Tutorial for Final Exam

The final exam will consist of five sections covering the following topics:

Section A: Three-phase systems
Section B: Energy conversion
Section C: Induction machines
Section D: Synchronous machines
Section E: Power systems

Students will have to answer all questions from any four of the five sections above.

Following questions are similar in terms of topics and difficulty to those that will be found in the final exam papers.

A. Three-phase systems

A.1. Calculate the magnitude of a line current in the circuit shown in Figure A.1.

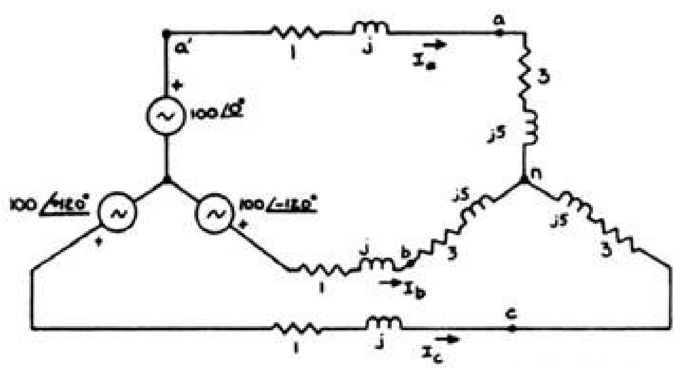


Figure A.1

A.2. A three-phase, Y-connected system with 220 V per phase is connected to three loads: 10 Ω, 20∠20° Ω, and 12∠ – 350 Ω to phases 1, 2 and 3, respectively. Find the current in each line and in the neutral line.

A.3. Figure A.2 shows an unbalanced set of impedances connected in Y, to which are applied balanced line voltages. Find the line currents and line voltages. in the figure, impedances are expressed in Ohms.

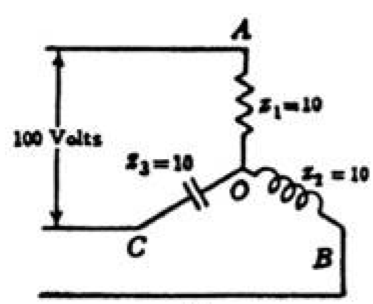


Figure A.2

A.4. In the circuit of Figure A.3, $\overline{Z}_1 = 1\angle 60°$ and $\overline{Z}_2 = 5\angle 36.9°$. The line voltages at the terminals a, b, c, are 230 V. Find the magnitude of the line currents, and that of the line voltages at the load terminals.

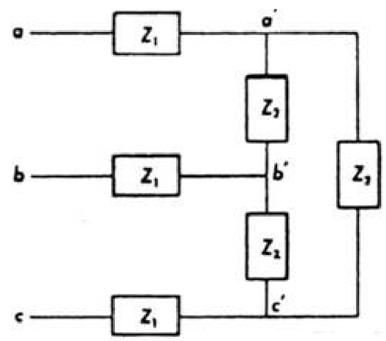


Figure A.3

A.5. Find the total power in the delta-connected load shown in Figure A.4 where:

$$\overline{V}_{ba} = 220\angle 0° \text{ V}$$

$$\overline{V}_{cb} = 220\angle -120° \text{ V}$$

$$\overline{V}_{cb} = 220\ \angle 120° \text{ V}$$

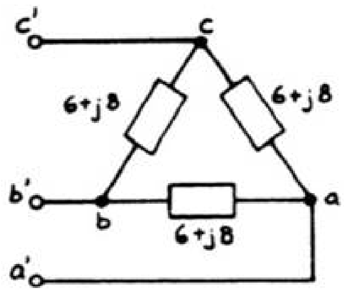


Figure A.4

B. Energy Conversion

B.1. Figure B.1 shows a magnetic circuit whose parameters are specified in the table below. For a coil of 800 turns carrying 1.5 amp, determine the flux densities in each material, the inductance of the coil, the energy storage of the circuit, and the force between the faces of the air gap. Leakage flux and fringing at the air gap will be neglected.

