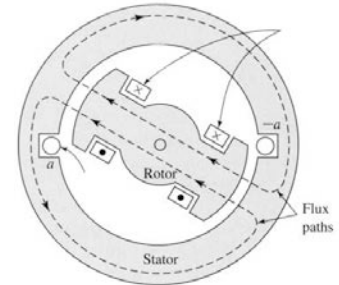
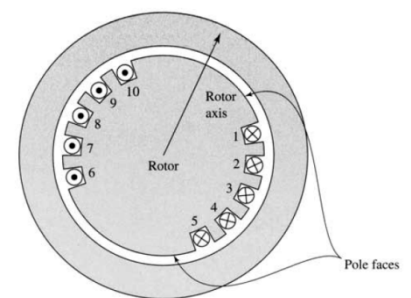


Fundamentals of AC Machines

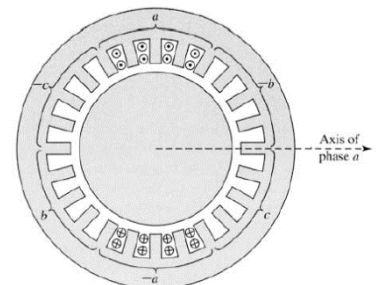
- The pole arc of a 2-pole, salient-pole synchronous generator is $\frac{2}{3}$ of the pole pitch. The number of turns per pole is 50 turns. The field current is 20 A. Calculate the amplitude of the fundamental, third, and fifth harmonics of the field waveform.



- The rotor of a 2-pole, 50 Hz turbo-generator is 120 cm long and 90 cm diameter. The air gap length is 3 cm. The rotor winding consists of 200 turns spread over $\frac{3}{4}$ of the circumference. The field current is 100 Amps. Neglecting the magnetic reluctance of the iron parts.
 - Plot to scale the MMF distribution in the air gap.
 - Calculate the maximum value of the air gap flux density.
 - Find the total flux per pole.



- The stator of a 2-pole, 3-phase, star connected machine having a uniformly distributed winding with a spread of 60 degrees has a total number of conductors of 200, and carries a current of 100 A. Plot to scale the mmf distribution of the stator when the current in phase (a) is at its maximum. Determine the values of the MMF at 30 and 60 mechanical degrees at the above case.



- A six-pole, 50 Hz cylindrical rotor synchronous machine has rotor winding with a total of 138 series turns and a distribution factor $(k_d) = 0.935$. The rotor length is 1.97 m, rotor radius is 58 cm and the air-gap length is 3.15 cm.
 - Calculate the field current required to achieve peak fundamental air-gap flux density of 1.23 T.
 - Calculate the corresponding flux per pole.
 - If the generator has an armature that consists of 54 double-layer slots and the number of turns per coil is 10. The coils are full pitched and all the coils per phase are connected in series. Calculate the rms voltage generated per phase.
- The fundamental flux per pole in a 6-pole, 3-phase, 50 Hz, delta connected synchronous generator is 1.4 M lines. The synchronous generator has 90 slots; the coil pitch is 12 slots and 4 cond./slot. The equation of the flux distribution in the air gap is:

$$B = B_1 \cos\theta + 0.3 B_1 \cos(3\theta) + 0.1 B_1 \cos(5\theta)$$
 - Determine the voltage per phase and the line voltage due to the fundamental, the 3rd and the 5th harmonics of the flux. Calculate also the circulating current if the resistance and inductance per stator phase are 0.03 ohm and 0.4 mH respectively.

- b) Determine the best possible choice for the windings pitch angle if it desired to eliminate the fifth harmonic component of the voltage.
7. Calculate the EMF per phase of a 4-pole AC generator from the following particulars: flux/pole = 12 M lines, slots/pole/phase = 4, cond./slot = 4, coil span = 150° electrical, frequency = 50 Hz, two parallel paths per phase.
8. A 3-phase, 4-pole, 2-layer winding is to be installed on a 48 slots stator. The coil pitch is chorded by two-slot pitches and there are 10 cond./slot. All coils in each phase are connected in series and the three phases are connected in delta. The flux/pole is 0.054 wb and the speed of rotation of the magnetic field is 1500 rpm. Calculate:
- The winding factor.
 - The stator terminal voltage.

