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Internal Assesment Test - I

Sub:	REACTIVE POWER MANAGEMENT							Code:	10EE831
Date:	30 / 03 / 2017	Duration:	90 mins	Max Marks:	50	Sem:	8	Branch:	EEE

Answer Any **FIVE** FULL Questions

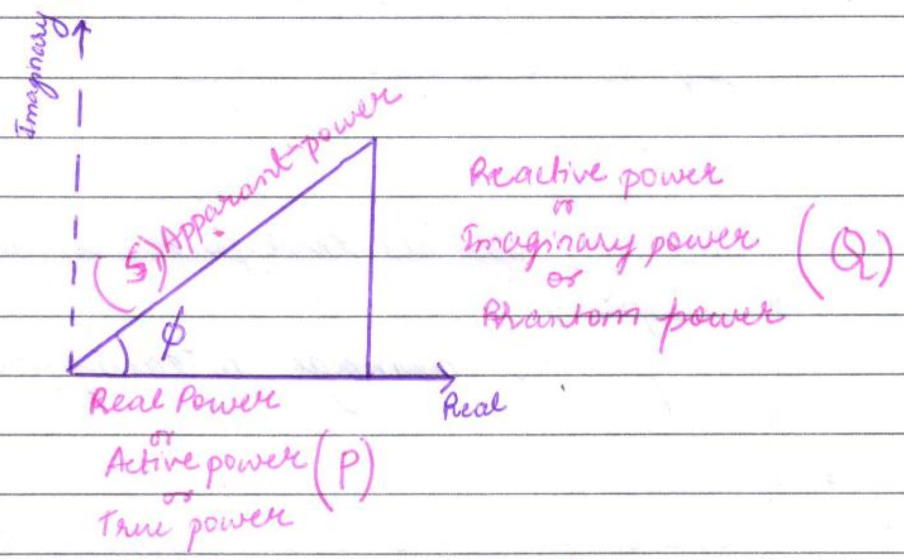
		Marks	OBE	
			CO	RBT
1	Discuss the importance of reactive power control in an electrical power system.	[10]	CO1	L2
2	List out the different reactive power devices in electrical power system.	[10]	CO1	L1
3	Define an ideal compensator. Explain the objectives in load compensation.	[10]	CO3	L1
4	List out the specifications of a load compensator	[10]	CO3	L1
5	Explain the concepts of phase balancing and power factor correction of an Unsymmetrical load and derive expression for compensating susceptance.	[10]	CO2	L4
6	Justify that a purely reactive compensator cannot maintain both constant voltage and unity power factor at the same time.	[10]	CO2	L5
7	Explain the fundamental requirements in ac power transmission.	[10]	CO3	L4

Answer key

1\.

Reactive power exists in a.c. network where there is a presence of phase difference.

Power triangle :



Real power, $P = VI\cos\phi$ (W)

Reactive power, $Q = VI\sin\phi$ (VAR)

Apparent power, $S = VI$ (VA)

Active power is the power dissipated and used to run motors, lights etc.

Reactive power is the power absorbed by the elements

Apparant power is the sum of ~~that~~ power dissipated and power absorbed

Active power, $P = I^2R$ (W)
Reactive power, $Q = I^2X$ (VAR)
Apparant power, $S = I^2Z$ (VA)

Methods to inject the reactive power into the system using the following:

Basic concepts for reactive power (Q):

1. Why reactive power Q?
Real power is used for the running of motor lamp etc. Reactive power, Q gives voltage support to the real power P.

2. Q is the by product of a.c since there is phase difference between V and I

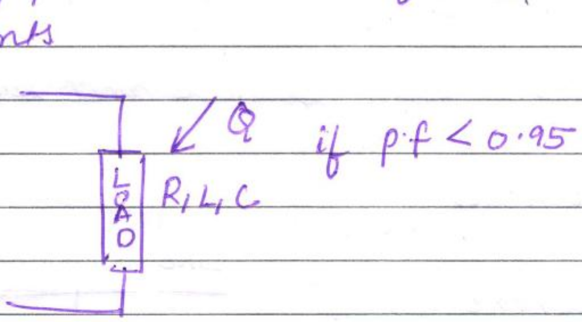
$$Q = VI \sin\phi$$

3. Using reactive power compensator we can control the voltage.

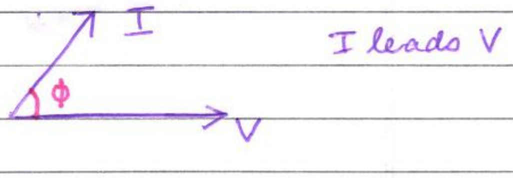
4. Relationship between reactive power and power factor:

Ideal power factor is considered as unity i.e $\cos\phi = 1$.
For this, $\phi = 0°$. i.e. no phase difference between V and I
If the load is purely resistive its possible but in our actual elements there is R, L and C, so unity p.f is practically not possible.

