**Exercise 4.5.2**

1. **What is a Transformer?**

A transformer is a static electrical apparatus designed to convert alternating current from one voltage to another .It transforms electrical energy from one circuit to another without any direct electrical connection, with the help of mutual induction between to windings. It can be designed to “step up” or “step down” voltages.

1. **Explain the working principle of Transformer?**

Working principle of Transformer is based on Faraday’s Laws of Electromagnetic Induction. If an alternating current is applied to an electric coil, there will be an alternating flux surrounding that coil. Now if we bring another coil near the first one, there will be an alternating flux linkage with that second coil. As the flux is alternating, there will be obviously a rate of change of flux linkage with respect to time in the second coil. The emf will be induced in it as per Faraday’s laws electromagnetic induction.

1. **How transformers are classified, based on their construction?**

They are distinguished from each other based on merely the manner by which primary and secondary windings are placed around the core.

1. **Core type**: In these windings surround considerable part of the core.
2. **Shell type**: In these core surrounds considerable part of windings.
Another recent development is wound core type or spiral core.
3. **What is an exciting current in a transformer?**

Exciting current is the current or amperes required for excitation. The exciting current on most lighting and power transformers varies from approximately 10% on small sizes of about 1 KVA and smaller to approximately 0.5% to 4% on larger sizes of 750 KVA. The exciting current is made up of two components, one of which is a real component and is in the form of losses or referred to as no load watts; the other is in the form of reactive power and is referred to as KVAR

1. **What are transformer taps and when are they used?**

Taps are provided on some transformers on the high voltage winding to correct for high or low voltage conditions, and still deliver full rated output voltages at the secondary terminals

1. **In a tap changing transformer on which side is the tap connected to the primary side or the secondary side?**

Tapings are always connected to high voltage winding side, because of low current. If tapings are connected to low voltage side, sparks will produce while tap changing operation due to high current.

1. **What is an ideal transformer?**

Transformer having an overall efficiency of 100 per cent is called an ideal transformer.

1. **Explain how do the losses in a transformer occur?**

As the Transformer is a static device mechanical losses do not come into picture. Transformer losses have two sources-copper loss and core loss.
Copper losses are caused by the resistance of the wire (I2R). In primary side it is $I\_{1}^{2}R\_{1}$  and in secondary side it is $I\_{2}^{2}R\_{2}$   loss, where $I\_{1}$& $I\_{2}$are primary & secondary currents of transformer and $R\_{1}$ & $R\_{2}$ are resistances of primary & secondary winding. As the both primary & secondary currents depend upon load of transformer, copper losses vary with load.

Core losses are caused by eddy currents and hysteresis in the core.
Eddy current losses: In transformer we supply alternating current in the primary, this alternating current produces alternating magnetizing flux in the core and as this flux links with secondary winding there will be induced voltage in secondary, resulting current to flow through the load connected with it. Some of the alternating fluxes of transformer may also link with other conducting parts like steel core or iron body of transformer etc. As alternating flux links with these parts of transformer, there would be an locally induced emf. Due to these emfs there would be currents which will circulate locally at that parts of the transformer. This type of energy loss is called eddy current loss of transformer.

Hysteresis losses: The magnetic core of transformer is made of Silicon Steel, Steel is very good ferromagnetic material. The domains are arranged inside the material structure in such a manner, that net resultant magnetic field of the said material is zero. Whenever external magnetic field or mmf is applied to that substance, these randomly directed domains arrange themselves in parallel to the axis of applied mmf. After removing this external mmf, maximum numbers of domains again come to random positions, but some few of them still remain in their changed position. Because of these unchanged domains the substance becomes slightly magnetized permanently. This magnetism is called “Spontaneous Magnetism”. To neutralize this magnetism some opposite mmf is required to be applied. For this reason, there will be a consumption of electrical energy which is known as Hysteresis loss of transformer.
Hysteresis loss is constant for a particular voltage and current. Eddy-current loss, however, is different for each frequency passed through the transformer.

1. **Why are the transformer ratings expressed in kVA?**

Since the power factor of transformer is dependent on load only VA rating defined and does not include power factor. In case of motors, power factor depends on construction and hence rating of motors is in KW and include power factor.

1. **Is copper loss affected by change in power factor?**

Yes. Copper loss varies inversely with power factor. It depends on current in primary and secondary windings. It is known that current required is higher when power factor is lower

1. **How do we minimize eddy current loss in a transformer?**

By laminating the core so as to minimize eddy current loss.