Material	Length	Area	μ_r
1	15.24 cm	3.23 cm^2	300
2	15.24 cm	3.23 cm^2	500
3	50.8 cm	6.45 cm^2	1000
Gap	0.127 cm	6.45 cm^2	1

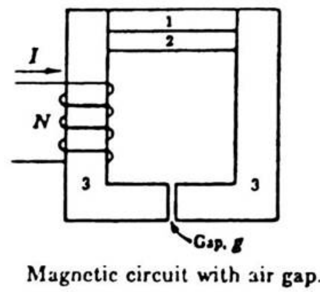


Figure B.1

B.2. For the doubly excited system in Figure B.2, the inductances are approximated as follows: $L_1 = 11 + 3 \cos 2\vartheta$, $L_2 = 7 + 2 \cos 2\vartheta$, $M = 11 \cos \vartheta$ H. The coils are energized with direct currents. $I_1 = 0.7$ A. $I_2 = 0.8$ A.

Determine:

(a) The torque as a function of ϑ.
(b) The energy stored in the system as a function of ϑ.

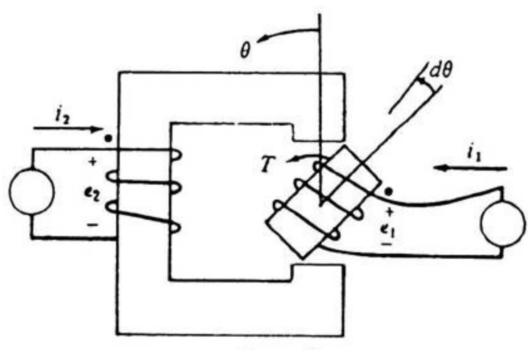


Figure B.2

B.3. The magnetic circuit shown in Figure B.3. is made of cast steel. The rotor is free to turn about a vertical axis. The dimensions are shown in the figure.

1. Derive an expression for the torque acting on the rotor in terms of the dimensions and the magnetic field in the two air gaps. Neglect the effects of fringing.
2. The maximum flux density in the overlapping portions of the air gaps is limited to approximately 0.2 mWb/cm^2, because of saturation in the steel. Compute the maximum torque in Nm for the following dimensions: r_1 = 2.54 cm.; h = 2.54 cm; g = 0.254 cm.

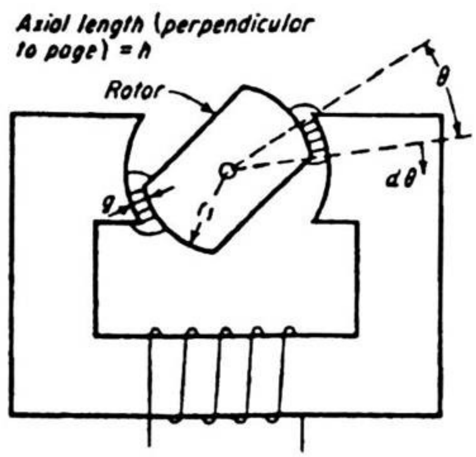
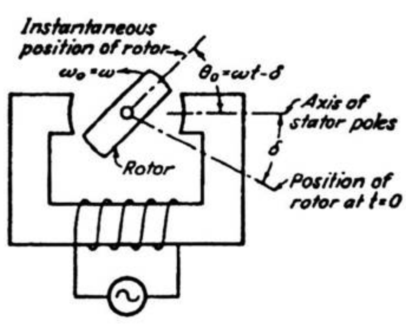


Figure B.3

B.4. When the rotor of a reluctance motor like that shown in Figure B.4 is in the direct-axis position, the inductance of its exciting winding is L_d = 1.00 henry. When the rotor is in the quadrature-axis position, the inductance is L_q = 0.50 henry. The exciting winding has N = 1,000 turns. Determine approximately the maximum torque that the motor can develop with 115 V at 60 Hz applied to its exciting winding.



Elementary reluctance motor.