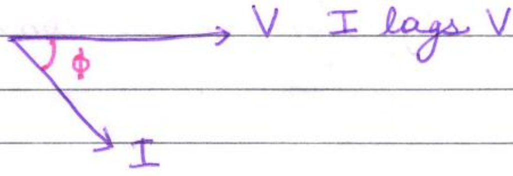
So, if p.f < 0.95, then Q is absorbed in the components



NOTE : Leading p.f →
$\phi = +ve$

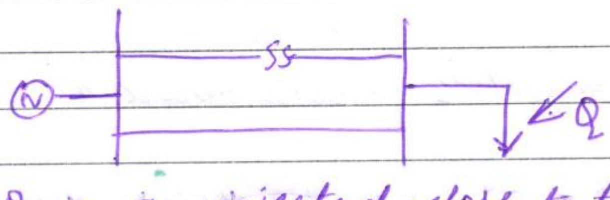


Lagging p.f →
$Q_P = -ve$



5. Limitations of Reactive power.

(i) Reactive power will not travel very far. So it should be produced very close to the load

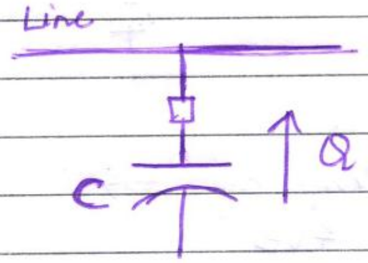


If Q is injected close to the source, Q has to travel the length of the transmission line which leads to conflict since P and Q should travel together.
So its always injected close to the load absorbing the reactive power.

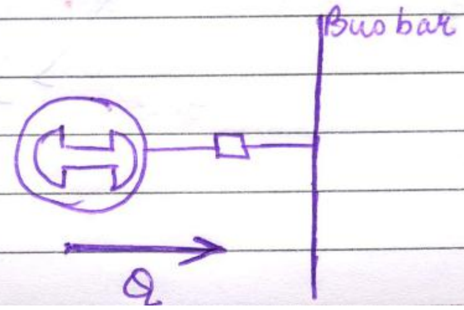
6. Reactive power sources and sinks

Q. sources

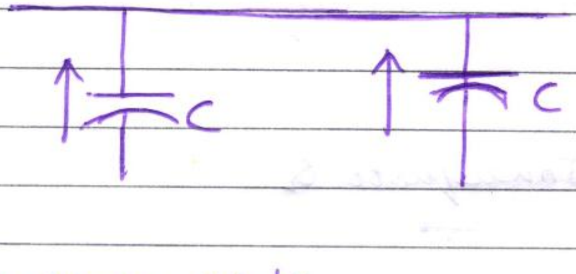
(i) Capacitor



(ii) Synchronous condensor/generator

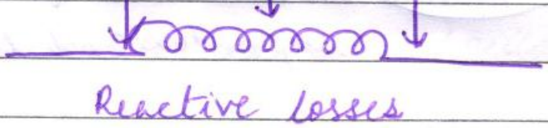


(iii) Shunt capacitors / line charging capacitors

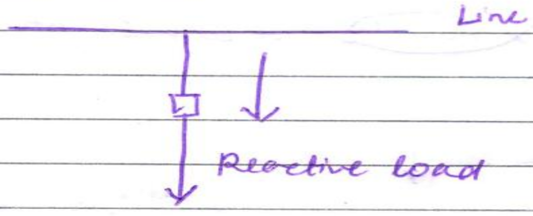


Reactive power sinks.

