Indian Institute of Technology Patna
Department of Electrical Engineering
EE280 -Electrical Machines
Spring - 2022
Mid Semester Exam – Solution
26 February 2022

There are 5 questions. They carry equal marks.

$(5 \times 6 = 30)$

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1. A wattmeter reads 5 kW when its current coil is connected in R phase and voltage coil is connected between R and neutral of a symmetrical 3-phase star connected system supplying a 3-phase balanced inductive load of 25 A at 400 V.

   (a) What will be the reading of the wattmeter if the connections of the current coil remain unchanged and voltage coil be connected between Y and B phases?

   (b) What are the real and reactive power of the load?

The watt meter reads 1φ power.

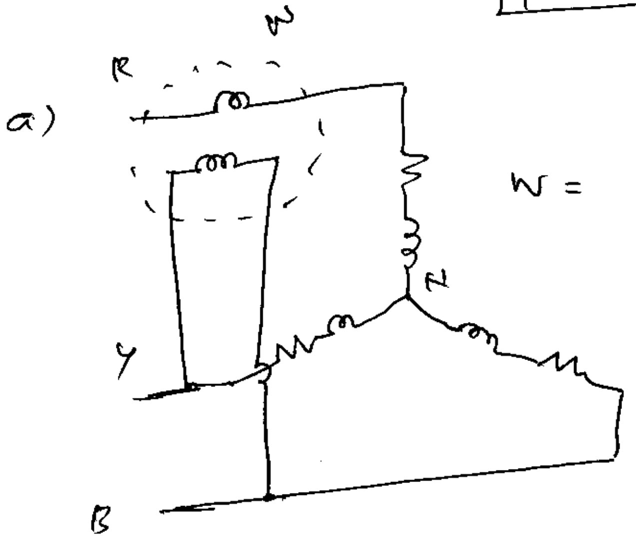
$P_{1\phi} = 5000$ W

$V_{ph} I_{ph} \cos\phi = 5000$

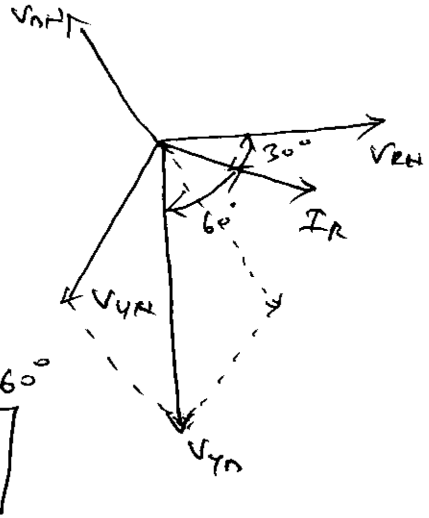
$\frac{400}{\sqrt{3}} \times 25 \times \cos\phi = 5000$

$\boxed{\phi = 30^\circ}$

a)



$W = V_{YB} I_R \cos(\angle V_{YB} - \angle I_R)$



$W = 400 \times 25 \times \cos 60^\circ$

Watt Meter reading = 5000 Watt

b) $P_{3\phi} = 3 \times P_{1\phi} = 3 \times 5000 =$ 15000 Watt

$Q_{3\phi} = \sqrt{3} \times V_L \times I_L \times \sin\phi =$ 8660.2 VAr

2. A 50 kVA, 2400/240 V transformer gives the following test results.
OC Test : 240 V, 5.41 A, 186 W
SC Test : 48 V, 20.8 A, 617 W

(a) Determine the primary voltage, input current and input power factor when the transformer supplies a half the rated load 0.8 power factor lagging at rated voltage in 240 V side.

(b) Draw the phasor diagram showing load voltage, load current, primary voltage and primary current.

