The University Of Sheffield.

Data Provided: Slot diagram sheet for Q1 and Q3 (to be submitted with answer book)

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2014-15 (3.0 hours)

EEE6200 AC Machines

Answer **FOUR** questions. **No marks will be awarded for solutions to a fifth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. A 2-pole, 3-phase AC synchronous machine stator has 18 slots. It is equipped with a double-layer, integral slot winding with a coil span of 7 slots.

a. Complete the slot diagram provided to show the layout of this winding, taking care to indicate the direction of the winding in each section of each slot (e.g. by using upper and lower case, plus and minus signs etc). Ensure that you attach your completed slot diagram to your answer book. **(4)**

b. Draw in your answer book a phasor diagram **<u>to scale</u>** for phase A only for this winding arrangement, taking care to label each individual phasor with the appropriate slot number. (Suggested scale of 1cm for each individual phasor) **(5)**

c. Calculate the overall winding factor for the fundamental and the 5th harmonic and compare the magnitude of the fundamental winding factor with the value that could be obtained from appropriate measurement of your phasor diagram in part (b). **(5)**

d. In order to reduce the cost of the machine for a particular application, the manufacturer decides to re design the winding for the same 18 slot stator core such that it now has a single-layer winding. Complete the slot diagram provided to show the layout of this winding, again taking care to indicate the direction of the winding in each section of each slot (e.g. by using upper and lower case, plus and minus signs etc). Ensure that you attach your completed slot diagram to your answer book. **(3)**

e. Calculate the overall winding factor for the fundamental and the 5^{th} harmonic for this single-layer winding and hence comment on any changes that might be expected in machine performance. **(3)**

2. A three-phase, star-connected, 6-pole synchronous generator supplies power to a network at 3.3kVrms (line to line voltage). Figures 1.1 shows the measured short circuit characteristics for one phase of the machine. The machine has a measured synchronous reactance per phase of magnitude 5.5Ω.

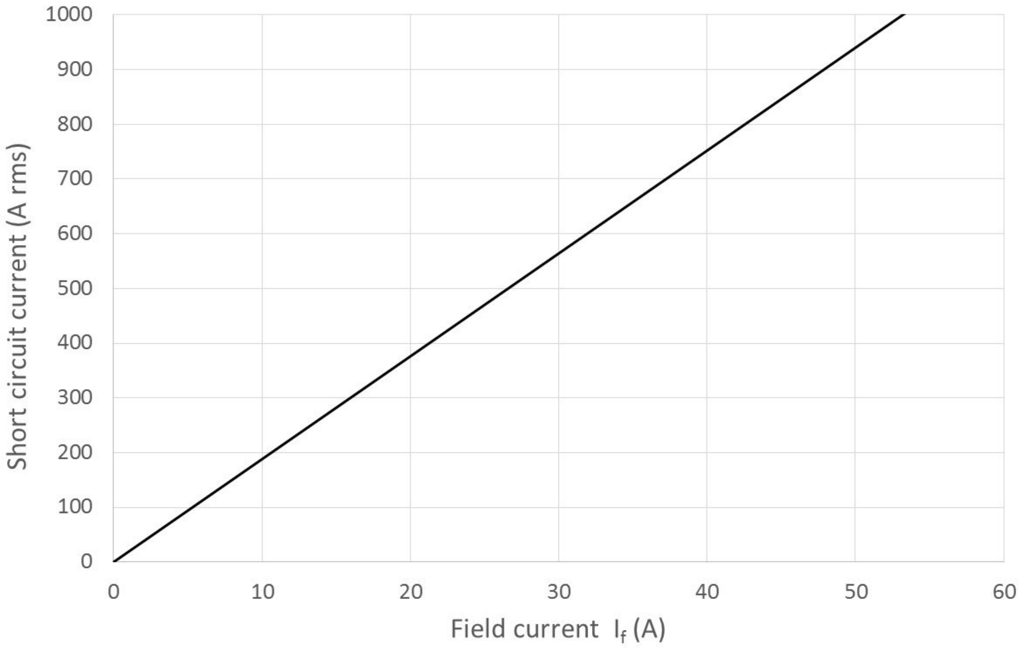

Figure 1.1 Measured short-circuit characteristics for one phase

a. The generator supplies a power of 1.2MW to the network at a lagging power of 0.92. Calculate the load angle and the excitation current (I_f) at this operating point. **(7)**

b. The load on the generator is then increased in a step-change manner to 2.1MW with the same field current. Listing any assumptions that you make, determine by appropriate calculations, whether the generator remains stable or loses synchronism. **(5)**

c. Calculate the maximum value of the load angle achieved during this transient change in load. **(5)**

d. Briefly describe one practical means that is employed to prevent continuous oscillation of the rotor around its new load angle when a change of load is applied, and explain the principles on which it operates in term of energy transfer. **(3)**