Figure B.4

C. Induction Machine

C.1. The results of the no–load and blocked–rotor tests on a three phase, Y–connected induction motor are as follows:

No-load test:	Line-to-line voltage	= 220 V
	total input power	= 1000 W
	line current	= 20 A
	friction losses	= 400 W
Blocked–rotor test:	Line–to–line voltage	= 30 V
	total input power	= 1500 W
	line current	= 50 A

Assuming $R'_2 = R_1$, calculate the parameters of the approximate equivalent circuit.

C.2. A 3–phase, wye–connected, 60 Hz, 220 V, 3677.5 W, 1800 rpm induction motor has the following test data:

Quantity	**No load**	**Blocked rotor**
Voltage	220 (127/phase)	68 (39.3/phase)
Current	4.35	20
Power	244 (81.3/phase)	1265 (422/phase)
Windage and friction	65 (21.7 phase)	

The stator resistance at conventional temperature and including skin effect is $R_1 = 0.545$ ohms per phase. Determine the constants.

C.3. A 36.8 kW, 2.2 kV, 13.5 A, [(1160r)/(min)], 60 Hz, wound–rotor induction motor has the following equivalent–circuit parameters:

$$R_1 = 2.22\ \Omega \qquad X'_{sc} = 14.2\ \Omega$$

$$R'_2 = 2.97\ \Omega \qquad X_{mu} = 324.0\ \Omega$$

The effective turns ratio is $N_1/N_2 = 1.22$.

a) Determine the external rotor–circuit resistance per phase required to hold down the starting current to three times the rated value.

b) Determine the speed at which the motor would develop an internal torque equal to 125% of the rated torque with this starting resistance still in circuit.

c) Determine the line current that would result if the starting resistance were shorted out of circuit at the speed determined in (b).

C.4. A 3–phase, Y–connected, 60 Hz, 220 V, 3677.5 W, 1800–rpm, wound–rotor induction motor has the following constants: $R_1 = 0.545$, $R_2' = 0.541$, $X_1 + X_2' = 1.68$ Ohms. The slip at full load is $s = 0.05$. The line current during the starting cycle is not to exceed 3 times the nominal current. The load torque equation is $T_{load}(s) = 13.6 + 8.27\,(1 - s)^2$ Nm. Neglecting the exciting current, investigate the feasibility of starting the motor as is or by connecting an external resistance to the rotor.

C.5. A 60–Hz, four-pole, Y–connected induction motor is rated 3677.5 W, 220 V (line to line). The equivalent circuit parameters are:

$R_1 = 0.48\ \Omega$ $\quad R'_2 = 0.42\ \Omega$ $\quad B_{mu} = -1/30\ \Omega^{-1}$

$X_1 = 0.80\ \Omega$ $\quad X'_2 = 0.80\ \Omega$

The motor is operating with slip of 0.04. Find the input current and power factor. Find the air gap power, the mechanical power, and the electromagnetic torque.

C.6. A 3,677.5 W, 60 Hz, 115 V; 8 pole; three-phase induction motor was tested, and the following data were obtained:

No-load test: $V_1 = 115$ V; $\quad P_1 = 300$ W; $\quad I_1 = 10$ A

Load test: $V_1 = 115$ V; $\quad P_1 = 4{,}710$ W; $\quad I_1 = 27.3$ A; $\quad rpm_{rotor} = 810$

The DC stator resistance between terminals is $R_1 = 0.128\ \Omega$.

Calculate:

(a) the power output;

(b) the torque;

(c) the percent efficiency;

(d) the power factor of the motor for the given load values.

C.7. The following constants are for a 184-W 60-Hz 115-V four-pole induction motor:

$$r_1 = 2.15\ \Omega \qquad r_2 = 4.45\ \Omega$$

$$x_1 = 3.01\ \Omega \qquad x_2 = 2.35\ \Omega$$

$$x_M = 70.5\ \Omega$$

Core loss = 26.0 W, windage and friction loss = 14.0 W.

Calculate for a slip of 0.05 the

(a) current,

(b) power factor,

(c) output,

(d) torque, and

(e) efficiency.

D. Synchronous Machine

D.1. (a) A 60-Hz alternator has 2 poles. What is the speed of the alternator?

