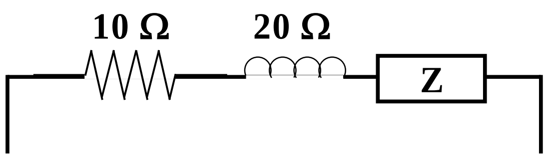
Cairo University
Faculty of Engineering
Electrical Power Engineering Dept.

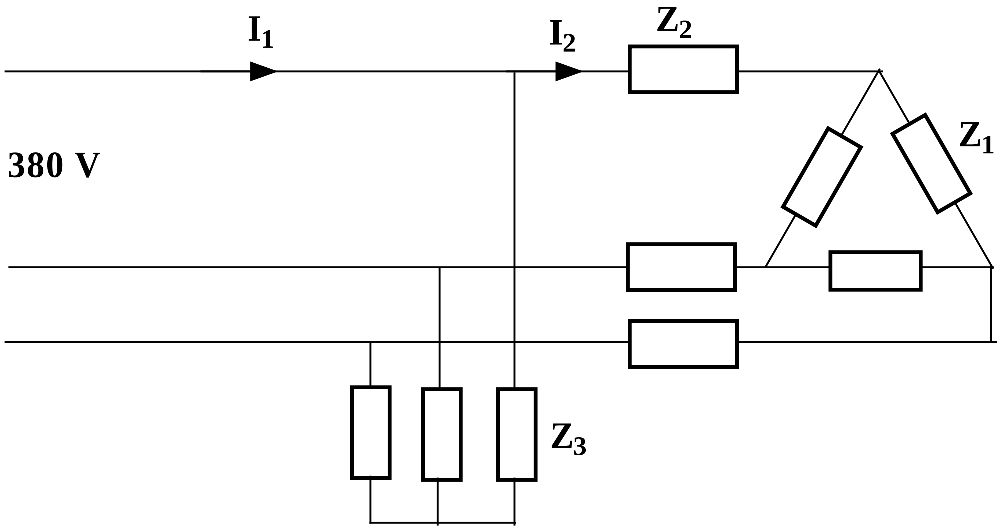
Elective Course
EPM332: Electrical Machines
Sheet (1)

Revision

1. A series circuit consists of a resistance of 5.0 ohm and an inductor of 5.0 ohm at 50 Hz. If a supply voltage of 220 volts, 50 Hz is applied to the above circuit calculate the supply current, power factor and power. Draw a phasor diagram for the voltages across each element and the current.
2. A series circuit draws a current of 10.0 Amp at 0.8 power factor lagging from a supply voltage of 200.0 volts. Determine the components of the circuit. If the supply voltage and frequency are doubled, what will be the supply current and power factor?
3. The series circuit shown in figure draws a current of 10.0 Amp at 0.8 power factor lagging from a supply voltage of 200.0 volts. Determine the components of the impedance Z.

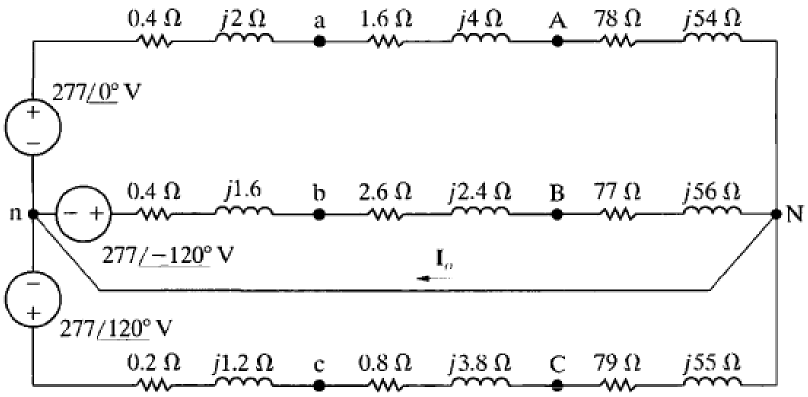


4. For the circuit shown calculate I_1, I_2 if $Z_1 = 12 + j9$, $Z_2 = 1 + j2$ and $Z_3 = 10 - j20$.



5. A balanced Δ-connected load has an impedance of 864-j252 Ω,/phase. The load is fed through a line having an impedance of 0.5-j4 Ω/phase. The phase voltage at the terminals of the load is 69 kV. The phase sequence is positive. Use V_{AB} as the reference.
   a) Calculate the three phase currents of the load.
   b) Calculate the three line currents.
   c) Calculate the three line voltages at the sending end of the line.

