Module 7

Transformer

Lesson 25

Testing, Efficiency & Regulation

Contents

25.1 Goals of the lesson

In the previous lesson we have seen how to draw equivalent circuit showing magnetizing reactance (X_m), resistance (R_{cl}), representing core loss, equivalent winding resistance (r_e) and equivalent leakage reactance (x_e). The equivalent circuit will be of little help to us unless we know the parameter values. In this lesson we first describe two basic simple laboratory tests namely (i) open circuit test and (ii) short circuit test from which the values of the equivalent circuit parameters can be computed. Once the equivalent circuit is completely known, we can predict the performance of the transformer at various loadings. *Efficiency* and *regulation* are two important quantities which are next defined and expressions for them derived and importance highlighted. A number of objective type questions and problems are given at the end of the lesson which when solved will make the understanding of the lesson clearer.

Key Words: O.C. test, S.C test, efficiency, regulation.

After going through this section students will be able to answer the following questions.

- Which parameters are obtained from O.C test?
- Which parameters are obtained from S.C test?
- What percentage of rated voltage is needed to be applied to carry out O.C test?
- What percentage of rated voltage is needed to be applied to carry out S.C test?
- From which side of a large transformer, would you like to carry out O.C test?
- From which side of a large transformer, would you like to carry out S.C test?
- How to calculate efficiency of the transformer at a given load and power factor?
- Under what condition does the transformer operate at maximum efficiency?
- What is regulation and its importance?
- How to estimate regulation at a given load and power factor?
- What is the difference between *efficiency* and *all day efficiency*?

25.2 Determination of equivalent circuit parameters

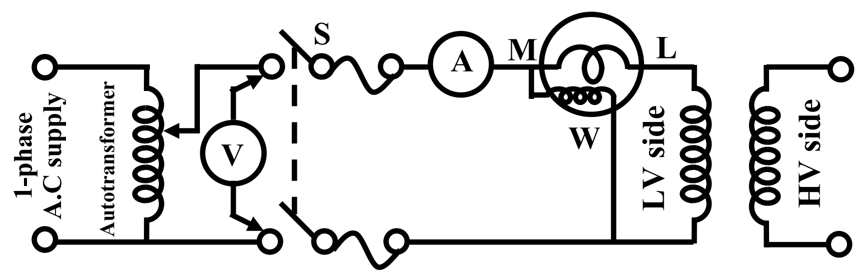
After developing the equivalent circuit representation, it is natural to ask, how to know equivalent circuit the parameter values. Theoretically from the detailed design data it is possible to estimate various parameters shown in the equivalent circuit. In practice, two basic tests namely the *open circuit test* and the *short circuit test* are performed to determine the equivalent circuit parameters.

25.2.1 Qualifying parameters with suffixes LV & HV

For a given transformer of rating say, 10 kVA, 200 V / 100 V, 50 Hz, one should not be under the impression that 200 V (HV) side will always be the primary (as because this value appears first in order in the voltage specification) and 100 V (LV) side will always be secondary. Thus, for a given transformer either of the HV and LV sides may be used as primary or secondary as decided by the user to suit his/her goals in practice. Usually suffixes 1 and 2 are used for expressing quantities in terms of primary and secondary respectively – there is nothing wrong in it so long one keeps track clearly which side is being used as primary. However, there are situation, such as carrying out O.C & S.C tests (discussed in the next section), where naming parameters with suffixes HV and LV become imperative to avoid mix up or confusion. Thus, it will be useful to qualify the parameter values using the suffixes HV and LV (such as $r_{e\,HV}$, $r_{e\,LV}$ etc. instead of r_{e1}, r_{e2}). Therefore, it is recommended to use suffixes as LV, HV instead of 1 and 2 while describing quantities (like voltage V_{HV}, V_{LV} and currents I_{HV}, I_{LV}) or parameters (resistances r_{HV}, r_{LV} and reactances x_{HV}, x_{LV}) in such cases.