(b) A 60-Hz alternator has a speed of 120 rpm. How many poles has it?

D.2. An AC generator has six poles and operates at 1,200 rpm.

(a) What frequency does it generate?

(b) At what speed must the generator operate to develop 25 Hz? 50 Hz?

(c) How many poles are there in a generator that operates at a speed of 240 rpm and develops a frequency of 60 cycles?

D.3. A 60-kVA 220-V 60-Hz alternator has an effective armature resistance of 0.016 Ω and an armature leakage reactance of 0.070 Ω. Determine induced emf when the machine is delivering rated current at a load power factor of unity.

D.4. A 1,000-kVA, 4,600-V, three-phase, wye-connected alternator has an armature resistance of 2 Ω per phase and a synchronous reactance, X_s, of 20 Ω per phase. Find the full-load generated voltage per phase at:

(a) Unity power factor;

(b) A power factor of 0.75 lagging.

(c) A leading load of 0.75 power factor;

(d) A leading load of 0.4 power factor.

D.5. A three-phase synchronous generator has the following per-unit parameters:

Synchronous reactance $x_s = 0.4$

Effective armature resistance $r_e = 0.02$

Neglecting the effect of saturation on the synchronous reactance, calculate the per-unit and percent open-circuit phase voltage which corresponds to the field excitation that produces rated terminal voltage when the generator operates with a full kVA inductive load of 0.8 power factor.

D.6. A 50-kVA 550-V single-phase alternator has an open- circuit emf of 300 V when the field current is 14 A. When the alternator is short-circuited through an ammeter, the armature current is 160 A, the field current still being 14 A. The ohmic resistance of the armature between terminals is 0.192 Ω. Determine:

(a) synchronous impedance;

(b) synchronous reactance;

(c) regulation at 0.8 power factor, current lagging.

E. Power Systems

E.1. The system shown in Figure E.1 feeds an induction motor and a load. At start-up, the motor current is purely inductive and 5 times the nominal current. Assuming that the voltage at bus 1 is constant, determine the voltage at bus 4 when the motor starts up in the following two scenarios:

i) The load can be modelled as an equivalent constant impedance;

ii) The load is a constant PQ.

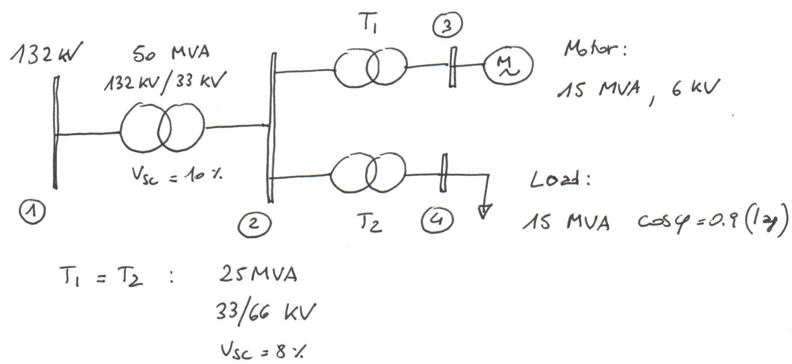


Figure E.1

E.2. For the system shown in Figure E.2, determine the voltage at bus A. Then, assuming that the voltage at bus A is constant and equal to the value previously determined, determine the value of the capacitor to install at bus B to obtain $v_B = 1$ pu.

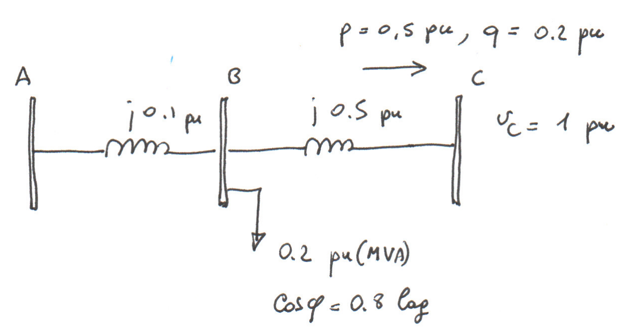


Figure E.2

E.3. Figure E.3 shows a radial transmission system where all values are in per unit with respect to transformer nominal voltages and 100 MVA. Determine the power factor at the 275 kV bus to have 11 kV at the other end of the system.

