[ENG18]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG (HONS) ELECTRICAL & ELECTRONIC ENGINEERING

SEMESTER ONE EXAMINATION 2018/2019

ELECTRICAL MACHINES & POWER ELECTRONIC DRIVES

MODULE NO: EEE6011

Date: Monday 14th January 2019 **Time: 14:00 – 16:00**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

Electronic calculators may be used provided that data and program storage memory is cleared prior to the examination.

CANDIDATES REQUIRE: **Formula Sheet (attached).**

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Question 1

a) For the rotating wire loop shown in figure Q_1 , give the dynamical equations of this loop and build the SIMULINK model so that the inputs are the supply voltage V and the applied mechanical load torque T_m .You can assume that the angular rotational speed ω and the loop current i as the outputs for this model. You need to take the following parameters into your consideration: B=magnetic field density (T), R=resistance of the wire (Ω), L=inductance of the wire (H), J=moment of inertia of the loop (kg.m^2).

[10 marks]

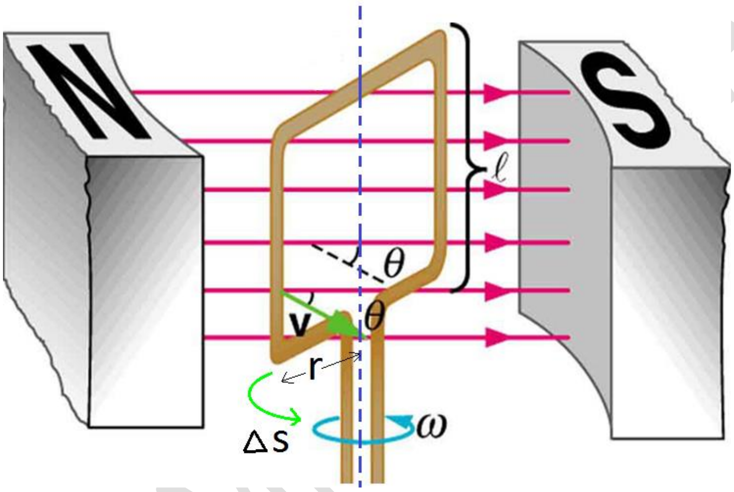

Figure Q_1 a rotating wire-loop in a magnetic field

(b) A 3-phase, 50 Hz, 6600 Δ/1000 Δ /440 Y V. transformer.

(i) What is the purpose of using three winding transformers? **[3 marks]**

(ii)Determine suitable numbers of turns to ensure the peak flux does not exceed 0.03 Web. **[4 marks]**

(iii) Determine the primary line current and power factor if the 1000 V winding delivers a balanced load of 100 kVA at 0.8 power factor lagging and the 440 V winding delivers a balanced load of 50 kW at unity power factor. **[8 marks]**

Total 25 marks

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Question 2

The equivalent circuit of a 440 V, 3-phase, 8 pole, and 50 Hz star-connected induction motor is shown in Fig. Q_2 . The short-circuit test is conducted with a locked rotor and a line current of 80 A. The open-circuit test is conducted by supplying the stator winding at rated voltage and at the rotor is rotating freely without any mechanical load.

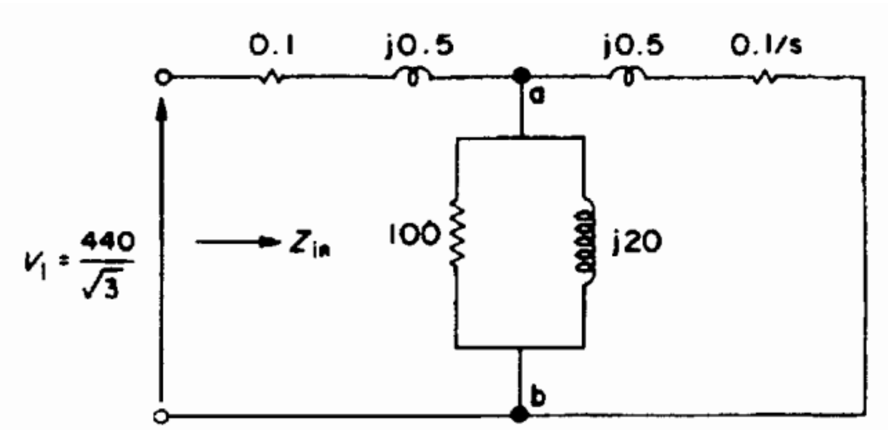

Fig. Q_2 The per-phase equivalent circuit of a 3-phase induction motor

a) Determine the line voltage and power factor on the short circuit test; **[5 marks]**