1. **Explain the type of current flowing in the transformer primary windings when its secondary is open?**

When the secondary is open, there is no current in the secondary of the transformer. The primary takes a small current ($I\_{O}$) from the source called no-load current which has a magnetizing component$(I\_{O}Sinθ$) producing the magnetic flux and a working component ($I\_{O}Cosθ $) supplying real power for iron losses.

1. **What is the difference between delta-delta, delta-star transformer?**

Delta-delta transformer is used at generating station or a receiving station for Change of Voltage (i,e) generally it is used where the Voltage is high & Current is low whereas Delta-star is a distribution kind of transformer where from secondary star neutral is taken as a return path and this configuration is used for Step down voltage phenomena.

1. **What is the function of transformer oil?**

Transformer Oil serves mainly two purposes:

-It acts as liquid insulation in electrical power transformer.

-It dissipates heat of the transformer i.e acts as coolant. In addition to these, this it serves other two other purposes, it helps to preserve the core and winding as these are fully immersed inside oil and also prevents direct contact of atmospheric oxygen with cellulose made paper insulation of windings, which is susceptible to oxidation.

1. **What is voltage ratio of a transformer?**

Voltage ratio is the ratio of the voltage between the line terminals of one winding to that between the line terminals of another winding at no load.

1. **Explain the operation of variable frequency transformer?**

A variable frequency transformer is used to transmit electricity between two asynchronous alternating current domains. It is a double fed electric machine resembling a vertical shaft hydroelectric generator with a three-phase wound rotor, connected by slip rings to one external ac power circuit. A direct-current torque motor is mounted on the same shaft. Changing the direction of torque applied to the shaft changes the direction of power flow; with no applied torque, the shaft rotates due to the difference in frequency between the networks connected to the rotor and stator. Thus it acts as a continuously adjustable phase shifting transformer. It allows control of the power flow between two networks.

1. **Why Delta Star Transformers are used for Lighting Loads?**

For lighting loads, neutral conductor is must and hence the secondary must be star winding. This lighting load is always unbalanced in all three phases. To minimize the current unbalance in the primary we use delta winding in the primary. So delta / star transformer is used for lighting loads.

1. **What are the types of cooling systems in transformers?**
2. ONAN (oil natural, air natural)
3. ONAF (oil natural, air forced)
4. OFAF (oil forced, air forced)
5. ODWF (oil direct, water forced)
6. OFAN (oil forced, air forced)
7. **Can a Single Phase Transformer be used on a Three Phase source?**

Yes. Three phase transformers are sometimes not readily available whereas single phase transformers can generally be found in stock. Three single phase transformers can be used in delta connected primary and wye or delta connected secondary. They should never be connected wye primary to wye secondary, since this will result in unstable secondary voltage. The equivalent three phase capacity when properly connected of three single phase transformers is three times the nameplate rating of each single phase transformer.

1. **Can Transformers develop Three Phase power from a Single Phase source?**

NO. Phase converters or phase shifting devices such as reactors and capacitors are required to convert single phase power to three phase.

1. **Can Single Phase Transformers be used for Three Phase applications?**

Yes. Three phase transformers are sometimes not readily available whereas single phase transformers can generally be found in stock. Three single phase transformers can be used in delta connected primary and wye or delta connected secondary. They should never be connected wye primary to wye secondary, since this will result in unstable secondary voltage. The equivalent three phase capacity when properly connected of three single phase transformers is three times the nameplate rating of each single phase transformer.

Example: Three 10 K VA single phase transformers can be used to accommodate a 30 KVA three phase load.

1. **Explain the open and short circuit tests on a transformer?**

Open circuit test (No load test) and short circuit test (full load test) are performed on a transformer to determine

1. Equivalent circuit of transformer
2. Voltage regulation of transformer
3. Efficiency of transformer.

The power required for these tests on transformer is equal to the power loss occurring in the transformer.

**Open circuit test on transformer** is used to determine core losses in transformer and parameters of shunt branch of the equivalent circuit of transformer.

**Short Circuit test on transformer** is used to determine copper loss in transformer at full load and parameters of approximate equivalent circuit of transformer.

