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9.12 DISCUSSION QUESTIONS

1. A PM synchronous motor can also be realized with permanent magnets on the stator and armature windings on the rotor. Discuss its merits and demerits compared to a PMSM with magnets on the rotor.
2. A cage rotor with PMs (called a *line-start PM synchronous motor*) can be used to start the motor as an induction motor and run it as a synchronous machine at utility frequency. Such an arrangement will improve the efficiency of the motor in comparison to induction motors. Discuss its construction, detailed operation, and possible applications.
3. The line-start PMSMs can also be operated from an inverter. In that case, the cage rotor will act as damper windings to damp out oscillations and, in case of loss of synchronization, the machine can run as an induction motor without disrupting the motion. Discuss an application scenario for such a motor drive. (Hint: High-reliability propulsion applications.)
4. Synchronous machines with surface-mount magnets have very little difference between direct-axis and quadrature-axis inductances. Explain why.
5. Interior PMSMs are preferred for high L_q/L_d ratios. Where would such a feature find application?
6. If the rotor is made salient with neither windings nor PMs, then the machine is a synchronous-reluctance motor. Its stator is that of the conventional PM synchronous motor. Due to its difference in quadrature- and direct-axis path reluctances, a torque is produced for an armature excitation. Since its field excitation is not from PMs, it must come from stator excitation. Since the inverter gets only active power from the dc link, where will the reactive power be generated for the excitation of the machine?
7. For equal power rating of the synchronous reluctance and PM synchronous motor, will the ratings of their inverters be equal? Explain.

8. Is L_q greater than L_d in the wound-rotor salient-pole synchronous machine?
9. What is the consequence of $L_q > L_d$ in control of the PMSM? (Hint: Consider maximum torque generated per unit input current.)
10. High-speed PMSMs have the rotor enclosed in a stainless sleeve to restrain the magnets against centrifugal forces. Ideally, will there be losses in the sleeve?
11. If the stator currents are sinusoids at fundamental frequency superposed with harmonics, will there be losses in the magnet sleeves? If there are losses, will they increase with rotor speed?
12. Injecting ac rectangular currents into PMSM is used in low-performance applications. Give reasons for such a control strategy and discuss the disadvantages of this control.
13. Torque pulsation is one of the measures for evaluating the suitability of a motor drive for an application. For a critical application requiring minimum torque pulsation, which is a suitable candidate between PMSM and PMBDCM drive?
14. A large number of control strategies have been developed and discussed for PMSM drives. Consider a four-quadrant application requiring speed variation to a maximum of base speed only. Which control strategy will be ideal, based on each one of the following considerations?
    (i) Simplicity in implementation.
    (ii) Maximum utilization of the inverter or minimum rating of the inverter.
    (iii) Optimal output of the machine.
    (iv) Optimal voltage utilization of the inverter and machine.
15. For implementation of any control strategy, a mapping from the torque and flux commands to the stator current and torque angle has to be performed. Is it a good choice to recommend on-line computation for this mapping? If so, justify it in the context of present computational capability available with processors.
16. A look-up-table implementation is considered for the control of a PMSM and PMBDCM drive system. Discuss the merits and demerits of the performance obtained with this implementation. Relate the bit resolution and accuracy in stator current and torque with the memory requirement for the implementation for each motor drive.
17. The inner current-control loops can use stator currents in stator or rotor reference frames. Discuss the merits and demerits of using each of the reference frame currents for current-feedback control.
18. An interior PMSM is completely demagnetized by injecting a negative *d* axis current. What is the magnitude of stator current to achieve demagnetization?
19. An interior PMSM is completely demagnetized by injecting a negative *d* axis current. Assume also a *q* axis stator current in the machine during this operation. Determine the electromagnetic torque generated in the machine.
20. Can magnet flux linkages be reduced by stator currents?
21. Can magnet flux linkages be increased by stator currents?
22. Air gap flux linkage is varied for flux-weakening. Will this affect the stator flux linkages?
23. Discuss the effects of losing control over *d* axis current in the high-speed operational region in a PMSM.
24. What are the salient differences between the maximum-torque-per-ampere strategy and the constant-mutual-flux-linkages strategy?
25. Including the effects of core losses in the formulation of control strategy is desirable. How can it be achieved?

