Electric Engineering

Name

Institution:

Table of Contents

Question 1

1. Derive a computer equivalent circuit for one phase of the transformer, showing all calculations.

For a three phase transformer, each phase is taken as a single phase transformer to make the calculations easier. The following is a diagram of a star connection of a three phase transformer.

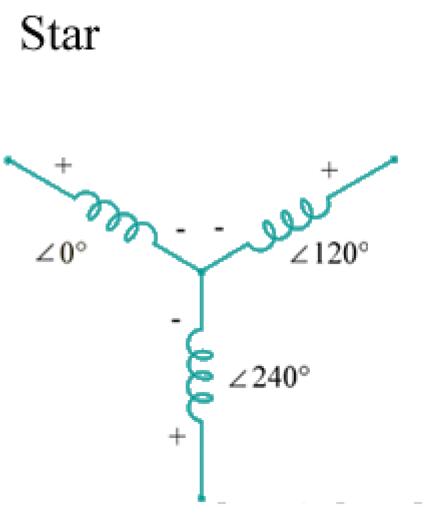


Figure 1: star connection

A transformer can be said to be either operating on no load and on load.

Operation of transformer under no load

This is when there is no load connected on the secondary side. When a transformer is taken to be under no load, there is no winding resistance and no leakage reactance, only core losses are taken into consideration. The secondary winding is taken to be open circuited. The current on this side will be zero. The source supplied current used for magnetizing the transformer's core. This current is divided into two components; one for compensating core losses and the other for magnetizing the core. The core loss compensation current makes supplied current not exactly at 90^{O} lag but at angle less than 90^{0}. The power factor is very low in the range of 0.1 to 0.15.

As Hernandez, Canedo, Olivares-Galvan & Betancourt discussed in their paper that the total current supplied from the source is I_0 (2016). This is usually 2-10% of the rated current rating. The core loss component is denoted as I_w and is in phase with the supply voltage V_1. The magnetizing current is denoted as I_μ. Since it is the reactive part of the transformer source, it is watt-less. The total primary currents in a no load transformer is given as;

$$I_0 = I_w + I_\mu$$

$$|I\mu| = |I_0| \cos\theta$$

$$|I_w| = |I_0| \sin\theta$$

$$|I_w| = \sqrt{|I\mu|^2 + |I_w|^2}$$

Power factor= $\cos\theta = I_w / I_\mu$

The power factor angle is the phasor difference between V_1 and I_1 of the primary side of the transformer. The one on the secondary side solely depends on the load type. If there is an inductive load, the power factor will be lagging and if it is capacitive, it will be leading.

No load power input = $P_o = V_1 I_0 \cos \Phi_o$

Efficiency is taken to be = (output voltage- input voltage)* 100/ input voltage.

Operation of transformer under load

When a load is connected to the secondary winding, a load current is observed to start flowing. This current's characteristics solely depends on the type of load connected and the secondary voltage. The load can either be resistive, inductive or capacitive. It is known as secondary current or the load current. It is denoted as $I_{2.}$ The nature of the load determines the phase angle.

As the load current flows through the load, it induces an mmf in the winding. This mmf is calculated as N_2I_2. N_2 is the number of secondary winding turns. This mmf (magneto motive force) produces a flux denoted as Φ_2. This tries to reduce the main magnetizing flux and weakens the emf E_1. If E_1 gets below V1, an extra current flows from the source to the primary winding. It introduces an extra flux, Φ' which will then neutralize the $\Phi_{2.}$ This is according to Lenz law. This shows that the main magnetizing flux remains unchanged regardless of the load.

In instances where there will be a leakage reactance, the reactances are denoted as X1 and X2, found on the primary and secondary windings respectively. The total impedance will be given as

Primary winding impedance;

$Z_1 = R_1 + jX_1$

$Z_2= R_2 ++jX_2$

This changes the voltage equation to;

$V_1= E_1 +I_1Z_1$

$V_2=E2-I_2Z_2$

Substituting for Z;

$V_1 = E_1 +I1R_1 +JI_1X_1$

$V_1 = E_1 -I_1R_1 +JI_1X_1$

The resistance drop is in the current vector's direction whereas the reactive drop is perpendicular to the current vector.