**Exercise 4.5.3**

1. A 30 kVA transformer with a winding ratio of 50:1 is connected in delta-star formation to supply a farm with a line voltage of 380 V. Calculate the following:
2. Secondary phase voltage
3. Primary line voltage
4. Power delivered at full-load at a power factor of 0,85 lagging

Solution:

$$V\_{2L}=√3V\_{2PH}$$

$$V\_{2PH}=\frac{V\_{2L}}{√3}$$

$$V\_{2PH}=\frac{380V}{√3}$$

 $=219,4V$

$$V\_{1L}=V\_{1PH}$$

$$V\_{1PH}=\frac{N\_{1}}{N\_{2}}×V\_{2PH}$$

$$=\frac{50}{1}×219,4$$

$$=10,97kV$$

$$S=√3×V\_{2L}×I\_{2L}$$

$$I\_{2L)}=\frac{S}{√3V\_{2L}}$$

$$=\frac{30 kVA}{√3×380}$$

$$=45.58A$$

$$P\_{OUT}=√3×V\_{2L}×I\_{2L}Cos∅$$

$$P\_{OUT}=√3×380×45,58×0,85$$

$$=25,5 kW$$

1. A delta-star connected transformer supplies a factory with 66 kW at a power factor of 0, 85. The primary line voltage is 11 kV, the secondary line voltage is 380 V. The transformer is 100% efficient.

Given:

|  |  |  |
| --- | --- | --- |
| Pout  | =  | 66 kW |
| VL(p)  | = | 11 kV  |
| VL(s)  | = | 380 V  |
| Pf | = | 0,85 |
| $$η$$ | = | 100% |

Calculate:

1. The secondary line current
2. The primary line current

Solution:-

$$P\_{OUT}=\sqrt{3}V\_{L(s)}I\_{L(S)}Cosθ$$

$$I\_{L(S)}=\frac{P\_{OUT}}{\sqrt{3}V\_{L(s)}Cosθ}$$

$$=\frac{66×10^{3}}{\sqrt{3}×380×0.85}$$

$$∴I\_{L(S)}=117.97A$$

$$P\_{IN}=P\_{OUT}$$

$$P\_{IN}=\sqrt{3}V\_{L(P)}I\_{L(P)}Cosθ$$

$$I\_{L(P)}=\frac{P\_{OUT}}{\sqrt{3}V\_{L(P)}Cosθ}$$

$$=\frac{66×10^{3}}{\sqrt{3}×11 000×0.85}$$

$$∴I\_{L(P)}=4.08A$$

1. A 240 kVA three-phase transformer supplies power to a soccer stadium. The transformer is connected in delta-star. The input line voltage is 11 kV and the output line voltage is 415 V at a lagging power factor of 0,85.

Given:

|  |  |  |
| --- | --- | --- |
| S | = | 240 *kVA*  |
| VL(p)  | = | 11 000 V |
| VL(p)  | = | 415 V |
| Cos θ | = | 0,85 |

Calculate:

1. The secondary phase voltage
2. The current drawn from the supply by the transformer at full load
3. The power delivered at full load to the stadium

Solution:-

$$V\_{L(S)}=\sqrt{3}V\_{Ph(S)}$$

$$∴V\_{Ph(S)}=\frac{V\_{L(S)}}{\sqrt{3}}$$

$$=\frac{415}{\sqrt{3}}$$

$$=239.6V$$

$$S=\sqrt{3}V\_{L(P)}I\_{L(P)}$$

$$I\_{L(S)}=\frac{S}{\sqrt{3}V\_{L(P)}}$$

$$=\frac{24 000}{\sqrt{3}×11 000}$$

$$=12.59A$$

$$P\_{OUT}=\sqrt{3}V\_{L(P)}I\_{L(P)}Cosθ$$

$$=\sqrt{3}×11000×12.59×0.85$$

$$=203.89kW$$

1. A three-phase transformer with a turns ratio of 50 : 1 is connected in delta-star. The supply voltage is 11 kV and the secondary phase current is 450 A.

Given:

|  |  |  |
| --- | --- | --- |
| Ratio | = | 50 : 1 |
| VL(P) | = | 11 kV |
| IPh(S) | = | 450 A |

Calculate:

1. The secondary phase voltage
2. The secondary line voltage
3. The primary phase current
4. The primary line current

Solution:-

$$V\_{Ph(s)}=\frac{V\_{Ph(p)}×N\_{S}}{N\_{P}}$$

$$=\frac{11000 ×1}{50}$$

$$=220V$$

$$V\_{L(S)}=\sqrt{3}V\_{Ph(S)}$$

$$=\sqrt{3}×220$$

$$=380V$$

$$I\_{Ph(P)}=\frac{I\_{Ph(S)}×N\_{S}}{N\_{P}}$$

$$=\frac{450×1}{50}$$

$$=9A$$

$$I\_{L(P)}=\sqrt{3}I\_{Ph}$$

$$=\sqrt{3}×9$$

$$=19.59A$$

1. A 250 kVA, three-phase transformer with 400 turns on the primary is connected in delta-star. The supply voltage is 6 600 V. The full-load line current on the primary is 20 A, the secondary line voltage is 415 V and the power factor is 0,9.

