

Electrical Theory

Transformer Theory

PJM State & Member Training Dept.

- 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

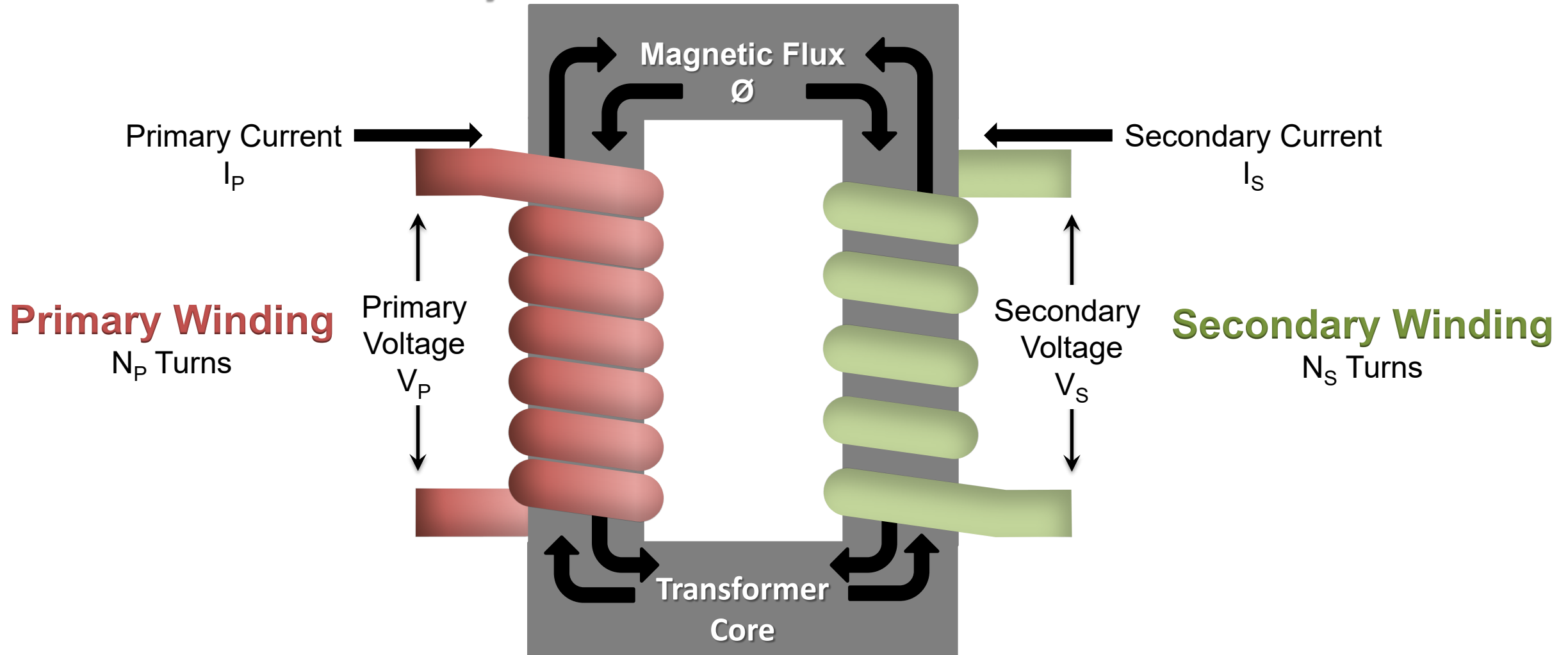


Transformer Theory

- **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

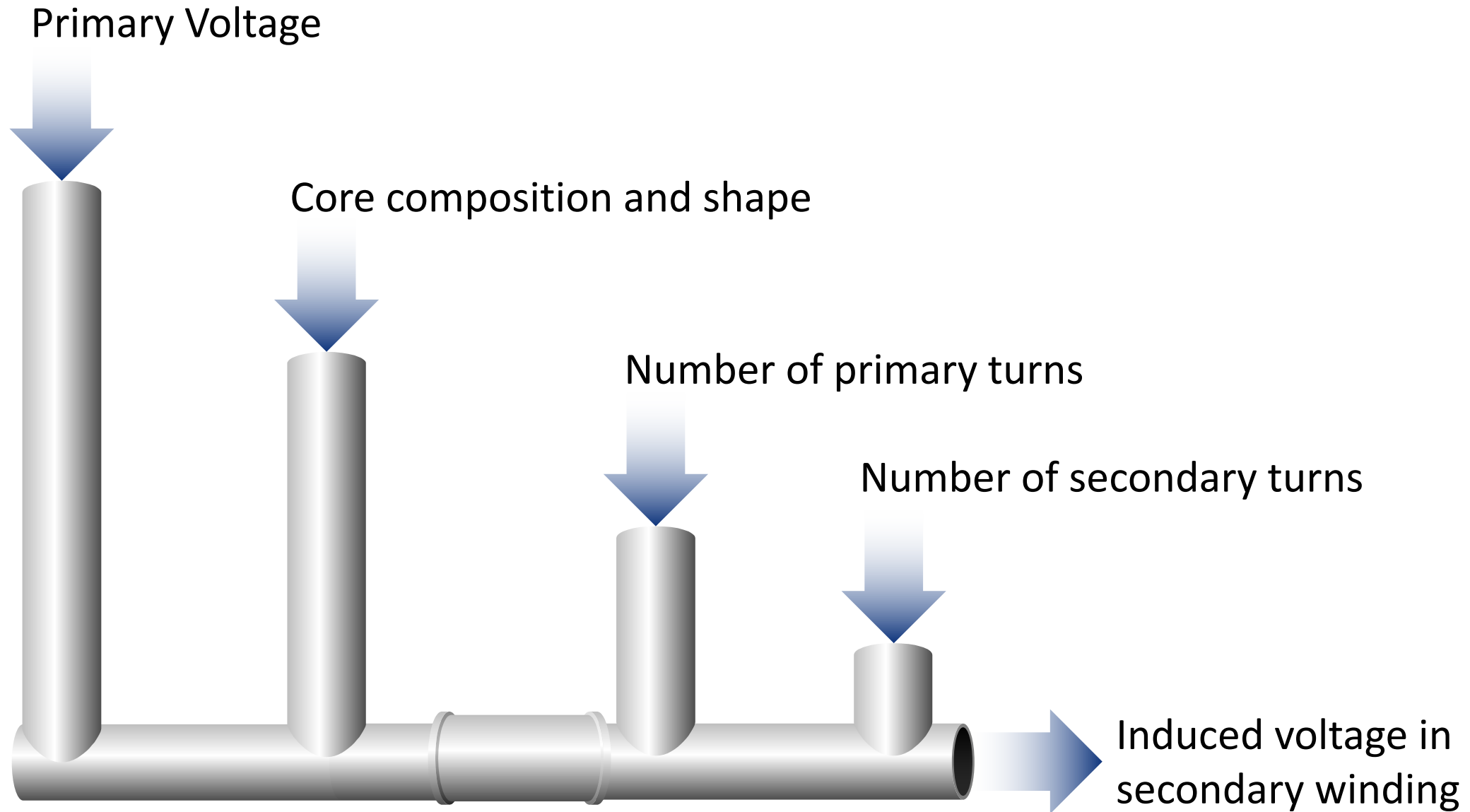


Transformer Theory

“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



Transformer Turns Ratio