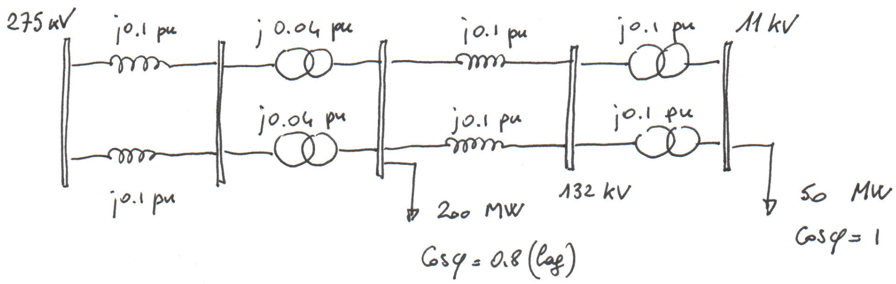


Figure E.3

E.4. Determine the single-phase equivalent circuit of the three-phase system shown in Figure E.4, using the following bases:

i) 100 MVA and transformer nominal voltages.
ii) 25 MVA and transformer nominal voltages.
iii) 100 MVA and 10 kV at bus 4.
iv) The maximum power that can be delivered to bus 4 for assigned values of v_1 and v_4.
iv) Assume the bases indicated at point (i) and that the voltage bus 1 is 15 kV and is the phase reference. Indicate which of the following statements is true and why:

a) The voltage magnitude at bus 4 is lower than 1 pu.
b) The phase angle at bus 3 is leading with respect to the phase reference.
c) The following condition must hold: $v_1 > v_2 > v_3 > v_4$, where v_i is the voltage magnitude of the voltage phasor at bus i.
d) The following condition must hold: $\vartheta_1 > \vartheta_2 > \vartheta_3 > \vartheta_4$, where ϑ_i is the phase angle of the voltage phasor at bus i.

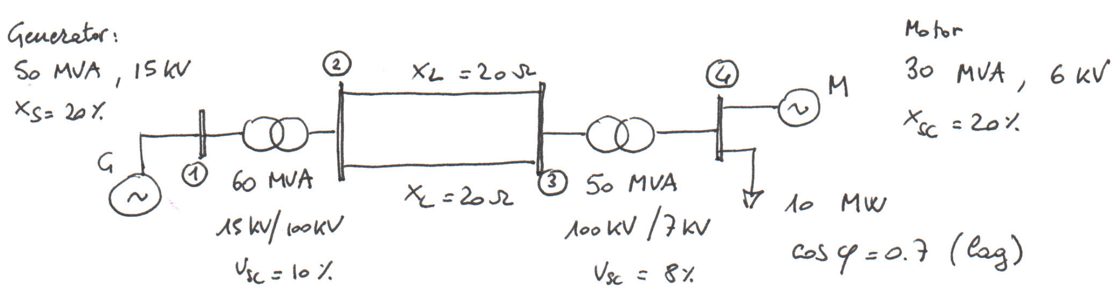


Figure E.4

E.5. Figure E.5 shows a three-phase radial distribution system. The load at the end of the feeder consume 50 MW with 0.8 lagging power factor. What is the value of the voltage at the generator bus required to keep the voltage on the load equal to 30 kV? Determine also the power factor of the generator in the operating conditions determined above.

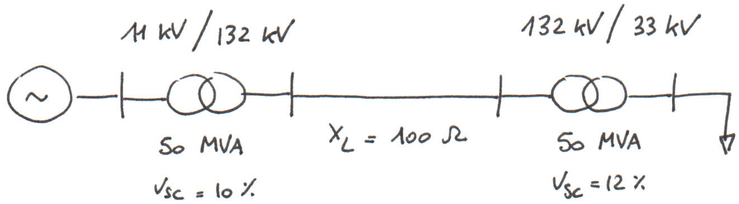


Figure E.5