Example 15.8. A 3-phase, 50 Hz, 20 pole salient pole alternator with star-connected stator winding has 180 slots on the stator. Each slot consists of 8 conductors. The flux per pole is 25 mWb and is sinusoidally distributed. The coils are full-pitched. Calculate (i) the speed of the alternator (ii) winding factor (iii) generated emf per phase and (iv) line voltage.

Solution:

$$\text{Flux per pole, } \Phi = 25 \text{ mWb} = 0.025 \text{ Wb}$$

$$\text{Frequency, } f = 50 \text{ Hz}$$

$$\text{Number of armature conductors, Z} = 180 \times 8 = 1{,}440$$

$$\text{Number of armature conductors per phase} = \frac{1{,}440}{3} = 480$$

$$\text{Number of turns per phase, T} = \frac{480}{2} = 240$$

Number of poles, P = 20

$$(i) \text{ Speed, N} = \frac{120\,f}{\text{P}} = \frac{120 \times 50}{20} = 300 \text{ rpm } \textbf{Ans.}$$

$$(ii) \text{ Number of slots per pole, } n = \frac{180}{20} = 9$$

Number of slots per pole per phase,

$$m = \frac{n}{\text{Number of phases}} = \frac{9}{3} = 3$$

Angular displacement between the slots,

$$\beta = \frac{180^\circ}{n} = \frac{180^\circ}{9} = 20^\circ \text{ (elec.)}$$

$$\text{Distribution factor, K}_d = \frac{\text{Sin}\dfrac{m\beta}{2}}{m\sin\dfrac{\beta}{2}} = \frac{\text{Sin}\dfrac{3 \times 20^\circ}{2}}{3\sin\dfrac{20^\circ}{2}} = \frac{\text{Sin } 30^\circ}{3 \sin 10^\circ} = 0.96$$

$$\text{Pitch factor, K}_p = 1 \qquad \because \text{Coils are full-pitched}$$

$$(ii) \text{ Winding factor, K}_\text{W} = \text{K}_d\,\text{K}_p = 0.96 \times 1 = 0.96 \quad \textbf{Ans.}$$

$$\begin{aligned}(iii) \text{ Generated emf per phase} &= 4.44\ \text{K}_d\,\text{K}_p\ \Phi f \text{T volts} \\ &= 4.44 \times 0.96 \times 1 \times 0.025 \times 50 \times 240 \\ &= 1.280 \text{ V } \textbf{Ans.}\end{aligned}$$

$$(iv) \text{ Line voltage, V}_\text{L} = \sqrt{3} \times 1{,}280 = 2{,}215 \text{ V } \textbf{Ans.}$$

Example 15.19. A 3-phase star-connected alternator is rated at 1,600 kVA, 13.5 kV. The per phase armature effective resistance and synchronous reactance are 1.5 Ω and 30 Ω respectively. Calculate voltage regulation for a load of 1.280 MW at power factors of (*i*) 0.8 leading (*ii*) unity and (*iii*) 0.8 lagging.

[U.P. Technical Univ. Electromechanical Energy Conversion-II, 2005-06]

Solution: Load, $P = 1.28$ MW

$$\text{Phase voltage, } V_P = \frac{V_L}{\sqrt{3}} = \frac{13.5 \times 1{,}000}{\sqrt{3}} = 7{,}794 \text{ V}$$

Effective resistance per phase, $R_e = 1.5\ \Omega$

Synchronous reactance per phase, $X_S = 30\ \Omega$

(*i*) At power factor 0.8 leading.

$$\text{Load current, } I = \frac{\text{Load in MW} \times 10^6}{\sqrt{3}\, V_L \cos\phi} = \frac{1.28 \times 10^6}{\sqrt{3} \times 13.5 \times 10^3 \times 0.8}$$

$$= 68.4 \text{ A}$$

Power factor, $\cos\phi = 0.8$

$$\text{Sin}\,\phi = \sqrt{1 - 0.8^2} = -0.6 \quad \text{minus sign for leading pf}$$