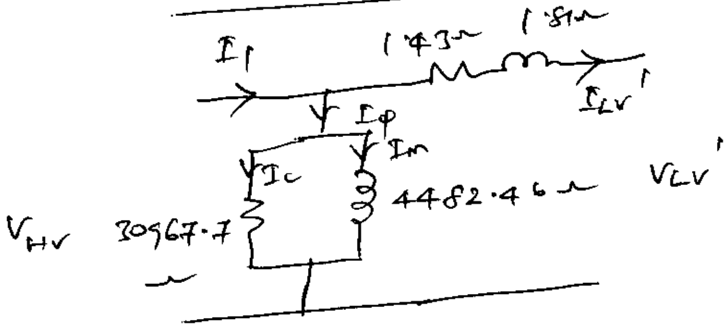
From OC Test:

$R_c = 309.677\ \Omega$
$X_m = 44.8246\ \Omega$ } LV side

From SC Test:

$R_{eq} = 1.43\ \Omega$
$X_{eq} = 1.81\ \Omega$ } HV side

Eqt ckt referring to HV side:



a) $V_{HV} = 2400\angle 0^\circ + 10.4\angle -36.87^\circ (1.43 + j1.81)$

$V_{HV} = 2423.2\angle 0.15^\circ$ V

i/p power factor:

$= \cos(38.5 + 0.15^\circ)$

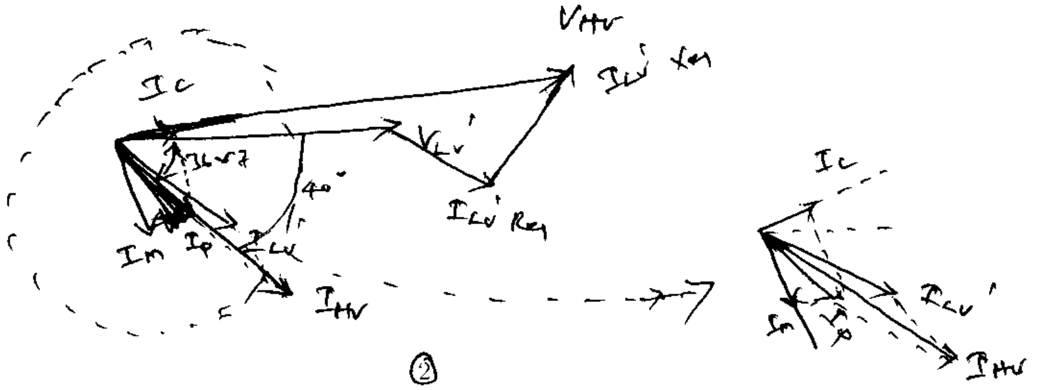
$= 0.7766$ lagging

$I_{HV} = I_{LV}' + I_\phi$

$I_{HV} = 10.4\angle -36.87 + 0.541\angle -81.76^\circ$

$I_{HV} = 10.8\angle -38.5^\circ$

b)



3. A single phase, 25 kVA, 2300/230 V, 50 Hz distribution transformer draws 250 W when excited at rated voltage and frequency with secondary open. At reduced voltage with full load current, the transformer requires 300 W input, when the secondary is short circuited.

(a) Determine the efficiency of the transformer when it delivers rated load at 0.8 power factor lagging.

(b) Find the all-day efficiency, if the transformer has the following load cycle:
5 kW at 0.8 power factor for 4 hours
10 kW at 0.8 power factor for 10 hours
15 kW at 0.8 power factor for 6 hours
20 kW at 0.8 power factor for 4 hours

Core loss = 250 Watts

Full load Cu loss = 300 Watts

a)

$$\% \eta = \frac{25 \times 0.8}{25 \times 0.8 + 0.250 + 0.300} \times 100 = \boxed{97.32}$$

b)

