

EE3124 Test 2 with Solutions

Name:

Student No.:

Q1 – What are the differences between brushless DC (BLDC) and Synchronous AC Motors? And briefly introduce the advantages of BLDC. (20 pts)

Solution

Any reasonable five key points can have full scores.

Basis of Difference	BLDC Motor	PMSM Motor
Full form	BLDC Motor is the abbreviated name for Brushless Direct Current Motor.	PMSM stands for Permanent Magnet Synchronous Motor.
Definition	A BLDC motor is an electronically commutated DC motor which does not have carbon brushes and commutator assembly.	A PMSM motor is an AC synchronous motor that uses permanent magnets to provide the necessary field excitation.
Type of motor	BLDC motor is a direct current (DC) motor.	PMSM motor is an alternating current (AC) motor.
Waveform of back emf	The waveform of back emf of a BLDC motor is trapezoidal shaped.	The waveform of back emf of a PMSM motor is sinusoidal shaped.
Torque	The torque produced by a BLDC motor is comparatively lower.	A PMSM motor produces higher torque as compared to BLDC motor.
Efficiency	The efficiency of a BLDC motor is less, around 85% to 90%.	PMSM motors are comparatively more efficient. The typical efficiency is about 92% to 97%
Switching losses	At same switching frequency, a BLDC motor has less switching losses.	The switching losses in a PMSM motor are high.
Core losses	BLDC motor has high core losses because of harmonics.	The core losses are less in a PMSM motor due to less harmonic content.
Torque ripple	In BLDC motors, the torque ripples present at the commutation.	There is no torque ripple at the commutation in case of PMSM motor.
Control algorithm	BLDC motor uses comparatively simple control algorithms.	The control algorithms used in PMSM motors are complex and mathematically intensive.
Cost	The BLDC motor is comparatively less expensive.	The cost of PMSM motor is high.
Applications	BLDC motors are used in hard drives, CD/DVD drives, washing machines, fans, pumps, robotics, etc.	PMSM motors are used in servo drives, traction control, robotics, aerospace, power factor improvement, machine tools, etc.

Advantages of BLDC Motor

- Better speed versus torque characteristics
- High dynamic response
- High efficiency
- Long operating life
- Noiseless operation
- Higher speed ranges
- Ratio of torque to size of the motor is higher

Applications

Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation.

Q2 – A 100-MVA, 14.4-kV, 0.8-PF-lagging, 50-Hz, two-pole, Y-connected synchronous generator has a synchronous reactance of $2.281 \, \Omega$ and an armature resistance of $0.0228 \, \Omega$.

(a) What is the magnitude of the internal generated voltage E_A at the rated conditions? What is its torque angle δ at these conditions? (10 pts)

(b) Ignoring losses in this generator, what torque must be applied to its shaft by the prime mover at full load? (10 pts)

Solution

(a) The rated armature current is

$$I_A = I_L = \frac{S}{\sqrt{3} V_T} = \frac{100 \text{ MVA}}{\sqrt{3} (14.4 \text{ kV})} = 4009 \text{ A}$$

The power factor is 0.8 lagging, so $\mathbf{I}_A = 4009 \angle -36.87^\circ \text{ A}$. Therefore, the internal generated voltage is

$$\mathbf{E}_A = \mathbf{V}_\phi + R_A \mathbf{I}_A + jX_S \mathbf{I}_A$$

$$\mathbf{E}_A = 8314 \angle 0^\circ + (0.0228 \, \Omega)(4009 \angle -36.87^\circ \text{ A}) + j(2.281 \, \Omega)(4009 \angle -36.87^\circ \text{ A})$$

$$\mathbf{E}_A = 15,660 \angle 27.6^\circ \text{ V}$$

Therefore, the magnitude of the internal generated voltage $E_A = 15,660 \text{ V}$, and the torque angle $\delta = 27.6^\circ$.

