Lecture 13: Transformers

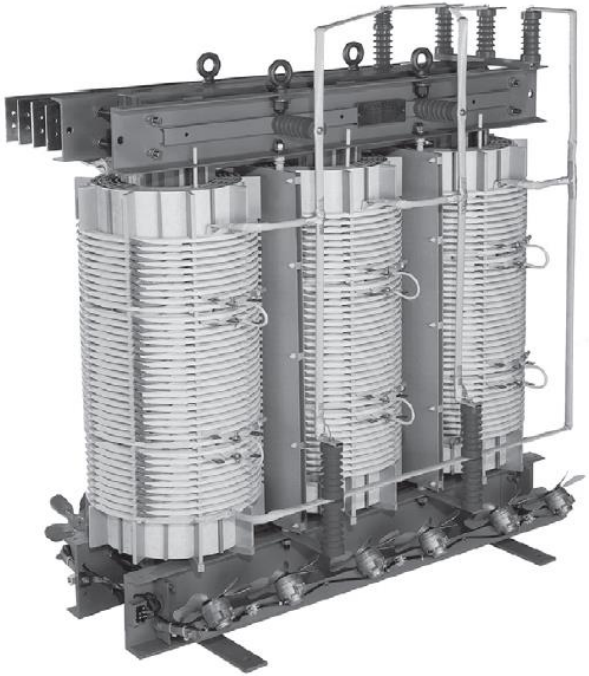
ELEC1111 Electrical and Telecommunications Engineering

UNSW AUSTRALIA

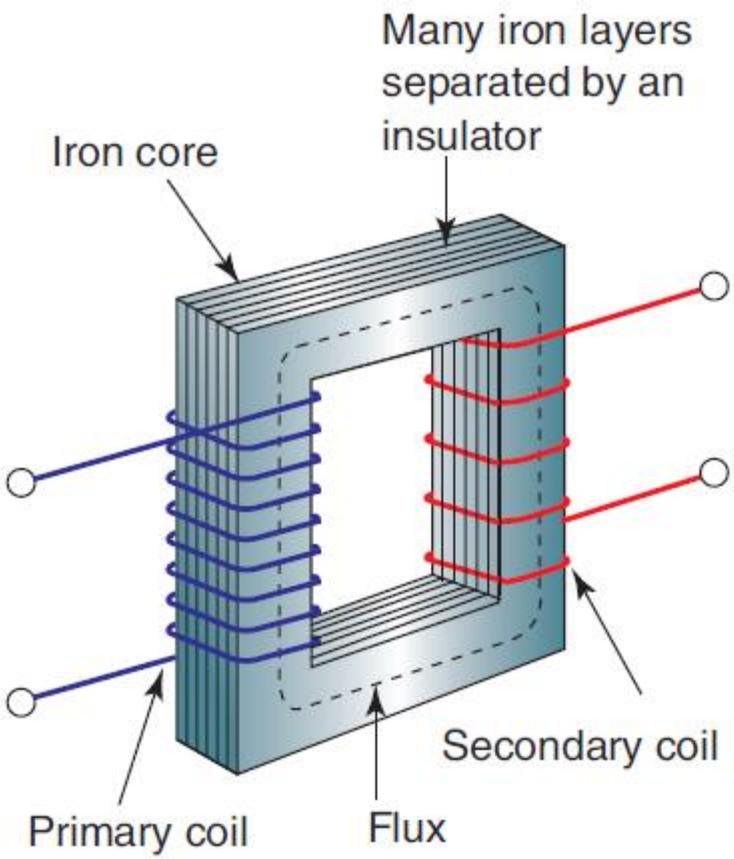
Never Stand Still | Faculty of Engineering | School of Electrical Engineering and Telecommunications

A transformer is an AC device which helps to transfer power from one circuit to another, without a change in frequency.

It is used to convert AC power at a certain voltage to AC power at a different voltage, but at the same frequency.



Construction



- A transformer in its simplest form will consist of a rectangular laminated magnetic structure on which two coils of different number of turns are wound.

- The winding to which AC voltage is impressed is called the primary of the transformer and the winding across which the load is connected is called the secondary of the transformer. This arrangement induces AC voltage in the secondary coil.

Principle of operation

- When an AC voltage is applied to the primary coil, an alternating current flows through the coil, which in turn, produces an alternating magnetic flux that 'flows' around the ferromagnetic core.

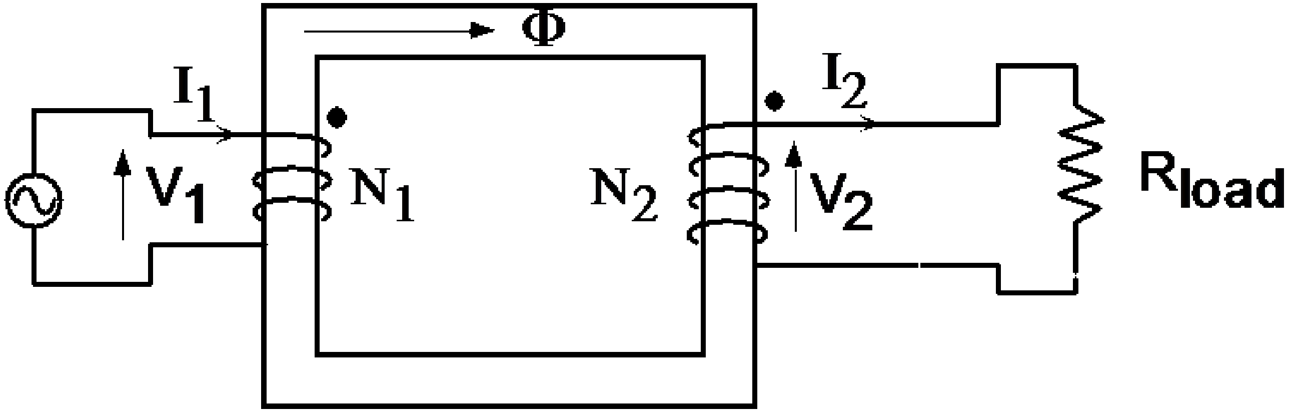
- This changing flux links with the primary coil and induces an AC voltage, which opposes the applied voltage.

- This changing flux also links with the secondary coil and hence induces an alternating voltage in this coil at the same frequency.

- The voltage at each of the secondary coils is directly related to the primary voltage by the turns ratio.

- If a load is connected to the secondary, an alternating current flows through the load.

