ICT 103: Electrical Science

UNIT 4 : Transformers

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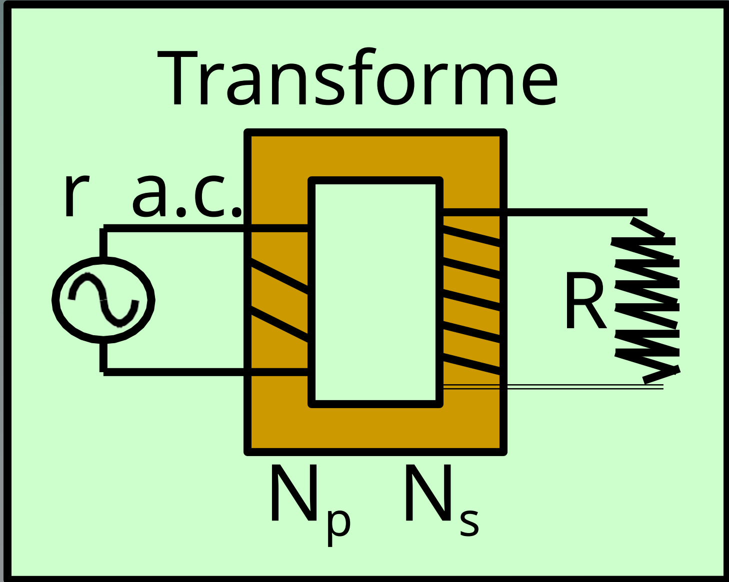
The Transformer

A transformer is a device that uses induction and ac current to step voltages

An ac source of emf E_p is connected to primary coil with N_p turns. Secondary has N_s turns and emf of E_s.



Induced emf's are:

$$\mathbf{E}_P = -N_P \frac{\Delta\Phi}{\Delta t}$$

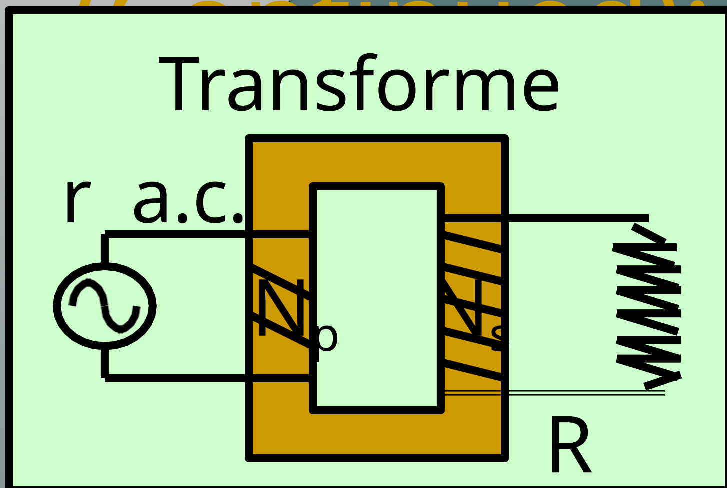
$$\mathbf{E}_S = -N_S \frac{\Delta\Phi}{\Delta t}$$

The output voltage V_s depends almost entirely on the input voltage V_p and the ratio of the number of loops in the primary and secondary coils. Faraday's law of induction for the secondary coil gives its induced output voltage V_s to be

$$V_s = -N_s \cdot \Delta\Phi / \Delta t$$

where N_s is the number of loops in the secondary coil and $\Delta\Phi/\Delta t$ is the rate of change of magnetic flux.

Transformers (Continued):



$$E_P = -N_P \frac{\Delta\Phi}{\Delta t}$$

$$E_S = -N_S \frac{\Delta\Phi}{\Delta t}$$

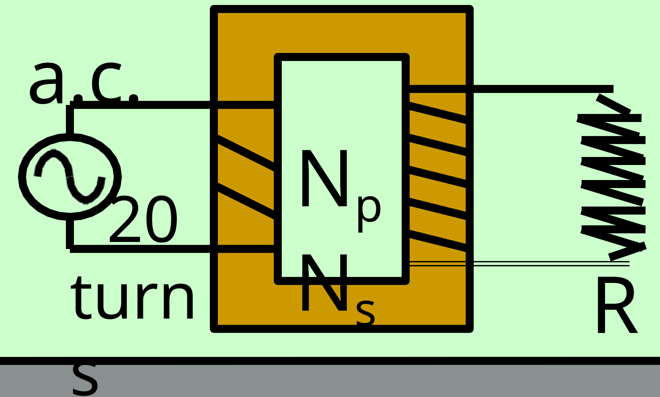
Recognizing that $\Delta\phi/\Delta t$ is the same in each coil, we divide first relation by second and obtain:

The transformer equation:

$$\frac{E_P}{E_S} = \frac{N_P}{N_S}$$

Example 7: A generator produces 10 A at 600 V. The primary coil in a transformer has 20 turns. How many secondary turns are needed to step up the voltage to 2400 V?