25.2.2 Open Circuit Test

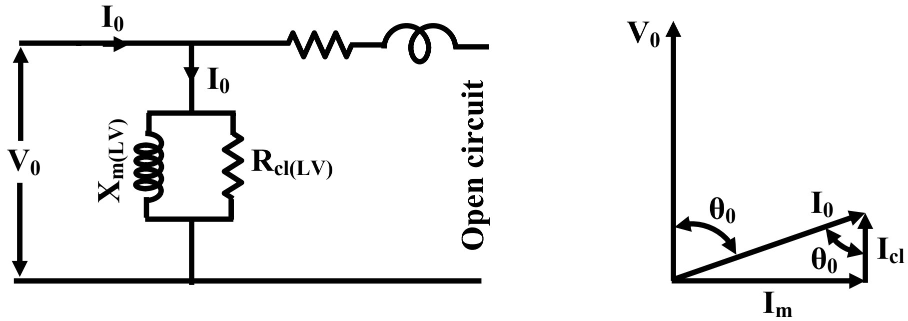
To carry out open circuit test it is the LV side of the transformer where rated voltage at rated frequency is applied and HV side is left opened as shown in the circuit diagram 25.1. The voltmeter, ammeter and the wattmeter readings are taken and suppose they are V_0, I_0 and W_0 respectively. During this test, rated flux is produced in the core and the current drawn is the no-load current which is quite small about 2 to 5% of the rated current. Therefore low range ammeter and wattmeter current coil should be selected. Strictly speaking the wattmeter will record the core loss as well as the LV winding copper loss. But the winding copper loss is very small compared to the core loss as the flux in the core is rated. In fact this approximation is built-in in the approximate equivalent circuit of the transformer referred to primary side which is LV side in this case.



Open Circuit Test

Figure 25.1: Circuit diagram for O.C test

The approximate equivalent circuit and the corresponding phasor diagrams are shown in figures 25.2 (a) and (b) under no load condition.



(a) Equivalent circuit under O.C test **(b) Corresponding phasor diagram**

Figure 25.2: Equivalent circuit & phasor diagram during O.C test

Below we shall show how from the readings of the meters the parallel branch impedance namely $R_{cl(LV)}$ and $X_{m(LV)}$ can be calculated.

$$\text{Calculate no load power factor } \cos\theta_0 = \frac{W_0}{V_0 I_0}$$

Hence θ_0 is known, calculate $\sin\theta_0$

$$\text{Calculate magnetizing current } I_m = I_0 \sin\theta_0$$

$$\text{Calculate core loss component of current } I_{cl} = I_0 \cos\theta_0$$

$$\text{Magnetising branch reactance } X_{m(LV)} = \frac{V_0}{I_m}$$

$$\text{Resistance representing core loss } R_{cl(LV)} = \frac{V_0}{I_{cl}}$$

We can also calculate $X_{m(HV)}$ and $R_{cl(HV)}$ as follows:

$$X_{m(HV)} = \frac{X_{m(LV)}}{a^2}$$

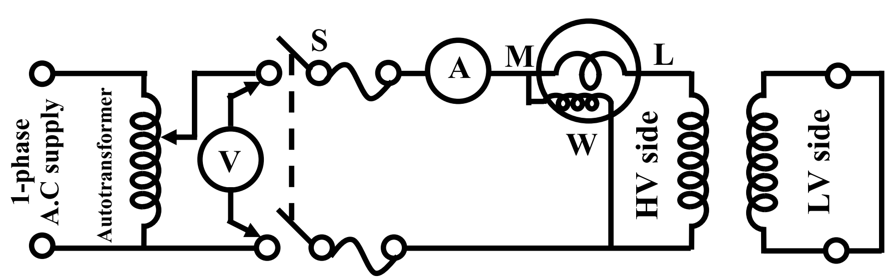
$$R_{cl(HV)} = \frac{R_{cl(LV)}}{a^2}$$

$$\text{Where, } a = \frac{N_{LV}}{N_{HV}} \text{ the turns ratio}$$

If we want to draw the equivalent circuit referred to LV side then $R_{cl(LV)}$ and $X_{m(LV)}$ are to be used. On the other hand if we are interested for the equivalent circuit referred to HV side, $R_{cl(HV)}$ and $X_{m(HV)}$ are to be used.

