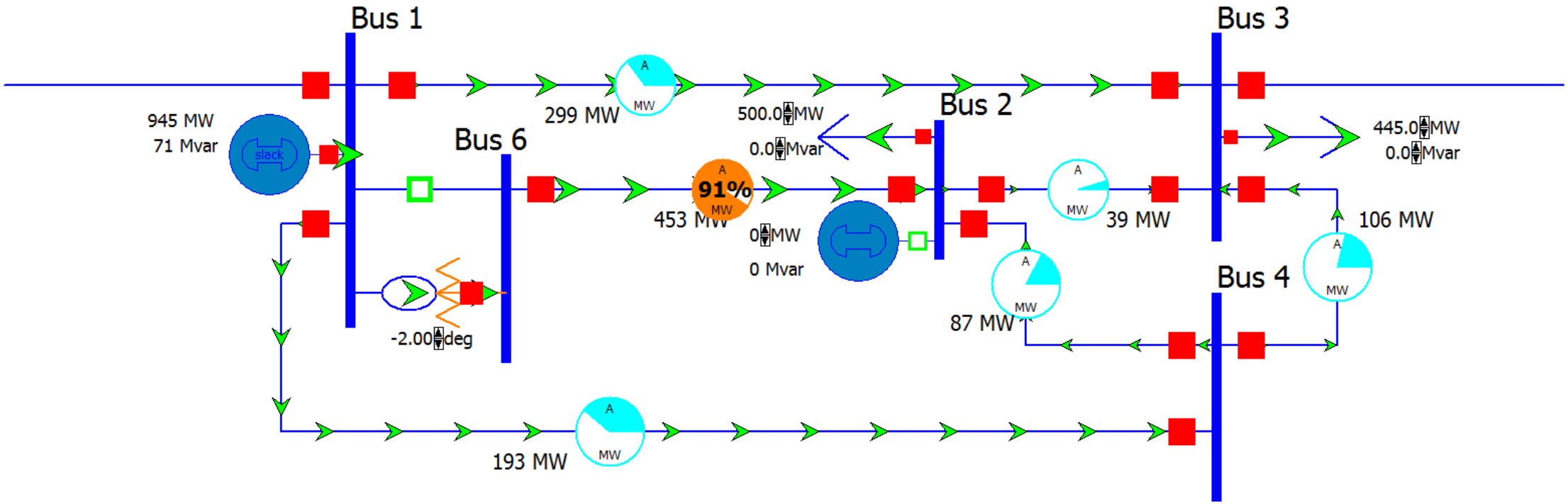


Step Down Autotransfomer

Types of Transformers

- **Phase Shift Transformer (PAR)**
  - Controls power flow over parallel lines by adjusting the voltage phase angle at one end of the line
  - Interconnection of the windings within the transformer creates the phase shift similar to the operation of power transformers

Types of Transformers



Types of Transformers

- **Distribution Transformer**
  - Used to reduce voltage to a level which is usable by customers
  - Mounted on poles, concrete pads, or in underground vaults
  - Operation is similar to power transformers

Questions?

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Toll Free Telephone: (866) 400-8980

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- Blume, S. (n.d.) *Electric Power System Basics for the Nonelectrical Professional*. New York: John Wiley and Son
- Miller, R. & Malinowski, J. (1994). *Power System Operation*. Boston, MA. McGraw-Hill
- Rustebakke, H.M. (Ed) (1983). *Electric Utility Systems & Practices*. 4th edition, Wiley Interscience