1. A 4-pole alternator has an armature with 25 slots and 8 conductors per slot and rotates at 1500 r.p.m. and the flux per pole is 0.05 Wb. Find the e.m.f. generated, if winding factor is 0.96 and all the conductors are in series.

Solution

Given : $P = 4$

Slots = 25

$$\text{Conductors / Slot} = 8$$

N=1500rpm

$$\text{Flux/Pole } (\phi) = 0.05\text{Wb}$$

K_w=0.96

Frequency

$$f = \frac{PN}{120}$$

$$f = \frac{4 \times 1500}{120} = 50Hz$$

Total number of conductor (Z)

$$\text{Z} = \frac{\text{Conductors}}{\text{Slot}} \times \text{Slots}$$

$$\text{Z} = 8 \times 25 = 200$$

Number of conductors per phase

Z_{ph}= 200/3

Number of turns per phase

N_{ph}= Z_{ph}/2 = 200/6

Emf induced per phase

E_f= K_w 4.44$f N_{ph}$ ϕ

$$Ef = \frac{0.96 \times 4.44 \times 50 \times 200 \times 0.05}{6} = 355.2\ kV$$

2. Determine the breadth and pitch factors for a 3-φ winding with two slots per pole per phase .The coil span is five-slot pitches. If the flux density wave in the air-gap consists of the fundamental and a 24% third harmonic , calculate the percentage increase in the r.m.s. value of phase voltage due to the harmonic.

<u>*Solution*</u>

Given slots / pole / phase or SPP(m) = 2

Coil Span = 5 Slots

Third harmonic flux density = 0.24 fundamental flux density

⇨ $\Phi_3 = 0.24\Phi_1$

Slots per pole = SPP×3 = 2×3=6

Slot angle (γ)

$$\gamma = Pole\ pitch\ /\ Slots\ per\ pole$$

$$\gamma = 180° / 6$$

$$\gamma = 30°$$

Short pitch angle (α)

$$\alpha = (Pole\ pitch - coil\ pitch) \times Slot\ angle$$

$$\alpha = (6-5) \times 30° = 30°$$

Pitch Factor of **fundamental** component (K_{p1})

$$K_P = \cos\frac{\alpha}{2} = \cos 15° = 0.966$$

Distribution Factor of **fundamental** component (K_{d1})

$$K_d = \frac{\sin\frac{m\gamma}{2}}{m\sin\frac{\gamma}{2}}$$

$$K_d = \frac{\sin\frac{2\times 30°}{2}}{2\sin\frac{30°}{2}}$$

$$K_d = \frac{\sin 30°}{2\times\sin 15°} = 0.966$$

Winding factor of fundamental component (K_{w1})

$$K_{w1}=K_{p1}\times K_{d1}$$

$$K_{w1}=0.966\times 0.966=0.93$$

Pitch Factor of **third harmonic** component (K_{p3})

$$K_{P3} = \cos\frac{3\alpha}{2} = \cos 45° = 0.707$$

Distribution Factor of **third harmonic** component (K_{d3})

$$K_{d3} = \frac{\sin\frac{m3\gamma}{2}}{m\sin\frac{3\gamma}{2}}$$

$$K_{d3} = \frac{\sin\frac{2\times 3\times 30°}{2}}{2\sin\frac{3\times 30°}{2}}$$

$$K_{d3} = \frac{\sin 90°}{2\times\sin 45°} = 0.707$$

Winding factor of **third harmonic** component (K_{w3})

$$K_{w3}=K_{p3}\times K_{d3}$$

$$K_{w3}=0.707\times 0.707=0.5$$

Pitch Factor of third harmonics component (K_{p3})

$$K_P = \cos\frac{\alpha}{2} = \cos\frac{\alpha}{2}$$

Fundamental component of RMS voltage

$$E_1 = K_{w1} 4.44\, f \text{ Nph } \Phi_1$$

$$E_1 = 0.93 \times 4.44\, f \text{ Nph } \Phi_1$$

$$E_1 = 4.13 f \text{ Nph } \Phi_1 = 4.13C \quad Volt$$

Third harmonics component of RMS voltage

$$E_3 = K_{w3} 4.44\, f \text{ Nph } \Phi 3$$

$$E_3 = 0.5 \times 4.44\, f \text{ Nph } \times 0.24\Phi_1$$

$$E_3 = 0.53 \text{Nph } \Phi_1 = 0.53C \quad Volt$$

Resultant RMS Voltage

$$E_R = \sqrt{{E_1}^2 + {E_3}^2}$$

$$E_R = \sqrt{(4.13C)^2 + (0.53C)^2} = \sqrt{17.34} = 4.16C \quad Volt$$

Percentage increase in the RMS value of phase voltage due to the harmonic

$$= \frac{E_R - E_1}{E_1} \times 100 = \frac{4.16C - 4.13C}{4.13C} \times 100$$

$$= \frac{0.03}{4.13} \times 100 = 0.726\,\%$$

3. A 3-phase, Y-connected synchronous generator rated at 10 KVA and 230 V has a synchronous reactance of 1.2 ohm per phase and an armature resistance of 0.5 ohm per phase. Calculate the % voltage regulation at full load with 0.8 lagging power factor.