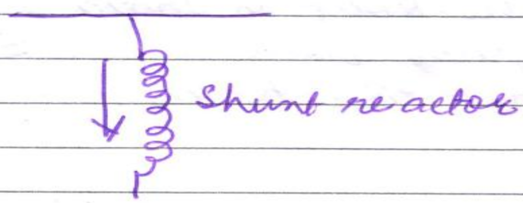
(i) Inductor



(ii) ~~Reatt~~ Reactive load



(iii) Shunt reactor



7. Reactive power and blackout :

Suppose there is inadequate reactive power, th

Inadequate Q

- (Results in) Decrease in voltage
- (Results) in Reduced Q supply by capacitors and line chargers
- (Results) in less reactive power support in the system
- (Again) results in greater voltage reduction in the system
- (Results) in the tripping of generator

Blackout [voltage collapse]

Explain any ten main points = 10 marks

2.

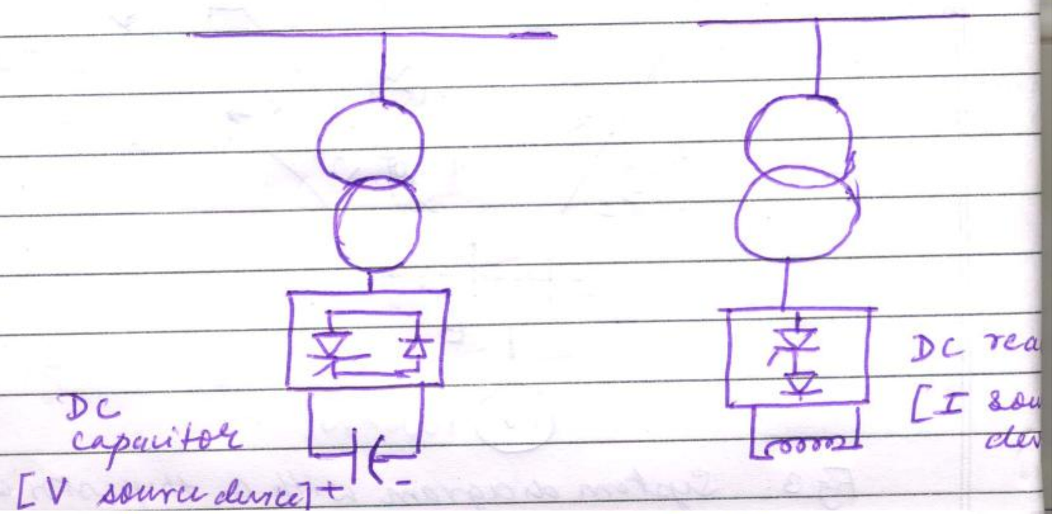
13. Reactive power devices :

I Compensating devices :

(i) STATCOM - [static compensator]

It is a static synchronous compensator. It i

shunt connected compensator.



(v) SVC [Static Var Compensator]

→ Injects C or L current.

(vi) TCR [Thyristor controlled reactor]

→ Controlled reactor

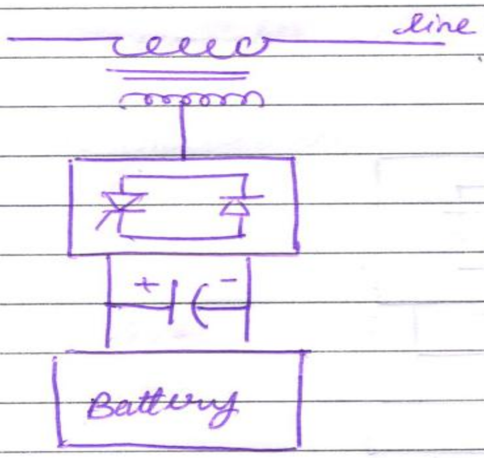
→ Reactor is varied in a continuous manner

(vii) TSR [Thyrister Switched reactor]

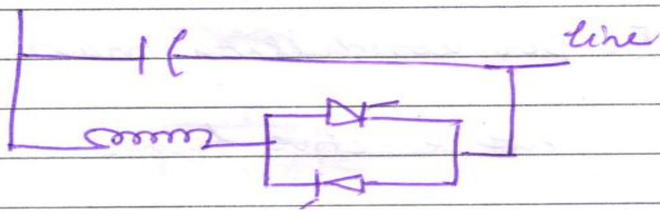
→ Reactor is varied in stepwise manner.