25.2.3 Short circuit test

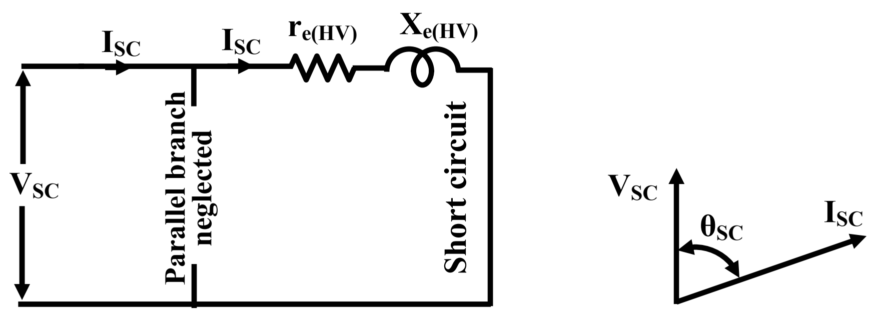
Short circuit test is generally carried out by energizing the HV side with LV side shorted. Voltage applied is such that the *rated* current flows in the windings. The circuit diagram is shown in the figure 25.3. Here also voltmeter, ammeter and the wattmeter readings are noted corresponding to the rated current of the windings.



Short Circuit Test

Figure 25.3: Circuit diagram during S.C test

Suppose the readings are V_{sc}, I_{sc} and W_{sc}. It should be noted that voltage required to be applied for rated short circuit current is quite small (typically about 5%). Therefore flux level in the core of the transformer will be also very small. Hence core loss is negligibly small compared to the winding copper losses as rated current now flows in the windings. Magnetizing current too, will be pretty small. In other words, under the condition of the experiment, the parallel branch impedance comprising of $R_{cl(HV)}$ and $X_{m(LV)}$ can be considered to be absent. The equivalent circuit and the corresponding phasor diagram during circuit test are shown in figures 25.4 (a) and (b).



(a) Equivalent circuit under S.C test **(b) Corresponding phasor diagram**

Figure 25.4: Equivalent circuit & phasor diagram during S.C test

Therefore from the test data series equivalent impedance namely $r_{e(HV)}$ and $x_{e(HV)}$ can easily be computed as follows:

$$\text{Equivalent resistance ref. to HV side } r_{e(HV)} = \frac{W_{sc}}{I_{sc}^2}$$

$$\text{Equivalent impedance ref. to HV side } z_{e(HV)} = \frac{V_{sc}}{I_{sc}}$$

$$\text{Equivalent leakage reactance ref. to HV side } x_{e(HV)} = \sqrt{z_{e(HV)}^2 - r_{e(HV)}^2}$$

We can also calculate $r_{e(LV)}$ and $x_{e(LV)}$ as follows:

$$r_{e(LV)} = a^2 r_{e(HV)}$$

$$x_{e(LV)} = a^2 x_{e(HV)}$$

$$\text{where, } a = \frac{N_{LV}}{N_{HV}} \text{ the turns ratio}$$

Once again, remember if you are drawing equivalent circuit referred to LV side, use parameter values with suffixes LV, while for equivalent circuit referred to HV side parameter values with suffixes HV must be used.

25.3 Efficiency of transformer

In a practical transformer we have seen mainly two types of major losses namely core and copper losses occur. These losses are wasted as heat and temperature of the transformer rises. Therefore output power of the transformer will be always less than the input power drawn by the primary from the source and efficiency is defined as

$$\eta = \frac{\text{Output power in KW}}{\text{Output power in Kw} + \text{Losses}}$$

$$= \frac{\text{Output power in KW}}{\text{Output power in Kw} + \text{Core loss} + \text{Copper loss}} \quad (25.1)$$

We have seen that from no load to the full load condition the core loss, P_{core} remains practically constant since the level of flux remains practically same. On the other hand we know that the winding currents depend upon the degree of loading and copper loss directly depends upon the square of the current and not a constant from no load to full load condition. We shall write a general expression for efficiency for the transformer operating at x per unit loading and delivering power to a known power factor load. Let,

$$
\begin{aligned}
\text{KVA rating of the transformer be} &= S \\
\text{Per unit degree of loading be} &= x \\
\text{Transformer is delivering} &= x\,S\ \text{KVA} \\
\text{Power factor of the load be} &= \cos\theta \\
\text{Output power in KW} &= xS\cos\theta \\
\text{Let copper loss at full load (i.e., x = 1)} &= P_{cu} \\
\text{Therefore copper loss at x per unit loading} &= x^2 P_{cu} \\
\text{Constant core loss} &= P_{core} \qquad (25.2)
\end{aligned}
$$

(25.3)