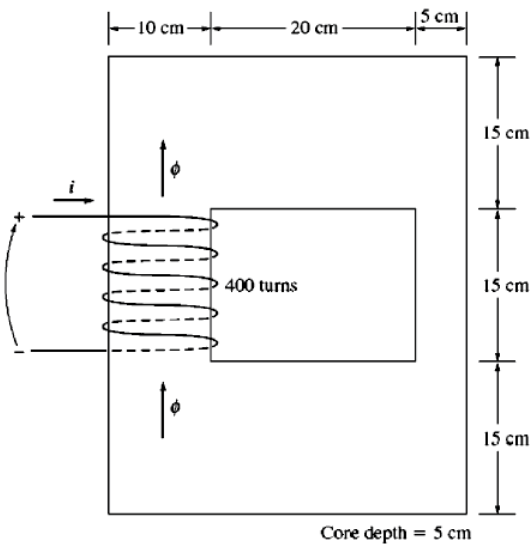
6. For the circuit in the shown figure:
   a) Find I_o.
   b) Find V_{AN}.
   c) Find V_{AB}.
   d) Is the circuit a balanced or unbalanced three phase system?



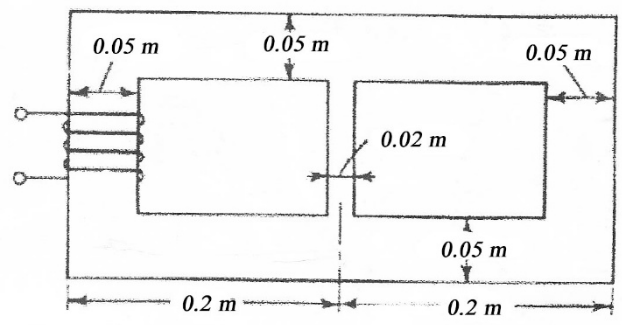
7. A series circuit consists of a resistance of 8.0 Ω and a capacitor of 6.0 Ω and a coil of 8.0 Ω at 50 Hz. If a supply voltage of 220 volts, 50 Hz is applied to the above circuit calculate the supply current, power factor, reactive power and power. Draw a phasor diagram for the voltages across each element and the current.

8. A balanced star-connected load with per phase impedance of (20+j10) Ω is connected to a balanced 415 V, 3-phase supply through three conductors, each of which has a series impedance of (2+j4) Ω. Find:
   i. The line current.
   ii. The voltage across the load.
   iii. The power delivered to the load, and the power lost in the line conductors.

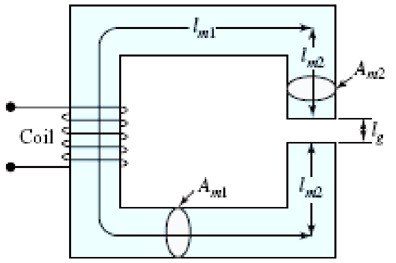
9. A ferromagnetic core is shown in Fig. 2. The depth of the core is 5 cm. The other dimensions of the core are as shown in the figure. Find the value of the current that will produce a flux of 0.005 Wb. With this current, what is the flux density at the top of the core? What is the flux density at the right side of the core? Assume that the relative permeability of the core is 1000.



10. The thickness of the magnetic circuit shown in the figure is 0.04 m and the relative permeability of the iron core is 8000. Determine the coil MMF needed to produce a flux of 0.0014 Wb in the right leg of the core.



11. For the magnetic circuit shown in Fig.(4), neglecting leakage and fringing, Determine the MMF of the exciting coil required to produce a flux density of 1.6 T in the air gap. The core has a relative permeability of 2500. The dimensions are: l_{m1} = 60 cm, A_{m1} = 24 cm^2, l_{m2} = 10 cm, A_{m2} = 16 cm^2, l_g = 0.1 cm.



