Cover Type B

University of Technology, Sydney

TO BE RETURNED AT THE END OF THE EXAMINATION.
THIS PAPER MUST NOT BE REMOVED FROM THE EXAM CENTRE.

SURNAME: ____________________

FIRST NAME: ____________________

STUDENT NUMBER: ____________________

COURSE: ____________________

SPRING SEMESTER 2011

SUBJECT NAME	:	ELECTRICAL MACHINES
SUBJECT NO.	:	48571
DAY/DATE	:	TUESDAY 15 NOVEMBER 2011
TIME ALLOWED	:	3 Hours plus 10 Min. reading time
START/END TIME	:	9:30 / 12:40

NOTES/INSTRUCTIONS TO CANDIDATES:

- ONLY NON-PROGRAMMABLE CALCULATORS MAY BE USED.
- ONE DOUBLE SIDED A4 SHEET OF HANDWRITTEN NOTES MAY BE TAKEN INTO THE EXAM ROOM.
- ALL QUESTIONS MAY BE ATTEMPTED.
- THE MARKS TOTAL 120, BUT IT WILL BE SCALED TO 100, i.e. DIVIDED BY 1.20, AFTER MARKING.
- ROUGH WORK CAN BE DONE ON THE LAST THREE BLANK SHEETS OF THE ANSWER BOOK.

Examiner: Prof. J.G. Zhu
Assessor: A/Prof. D. Dorrell

Problem One

A three phase 250 kVA 2400:415 V 50 Hz distribution transformer is constructed by connecting three single phase transformers in the *Dyn11* vector group as shown in Fig.P1(a) below. The per phase equivalent circuit parameters on the high voltage side are:

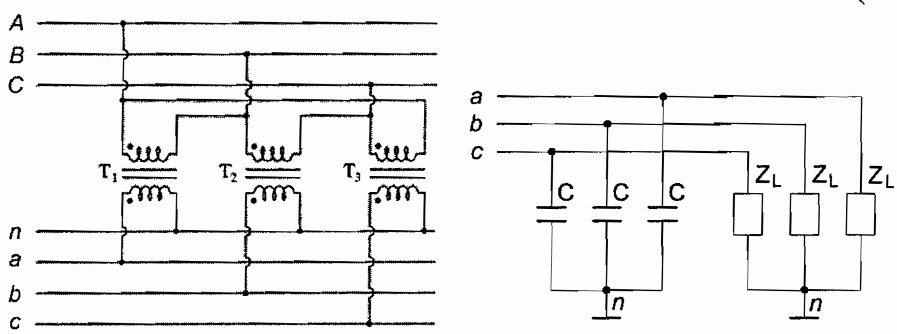
$$R_1 = 0.75\ \Omega,\ X_{l1} = 0.92\ \Omega,\ R_2' = 0.75\ \Omega,\ X_{l2}' = 0.92\ \Omega,$$
$$R_c = 328.49\ \Omega,\ \text{and}\ X_m = 44.61\ \Omega$$

(a) Sketch the corresponding phasor diagram of the primary and secondary voltages for the *Dyn11* vector group;

(b) Calculate the voltage regulation for the rated load with a power factor 0.75 lagging; and

(c) If three identical capacitors are connected in star and then in parallel to the rated three phase load in (b), as shown in Fig.P1(b), to achieve ***zero voltage regulation***, calculate the capacitance C per phase.

(15 marks)



(a) (b)

Fig.P1 (a) Three phase transformer connected in *Dyn11* vector group, and (b) three capacitors connected in star and parallel to the three phase load

Problem Two

A three phase ***four*** pole stator winding of a ***round rotor*** rotating electrical machine is excited by balanced three phase 50 Hz currents. Although the winding distribution has been designed to minimize the harmonics, there still remain some third and fifth spatial harmonics. Thus, the phase *A mmf* can be written as

$$F_a = \left(F_1 \cos\theta + F_3 \cos 3\theta + F_5 \cos 5\theta\right)\cos\omega t$$

Similar expressions can be written for phase B (replacing θ by $\theta-120^o$ and ωt by $\omega t-120^o$) and phase C (replacing θ by $\theta+120^o$ and ωt by $\omega t+120^o$).

(a) Derive the expression for the total three phase *mmf*, and show that the fundamental and the 5^{th} harmonic components are rotating.

(b) What are the angular velocity in rad/s and the rotating direction of each harmonic component of the *mmf*?

(c) If the airgap length is g, what is the expression of airgap flux density?

