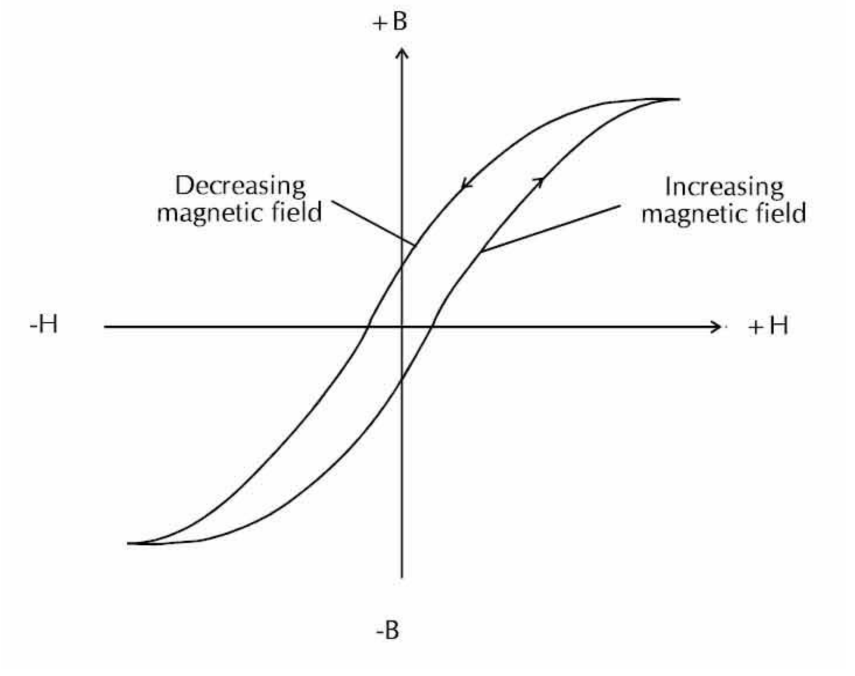
Transformer Example Sheet Solutions

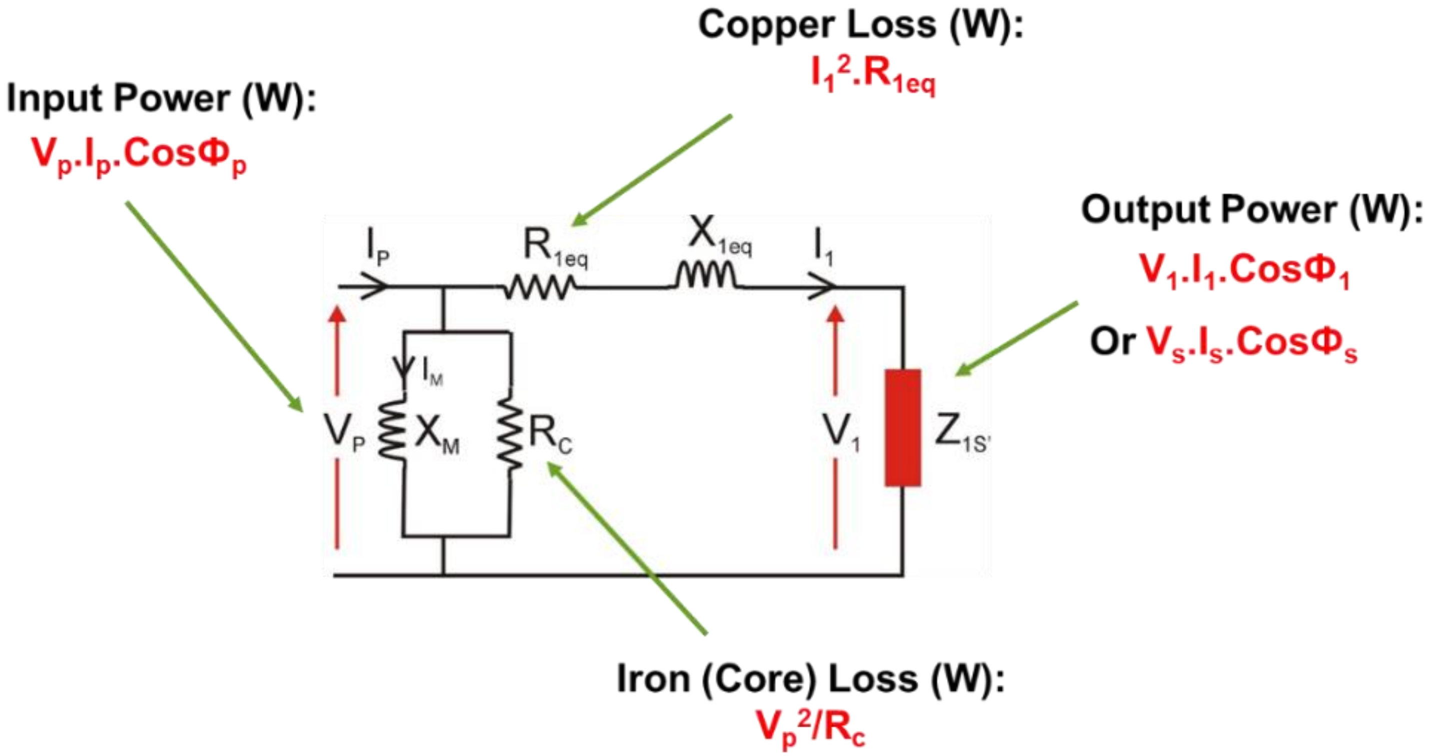
15th November 2021

Q1.a Draw a H-H curve for a transformer core. Using the diagram briefly explain what is meant by hysteresis loss.



Magnetic Hysteresis results in the dissipation of wasted energy in the form of heat. The energy wasted is in proportion to the area of the magnetic hysteresis loop of the B-H curve. Hysteresis losses will always be a problem in AC transformers where the current is constantly changing direction and thus the magnetic poles in the core will cause losses, because they constantly reverse direction.