(b) Ignoring losses, the input power would equal the output power. Since

$$P_{\text{OUT}} = (0.8)(100 \text{ MVA}) = 80 \text{ MW}$$

and

$$n_{\text{sync}} = \frac{120 f_{se}}{P} = \frac{120(50 \text{ Hz})}{2} = 3000 \text{ r/min}$$

the applied torque would be

$$\tau_{\text{app}} = \tau_{\text{ind}} = \frac{80,000,000 \text{ W}}{(3000 \text{ r/min})(2\pi \text{ rad/r})(1 \text{ min}/60 \text{ s})} = 254,700 \text{ N} \cdot \text{m}$$

Q3 – A 380-V three-phase eight-pole 60-Hz induction motor is running at a slip of 2.5 percent. Find:

(a) The speed of the magnetic fields in revolutions per minute; (5 pts)

(b) The speed of the rotor in revolutions per minute; (5 pts)

(c) The slip speed of the rotor; (5 pts)

(d) The rotor frequency in hertz. (5 pts)

Solution

Refer to Tutorial 6 - Induction motor Q3

Q4 – A 460-V 60-Hz four-pole Y-connected induction motor is rated at 25 hp. The equivalent circuit parameters are

$$R_1 = 0.15$$

$$R_2 = 0.154$$

$$X_M = 20$$

$$X_1 = 0.852$$

$$X_2 = 1.066$$

$$P_{F\&W} = 400 \text{ W}$$

$$P_{misc} = 150 \text{ W}$$

$$P_{core} = 400 \text{ W}$$

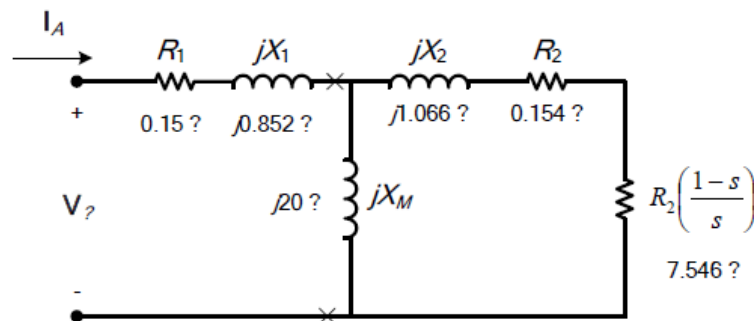
For a slip of 0.02, find

- The line current I_L
- The stator power factor
- The rotor power factor
- The rotor frequency
- The stator copper losses P_{SCL}
- The air-gap power P_{AG}
- The power converted from electrical to mechanical form P_{conv}
- The induced torque τ_{ind}
- The load torque τ_{load}
- The overall machine efficiency
- The motor speed in revolutions per minute and radians per second

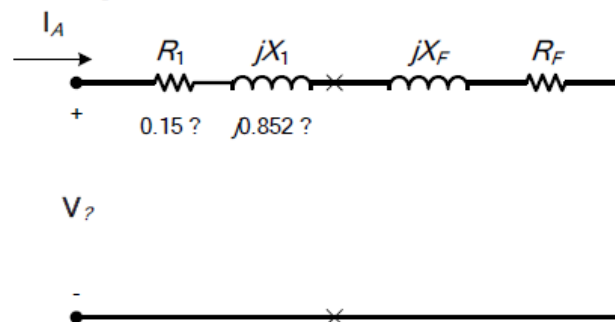
(Any correct 8 answers will have full score)

(40 pts)

Solution



(a) The easiest way to find the line current (or armature current) is to get the equivalent impedance Z_F of the rotor circuit in parallel with jX_M , and then calculate the current as the phase voltage divided by the sum of the series impedances, as shown below.



The equivalent impedance of the rotor circuit in parallel with jX_M is:

$$Z_F = \frac{1}{\frac{1}{jX_M} + \frac{1}{Z_2}} = \frac{1}{\frac{1}{j20 \Omega} + \frac{1}{7.70 + j1.066}} = 6.123 + j3.25 = 6.932 \angle 28.0^\circ \Omega$$