(viii) TSC [Thyrister switched capacitor]

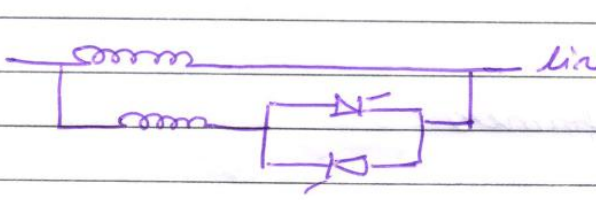
(ix) SSSC [Static synchronous series compensat



(x) TCSC [Thyristor controlled series capacitor]



(xi) TCSR [Thyristor controlled series reactor]



II Other devices :

(i) Synchronous generator :

Generator absorbs/injects reactive power depending on excitation.
Over excited generator produces reactive power
Under excited generator absorbs reactive power.
It is equipped with AVR [Automatic voltage regulator]

(ii) Overhead lines :
→ Depending on the load on it absorbs or supply reactive power.
→ If the load is less than SIL [Surge impedence loading] produces Q
→ If the load is more than SIL absorbs Q.

(iii) Underground cables :
→ High ~~capacitance~~ capacitance
→ Loading capacity is high
→ But the lines are ~~not~~ ~~also~~ always loaded below the maximum capacity. So always produce Q.

(iv) Transformer :
→ absorbs reactive power
→ At no load there is shunt magnetizing reactance and at full load there is series leakage inductance.

(v) Load - absorbs reactive power.

3ans:

OBJECTIVES OF LOAD COMPENSATION :

* Load compensation is actually management of reactive Power to improve the Quality of supply.
* Carried for a single load or group of loads.
* Compensating equipment is installed nearer to the load.

3 main objectives of load compensation:

→ P.f correction
→ Improvement of Voltage regulation.
→ Load balancing

* In cases where supply V is stiff, P.f correction & load balancing are desirable.

1

1. P.f correction:

* means generating reactive power as close as possible to the load.
* Other than supplying it from a remote power station.
* a poor P.f is as a result of phase difference between voltage & current at load terminals.
* or it may be due to harmonic content or distorted current waveform.
* Most industrial loads have lagging power factor.
  ↓
  they absorb reactive power
* So Load current will be larger than that required to supply real power.
* Only real power is used in Energy conservation.
* The excess load current represents a waste to consumers.
* The consumer has to pay for the excess cable capacity & also excess Energy loss produced in Supply cable.

2. VOLTAGE REGULATION :

* Voltage regulation is a measure of change in voltage magnitude between Sending end & receiving end.

* Voltage regulation becomes important in cases where load varies their demand for reactive power.

* All loads will vary their demand for reactive power. Only the rate of variation differ.

* So due to this variation in demand for reactive power, it causes variation in Voltage at Supply point.

* So it will interfere with efficient operation of all plants connected at that point.

* So to avoid this problem, we have to maintain the Supply voltage within defined limits.
  ↓
  ± 5% averaged over few mins / hours

* Compensating devices have a vital role in maintaining Supply voltage within the limits.

* The best way to improve voltage regulation will be to strengthen the power system by increasing the size & number of generating units. & by making the n/w more densely interconnected.

* But this approach is uneconomic & would introduce problems associated with high fault levels & Switchgear ratings.

* So it is advisable to use Compensating devices to manage reactive power as it will not contribute to fault levels.

3. LOAD BALANCING :

* very important concept of load compensation is load balancing.
* It is always desirable to operate a 3 Ph s/m under balanced condition.
* Unbalanced condition results in flow of negative sequence current in the system & it is slightly dangerous to rotating machines.
* These negative sequence & zero sequence currents which flow as a result of Unbalanced condition can have few undesirable effects, like additional losses in motor, & generating units, Oscillating Torque in ac machines, increased ripple in rectifier, malfunction of several equipments, Saturation of transformers, excessive neutral currents.

4. HARMONIC DISTORTION :

* Harmonic distortion is change in waveform of Supply voltage from the ideal Sinusoidal waveform.
* It is caused by the interaction of Customer loads with the impedance of supply n/w.
* Adverse effects are →
    - heating of induction motor
    - heating of transformers & Capacitors
    - Overloading of neutrals
* Eliminated usually with the help of filters.
* Many Compensators will also generate harmonics which may be suppressed internally or filtered externally.

