UNIVERSITY OF JOHANNESBURG

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| **PROGRAM** | : | BACCALAUREUS TECHNOLOGIAE<br>*ENGINEERING: ELECTRICAL* |
| **SUBJECT** | : | **ELECTRICAL MACHINES IV** |
| **CODE** | : | **TEF441** |
| **DATE** | : | SUMMER SSA EXAMINATION 2015<br>9 DECEMBER 2015 |
| **DURATION** | : | (SESSION 2) 11:30 - 14:30 |
| **WEIGHT** | : | 40: 60 |
| **TOTAL MARKS** | : | **100** |
| **FULL MARKS** | : | **100** |

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| **ASSESSOR** | : | MR. M.C MUTEBA |
| **MODERATOR** | : | Prof. A.A JIMOH |
| **NUMBER OF PAGES** | : | 5 PAGES |

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## REQUIREMENTS

- STANDARD STATIONARY.
- NO-PROGRAMMABLE CALCULATOR MAY BE USED

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## INSTRUCTIONS

- READ INSTRUCTIONS CAREFULLY.
- ALL CALCULATIONS AND ANSWERS MUST BE DONE WITH A MINIMUM OF 3 DECIMALS.
- WRITING MUST BE IN BLUE OR BLACK INK PEN ONLY- NO PENCIL WRITING WILL BE MARKED
- WORK NEATLY, UNTIDY WORK MAY BE PENALIZED.
- ALL UNITS MUST BE SHOWN-MARKS WILL BE DEDUCTED FOR NO OR WRONG UNITS
- ALL CALCULATIONS MUST BE DONE IN COMPLEX NOTATION AND ANSWERS MUST BE WRITTEN IN POLAR FORM, WHERE APPLICABLE.

**SECTION A:**

GENERAL INTRODUCTION AND OPERATION OF SYNCHRONOUS MACHINES

**QUESTION 1** **[17 Marks]**

**1.1.** A 16-pole, 144-slots, three-phase, star-connected, synchronous generator has 10 conductors per slot in two layers. The rotor is driven at a speed of 375 rpm. The flux per pole has a fundamental component of 25 mWb, a 20 % third component and 10 % fifth component. Coils are short-pitched by 1 slot. Compute the RMS value of the induced (line) e.m.f. **(11)**

**1.2.** Discuss the three modes of operation of synchronous machines. **(6)**

**QUESTION 2** **[13 Marks]**

**2.1** A 100-kVA, 3000-V, 50 Hz, three-phase star-connected synchronous generator has effective armature resistance of 0.2 Ω. The field current of 40 A produces short-circuit current of 200-A and an open-circuit voltage of 1040-V (line value). Calculate the full-load voltage regulation at 0.8 power factor lagging and 0.8 power factor leading. **(6)**

**2.2** A three-phase salient pole synchronous generator has $X_d$ = 0.8 p.u. ; $X_q$= 0.5 p.u. and $R_a$ = 0. The generator supplies full-load at 0.8 power factor lagging at rated terminal voltage. Compute;

**2.2.1** The power angle **(2)**

**2.2.2** The no-load voltage if the excitation remains constant. **(3)**

**2.2.3** The full-load voltage regulation. **(2)**

**QUESTION 4** **[10 Marks]**

A 75-kW, three-phase, star-connected, 50-Hz, 440-V cylindrical rotor synchronous motor operate at rated condition with 0.8 power factor leading. The motor efficiency excluding field and stator losses, is 95 % and the $Xs$ = 2.5 Ω. Calculate:

**4.1** The input power **(2)**

**4.2** The armature current **(2)**

**4.3** The back e.m.f and power angle. **(3)**

**4.4** The maximum torque (pull-out torque). **(3)**

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**[40]**

## SECTION B

APPLICATION AND STABILITY OF SYNCHRONOUS MACHINES

### QUESTION 1 [19 Marks]

**1.1** Discuss hunting (Self-oscillation) under the headings:

**1.1.1** Disadvantages **(3)**

**1.1.2** Causes **(4)**

**1.2** One of the techniques to determine whether the synchronous generator connected to infinite bus bar will attain its steady equilibrium position after oscillation is by means of the Swing Equation *Equal-Area Criterion.* Discuss the technique; neglect the damping torque. **(6)**

**1.3** Draw a typical synchronous machine capability curve and clearly indicate the thermal limits for field and armature currents. Also indicate the stability limit, the MVA and power factor Ratings. **(6)**

### QUESTION 2 [6 Marks]

Two 10 MVA synchronous generators are connected to 50 Hz to 50 Hz bus bars having a constant voltage of $1 \angle 0^o$ p.u. Generator A has an induced e.m.f of $1.3 \angle 22^o$ p.u. and a reactance of 0.5 p.u, generator B an e.m.f of $1.25 \angle 36^o$ p.u. and a reactance of 0.75 p.u. Find the current, kW and kVAR supplied by each generator.