I = 10 A; V_p = 600 V



Applying the transformer equation:

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

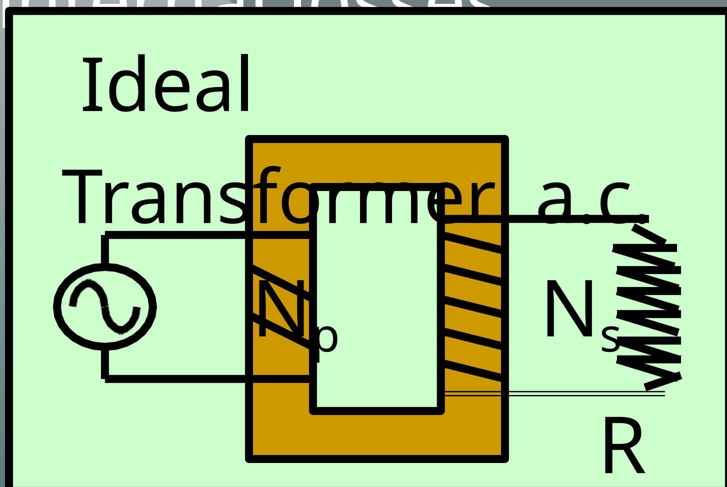
$$N_S = \frac{N_P V_S}{V_P} = \frac{(20)(2400)}{600}$$

N_S = 80 turns

This is a step-up transformer; reversing coils will make it a step-down transformer.

Transformer Efficiency

There is no power gain in stepping up the voltage since voltage is increased by reducing current. In an ideal transformer with no internal losses:

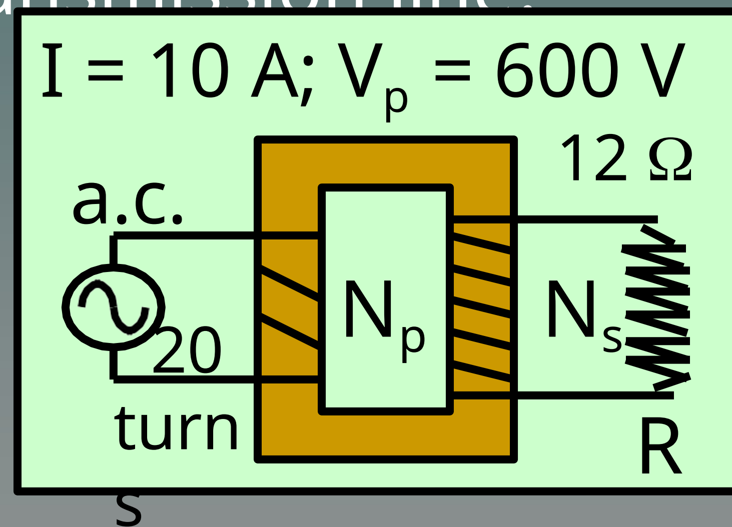


An ideal transformer:

$$E_P i_P = E_S i_S \quad \text{or} \quad \frac{i_P}{i_S} = \frac{E_S}{E_P}$$

The above equation assumes no internal energy losses due to heat or flux changes. Actual efficiencies are usually between 90 and 100%.

Example 7: The transformer in Ex. 6 is connected to a power line whose resistance is 12 Ω. How much of the power is lost in the transmission line?



V_S = 2400 V

$$E_P i_P = E_S i_S \qquad i_S = \frac{E_P i_P}{E_S}$$

$$i_S = \frac{(600\text{ V})(10\text{ A})}{2400\text{ V}} = 2.50\text{ A}$$

$P_{lost} = i^2R = (2.50\text{ A})^2(12\ \Omega)$ $\qquad$ P_{lost} = 75.0 W

P_{in} = (600 V)(10 A) = 6000 W

%Power Lost = (75 W/6000 W)(100%) = 1.25%

What is the Efficiency of Transformer?