4ans:

SPECIFICATION OF A LOAD COMPENSATOR

The parameters & factors to be considered are listed below.

1. Maximum continuous reactive power requirement, both absorbing & generating.
2. Overload rating & duration (if any).
3. rated voltage & limits of reactive power ratings which should not be execded.
4. Frequency and its variations.
5. Accuracy of voltage regulation required.
6. Response time of the compensator for specified disturbance.
7. Special control requirements.
8. Protection arrangements for the compensator.
9. Maximum harmonic distortion with compensator in service.
10. Energization procedure and precautions.
11. Maintenance, spare parts, provision for future expansion.
12. Environmental factors: noise level, indoor/outdoor installation, temperature, humidity, pollution, wind and seismic factors, leakage from transformer, capacitors, cooling systems.
13. Performance with unbalanced supply voltages & with unbalanced load.
14. Cabling Requirements and layout: acess, enclosure, grounding.
15. Reliability & redundancy of components.

Any 8 points = 4 marks (0.5*8)

4.

PHASE BALANCING & POWER FACTOR CORRECTION OF UNSYMMETRICAL LOADS

① In this section, we will focus on balancing of 3Ph unbalanced (unsymmetrical) loads.

② In case of unbalanced load, we have to model the load & the compensator in terms of admittance & impedances.

③ → Fig shows a general unbalanced 3Ph load.

* Here supply voltages will be assumed balanced.
* Load is represented by Delta connected network.
* The admittances Y_{ab_ℓ}, $Y_{bc\ell}$ & Y_{ca_ℓ} are complex and unequal.

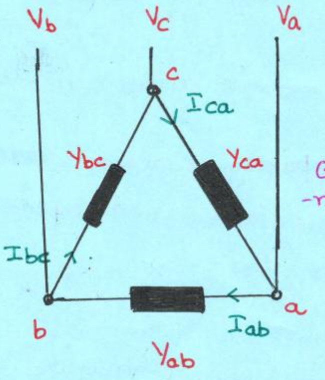


Fig 1. General Unbalanced 3Ph load

* Any changes in the load are assumed to be sufficiently slow or quasi-stationary, so phasor analysis can also be done & load is assumed to be **linear.**

④ * An ideal load compensator is considered as any passive admittance (3Ph) network, when combined in parallel with the load, ⇒ will present a REAL & SYMMETRICAL LOAD.

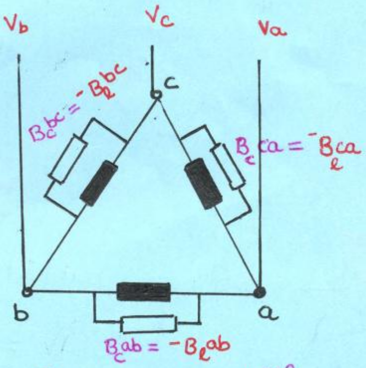


Fig 2. Connection of P.f correcting susceptance in individual phases

* It is made REAL as shown in fig 2 by connecting a parallel compensating susceptance = to −ve of load susceptance.

So we can write,

$$Y_\ell ab = G_\ell ab + j B_\ell ab$$

The compensating susceptance is,

$$B_c ab = -B_\ell ab$$

Similarly $B_c bc = -B_\ell bc$, $B_c ca = -B_\ell ca$

⑤ * The resulting load admittance will now contain only conductance component G as in figure ③.

* They are REAL, giving an overall P.f equal to Unity. But they are still Unbalanced.

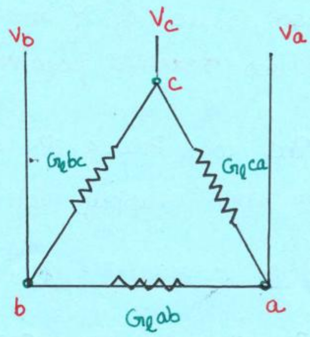


Fig 3. Resultant Load Unbalanced but with Unity P.f

⑥ Now we have to **Balance** this unbalanced load.

→ First consider single phase load $G_{\ell}ab$ as in fig 4.