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**[25]**

## SECTION C:

BASICS OF ELECTRICAL MACHINE DRIVES AND CONTROL

### QUESTION 1 [8 Marks]

**1.2** A trolley-bus is driven by a 150 hp, 1500 RPM, 600 series dc motor as in figure 1. The nominal full-load current is 200 A and the total resistance of the armature and field is 0.1 Ω. The bus is fed from a 700 V dc catenary line. A chopper controls the torque and the speed. The chopper frequency varies from 50 Hz to 1600 Hz, but "ON" time $T_a$ is fixed at $600 \times 10^{-6}$ seconds.

**1.2.1** Calculate the chopper frequency and the current drawn from the catenary line when the motor is at standstill and drawing a current of 240 A. **(4)**

**1.2.2** Calculate the chopper frequency when the motor delivers its rated output. **(4)**

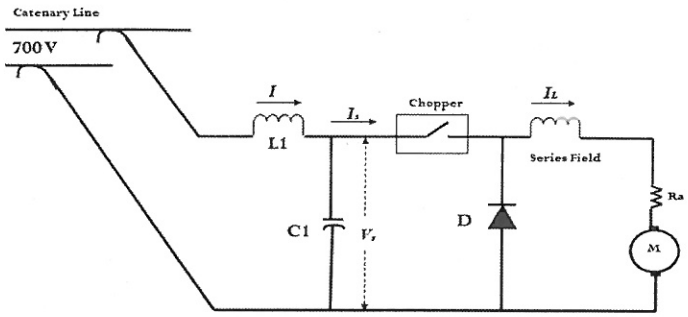


*Figure 1*: Direct Current motor driven by a chopper

**QUESTION 2** **[18 Marks]**

**2.1** Discuss the advantages of ac drives over dc drives. **(6)**

**2.2** Draw a difference between Rectifier inverter with self-commutation and Rectifier inverter systems with line commutation. **(4)**

**2.3** A three-phase, 3000 hp, 4000 V, 60 Hz, 8-pole, wound-rotor induction motor in **figure.2.** drives a variable-speed centrifugal pump. When the motor is connected to a 4160 V line, the open-circuit rotor line voltage is 1800 V. A three-phase, 4616 V/480 V transformer is connected between the inverter and the line. If the motor has to develop 800 kW at a speed of 700 RPM, calculate the following:

**2.3.1** The power output of the rotor. **(4)**

**2.3.2** The rotor voltage and link voltage. **(2)**

**2.3.3** Link current $I_d$ and rotor current. **(2)**

**2.3.4** Firing angle of the inverter. **(2)**

**2.3.5** Current in the primary and secondary lines of transformer T. **(2)**

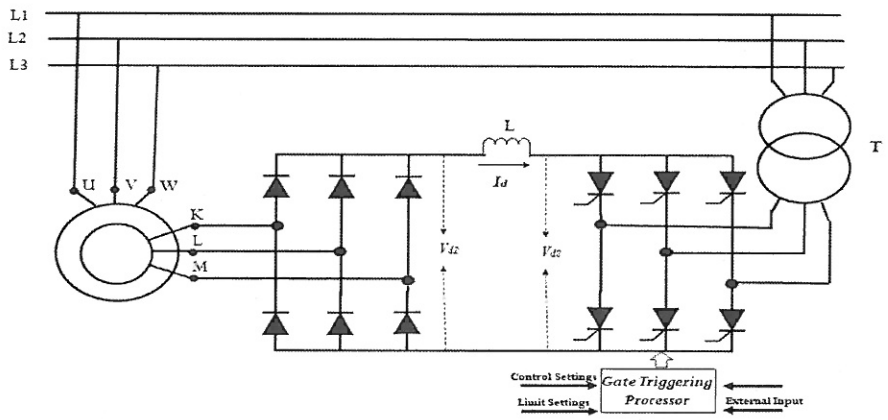


**Figure.2:** Speed control using a rectifier and naturally commutated inverter.

**[26]**

**SECTION D**

INTRODUCTION TO GENERALIZED MACHINE AND REFERENCE FRAME THEORIES

**QUESTION 1** **[9 Marks]**

**1.1** Write the voltage equations of stator and rotor coils of the primitive machine **(4)**

**1.2** A change of variables that formulates a transformation of 3-phase variables of stationary circuit elements to the arbitrary reference frame can be expressed as follows:

$$f_{qd\,0s} = K_S\, f_{abc}$$

Express $(K_S)^{-1}$ in simple matrix equations **(5)**

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**[9]**

**END**