(15 marks)

Problem Three

Fig.P3 illustrates a Ward-Leonard system for DC motor speed control. The system consists of two identical 10 kW 230 V 36 A separately excited DC machines, operated as the generator and motor, respectively, and the generator is driven by a synchronous motor rotating at 1500 rev/min. The armature circuit resistance of each DC machine is 0.25 Ω (including brushes), and the armature reaction is negligible. The table below tabulates the magnetisation curve of each DC machine measured at 1500 rev/min.

Over ...

I_f (A)	0	0.3	0.6	0.9	1.2	1.5	1.8
E_a (V)	0	108	183	230	254	267	276

(a) Calculate the electromagnetic torque of the DC motor in Nm at full load armature current (36 A) if the DC motor field current is 0.90 A.

(b) Determine the maximum and minimum values of the DC generator field current needed to give the DC motor a speed range from 300 to 1500 rev/min at full load armature current with the DC motor field current held constant at 0.90 A.

(c) What is the maximum DC motor speed in rev/min obtainable at full load armature current if the DC motor field current cannot be reduced below 0.60 A and the DC generator field current is not allowed to exceed 1.60 A?

(d) Based on the results of (b) and (c), sketch the operational region of the DC motor in the torque/speed or T/ω_r plane with the torque, T, as the horizontal axis.

(20 marks)

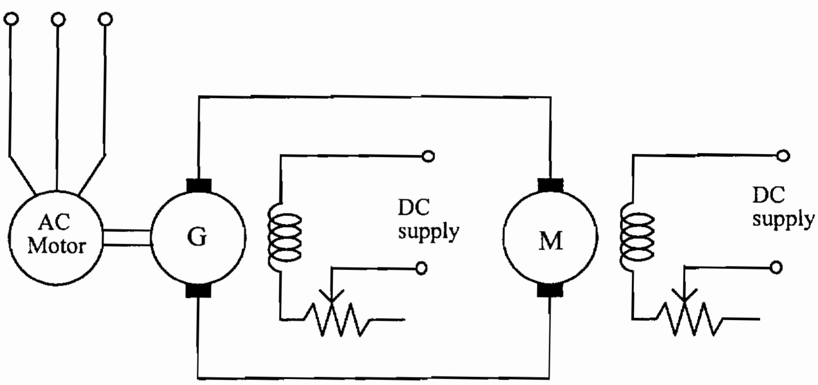


Fig.P3 Ward-Leonard system of DC motor speed control

Problem Four

Fig.P4 below illustrates schematically the per phase equivalent circuit model of a round rotor synchronous machine operated as motor. Ignoring the stator winding resistance, R_a,

(a) Draw a phasor diagram (not to scale) corresponding to a stator phase current of leading power factor (over excitation);

(b) Derive an expression of the electromagnetic torque, T, versus the load angle (also known as power angle), δ; and

(c) Sketch the curve of T versus δ.

(15 marks)

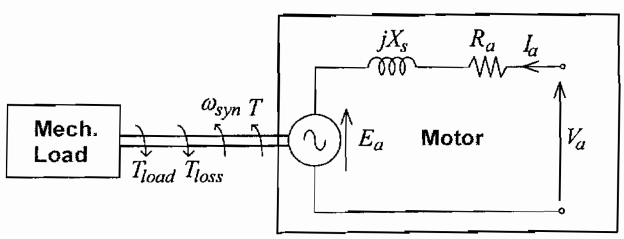


Fig.P4 Per phase equivalent circuit model of a round rotor synchronous generator

Problem Five

When operated at the full capacity, the power factor of a 5 MW inductive load is 0.7 lagging. The grid power supply however requires the power factor to be no less than 0.8 lagging. For power factor compensation, a 3 phase, star connected, 4 pole, 6000 V (line-line), 50 Hz, round rotor synchronous machine is operated as a motor at no load. The synchronous reactance of the machine is 15 Ω per phase, and the field current is 150 A DC when the stator open circuit terminal voltage equals the rated voltage. Assume a linear open circuit characteristic and ignore the stator winding resistance and all rotational power losses.

(a) Calculate the capacity in MVA of the synchronous machine required to achieve the satisfactory power factor;
(b) Draw a phasor diagram (not to scale) for this condition of operation; and
(c) Calculate the corresponding field current.

(15 marks)

Problem Six

A 3-phase, 4-pole, star connected, 415 V (line to line), 50 Hz, ***wound rotor*** induction motor has the following per phase T equivalent circuit parameters:

$R_1 = 0.56\ \Omega$, $R_2' = 0.56\ \Omega$, $X_{l1} = X_{l2}' = 1.35\ \Omega$, and $X_m = 57.92\ \Omega$, R_c can be ignored

The retarding torque due to the total of friction, windage and core losses may be assumed to be 5 Nm, independent of load and speed.