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

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

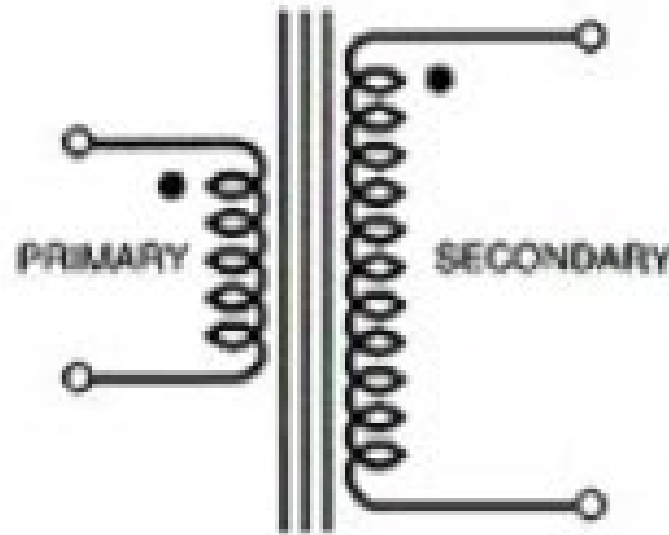
where,

- 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**

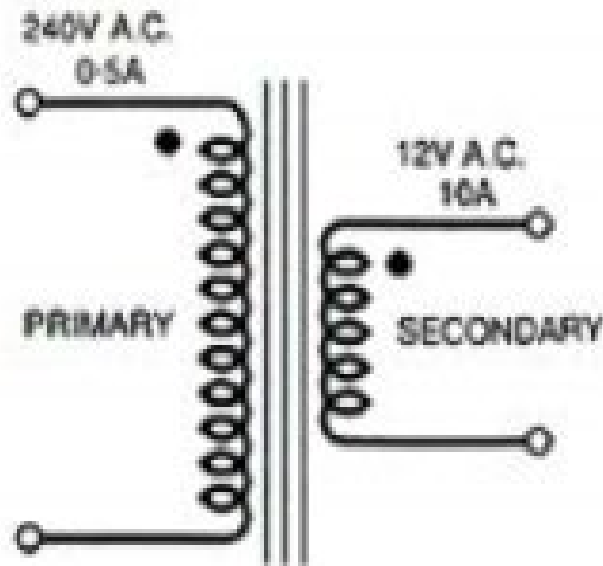
- Transfers energy from a low-voltage to a high-voltage circuit ($N_s > N_p$)
- A turns ratio of $1/8$ (1:8) implies that the secondary coil has eight times more turns as the primary coil







