G.PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY

DEPT OF EEE

Electrical Distribution Systems

UNIT-4

BASIC TERMS AND DEFINITIONS:

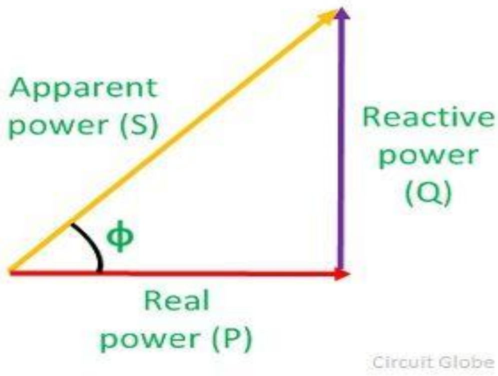
Power	Electrical power is the rate at which electrical energy is converted to another form, such as motion, heat, or an electromagnetic field. The common symbol for power is the uppercase letter P. The standard unit is the watt, symbolized by W. In utility circuits, the kilowatt (kW) is often specified instead;1 kW = 1000 W.
Power factor	In electrical engineering, the power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load to the apparent power in the circuit, and is a dimensionless number in the closed interval of 0 to 1.
Real power	Active power does do work, so it is the real axis. The unit for all forms of power is the watt (symbol: W)
Reactive power	In electric power transmission and distribution, volt-ampere reactive (var) is a unit by which reactive power is expressed in an AC electric power system. Reactive power exists in an AC circuit when the current and voltage are not in phase.
Apparent power	The combination of reactive power and true power is called apparent power, and it is the product of a circuit's voltage and current, without reference to phase angle. Apparent power is measured in the unit of Volt-Amps (VA) and is symbolized by the capital letter S.
Power triangle	Power Triangle is the representation of a right angle triangle showing the relation between active power, reactive power and apparent power.
Voltage drop	Wires carrying current always have inherent resistance, or impedance, to current flow. Voltage drop is defined as the amount of voltage loss that occurs through all or part of a circuit due to impedance
Compensation	compensation is defined as the management of reactive power to improve the performance of alternating-current (ac) power systems. In general, the problem of reactive power compensation is related to load and voltage support.
Capacitor	A capacitor is a passive two-terminal electrical component that stores potential energy in an electric field. The effect of a capacitor is known as capacitance.
Phase advancer	Phase advancers are used to improve the power factor of induction motors. The low power factor of an induction motor is due to the fact that its stator winding draws exciting current which lags be-hind the supply voltage by 90 degrees. If the exciting ampere turns can be provided from some other a.c. source, then the stator winding will be relieved of exciting current and the power factor of the motor can be

	improved. This job is accomplished by the phase advancer which is simply an a.c. exciter.
Balanced network	In the language of Power Systems, a three-phase circuit is said to be balanced if the following conditions are true. ➢ If all the sources and loads are y-connected. ➢ There is no mutual inductance between the phases. ➢ All neutrals are at the same potential. ➢ As a consequence of the points (2) and (3) above, all phases are decoupled. ➢ All network variables are balanced sets in the same sequence as the sources.
Power loss	A power outage (also called a power cut, a power out, a power blackout, power failure or a blackout) is a short-term or a long-term loss of the electric power to a particular area. There are many causes of power failures in an electricity network

Concepts

Power Factor:

The power factor is defined as the ratio of the active power (P) and volt-amperes. The active power is the real power which is assumed in an AC circuit, whereas volt-amperes is the apparent power which is produced in the circuit when the waves of voltage or current are not in phase.



$$Power\ Factor = \frac{P}{S} = \frac{P}{VI}$$

For sinusoidal waveforms, the power factor is the cosine of the angle (phase angle) between voltage and current.

$$Power\ factor = cos\emptyset$$
$$cos\emptyset = \frac{P}{VI}$$

$$I = \frac{P}{VICOS\emptyset} \qquad (1)$$

Equation (1) shows that the current is affected by the power factor. Hence, for a given power

P by the load, the current I, taken by the load varies inversely as the load power factor cosΦ. Thus, a given load takes more current at a low power factor than it does at a high power factor.

