### 0.1 Single Phase AC Transformer

Transformer: It is a static device which transfers electric energy from one electric circuit to another with the desired change in voltage and current levels without any change in power and frequency. Transformer is used to increase or decrease a.c. voltage with a proportional increase or decrease in the current ratings. Sometimes transformer is used to create an isolation between primary voltage to secondary voltage which is called as one to one transformer.

### 0.1.1 Working Principle:

The main principle of operation of a transformer is mutual inductance between two electrical windings which is linked by a common magnetic flux. A basic transformer consists of two coils that are electrically separate and inductive, but are magnetically linked through a path of reluctance. The pictorial diagram of a transformer is as shown in Figure 1.

### 0.1.2 Construction Of Transformer:



Figure 1
The transformer mainly consists of two basic components which are core and winding. Usually the core of the transformer is rectangular or square in shape. The core is made up of high permeable and low hysteresis co-efficient silicon steel. The core is consists of Yoke and Limb. The top and bottom horizontal portion of the transformer is called Yoke.

The copper wire is wounded on vertical portion of the core called Limb. Two windings are wounded at the left and right vertical portion of the transformer, which are called primary winding and secondary winding. The primary winding having $N_{1}$ number of turns is connected to the AC supply voltage. The voltage is induced in the secondary winding. The secondary winding consists of $N_{2}$ number of turns. The magnetic field is produced in around the core.

The primary winding and secondary winding are magnetically coupled with each other. When an AC is connected to the primary winding an alternating flux is produced in the core, which will produce voltage in the secondary winding. Consider an emf of $E_{1}$ is applied to primary winding having $N_{1}$ turns which will produce and emf of $E_{2}$ in the secondary winding having $N_{2}$ turns. The relation between emf $E_{1}, E_{2}, N_{1}$ is $N_{2}$

$$
\begin{aligned}
\frac{E_{1}}{E_{2}} & =\frac{N_{1}}{N_{2}} \\
E_{2} & =\frac{N_{2}}{N_{1}} E_{1}
\end{aligned}
$$

For no load condition the current flowing in primary winding $I_{1}$ and secondary winding $I_{2}$ are related by

$$
\begin{aligned}
E_{1} I_{1} & =E_{2} I_{2} \\
\frac{E_{1}}{E_{2}} & =\frac{I_{2}}{I_{1}}=\frac{N_{1}}{N_{2}}
\end{aligned}
$$

### 0.1.3 Types Of Transformer:

There are two type transformers based on its construction:

1. Core type transformer
2. Shell type transformer

### 0.1.4 Emf Equation:

Consider an ideal transformer for which an alternating voltage of $V_{m} \sin \omega t$ is to primary winding of the transformer. The alternating voltage flowing in primary winding produces an alternating flux $\phi$ which links both primary and secondary windings. The emf $e_{1}$ induces an voltage in secondary windings $e_{2}$.

$$
e_{1}=N_{1} \frac{d \phi}{d t}
$$

The sinusoidal voltage produces flux is which is also sinusoidal in nature as shown in Figure 2 and given is by

$$
\phi=\phi_{m} \sin \omega t
$$



Figure 2

$$
\begin{aligned}
e & =N_{1} \frac{d \phi}{d t} \\
& =N_{1} \frac{d \phi_{m} \sin \omega t}{d t} \\
& =-N_{1} \phi_{m} \cos \omega t \times \omega \\
& =-2 \pi f N_{1} \phi_{m} \cos \omega t \\
& =2 \pi f N_{1} \phi_{m} \sin \left(\omega t-90^{\circ}\right) \\
& =2 \pi f N_{1} \phi_{m}
\end{aligned}
$$

The rms value of the induced emf is

$$
\begin{aligned}
E_{1} & =\frac{E_{m 1}}{\sqrt{2}}=\frac{2 \pi f N_{1} \phi_{m}}{\sqrt{2}} \\
& =4.4 \pi f \phi_{m} N_{1}
\end{aligned}
$$