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Transformers

1. A 50 HZ single-phase transformer has a primary voltage of 33 KV and a secondary voltage of 6.6 KV. If the maximum flux density permissible is 1.2 Tesla and the number of primary turns is 1250. Calculate the number of secondary turns and the cross-sectional area of the core.

2. Determine the rated primary and secondary currents of a 20 KVA 1200/120 V, 1-ph transformer. If this transformer delivers a load of 12 KW at 0.8 power factor, find the primary and secondary currents and the impedance of the load referred to the primary side.

3. A single-phase transformer has a turns ratio of 4:1. The transformer may be considered ideal. A load impedance of $10\angle 30°$ ohm is connected across the secondary terminals and the secondary voltage is 120 V. Find the currents in the primary and secondary windings and the primary voltage.

4. The parameters of a 200/100 V, 50 HZ, single-phase transformer are:

   $r_1 = 0.1 \ \Omega \qquad x_1 = 0.4 \ \Omega \qquad r_2 = 0.03 \ \Omega \qquad x_2 = 0.1 \ \Omega$

   $R_c = 8400 \ \Omega \qquad X_m = 2500 \ \Omega$

   The transformer supplies a secondary load current of 20 A at 0.8 power factor lagging with rated secondary voltage. Calculate:
   a) The primary applied voltage using the exact equivalent circuit.
   b) Repeat "a" using the approximate equivalent circuit. Comment.

5. A 550 kVA, 11000/220, 50 Hz, transformer has the following parameters:
   $r_1 = 2\ \Omega$, $x_1 = 10\ \Omega$, $r_2 = 8*10^{-4}\ \Omega$, $x_2 = 4*10^{-3}\ \Omega$
   The no-load power factor 0.1 and the no-load impedance is 3000 Ω. Calculate:
   a) The parameters of the equivalent circuit in p.u.
   b) The iron losses and full load copper losses.

6. A 10 KVA, 480/120 V, single-phase transformer has the following parameters:

   $r_1 = 0.6 \ \Omega \qquad x_1 = 1.0 \ \Omega \qquad r_2 = 0.0375 \ \Omega \qquad x_2 = 0.0625 \ \Omega$

   $R_c = 3000 \ \Omega \qquad X_m = 500 \ \Omega$

   Using the approximate equivalent circuit calculate
   a) The voltage and current at the primary terminals for a load of 10 KVA at 120 V and a power factor of 0.85 lagging.
   b) The voltage and current at the primary terminals for a load of 10 KVA at 120 V and a power factor of 0.85 leading. Comment.

7. A 500 KVA, 2300/230 V, single-phase distribution transformer is tested to find the equivalent circuit parameters. The following data were obtained:

	Voltage (V)	Current (A)	Power (W)
Open circuit test	230	94	2250
Short circuit test	100	230	9200

   Find the equivalent circuit parameters referred to the primary.

8. A 100 KVA, 1200/240 V, 60 HZ, single-phase transformer is tested to obtain the equivalent circuit parameters using a short-circuit test. The voltage applied during the test is 600 V with a short-circuit current equals to the rated current and short-circuit power of 1200 W.
   a) Find the parameters of the transformer.
   b) Assume that the transformer supplies a load of 100 KVA at 240 V and 0.8 power factor lagging. Find the voltage required at the primary side.

9. A 4.4 KVA, 220/110, 50 HZ transformer gave the following open circuit and short circuit test results:

	Voltage (V)	Current (A)	Power (W)
Open circuit test	110	2.0	64
Short circuit test	12	18	81

   Draw the approximate equivalent circuit showing the value of each element in ohm referred to the secondary. If an inductive load impedance of 3 ohm and 0.8 power factor is connected to the secondary terminals and a 220 V is applied to the primary, determine:
   a) The secondary and primary currents.
   b) The secondary voltage.

10. A 55 KVA, 220/110, 50 HZ single-phase transformer has the following particulars:
    - Maximum efficiency occurs at half of its full-load.
    - The maximum efficiency has a value of 98% at 0.8 power factor lagging.
    - Maximum regulation of 5% at full-load.
    - The no-load power factor is 0.1

    Determine:
    a) The iron losses and the full-load copper losses in watts.
    b) The equivalent circuit parameters referred to the secondary.
    c) The power factor of the load at which zero regulation occurs.