Disadvantages of low Power Factor:

The undesirable effect of operating a low load at a low power factor is due to the large current required for a low power factor. The important disadvantages of low power factor are

1. Higher current is required by the equipment, due to which the economic cost of the equipment is increased.
2. At low power factor, the current is high which gives rise to high copper losses in the system and therefore the efficiency of the system is reduced.
3. Higher current produced a large voltage drop in the apparatus. This results in the poor voltage regulation.

Since both the capital and running cost are increased, the operation of the system at low power factor (whether it is lagging or leading) is uneconomical from the supplier's point of view.

Causes of Low Power Factor and It's Correction (PF Improvement):

Causes of Low Power Factor:

Inductive Loads:

- 90% of the industrial load consists of Induction Machines (1-ϕ and 3-ϕ). Such machines draw magnetizing current to produce the magnetic field and hence work at low power factor.
- For Induction motors, the pf is usually extremely low (0.2 - 0.3) at light loading conditions and it is 0.8 to 0.9 at full load.
- The current drawn by inductive loads is lagging and results in low pf.
- Other inductive machines such as transformers, generators, arc lamps, electric furnaces etc work at low pf too.

Variations in Power System Loading:

- Today we have interconnected power systems. According to different seasons and time, the loading conditions of the power system vary. There are peak as well as low load periods.
- When the system is loaded lightly, the voltage increases and the current drawn by the

machines also increases. This results in low power factor.

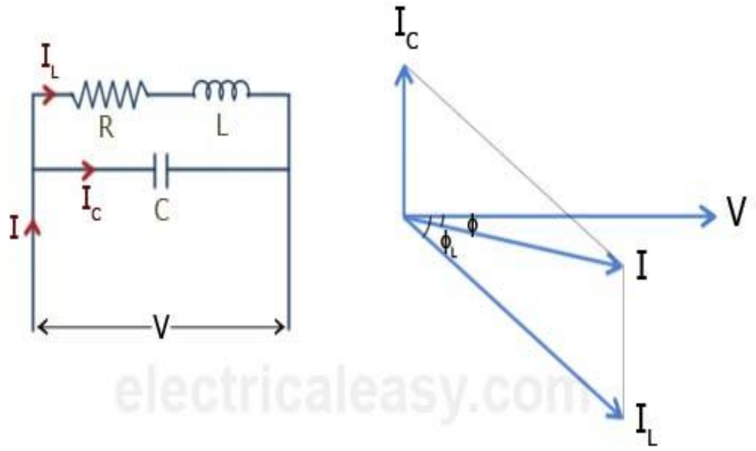
Harmonic Currents:

- The presence of harmonic currents in the system also reduces the power factor.
- In some cases, due to improper wiring or electrical accidents, a condition known as 3-ϕ power imbalance occurs. This results in low power factor too.

Power Factor Correction:

As discussed above, low power factor is mainly due to lagging currents drawn by inductive loads. Before we study the schemes for Power Factor Correction (PFC), note the following points:

- For pure inductance, current lags behind voltage by 90°.
- For pure capacitance, current leads voltage by 90°.
- So, the solution is simple. If we use capacitors to draw leading current, we can cancel the effects of lagging inductive current and hence improve the power factor.



The above fig shows a common circuit. The R and L are present in all inductive equipments and the C is used for pf improvement.