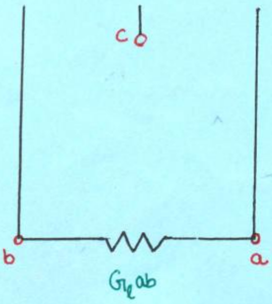


Fig 4: 1Ph, Unity Pf load before +ve seq balancing

* The 3Ph +ve seq line currents can be balanced by connecting phases b & c with capacitive susceptance

$$B_C^{bc} = \frac{G_{\ell}ab}{\sqrt{3}}$$

togather with the inductive Susceptance (fig 5).

$$B_C^{ca} = \frac{-G_{\ell}ab}{\sqrt{3}}$$

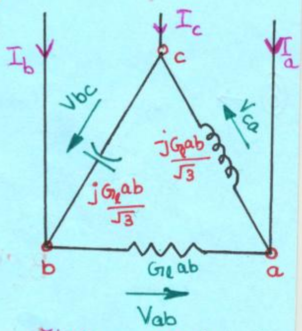


Fig 5: +ve seq balancing of 1Ph Unity P.f load

⑦

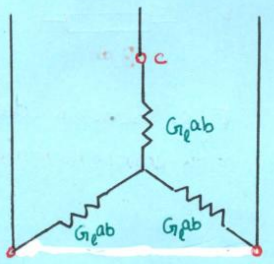


Fig 6: +ve seq equivalent circuit of compensated single phase load

→ The construction of line currents I_a, I_b & I_c for +ve seq voltages Vab, Vbc & Vca is shown in fig 7.

* From the phasor we can say that the line currents are balanced & are also in phase with their respective Voltages.

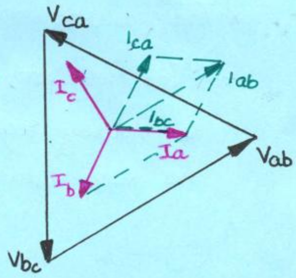


Fig 7: +ve seq phasor diagram

⟹ So each phase of Y connected resistors each with conductance $G_{\ell}ab$ as in fig 6 is the equivalent circuit for +ve seq Voltages.

→ each phase of Y connected supply s/m would supply 1/3 rd of total Power & no reactive power.

→ The total Power is $3V^2 G_l^{ab}$, where V is the rms value of line to neutral supply Voltage.

→ Both overall P.f & P.f in each phase of supply are Unity.

→ Eventhough the current in three branches of delta are Unbalanced, there is **reactive power equilibrium** within delta (Fig 5)
∴ the reactive power generated by the capacitor between line b & c equals that absorbed by inductor between lines c & a.
⇒ So there is no net reactive power power in the system.

⑧ → So in this way all the 3 branches are balanced.

* So the net compensating susceptance is given by eqns,

$$B_c^{ab} = -B_l^{ab} + (G_l^{ca} - G_l^{bc})/\sqrt{3}.$$

$$B_c^{bc} = -B_l^{bc} + (G_l^{ab} - G_l^{ca})/\sqrt{3}$$

$$B_c^{ca} = -B_l^{ca} + (G_l^{bc} - G_l^{ab})/\sqrt{3}$$

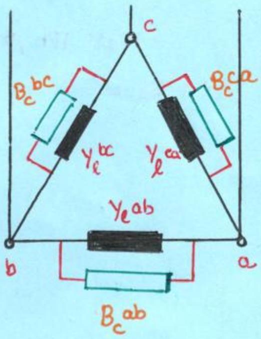


Fig 8. General ideal 3 Ph compensating network

* This is shown in fig 8.

* The resulting compensated load admittance is purely reactive. This is valid only for +ve seq voltages. (fig 9).

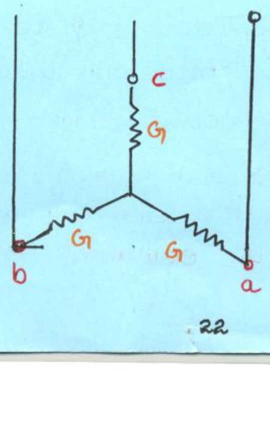


Fig 9: Equivalent ckt for +ve seq voltages

⑨

→ If the load conductances are balanced, we can say

$$G_l^{ca} - G_l^{bc} = 0$$

IIIly in all the 3Ph it will be zero.

→ Thus compensating network need to cancel reactive power in each branch of load only.

⑩ So we can summarize as:

1. Any unbalanced 3Ph load can be transformed into a balanced real 3 Ph load, without changing real power exchange between source & load by connecting a compensating network in parallel with it.