5 KW → $\frac{1}{4}$th of Full load

10 KW → $\frac{1}{2}$ load

15 kW → $\frac{3}{4}$th of Full load

20 kW → Full load

$$\text{All day efficiency} = \frac{\text{Energy o/p over 24 hrs}}{\text{Energy i/p over 24 hrs}}$$

$$= \frac{5 \times 4 + 10 \times 10 + 15 \times 6 + 20 \times 4}{5 \times 4 + 10 \times 10 + 15 \times 6 + 20 \times 4 + \text{losses}}$$

$$\text{losses} = 0.25 \times 24 + 0.3 \times \left(\frac{4}{16} + \frac{10}{4} + 6 \times \frac{9}{16} + 4 \right)$$

$$= 9.0375 \text{ kWhr/day}$$

All day eff = 96.98 %

③

1. A transformer of 30 kVA with 1 % resistance and 4 % leakage reactance is operating in parallel with another 60 kVA transformer having 1 % resistance and 6 % leakage reactance. The combination is delivering a load of 90 kVA at 230 V and unity power factor. Find the kVA loading on the 30 kVA transformer and the additional reactance to be connected in series with it to provide rated kVA loading on this transformer. (The per unit values are calculated with respect to their own base.)

The actual values of Z_{eq} are

$$(Z_1)\quad Z_{(30\ kVA)} = (0.01 + j0.04) \times Z_{base}$$

$$= (0.01 + j0.04) \times \frac{(0.230)^2}{0.03}$$

$$= (0.018 + j0.07)\,\Omega$$

$$(Z_2)\quad Z_{(60\ kVA)} = (0.01 + j0.06) \times \frac{(0.230)^2}{0.06}$$

$$Z_{(60\ kVA)} = (0.009 + j0.053)\,\Omega$$

$$S_{(30\ kVA)} = |V_L|\,|I_L| \times \frac{|Z_2|}{|Z_1| + |Z_2|}$$

$$= 90 \times \frac{0.009 + j0.053}{Z_1 + Z_2}$$

$$= 38.2 + j1.76 \quad \text{(Complex power)}$$

$$\boxed{S_{30\,kVA} = 38.23\ \text{KVA}}$$ KVA loading on 30 KVA transformer.

In order to make it's loading equal to 30 KVA

$$\frac{S_1}{S_2} = \frac{Z_{2\,p.u}}{Z_{1\,p.u}} \times \frac{S_{1\,base}}{S_{2\,base}}$$

$$Z_{1\,p.u} = Z_{2\,p.u}$$

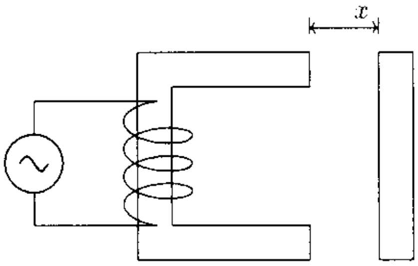
$$\therefore\quad jX_1 = j0.06$$

$$X_{add} = 0.06 - 0.04 = 0.02\ \text{p.u}$$

$$X_{add\ in\ \Omega} = 0.02 \times \frac{(0.230)^2}{0.03}$$

$$\boxed{= 0.0353\,\Omega}$$

5. The magnetic circuit of a relay is shown here. It is connected to an AC source of 50 Hz. The air gap x is 2 cm , the cross section area of the core is 50 cm^2 and the number of turns in the coil is 2000. Determine the voltage required to produce force of 150 N on the bar. Neglect the fringing effect, the reluctance of the magnetic circuit in the core and the resistance of the coil.



$$F = - \frac{I_{rms}^2 N^2 \mu_0 A_g}{4 x^2} \quad N$$

$|F| = 150$ N

$I_{rms} = 3.1$ A

$V_{rms} : I_{rms} X_L$

$V_{rms} = I_{rms} \omega L$

$$L = \frac{N^2}{\mathcal{R}_g} = \frac{(2000)^2 \times \mu_0 \times A_g}{2 \times x}$$

$L = 0.6283$ H

$V_{rms} = 3.1 \times 2 \times \pi \times 50 \times 0.6283$

$V_{rms} = 610$ V