Here, IL = current drawn by the circuit capacitor C isn't used,

ϕ_L = phase angle between voltage V and load current IL,

IC = capacitive current drawn by C,

I = resultant current when C is used,

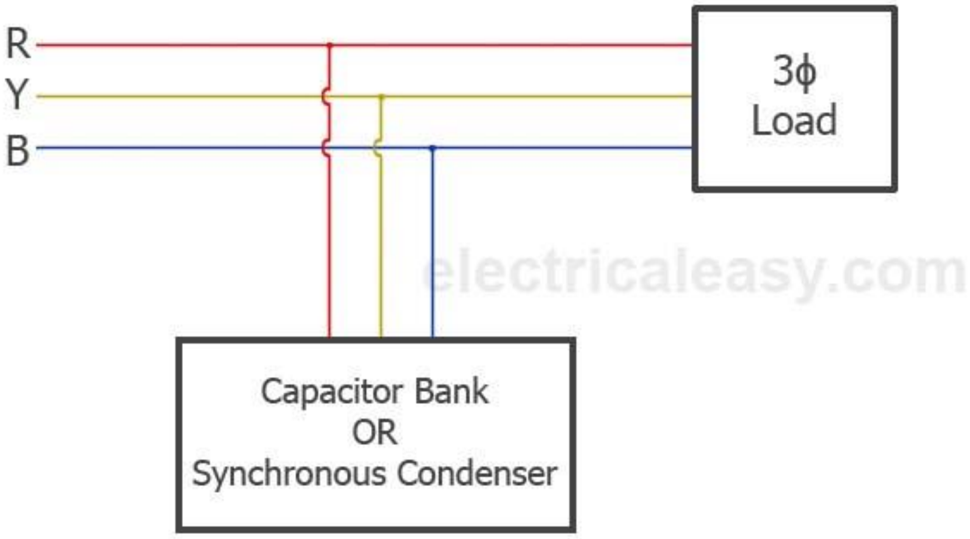
ϕ = phase angle between voltage V and net current I.

- As shown in the above phasor diagram, $\phi < \phi_L$

- Therefore cos ϕ > cos ϕ_L, hence power factor is improved

Based upon this principle, following methods are used for power factor correction (PFC).

Methods Of Power Factor Correction Or Improvement:



Power Factor Improvement

1. Capacitor Bank

- Simplest method.
- Applied at areas where large inductive loads (lagging currents) are present.
- Static capacitors are used which produce capacitive reactance that cancels out the inductive reactance of the lagging current.
- These banks can be star connected or delta connected.
- A control system is usually provided which monitors the pf and switches the capacitors ON or OFF.

Advantages of using capacitor banks for PF correction:

- low losses
- low maintenance
- light weight
- easy to install
- no foundation required

Disadvantages:

- short life (8-10 years)
- capacitors can get easily damaged due to over voltage
- once damaged, the repair is costly and uneconomic
- due to constant switching, switching surges and harmonics may be produced.

2. Synchronous Condenser:

- When a synchronous motor is over excited, it draws leading current. In a way, it behaves like a capacitor.
- When such a motor is over excited and run at no load, it is called a Synchronous Condenser.
- The most attractive feature is that it allows step less power factor correction. In a static capacitor, the leading kVAR supplied are constant. But in a synchronous condenser, we can vary the field excitation and hence control the amount of capacitive reactance produced.
- Synchronous Condensers are used in large factories, industries and major supply substations.

Advantages :

- longer lifespan (almost 25 years)
- flexible and step less control of power factor
- reliable
- does not get affected by harmonics
- No switching is required hence harmonics are not produced

Disadvantages:

- higher losses
- expensive
- higher maintenance costs
- produces noise
- Synchronous motor is not self starting, so auxiliary device is needed.
- uneconomical for equipment below 500 kVA

3. Phase Advancer:

- Can be used only for Induction Motors
- We know that stator winding draws lagging current in a motor. This current is drawn from the main supply.
- Hence, to improve pf, we supply this lagging current from an alternative source. This alternative source is the phase advancer.
- A phase advancer is basically an AC exciter. It is mounted on the same shaft as the main

motor and connected in the rotor circuit. It supplies exciting ampere turns to the rotor circuit at slip frequency. This improves the power factor.

- Another attractive feature is that if we supply more amp-turns than needed, the motor will operate in an over excited state (at leading pf).

Advantages :

- Lagging kVAR drawn by the motor are reduced because the exciting ampere turns are supplied at slip frequency.
- Can be utilized easily where synchronous motor is inadmissible

Disadvantages :

- Uneconomical for motors below 200 HP (150 kW)

Capacitor Bank | Reactive Power Compensation:

The demand of active power is expressing Kilo Watt (kw) or mega watt (mw). This power should be supplied from electrical generating station. All the arrangements in electrical pomes system are done to meet up this basic requirement. Although in alternating power system, reactive power always comes in to picture. This reactive power is expressed in Kilo VAR or Mega VAR.