Given:

|  |  |  |
| --- | --- | --- |
| S | = | 250 kVA |
| Np | = | 400 |
| VL(p) | = | 6 600 V |
| IL(s)  | = | 415 V |

Calculate:

1. The secondary phase voltage
2. The turns ratio
3. The secondary current of the transformer at full load

Solution:-

$$V\_{Ph(S)}=\frac{V\_{L(S)}}{\sqrt{3}}$$

$$=\frac{415}{\sqrt{3}}$$

$$=239.6V$$

$$Turns Ratio= \frac{V\_{Ph(P)}}{V\_{Ph(S)}}$$

$$=\frac{6600}{239.6}$$

$$=27.55:1$$

$$=28:1$$

$$I\_{L(S)}=\frac{S}{\sqrt{3}V\_{L(s)}}$$

$$=\frac{250000}{\sqrt{3}×415}$$

$$=347.8A$$

$$OR$$

$$I\_{S}=\frac{I\_{P}}{\sqrt{3}}×\frac{N\_{P}}{N\_{S}}$$

$$=\frac{20}{\sqrt{3}}×27.55$$

$$=318.12A$$

1. The delta-connected primary winding of a three-phase transformer is supplied with 11 kV. The secondary winding is star-connected and supplies 400 V to a balanced star-connected load of 10 kW with a power factor of 0,8. Calculate the following at full load:
2. The total kVA of the load
3. The secondary line current
4. The secondary phase current

Solution:-

$$S=\frac{P}{Cosθ}$$

$$=\frac{10 000}{0.8}$$

$$=12.5 kVA$$

$$I\_{L(S)}=\frac{P}{\sqrt{3}V\_{L(S)}Cosθ}$$

$$=\frac{10 000}{\sqrt{3}×400×0.8}$$

$$=18.04A$$

$$I\_{Ph(s)}=I\_{L(S)}$$

$$=18.04A$$

1. A 24 kVA transformer supplies power to a football stadium that is being erected for the 2010 FIFA Soccer World Cup. The transformer supplies the stadium with an output line voltage of 415 V when it is connected in delta-star. The input voltage to the transformer is 11 000 V.

Calculate the following:

1. The phase voltage supplied to the stadium
2. The maximum line current that can be drawn from the supply (the primary current)
3. The maximum power that can be delivered at full load if the power factor is lagging at 0,85

Solution:-

$$V \_{Ph}=\frac{V\_{L}}{\sqrt{3}}$$

$$=\frac{415}{\sqrt{3}}$$

$$=239.6V$$

$$S=\sqrt{3}V\_{L}I\_{L}$$

$$I\_{L}=\frac{S}{\sqrt{3}V\_{L}}$$

$$=\frac{24000}{\sqrt{3}×11000}$$

$$=1.26 A$$

$$P=SCosθ$$

$$=24000×0.85$$

$$20.4 kW$$

1. A three-phase transformer is connected in delta-star and delivers 12 kW at full load. The transformer has a power factor of 0,8 and an efficiency of 100%.

Given:

|  |  |  |
| --- | --- | --- |
| POUT  | = | 12 kW  |
| η  | = | 100%  |
| Cos θ  | = | 0,8  |

Calculate the input kVA to the transformer (apparent power).

Solution:-

$$S=\frac{P}{Cosθ}$$

$$=\frac{12000}{0.8}$$

$$=15 kVA$$

1. A three-phase 300 kVA transformer has a star-connected secondary winding with a phase voltage of 240 V at a lagging power factor of 0,8.

Given:

|  |  |  |
| --- | --- | --- |
| S | = | 300 kVA  |
| VPh(S) | = | 240 V |
| Pf | = | 0,8  |

Calculate the:

1. Secondary line voltage
2. Secondary phase current
3. Output power at full load

Solution:-

$$V\_{L(s)}=\sqrt{3}V\_{Ph(s)}$$

$$=\sqrt{3}×240$$

$$=415.69 V$$

$$I\_{PH}=I\_{L }(Star connection)$$

$$S=\sqrt{3}V\_{L}I\_{L}$$

$$I\_{L}=\frac{S}{\sqrt{3}V\_{L}}$$

$$=\frac{3 000 000}{\sqrt{3}×415.69}$$

$$∴I\_{Ph}=416.67 A$$

$$P\_{OUT}=\sqrt{3}V\_{L}I\_{L}Cosθ$$

$$=\sqrt{3}×415.69×416.67×0.8$$

$$=240 kW$$

1. A star-star-connected transformer has 800 turns per phase on its primary windings and 60 turns per phase on its secondary windings. The transformer is connected to an 8 kV supply.