11. A single-phase 55 KVA, 220/110 V, 50 HZ transformer has the following particulars:
    - The efficiency at full-load and 0.85 power factor equals to 96.6%.
    - The efficiency at half full-load and 0.85 power factor equals to 96.6%.
    - The power factor at short circuit test is 0.2.

    Determine:
    i. Iron losses and full-load copper losses.
    ii. R_{eq} and X_{eq} referred to primary.
    iii. The voltage regulation at full-load and unity power factor.

12. The daily variation of load on a 100 kVA distribution transformer is approximately as follows:

From	To	kW	kVAR
8 AM	1PM	65	54
1 PM	6 PM	80	50
6 PM	12 PM	30	30
12 PM	8 AM	0.0	0.0

The no-load core loss is 370 Watts and the full-load copper loss is 1200 Watts. Determine
i. The all-day efficiency of the transformer.
ii. The all-day efficiency of the transformer if it is disconnected from the supply during the no-load period. Comment.
iii. The efficiency at full-load and 0.6 power factor lagging.

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Three-Phase Induction Machines

1. A 3-phase, 208 V, 6 pole, 60 Hz, wound-rotor induction machine has a stator-to-rotor turns ratio of 1:0.5 and both stator and rotor windings are connected in star. When the stator of the induction machine is connected to a 3-phase, 208, 60 Hz supply and the rotor winding is short circuited, the motor runs at 1140 rpm. Determine:
   a) The per-unit slip.
   b) The voltage induced in the rotor per phase and its frequency.
   c) The speed of the rotor field with respect to the rotor and with respect to the stator.

2. A 3-phase squirrel cage induction motor runs at almost 1198 rpm at no-load and 1140 at full load when supplied with power from 60 Hz 3-phase supply. Determine:
   a) The motor number of poles.
   b) The percent slip at full load.
   c) The frequency of the rotor voltages and currents.
   d) The speed of the rotor field w.r.t the rotor, and w.r.t. the stator.
   e) The speed of the stator field w.r.t the stator, and w.r.t the rotor.
   f) The motor speed at slip of 10% and the rotor frequency at this speed.

3. A 3-phase, delta-connected, 280 V, 60 Hz, 20 HP, four-pole induction motor has the following equivalent circuit parameters:
   R_1=0.12 R_2'=0.1 X_1= X_2'=0.25 X_μ = 10
   The rotational losses is 400 W. For 5% slip, determine:
   a) The line current.
   b) The stator copper loss.
   c) The air gap power.
   d) The rotor copper loss.
   e) The developed power and the shaft power.
   f) The developed torque and the shaft torque.
   g) The efficiency.

4. A 3-phase, Y-connected, 480-V, 30-hp, 60-Hz, 4-pole induction motor has the following equivalent circuit constants in ohms/phase referred to the stator:
   R_1=0.24 R_2'=0.2 X_1=1.3 X_2'=1.2 X_μ = 37
   The no-load losses is 1340 W. The rotor is connected directly to a 480 V source. Compute the speed, output torque, output power in HP, efficiency and terminal power factor at slips of 1% and 2%.

5. A 100-hp, 3-phase, Y-connected, 440-V, 50-Hz, 8-pole squirrel cage induction motor has the following equivalent-circuit constants all expressed in ohms/phase referred to the stator:
   R_1=0.085 R_2'=0.067 X_1=0.196 X_2'=0.161 X_μ = 6.65
   The no-load rotational loss is 2.7 kW. Calculate:

a) The starting current, power factor, and developed torque.
b) The pull-out torque and the speed at which is occurs.
c) The HP output, stator current, power factor and efficiency at slip of 3 %.
d) If the motor drives a load of constant torque of 300 N.m. Determine the speed at which the motor will drive this load. Assume that the torque-speed characteristic in the operating region is almost linear.

6. A 4-pole, 50-Hz, 3-phase induction motor running at full load develops a torque of 25 Kg.m and it is observed that the rotor emf makes 98 cycle/min. If the mechanical torque lost due to friction and windage is 2 Kg.m. Find :
   a) the output hp.
   b) the rotor copper losses.
   c) the input power to the motor.
   d) the efficiency.