Turns ratio - *n*



- ϕ: magnetic flux

$$v_1 = N_1 \frac{d\phi}{dt}$$

$$v_2 = N_2 \frac{d\phi}{dt}$$

Power in = Power out

$$v_1 i_1 = v_2 i_2$$

$$\frac{v_2}{v_1} = \frac{N_2}{N_1} = \frac{i_1}{i_2} = n$$

$$\frac{v_2}{v_1} = \frac{N_2}{N_1}$$

- Step-up transformers: $N_2 > N_1$ -> $V_2 > V_1$
- Step-down transformers: $N_2 < N_1$ -> $V_2 < V_1$

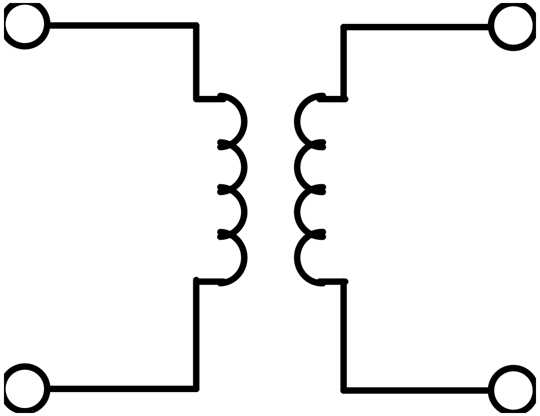
Ideal transformer

The windings have no resistance so no losses.

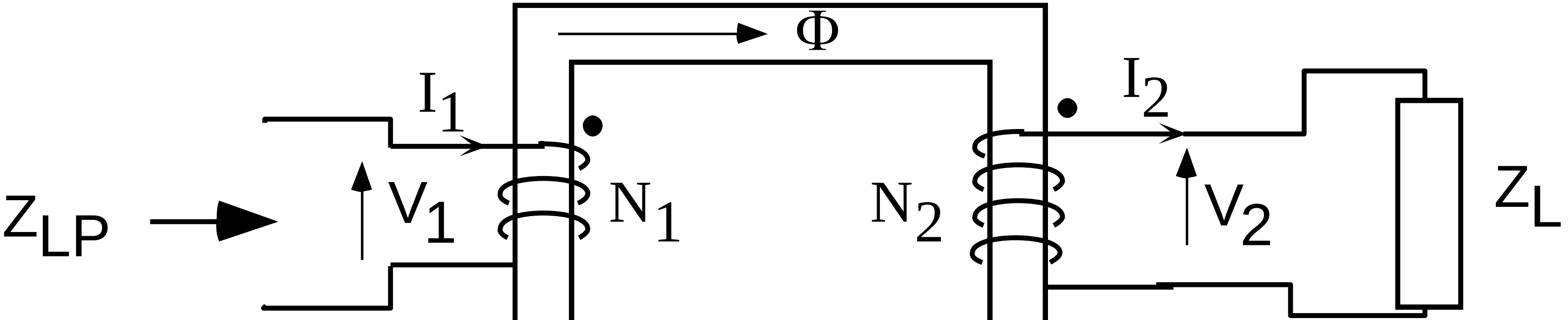
The core has zero reluctance (opposition to flux) so it requires no current to establish a flux in the core.

No losses in the core due to stray currents.

All the flux produced by the primary winding couples the secondary winding.



Impedance ratio



$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = n$$

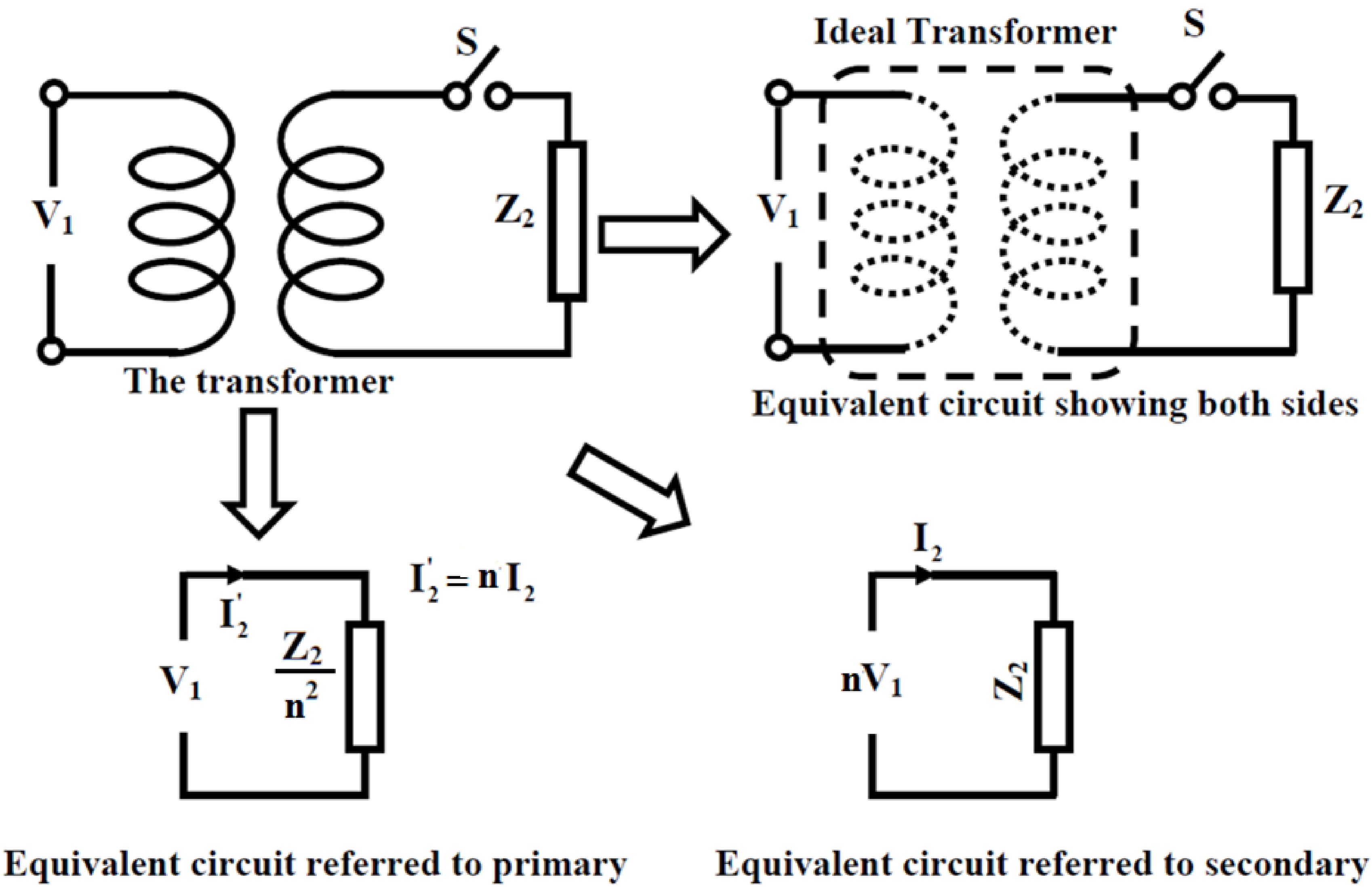
$$Z_L = \frac{V_2}{I_2}$$

$$Z_{LP} = \frac{V_1}{I_1} = \frac{V_2 \times \frac{N_1}{N_2}}{I_2 \times \frac{N_2}{N_1}} = \frac{V_2}{I_2} \times \left(\frac{N_1}{N_2}\right)^2$$