The phase voltage is $460/\sqrt{3} = 266$ V, so line current I_L is

$$I_L = I_A = \frac{V_\phi}{R_1 + jX_1 + R_F + jX_F} = \frac{266 \angle 0^\circ \text{ V}}{0.15 \Omega + j0.852 \Omega + 6.123 \Omega + j3.25 \Omega}$$

$$I_L = I_A = 35.5 \angle -33.2^\circ \text{ A}$$

(b) The stator power factor is

$$\text{PF} = \cos(33.2^\circ) = 0.837 \text{ lagging}$$

(c) To find the rotor power factor, we must find the impedance angle of the rotor

$$\theta_R = \tan^{-1} \frac{X_2}{R_2 / s} = \tan^{-1} \frac{1.066}{7.70} = 7.88^\circ$$

(d) The rotor frequency is

$$f_r = sf_s = (0.02)(60 \text{ Hz}) = 1.2 \text{ Hz}$$

Therefore the rotor power factor is

$$\text{PF}_R = \cos 7.88^\circ = 0.991 \text{ lagging}$$

(e) The stator copper losses are

$$P_{\text{SCL}} = 3I_A^2 R_1 = 3(35.5 \text{ A})^2 (0.15 \Omega) = 567 \text{ W}$$

(f) The air gap power is $P_{\text{AG}} = 3I_2^2 \frac{R_2}{s} = 3I_A^2 R_F$

OR another simple solution by using the power flow $P_{\text{AG}} = P_{\text{in}} - P_{\text{SCL}} - P_{\text{core}}$

$$P_{\text{AG}} = \sqrt{3} V_T I_L \cos \theta - P_{\text{SCL}} - P_{\text{core}}$$

$$= 23.67 - 0.4 - 0.567 \text{ kW}$$

$$= 22.7 \text{ kW}$$

(g) The power converted from electrical to mechanical form is

$$P_{\text{conv}} = (1 - s) P_{\text{AG}} = 0.98 * 22.7 \text{ kW} = 22.25 \text{ kW}$$

(h) The synchronous speed of this motor is

$$n_{\text{sync}} = \frac{120 f_s}{P} = \frac{120 (60 \text{ Hz})}{4} = 1800 \text{ r/min}$$

$$\omega_{\text{sync}} = (1800 \text{ r/min}) \left(\frac{2\pi \text{ rad}}{1 \text{ r}} \right) \left(\frac{1 \text{ min}}{60 \text{ s}} \right) = 188.5 \text{ rad/s}$$

Therefore the induced torque in the motor is

$$\tau_{\text{ind}} = \frac{P_{\text{AG}}}{\omega_{\text{sync}}} = \frac{22.7 \text{ kW}}{(1800 \text{ r/min}) \left(\frac{2\pi \text{ rad}}{1 \text{ r}} \right) \left(\frac{1 \text{ min}}{60 \text{ s}} \right)} = 120.4 \text{ Nm}$$

(i) The output power of this motor is

$$P_{\text{OUT}} = P_{\text{conv}} - P_{\text{mech}} - P_{\text{misc}} = 22.25 - 0.15 - 0.4 \text{ kW} = 21.74 \text{ kW}$$

The output speed is

$$n_m = (1 - s) n_{\text{sync}} = (1 - 0.02) (1800 \text{ r/min}) = 1764 \text{ r/min}$$

Therefore the load torque is

$$\tau_{\text{load}} = \frac{P_{\text{OUT}}}{\omega_m} = \frac{21.74 \text{ kW}}{(1764 \text{ r/min}) \left(\frac{2\pi \text{ rad}}{1 \text{ r}} \right) \left(\frac{1 \text{ min}}{60 \text{ s}} \right)} = 117.7 \text{ N} \cdot \text{m}$$

(j) The overall efficiency is

$$\eta = \frac{P_{\text{OUT}}}{P_{\text{IN}}} \times 100\% = \frac{P_{\text{OUT}}}{3V_{\phi} I_A \cos \theta} \times 100\%$$

$$\eta = \frac{21.74 \text{ kW}}{3(266 \text{ V})(35.5 \text{ A}) \cos(33.2^\circ)} \times 100\% = 91.7\%$$

(k) The motor speed in revolutions per minute is 1764 r/min. The motor speed in radians per second is

$$\omega_m = (1764 \text{ r/min}) \left(\frac{2\pi \text{ rad}}{1 \text{ r}} \right) \left(\frac{1 \text{ min}}{60 \text{ s}} \right) = 184.7 \text{ rad/s}$$