Therefore efficiency of the transformer for general loading will become:

$$\eta = \frac{xS\cos\theta}{xS\cos\theta + P_{core} + x^2 P_{cu}}$$

If the power factor of the load (i.e., cos θ) is kept constant and degree of loading of the transformer is varied we get the *efficiency* Vs *degree of loading* curve as shown in the figure 25.5. For a given load power factor, transformer can operate at maximum efficiency at some unique value of loading i.e., x. To find out the condition for *maximum efficiency*, the above equation for η can be differentiated with respect to x and the result is set to 0. Alternatively, the right hand side of the above equation can be simplified to, by dividing the numerator and the denominator by x. the expression for η then becomes:

$$\eta = \frac{S\cos\theta}{S\cos\theta + \frac{P_{core}}{x} + x\,P_{cu}}$$

For efficiency to be maximum, $\frac{d}{dx}$ (Denominator) is set to zero and we get,

$$\text{or } \frac{d}{dx}\left(S\cos\theta + \frac{P_{core}}{x} + x\,P_{cu}\right) = 0$$

$$\text{or } -\frac{P_{core}}{x^2} + P_{cu} = 0$$

$$\text{or } x^2 P_{cu} = P_{core}$$

$$\text{The loading for maximum efficiency, } x = \sqrt{\frac{P_{core}}{P_{cu}}}$$

Thus we see that for a given power factor, transformer will operate at maximum efficiency when it is loaded to $\sqrt{\frac{P_{core}}{P_{cu}}}\, S$ KVA. For transformers intended to be used continuously at its rated KVA, should be designed such that maximum efficiency occurs at $x = 1$. Power transformers fall under this category. However for transformers whose load widely varies over time, it is not desirable to have maximum efficiency at $x = 1$. Distribution transformers fall under this category and the typical value of x for maximum efficiency for such transformers may between 0.75 to 0.8. Figure 25.5 show a family of efficiency Vs. degree of loading curves with power factor as parameter. It can be seen that for any given power factor, maximum efficiency occurs at a loading of $x = \sqrt{\frac{P_{core}}{P_{cu}}}$. Efficiencies η_{max1}, η_{max2} and η_{max3} are respectively the maximum efficiencies corresponding to power factors of unity, 0.8 and 0.7 respectively. It can easily be shown that for a given load (i.e., fixed x), if power factor is allowed to vary then maximum efficiency occurs at unity power factor. Combining the above observations we can say that the efficiency is obtained when the loading of the transformer is $x = \sqrt{\frac{P_{core}}{P_{cu}}}$ and load power factor is unity. Transformer being a static device its efficiency is very high of the order of 98% to even 99%.

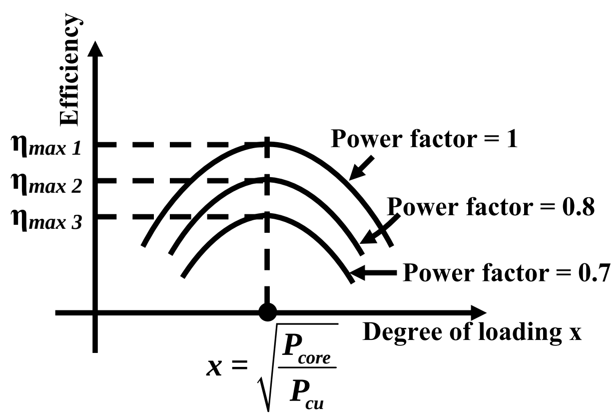


Figure 25.5: Efficiency VS degree of loading curves.

25.3.1 All day efficiency

In the earlier section we have seen that the efficiency of the transformer is dependent upon the degree of loading and the load power factor. The knowledge of this efficiency is useful provided the load and its power factor remains constant throughout.