Transformer Turns Ratio

- **Step-Down Transformer**

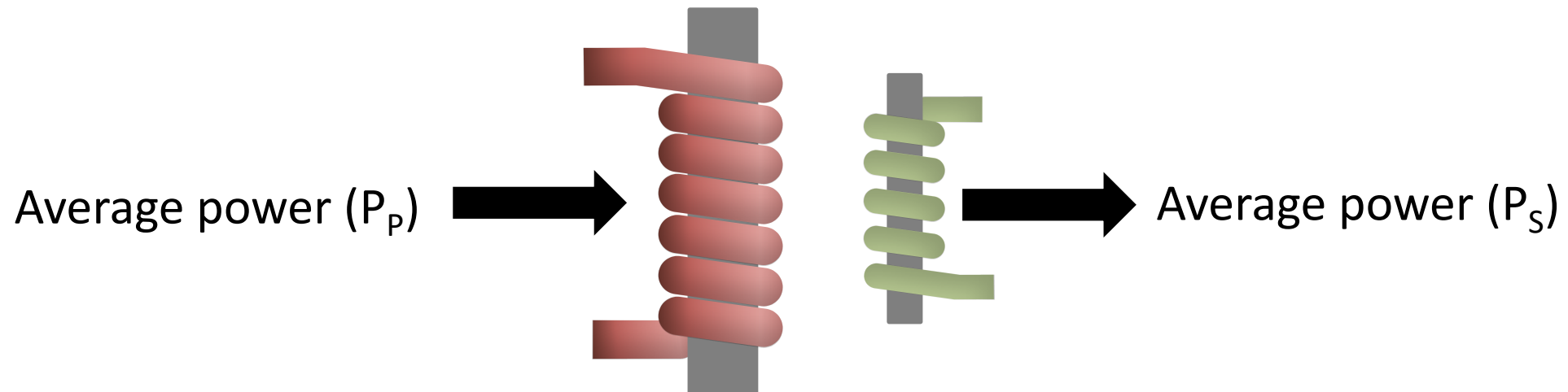
- Transfers energy from a high-voltage to a low-voltage circuit ($N_p > N_s$)
- A turns ratio of 8/1 (8:1) means that the primary coil has eight times more turns than the secondary coil



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:

