ENG02

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

B.ENG (HONS) ELECTRICAL & ELECTRONIC ENGINEERING

EXAMINATION SEMESTER 1 - 2023/2024

ELECTRICAL MACHINES & POWER ELECTRONIC DRIVES

MODULE NO: EEE6011

Date: Monday 8th January 2024 **Time: 2:00 – 4:30**

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) A 200-kVA single-phase transformer with a voltage ratio 6350/660 V has the following winding resistances and reactances:

$$R_1 = 1{\cdot}56\,\Omega \quad R_2 = 0{\cdot}016\,\Omega \quad x_1 = 4{\cdot}67\,\Omega \quad x_2 = 0{\cdot}048\,\Omega.$$

On no load the transformer takes a current of 0.96 A at a power factor of 0.263 lagging.

(i) Calculate the equivalent-circuit parameters referred to the high-voltage winding.

[6 marks]

(ii) Calculate transformer efficiency and voltage regulation at 50% full load with 0.85 power factor lagging. **[6 marks]**

(b) Answer the following questions:

(i) What are the conditions to connect two three-phase transformers in parallel?

[4 marks]

(ii) What is the effect of eddy current and hysteresis power loss on the function of a transformer? How do designers and manufacturers mitigate this problem?

[4 marks]

(iii) The voltage regulation of a transformer is negative for certain type of loads. Explain this case with the aid of circuit and phasor diagrams. **[5 marks]**

Total 25 marks

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Question 2

(a) Explain with the aid of drawings why a DC machine armature produces armature reaction and show its cross and demagnetizing components. How do we overcome the demagnetizing effect of armature reaction. **[10 marks]**

(b) (b) A 60-hp, 240-V, 1400 r/min dc shunt motor with compensating windings has an armature resistance (including the brushes, compensating windings, and interpoles) of 0.055 ohm. Its field circuit has a total resistance $R_{adj} + R_f$ of 60 ohms, which produces a no-load speed of 1400 r/min. There are 1200 turns per pole on the shunt field winding.

(i) What is the shape of the torque-speed relationship and find the speed of this motor when its input current is 190 A. **[7 marks]**

(ii) If an external resistance of 0.04 ohm is added in series to its armature circuit what would be the motor torque, speed and efficiency when its armature current is 75 A. **[8 Marks]**

Total 25 marks

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Question 3.

a) Prove that the stator magnetic flux of a 3-phase induction motor has a constant magnitude and rotates at synchronous speed in space. You may use the analytical or the graphical method using only three successive time intervals.

[10 marks]

b) A 500-V, 3-phase, 50 Hz, 8-pole, star-connected induction motor has the following equivalent-circuit parameters: R_1=0.13, R_2=0.32, X_1=0.6, X_2= 1.48 (all in ohms), magnetising branch admittance Ym = 0.004-j0.05 Ω^{-1} referred to primary side. The full-load slip is 5 %. Using approximate and exact equivalent circuit to determine:

(i) the full-load electromagnet torque; **[2 marks]**
(ii) stator input current and power factor; **[10 marks]**
(iii) efficiency if approximate equivalent circuit is used. **[3 marks]**

The effective stator/rotor turns ratio per phase is 1/1.57. Neglect mechanical loss. Comment on the results. **Total 25 marks**

Question 4

(a) Draw the voltage, current and flux phasor diagram of a 3-phase synchronous generator loaded with inductive load. Explain the effect of armature reaction on the field flux.

[8 marks]

(b) A 3-phase, 100-hp, 440-V, star-connected synchronous motor has a synchronous impedance per phase of 0.1 +j1 ohm. The excitation and torque losses are 4 kW and may be assumed constant. Calculate:

(i) the line current and power factor; **[15 marks]**
(ii) efficiency when operating at full load with an excitation equivalent to 400 line volts.

[2 marks]

Total 25 marks

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Question 5

(a) Explain briefly how a single-phase induction motor can produce a revolving flux in space. **[8 marks]**

(b) A 200 W, 110 V, 50 Hz, 4-pole, capacitor-start motor has the following equivalent circuit parameter values (in ohms) and losses:

$$R_{1,main} = 2.02, X_{1,main} = 2.79\ , R_{2,main} = 4.12\ , X_{2,main} = 2.12,$$

$$X_{m,,main} = 66.8$$

Core loss=30 W, Friction and windage loss=18 W.

When this motor is running as a single-phase motor at rated voltage and frequency with its starting winding open and for a slip of 0.05, determine:

(i)	The stator current and power factor;	**[8 marks]**
(ii)	Power output, speed, and torque and	**[6 marks]**
(iii)	Efficiency	**[3 marks]**

Total 25 marks

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Question 6

(a) Explain with drawings the relationship between speed and torque of a separately excited DC motor. Show that its speed can be controlled by changing the magnetic field **[6 marks]** and explain how a power electronic drive can control the motor speed. **[6 marks]**

(b) Explain with drawings the relationship of torque-speed of a 3-phase induction motor. Show how can speed be controlled by changing the voltage and frequency **[7 marks]**. Also explain how a power electronic drive can be used to control the speed of 3-phase induction motor. **[6 marks]**

Total 25 marks

END OF QUESTIONS

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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: $R_2' = (\frac{N_1}{N_2})^2 R_2$, $X_2' = (\frac{N_1}{N_2})^2 X_2$,

$I_2' = \frac{N_2}{N_1} I_2$, $V_2' = \frac{N_1}{N_2} V_2$, $P = \sqrt{3} V_L I_L \cos\theta$, $Q = \sqrt{3} V_L I_L \sin\theta$

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

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

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

Synchronous machines

Voltage vector equation: $E = V + I.Z$

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

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For generator

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

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

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 $E_2 = 1.35\ E_T cos\alpha$

END OF FORMULA SHEET

END OF PAPER