Similarly induced emf in the secondary winding is

$$
\begin{aligned}
E_{2} & =\frac{E_{m 1}}{\sqrt{2}}=\frac{2 \pi f N_{2} \phi_{m}}{\sqrt{2}} \\
& =4.4 \pi f \phi_{m} N_{2} \\
\frac{E_{2}}{E_{1}} & =\frac{4.4 \pi f \phi_{m} N_{2}}{4.4 \pi f \phi_{m} N_{1}}=\frac{N_{2}}{N_{1}}
\end{aligned}
$$

Or

$$
\frac{E_{1}}{N_{1}}=\frac{E_{2}}{N_{2}}
$$

### 0.1.5 Losses in a transformer:

There are two types of power losses occurs in a transformer

1. Iron losses
2. Copper losses

### 0.1.6 Iron loss $P_{i}$ :

Iron loss is the power loss that occurs in the iron part the transformer. Iron loss is depends on alternating frequency of the emf. The Iron losses are called as the constant losses. There are two types Iron loss those are.

- Eddy current loss
- Hysteresis loss


## Eddy current loss ( $W_{e}$ ):

- This is power loss which is due to the alternating flux linking the core, which will induces an emf.
- Due to the induced emf there is a current called the eddy current which is being circulated in the core.
- Due to the presence of some resistance in the core the eddy current is converted into heat called the eddy current power loss.
- Eddy current loss is proportional to the square of the supply frequency.
- Eddy current loss can be minimized by using the core made of thin sheets of silicon steel material, and each lamination is coated with varnish insulation to suppress the path of the eddy currents.

Hysteresis loss $\left(W_{h}\right)$ :

- Eddy current loss occurs in the iron core, due to the magnetic reversal of the flux in the core, which results in the form of heat in the core.
- This loss is directly proportional to the supply frequency.
- Hysteresis loss can be minimized by using the core material having high permeability.


### 0.1.7 Copper loss $P_{c u}$ ):

- This is the power loss that occurs in the primary and secondary coils when the transformer is on load.
- This power is wasted in the form of heat due to the resistance of the coils.
- This loss is proportional to the sequence of the load hence it is called the Variable loss where as the Iron loss is called as the Constant loss as the supply voltage and frequency are constants


## Total losses of the transformer are

$$
=P_{i}+P_{c u}
$$

## Efficiency:

Efficiency is the ratio of the output power to the input power of a transformer. It is defined as:

$$
\eta=\frac{\text { output power }}{\text { input power }}
$$

Input power
Input power $=$ output power + Iron loss + Copper loss

$$
\begin{aligned}
\eta & =\frac{\text { output power }}{\text { input power }} \\
& =\frac{\text { output power }}{\text { output power }+ \text { Iron loss }+ \text { Copper loss }} \\
& =\frac{V_{2} I_{2} \cos \phi}{V_{2} I_{2} \cos \phi+W_{\text {Iron }}+W_{\text {Copper }}}
\end{aligned}
$$

Where, $V_{2}$ is the transformer output voltage, $I_{2}$ is the output current and $\cos \phi$ is the power factor of the load.

The transformers are specified with KVA ratings

$$
\eta=\frac{K V A\left(10^{3}\right) \cos \phi}{K V A\left(10^{3}\right) \cos \phi+P_{i}+P_{C u}}
$$

The efficiency at any load and p.f is given by

$$
\eta=\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}}
$$

where $x$ is the load condition.