(a) Calculate the starting internal torque and the corresponding stator current;
(b) Calculate the maximum internal torque and the corresponding rotor speed;
(c) Sketch the torque/speed curve for 415 V (line to line) 50 Hz operation, using the results of (a) and (b);
(d) Outline all possible methods for speed control of this induction motor, and wherever possible illustrate these methods by torque/speed curves.

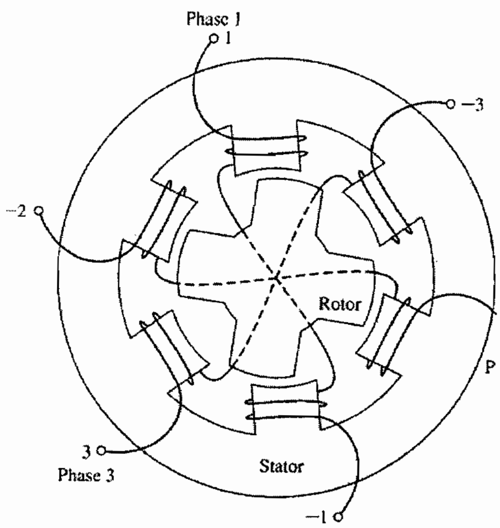
(20 marks)

Problem Seven

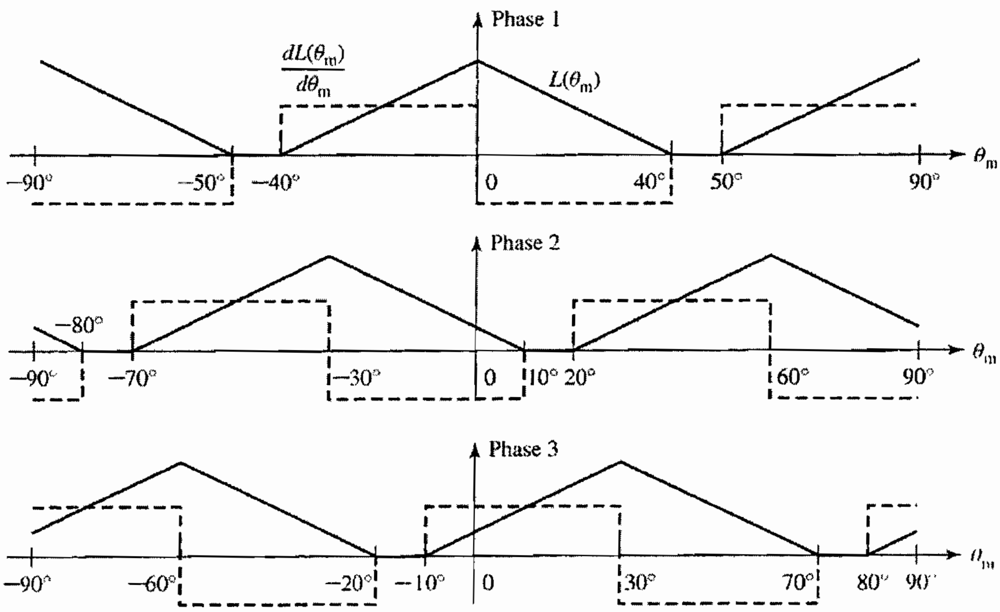
Fig.P7 illustrates the schematic cross section, the phase winding self-inductances and their derivatives versus rotor position of a three phase 6/4 pole switched reluctance motor (SRM). Under the assumption that the permeability of iron is infinite, the mutual inductances between the three phase stator windings can be ignored.

(a) Derive an expression of the electromagnetic torque in terms of the phase winding currents and self-inductances;
(b) Sketch the curve of electromagnetic torque versus rotor position for $-90^o \le \theta_m \le 90^o$ if the SRM is operated in the ***motor mode*** and the phase current is maintained constant when the phase winding is excited;
(c) Sketch the curve of electromagnetic torque versus rotor position for $-90^o \le \theta_m \le 90^o$ if the SRM is operated in the ***generator mode*** and the phase current is maintained constant when the phase winding is excited;
(d) Sketch a suitable drive circuit for the SRM, and indicate if this drive circuit is uni-polar or bi-polar?

(20 marks)



(a)



(b)

Fig.P7 A three phase 6/4 pole switched reluctance motor (a) Cross section, and (b) Self-inductances of phase windings and their derivatives versus rotor position

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