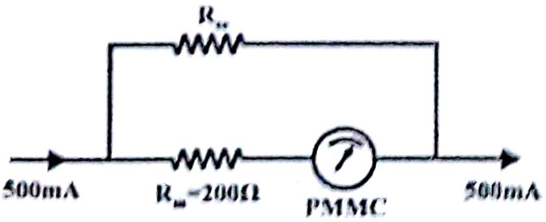
Measuring Instruments

Question 1:
Sketch the circuit of an electro-mechanical ammeter, and briefly explain its operation. Comment on the resistance of an ammeter.

Problem 1:
Following figure shows a PMMC instrument has a coil resistance of 200Ω and gives a FSD (full-scale deflection) for a current200 μA. Calculate the value of shunt resistance required to convert the instrument into a 500 mA ammeter.

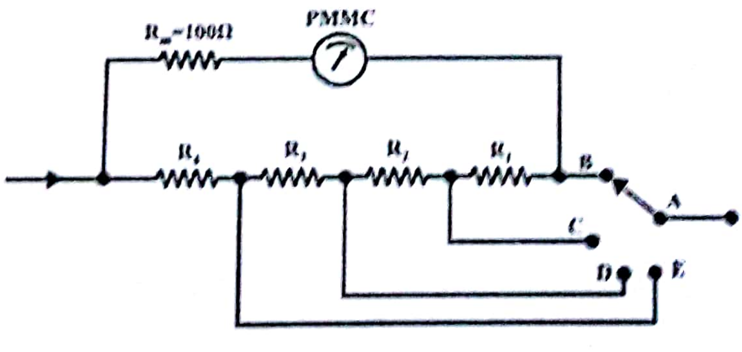
Ans: 0.08Ω



Problem 2:

A PMMC instrument has a resistance of 100Ω and FSD for a current of 400μA. A shunt arrangement is shown in following figure in order to have an multi-range ammeters. Determine the various ranges to which the ammeter may be switch. Assume $R_1 = R_2 = R_3 = R_4 = 0.001\Omega$

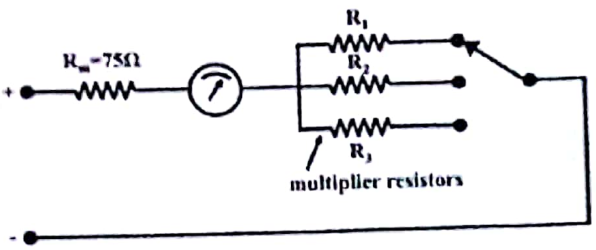
Ans: 10A, 13.32A, 20A, *and* 40A



Problem 3:

Following figure shows a PMMC instrument with a resistance of 75Ω and FSD current of 100μA is to be used as a voltmeter with 200V, 300V and 500V ranges. Determine the required value of multiplier resistor of each range.

Ans: 2MΩ, 3MΩ and 5MΩ



Problem 4:

Two resistors are connected in series across a $200V$ dc supply. The resistor values are $R_1 = 300k\Omega$ and R_2=$200k\Omega$. The voltmeter FSD is $250V$ and its sensitivity is $10k\Omega/V$. Determine the voltage across the resistance R_2: (i) without voltmeter in the circuit and (ii) with voltmeter connected.

Ans: 80V, $76.33V$

$$\text{Voltmeter sensitivity} = \frac{Meter\ \ resistance\ + resistance\ of\ multiplier}{Range\ of\ voltmeter}$$