7. A 50-hp, 440-V, 3-phase, 4-poles, 50-Hz wound rotor induction motor develops a maximum internal torque of 250 % at slip of 16% when operated at rated voltage and frequency and with its rotor short circuited directly at the slip rings. Stator impedance and rotational losses can be neglected. Determine the slip at full-load, the rotor copper losses, and the starting torque at rated voltage and frequency.

8. For a 25-kW, 230-V, three-phase, 60-Hz squirrel-cage induction motor operating at rated voltage and frequency, the rotor copper loss at maximum torque is 9 times that at full load, and the slip at full-load is 0.023. No-load losses and stator impedance may be both neglected. Find:
   a) The slip at maximum torque.
   b) The maximum torque as a percentage of the full load torque.
   c) The starting torque as a percentage of the full load torque.

9. A 208-V, 6-pole, Y-connected 25-hp induction motor is tested in the laboratory, with the following results:

No-load test	208 V, 22 A, 1200 W, 60 Hz
Locked rotor test	24.6 V, 64.5 A, 2200 W
DC test	13.5 V, 64 A

   a) Determine the equivalent circuit parameters.
   b) If the motor was running at full-load at a slip of 3.8%, and it’s required to stop the motor using plugging method, find immediately after switching the stator leads the slip and the induced torque

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<u>2-phase Servo Motors</u>

1. An unbalanced two-phase voltage system is described by:
   V_m=115 ∟0 volts and V_c = 75 ∟-65^o volts
   Find the positive and negative sequence components that can be used to represent the unbalanced voltage system.

2. Determine the unbalanced two-phase voltage system that is represented by a positive sequence component of 80∟15^o and a negative-sequence component of 20∟40^o.

3. The parameters of 115 V, 50Hz, 2-pole, two-phase servomotor are:
   R_1 = 300 Ω, R_2' = 1380 Ω, X_1 = X_2' = 385 Ω, X_m = 695 Ω.
   This servomotor is operated with V_m = 115∟0 V and V_c = 80∟-60 V and at a slip of 0.25.
   a. Draw the two-part equivalent circuit of the motor. Show the proper applied voltage in each part.
   b. Compute the developed torque, expressed in synchronous watts and N.m.
   c. Calculate the main and control winding currents.
   d. Calculate the power supplied to the main and control windings.
   e. Find the ratio between the forward and backward fluxes. Assume linear magnetic circuit.
   f. Will the motor tend to single-phase operation? Verify your answer.
   g. Repeat "b" using the design formula.

4. Three points on the torque-slip characteristic of a servomotor, with balanced two phase voltage of 200 V at 50 HZ applied to its terminals, are:

Torque (N.m.)	0.096	0.123	0.132
Slip (p.u.)	0.5	1.0	1.5

The main phase voltage is held constant at 200 V, 50 Hz, and the control phase voltage is 80 V, the two voltages are in time quadrature. Find the developed torque at a slip of 0.6.

5. The torque-speed characteristic of a servomotor is given by:
   $T_m = 0.00174\ V_c - 64 * 10^{-5}\ \omega$
   The moment of inertia of the motor and the load is 10^{-5} Kg.rn^2, and the viscous friction of the load is 11*10^{-5} N.m/(rad/sec). Obtain the position transfer function of this servomotor.

6. A 2-phase servomotor has 115∟0 V applied to the main winding. At a particular point of operation corresponding to a control winding voltage of 75∟80^o V, the positive and negative sequence impedances are 220∟67^o and 175∟57^o respectively.
   Determine:
   a. The main and control winding currents.
   b. The main and control winding powers.

c. The developed torque in synchronous watts, assume the stator resistance is 20 ohm.

7. Three points on the T-s characteristic of a 2-pole servomotor, with balanced 2-phase voltages of 200 V, 50 HZ applied to its terminals, are:

Torque (N.m.)	0.4	0.8	1.2
Slip (p.u.)	0.5	1.0	1.5

The main phase voltage is held constant at rated value, and the control phase voltage is in time quadrature with the main phase voltage. It is found that the motor has a starting torque of 0.64 N.m. at a particular point of operation corresponding to certain value of the control phase voltage.

a. Calculate the operating control phase voltage.
b. Find the developed torque at a slip of 0.5.
c. If the motor has an inertia load and the moment of inertia of the load and the motor is 10^{-5} Kg.m^2, obtain the position transfer function of the servomotor.