There are several losses found on the transformer. These include (Song & Kang, 2009);

a) Leakage flux; this is present on both the primary and secondary sides. They give rise to leakage reactance's on both sides. They are denoted as X_1 and X_2.

b) Winding resistances; these are denoted by R_1 and R_2 respectively. They cause a voltage drop calculated as I_1R_1 and I_2R_2 respectively.

c) Copper losses are given as $I_1^2R_1$ and $I_2^2R_2$.

Calculating the impedances

The complete vector diagram of a transformer's primary and secondary sides is given below.

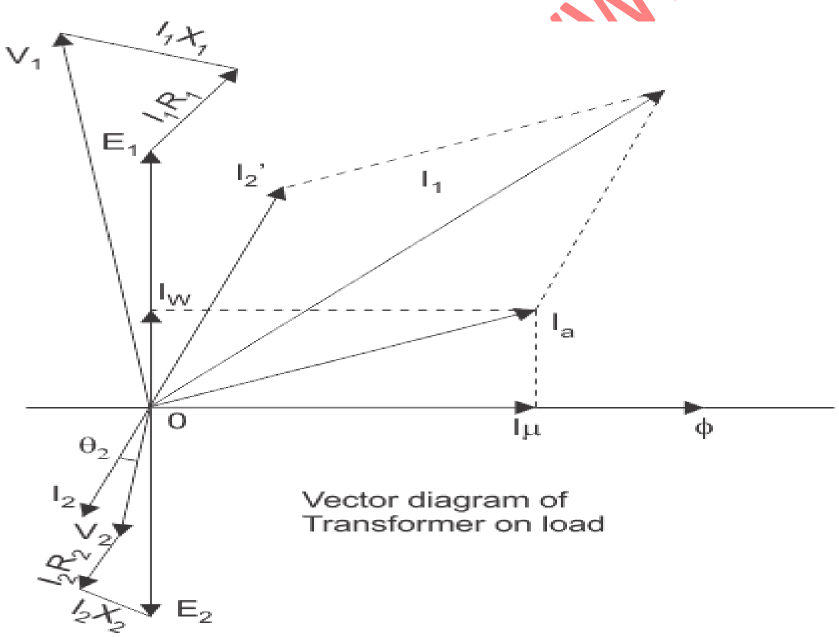
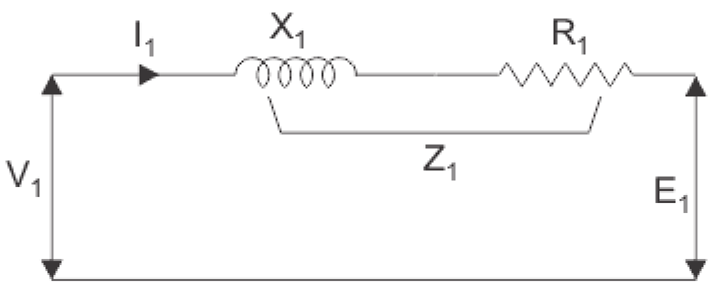


Figure 2: vector diagram

The source voltage on the primary side is given as V_1 while the voltage across the windings is given as E_1. Before this voltage gets to the windings, it has to drop by $I_1R_1 + j.I_1X_1$, due to the impedance in the windings (Dzafic, Jabr& Neisius, 2015). The voltage at the windings is countered by the induced emf. This results to the voltage at the windings being;

$$V_1 - (I_1R_1 + jI_1X_1) = E_1$$

The equivalent circuit for the winding portion is given as;



