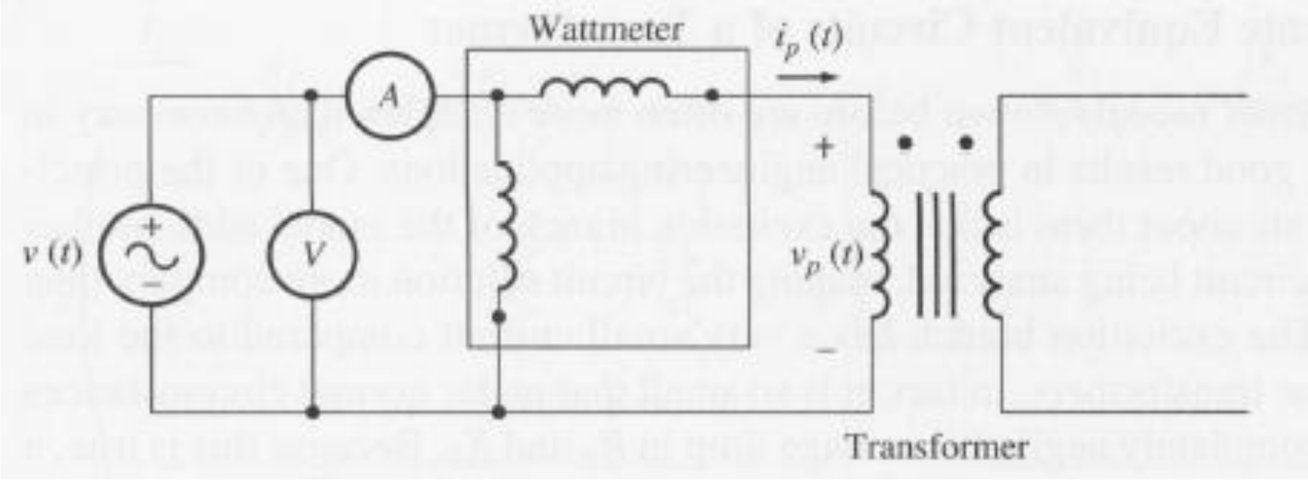
Determining the Values of Components in the Transformer Model

It is possible to experimentally determine the parameters of the approximate the equivalent circuit. An adequate approximation of these values can be obtained with only two tests….

- *open-circuit test*
- *short-circuit test*

Circuit Parameters: Open-Circuit Test



- Transformer's secondary winding is open-circuited
- Primary winding is connected to a full-rated line voltage. All the input current must be flowing through the excitation branch of the transformer.
- The series elements R_p and X_p are too small in comparison to R_C and X_M to cause a significant voltage drop, so essentially all the input voltage is dropped across the excitation branch.
- Input voltage, input current, and input power to the transformer are measured.

Circuit Parameters: Open-Circuit Test

The magnitude of the excitation admittance:

$$|Y_E| = \frac{I_{oc}}{V_{oc}}$$

The open-circuit power factor and power factor angle:

$$PF = \cos\theta = \frac{P_{oc}}{V_{oc}\, I_{oc}} \quad or,\ \theta = \cos^{-1}\left[\frac{P_{oc}}{V_{oc}\, I_{oc}}\right]$$

The power factor is always lagging for a transformer, so the current will lag the voltage by the angle θ. Therefore, the admittance Y_E is:

$$Y_E = \frac{1}{R_C} - j\frac{1}{X_M} = \frac{I_{oc}}{V_{oc}}\angle -\cos^{-1}(PF)$$

Open circuit Test

- It is used to determine L_{m1} (X_{m1})and R_{c1}
- Usually performed on the low voltage side
- The test is performed at rated voltage and frequency under no load