3. A small 3-phase, 6-pole synchronous generator is equipped with a single-layer, integral slot stator winding in an 18 slot stator core. The machine has the following design features:

- A stator bore diameter of 250mm.
- Stator tooth pitch to slot pitch ratio of 0.85.
- Each stator slot contains 100 series connected conductors.
- A rotor outer diameter of 248mm.
- 6 rotor slots
- Rotor tooth pitch to slot pitch ratio of 0.92
- Stator and rotor axial length of 300mm.

a. Complete the slot diagram provided to show the layout of this winding, taking care to indicate the direction of the winding in each section of each slot (e.g. by using upper and lower case, plus and minus signs etc). Ensure that you attach your completed slot diagram to your answer book. **(3)**

b. By taking account of stator and rotor slotting, calculate the equivalent magnetic airgap of the generator. **(5)**

c. Calculate the average magnitude of the airgap flux density when the **<u>rotor</u>** winding is excited at a level equivalent to an mmf in each rotor slot of 1500 A.turns. **(3)**

d. Using the flux density calculated in part (c) calculate the peak stator flux-linkage in one phase of the generator for this rotor excitation condition. **(3)**

e. Calculate the self-inductance of one **<u>stator</u>** phase assuming that the appropriate flux-linkage is dominated by the component of flux crossing the airgap to the rotor. **(4)**

f. List any other components of flux-linkage that could be added into your calculation to establish a more accurate estimate of the generator stator self-inductance. **(2)**

4. The torque produced by a 3-phase AC synchronous reluctance motor with p pole-pairs can be expressed within a d-q axis frame by:

$$T = \frac{3}{2}p\left(\psi_d i_q - \psi_q i_d\right)$$

a. Starting from the above equation, derive an expression for the torque as a function of the angle, δ, between the net current phasor and the d-axis **(5)**

Figure 4.1 shows the variation in d-axis self-inductance of one phase as a function of d-axis current for a particular motor with $p = 2$. The q-axis self-inductance, L_q, is not affected to any significant degree by saturation for values of I_q up to 20 Arms and can be reasonably considered to have a fixed value of 0.028 H.

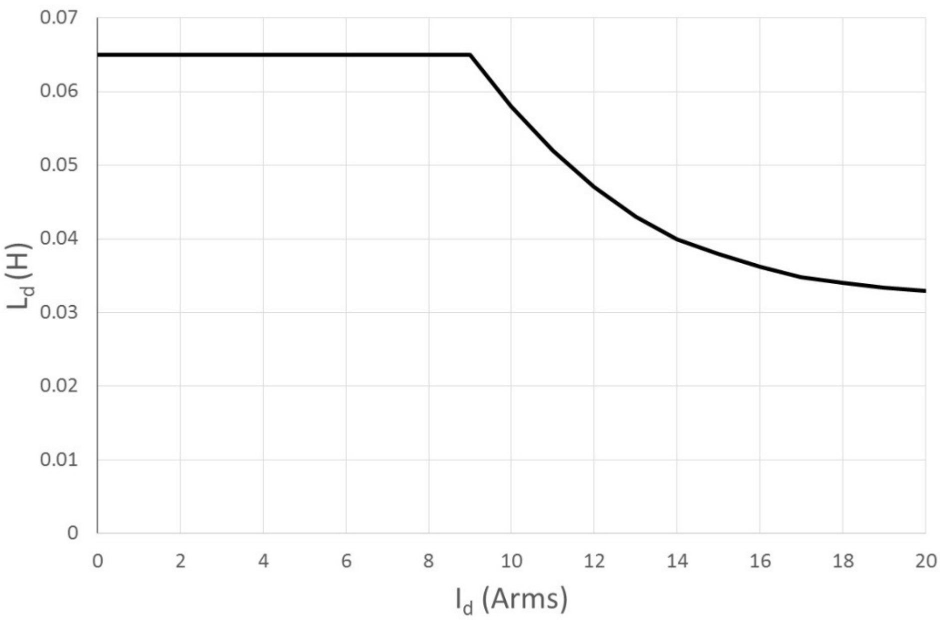

Figure 4.1 Variation in d-axis self-inductance for one phase of the machine as a function of d-axis current