Three-Phase Induction Machines (1)

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 in ohms:
 $R_1=0.12$ $R_2'=0.1$ $X_1=X_2'=0.25$ $X_\mu = 10$
The rotational losses is 400 W. For 2% 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 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:
 $R_1=0.085$ $R_2'=0.067$ $X_1=0.196$ $X_2'=0.161$ $X_\mu = 6.65$
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 it occurs.
 - c) The output power in hp, 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.

5. 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 :
- the output hp.
 - the rotor copper losses.
 - the input power to the motor.
 - the efficiency.
6. 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.
7. 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:
- The slip at maximum torque.
 - The maximum torque as a percentage of the full load torque.
 - The starting torque as a percentage of the full load torque.
8. A 3-phase, 250-kW, 460-V, 60 Hz, eight-pole induction machine is driven by a wind turbine. The induction machine has the following parameters:
 $R_1=0.015 \Omega$ $R_2'=0.035\Omega$ $L_1 = L_2'=0.385 \text{ mH}$ $L_\mu = 17.24 \text{ mH}$
 The induction machine is connected to a 460 V infinite bus through a feeder having a resistance of 0.01Ω and an inductance of 0.08 mH. The wind turbine drives the induction machine at a slip of -25%.
- Determine the speed of the wind turbine.
 - Determine the voltage at the terminals of the induction machine.
 - Determine the power delivered to the infinite bus and the power factor.
 - Determine the efficiency of the system. Assume the rotational and iron losses to be 3 kW.

Three-Phase Induction Machines (2)

1. A 30-hp, 400-V, delta-connected, eight-pole, 50-Hz, squirrel-cage induction motor takes a full load current of 37 A, and has a full load slip of 4.5%. The standstill impedance/phase is 3.9 ohm. The power factor at starting is 0.5.
 - a) Determine the starting torque and the supply starting current if the motor is started by direct online starting.
 - b) If the motor is supplied from the utility through a 11000/400 V transformer, the transformer impedance referred to the secondary side is $Z_T = 1.57 + j7.84 \text{ m}\Omega$, the impedance of the feeder from the transformer supplying the point of common coupling (PCC) is $Z_F = 20.55 + j65.1 \text{ m}\Omega$, the impedance of the feeder supplying the motor from the PPC is $Z_L = 25 + j60 \text{ m}\Omega$, determine the percentage voltage drop at the PCC at starting.
 - c) Determine the starting torque and the supply starting current using:
 - i) A 1 ohm series resistance.
 - ii) An auto transformer started with a 70% tapping.
 - iii) A star-delta starter.
2. A 3-phase, 400-V, 6-pole, 60-Hz, 30-hp, star-connected, deep-bar induction motor, has its maximum torque of 250% at slip of 18%. The rotor dc resistance per phase referred to the stator side is 2.8 ohm, and its AC resistance at 60 Hz is 4.0 ohm. Neglect the stator impedance. Determine:
 - a) The full load slip, current and developed torque.
 - b) The minimum voltage to be applied such that the motor still supplies its full load torque.
 - c) The current and developed torque at the minimum voltage calculated in (b).
3. The equivalent standstill impedances referred to the stator of the two cages of a double-cage induction motor are $6 + j2$ and $1 + j5$ ohm/phases. Find the ratio between the individual torque due to each cage, neglecting stator impedance:
 - a) At starting.
 - b) When running at a slip of 3%.
4. The resistance measured between each pair of slip rings of a three-phase, 50-Hz, 300-hp, 16-pole, star-connected wound-rotor induction motor is 0.035 ohm. With the slip rings short-circuited the full load slip is 0.025, and it may be assumed that the torque/speed curve is a straight line from no-load to full-load. This motor drives a fan which requires 300 hp at the full load speed of the motor. The torque required to drive the fan varies as the square of the speed. Determine the resistance that should be connected in series with each slip ring so that the fan will run at 300 rpm.
5. A 50-hp, 440-V, 3-phase, 4-pole, 60-Hz, wound-rotor induction motor developed its rated full load output at a speed of 1746 rpm when operating at rated voltage and frequency with its slip rings short circuited. The maximum torque is 200 % of full load torque. The resistance of the rotor is 0.1 ohm/phase. Compute:
 - a) The rotor copper losses at full load.