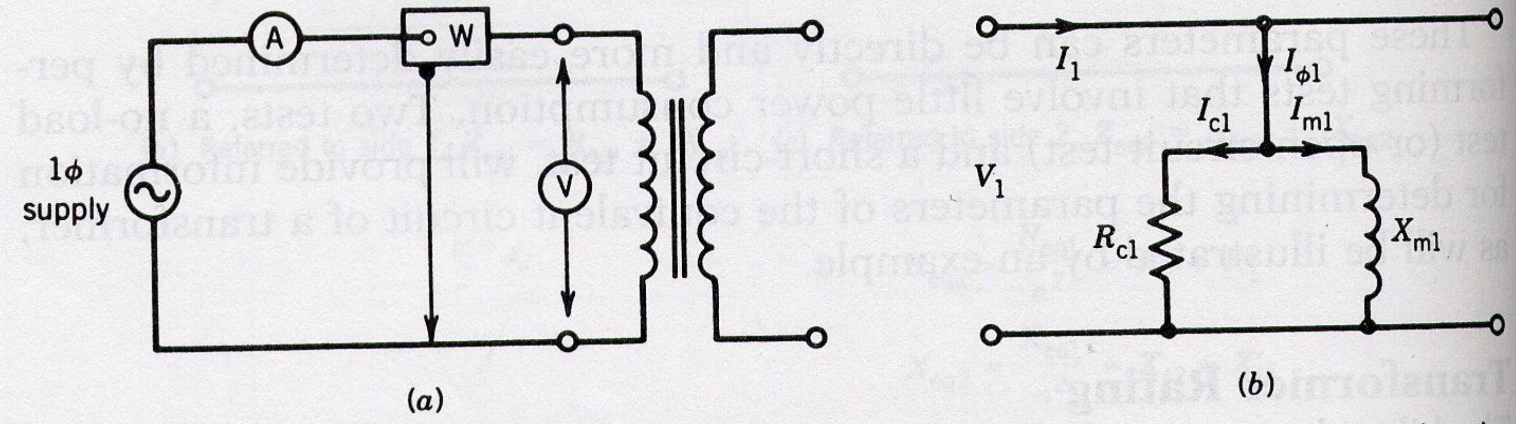


FIGURE 2.12 No-load (or open-circuit) test. (*a*) Wiring diagram for open-circuit test. (*b*) Equivalent circuit under open circuit.

Short circuit Test

- It is used to determine Ll_p (X_{eq}) and R_p(R_{eq})
- Usually performed on the high voltage side
- This test is performed at *reduced* voltage and rated frequency with the output of the low voltage winding short circuited such that rated current flows on the high voltage side.

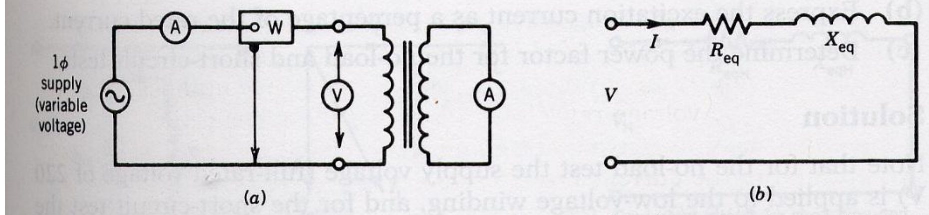


FIGURE 2.13 Short-circuit test. (*a*) Wiring diagram for short-circuit test. (*b*) Equivalent circuit at short-circuit condition.

Transformer Regulation

- Loading changes the output voltage of a transformer. Transformer regulation is the measure of such a deviation.

Definition of % Regulation

$$= \frac{|V_{no-load}| - |V_{load}|}{|V_{load}|} * 100$$

$V_{no\text{-}load}$ =RMS voltage across the load terminals without load

V_{load} = RMS voltage across the load terminals with a specified load

Maximum Transformer Regulation

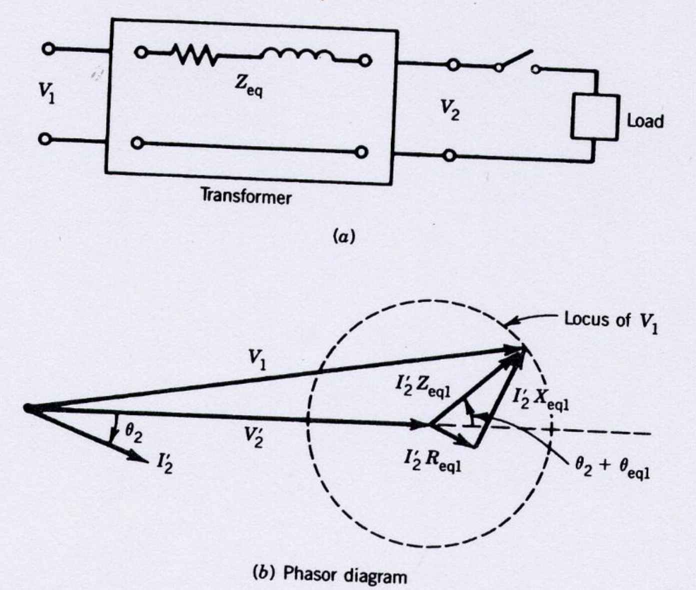


FIGURE 2.14 Voltage regulation.

$$V_1 = V_2^{'}\angle 0^0 + I_2^{'}\angle \theta_2^{\,0} . Z_{eq1}\angle \theta_{eq1}^{\,0}$$

Clearly V_1 *is* max *imum when*

$$\theta_2 + \theta_{eq1} = 0; or\ \theta_2 = -\theta_{eq1}$$

Transformer Losses and Efficiency

- Transformer Losses
  - Core/Iron Loss $=V_1^2 / R_{c1}$
  - Copper Loss $= I_1^2 R_1 + I_2^2 R_2$