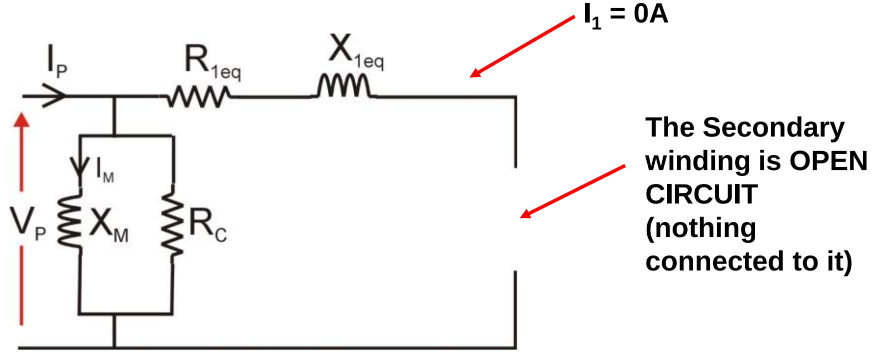
Q1b. Draw the equivalent circuit of a transformer referred to the primary side. In your circuit show how the copper and iron losses are represented.



Q1c. Explain how you would determine, experimentally, the component values in the equivalent circuit.

- Open Circuit Test

1. Since $I_P = I_M$ the values of X_M, R_C and turns ratio can be found.



Measurement: Primary voltage (Vp), Primary current (Ip), Primary real power (Pp) and secondary open circuit voltage (Vsoc).

