8-24 Repeat Problem 8-22 when the DFIG operates with 0.9829 pu rotor speed and stator power factor of 0.9 leading. The corresponding equivalent resistance *Req* and reactance *Xeq* for the rotor side converter are found to be 0.24546Ω and

Answers:

a) $T_m = -47311\ \text{N.m}$, $P_m = -5697\times10^3\ \text{W}$ b) $\bar{I}_s = 794.56\angle-205.84°\ \text{A (rms)}$, $\bar{I}_r = 960.63\angle138.58°\ \text{A (rms)}$

b) $V_{ds} = 2309.4\ \text{V (rms)}$, $V_{qs} = 0\ \text{V (rms)}$, $V_{dr} = -341.06\ \text{V (rms)}$, $V_{qr} = -30.17\ \text{V (rms)}$

c) $I_{ds} = -715.1\ \text{A (rms)}$, $I_{qs} = 346.34\ \text{A (rms)}$, $I_{dr} = -720.35\ \text{A (rms)}$, $I_{qr} = 635.53\ \text{A (rms)}$

d) $\Lambda_{ds} = -0.0296\ \text{Wb (rms)}$, $\Lambda_{qs} = -7.4122\ \text{Wb (rms)}$, $T_e = 47236\ \text{N.m}$

e) $P_s = -4954\times10^3\ \text{W}$, $Q_s = -2399\times10^3\ \text{VAR}$

8-25 (Solved Problem) Consider a 1.5MW/690V/50Hz/1750 rpm DFIG wind energy system operating with stator voltage oriented control (SVOC). Parameters of generator are given in Table B-5 of Appendix B. Generator operates with an MPPT scheme. Stator voltage *Vs* is kept at its rated value of $690/\sqrt{3}$ by stator voltage oriented controller. At a given wind & generator speed, the stator active and reactive powers *Ps* & *Qs* are found to be – 507.98 kW & 246.02 kVAR respectively. Calculate following:

a) *dq*-axis and rms stator and rotor currents,

b) *dq*-axis stator flux linkages,

c) generator mechanical torque and power,

d) rotor mechanical and electrical speeds and slip,

e) rms and *dq*-axis stator and rotor voltages, and

f) equivalent resistance and reactance for the rotor side converter.

Solution:

a) Stator active & reactive power of DFIG can be calculated by

$$P_s = \frac{3}{2} v_{ds} i_{ds} \text{ W}$$

$$Q_s = -\frac{3}{2} v_{ds} i_{qs} \text{ VAR}$$

From which peak *dq*-axis stator currents can be given by

$$i_{ds} = \frac{P_s}{1.5 \times v_{ds}} = \frac{-507.98 \times 10^3}{1.5 \times \sqrt{2} \times 690 / \sqrt{3}} = -601.11 \text{ A}$$

$$i_{qs} = \frac{-Q_s}{1.5 \times v_{ds}} = \frac{-246.02 \times 10^3}{1.5 \times \sqrt{2} \times 690 / \sqrt{3}} = -291.13 \text{ A}$$

From which the rms *dq*-axis stator currents can be given by

$$I_{ds} = i_{ds} / \sqrt{2} = -425.05 \text{ A (rms)}$$

$$I_{qs} = i_{qs} / \sqrt{2} = -205.86 \text{ A (rms)}$$

Stator current phasor can be calculated by

$$\bar{I}_s = (I_{ds} + jI_{qs}) = 472.28\angle -154.16^\circ \text{ A (rms)}$$

The stator power factor angle is:

$$\varphi_s = \angle \bar{V}_s - \angle \bar{I}_s = 0° - (-154.16°) = 154.16°$$

from which the stator power factor is

$$PF_s = \cos(154.16°) = 0.9 \text{ lagging}$$

The *dq*-axis rotor currents can be given by

$$i_{dr} = \frac{2L_s}{3v_{ds}L_m}P_s = \frac{2\times 5.6436\times 10^{-3}}{2\times 563.38\times 5.4749\times 10^{-3}}\times -507.981\times 10^{3} = -619.63\ \text{A (rms)}$$

$$i_{qr} = -\frac{2L_s}{3v_{ds}L_m}Q_s + \frac{v_{ds}}{\omega_s L_m} = -\frac{2\times 5.6436\times 10^{-3}}{2\times 563.38\times 5.4749\times 10^{-3}}\times 246.027\times 10^{3} + \frac{563.38}{100\pi\times 5.4749\times 10^{-3}} = 27.45\ \text{A (rms)}$$

From which the rms *dq*-axis rotor currents can be given by

$$I_{dr} = i_{dr}/\sqrt{2} = -438.15\ \text{A (rms)}$$

$$I_{qr} = i_{qr}/\sqrt{2} = 19.41\ \text{A (rms)}$$

Rotor current phasor can be calculated by

$$\bar{I}_r = (I_{dr} + jI_{qr}) = 438.58\angle 177.5° \text{ A (rms)}$$

b) The *dq*-axis stator flux linkages can be calculated by

$$\Lambda_{ds} = \frac{V_{qs} - R_s I_{qs}}{\omega_s} = 0.00174 \;\; \text{Wb (rms)}$$

$$\Lambda_{qs} = -\frac{V_{ds} - R_s I_{ds}}{\omega_s} = -1.2716 \;\; \text{Wb (rms)}$$

c) Electromagnetic torque developed by DFIG can be given by

$$T_e = T_m = \frac{3PL_m}{2\omega_s L_s} i_{dr} v_{ds} = -3233.2\,\mathrm{N.m}$$