Given:

|  |  |  |
| --- | --- | --- |
| NP | = | 800 |
| VL(P)  | = | 8 kV |
| NS | = | 60 |

Calculate the following:

1. The primary phase voltage
2. The secondary phase voltage

Solution:-

$$V\_{L}=\sqrt{3}×V\_{PH}$$

$$V\_{PH}=\frac{V\_{L}}{\sqrt{3}}$$

$$V\_{PH}=\frac{8000}{\sqrt{3}}$$

$$=4618.8 V$$

$$\frac{V\_{Ph(s)}}{V\_{Ph(P)}}=\frac{N\_{S}}{N\_{P}}$$

$$V\_{Ph(s)}=\frac{N\_{S}}{N\_{P}}×V\_{Ph(P)}$$

$$V\_{Ph(s)}=\frac{60}{800}×4618.8$$

$$=346.41 V$$

1. A three-phase transformer is connected in delta-star. The supply voltage is 11 000 volts and the turns ratio is 46 : 1. The transformer draws 6 amperes at a power factor of 0,84.

Given:

|  |  |  |
| --- | --- | --- |
| VL(p)  | = | 11 000 V |
| Np: Ns | = | 46 : 1 |
| IL(p)  | = | 6 A |
| Cos θ | = | 0,84 |
| η | = | 100% |

If losses are ignored, calculate at full load the following:

1. Secondary phase voltage
2. The power drawn by the transformer
3. The primary phase current

Solution:-

$$V\_{Ph(S)}=\frac{V\_{Ph(P)}N\_{S}}{N\_{P}}$$

$$=\frac{11000 ×1}{46}$$

$$=240 V$$

$$P\_{IN}=\sqrt{3}V\_{L(P)}I\_{L(P)}Cosθ$$

$$\sqrt{3}×11000×6×0.84$$

$$=96.02 kW$$

$$I\_{Ph(p)}=\frac{I\_{L(P)}}{\sqrt{3}}$$

$$=\frac{6}{\sqrt{3}}$$

$$=3.46 A$$

1. The transformer supplying Tetelo Comprehensive School with power is connected in delta to an 11 kV supply. The secondary side supplies the school with a three-phase four-wire system. The school receives a single-phase voltage of 220 V and three-phase line voltage of 380 V from the transformer.
2. Show by means of a simple diagrams, how the secondary side of the transformer is connected to the school.
3. Calculate the value of the line current in the primary side at full load if the school consumes 500 kW at a power factor of 0,85.
4. Calculate the transformation ratio.

Solution:-

$$P\_{IN}=\sqrt{3}V\_{L}I\_{L}Cosθ$$

$$I\_{L}=\frac{P}{\sqrt{3}×V\_{L}×Cosθ}$$

$$=\frac{500000}{\sqrt{3}×380×0.85}$$

$$=893.73 A$$

$$\frac{V\_{1}}{V\_{2}}=\frac{N\_{1}}{N\_{2}}×\frac{I\_{2}}{I\_{1}}$$

$$Turns Ratio=\frac{V\_{1(ph)}}{V\_{2(Ph)}}$$

$$=\frac{11000}{220}$$

$$=50:1$$

1. Three single-phase transformers are connected in delta-star to form one three-phase transformer. The supply voltage is 11 kV and the turns ratio is 45:1. Ignore the transformer losses and calculate at full load:
2. The secondary phase voltage
3. The secondary line voltage

Solution:-

$$\frac{V\_{Ph(p)}}{V\_{Ph(S)}}=\frac{N\_{P}}{N\_{S}}$$

$$V\_{Ph(S)}=\frac{V\_{Ph(P)}N\_{S}}{N\_{P}}$$

$$=\frac{11000×1}{45}$$

$$=244.44 V$$

$$V\_{L(S)}=\sqrt{3}V\_{Ph(S)}$$

$$=\sqrt{3}×244.44$$

$$=423.38 V$$

1. A three-phase 250 kVA transformer has a star-connected secondary with a phase voltage of 220 V. Calculate the output power of the transformer at a power factor of 0,8 lagging.

$$P\_{OUT}=S×Cosθ$$

$$=250 000×0.8$$

$$=200 kW$$