- b) *The speed at maximum torque.*
 c) *The resistance connected in series to the rotor circuit to produce maximum torque at starting.*
6. A 208-V, 6-pole, Y-connected 25-hp squirrel-cage 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
7. *The following data were obtained from tests on a 6-pole, 60-Hz, 440-volts, 3-phase, 1152- rpm, star-connected, deep-bar induction motor:*
- | | |
|-----------------------------------|------------------------------|
| <i>No-load test</i> | <i>440 V, 24 A, 2.56 kW</i> |
| <i>Locked rotor test at 15 Hz</i> | <i>25.4 V, 90 A, 2.77 kW</i> |
| <i>Locked rotor test at 60 Hz</i> | <i>440 V, 503 A, 150 kW</i> |
| <i>DC test</i> | <i>10 V, 100 A</i> |
- a) *The parameters of the equivalent circuit.*
 b) *The torque at full load.*
 c) *If the load torque is constant and its value equals the full load torque, determine the minimum turns ratio for the auto transformer used to start-up this motor at this load.*
8. The supply phase voltage of a 3-phase, star-connected, 5-hp, 208-V, 60 Hz, four-pole induction motor has the following component voltages:
- Fundamental voltage, rms = 100 V,
 Fifth harmonic voltage, rms = 15 V,
 Seventh harmonic voltage, rms = 10 V,
 The parameters of the equivalent circuit at fundamental frequency are:
 $R_2' = 0.5 \Omega$ $X_2' = 1 \Omega$ $X_\mu = 35 \Omega$.
- The motor is loaded and runs at 1710 rpm. Determine the torques produced by the fundamental, fifth harmonic and seventh harmonic voltages.

Single-Phase Induction Machines

1. An unbalanced two-phase voltage system is described by: $V_m = 115 \angle 0^\circ$ volts & $V_c = 75 \angle -65^\circ$ volts. Find the positive and negative sequence components that can be used to represent the unbalanced voltage system.
2. A 1.5 hp, 220 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:
 $R_1 = 1.3$ $R_2' = 1.73$ $X_1 = 2.0$ $X_2' = 2.0$ $X_\mu = 105$
 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 the 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 circuit.

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 1-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 1/3 HP, 120 V, 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

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

Synchronous Generators (1)

1. A 2-pole, 3-phase, star connected, turbo-alternator rated at 2500 KVA, 6600 V, 50 Hz. The armature resistance and leakage reactance per phase are 0.07Ω and 0.9 ohm , respectively. The friction and windage losses are 20 KW, and its core losses are 12 KW. The armature winding is distributed in 60 slots with 4 cond/slot. The O.C.C. at rated frequency is as follows:

MMF	5000	10000	15000	20000	25000	30000
Voltage	1500	2800	3700	4200	4400	4600

- a) Find the excitation necessary for full-load operation at 0.8 lagging, 0.8 leading and unity power factor at rated voltage.
 b) Determine the power angle and the shaft torque at the above cases.

2. A 8-pole, 3-phase, star connected alternator is rated at 5000 KVA, 6600 V, 50 Hz. The armature has 360 slots with two conductors per slot, and the coil pitch is $2/3$ of the pole pitch. The field winding has 68 turns per pole. The leakage reactance per phase is 1.0 ohm . The O.C.C. at rated speed is as follows:

I_f	100	150	200	250
E	4500	6550	7500	8000

Determine the excitation current necessary for full-load operation at 0.75 lagging power factor, and for half load operation at unity power factor at rated voltage.

3. A 2300 V, 1000 KVA, 0.8 power factor lagging, 60 Hz, two-pole star connected synchronous generator has a synchronous reactance of 1.1Ω and an armature resistance of 0.15Ω . The friction and windage losses are 24 KW, and its core losses are 18 KW. The field circuit has a dc voltage of 200 V, and the maximum I_f is 10 A. The resistance of the field circuit is adjustable over a range of 20 to 200 Ω . The OCC at rated speed is as follows:

I_f	1	2	3	4	5	6	7	8
E	600	1200	1800	2250	2500	2700	2800	2850

- a) Determine the internal generated voltage and the corresponding field current at rated conditions.
 b) Determine the prime mover power and torque at rated conditions.
 c) If the field current is adjusted to 4.5 A, determine:
 i) The terminal voltage and generator efficiency at half load with unity power factor.
 ii) The terminal voltage and generator efficiency at full load with 0.8 power factor lagging.
 iii) Determine the adjustment needed to the field resistance for the above two cases to restore the terminal voltage to its rated value.