$$Z_{LP} = Z_L \left(\frac{N_1}{N_2}\right)^2 = \frac{Z_L}{n^2}$$

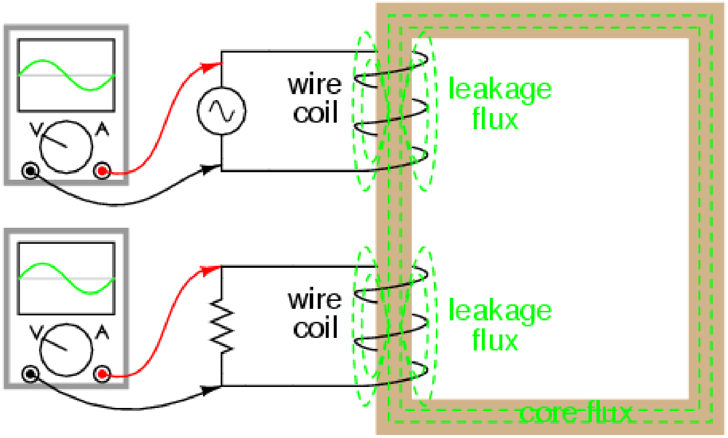
***Z**$_{LP}$* means ***Z**$_L$* referred to primary

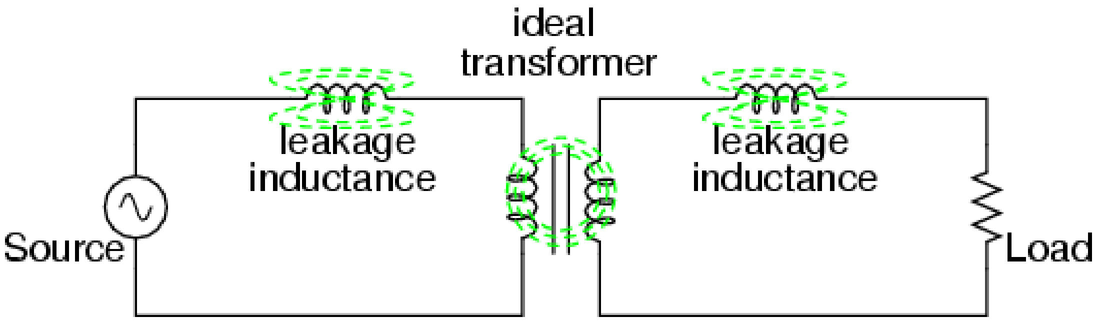
Equivalent circuit of ideal transformer



Ideal vs. real transformer

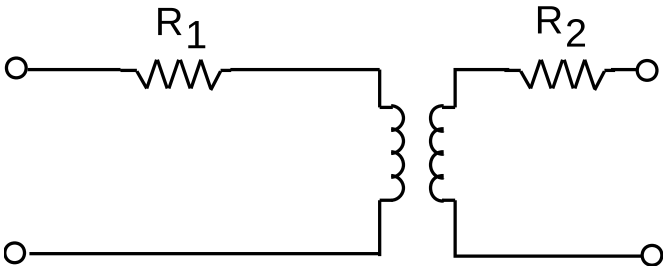
Ideal	Practical	Effect
No losses in windings	Windings have losses	Resistances R_1 & R_2
Zero reluctance in core	Non-zero reluctance	Reactance X_m
No losses in core	Core has losses	Resistance R_m
No flux leakage	Flux leakage is present	Reactances X_1 & X_2



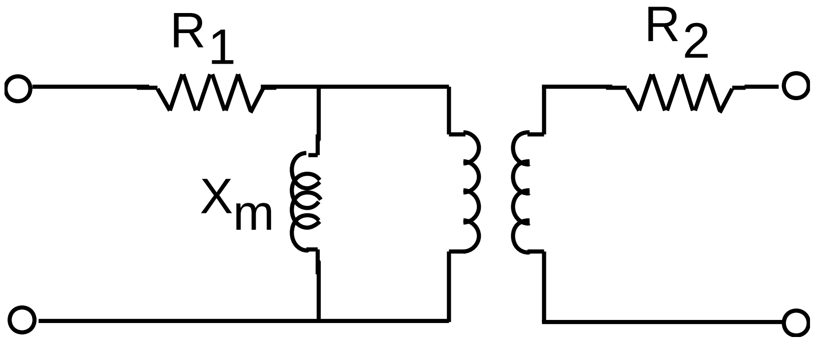


Real Transformer

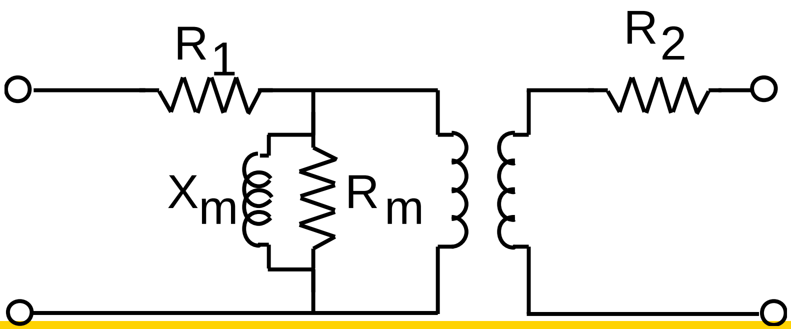
The windings have resistance .. so losses R_1 & R_2.



The core has a non zero reluctance so it requires current to establish a flux in the core.....X_m .



Core has losses due to stray currents in the core R_m.