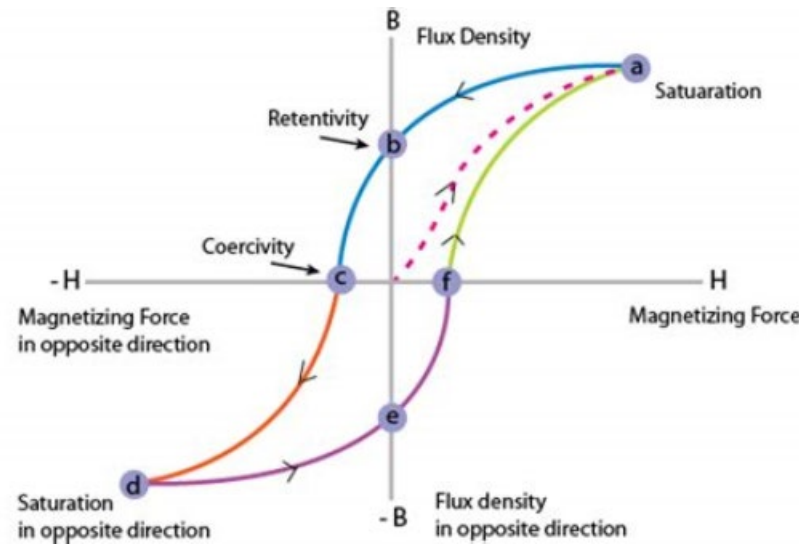
$$\text{Efficiency} = \frac{\text{Output Power}}{\text{Input Power}} \times 100$$

- 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**

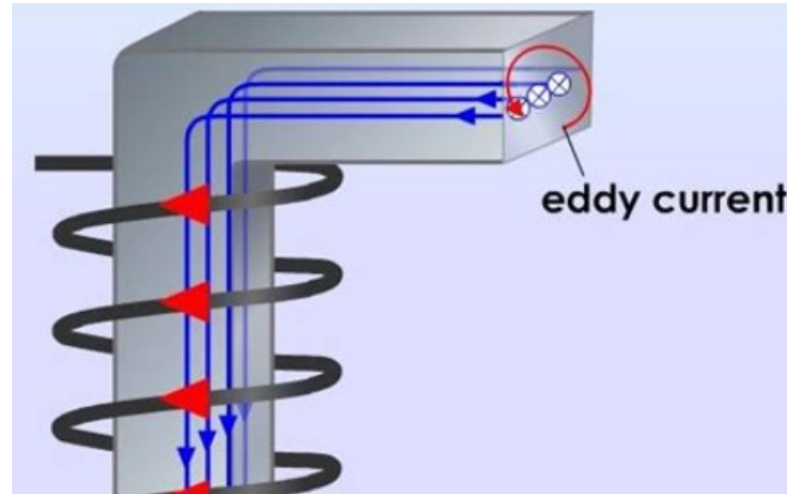
- Due to residual magnetism which remains after the magnetizing force is removed
- Occurring every half-cycle, hysteresis loss is the energy required to reduce the residual magnetism to zero



Transformer Efficiency/Losses

- **Eddy current**

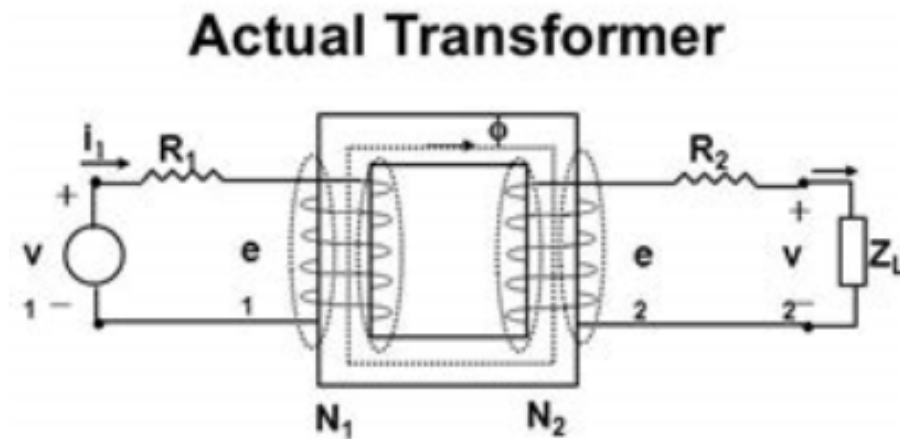
- Flows in the transformer's core caused by the induced voltage from the primary winding (Induced voltage is converted to heat)
- Eddy current can be reduced by laminating the core with a higher resistance material