## Condition For Maximum Efficiency:

$$
\begin{aligned}
\eta & =\frac{\text { output power }}{\text { input power }} \\
& =\frac{\text { output power }}{\text { output power }+ \text { Iron loss }+ \text { Copper loss }} \\
& =\frac{V_{2} I_{2} \cos \phi}{V_{2} I_{2} \cos \phi+P_{i}+I_{2}^{2} R_{2 c}} \\
\eta & =1+\frac{V_{2} I_{2} \cos \phi}{P_{i}}+\frac{V_{2} \cos \phi}{I_{2} R_{2 c}}
\end{aligned}
$$

The condition for maximum efficiency is

$$
\frac{d \eta}{d I_{2}}=0
$$

$$
\begin{aligned}
\frac{d \eta}{d I_{2}} & =0+\frac{V_{2} \cos \phi}{P_{i}}-\frac{V_{2} \cos \phi}{I_{2}^{2} R_{2 c}}=0 \\
\frac{V_{2} \cos \phi}{P_{i}} & =\frac{V_{2} \cos \phi}{I_{2}^{2} R_{2 c}} \\
P_{i} & =I_{2}^{2} R_{2 c}
\end{aligned}
$$

The condition for maximum efficiency of a transformer is

$$
\begin{aligned}
P_{i} & =I_{2}^{2} R_{2 c} \\
\text { Iron loss } & =\text { Copper loss }
\end{aligned}
$$

### 0.2 Problems on Transformer

Q1) A $50 \mathrm{kVA}, 3300 / 330 \mathrm{~V}$, single phase transformer has iron loss and full load copper loss 400 W and 600 W respectively. Calculate the efficiency at half full load and 0.9 p.f. Also calculate the load at which the efficiency is maximum
Solution: The efficiency at any load and p.f is given by

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{0.5 \times 50 \times 1000 \times 0.9}{0.5 \times 50 \times 1000 \times 0.9+400+0.5^{2} \times 600} \\
& =0.976 \\
& =97.6 \%
\end{aligned}
$$

Load at which the maximum efficiency is

$$
\begin{aligned}
& =\text { Full load } k V A \sqrt{\frac{\text { Iron loss }}{\text { Full load copper loss }}} \\
& =50 \sqrt{\frac{400}{600}} \\
& =40.823 \mathrm{kV} A
\end{aligned}
$$

Q2) In a $25 \mathrm{kVA}, 2000 / 200 \mathrm{~V}$, s transformer has iron loss and full load copper loss 350 W and 400 W respectively. Calculate the efficiency at UPF at half and $\frac{3}{4}$ th full load.

## Solution:

i) At half load with UPF The efficiency at any load and p.f is given by

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{0.5 \times 25 \times 1000 \times 1}{0.5 \times 25 \times 1000 \times 1+350+0.5^{2} \times 400} \\
& =0.9652 \\
& =96.52 \%
\end{aligned}
$$

i) At $\frac{3}{4}$ th load with UPF

The efficiency at any load and p.f is given by

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{0.75 \times 25 \times 1000 \times 1}{0.75 \times 25 \times 1000 \times 1+350+(.75)^{2} \times 400} \\
& =0.9702 \\
& =97.02 \%
\end{aligned}
$$

Q3) The no load ratio of a $50 \mathrm{~Hz} 25 \mathrm{kVA}, 6000 / 250$ V. Determine the number of turns on each of the windings if the maximum flux in the core is 0.05 Wb .

Also determine primary and secondary currents on full load.
Solution:

$$
\begin{aligned}
\text { voltage } / \text { turn } & =4.44 f \phi_{m} \\
& =4.44 \times 50 \times 0.05=11.1 \mathrm{~V}
\end{aligned}
$$

Number of turns in primary is

$$
\begin{aligned}
N_{1} & =\frac{6000}{11.1}=540.5 \\
& \simeq 541
\end{aligned}
$$

Number of turns in secondary is

$$
\begin{aligned}
N_{2} & =\frac{250}{11.1}=22.5 \\
& \simeq 23
\end{aligned}
$$

Primary current is

$$
I_{1}=\frac{25 \times 10^{3}}{6000}=4.167 \mathrm{~A}
$$

Secondary current is

$$
I_{1}=\frac{25 \times 10^{3}}{250}=100 \mathrm{~A}
$$

2020-Jan 5 b) A 40 kVA , single phase transformer has core loss 450 W and full load copper loss 850 Watts. If the power factor of the load is 0.8 Calculate:
i) full load efficiency
ii) maximum efficiency at UPF
iii) load for maximum efficiency