For example take the case of a *distribution transformer*. The transformers which are used to supply LT consumers (residential, office complex etc.) are called distribution transformers. For obvious reasons, the load on such transformers vary widely over a day or 24 hours. Some times the transformer may be practically under no load condition (say at mid night) or may be over loaded during peak evening hours. Therefore it is not fare to judge efficiency of the transformer calculated at a particular load with a fixed power factor. *All day efficiency*, alternatively called *energy efficiency* is calculated for such transformers to judge how efficient are they. To estimate the efficiency the whole day (24 hours) is broken up into several time blocks over which the load remains constant. The idea is to calculate total amount of energy output in KWH and total amount of energy input in KWH over a complete day and then take the ratio of these two to get the energy efficiency or all day efficiency of the transformer. Energy or All day efficiency of a transformer is defined as:

$$\eta_{\text{all day}} = \frac{\text{Energy output in KWH in 24 hours}}{\text{Energy input in KWH in 24 hours}}$$

$$= \frac{\text{Energy output in KWH in 24 hours}}{\text{Output in KWH in 24 hours} + \text{Energy loss in 24 hours}}$$

$$= \frac{\text{Output in KWH in 24 hours}}{\text{Output in KWH in 24 hours} + \text{Loss in core in 24 hours} + \text{Loss in the Winding in 24 hours}}$$

$$= \frac{\text{Energy output in KWH in 24 hours}}{\text{Energy output in KWH in 24 hours} + 24\,P_{\text{core}} + \text{Energy loss (cu) in the winding in 24 hours}}$$

With primary energized all the time, constant P_{core} loss will always be present no matter what is the degree of loading. However copper loss will have different values for different time blocks as it depends upon the degree of loadings. As pointed out earlier, if P_{cu} is the full load copper loss corresponding to $x = 1$, copper loss at any arbitrary loading x will be $x^2\,P_{cu}$. It is better to make the following table and then calculate $\eta_{all\,day}$.

Time blocks	KVA Loading	Degree of loading x	P.F of load	KWH output	KWH cu loss
T_1 hours	S_1	$x_1 = S_1/S$	$\cos\theta_1$	$S_1\cos\theta_1 T_1$	$x_1^2\,P_{cu}\,T_1$
T_2 hours	S_2	$x_2 = S_2/S$	$\cos\theta_2$	$S_2\cos\theta_2 T_2$	$x_2^2\,P_{cu}\,T_2$
…	…	…	…	…	…
T_n hours	S_n	$x_n = S_n/S$	$\cos\theta_n$	$S_n\cos\theta_n T_n$	$x_n^2\,P_{cu}\,T_n$

$$\text{Note that } \sum_{i=1}^{n} T_i = 24$$

$$\text{Energy output in 24 hours} = \sum_{i=1}^{n} S_i\,cos\,\theta_i\,T_i$$

$$\text{Total energy loss} = 24\,P_{core} + \sum_{i=1}^{n} x_i^2\,P_{cu}\,T_i$$

$$\eta_{allday} = \frac{\sum_{i=1}^{n} S_i\,cos\,\theta_i\,T_i}{\sum_{i=1}^{n} S_i\,cos\,\theta_i\,T_i + \sum_{i=1}^{n} x_i^2\,P_{cu}\,T_i + 24\,P_{core}}$$

25.4 Regulation

The output voltage in a transformer will not be maintained constant from no load to the full load condition, for a fixed input voltage in the primary. This is because there will be internal voltage drop in the series leakage impedance of the transformer the magnitude of which will depend upon the degree of loading as well as on the power factor of the load. The knowledge of *regulation* gives us idea about change in the magnitude of the secondary voltage from no load to full load condition at a given power factor. This can be determined experimentally by direct loading of the transformer. To do this, primary is energized with rated voltage and the secondary terminal voltage is recorded in absence of any load and also in presence of full load. Suppose the readings of the voltmeters are respectively V_{20} and V_2. Therefore change in the magnitudes of the secondary voltage is $V_{20} - V_2$. This change is expressed as a percentage of the no load secondary voltage to express regulation. Lower value of regulation will ensure lesser fluctuation of the voltage across the loads. If the transformer were ideal regulation would have been zero.

$$\text{Percentage Regulation}, \% R = \frac{(V_{20} - V_2)}{V_{20}} \times 100$$

For a well designed transformer at full load and 0.8 power factor load percentage regulation may lie in the range of 2 to 5%. However, it is often not possible to fully load a large transformer in the laboratory in order to know the value of regulation. Theoretically one can estimate approximately, regulation from the equivalent circuit. For this purpose let us draw the equivalent circuit of the transformer referred to the secondary side and neglect the effect of no load current as shown in the figure 25.6. The corresponding phasor diagram referred to the secondary side is shown in figure 25.7.