Generator mechanical torque can be related to pu rotor speed as

$$T_m = T_{m,R} \times (\omega_{m,\mathrm{pu}})^2 \text{ N.m}$$

From which pu rotor speed can be calculated by

$$\omega_{m,\mathrm{pu}} = \sqrt{\frac{T_m}{T_{m,R}}} = \sqrt{\frac{-3233.2}{-8185}} = 0.6286$$

The rated mechanical power:

$$P_{m,R} = \omega_{m,R} \times T_{m,R} = 1750(2\pi)/60 \times (-8185) = -1500 \times 10^3 \text{ W}$$

The generator mechanical power at 0.6286pu rotor speed:

$$P_m = P_{m,R} \times (\omega_{m,\mathrm{pu}})^3 = -1500 \times 10^3 \times \left(0.6286\right)^3 = -372.52 \times 10^3 \text{ W}$$

d) The rotor mechanical and electrical speeds:

$$\omega_m = \omega_{m,R} \times \omega_{m,\text{pu}} = 1750(2\pi)/60 \times 0.6286 = 115.19 \text{ rad/sec} \quad (1100 \text{ rpm})$$

$$\omega_r = \omega_m \times P = 115.19 \times 2 = 230.38 \text{ rad/sec}$$

The slip can be calculated by:

$$s = (\omega_s - \omega_r) / \omega_s = (314.16 - 230.38) / 314.16 = 0.2667$$

e) The *dq*-axis stator voltages can be given by

$$V_{ds} = V_s = 398.37 \text{ V (rms)}$$

$$V_{qs} = 0 \text{ V (rms)}$$

The magnetizing branch voltage:

$$\overline{V}_m = \overline{V}_s - \overline{I}_s\left(R_s + j\omega_s L_{ls}\right) = 389.27\angle 3.4^\circ \ \text{V (rms)}$$

The rotor voltage:

$$\overline{V_r} = s\overline{V_m} - \bar{I}_r\left(R_r + js\omega_s L_{lr}\right) = 105.57\angle 5.99^\circ \ \text{V (rms)}$$

The *dq*-axis rotor voltages can be given by

$$V_{dr} = V_r \cos \angle V_r \ = 105.57 \times \cos(5.99°) = 104.99 \ \text{ V (rms)}$$

$$V_{qr} = V_r \sin \angle V_r \ = 105.57 \times \sin(5.99°) = 11.01 \ \text{ V (rms)}$$

f) The equivalent impedance for the rotor side converter is given by

$$\overline{Z}_{eq} = \overline{V}_r / \overline{I}_r = -0.23805 - j0.03567 \ \Omega$$

from which $R_{eq} = -0.23805 \ \Omega$ & $X_{eq} = -0.03567 \ \Omega$

Cross Check:

$$P_s = 3V_s I_s \cos\varphi_s = 3\times 398.37\times 472.28\times \cos(154.16°) = -507.992\times 10^3 \text{ W}$$

$$Q_s = 3V_s I_s \sin\varphi_s = 3\times 398.37\times 472.28\times \sin(154.16°) = 246.011\times 10^3 \text{ VAR}$$

8-26 Repeat Problem 8-25 if stator active & reactive powers *Ps* and *Qs* are –822.85 kW & 270.46 kVAR respectively.

Answers:

a) $I_{ds} = -688.51$ A (rms), $I_{qs} = -226.3$ A (rms), $\bar{I}_s = 724.75\angle -161.8°$ A (rms), $I_{dr} = -709.72$ A (rms),

$I_{qr} = -1.66$ A (rms), $\bar{I}_r = 709.72\angle -179.87°$ A (rms) b) $\Lambda_{ds} = 0.0019$ Wb (rms), $\Lambda_{qs} = -1.2739$ Wb (rms)

c) $T_m = -5238.4$ N.m, $P_m = -767.99 \times 10^3$ W

d) $\omega_m = 146.61$ rad/sec (1400 rpm), $\omega_r = 293.22$ rad/sec, $s = 0.0667$

e) $V_{ds} = 398.37$ V (rms), $V_{qs} = 0$ V (rms), $V_{dr} = 27.74$ V (rms), $V_{qr} = 4.46$ V (rms)

f) $R_{eq} = -0.03910\ \Omega$, $X_{eq} = -0.00620\ \Omega$

8-27 Repeat Problem 8-25 if stator active & reactive powers *Ps* & *Qs* are –1213.28 kW & –587.62kVAR respectively.

Answers:

a) $I_{ds} = -1015.2\ \text{A (rms)}$, $I_{qs} = 491.68\ \text{A (rms)}$, $\bar{I}_s = 1128\angle -205.84°\ \text{A (rms)}$, $I_{dr} = -1046.48\ \text{A (rms)}$, $I_{qr} = 738.45\ \text{A (rms)}$, $\bar{I}_r = 1280.7\angle 144.8°\ \text{A (rms)}$

b) $\Lambda_{ds} = -0.00415\ \text{Wb (rms)}$, $\Lambda_{qs} = -1.2766\ \text{Wb (rms)}$

c) $T_m = -7723.97\ \text{N.m}$, $P_m = -1375.05 \times 10^3\ \text{W}$

d) $\omega_m = 178.02\ \text{rad/sec}$ (1700 rpm), $\omega_r = 356.04\ \text{rad/sec}$, $s = -0.133$

e) $V_{ds} = 398.37\ \text{V (rms)}$, $V_{qs} = 0\ \text{V (rms)}$, $V_{dr} = -58.33\ \text{V (rms)}$, $V_{qr} = -14.8\ \text{V (rms)}$

f) $R_{eq} = 0.03055\ \Omega$, $X_{eq} = 0.03570\ \Omega$