Balanced Y/Δ Conversion

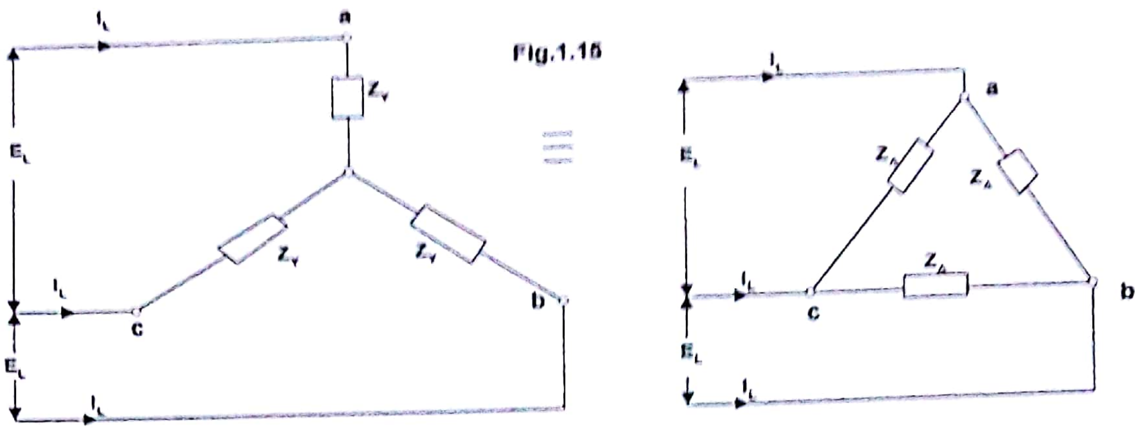


Fig.1.15

When a balanced star-connected load is equivalent to a balanced delta-connected load as shown in Fig.1.15, the line voltages and currents must have the same values in both the cases.

For balanced Y-load:

$$E_{ph} = \frac{E_L}{\sqrt{3}} \quad \text{and} \quad I_{ph} = I_L$$

$$\therefore Z_Y = \frac{E_{ph}}{I_{ph}} = \frac{1}{\sqrt{3}} \cdot \frac{E_L}{I_L}$$

For balanced Δ - load:

$$E_{ph} = E_L \quad \text{and} \quad I_{ph} = \frac{I_L}{\sqrt{3}}$$

$$\therefore Z_\Delta = \frac{E_{ph}}{I_{ph}} = \sqrt{3}.\frac{E_L}{I_L} = 3.\left[\frac{1}{\sqrt{3}} \cdot \frac{E_L}{I_L}\right] = 3.Z_Y$$

Hence, for Y to Δ conversion: $Z_\Delta = 3Z_Y$

and for Δ to Y conversion : $Z_Y = \frac{1}{3}.Z_\Delta$

Example – 1

A balanced load of $(8+j6)\Omega$ per phase is connected to a three-phase, 230V supply. Find the line current, power-factor, power, reactive VA and total VA when the load is i) star connected and ii) delta connected.

Solution

$$Z_{ph} = 8 + j6 = 10\angle 36.87^{\circ}\,\Omega.$$

Star Connection: $V_{ph} = 230/\sqrt{3} = 132.8\text{ V}$

$$\therefore I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{132.8}{10} = 13.28\text{A}.$$

$$\therefore I_L = I_{ph} = 13.28\text{A}.$$

$$\cos\phi = \cos 36.87^{\circ} \quad = 0.8\text{ (lag)}.$$

$$P = \sqrt{3} \times 230 \times 13.28 \times 0.8 \qquad = 4232.3\text{ W}$$

$$VAR = \sqrt{3} \times 230 \times 13.28 \times 0.6 \qquad = 3174.2\text{ VAR}$$

$$VA = \sqrt{3} \times 230 \times 13.28 \qquad = 5290.4\text{ VA}$$

Delta Connection: $V_{ph} = 230\text{ V}.$

$$\therefore I_{ph} = \frac{230}{10} = 23\text{ A}$$

$$\therefore I_L = \sqrt{3}.\, I_{ph} = \sqrt{3} \times 23 \quad = 39.8\text{ A}.$$

$$\cos\phi = 0.8\text{ (lag)}$$

$$\therefore P = \sqrt{3} \times 230 \times 39.8 \times 0.8 \qquad = 12684.1\text{ W}$$

$$VAR = \sqrt{3} \times 230 \times 39.8 \times 0.6 \qquad = 9513.1\text{ VAR}$$

$$VA = \sqrt{3} \times 230 \times 39.8 \qquad = 15855.2\text{ VA}.$$

Example – 2

A balanced three-phase, star-connected load of 150 kW takes a leading current of 100A with a line voltage of 1100V at 50Hz. Find the circuit constants of the load per phase.

Solution

$$P = 150 \text{ kW} = 150{,}000 \text{ W}$$

Given, $V_L = 1100$ V and $I_L = 100$ A.

$$\therefore \quad 150{,}000 = \sqrt{3} \times 1100 \times 100 \times \cos\phi$$

$$\therefore \cos\phi = 0.787 \text{ (lead)}$$

Now,

$$E_{ph} = \frac{1100}{\sqrt{3}} = 635.1\text{V} \quad \text{and } I_{ph} = 100\text{A}.$$

$$\therefore Z_{ph} = \frac{635.1}{100} = 6.35\Omega$$

$$\therefore R_{ph} = 6.35 \times 0.787 = 5\ \Omega$$

and $X_{cph} = 6.35 \times \sin(\cos^{-1} 0.787) = 6.35 \times 0.617 = 3.917\ \Omega$

$$\therefore C_{ph} = \frac{1}{2\pi \times 50 \times 3.917} = 812.6\mu F.$$

Example – 3

Three star-connected impedances $Z_1 = 20 + j37.7\ \Omega$ per phase are in parallel with three delta-connected impedances $Z_2 = 30 - j159.3\ \Omega$ per phase. The line voltage is 398V. Find the line current, power-factor, power and reactive VA taken by the combination.