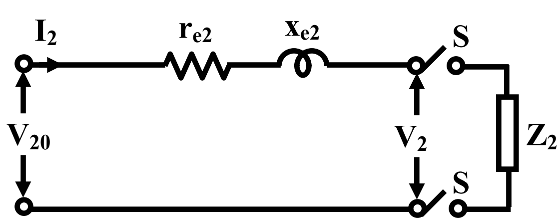


Figure 25.6: Equivalent circuit ref. to secondary.

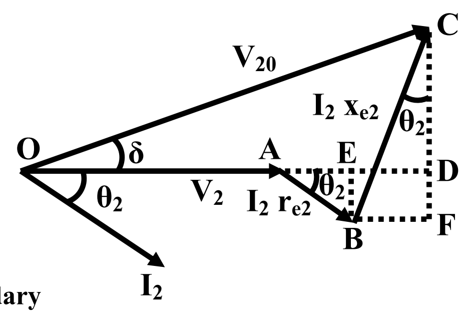


Figure 25.7: Phasor diagram ref. to secondary.

It may be noted that when the transformer is under no load condition (i.e., S is opened), the terminal voltage V_2 is same as V_{20}. However, this two will be different when the switch is closed due to drops in $I_2\ r_{e2}$ and $I_2\ x_{e2}$. For a loaded transformer the phasor diagram is drawn taking terminal voltage V_2 on reference. In the usual fashion I_2 is drawn lagging V_2, by the power factor angle of the load θ_2 and the drops in the equivalent resistance and leakage reactances are added to get the phasor V_{20}. Generally, the resistive drop $I_2\ r_{e2}$ is much smaller than the reactive drop $I_2\ x_{e2}$. It is because of this the angle between OC and OA (δ) is quite small. Therefore as per the definition we can say regulation is

$$R = \frac{(V_{20} - V_2)}{V_{20}} = \frac{OC - OA}{OC}$$

An approximate expression for regulation can now be easily derived geometrically from the phasor diagram shown in figure 25.7.

$$\begin{aligned}
OC &= OD \text{ since, } \delta \text{ is small} \\
\text{Therefore, } OC - OA &= OD - OA \\
&= AD \\
&= AE + ED \\
&= I_2\, r_{e2} \cos\theta_2 + I_2\, x_{e2} \sin\theta_2 \\
\text{So per unit regulation, } R &= \frac{OC - OA}{OC} \\
&= \frac{I_2\, r_{e2} \cos\theta_2 + I_2\, x_{e2} \sin\theta_2}{V_{20}} \\
\text{or, } R &= \frac{I_2\, r_{e2}}{V_{20}} \cos\theta_2 + \frac{I_2\, x_{e2}}{V_{20}} \sin\theta_2
\end{aligned}$$

It is interesting to note that the above regulation formula was obtained in terms of quantities of secondary side. It is also possible to express regulation in terms of primary quantities as shown below:

$$\text{We know, } R = \frac{I_2\, r_{e2}}{V_{20}} \cos\theta_2 + \frac{I_2\, x_{e2}}{V_{20}} \sin\theta_2$$

Now multiplying the numerator and denominator of the RHS by *a* the turns ratio, and further manipulating a bit with *a* in numerator we get:

$$\mathrm{R} = \frac{(I_2/a)a^2\, r_{e2}}{aV_{20}} \cos\theta_2 + \frac{(I_2/a)a^2\, x_{e2}}{aV_{20}} \sin\theta_2$$

Now remembering, that $(I_2 / a) = I_2'$, $a^2 r_{e2} = r_{e1}$, $a^2 x_{e2} = x_{e1}$ and $aV_{20} = V_{20}' = V_1$; we get regulation formula in terms of primary quantity as:

$$\begin{aligned}
R &= \frac{I_2'\, r_{e1}}{V_{20}'} \cos\theta_2 + \frac{I_2'\, x_{e1}}{V_{20}'} \sin\theta_2 \\
\text{Or, } R &= \frac{I_2'\, r_{e1}}{V_1} \cos\theta_2 + \frac{I_2'\, x_{e1}}{V_1} \sin\theta_2 \\
\text{Neglecting no load current: } R &\approx \frac{I_1\, r_{e1}}{V_1} \cos\theta_2 + \frac{I_1\, x_{e1}}{V_1} \sin\theta_2
\end{aligned}$$