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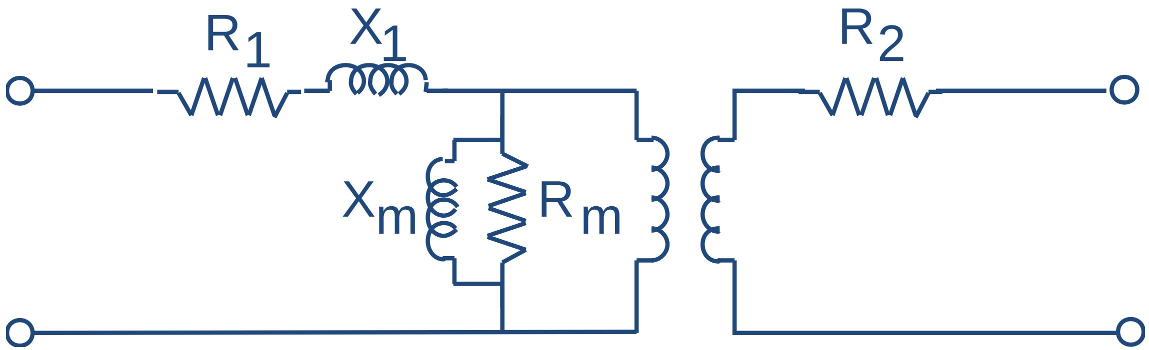
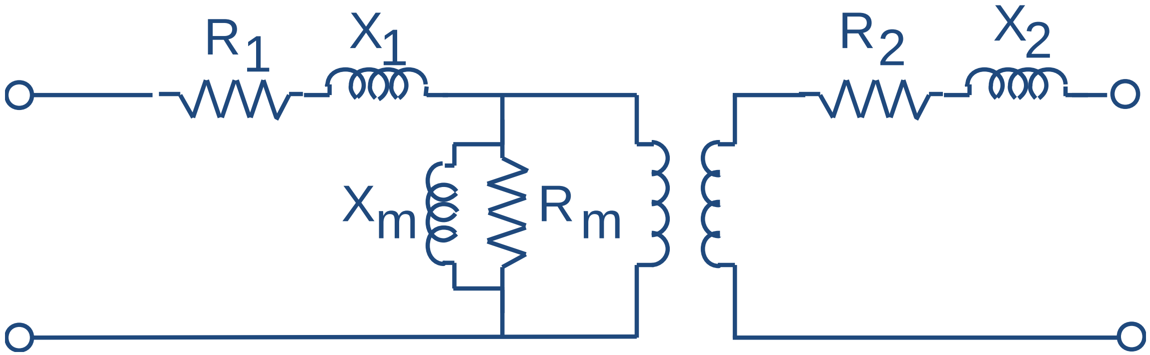
Real Transformer

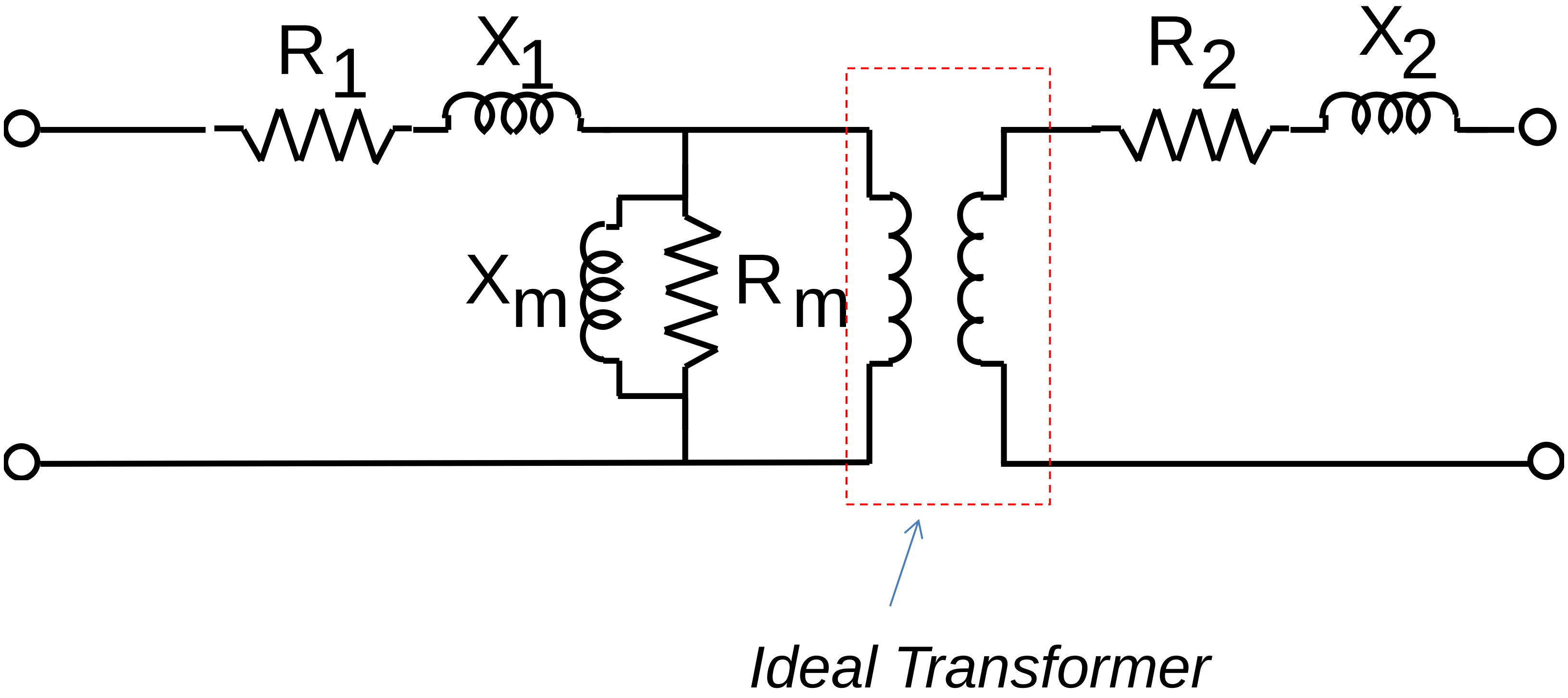
Some of the flux produced by the primary winding does not couple to the secondary winding - X_1.



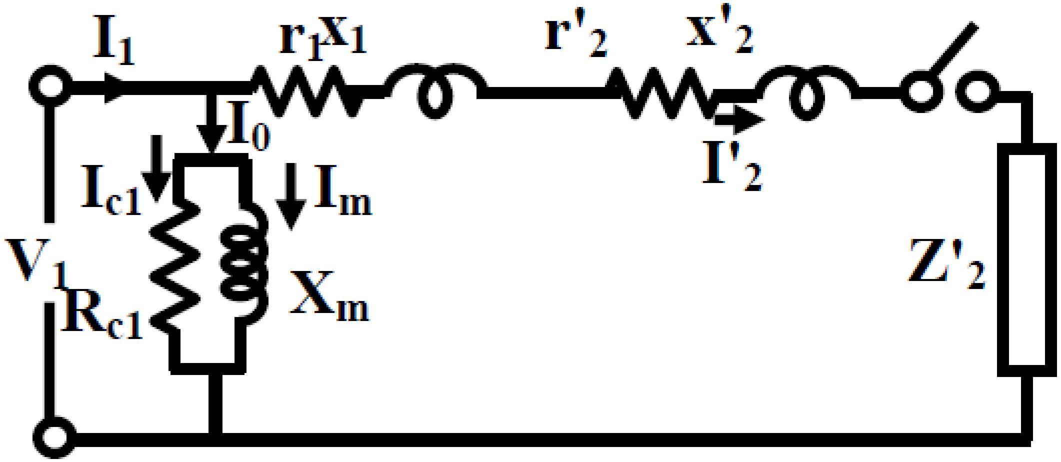
Some of the flux produced by the secondary winding does not couple the primary winding - X_2.