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

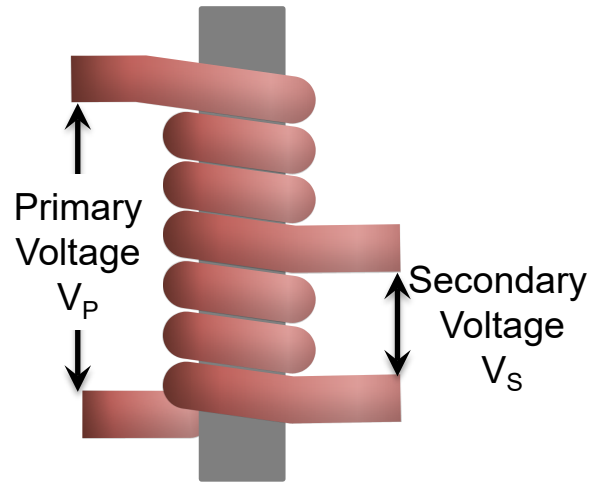
- **Power Transformer**

- 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

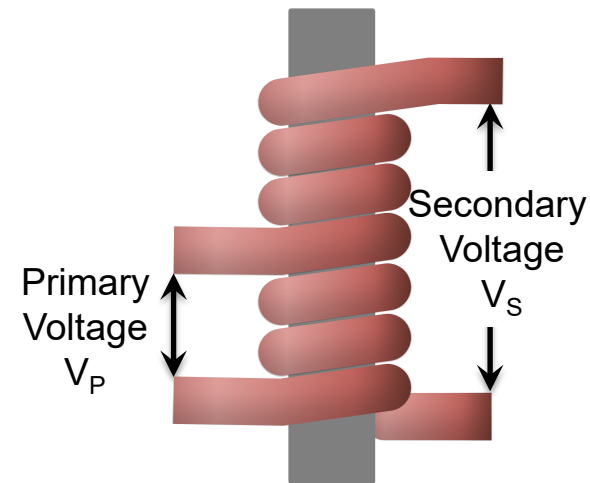
Types of Transformers

- **Autotransformer**

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



Step Down Autotransformer



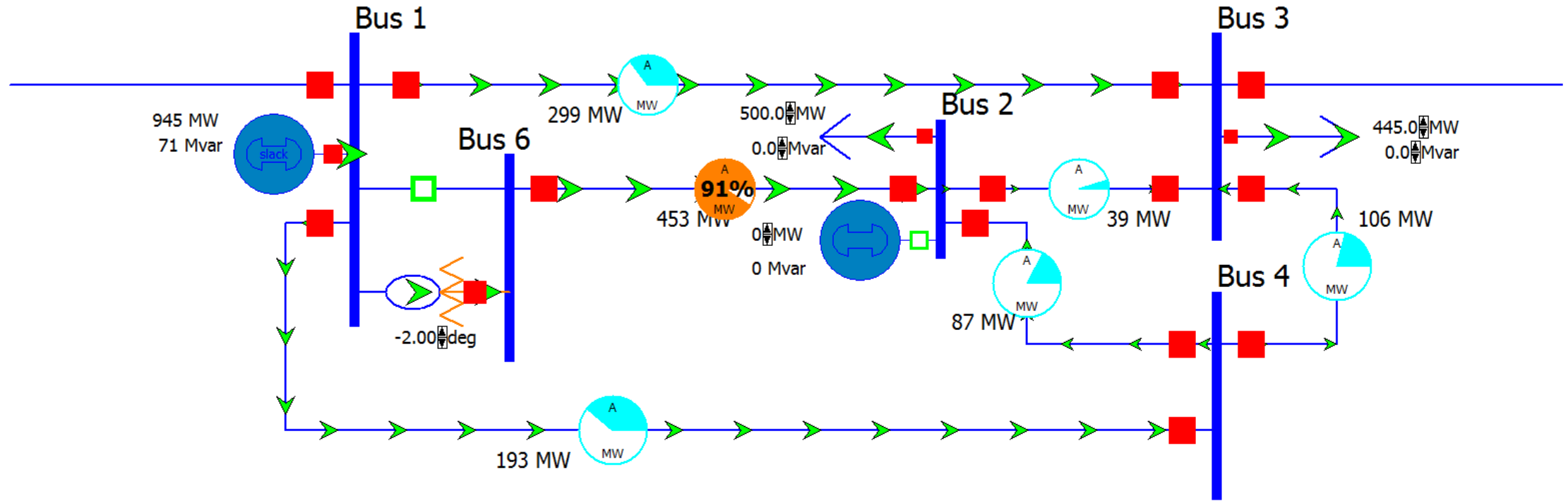
Step Down Autotransformer

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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