26. Core losses are constant in one of the following schemes for constant-speed but variable-torque operation in a PMSM drive:
    (i) maximum-torque-per-ampere control;
    (ii) constant-flux-linkages control;
    (iii) constant-torque-angle control.

    Identify the control strategy that gives constant core losses.
27. Propose a method of measurement for L_d and L_q of a PMSM, using the model developed in the text. {Hint: (i) Connect two phases together in a star-connected machine. (ii) Lock the rotor for each measurement.}
28. Almost all flux-weakening control schemes are dependent on machine parameters. Is there a control method to weaken the flux independent of machine parameters? If so, how can it be achieved?
29. Is flux-weakening possible in surface-mount-magnet machines?
30. Discuss a discrete-IC-chip-based implementation of a PMSM-drive constant-torque-angle control strategy.
31. Is it possible to implement other control strategies with discrete IC chips?
32. Why are processor-based implementations popular, and what are their advantages over discrete-IC-chip-based implementations?
33. Parameter sensitivity of PMSM has been discussed in this chapter. Can the state of the rotor magnet flux linkages be used to approximately predict stator temperature? If so, justify it with reasoning.
34. How critical is it to have parameter adaptation for a torque-controlled PMSM drive?
35. In the flux-weakening region, eventually the current loops saturate and six-step voltage operation will result. Discuss the effects of such an operation.
36. "Resorting to six-step operation in the flux-weakening region will give an enhanced torque-vs.-speed characteristic compared to the current-controlled operating region." Is this true? Develop a justification.
37. Sensorless operation is desirable. Enumerate the reasons and explain them.
38. Starting with precision from any rotor position without position transducers is difficult with many of the sensorless control algorithms. Explain the underlying reason for this statement.
39. The direct-axis self-inductance of the PMSM in stator reference frames can be modeled as $L_d^s = L_1 + L_2 \cos 2\theta_r$. Could this information be used to identify the rotor position, θ_r? {Hint: Ref. [21].}
40. A voltage-source PWM inverter applies a fundamental and a number of higher-order harmonics into a PMSM. The dominant-harmonic current can be detected, from which the inductance can be calculated. This is achievable, because the harmonic inductive voltage drops are dominant compared to the resistive voltage drops. From inductances, the instantaneous rotor position can be extracted for control. The following steps are involved in the detection algorithm:

$$v_h = L\frac{di_h}{dt}$$

$$L = \begin{bmatrix} L_0 + L_1 \cos 2\theta_r & L_1 \sin 2\theta_r \\ L_1 \sin 2\theta_r & L_0 - L_1 \cos 2\theta_r \end{bmatrix}$$

where $v_h = [v_{qsh} \quad v_{dsh}]^T$ and $i_h = [i_{qsh} \quad i_{dsh}]^T$.

v_h is the stator *qd* axis harmonic-voltages vector, and i_h is the stator *qd* axis harmonic-current vector. By measuring v_h and i_h and by using the inductances of the machine, θ_r can be estimated. What is the difference between this method and the one given in discussion question 39? {Hint: Ref. [22].}