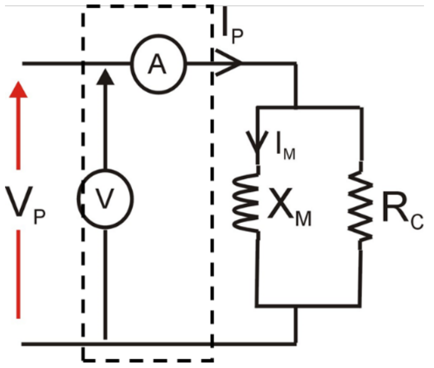
$$R_C = \frac{V_P^2}{P_P}$$

$$S_P = V_P . I_P$$

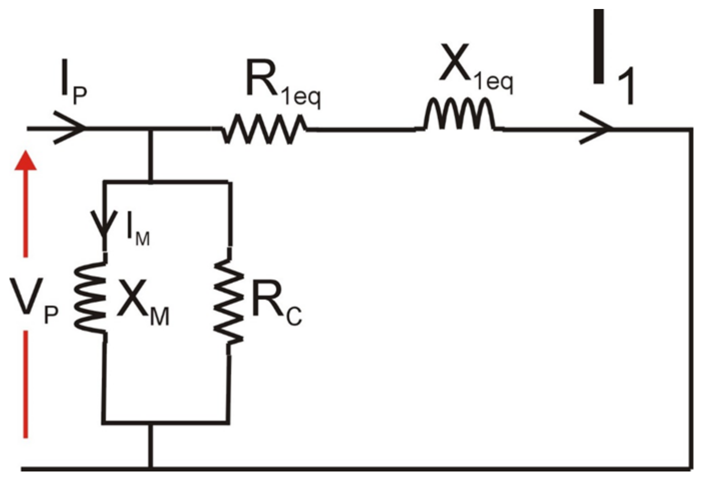
$$Turns\_Ratio = \frac{V_P}{V_{SOC}}$$

$$Q_P = \sqrt{\left(S_P^2 - P_P^2\right)}$$

$$X_M = \frac{V_P^2}{Q_P}$$



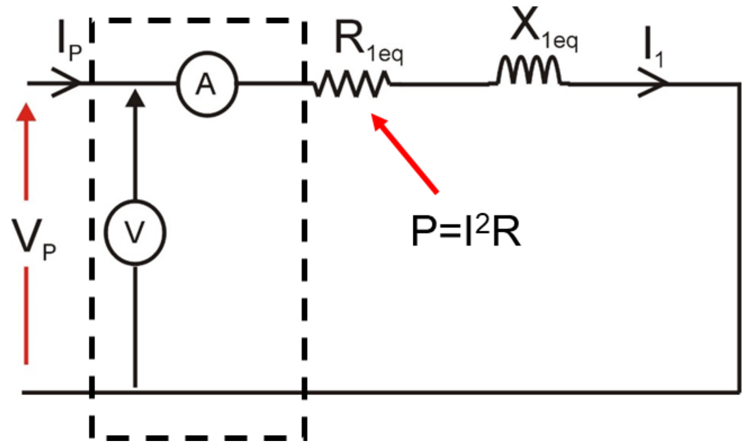
2. Short Circuit Test



It turns out that I_1 is significantly bigger than I_M (&I_C) and therefore we can simplify the Equivalent Circuit to determine X_{1eq}, R_{1eq}

Measurements: Vp, Ip and Primary real power Pp

REAL Power Meter (W)



$$R_{1eq} = \frac{P_P}{I_P^2}$$

$$S_P = V_P . I_P$$

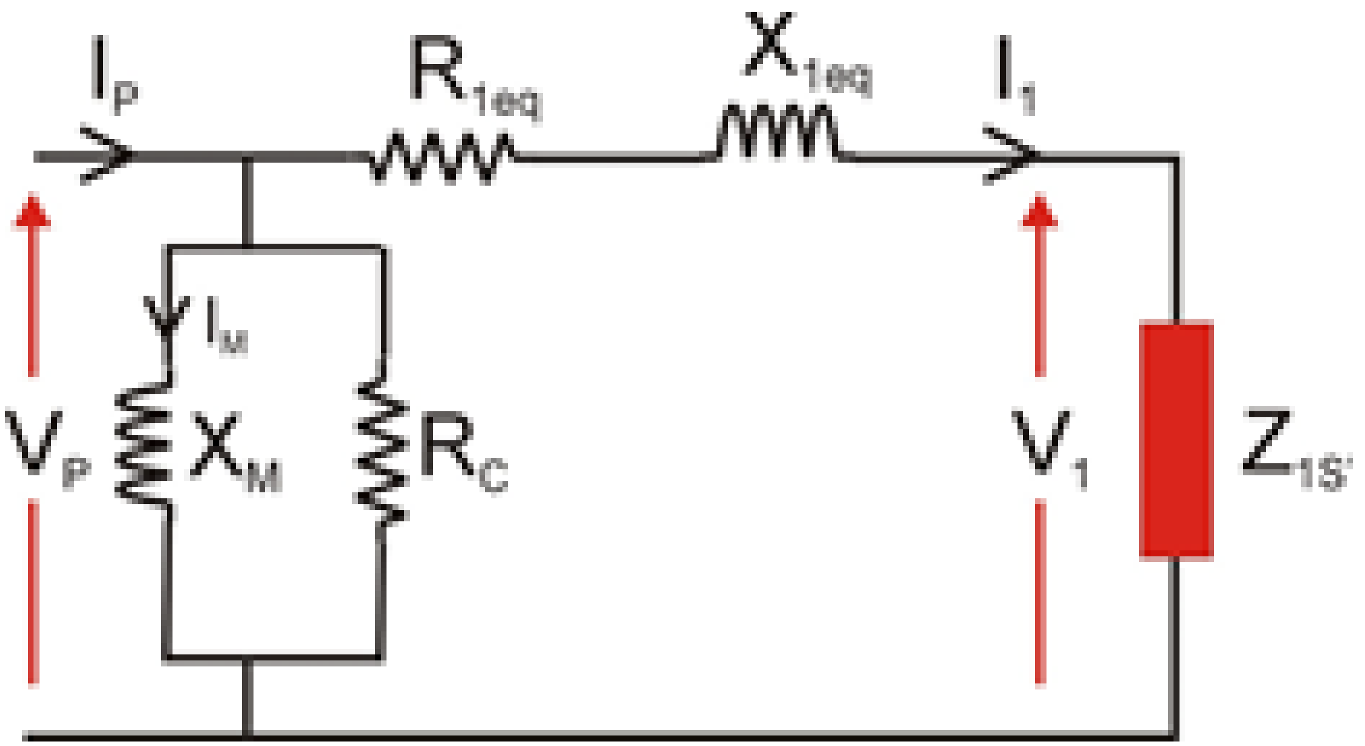
$$Q_P = \sqrt{\left(S_P^2 - P_P^2\right)}$$