Solution: i) full load efficiency

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{1 \times 40 \times 1000 \times 0.8}{1 \times 40 \times 1000 \times 0.8+450+1^{2} \times 850} \\
& =0.961 \\
& =96.1 \%
\end{aligned}
$$

ii) maximum efficiency at UPF

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{1 \times 40 \times 1000 \times 1}{1 \times 40 \times 1000 \times 1+450+1^{2} \times 850} \\
& =0.968 \\
& =96.8 \%
\end{aligned}
$$

iii) Load at which the maximum efficiency is

$$
\begin{aligned}
& =\text { Full load } k V A \sqrt{\frac{\text { Iron loss }}{\text { Full load copper loss }}} \\
& =40 \sqrt{\frac{450}{850}} \\
& =29.104 \mathrm{kV} A
\end{aligned}
$$

2019-June 5 c) A $250 \mathrm{kVA}, 11000 / 415$ volts 50 Hz transformer has 80 turns on the secondary. Calculate i)Rated primary and secondary currents ii) Number of primary turns iii) Maximum value of flux in the core iv)Voltage induced /turn on secondary

## Solution:

i)Rated primary and secondary currents

$$
\begin{aligned}
E_{1} I_{1} & =\text { rated } k V A \times 1000 \\
I_{1} & =\frac{250 \times 1000}{11000}=22.72 A \\
E_{2} I_{2} & =\text { rated } k V A \times 1000 \\
I_{2} & =\frac{250 \times 1000}{415}=602.4 A
\end{aligned}
$$

ii) Number of primary turns

$$
\begin{aligned}
\frac{E_{2}}{E_{1}} & =\frac{N_{2}}{N_{1}} \\
N_{1} & =\frac{E_{1} N_{2}}{E_{2}}=\frac{11000 \times 80}{415} \\
& =2120
\end{aligned}
$$

iii)Maximum value of flux

$$
\begin{aligned}
E_{2} & =4.44 f \phi_{m} N_{2} \\
\phi_{m} & =\frac{415}{4.44 \times 50 \times 80}=23.36 \mathrm{mWb}
\end{aligned}
$$

iv)Voltage induced /turn on secondary

$$
\begin{aligned}
& =\frac{\text { Voltage in secondary }}{\text { Number pf turn onsecondary }} \\
& =\frac{415}{80} 5.18 \mathrm{~V}
\end{aligned}
$$

2019-June 6 a) A 500 kVA , single phase transformer has efficiency of $92 \%$ at full load unity p.f. and at half load 0.9 p.f. Determine its efficiency at $80 \%$ of the full load and 0.95 p.f.

## Solution:

i) full load efficiency

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
0.92 & =\frac{1 \times 500 \times 1000 \times 1}{1 \times 500 \times 1000 \times 1+W_{i}+1 \times W_{C u}}
\end{aligned}
$$

$$
\begin{gather*}
500000+W_{i}+W_{C u}=\frac{500000}{0.92} \\
500000+W_{i}+W_{C u}=543478.9 \\
W_{i}+W_{C u}=43478.9  \tag{1}\\
\eta=\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
=\frac{0.5 \times 500 \times 1000 \times 0.9}{0.5 \times 500 \times 1000 \times 0.9+W_{i}+0.5^{2} \times W_{C u}} \\
225000+W_{i}+0.5^{2} \times W_{C u} \\
=\frac{225000}{0.92} \\
225000+W_{i}+0.25 W_{C u}
\end{gather*} \begin{aligned}
& =244565.21  \tag{2}\\
W_{i}+0.25 W_{C u} & =19565.21
\end{aligned}
$$

Solving 1 and 2

$$
\begin{aligned}
W_{i}+W_{C u} & =43478.9 \\
W_{i}+0.25 W_{C u} & =19565.21 \\
0.75 W_{C u} & =23912.68 \\
W_{C u} & =31883.57 \\
W_{i} & =11594.23
\end{aligned}
$$

