Objectives

At the end of this presentation the Student will 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

Primary Winding
- Primary Current $I_P$
- Primary Voltage $V_P$
- $N_P$ Turns

Transformer Core
- Magnetic Flux $\Phi$

Secondary Winding
- Secondary Current $I_S$
- Secondary Voltage $V_S$
- $N_S$ Turns

Secondary Current $I_S$
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

Primary Voltage

Core composition and shape

Number of primary turns

Number of secondary turns

Induced voltage in secondary winding
The amount voltage and current changes in a transformer is determined by the:

$$\text{Turns Ratio} = \frac{N_P}{N_S}$$

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 than the primary coil

- **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

Average power ($P_p$) → Average power ($P_s$)
Answer Question 1
Question #1

- A step-up transformer has 50 turns in the primary coil and 1250 turns in the secondary coil. The primary current is 10,000 amps and the secondary voltage is 230 kV. Find (a) the primary voltage (b) the secondary current and (c) the average power delivered to the load

\[ N = \frac{50}{1250} = \frac{1}{25} \]

1:25 turns ratio

a) \( \frac{N_P}{N_S} = \frac{V_P}{V_S} \) so \( \frac{1}{25} = \frac{V_P}{230 \text{ kV}} \) so \( V_P = \frac{230 \text{ kV} \times 25}{25} = 9200 \text{ volts} \)

b) \( \frac{I_S}{I_P} = \frac{N_P}{N_S} \) so \( \frac{I_S}{10,000 \text{ amps}} = \frac{1}{25} \) so \( I_S = \frac{10,000 \text{ amps} \times 25}{25} = 400 \text{ amps} \)

c) \( P_{AVG} = (400 \text{ amps})(230,000 \text{ volts}) = 92 \text{ MVA} \)
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 (losses) 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

**Eddy current**

- Flows in the transformer’s core and is caused by the induced voltage in the core from the primary winding
- Voltage is induced in the core and 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
Answer Question 2
An ideal transformer serves a 50 MVA load. The primary voltage is 138 kV and the secondary current is 2174 amps. Find (a) the primary current (b) the secondary voltage and (c) the turns ratio.

\[ a) I_P = \frac{50 \text{ MVA}}{138 \text{ kV}} = 362 \text{ amps} \]

\[ b) V_S = \frac{50 \text{ MVA}}{2174 \text{ amps}} = 23 \text{ kV} \]

\[ c) \frac{N_P}{N_S} = \frac{V_P}{V_S} \]

\[ \frac{138 \text{ kV}}{23 \text{ kV}} = \frac{6}{1} \text{ Turns ratio is 6:1} \]
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
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
Answer Question 3
Question #3

A generating station is producing power that is feeding a 5000 kW resistive load across a line with 0.5 ohms of resistance. Find:

a) The current flow if the power is transmitted at 5 kV

b) The current flow if a 1:46 step-up transformer is used to raise the voltage before the power is transmitted

c) How many MWs the generator has to produce in each case
Question #3 Answer

a) 5000 volts:

\[ I_{Total} = \frac{5000 \, kW}{5 \, kV} = 1000 \, \text{amps} \]

\[ P_{Losses} = (1000 \, \text{amps})^2 (0.5 \, \Omega) = 500 \, kW \]

Total Generation = 5500 kW or 5.5 MW

b) Step – up Transformer

\[ V_{New} = (46)(5000 \, volts) = 230 \, kV \]

\[ I_{Total} = \frac{5000 \, kW}{230 \, kV} = 21.7 \, \text{amps} \]

\[ P_{Losses} = (21.7 \, \text{amps})^2 (0.5 \, \Omega) = 236.3 \, \text{watts} \]

Total Generation = 5000.236 kW or 5.000236 MW
• Do LabVolt exercises 7.1 and 8.1
Summary

- Discussed the basic theories associated with transformer operation
- Described and applied the formula for calculating transformer turns ratio
- Examined transformer efficiency and losses
- Described the operation of transformer tap changers
- Explained the different types of transformers and their uses
Questions?

**PJM Client Management & Services**

**Telephone:** (610) 666-8980

**Toll Free Telephone:** (866) 400-8980

**Website:** [www.pjm.com](http://www.pjm.com)

The Member Community is PJM’s self-service portal for members to search for answers to their questions or to track and/or open cases with Client Management & Services.
Resources and References


• Blume, S. *Electric Power System Basics For the Nonelectrical Professional*. New York: John Wiley and Sons