b) We need to apply a low voltage in a short-circuit test. What is the reason for using low voltage? **[3 marks]**

c) Determine the line current and power factor on the open-circuit test; **[4 marks]**

d) The electromagnetic torque if the motor is running at speed of 720 rpm **[4 marks]**

e) The starting torque, starting current; and **[4 marks]**

f) The efficiency for case (c) if mechanical losses are 4 kW **[5 marks]**

Total 25 marks

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Question 3

A 3300 V, 3-phase, 50 Hz, star-connected synchronous motor has a synchronous impedance of 2+j 15 Ω per phase. Operating with a line emf of 2500 V, it just falls out of step at full load.

a) Draw the equivalent circuit of a synchronous motor. **[3 marks]**

b) To what open-circuit emf will it have to be excited so that it will just remain in synchronism at 50% above rated torque? **[8 marks]**

c) With this emf , what will then be:

(i) the input power; **[6 marks]**

(ii) current; and **[4 marks]**

(iii) Power factor at full load. **[4 marks]**

Total 25 marks

Question 4

An eight-pole, 25 kW, 120 V DC generator has a duplex lap-wound armature, which has 64 coils with 16 turns per coil. Its rated speed is 2400 rpm.

(a) Define a duplex lap-wound DC armature.

[3 marks]

(b) How much flux per pole is required to produce the rated voltage in this generator at no load conditions?

[5 marks]

(c) What is the induced torque in this machine at rated load?

[5 marks]

(d) Determine path current in the armature of this generator at the rated load?

[5 marks]

(e) How many brushes must this generator have?

[3 marks]

(f) If the resistance of this winding is 0.011 Ω per turn, what is the armature resistance of this machine?

[4 marks]

Total 25 marks

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Question 5

(a) A 2.5 kW, 120 V, 50 Hz capacitor-start motor has the following impedances for the main and auxiliary windings(at starting):

$Z_{main}=4.5+j3.7\ \Omega$, $Z_{auxiliary}=9.5+j3.5\ \Omega$

Find the value of starting capacitance that will place the main and auxiliary winding currents in quadrature at starting; **[8 marks]**

(b) Explain briefly the effect of adding capacitor to the auxiliary winding of a single-phase induction motor. **[5 marks]**

(c) Two single-phase transformers operate in parallel to supply a load of 24+j 10 Ω . Transformer A has a secondary emf of 400 V on open-circuit and an internal impedance referred to secondary side of 1+j 3 Ω . The corresponding figures for transformer B are 450 V and 1+4 Ω .

(i) Calculate the load voltage; **[6 marks]**
(ii) Calculate the load current; and **[3 marks]**
(iii) Calculate the terminal power factor of each transformer **[3 marks]**

Total 25 marks

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Question 6

A DC motor is driven by a thyristor-bridge rectifier as shown in figure Q_6 below. Determine the following conditions:

(i) The appropriate firing angle of the bridge; **[6 marks]**

(ii) The DC machine back emf; **[6 marks]**

(iii) The torque and speed when the flux is at rated value; and **[6 marks]**

(iv) The firing angle of the bridge to have the motor running at half rated speed with rated flux. Assume torque is proportional to $(\text{speed})^2$. **[7 marks]**

R_A=0.05 per unit, R_{ext}=0.06 per unit, E_d=300 V, rated voltage of the machine=250 V.