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{\text{output power}}{\text{output power} + \text{losses}}$$

$$\eta = \frac{\text{output power}}{\text{output power} + \text{iron losses} + \text{copper losses}}$$

$$\eta = \frac{V_2 I_2 \text{Cos}\varphi_2}{V_2 I_2 \text{Cos}\varphi_2 + P_i + P_c}$$

A transformer having the efficiency of 90% is working on 200V and 3kW power supply. If the current in the secondary coil is 6A, the voltage across the secondary coil and the current in the primary coil.

A. 300V, 15A
B. 450V, 15A
C. 450V, 13.5A
D. 600V, 15A

Ans: B

The Equivalent Circuit of a Transformer

The losses that occur in transformers have to be accounted for in any accurate model of transformer behavior.

1. *Copper (I^2R) losses*. Copper losses are the resistive heating losses in the primary and secondary windings of the transformer. They are proportional to the square of the current in the windings.

2. *Eddy current losses*. Eddy current losses are resistive heating losses in the core of the transformer. They are proportional to the square of the voltage applied to the transformer.

3. *Hysteresis losses*. Hysteresis losses are associated with the rearrangement of the magnetic domains in the core during each half-cycle. They are a complex, nonlinear function of the voltage applied to the transformer.

4. *Leakage flux*. The fluxes which escape the core and pass through only one of the transformer windings are leakage fluxes. These escaped fluxes produce a self-inductance in the primary and secondary coils, and the effects of this inductance must be accounted for.

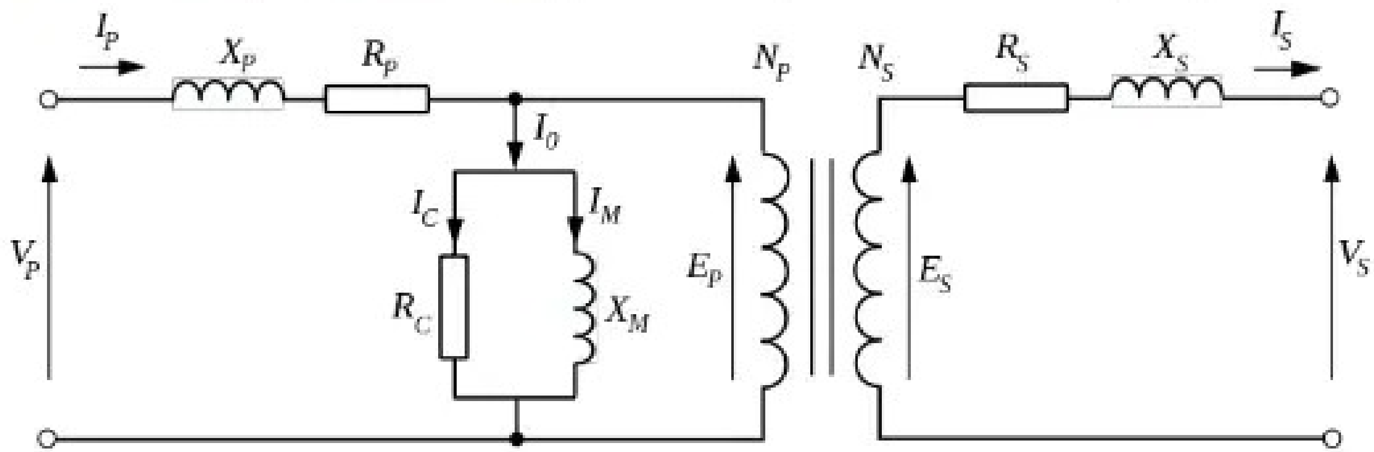
The Exact Equivalent Circuit of a Transformer

Modeling the copper losses: resistive losses in the primary and secondary windings of the core, represented in the equivalent circuit by R_P and R_S.

Modeling the leakage fluxes: primary leakage flux is proportional to the primary current I_P and secondary leakage flux is proportional to the secondary current I_S, represented in the equivalent circuit by X_P ($=\phi_{LP}/I_P$) and X_S ($=\phi_{LS}/I_S$).

Modeling the core excitation: I_m is proportional to the voltage applied to the core and lags the applied voltage by 90°. It is modeled by X_M.

Modeling the core loss current: I_{h+e} is proportional to the voltage applied to the core and in phase with the applied voltage. It is modeled by R_C.