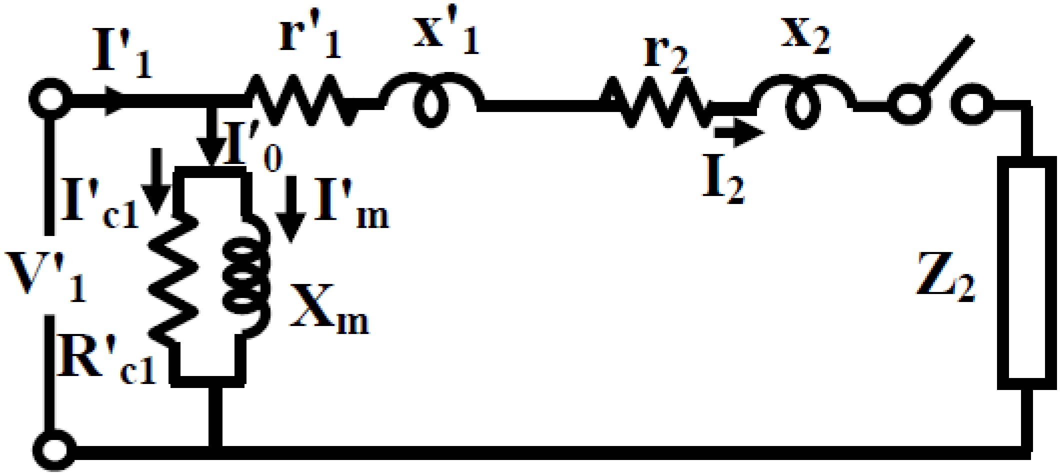
Real Transformer Equivalent Circuit



Removing magnetic coupling



Approximate Equivalent circuit referred to primary



Approximate Equivalent circuit referred to secondary

Transferring parameters

Z_2 to primary: $Z_2' = Z_2 / n^2$

V_2 to primary: $V_2' = V_2 / n$

I_2 to primary: $I_2' = I_2 \times n$

Z_1 to secondary: $Z_1' = Z_1 \times n^2$

V_1 to secondary: $V_1' = V_1 \times n$

I_1 to secondary: $I_1' = I_1 / n$

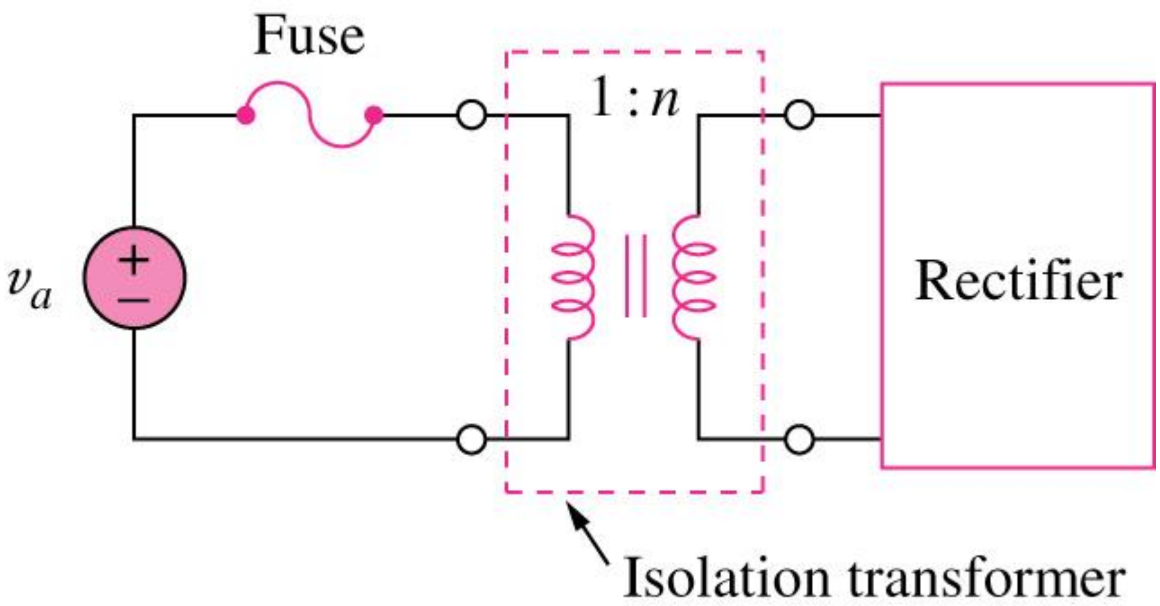
$n = N_2 / N_1$

The general rule for eliminating the transformer and reflecting the secondary circuit to the primary side is: divide the secondary impedance by n^2, divide the secondary voltage by n, and multiply the secondary current by n.

The rule for eliminating the transformer and reflecting the primary circuit to the secondary side is: multiply the primary impedance by n^2, multiply the primary voltage by n, and divide the primary current by n.