Thus regulation can be calculated using either primary side quantities or secondary side quantities, since:

$$R = \frac{I_2\, r_{e2}}{V_{20}} cos\,\theta_2 + \frac{I_2\, x_{e2}}{V_{20}} sin\,\theta_2 = \frac{I_1\, r_{e1}}{V_1} cos\,\theta_2 + \frac{I_1\, x_{e1}}{V_1} sin\,\theta_2$$

Now the quantity $\frac{I_2 r_{e2}}{V_{20}}$, represents what fraction of the secondary no load voltage is dropped in the equivalent winding resistance of the transformer. Similarly the quantity $\frac{I_2 x_{e2}}{V_{20}}$ represents what fraction of the secondary no load voltage is dropped in the equivalent leakage reactance of the transformer. If I_2 is rated curerent, then these quantities are called the per unit resistance and per unit leakage reactance of the transformer and denoted by $\in_r$ and $\in_x$ respectively. The terms $\in_r = \frac{I_{2\,rated} r_{e2}}{V_{20}}$ and $\in_x = \frac{I_{2\,rated} x_{e2}}{V_{20}}$ are called the per unit resistance and per unit leakage reactance respectively. Similarly, per unit leakage impedance $\in_z$, can be defined.

It can be easily shown that the per unit values can also be calculated in terms of primary quantities as well and the relations are summarised below.

$$\in_r = \frac{I_{2\,rated}\, r_{e2}}{V_{20}} = \frac{I_{1\,rated}\, r_{e1}}{V_1}$$

$$\in_x = \frac{I_{2\,rated}\, x_{e2}}{V_{20}} = \frac{I_{1\,rated}\, x_{e1}}{V_1}$$

$$\in_z = \frac{I_{2\,rated}\, z_{e2}}{V_{20}} = \frac{I_{1\,rated}\, z_{e1}}{V_1}$$

where, $z_{e2} = \sqrt{r_{e2}^2 + x_{e2}^2}$ and $z_{e1} = \sqrt{r_{e1}^2 + x_{e1}^2}$.

It may be noted that the per unit values of resistance and leakage reactance come out to be same irrespective of the sides from which they are calculated. So regulation can now be expressed in a simple form in terms of per unit resistance and leakage reactance as follows.

$$\text{per unit regulation, } R = \in_r cos\,\theta_2 + \in_x sin\,\theta_2$$

$$\text{and \% regulation } R = \left(\in_r cos\,\theta_2 + \in_x sin\,\theta_2\right) \times 100$$

For leading power factor load, regulation may be negative indicating that secondary terminal voltage is more than the no load voltage. A typical plot of *regulation versus power factor* for rated current is shown in figure 25.8.

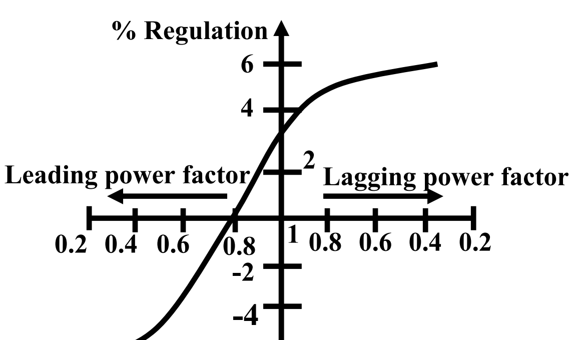


Figure 25.8: Regulation VS power factor curve.

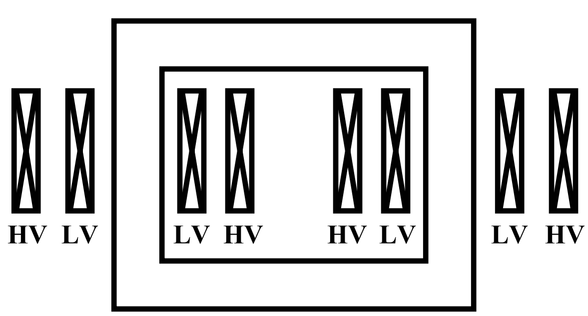


Figure 25.9: LV and HV windings in both the limbs.

To keep the regulation to a prescribed limit of low value, good material (such as copper) should be used to reduce resistance and the primary and secondary windings should be distributed in the limbs in order to reduce leakage flux, hence leakage reactance. The hole LV winding is divided into two equal parts and placed in the two limbs. Similar is the case with the HV windings as shown in figure 25.9.