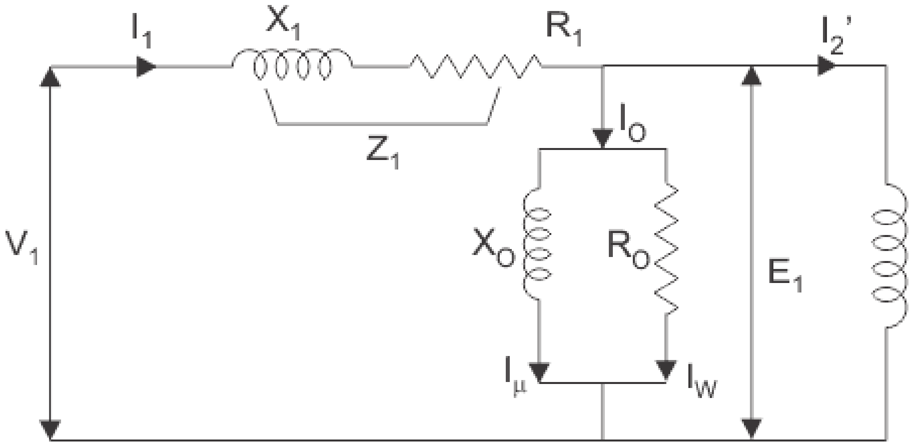
Equivalent Circuit

From the above given vector diagram, it can be seen that the total primary current is composed of two components. These are the no load component, I_1 and the load component I_2'

The primary component has to have a parallel path of current which is known as the excitation circuit (Falke, 1998). Its reactive and resistive components are represented as;

$$R_0 = \frac{E_1}{I_w} \; and \; X_0 = \frac{E_1}{I_\mu}$$

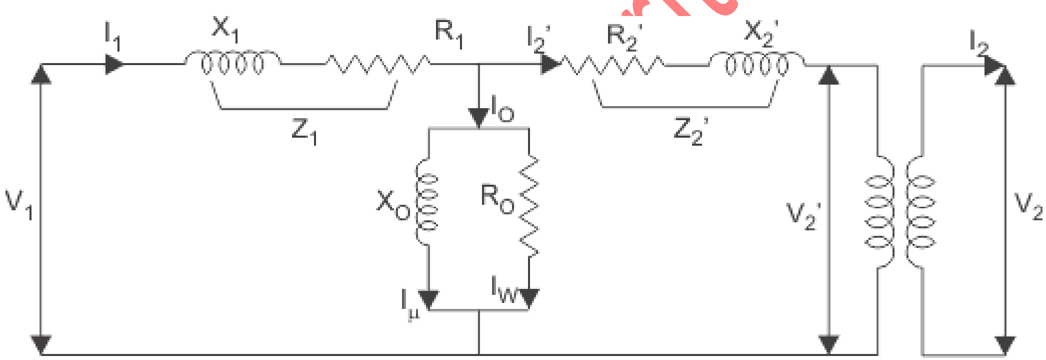
The equivalent circuit is as shown below;



Equivalent Circuit of Primary Side of Transformer

The load current component, I_2', gets through the primary windings and induces a voltage across the winding resulting to E_1. The induced voltage is transformed to the secondary winding as E_2. This has partly dropped because of I_2Z_2 or $I_2R_2 + j.I_2X_2$.

The complete equivalent circuit of the transformer becomes;



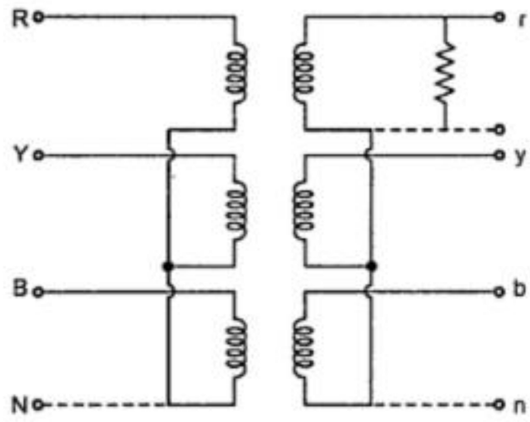
Equivalent Circuit of Transformer referred to Primary

When there is no power loss in the circuit (an ideal circuit);

$P_{in} = P_{out}$

$V_1I_1 = V_2I_2$

Circuit Y-Y Connection



There is usually no phase displacement or difference between the secondary and primary voltages. The primary winding in each phase is 120 ^{0} out of phase with the other two phases (Hernandez, Canedo, Olivares-Galvan & Betancourt, 2016). However, the phase voltage is line voltage/ √3. This reduces the phase voltage which in turn reduces the amount of insulation needed plus the number of turns per phase.