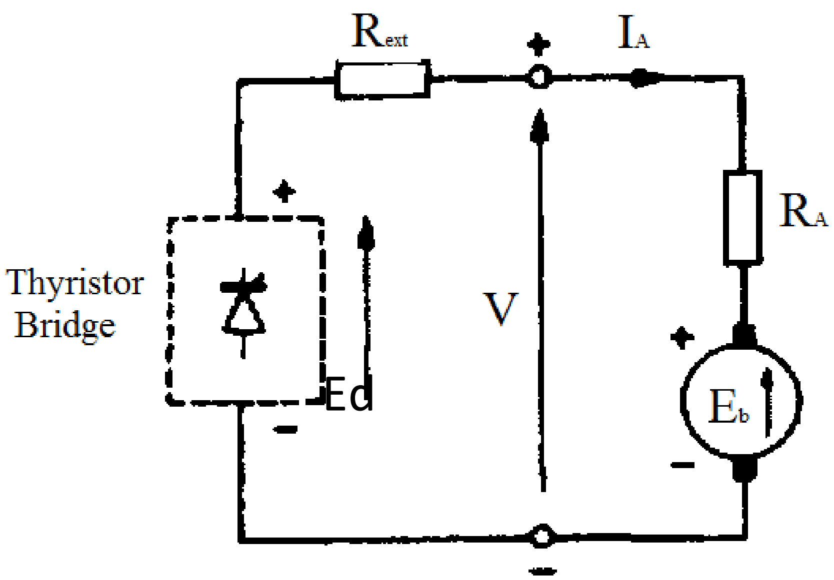

Figure Q_6 ADC motor driven by Thyristor Bridge Rectifier

Total 25 marks

END OF QUESTIONS

Formula sheets over the page….

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Formula sheet

These equations are given to save short-term memorisation of details of derived equations and are given without any explanation or definition of symbols; the student is expected to know the meanings and usage.

DC Machines

$E=V+I_A.R_A$ (Generator voltage equation)

$E=V-I_A.R_A$ (Motor voltage equation)

$K_e=K_t=(2pCN/a)$, $E=K_e.\omega.\Phi$, $T=K_t.I_A.\Phi$

$P_{conv} = E.I_A = \omega.T$

Transformers and Induction motors

Transformer voltage ratio: $\frac{E_1}{E_2} = \frac{N_1}{N_2}$

Secondary parameters referred to primary side: $R_2' = (\frac{N_1}{N_2})^2 R_2$, $X_2' = (\frac{N_1}{N_2})^2 X_2$,
$I_2' = \frac{N_2}{N_1} I_2$, $V_2' = \frac{N_1}{N_2} V_2$, $P = \sqrt{3} V_L I_L \cos\theta$, $Q = \sqrt{3} V_L I_L \sin\theta$

$slip\ \ s = \frac{n_s - n_r}{n_s}$, $P_{AG} = 3 I_2^2 \frac{R_2}{s}$, $P_{conv} = 3 I_2^2 R_2 \left(\frac{1-s}{s}\right)$, $P_{core} = 3 E_1^2 G_C$,

$\tau_{ind} = \frac{(1-s) P_{AG}}{(1-s)\omega_{sync}}$

$\tau_{ind} = \frac{P_{AG}}{\omega_{sync}}$

Synchronous machines

Voltage vector equation: E =V + I.Z

Power equations: $P = \frac{EV}{Z}\cos(\psi - \delta) - \frac{V^2}{Z}\cos(\psi)$, $Q = \frac{EV}{Z}\sin(\psi - \delta) - \frac{V^2}{Z}\sin(\psi)$

For generator

$P_{in} = \tau_{app}\omega_m$, $P_{conv} = \tau_{ind}\omega_m = 3 E_A I_A \cos\gamma$, $P_{out} = \sqrt{3}\, V_L\ I_L \cos\theta$

For motor the above equations will be used in the reversed order.

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Motor Drives

The rotor terminals ac voltage with the open-circuit rotor voltage at standstill, $E = sE_{oc}$

The rectified output voltage $E_d = 1.35\,E$

$$s = \frac{E_2}{1.35 E_{OC}}$$

DC Voltage developed by the inverter $E_2 = 1.35\ E_T cos\alpha$

Single-phase Induction motor

$$Z_f = R_f + jX_f = \frac{jX_m\left(R'_2/s + jX'_2\right)}{jX_m + \left(R'_2/s + jX'_2\right)}$$

$$Z_b = R_b + jX_b = \frac{jX_m\left(R'_2/(2-s) + jX'_2\right)}{jX_m + \left(R'_2/(2-s) + jX'_2\right)}$$

$$P_{g,f} = I_1^2\left(0.5R_f\right)$$

$$P_{g,b} = I_1^2\left(0.5R_b\right)$$

$$T_{d,f} = \frac{P_{g,f}}{\omega_s}$$

$$T_{d,b} = \frac{P_{g,b}}{\omega_s}$$

$$P_g = P_{g,f} - P_{g,b}$$

$$T_d = \frac{P_g}{\omega_s} = \frac{P_{g,f} - P_{g,b}}{\omega_s} = T_{d,f} - T_{d,b}$$

$$P_{2,Cu,f} = sP_{g,f}$$

$$P_{2,Cu,b} = \left(2-s\right)P_{g,b}$$

$$I_1 = \frac{V_1}{R_1 + jX_1 + 0.5Z_f + 0.5Z_b}$$

END OF PAPER