$$X_{1eq} = \frac{Q_P}{I_P^2}$$

Q1d. In the design of a transformer explain how you might mitigate against Eddy Currents.

- The main strategy in mitigating against eddy currents in transformer cores is to form the iron core in sheets. Each sheet is covered with an insulating varnish so that the core is divided up into thin slices. The result is very little width in the core for eddy currents to circulate in.

Q2a. Draw the equivalent circuit of the transformer.



Determine the Output Current, Output Voltage, Magnetizing Current and Transformer Efficiency

R_{1eq}	2.5 Ω
X_{1eq}	6.7 Ω
X_M	2 kΩ
R_C	2.2 kΩ

$$Z_{1S}^{'} = (Vp/Vs)^2 \times Z_s = (55/220)^2 \times 800 = 50\Omega$$

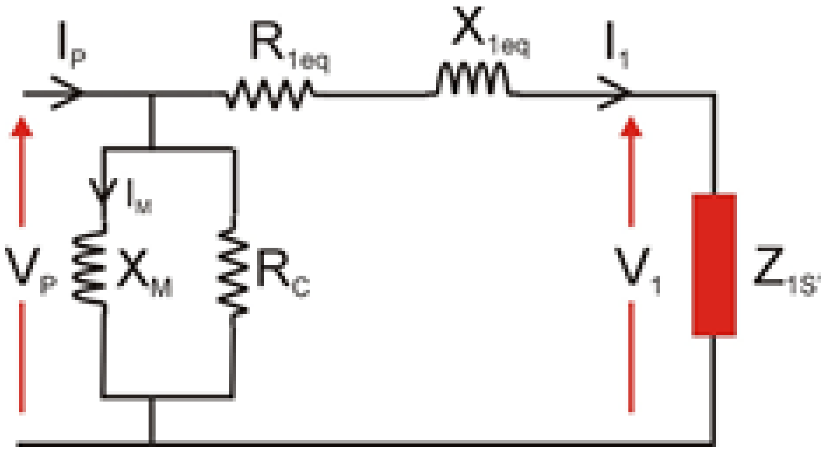
$$I_1 = \frac{Vp}{\sqrt{(Z_{1s^{'}} + R_{1e1})^2 + X_{1eq}{}^2}} = \frac{55}{\sqrt{(50+2.5)^2 + 6.7^2}} = \frac{250}{241.66} = 1.04A$$