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Single-Phase Induction Machines

1. A 0.25 hp, 110 V, 60 Hz, 4-pole single-phase induction motor has a rotational loss of 15 watts at normal speed. The equivalent circuit parameters are as follows:
   R_1=1.3 R_2'=3.2 X_1=2.5 X_2'=2.2 X_μ = 48

Calculate for a slip of 5%:
   a) The supply current and power factor.
   b) The output power and the efficiency.
   c) Would you permit continuous operation of this motor.

2. A 1.5 hp, 22A V, 50 Hz, 6-pole single-phase induction motor has a rotational loss of 290 watts at normal speed. The equivalent circuit parameters are as follows:
   R_1=1.3 R_2'=3.2 X_1=2.5 X_2'=2.2 X_μ = 48
   Calculate for a slip of 4%:
   a) The developed torque and the shaft torque.
   b) The motor efficiency.
   c) If the rotor of the motor is blocked and rated voltage is applied. Compute the readings of a line wattmeter and ammeter.

3. The following no load and blocked rotor test data are available for a single-phase induction motor:

	Voltage (V)	Current (A)	Power (W)
Blocked rotor test	53	6.6	210
No-load test	208	3.85	160

   The stator resistance is 1.48 ohms. Determine the parameters of the equivalent method

4. A 0.2 hp, 220 V, 50 HZ, 2-pole single-phase induction motor has two identical windings. The locked rotor test (when one winding only is fed from a l-ph supply) gives the following results: V = 44 V, I = 2.42 A, P =64 W, Determine:
   a) The value of the resistance, when connected in series with one winding, would yield the maximum starting torque.
   b) The value of the capacitor, when connected in series with one winding, would yield the maximum starting torque.
   c) Compare the starting torque, current and power factor of the above two cases.

5. Two short circuit tests were carried on l/3 HP, 120 Y, 50 Hz, 4-pole capacitor start single-phase induction motor:

	Voltage (V)	Current (A)	Power (W)
Main winding	12	2	18
Auxiliary winding	12	1.2	13.7

   Assume R_{1m} = 1.0 ohm and R_{1a} = 2.0 ohm, Determine:
   a) The main and auxiliary winding impedances.
   b) The effective turns ratio ($a = N_a/N_m$).
   c) The value of the capacitor required to obtain maximum starting torque. And the value of this torque.

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Stepper Motors

1. A single-stack, four-phase multi-pole stepper motor is required to produce an 18^o step motion. Determine the number of rotor poles (teeth) and the sequence of excitation of the stator phases. Draw a cross-sectional view of the stepper motor.

2. A single-stack, eight-phase multi-pole stepper motor has six rotor teeth. The phases are excited one at a time. Determine:
   a. The step size.
   b. The steps per revolution.
   c. The speed of rotation in rpm if the excitation frequency is 120 Hz.

3. A three-stack, four-phase multi-pole stepper motor has eight teeth on the rotor as well as on the stator. Determine the step size as excitation is changed from one stack to the next.

4. A three-stack stepper motor is used to produce a step size of 2^o. Determine:
   a. The steps per revolution.
   b. The number of rotor teeth.

5. A variable-reluctance stepper motor has the following parameters:
   $R_w = 2\ \Omega$, $L_w = 50$ mH, $I_{rated} = 5$ A
   Each phase is controlled by a unipolar drive circuit. The resistance connected in series with the winding is $R_{ex} = 10\ \Omega$ and that with the free-wheeling diode is $R_f = 5\ \Omega$. Determine:
   a. The electrical time constants at turn-on and turn-off of a phase.
   b. The value of the supply voltage V_s.
   c. The voltage and current ratings of the transistor and diode.
   d. If phase current conducts for $3(\tau_{on}$ and $\tau_{off})$, determine the maximum value of the stepping rate (steps per second) of the motor.