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{0.8 \times 500 \times 10^{3} \times 0.95}{.8 \times 500 \times 10^{3} \times 0.95+11594.23+.8^{2} \times 31883.57} \\
& =0.9223 \\
& =92.23 \%
\end{aligned}
$$

2020-Jan 9 c) (2017 Scheme) A 200 kVA, 10000/400V 50 Hz single phase transformer has 200 turns on the secondary. Calculate i) Primary and secondary currents ii) Number of Primary turns iii) Maximum value of flux iv) Flux density at area=18 $\mathrm{cm}^{2}$.

## Solution:

$$
\begin{aligned}
& N_{1}=?, N_{2}=200 E_{1}=10000 \\
& E_{2}=400 ? I_{1}=? I_{2}=? \phi_{m}=?
\end{aligned}
$$

ii) Primary and secondary currents

$$
\begin{aligned}
& I_{1}=\frac{200 \times 10^{3}}{10000}=20 \mathrm{~A} \\
& I_{2}=\frac{200 \times 10^{3}}{400}=500 \mathrm{~A}
\end{aligned}
$$

iI) Number of Primary turns

$$
\begin{aligned}
\frac{N_{1}}{N_{2}} & =\frac{E_{1}}{E_{2}} \\
& =\frac{N_{1}}{200}=\frac{10000}{400} \\
N_{1} & =25 \times 200=5000
\end{aligned}
$$

iii) Maximum value of flux

$$
\begin{aligned}
E_{1} & =4.44 f \phi_{m} N_{1} \\
\phi_{m} & =\frac{E_{1}}{4.44 f N_{1}} \\
\phi_{m} & =\frac{10000}{4.44 \times 50 \times 5000} \\
& =9 \times 10^{-3} \mathrm{~Wb}
\end{aligned}
$$

iv) Flux density at area $=18 \mathrm{~cm}^{2}$.

$$
\begin{aligned}
& \text { Area } A=\frac{\phi_{m}}{B_{m}} \\
& \qquad \begin{aligned}
B_{m} & =\frac{\phi_{m}}{A}=\frac{9 \times 10^{-3}}{18} \\
& =5 \times 10^{-4} \mathrm{~Wb} / \mathrm{cm}^{2}
\end{aligned}
\end{aligned}
$$

2020-Jan 10 c) (2017 Scheme) In a 25 kVA, 2000/200 V transformer has iron loss and full load copper loss 350 W and 400 W respectively. Calculate the efficiency at UPF on i) Full load ii) half full load.

## Solution:

i) Full load with UPF

The efficiency at any load and p.f is given by

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 10^{3} \times p . f .}{x \times k V A \times 10^{3} \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{1 \times 25 \times 10^{3} \times 1}{1 \times 25 \times 10^{3} \times 1+350+1^{2} \times 400} \\
& =0.9708 \\
& =97.08 \%
\end{aligned}
$$

i) At half load with UPF

The efficiency at any load and p.f is given by

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 10^{3} \times p . f .}{x \times k V A \times 10^{3} \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{0.5 \times 25 \times 10^{3} \times 1}{0.5 \times 25 \times 10^{3} \times 1+350+0.5^{2} \times 400} \\
& =0.9652 \\
& =96.52 \%
\end{aligned}
$$

2019-June 10 b) (2017 Scheme) The primary winding of a 25 KVA transformer has 200 turns and is connected to 230 V 50 Hz supply. The secondary turns are 50. Calculate i) no load secondary emf ii)
full load primary and secondary currents iii) the flux density in the core if the cross section of the core 60 $\mathrm{cm}^{2}$