Transformer Efficiency

$$\eta = \frac{Power\ \ Output}{Power\ \ Input}$$

$$= \frac{Power\ \ Input - Losses}{Power\ \ Input}$$

$$= 1 - \frac{Losses}{Power\ \ Input}$$

$$= 1 - \frac{P_{copper\,loss} + P_{core\,loss}}{P_{copper\,loss} + P_{core\,loss} + V_s I_s \cos\theta}$$

Usually the efficiency for a power transformer is between 0.9 to 0.99.
The higher the rating of a transformer, the greater is its efficiency.

Three-phase Voltage and Current

Connection	Phase Voltage	Line Voltage	Phase Current	Line Current
Star	$V_P = V_L \div \sqrt{3}$	$V_L = \sqrt{3} \times V_P$	$I_P = I_L$	$I_L = I_P$
Delta	$V_P = V_L$	$V_L = V_P$	$I_P = I_L \div \sqrt{3}$	$I_L = \sqrt{3} \times I_P$

Vp = Phase Voltage

VL = Line Voltage

Ip = Phase Current

I_L= Line Current

INTRODUCTION

A three-phase transformer can be obtained in two different ways.

- Three numbers of identical single-phase transformers can be suitably connected to make a three-phase transformer. Such three-phase transformers are called a *bank of three-phase transformer.*
- Alternatively, a three-phase transformer can be constructed as a single unit.

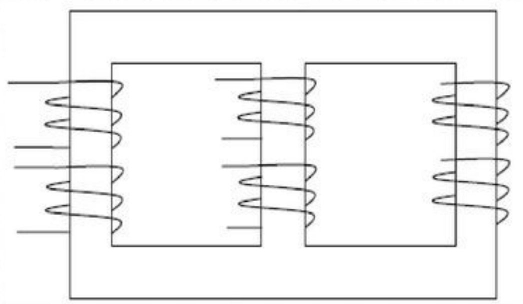
ADVANTAGES OF SINGLE UNIT THREE-PHASE TRANSFORMER

1. It occupies less space
2. Its weight is less
3. Its cost is comparatively less
4. It is much easier to transport
5. It is more efficient
6. Core size is comparatively small.

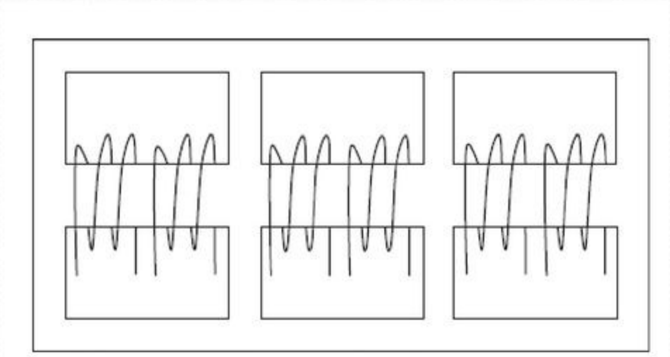
DISADVANTAGES OF SINGLE UNIT THREE-PHASE TRANSFORMER

- When one of the phases of a single-unit three-phase transformer becomes faulty, the entire unit of three-phase transformer needs to be removed from the supply for repair.
- But in the case of a bank of three-phase transformer, only the faulty transformer is removed from the supply for repair while the other two transformers remain connected in the system without interrupting the supply completely.