2. The ideal compensating network can be purely

* * * * *

6.

POWER FACTOR AND ITS CORRECTION

① Figure 1 shows 1 Ph load connected to the bus as in fig.

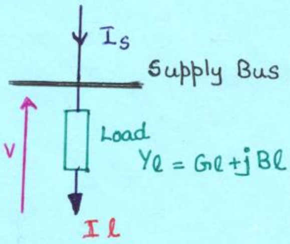


Fig 1

Admittance of Load,

$$Y_l = G_l + j B_l$$

G → Conductance
B → Susceptance

Supply voltage is V. & load current I_l.

Load Current I_l can be expressed as,

$$I_l = V Y_l$$
$$= V(G_l + j B_l)$$
$$= VG_l + j VB_l = I_R + j I_x \longrightarrow ①$$

② This equation ① is shown in phasor diagram (Fig 2).

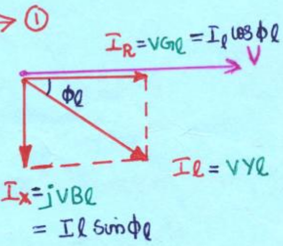


Fig.2

→ V is the reference phasor.

→ The load current has a resistive phasor component I_R, in phase with voltage V.
a reactive component $I_x = VB_l$ which is in phase quadrature with voltage V.

→ The load here is inductive, so I_l is lagging & I_x is negative.

→ The angle between V and I_l is ϕ_l.

③ The apparent power supplied to the load is

$$S_l = V I_l^*$$
$$= V[VG_l + j VB_l]^* = V^2 G_l - j V^2 B_l$$
$$= P_l + j Q_l$$

→ So apparent power has a real component P_l [Power converted to heat, light etc] & a reactive component Q_l [Power cannot be converted to useful Energy].

④ The relationship between S_l, P_l & Q_l is shown in figure 3.

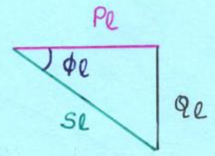


Fig 3.

→ In lagging inductive loads, Q_l is +ve
B_l is −ve
by convention.

→ Here $\cos\phi_l$ is the power factor

$$\cos\phi_l = \frac{P_l}{S_l}$$

⑤ The principle of power-factor correction is to compensate for the reactive power.

→ So a compensator is connected in parallel with the load.

→ The compensator will have a purely reactive admittance $-jB_l$.

→ The current supplied by the Power System to the combined installation of load & compensator is,

$$I_S = I_l + I_c$$
$$= V(G_l + jB_l) + (-jB_l)$$
$$= VG_l = I_R. \longrightarrow ②$$

→ So from equation ② it is very clear that when we add a compensator in the circuit, supply current becomes equal to resistive current.

→ Supply current I_S thus becomes inphase with Voltage, making overall power factor UNITY.

→ Now supply current I_S will provide the real power requirements P_l.

→ The reactive power required by the load is supplied by the compensator.

→ Fig 4 shows the phasor relationship.

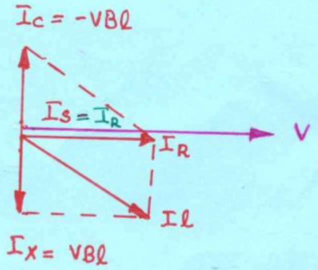


Fig 4.

→ The load is thus compensated fully.

→ The supply is relieved of reactive requirements of the load.

→ Supply now has excess capacity which is available for other loads.

⑥ Compensator current is given by

$$I_c = VY_c = -jVB_l$$

Apparent power exchanged with supply system (due to compensator)

$$S_c = P_c + jQ_c$$
$$= VI_c^* = V[-jVB_l]^*$$
$$= +jV^2B_l$$

→ Thus real power due to compensator $P_c = 0$

$Q_c = V^2B_l$ & $Q_c = -Q_l$

→ Thus compensator requires no mechanical power i/p.

→ Most loads are Inductive, requiring capacitive compensation. [B_c +ve, Q_c -ve].

⑦ The compensator is a fixed admittance (Y) or fixed Susceptance (B) incapable of following the variations in reactive power requirement of load.

So compensator such as Capacitive banks can be divided into parallel sections, each switched separately according to changes in reactive power.

****