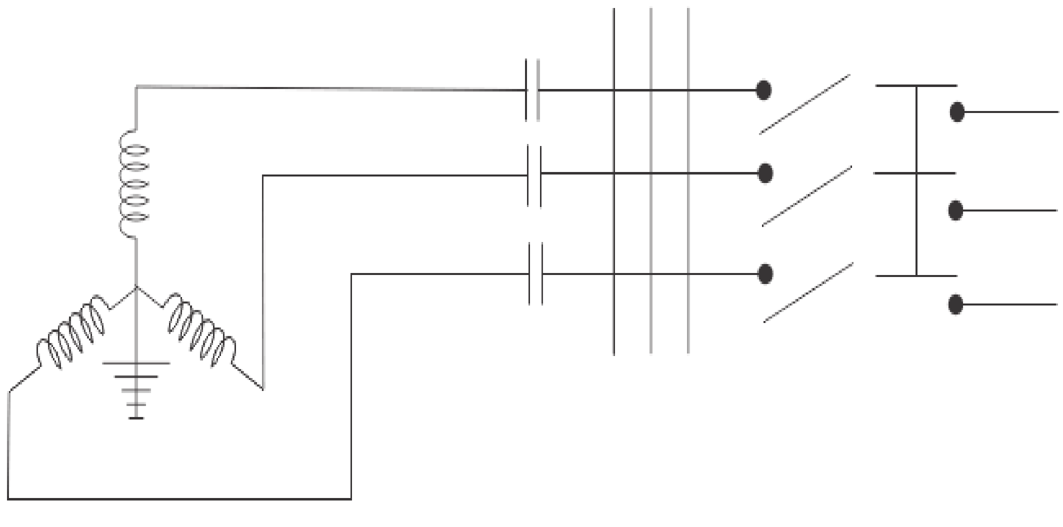
The demand of this reactive power is mainly originated from inductive load connected to the system. These inductive loads are generally electromagnetic circuit of electric motors, electrical transformers, inductance of transmission and distribution networks, induction furnaces, fluorescent lightings etc. This reactive power should be properly compensated otherwise, the ratio of actual power consumed by the load, to the total power i.e. vector sum of active and reactive power, of the system becomes quite less.

This ratio is alternatively known as electrical power factor, and fewer ratios indicates poor power factor of the system. If the power factor of the system is poor, the ampere burden of the transmission, distribution network, transformers, alternators and other equipments connected to the system, becomes high for required active power. And hence reactive power compensation becomes so important. This is commonly done by capacitor bank. Let's explain in details, we know that active power is expressed = $VI\cos\theta$ Where, $\cos\theta$ is the power factor of the system. Hence, if this power factor has got less valve, the corresponding current (I) increases for same active power P. As the current of the system increases, the Ohmic loss of the system increases. Ohmic loss means, generated electrical power is lost as unwanted heat originated in the system. The cross-section of the conducting parts of the system may also have to be increased for carrying extra ampere burden, which is also not economical in the commercial point of view. Another major disadvantage, is poor voltage regulation of the system, which mainly caused due to poor power factor.

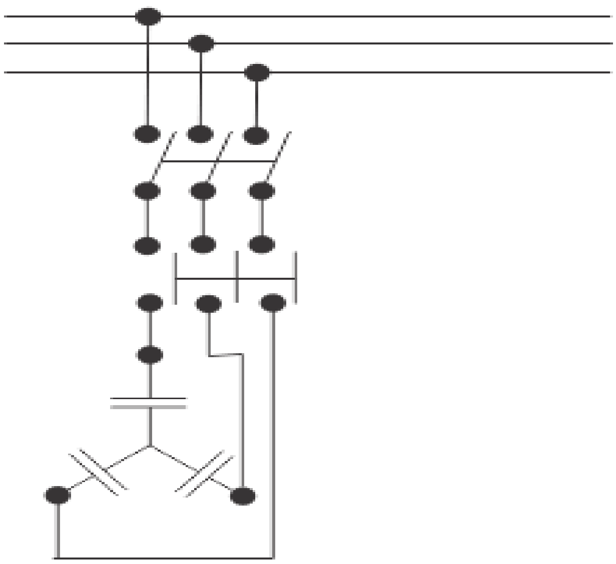
The equipments used to compensate reactive power. There are mainly two equipments used for this purpose. (1) synchronous condensers (2) Static capacitors or Capacitor Bank synchronous condensers, can produce reactive power and the production of reactive power can be regulated. Due to this regulating advantage, the synchronous condensers are very suitable for correcting power factor of the system, but this equipment is quite expensive compared to static capacitors. That is why synchronous condensers, are justified to use only for voltage regulation of very high voltage transmission system. The regulation in static capacitors can also be achieved to some extend by split the total capacitor bank in 3 sectors of ratio 1 : 2 : 2. This division enables the capacitor to run in 1, 2, 1 + 2 = 3, 2 + 2 = 4, 1 + 2 + 2 = 5 steps. If still further steps are required, the division may be made in the ratio 1 : 2 : 3 or 1 : 2 : 4. These divisions make the static capacitor bank more expensive but still the cost is much lower them synchronous condensers. It is found that maximum benefit from compensating equipments can be achieved when they are connected to the individual load side. This is practically and economically possible only by using small rated capacitors with individual load not by using synchronous condensers.