b. Calculate the torque produced by this machine with a net current phasor of magnitude 15Arms at an angle of 30° advanced relative to the d-axis **(5)**

c. Draw to **scale** a phasor diagram (in your answer book) for the operating point in part (b), taking care to label all phasors and key angles. **(4)**

d. If the motor is rotating at 1500rpm, calculate the magnitude of the applied voltage and the power factor for the operating point in part (b). **(3)**

e. If the motor is now operated at a value of δ which yields the maximum possible torque and the magnitude of the net current phasor is 10Arms, calculate the power factor at this operating point and comment on the sources of improvement from the value calculated in part (d). **(3)**

5.

a. Draw an equivalent circuit of a single phase induction motor which accounts for iron losses and clearly label all of the circuit elements. **(2)**

b. A single-phase 220V, 2-pole, 50Hz, 600W induction motor gave the following tests results:

No-Load test: V = 220V I = 0.584A power-factor = 0.167 lagging

Locked rotor test: V = 75V I = 2.1A power-factor = 0.618 lagging

Stator winding resistance = 10Ω

Assume that the stator leakage reactance is equal to the referred rotor leakage reactance.

Use the above test data to calculate numerical values for all the circuit elements of the equivalent circuit for a general value of slip, *s*. State any assumptions made in your derivation of the values. **(5)**

c. The motor is then connected to a 220V, 50Hz supply and drives a load at a constant speed of 2850 rpm. For this operating condition calculate the following:

(i) The input current to the motor **(4)**

(ii) The mechanical torque produced by the motor **(3)**

(iii) The total losses in the motor **(1)**

(iv) The efficiency of the motor **(1)**

d. Briefly describe, with appropriate diagrams, the operation of a single phase, shaded-pole induction motor. Give one benefit and one drawback of this type of machine **(4)**

6.

a. Sketch a typical torque-speed characteristic for a three-phase induction machine over the speed range zero to twice synchronous speed. Identify on the sketch the synchronous speed, motoring and generating operating regions, and any critical operating points. **(2)**

b. A large pump on an oil rig is driven from 6-pole, star-connected, three-phase induction motor having a diecast aluminium cage rotor. The motor is connected to a 3300V_{rms} (line to line voltage) 50Hz supply and has the following per-phase equivalent circuit parameters:

Stator resistance= 0.35Ω

Stator leakage reactance = 0.6 Ω

Referred rotor leakage reactance = 0.75Ω

The motor draws a magnetising current of $15.0\angle -90°$ A_{rms} on no-load. This magnetising current is small in comparison with the total input current drawn at rated load. For normal pumping operations the rated speed and torque produced by the motor are 960 rpm and 8575Nm respectively, and the magnitude of the input current is 163A_{rms}. Calculate the following:

(i) The magnetising reactance

(ii) The referred rotor resistance

(iii) The efficiency at the rated speed of 960rpm **(5)**

c. After a number of years of service the motor is overhauled and the existing rotor is replaced with a diecast copper rotor having a referred rotor resistance of 0.25Ω (assume all other equivalent circuit parameters remain unchanged). If the load torque remains at 8575Nm calculate the following for the motor with the new diecast copper rotor:

(i) The speed of operation **(5)**

(ii) The input phase current to the motor **(1)**

(iii) The total losses in the motor **(1)**

(iv) The efficiency of the motor **(1)**

d. When the oil rig is not pumping oil, waste gas is burnt in a gas turbine and is used to drive the machine as an induction generator. Assuming the machine has the new diecast copper rotor (from part **c** above) and runs at a speed of 1020rpm, calculate the net real power that the machine can provide and the reactive power drawn from the supply. **(5)**

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