25.5 Tick the correct answer

1. While carrying out OC test for a 10 kVA, 110 / 220 V, 50 Hz, single phase transformer from LV side at rated voltage, the watt meter reading is found to be 100 W. If the same test is carried out from the HV side at rated voltage, the watt meter reading will be

   (A) 100 W (B) 50 W (C) 200 W (D) 25 W

2. A 20 kVA, 220 V / 110 V, 50 Hz single phase transformer has full load copper loss = 200 W and core loss = 112.5 W. At what kVA and load power factor the transformer should be operated for maximum efficiency?

   (A) 20 kVA & 0.8 power factor (B) 15 kVA & unity power factor

   (C) 20 kVA & unity power factor (D) 15 kVA & 0.8 power factor.

3. A transformer has negligible resistance and has an equivalent *per unit* reactance 0.1. Its voltage *regulation* on full load at 30° leading load power factor angle is:

   (A) +5 % (B) -5 % (C) + 10 % (D) -10 %

4. A transformer operates most efficiently at $\frac{3}{4}$th full load. The ratio of its *iron loss* and *full load copper loss* is given by:

   (A) 16:9 (B) 4:3 (C) 3:4 (D) 9:16

5. Two identical 100 kVA transformer have 150 W iron loss and 150 W of copper loss at rated output. Transformer-1 supplies a constant load of 80 kW at 0.8 power factor lagging throughout 24 hours; while transformer-2 supplies 80 kW at unity power factor for 12 hours and 120 kW at unity power factor for the remaining 12 hours of the day. The *all day efficiency*:

   (A) of transformer-1 will be higher. (B) of transformer-2 will be higher.

   (B) will be same for both transformers. (D) none of the choices.

6. The current drawn on no load by a single phase transformer is $i_0 = 3 \sin(314t - 60°)$ A, when a voltage $v_1 = 300 \sin(314t) V$ is applied across the primary. The values of magnetizing current and the *core loss* component current are respectively:

   (A) 1.2 A & 1.8 A (B) 2.6 A & 1.5 A (C) 1.8 A & 1.2 A (D) 1.5 A & 2.6 A

7. A 4 kVA, 400 / 200 V single phase transformer has 2 % equivalent resistance. The equivalent resistance referred to the HV side in ohms will be:

   (A) 0.2 (B) 0.8 (C) 1.0 (D) 0.25

8. The % resistance and the % leakage reactance of a 5 kVA, 220 V / 440 V, 50 Hz, single phase transformer are respectively 3 % and 4 %. The voltage to be applied to the HV side, to carry out S.C test at rated current is:

   (A) 11 V (B) 15.4 V (C) 22 V (D) 30.8 V

25.6 Solve the Problems

1. A 30KVA, 6000/230V, 50Hz single phase transformer has HV and LV winding resistances of 10.2Ω and 0.0016Ω respectively. The *equivalent* leakage reactance as referred to HV side is 34Ω. Find the voltage to be applied to the HV side in order to circulate the full load current with LV side short circuited. Also estimate the full load % *regulation* of the transformer at 0.8 lagging power factor.

2. A single phase transformer on open circuit condition gave the following test results:

Applied voltage	Frequency	Power drawn
192 V	40 Hz	39.2 W
288 V	60 Hz	73.2 W

   Assuming Steinmetz exponent n = 1.6, find out the *hysteresis* and *eddy current* loss separately if the transformer is supplied with 240 V, 50 Hz.

3. Following are the test results on a 4KVA, 200V/400V, 50Hz single phase transformer. While no load test is carried out from the LV side, the short circuit test is carried out from the HV side.

No load test:	200 V	0.7 A	60 W
Short Circuit Test:	9 V	6 A	21.6 W

   Draw the equivalent circuits (i) referred to LV side and then (ii) referred to HV side and insert all the parameter values.

4. The following data were obtained from testing a 48 kVA, 4800/240V, 50 Hz transformer.

O.C test (from LV side):	240 V	2 A	120 W
S.C test (from HV side):	150 V	10 A	600 W

   (i) Draw the equivalent circuit referred to the HV side and insert all the parameter values.
   (ii) At what kVA the transformer should be operated for *maximum efficiency*? Also calculate the value of maximum efficiency for 0.8 lagging factor load.