## Solution:

$$
\begin{aligned}
& N_{1}=200, N_{2}=50 E_{1}=230 \\
& E_{2}=? I_{1}=? I_{2}=? \phi_{m}=?
\end{aligned}
$$

i) no load secondary emf

$$
\begin{aligned}
\frac{E_{1}}{E_{2}} & =\frac{N_{1}}{N_{2}} \\
E_{2} & =E_{1} \times \frac{N_{2}}{N_{1}} \\
E_{2} & =230 \times \frac{50}{200} \\
& =57.5
\end{aligned}
$$

ii) Primary and secondary currents

$$
\begin{aligned}
& I_{1}=\frac{25 \times 10^{3}}{230}=108.7 \mathrm{~A} \\
& I_{2}=\frac{25 \times 10^{3}}{57.5}=434.78 \mathrm{~A}
\end{aligned}
$$

the flux density in the core if the cross section of the core $60 \mathrm{~cm}^{2}$
iii) Maximum value of flux

$$
\begin{aligned}
E_{1} & =4.44 f \phi_{m} N_{1} \\
\phi_{m} & =\frac{E_{1}}{4.44 f N_{1}} \\
\phi_{m} & =\frac{230}{4.44 \times 50 \times 200} \\
& =5.18 \times 10^{-3} \mathrm{~Wb}
\end{aligned}
$$

iv) Flux density at area $=60 \mathrm{~cm}^{2}$.

$$
\begin{aligned}
\text { Area } A & =\frac{\phi_{m}}{B_{m}} \\
B_{m} & =\frac{\phi_{m}}{A}=\frac{5.18 \times 10^{-3}}{60} \\
& =0.863 \times 10^{-6} \mathrm{~Wb} / \mathrm{cm}^{2}
\end{aligned}
$$

2019-June 10 b) (2017 Scheme) A transformer is rated at 100 kVA . At full load its copper loss is 1200 W and iron loss 960 W Calculate i)the efficiency of full load at UPF ii) the efficiency at half load 0.8 p.f. iii) The load KVA at which maximum efficiency occurs iv) Maximum efficiency at 0.85 p.f.

## Solution:

i) Full load with UPF

The efficiency at any load and p.f is given by

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 10^{3} \times p . f .}{x \times k V A \times 10^{3} \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{1 \times 100 \times 10^{3} \times 1}{1 \times 100 \times 10^{3} \times 1+960+1^{2} \times 1200} \\
& =0.9788 \\
& =97.88 \%
\end{aligned}
$$

ii) the efficiency at half load 0.8 p.f.

The efficiency at any load and p.f is given by

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 10^{3} \times p . f .}{x \times k V A \times 10^{3} \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{0.5 \times 100 \times 10^{3} \times 0.8}{0.5 \times 100 \times 10^{3} \times 0.8+960+0.5^{2} \times 1200} \\
& =0.9694 \\
& =96.94 \%
\end{aligned}
$$

iii) The load KVA at which maximum efficiency occurs

$$
\begin{aligned}
X & =\text { Full Load } K V A \times \sqrt{\frac{W_{i}}{\text { Full Load } C_{u}}} \\
& =\left(100 \times 10^{3}\right) \sqrt{\frac{960}{1200}} \\
& =89.443 \text { KVA }
\end{aligned}
$$

iv) Maximum efficiency at 0.85 p.f.

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 10^{3} \times p . f .}{x \times k V A \times 10^{3} \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{1 \times 89.443 \times 10^{3} \times 0.85}{1 \times 89.443 \times 10^{3} \times 0.85+960+1^{2} \times 1200} \\
& =0.9723 \\
& =97.23 \%
\end{aligned}
$$

2019-Jan 5 b) A 50 kVA , single phase transformer has primary and secondary turns of 300 and 20 respectively. The primary winding is connected to 2200 V 50 Hz. Calculate i) No load secondary voltage ii) approximate values of the primary and secondary currents on full load. iii) Maximum value of flux density.