Definition of % efficiency

$$= \frac{V_2 I_2 Cos\theta_2}{Losses + V_2 I_2 Cos\theta_2} * 100$$

$$= \frac{V_2 I_2 Cos\theta_2}{V_1^2 / R_{c1} + I_1^2 R_1 + I_2^2 R_2 + V_2 I_2 Cos\theta_2} * 100$$

$$= \frac{V_2 I_2 Cos\theta_2}{V_1^2 / R_{c1} + I_2^2 R_{eq2} + V_2 I_2 Cos\theta_2} * 100$$

$Cos\theta_2$ = load power factor

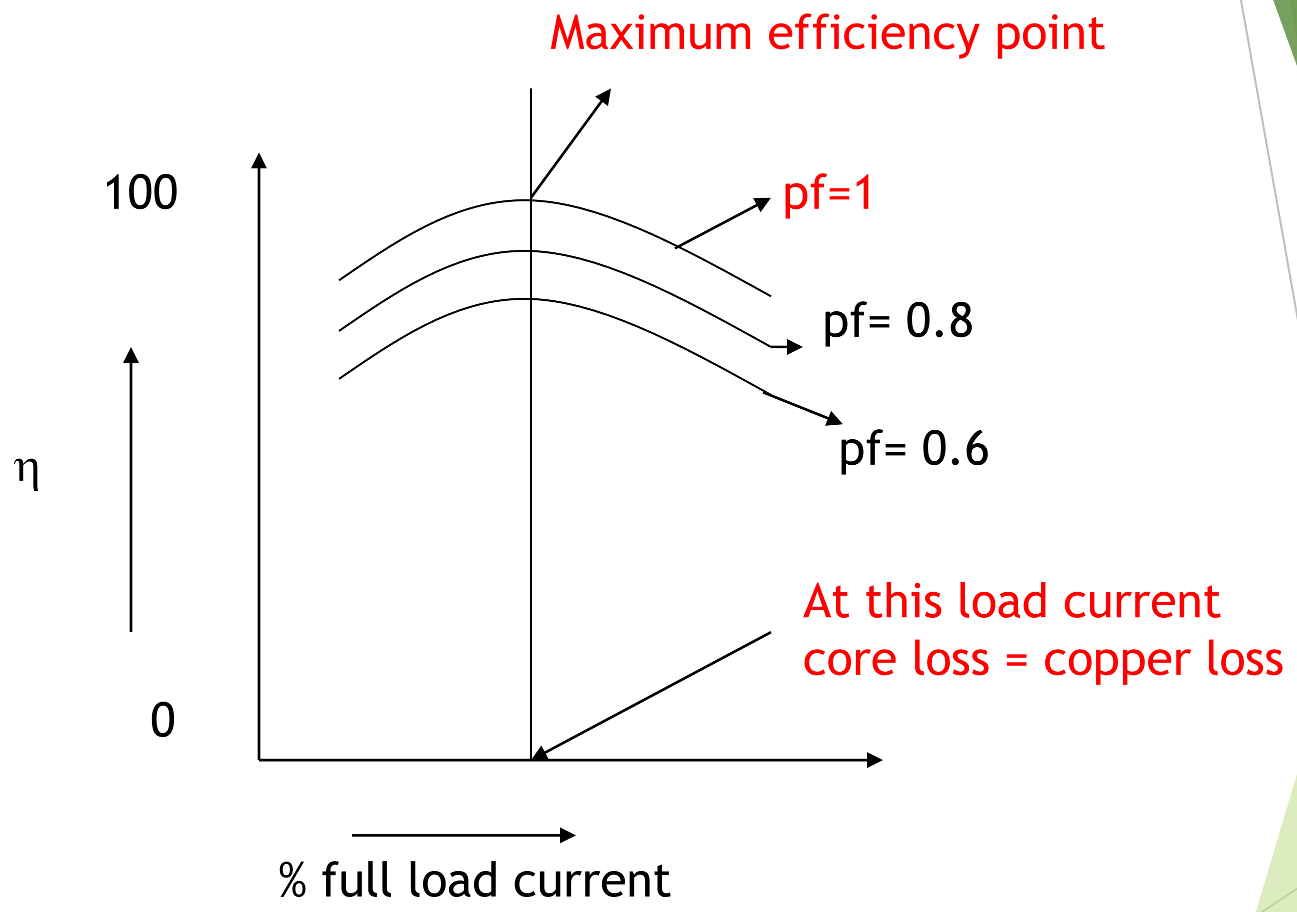
Maximum Transformer Efficiency

The efficiency varies as with respect to 2 independent quantities namely, current and power factor

- Thus at any particular power factor, the efficiency is maximum if core loss = copper loss .This can be obtained by differentiating the expression of efficiency with respect to I_2 assuming power factor, and all the voltages constant.

- At any particular I_2 maximum efficiency happens at unity power factor. This can be obtained by differentiating the expression of efficiency with respect to power factor, and assuming I_2 and all the voltages constant.

- Maximum efficiency happens when both these conditions are satisfied.


Maximum efficiency point
100
pf=1
pf= 0.8
pf= 0.6
η
At this load current
core loss = copper loss
0
% full load current