CONSTRUCTION

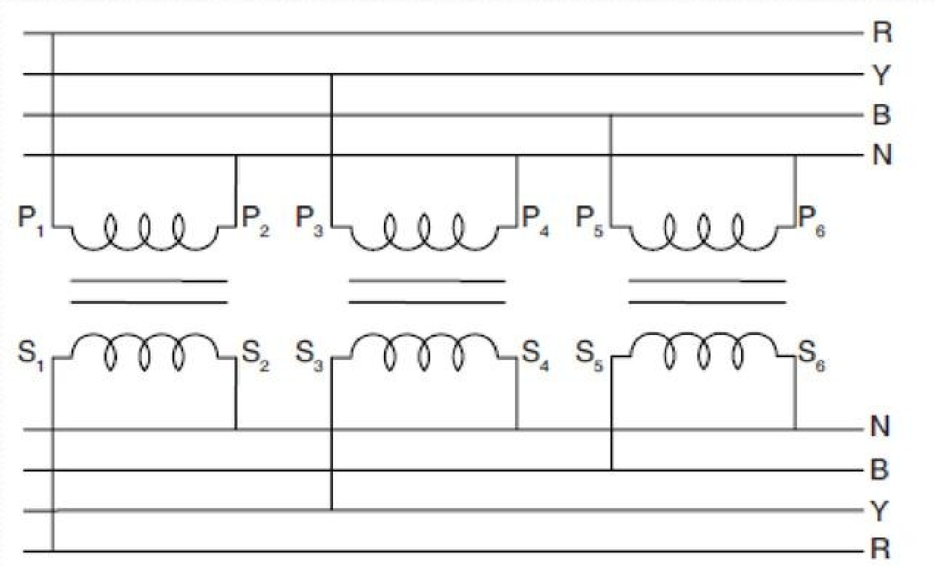


Core type

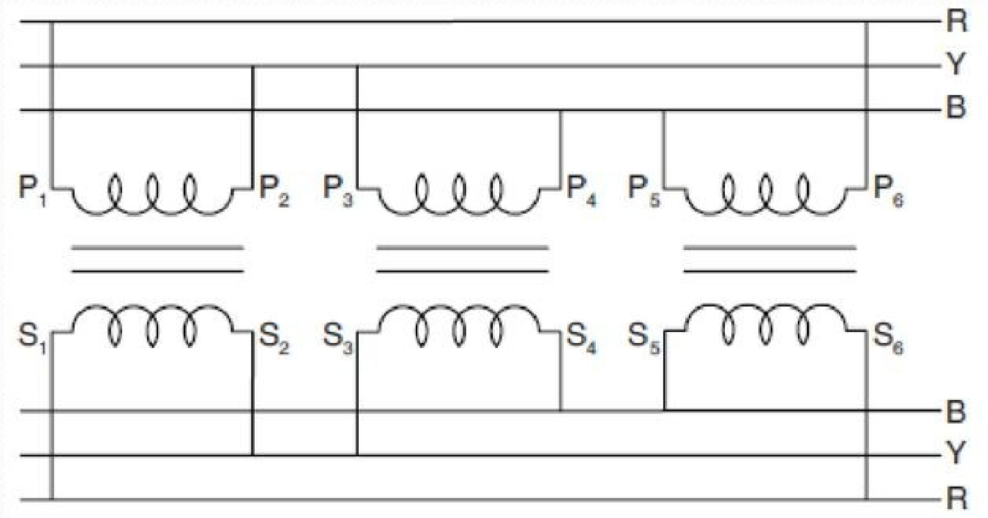


Shell type

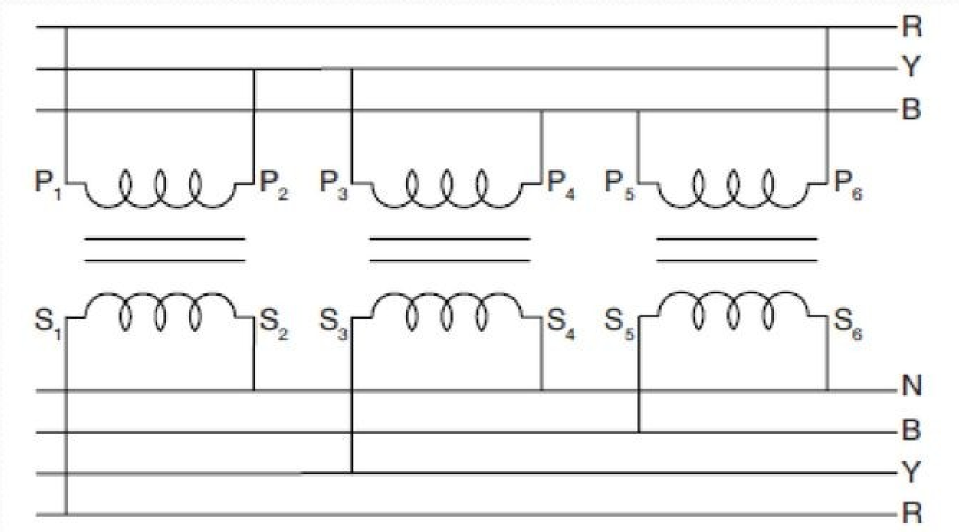
Star–Star (Y–Y) Connection of Three-phase Transformer



Delta–Delta (Δ–Δ) Connection of Three-phase Transformer



Delta–Star (Δ –Y) Connection of Three-phase Transformer



Star–Delta (Y–Δ) Connection of Three-phase Transformer