Duration: 2h00.

Notes:
*** Write your name on every exam sheet you submit**
*** Closed book exam**
*** The use of any calculator with graphic support is prohibited**

1. [1.5] Explain why BLDC motors are increasingly replacing brushed DC motors in modern electromechanical systems. Take into consideration the following three aspects: efficiency, lifespan and requirements on control hardware. Identify and justify typical automotive applications where BLDC motors are commonly used.

2. [1.5] A three-phase induction motor operates at rated conditions with nominal voltage V_n . The motor is subjected to a 10% reduction in supply voltage due to grid disturbances.
   a) Knowing that ($T/T_n \propto (V/V_n)^2$), calculate the torque reduction (%) and new torque if T_n=20 Nm
   b) Explain the effect on starting current and starting capability.
   c) Sketch the torque–speed and current–speed curves for both voltage levels, clearly indicating the main differences.

3. [1.5] An industrial system uses an induction motor + drive + mechanical transmission. When analysing the system-level efficiency, identify the main components involved and discuss the types of losses associated with each stage of the energy conversion chain.

4. [1.5] It is common to refer to both **servomotors** and **servo systems** in motion control applications.
   a) Clearly explain the difference between a servomotor and a servo system.
   b) Which type of electric motors are considered servomotors? Identify its mains components.

5. [1.5] Explain the operating principle of a Synchronous Reluctance Motor (SynRM), highlighting how torque is produced and how it differs from the torque production mechanism in an induction motor. Can a SynRM be operated directly from the electrical grid using Direct-On-Line (DOL) starting, as an induction motor? Justify your answer.

6. [1.5] An alternative to Direct-On-Line (DOL) starting is the use of soft starters. In which types of applications are soft starters typically used? What are their main advantages? List the three common starting modes of a soft starter.

7. [1.5] Consider a **Motor Protection Circuit Breaker** (MPCB) and a **thermal overload relay.**
   a) Describe the protection functions provided by each device, and explain how they are typically employed in a motor control circuit.
   b) Present their respective symbols, sketch and compare the trip characteristics (trip curves) of both devices.

8. [1.5] Consider a motor condition monitoring system used in industrial applications.
   What sensing parameters and operational functionalities would you expect such a device to provide?

9. [5.5] The use of hoists for lifting loads is very common in diversified industrial installations, involving maximum load values that can easily reach up to tens of tons. Given the specificity of this type of application, answer the following questions.
   a) Consider the motors included in the following table and the lifting requirements as specified below. Verify if it is possible to choose one of the motors from the table, assuming an adequate gear unit exists, that can best meet this specification.

- $C_{(load\ capacity)} = 5\ ton$
- $H_{(height\ displacement)} = 10\ m$
- $D_{(drum\ diameter)} = 160\ mm$
- $v_{(lifting\ speed)} = 15\ m/min$
- $\eta_{(gearbox)} = 90\%$

NB: The values in the table correspond to specifications at 50 Hz; ZBE corresponds to the option of motor with built-in brake.

4-pole Z.E. motors 100% CDF (IE2)

Type	P_N [kW]	n_N [rpm]	M_N [Nm]	I_N 400 V [A]	$\cos\varphi_N$	IE - 2 $\eta_{1/2}$ %	$\eta_{3/4}$ %	$\eta_{4/4}$ % [4]	I_A/I_N	M_A/M_N	M_K/M_N	J_{Mot} [kgm² x 10⁻³] ZNE	ZBE	Z_0 [1/h] 1)	2)	Brake Type	[Nm] M_{BStd}	Weight [kg] [3] ZNE	ZBE
Z.E 63 B4	0,18	1385	1,2	0,6	0,64	66,5	71,2	72,1	4,0	2,8	2,8	0,55	0,61	13000	13000	B003	2,5	7,8	10,5
Z.E 71 A4	0,25	1390	1,7	0,8	0,63	69,5	74,0	74,9	4,0	3,0	3,0	0,65	0,71	10000	12000	B007	3,4	8,5	11,2
Z.E 160 A4	11	1455	72	20,5	0,85	89,0	90,8	89,8	6,5	2,9	2,9	68,0	70,0	–	1200	B140	140	150	162
Z.E 160 B4	15	1450	99	28	0,85	89,2	91,8	90,6	6,8	3,3	3,2	68,0	75,0	–	1000	B280	185	150	170
Z.E 180 A4	18,5	1455	121	34,5	0,85	89,3	92,4	91,2	6,8	3,2	3,1	73,0	80,0	–	1000	B280	280	160	180
Z.E 180 B4	22	1470	143	39	0,88	89,2	92,3	91,6	7,5	2,9	2,7	287	294	–	800	B280	280	277	295
Z.E 200 A4	30	1470	195	53	0,88	88,4	92,8	92,3	7,8	3,1	2,8	287	308	–	600	B680	340	277	316
Z.E 225 A4	37	1470	240	68	0,84	90,8	93,2	92,7	8,2	3,6	3,1	480	501	–	550	B680	450	360	400
Z.E 225 B4	45	1470	290	80	0,86	92,2	93,5	93,1	8,3	3,7	3,2	480	501	–	400	B680	530	360	400

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▢ Only for operation with an inverter

1) Operation with brake rectifier without high-speed excitation
2) Operation with brake rectifier with high-speed excitation
3) Weight for B14 model
4) The nominal efficiencies as per efficiency class IE2 in accordance with IEC 60034-30 are specified

b) Represent the characteristic curve (T-ω) of the chosen motor, identifying its characteristic points, including the motor operating point (T_L, n_L) under the conditions of the lift load capacity (5 ton).

c) When lowering the full load (5 ton) at a constant speed (15 m/min), what would be the estimated regenerative power?

d) Taking into account that these motors can only be used with a frequency inverter (VFD), represent the characteristic curves (T-f) and (V-f) of this motor considering a maximum frequency of 70 Hz. Why using a VFD can be particularly important for this application?

e) Conical rotor design is an alternative to conventional cylindrical rotor in induction motors. Use a sketch that illustrates de main components and principle of operation of these type of induction motors. Indicate its main advantages relative to the conventional motors design.

10. [2.5] Synchronous servomotors can still be considered the first choice in applications with high requirements, for example in positioning accuracy, speed control and constant torque in a wide range of speeds. Explain why, describe the main steps of the procedure to select a specific synchronous servomotor for an application and represent the characteristic curves torque/speed and torque current of a typical synchronous servomotor.

Formules:

$$\frac{T}{T_0} = \frac{I}{I_0} \quad ; \quad J^{motor}_{carga\ linear} = \frac{m}{\eta} \cdot \left(\frac{v}{\omega}\right)^2 \quad ; \quad T^{f2>fbase}_{máx} = T^{fbase}_{máx} \cdot \left(\frac{fbase}{f2}\right)^2$$

$$\sum T_{ext} = J_{total} \cdot \alpha \qquad T^{fmáx}_{máx\ carga} < 130\% \ \frac{P_N^{variador\ freq.}}{\omega_{máx}}$$