## Solution:

$$
\begin{aligned}
& N_{1}=300, N_{2}=20 E_{1}=2200 \\
& E_{2}=? I_{1}=? I_{2}=? \phi_{m}=?
\end{aligned}
$$

i) No load secondary voltage

$$
\begin{aligned}
\frac{E_{2}}{E_{1}} & =\frac{N_{2}}{N_{1}}=\frac{E_{2}}{2200}=\frac{20}{300} \\
E_{2} & =0.067 \times 2200=146.6 \mathrm{~V}
\end{aligned}
$$

ii) approximate values of the primary and secondary currents

$$
\begin{aligned}
& I_{1}=\frac{50 \times 10^{3}}{2200}=22.72 \mathrm{~A} \\
& I_{2}=\frac{50 \times 10^{3}}{1474}=33.92 \mathrm{~A}
\end{aligned}
$$

iii) Maximum value of flux density

$$
\begin{aligned}
E_{1} & =4.44 f \phi_{m} N_{1} \\
\phi_{m} & =\frac{E_{1}}{4.44 f N_{1}} \\
\phi_{m} & =\frac{2200}{4.44 \times 50 \times 300} \\
& =0.033
\end{aligned}
$$

2019-Jan 5 b) A 400 kVA , single phase transformer has a core loss of 2 kW and maximum efficiency at 0.8 p.f. occurs when the load is 240 kW . Calculate i) maximum efficiency at unity power factor ii) the efficiency on full load at 0.71 power factor .

## Solution:

$$
\begin{aligned}
X & =\text { Full Load } K V A \times \sqrt{\frac{W_{i}}{\text { Full Load Cu }}} \\
240 & =(400 \times 0.8) \sqrt{\frac{2}{\text { Full Load C } C_{u}}}
\end{aligned}
$$

$$
\sqrt{\frac{2}{\text { Full Load } C_{u}}}=\frac{240}{320}=0.75
$$

$$
\frac{2}{\text { Full Load } C_{u}}=(0.75)^{2}=0.5625
$$

$$
\text { Full Load } C_{u}=\frac{2}{0.5625}=3.555 \mathrm{~kW}
$$

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{1 \times 240 \times 1000 \times 1}{1 \times 240 \times 1000 \times 1+2+1^{2} \times 2} \\
& =0.9836 \\
& =98.36 \%
\end{aligned}
$$

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{1 \times 400 \times 1000 \times 0.71}{1 \times 400 \times 1000 \times 0.71+2+1^{2} \times 3.555} \\
& =0.9808 \\
& =98.08 \%
\end{aligned}
$$

2019-Jan 10 c) (2017 -scheme) The maximum efficiency at full load and unity p.f. of a single
phase $25 \mathrm{kVA}, 500 / 1000 \mathrm{~V} 50 \mathrm{~Hz}$ transformer is $98 \%$. Determine its efficiency at i) $75 \%$ load 0.9 p.f. ii) $50 \%$ load 0.8 p.f..

## Solution:

Maximum efficiency occurs when $W_{i}+W_{C u}$

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
0.98 & =\frac{1 \times 25 \times 10^{3} \times 1}{1 \times 25 \times 10^{3} \times 1+W_{i}+1^{2} W_{C u}}
\end{aligned}
$$

$$
25 \times 10^{3}+W_{i}+1 W_{C u}=\frac{1 \times 25 \times 10^{3} \times 1}{0.98}
$$

$$
=25510.2
$$

$$
W_{i}+W_{C u}=25510.2-25 \times 10^{3}=510.2
$$

$$
2 W_{i}=25510.2-25 \times 10^{3}=510.2
$$

$$
W_{i}=W_{C u}=255.10
$$

i) $75 \%$ load 0.9 p.f.

$$
\begin{aligned}
\eta & =\frac{0.75 \times 25 \times 10^{3} \times 0.9}{0.75 \times 25 \times 10^{3} \times 0.9+255.1+(0.75)^{2} \times 255.1} \\
& =0.9769 \\
& =97.69 \%
\end{aligned}
$$

ii) $50 \%$ load 0.8 p.f.