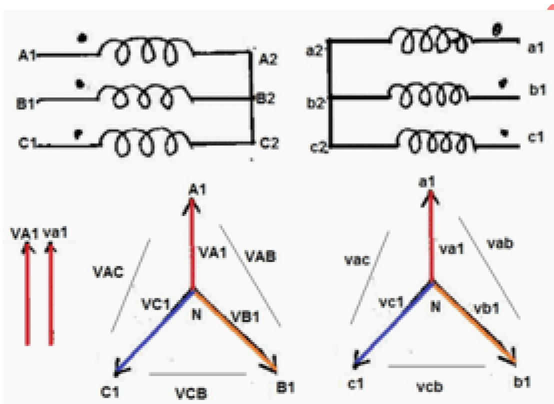


Figure 3: diagram of a y-y connected transformer

If VL_1 is taken as the line voltage on the primary side, the phase voltage is thus denoted as;

$$V_{PH} = \frac{v_L}{\sqrt{3}}$$

K is the turn’s ratio, which is also known as the transformation ratio which is given as;

$\frac{E_1}{E_2} = \frac{N_1}{N_2} = K$= a

Where E_1 and E_2 are the emf on the primary and secondary sides respectively.

Taking this into a wye connection;

The secondary phase voltage will be denoted as;

$$V_{ph2} = K\left(\frac{V_{L_1}}{\sqrt{3}}\right) \text{ as } \frac{V_{ph2}}{V_{ph1}} = K$$

The secondary line voltage will thus become;

$$V_{L_2} = \sqrt{3}\,V_{ph2} = \sqrt{3}\,K\left(\frac{V_{L_1}}{\sqrt{3}}\right) = K\,V_{L_1}$$

From this, it can be seen that the secondary line voltage is k times the primary line voltage.

The no load current is divided into two parts;

- The pure inductance X_0 (it takes the magnetizing component Iµ)
- Non induction resistance R_o (I_w)

Ro=E1 / I_w

X_0= E1 / Iµ

$$E_{Line} = \sqrt{3}E_{phase}\ and\ I_{Line} = I_{Phase}$$

Calculations from the given figures

Turns ratio

The turns ratio is calculated as;

N=440/220

=2

Phase voltage

V_{p1} = Vl/√3

=440/√3

=254.034V

On the secondary side; 220/√3

=127.017V

The impedance on the secondary side

$\mathbf{Z}=\sqrt{\boldsymbol{R}^2+\boldsymbol{x}^2}$

The values are= 0.09 + j0.085

=0.1238

Find the secondary terminal voltage

The secondary emf is 224V at 60H. 76% at 0.8 p.f. lagging.

Short circuit regulation =1/x

$P_{pn}= P_{scl} + P_{core} + P_{f2w} = 3I_1^2R_1 + P_{rot}$

$P_{rot} + P_{core} + P_{f2w}$

For a Y connected stator resistance per phase is given as; $R_1= R_{oc}/ 2$

$P_{NL} = P_{30NL}/3$

$P_{30NL} = 3 * P_{NL}$

3*270= 810 watts

$V_{NL}= V_{lNL}/ \sqrt{3}$

=250/√3

=144.34 volts

$R_2 = R_w$

Terminal voltage= $E_1' = V_{NL} - INL (R_1 + jX_1)$

144.34 -2.6(R_1 +jX_1)

=144.34 -2.6(0.09 + j0.085)

144.106<-0.088^{o} Volts

A backup fuse ruptures in one of the three phases during full load operation:

The backup protection of a transformer is a type of protection offered to shield against any overcurrent and earth faults occurring over the loads. It is installed on the infeed side of the transformer but generally trips both the primary and secondary sides of the circuit breakers (Song & Kang, 2009).

Discuss likely causes of the above fault.

Overcurrent

This can be caused by a power surge or inrush current brought about by a low line voltage or damaged core.

Short circuit to the ground

The windings and a bolt may get into contact with each other thus causing a short circuit in the transformer. The components may short circuit thus leading to a short circuit on the entire system. This will exceed the rated power of the fuse where it heats beyond the expected value. It will rupture as it cannot withstand the high heat values.