41. A sensorless-control algorithm injects a voltage signal at high frequency into the *d* axis of the PMSM. The current response is correlated with the rotor position by using machine-model-based current estimation. From the rotor position, rotor speed is derived. Compare this method with the method described in discussion questions 39 and 40. {Hint: Ref. [23].}
42. What is the effect of parameter sensitivity on the sensorless methods described in discussion questions 39, 40 and 41?
43. The mutual flux linkage increases with stator current. Will this saturate the stator core?
44. In PMBDCM, the induced emfs might not be exactly trapezoidal. What can cause their distortion?
45. "PMBDCMs have surface-mounted magnets." Is this true?
46. Considering fundamentals of voltages and currents only, the operation of PMBDCM and PMSM is similar. Is this true? If so, justify.
47. Commutation-torque ripple poses a serious problem (i) only at low speeds, (ii) only at high speeds, or (iii) at all speeds. Which is true?
48. Phase advancing in PMBDCM is equivalent to flux-weakening in PMSM to enable high-speed operation. What are the factors limiting the advance angle?
49. Torque-smoothing is feasible if the flux-density waveforms are known as a function of rotor position. If they are not known, how can torque-smoothing be accomplished?
50. In order to increase the high-speed operational region in PMBDCM, phase voltages are applied up until 150 degrees. How does this enable higher speed of operation?
51. Sensorless-control methods in PMBDCM are mainly induced-emf-based. Are the sensorless methods of PMSM applicable to PMBDCMs?
52. Rotor magnet sensitivity to temperature is significant in PMBDCMs. How can it be compensated for? Why does it need to be compensated for?
53. "Half-wave controlled PMBDCMs can deliver 4-quadrant operation." Is it true?
54. Why consider half-wave operation of PMBDCMs as against full-wave-controlled PMBDCMs?
55. "Half-wave operation of PMBDCMs transfers the power-device losses to the machine-armature losses." Is this statement, in general, true?
56. Half-wave operation of PMBDCMs underutilizes the machine. How can that be corrected?
57. In cost considerations of the PMBDCM drive, which one of the following alternatives is to be aimed for?
    (i) Lowering motor cost only;
    (ii) Lowering converter and controller cost only;
    (iii) Lowering the total system cost, i.e., (i) and (ii) combined.
58. Some of the PMBDCM half-wave converters are in use with switched-reluctance motor drives. A certain industrial firm manufacturing both these motor drives can achieve cost efficiency by using the same half-wave converter for both. How can this statement be justified?

59. All the half-wave converters for PMBDCMs are shoot-through-failure-proof. Justify this statement.
60. For better utilization of the PMBDCM with half-wave operation, the windings will have a larger number of turns. If the fill factor of the slots is a constant for both the half-wave and full-wave PMBDCMs, enumerate the consequences of increasing the number of turns in the half-wave PMBDCM.

9.13 EXERCISE PROBLEMS

1. (i) For a PMSM, derive the normalized machine equations assuming

$$\lambda_b = \lambda_{af}, \quad L_b = L_d, \quad I_b = \frac{\lambda_b}{L_b}, \quad \rho = \frac{L_q}{L_d}$$

(ii) What is the advantage of this normalization basis?

2. Prove that maximizing the mutual flux linkages with respect to stator current phasor results in

$$I_{sn} = \frac{-\cos\delta}{\cos^2\delta + \rho^2\sin^2\delta}$$

and that electromagnetic torque is,

$$T_{en} = \frac{-\rho^2\cos\delta\sin\delta(\cos^2\delta + \rho\sin^2\delta)}{(\cos^2\delta + \rho^2\sin^2\delta)^2}$$

Use the normalized model derived in problem 1(i).

3. Will the strategy given in problem 2 yield a better performance than the maximum-torque-per-ampere strategy? Compare the strategies by using the machine parameters used throughout the text. {Hint: Compute δ from the torque equation, and then I_{sn} in the above.}
4. Using the model in problem 1, find the torque and mutual flux linkages developed by using the maximum-torque-per-unit-current and torque-for-constant-mutual-flux-linkages strategy with mutual flux linkages fixed at 1 p.u. The parameter of the machine: P = 2, and resistance can be neglected. What is the base speed in each case for these operating points? Assume base voltage is 1 p.u.
5. The parameters of a star-connected, 6-pole, 1.5-kW, 9.2-A, 1500-rpm, 9.55-N·m, 3-phase PMSM are as follows:

$R_s = 0.513\ \Omega$, $L_d = 4.74$ mH, $L_q = 9.51$ mH, $B_l = 9.36 \times 10^{-4}$ N·m/(rad/sec),
$J = 0.01$ kg-m^2, Emf constant = 0.0669 V/rpm. Inverter input voltage = 285 V.

(i) Determine the maximum speed of the PMSM drive system.
(ii) Without exceeding the stator rated current and inverter input voltage, what is the maximum speed at which rated power is delivered?

The stator resistive drop can be neglected in the calculations for (ii), and the maximum stator-phase peak voltage obtained through the inverter is 55% of the dc-link voltage.