Solution

Δ to Y conversion:

$$Z_2' = \frac{1}{3}(30 - j159.3) = (10 - j53.1)\ \Omega = 54.03\angle -79.3^\circ\ \Omega$$

$$Z_1 = 20 + j37.7 = 42.67\angle 62.05^\circ\ \Omega$$

$$\therefore Z_{ph} = \frac{Z_1.Z_2'}{Z_1 + Z_2'} = \frac{54.03\angle -79.3^\circ \times 42.67\angle 62.05^\circ}{(20 + j37.7) + (10 - j53.1)}$$

$$= \frac{2305.46\angle -17.25^\circ}{30 - j15.4}$$

$$= \frac{2305.46\angle -17.25^\circ}{33.72\angle -27.17^\circ} = 68.37\angle 9.92^\circ\ \Omega$$

Given,

$$V_L = 398\,V, \quad \therefore V_{ph} = \frac{398}{\sqrt{3}} = 229.8V$$

$$\therefore I_{ph} = \frac{229.8}{68.37} = 3.36\,A.$$

$$\therefore I_L = I_{ph} = 3.36\,A.$$

$$\text{Power-factor} = \cos(9.92^\circ) = 0.985\ (\text{lag})$$

$$\therefore \quad \text{Power} = \sqrt{3} \times 398 \times 3.36 \times 0.985 = 2281.5\ W$$

$$\text{VAR} = \sqrt{3} \times 398 \times 3.36 \times \sin 9.92^\circ = 399\ \text{VAR}$$

Example – 4

A three-phase, star-connected alternator feeds a 2000 hp delta-connected induction motor having a power-factor of 0.85(lag) and an efficiency of 93%. Calculate the current and its active and reactive components in (a) each alternator phase, (b) each motor phase. The line voltage is 2200V.

Solution

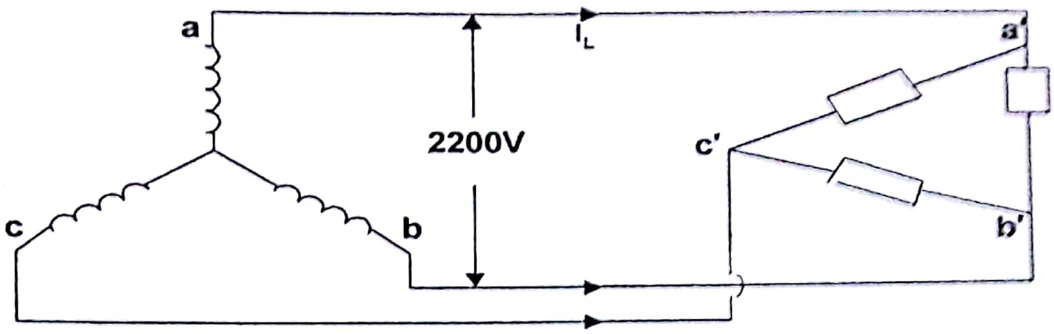


Fig.1.16

$$\text{Motor output} = 2000\,\text{hp} = 2000 \times 746 = 1492{,}000\ \text{W}$$

$$\therefore \text{Motor input} = \frac{1492{,}000}{0.93} = 1604301\ \text{W}$$

Given, $V_L = 2200\,\text{V}$ and $\cos\phi = 0.85$

$$\therefore I_L = \frac{1604301}{\sqrt{3} \times 2200 \times 0.85} = 495.3\,\text{A}$$

and $\phi = \cos^{-1} 0.85 = 31.79°$

$$\therefore I_L = 495.3\angle -31.79°\,\text{A}$$

Alternator :

$$I_{ph} = I_L = 495.3\angle -31.79°$$
$$= (421 - j260.93)\text{A}$$

Motor :

$$I_{ph} = \frac{I_L}{\sqrt{3}} = \frac{495.3}{\sqrt{3}}\angle -31.79°$$
$$= 285.96\angle -31.79°$$
$$= (243 - j150.65)\text{A}.$$