Overloading the transformer

There can be so many loads connected to the transformer beyond the rated value. This will put a huge strain on the transformer will it will be drawing more current than expected. This will eventually lead one of its fuses to blow as a means of protection.

Single phasing

When one fuse blows due to the above two reasons, there can be a cascade of other fuses blowing in the process (Cao, & Yang, 2015). This is because the other two phases are being overstretched in drawing of a load beyond their rated figures. This will also cause them to blow in quick succession.

Transformer fault

The transformer itself or its components can be faulty. For example these fuses can be old, and worn out. Hey therefore will not protect the transformer as required as they will blow at some very little current passing through it as it will be detected as an overload. The core of the transformer can also be faulty. It can cause massive short circuiting where the current overload will burst the fuse.

Discuss probable consequences of this situation

Unbalanced load

Since only two phases have been left in operation as the blown fuse phase will be open, it will continue operating as it strives to supply the required load (Lauss, Faruque, Schoder, Dufour, Viehweider & Langston, 2016). The voltages will be out of phase with each other. This will cause overdrawing of current on the other phases. This may cause single phasing or occurrence of unbalanced load on the system. It may eventually end up damaging any three phase machines connected on the system.

Single phasing

This is caused by the presence of an unbalanced load. This greatly damages the machines connected to it. An example is if a three phase motor is connected to it. The current in the other two phases increase to almost 173% of the normal drawn current (Falke, 1998). Since the motor is striving to deliver to its rated horsepower, it will continue doing so until the protective overload burns.

Cascade of blowing fuses

The other two phase fuses left will also blow eventually. This is because of the high current passing through them which may go beyond their rated value as they strive to supply the required power. They will get to a value beyond their rating and thus blow too. This will put the transformer components and load at risk as they will not be under any protection.

Open circuiting the secondary side

Since one of the fuses has ruptured, which can be followed by a cascade of other fuses rupturing, it may end up open circuiting the secondary side of the transformer. This will stop any load supply and if any machinery is connected on the secondary side, it will stop functioning.

Give a reason for inactivity of other protective devices

The other protective devices will eventually stop being active. The reason for this is that they may have been blown because of the high current rates being forced to pass through them. Another reason is because of the unbalanced load. This may cause the machines connected to this transformer to stop functioning. This will stop the load flow thus the other devices will be inactive as it will be operating like a machine on no load connection. The backup fuses also have the capability of tripping other protective devices on the primary side thus rendering them inactive. The rupturing may also open circuit the secondary side thus causing disruption of power supply. This condition will inactivate other protective devices.

Discuss probable consequences of this situation

The transformer will stop functioning eventually. When one fuse blows and causes a rapture of the others in a cascading effect, there will be an open circuit. There will be no load being fed since the transformer will not be supplying any power as the secondary side becomes open circuited. Any machines such as a motors connected on the secondary will also stop functioning as they will not be power supplied .

References

Cao, L, & Yang, J (2016). 'Linear Circuit Model of the Three-phase Insulated Core Transformer Power Supply', *IEEE Transactions On Nuclear Science*, 63, 1b, pp. 288-296

Dzafic, I, Jabr, R, & Neisius, H (2015). 'Transformer Modeling for Three-Phase Distribution Network Analysis', *IEEE Transactions On Power Systems*, 30, 5, pp. 2604-2611

Falke, S (1998). 'Unconventional transformer connections--Part 1', *EC&M Electrical Construction & Maintenance*, 97, 11, p. 66,

Hernandez, I, Canedo, J, Olivares-Galvan, J, & Betancourt, E (2016). 'Novel Technique to Compute the Leakage Reactance of Three-Phase Power Transformers', *IEEE Transactions On Power Delivery*, 31, 2, pp. 437-444

Lauss, G, Faruque, M, Schoder, K, Dufour, C, Viehweider, A, & Langston, J (2016). 'Characteristics and Design of Power Hardware-in-the-Loop Simulations for Electrical Power Systems', *IEEE Transactions on Industrial Electronics*, 63, 1, pp. 406-417

Song, G, & Kang, X (2009). 'Algorithm to identify the excitation inductance of power transformer with wye-delta connection', *IET Electric Power Applications*, 3, 1, pp. 1-7