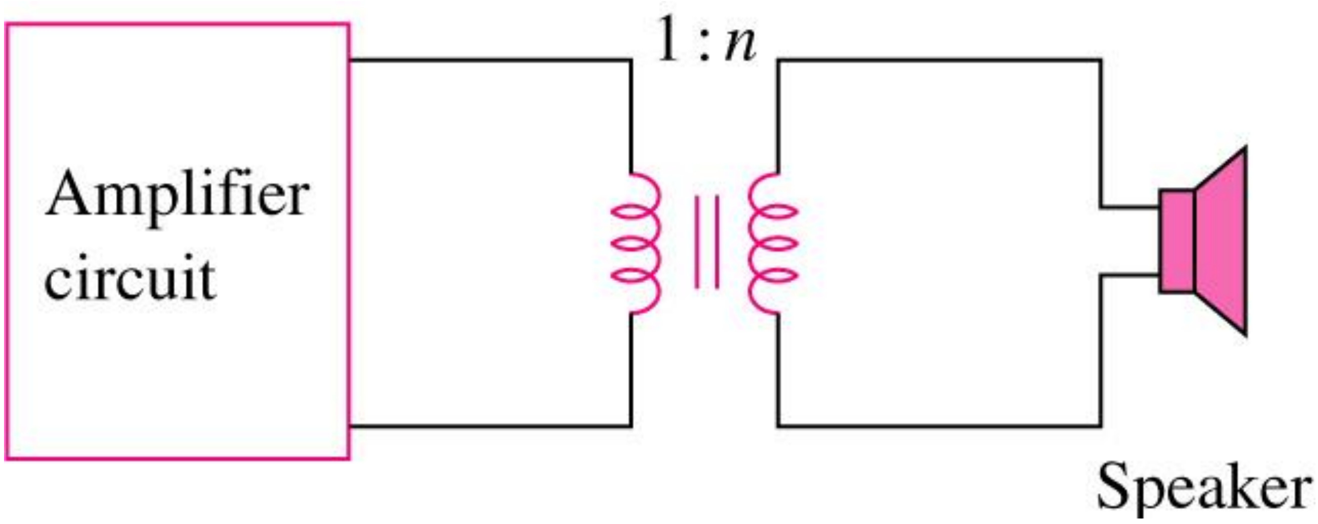
Applications (1)

- Transformer as an Isolation Device to isolate ac supply from a rectifier



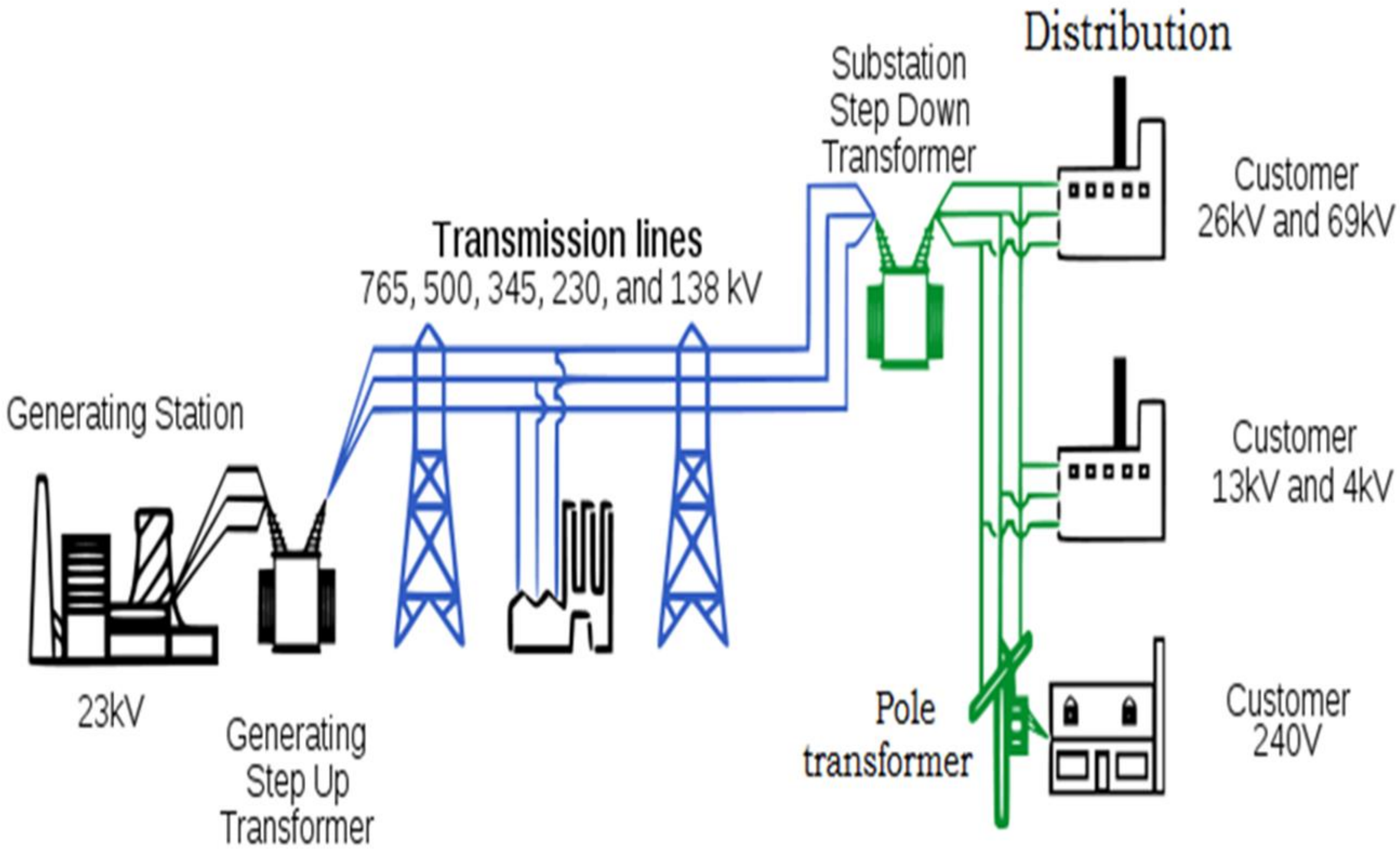
Applications (2)

- Transformer as a Matching Device



Applications (3)

- A typical power distribution system



Transformers work with AC NOT DC

If we supply DC to primary of transformer, there is no changing flux and hence no induced voltage both in the primary and the secondary.

It means the whole applied voltage is dropped in primary winding resistance which is very low.

So high current will flow through the primary winding which ultimately burns the primary winding.

Example 1

The transformer in an electric piano reduces a 240 V AC voltage to a 12.0 V AC voltage. If the secondary coil has 30 turns and the piano draws a current of 500 mA, calculate the following quantities:

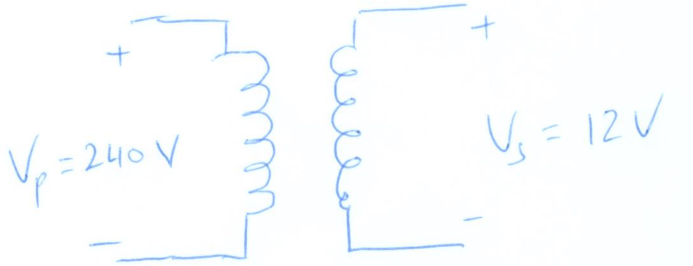
(a) the number of turns in the primary coil

(b) the current in the primary coil

(c) the power output of the transformer.