Solution

Given : KVA (rated) = 1000kVA

Line Voltage (V_L) = 230V

X_s = 1.2 Ω/phase

R_a = 0.5 Ω/phase

p.f =0.8 (lagging)

Full load current (I_a)

$$\sqrt{3} \times V_L \times I_a = Rated\ KVA$$

$$\sqrt{3} \times 230 \times I_a = 1000 \times 10^3$$

$$I_a = 25.10\ A$$

Power factor angle (Φ)

$$\Phi = \cos^{-1} 0.8 = 36.87°$$

$$\boldsymbol{I_a} = 25.10\angle - 36.87°\ A$$

Excitation Emf ($\boldsymbol{E_f}$)

$$\boldsymbol{E_f} = \boldsymbol{V_t} + \boldsymbol{I_a}(\boldsymbol{R_a} + \boldsymbol{jX_s})$$

$$\boldsymbol{E_f} = \frac{230}{\sqrt{3}} + 25.10\angle - 36.87°(0.5 + j1.2)$$

$$\boldsymbol{E_f} = 147.85 + j20.08 = 149.2\angle 7.73°$$

Percentage Voltage regulation

$$= \frac{\boldsymbol{E_f} - \boldsymbol{V_t}}{\boldsymbol{V_t}} \times 100$$

$$= \frac{149.2 - 147.85}{147.85} \times 100 = 0.91\%$$

4. Two 3-ϕ, 6.6 kV, star-connected alternators supply a load of 3000 kw at 0.8 power factor lagging. The synchronous impedance per impedance per phase of machine *A* is 0.5+ j10Ω and of machine B is 0.4 + j12 Ω The excitation of machine A is adjusted so that it delivers 150 A at a lagging p.f. and the governors are so set that the load is shared equally between the machine. Determine the current, power factor, induced e.m.f. and load angle of each machine.

Solution

Given: V_t(Line)= 6600 kV
Load = 3000 kW

$$Z_{sA} = 0.5 + j10\ \Omega$$
$$Z_{sB} = 0.4 + j12\ \Omega$$
$$I_{aA} = 150\ \text{A}$$

For machine 1

$$\sqrt{3} \times 6.6 \times 10^3\ I_{aA} \cos \emptyset_A = \frac{1}{2} \times 3000 \times 10^3$$
$$\text{Cos}\,\emptyset_A = \frac{1500 \times 10^3}{\sqrt{3} \times 6.6 \times 10^3 \times 150} = 0.8748(lagging)$$
$$\emptyset_A = 28.98° \boldsymbol{I_{aA}} = I_{aA}\angle - \emptyset_A = 150\angle - 28.98°\ A$$

Total current

$$I = \frac{Load(kW)}{\sqrt{3}V_L cos\emptyset} = \frac{3000 \times 10^3}{\sqrt{3} \times 6.6 \times 10^3 \times 0.8} = 328A \boldsymbol{I} = I\angle - \emptyset$$
$$= 328\angle - \cos^{-1} 0.8 = 328\angle - 36.87°A$$

Now

$$\boldsymbol{I_{aB}} = \boldsymbol{I} - \boldsymbol{I_{aA}} \boldsymbol{I_{aB}} = 328\angle - 36.87° - 150\angle - 28.98°\ A$$
$$\boldsymbol{I_{aB}} = 180.6\angle - 43.14°A$$

Power factor of the second machine (B)

$$\text{Cos}\,\emptyset_B = \text{Cos} -43.14° = 0.7264\ (lagging)$$

(Given)

$$\boldsymbol{E_{fA}} = \boldsymbol{V_t} + \boldsymbol{I_{aA}} \boldsymbol{Z_{sA}}$$

$$\boldsymbol{E_{fA}} = \frac{6600}{\sqrt{3}} + (150\angle - 28.98°)(0.5 + j10)$$

$$\boldsymbol{E_{fA}} = 4776\angle 15.49°V$$

Load angle of machine A

$$\delta_A = 15.49°$$

$$\boldsymbol{E_{fB}} = \boldsymbol{V_t} + \boldsymbol{I_{aB}} \boldsymbol{Z_{sB}}$$

$$\boldsymbol{E_{fB}} = \frac{6600}{\sqrt{3}} + (180.6\angle -43.14°)(0.4 + j12)$$

$$\boldsymbol{E_{fB}} = 5560.2\angle 16°\ V$$

Load angle of machine B

$$\delta_B = 16°$$