4. A 15 MVA, 11 KV, 50 HZ, 3000 rpm, Y-connected turbo-alternator has a leakage reactance of 0.9 ohm per phase. The O.C.C. and S.C.C at rated speed are as follows:

MMF (K AT)	10	18	24	30	40	45	50
$E_{o.c.}$ (KV)	2.8	4.85	5.83	6.64	7.39	7.68	7.88
I_{sc} (Amps.)	290						

The alternator is supplying power to an infinite bus bar. Calculate:

- The short circuit ratio (SCR).
- The full-load armature reaction MMF.
- The field MMF and the voltage regulation at full load, 0.8 lagging power factor (using the exact method).
- The unsaturated and saturated values of the synchronous reactance.
- The field MMF and the voltage regulation at full load, 0.8 lagging power factor (using the approximate method).

5. The no-load and full-load zero power factor curves for 5MVA, 12 KV, 50 HZ, 3-phase, Y-connected turbo-generator are as follows:

I_f (Amp)	10	20	30	40	43	50	60	70	80	100
$E_{o.c.}$ (V)	1750	3500	5520	6360	6700	7260	7860	8200	8580	8800
V_{fl} (V)					0	1080	2720	4250	5380	6750

- Draw the potier triangle and determine the leakage reactance in ohm.
 - Determine the armature reaction in terms of field amperes.
 - Draw the S.C.C.
 - Find the field current and the voltage regulation at half full-load, 0.8 lagging power factor (using the exact method).
 - The unsaturated and saturated values of the synchronous reactance in ohm.
6. A 5MVA, 11 KV, 50 HZ, 3-phase, Y-connected turbo-generator has the following O.C.C. at rated frequency:

I_f (Amps)	40	60	80	100
E (KV)	7.3	10.3	12.4	14

The excitation needed to produce full-load current on short circuit is 28 Amps. When the generator is supplying full-load current to a pure inductive load at 11 KV, the excitation is 100 Amps. Calculate:

- The leakage reactance.
- The armature reaction in terms of field amperes.
- The field current and the voltage regulation at 80 % of full-load, 0.8 lagging power factor (using the exact method).
- The unsaturated and saturated values of the synchronous reactance in ohm and in p.u.

Synchronous Generators (2)

1. A diesel generator unit is used to supply an inductive load at 380 V. The load active and reactive power requirements at rated voltage are 600 kW and 600 kVAR. The diesel engine drooping characteristics is such that the speed drop from 1.04 p.u. at no load to 1.0 p.u. at rated load. Assume the synchronous reactance of the generator to be 0.1Ω , Calculate:
 - a) The suitable kVA rating of the generator and the diesel engine rating.
 - b) The open circuit voltage corresponding to the required rated conditions.
 - c) If the load is changed such that the load active and reactive power requirements are 400 kW and 700 kVAR, determine the necessary changes in the drooping characteristics and in the excitation voltage to maintain both the terminal voltage and frequency constant.
 - d) If no adjustments for the drooping characteristics or the excitation are made, what will be the terminal voltage and frequency for a load current of 900 Amp at 0.8 pf lagging. Take the value of the open circuit voltage equal to that calculated in (b).

2. Two synchronous generators are operated in parallel to feed a load of 36 MVA, 0.866 pf lagging at 13.2 kV. The generators are rated as follows:
G1: 30 MVA, 13.2 kV, $X_s = 4.5 \Omega$
G2: 12 MVA, 13.2 kV, $X_s = 14.5 \Omega$.
If the excitation current of the two generators is adjusted to make the generators operate at the same power factor. The drooping characteristics of the two prime movers are adjusted such that the output powers of the generator are proportional to their ratings. Determine for each generator the output power, current, power factor, the power angle and the open circuit voltage.