Example 1:

a/ $\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{240}{12} = 20$



$\rightarrow N_p = 20 N_s = 20 \times 30 = 600 \text{ (turns)}$ $\quad N_p : N_s \quad (N_s = 30)$

b/ $\frac{I_p}{I_s} = \frac{N_s}{N_p} = \frac{30}{600} = \frac{1}{20}$

$\rightarrow I_p = \frac{I_s}{20} = \frac{500}{20} = 25 \text{ mA}$

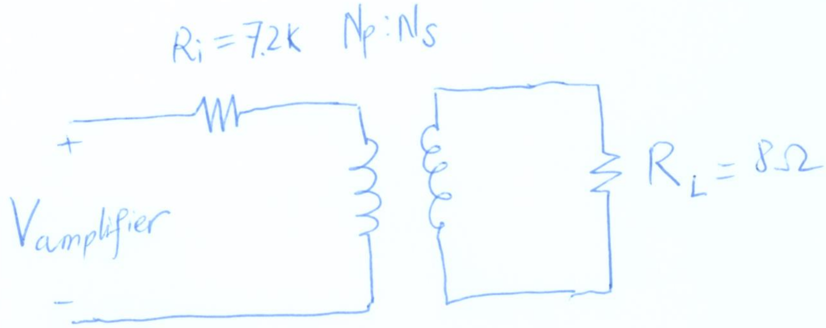
c/ $P_{secondary} = P_{primary} = V_p \times I_p = V_s \times I_s = 12 \times 0.5 = 6W$

Example 2

A stereo amplifier circuit with an output impedance of 7.2kΩ is to be matched to a speaker with an input impedance of 8Ω by a transformer whose primary side has 3000 turns. Calculate the number of turns required on the secondary side.

Example 2:

$N_p = 3000$ turns



To match the speaker with the amplifier:

$$R_{Lp} = R_i = 7200$$

$$R_{Lp} = \left(\frac{N_p}{N_s}\right)^2 \times R_L = 7200$$

$$\left(\frac{3000}{N_s}\right)^2 \times 8 = 7200$$

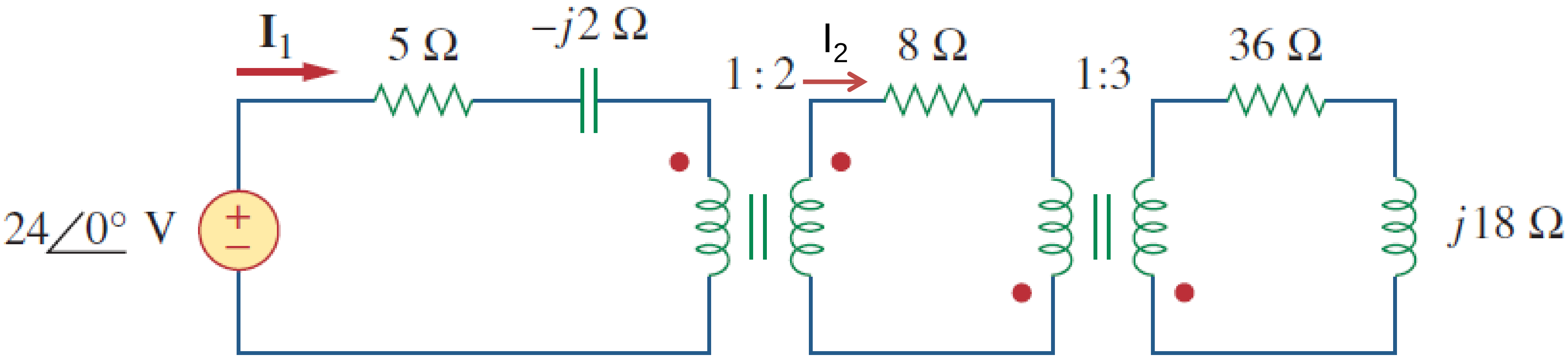
$$N_s = 100 \text{ turns}$$

Example 3

For the following circuit, use the concept of reflected to find:

a. The input impedance and current I_1

b. The current I_2



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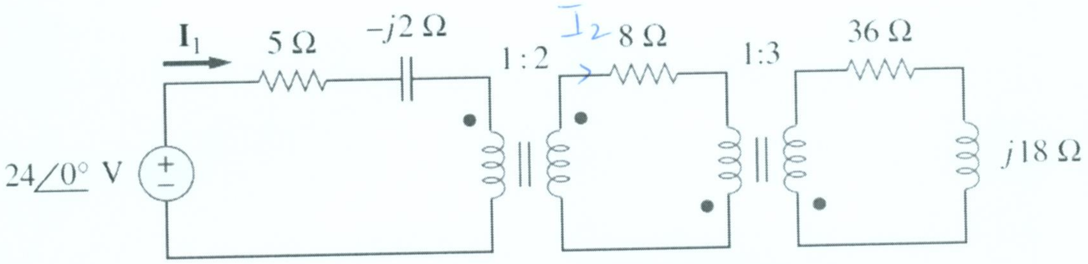
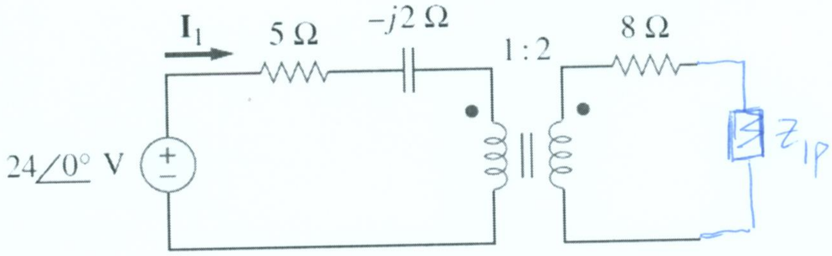
Example 3a:

$$Z_{1p} \xleftarrow{\text{Reflection}} \underbrace{Z_1 = 36 + j18}$$

a/



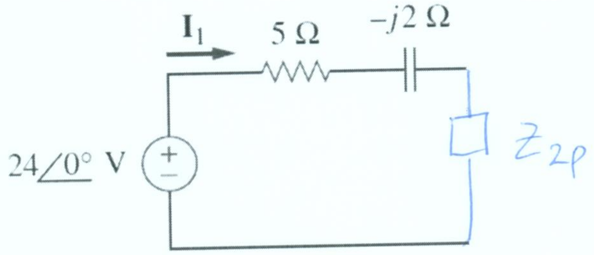
$$Z_{2p} \longleftarrow \underbrace{Z_2 = 8 + Z_{1p}}$$



$$\frac{Z_{1p}}{Z_1} = \left(\frac{1}{3}\right)^2 = \frac{1}{9}$$

$$Z_{1p} = \frac{Z_1}{9} = \frac{36 + j18}{9}$$

$$Z_{1p} = 4 + j2$$



$$\frac{Z_{2p}}{Z_2} = \left(\frac{1}{2}\right)^2 = \frac{1}{4}$$

$$Z_{2p} = \frac{Z_2}{4} = \frac{8 + 4 + j2}{4}$$

$$Z_{2p} = 3 + j0.5$$

$$I_1 = \frac{24\angle 0^\circ}{5 - j2 + Z_{2p}} = \frac{24\angle 0^\circ}{5 - j2 + 3 + j0.5}$$