$$I_S = I_1/(220/55) = 0.26A$$

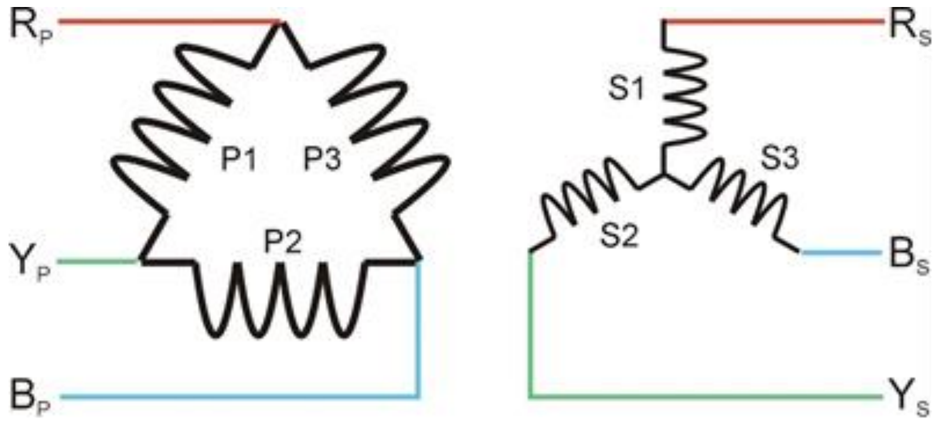
$$V_S = I_S \times 800 = 208V$$

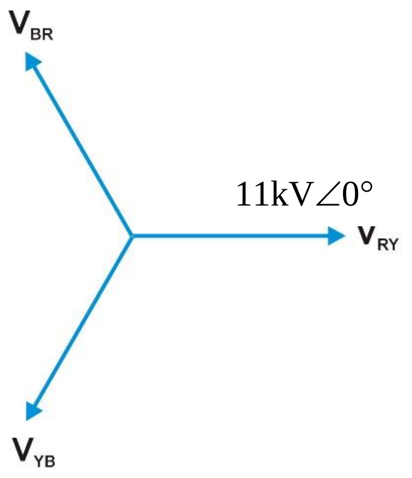
$$I_M = \frac{55}{X_M} = 0.028A$$

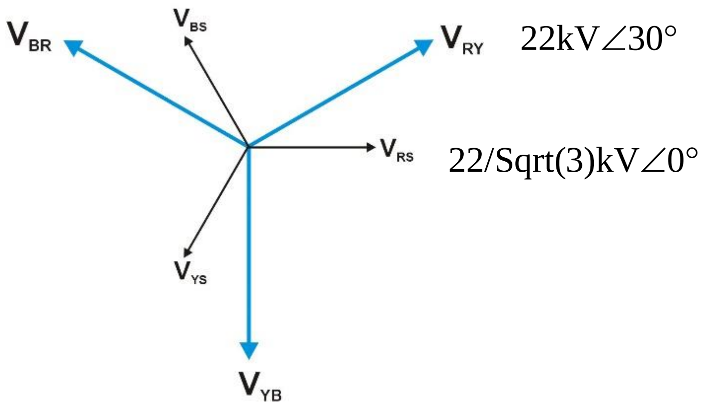
$$\eta = \frac{I_1^2 Z_{1S}^{'}}{I_1^2 Z_{1S}^{'} + I_1^2 \times R_{1eq} + Vp^2/R_c} = \frac{54.1}{54.1+2.7+1.5} = 92.8\%$$



Q3a. Construct a phasor diagram showing all primary phase voltages and secondary line voltages for the three-phase transformer in the question.





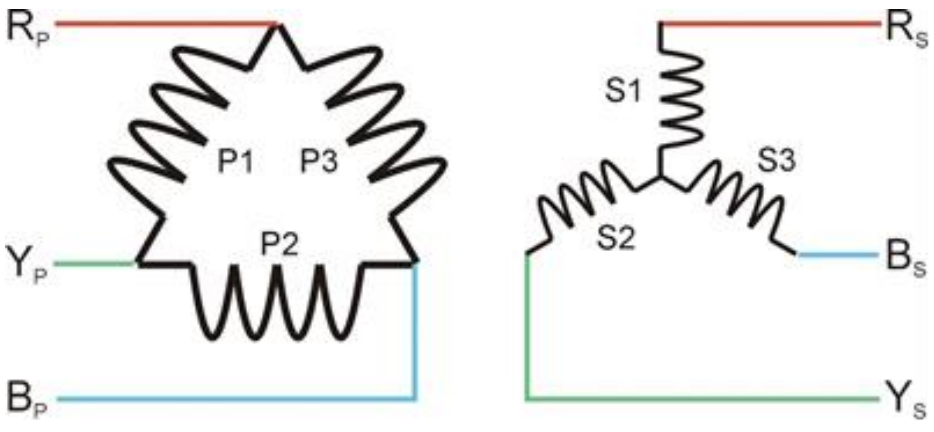


Q3b. The magnitudes of the primary side phase currents

$$220kVA = \sqrt{3}V_{PL}I_{PL}$$

$$I_{PL} = 11.5A$$

$$I_{phase} = I_{PL} / \sqrt{3} = 6.67A$$



Q4

The following results were obtained on a 50 kVA transformer:

Open circuit test – primary voltage, 3300 V; secondary voltage, 400 V; primary power, 400 W.

Short-circuit test – primary voltage, 124 V; primary current, 15.3 A; primary power, 495 W; secondary current, full-load value. Calculate the efficiencies at full load and at half load for 0.75 power factor

Solution (Full Load)

Core Loss = 400 W

I^2R loss of full load = 495 W

So total loss on full load = 895 W

$$\eta \text{ (Full Load)} = \frac{\text{outout power}}{\text{output power + losses}} = \frac{50 \times 0.75}{(50 \times 0.75) + 0.895} = 97.7\%$$

Solution (Half Load)

I^2R loss of half load = 495 x $(0.5)^2$=123.75 W

So total loss on full load = 523.75 W

$$\eta \text{ (half Load)=} \frac{\text{outout power}}{\text{output power + losses}} = \frac{25\times 0.75}{(25\times 0.75)+0.523} = 97.3\%$$