3. Two identical 2000 kW alternators operate in parallel. The governor of the first is such that the frequency drops from 50 Hz on no-load to 48 Hz on full-load. The corresponding drop of the second alternator is 50 to 47.5 Hz. How will the two alternators share a load of 3000 kW? What is the maximum load that can be delivered without overloading either alternator?

4. A generating station for a power system consists of four 120-MVA 15-kV 0.85-PF-lagging synchronous generators with identical speed droop characteristics operating in parallel. The governors on the generators' prime movers are adjusted to produce a 3-Hz drop from no load to full load. Three of these generators are each supplying a steady 75 MW at a frequency of 60 Hz, while the fourth generator (called the *swing generator*) handles all incremental load changes on the system while maintaining the system's frequency at 60 Hz.
 - a) At a given instant, the total system loads are 260 MW at a frequency of 60 Hz. What are the no-load frequencies of each of the system's generators?
 - b) If the system load rises to 290 MW and the generator's governor set points do not change, what will the new system frequency be?

- c) To what frequency must the no-load frequency of the swing generator be adjusted in order to restore the system frequency to 60 Hz?
5. A 480-V, 50-Hz, star-connected, six-pole synchronous generator is rated at 50 kVA at 0.8 pf lagging. It has a synchronous reactance 1Ω per phase. The generator is connected to a steam turbine capable of supplying 45 kW. The friction and windage losses are 1.5 kW, and the core losses are 1 kW. The stability limit for the power angle can be taken at 75° . The maximum field current is 105% of that necessary at rated conditions.
- Sketch the generator capability curve.
 - Can this generator supply a line current of 56 A at 0.7 pf lagging?
 - Determine the maximum amount of reactive power this generator can produce.
 - If the generator supplies 30 kW of real power, determine the maximum amount of reactive power that can be simultaneously supplied.

Synchronous Motors

1. A 3-phase, 11-kV, 750-rpm, Y-connected synchronous motor draws 60 A at 0.8 pf leading. The synchronous reactance is 30 ohms. Determine:
 - a) The output torque and the torque angle.
 - b) The minimum armature current for the input power. And the corresponding open circuit voltage.
 - c) The synchronizing power for a change of one mechanical degree in the power angle for the operating conditions of (b).
2. A 2300-V, 3-phase, Y-connected synchronous motor has a synchronous reactance of 2.2 ohms. It is operating at 0.5 leading pf with a line current of 200 A. Determine the open circuit voltage. With the same excitation maintained, the load on the motor is doubled; find the new values of the line current and power factor.
3. A 208-V, 45-kVA, 0.5-pf-leading, delta-connected, 60-Hz synchronous machine has a synchronous reactance of 2.5Ω and armature resistance of 0.2Ω . Its friction and windage losses are 1.5 kW, and its core losses are 1.0 kW. Initially, the shaft is supplying a 15-hp load, and the motor's power factor is 0.85 leading. The field current I_f at these conditions is 4.0 A
 - a) Find the line current, armature current and excitation voltage.
 - b) If the motor's excitation is increased by 25%, sketch the new phasor diagram of the motor. What are excitation voltage, armature current, and the power factor of the motor now?
4. A 100-hp, 440-V, 0.85-leading-pf, delta-connected synchronous motor has an armature resistance of 0.6Ω and a synchronous reactance of 3Ω . Its efficiency at full load is 89%.
 - a) Find the input power, line current, reactive power, copper losses and excitation voltage at full load.
 - b) If the excitation voltage is decreased by 10%, how much reactive power will be consumed by or supplied by the motor ?
5. A system of 3 loads at 480 V, load 1 is an induction motor consuming 100 kW at 0.78 pf lagging, load 2 is an induction motor consuming 200 kW at 0.8 pf lagging and load 3 is a synchronous motor that has an active power consumption of 150 kW.
 - a) If the synchronous motor is adjusted to operate at 0.85 pf lagging, determine the supply current for such system.
 - b) If the synchronous motor is adjusted to operate at 0.85 pf leading, determine the supply current for such system.
 - c) Compare the feeder losses in the two cases. Comment.