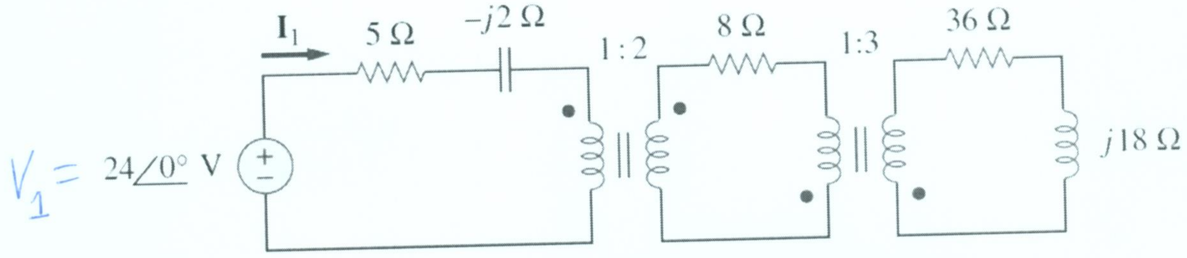
$$I_1 = 2.95\angle 10.6^\circ \quad (A)$$

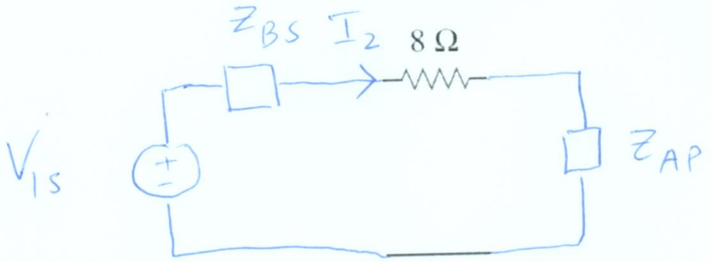
b/

$$\frac{I_1}{I_2} = \frac{2}{1} \rightarrow I_2 = \frac{I_1}{2} = 1.475\angle 10.6^\circ \quad (A)$$

Ex 3b (2nd method)

$Z_B = 5 - j2 \longrightarrow Z_{BS}$ $\qquad$ $Z_{AP} \longleftarrow Z_A = 36 + j18$





$$Z_B = 5 - j2 \rightarrow \frac{Z_B}{Z_{BS}} = \left(\frac{1}{2}\right)^2 = \frac{1}{4} \rightarrow Z_{BS} = 4 Z_B = 20 - j8\ \Omega$$

$$Z_A = 36 + j18 \rightarrow \frac{Z_{AP}}{Z_A} = \left(\frac{1}{3}\right)^2 = \frac{1}{9} \rightarrow Z_{AP} = \frac{Z_A}{9} = \frac{36 + j18}{9}$$

$$Z_{AP} = 4 + j2\ \Omega$$

$$\frac{V_1}{V_{1S}} = \frac{1}{2} \rightarrow V_{1S} = 2V_1 = 48\angle 0°\ V$$

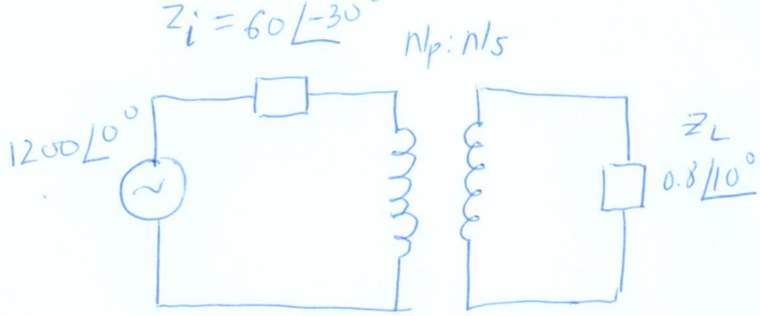
$$I_2 = \frac{V_{1S}}{Z_{BS} + 8 + Z_{AP}} = \frac{48\angle 0°}{20 - j8 + 8 + 4 + j2} = 1.475\angle 10.6°$$

Example 4

A 1200/240V rms transformer has impedance $60\angle -30^o$ on the primiary side. If the transformer is connected to a $0.8\angle 10^o$ load on the secondary, determine the primary and secondary current when the transformer is connected to 1200V rms.

Example 4:

$$\frac{V_p}{V_s} = \frac{1200}{240} = 5 = \frac{N_p}{N_s}$$

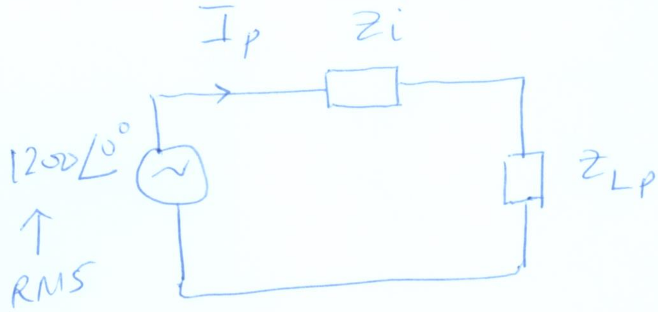


$$\frac{Z_{Lp}}{Z_L} = \left(\frac{N_p}{N_s}\right)^2 = 5^2 = 25$$

$$Z_{Lp} = 25\, Z_L = 25 \times 0.8\angle 10^\circ$$

$$Z_{Lp} \leftarrow Z_L$$

$$Z_{Lp} = 20\angle 10^\circ \ \Omega$$



$$I_p = \frac{1200\angle 0^\circ}{Z_i + Z_{Lp}}$$

$$I_p = \frac{1200\angle 0^\circ}{60\angle{-30} + 20\angle 10^\circ}$$

$$I_p = 15.7\angle 20.3^\circ$$

$$\frac{I_p}{I_s} = \frac{N_s}{N_p} \rightarrow I_s = I_p \times \frac{N_p}{N_s} = I_p \times 5 = 78.5\angle 20.3^\circ$$

$$i_p(t) = 15.7 \times \sqrt{2}\ \sin(\omega t + 20.3^\circ)\ A$$

$$i_s(t) = 78.5 \times \sqrt{2}\ \sin(\omega t + 20.3^\circ)\ A$$

assume $V_i(t) = 1200\sqrt{2}\ \sin(\omega t)$ ✓