$$
\begin{aligned}
\eta & =\frac{0.5 \times 25 \times 10^{3} \times 0.8}{0.5 \times 25 \times 10^{3} \times 0.8+255.1+(0.5)^{2} \times 255.1} \\
& =0.969 \\
& =96.9 \%
\end{aligned}
$$

2019-June 9 b) (2015 Scheme) A 100 KVA 6000/400V 50 Hz single phase transformer has 100 turns in the the secondary. Find i) full load primary and secondary currents ii) number of turns in the primary coil iii) maximum flux in the core

## Solution:

$$
\begin{aligned}
& N_{1}=?, N_{2}=100 E_{1}=6000 \\
& E_{2}=400 I_{1}=? I_{2}=? \phi_{m}=?
\end{aligned}
$$

i) Primary and secondary currents

$$
\begin{aligned}
& I_{1}=\frac{100 \times 10^{3}}{6000}=16.67 \mathrm{~A} \\
& I_{2}=\frac{100 \times 10^{3}}{400}=250 \mathrm{~A}
\end{aligned}
$$

the flux density in the core if the cross section of the core $60 \mathrm{~cm}^{2}$
i) number of turns in the primary coil

$$
\begin{aligned}
& \frac{E_{1}}{E_{2}}=\frac{N_{1}}{N_{2}} \\
& N_{1}=\frac{E_{1}}{E_{2}} \times N_{2}
\end{aligned}
$$

iii) Maximum value of flux

$$
\begin{aligned}
E_{1} & =4.44 f \phi_{m} N_{1} \\
\phi_{m} & =\frac{E_{1}}{4.44 f N_{1}} \\
\phi_{m} & =\frac{6000}{4.44 \times 50 \times 1500} \\
& =18.01 \times 10^{-3} \mathrm{~Wb}
\end{aligned}
$$

2019-June 10 c) (2015 Scheme) A 600 kVA, single phase transformer has efficiency of $92 \%$ at full load unity p.f. and at half load 0.9 p.f. Determine its efficiency at $75 \%$ of the full load and 0.9 p.f.

## Solution:

i) full load efficiency

$$
\begin{array}{r}
\eta=\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
0.92=\frac{1 \times 600 \times 10^{3} \times 1}{1 \times 600 \times 10^{3} \times 1+W_{i}+1 \times W_{C u}} \\
600 \times 10^{3}+W_{i}+W_{C u}=\frac{600 \times 10^{3}}{0.92} \\
600 \times 10^{3}+W_{i}+W_{C u}=652173.9 \\
W_{i}+W_{C u}=52173.39 \tag{3}
\end{array}
$$

$$
\begin{aligned}
\eta & =\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}} \\
& =\frac{0.5 \times 600 \times 10^{3} \times 0.9}{0.5 \times 600 \times 10^{3} \times 0.9+W_{i}+0.5^{2} \times W_{C u}}
\end{aligned}
$$

$$
270000+W_{i}+0.5^{2} \times W_{C u}=\frac{270000}{0.92}
$$

$$
270000+W_{i}+0.25 W_{C u}=293478.26
$$

$$
\begin{equation*}
W_{i}+0.25 W_{C u}=23478.26 \tag{4}
\end{equation*}
$$

Solving 3 and 4

$$
\begin{aligned}
W_{i}+W_{C u} & =52173.9 \\
W_{i}+0.25 W_{C u} & =23478.26 \\
0.75 W_{C u} & =28695.64 \\
W_{C u} & =38260.87 \\
W_{i} & =13913
\end{aligned}
$$

$$
\eta=\frac{x \times k V A \times 1000 \times p . f .}{x \times k V A \times 1000 \times p . f .+W_{i}+x^{2} W_{C u}}
$$

$$
=\frac{0.75 \times 600 \times 10^{3} \times 0.9}{.75 \times 600 \times 10^{3} \times 0.9+13913+.75^{2} \times 38260.87}
$$

$$
=0.9210
$$

$$
=92.10 \%
$$