Open-circuit voltage per phase,

$$E_{OP} = \sqrt{(V_P \cos\phi + IR_e)^2 + (V_P \sin\phi + I X_S)^2}$$

$$= \sqrt{(7{,}794 \times 0.8 + 68.4 \times 1.5)^2 + [7{,}794 \times (-0.6) + 68.4 \times 30]^2}$$

$$= 6{,}860 \text{ V}$$

Percentage regulation

$$= \frac{E_{OP} - V_P}{V_P} \times 100 = \frac{6{,}860 - 7{,}794}{7{,}794} \times 100 = -\,11.98\ \%\ \textbf{Ans.}$$

(*ii*) At unity power factor

$$\text{Load current, } I = \frac{1.28 \times 10^6}{\sqrt{3} \times 13.5 \times 10^3 \times 1.0} = 54.74 \text{ A}$$

$$\text{Cos}\,\phi = 1.0 \text{ and } \sin\phi = 0$$

Open-circuit voltage per phase,

$$E_{OP} = \sqrt{(7{,}794 \times 1.0 + 54.74 \times 1.5)^2 + (7{,}794 \times 0 + 54.74 \times 30)^2}$$

$$= \sqrt{(7{,}794 + 82.11)^2 + (0 + 1{,}642.2)^2} = 8{,}045.5 \text{ V}$$

$$\text{Percentage regulation} = \frac{8{,}045.5 - 7{,}794}{7{,}794} \times 100 = 3.227\ \%\ \textbf{Ans.}$$

(*iii*) At power factor 0.8 lagging

Load current, $I = 68.4$ A, same as in case (*i*)

$$\text{Cos}\,\phi = 0.8 \text{ and } \sin\phi = 0.6$$

Open-circuit voltage per phase,

$$E_{OP} = \sqrt{(7{,}794 \times 0.8 + 68.4 \times 1.5)^2 + (7{,}794 \times 0.6 + 68.4 \times 30)^2}$$

$$= 9{,}243 \text{ V}$$

$$\text{Percentage regulation} = \frac{9{,}243 - 7{,}794}{7{,}794} \times 100 = 18.6\ \%\ \textbf{Ans.}$$

Example 15.28. A 2000 kVA, 11 kV, 3-phase star-connected alternator has a resistance of 0.3 ohm and reactance of 5 ohms per phase. It delivers full-load current at a pf of 0.8 lagging and normal rated voltage. Compute the terminal voltage for the same excitation and load current at a 0.8 pf leading.

[U.P.S.C. I.E.S. Electrical Engineering, 2000; U.P. Technical Univ. Electromechanical Energy Conversion, 2006-07]

Solution: Rated voltage per phase, $V = \dfrac{11 \times 1,000}{\sqrt{3}} = 6,350.85$ V

Full-load current,

$$I = \frac{\text{Rated kVA} \times 1,000}{\sqrt{3} \times V_L} = \frac{2,000 \times 1,000}{\sqrt{3} \times 11,000} = 104.97 \text{ A}$$

Power factor, $\cos\phi = 0.8$ (lagging) and $\sin\phi = 0.6$

Open-circuit voltage per phase,

$$E_0 = \sqrt{(V\cos\phi + IR_e)^2 + (V\sin\phi + IX_S)^2}$$

$$= \sqrt{\begin{matrix}(6,350.85 \times 0.8 + 104.97 \times 0.3)^2 \\ + (6,350.85 \times 0.6 + 104.97 \times 5)^2\end{matrix}} = 6,703 \text{ V}$$

When supplying same load current at 0.8 pf (leading) for the same excitation

$$E_0 = \sqrt{(V\cos\phi + IR_e)^2 + (V\sin\phi + IX_S)^2}$$

or $\quad 6,703 = \sqrt{(V \times 0.8 + 104.97 \times 0.3)^2 + [V \times (-0.6) + 104.97 \times 5]^2}$

or $\quad V = 6,978$ V

Terminal voltage (line-to-line)

$$= \sqrt{3} \times 6,978 = 12,086 \text{ V} \quad \text{or} \quad 12.086 \text{ kV} \quad \textbf{Ans.}$$