Static Capacitor Bank:

Static capacitor can further be subdivided in to two categories, (a) Shunt capacitors (b) Series capacitor



Series Capacitor Bank



Capacitor Bank

These categories are mainly based on the methods of connecting capacitor bank with the system. Among these two categories, shunt capacitors are more commonly used in the power system of all voltage levels.

There are some specific advantages of using shunt capacitors such as,

1. It reduces line current of the system.
2. It improves voltage level of the load.
3. It also reduces system Losses.
4. It improves power factor of the source current.
5. It reduces load of the alternator.
6. It reduces capital investment per mega watt of the Load.

All the above mentioned benefits come from the fact, that the effect of capacitor reduces reactive current flowing through the whole system. Shunt capacitor draws almost fixed amount of leading current which is superimposed on the load current and consequently reduces reactive components of the load and hence improves the power factor of the system. series capacitor on the other hand has no control over flow of current. As these are connected in series with load, the load current always passes through the series capacitor bank. Actually, the capacitive reactance of series capacitor neutralizes the inductive reactance of the line hence, reduces, effective reactance of the line. Thereby, voltage regulation of the system is improved. But series capacitor bank has a major disadvantage. During faulty condition, the voltage across the capacitor maybe raised up to 15 times more than its rated value. Thus series capacitor must have sophisticated and elaborate protective equipments. Because of this, use of-series capacitor is confined in the extra high voltage system only.

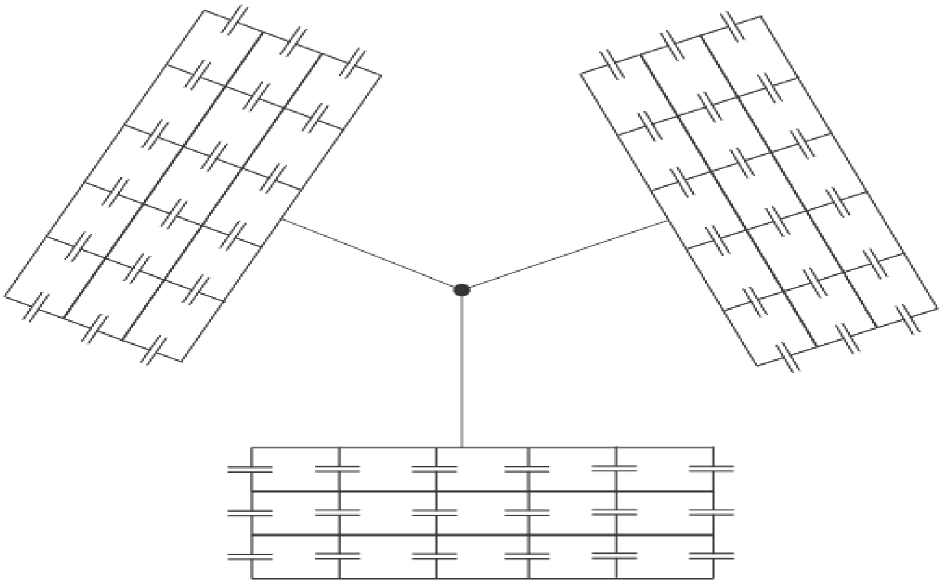
Shunt Capacitor:

Construction of Shunt Capacitor:

The active parts of capacitor unit are composed by two aluminum foils separated by impregnated papers. The thickness of the papers may vary from 8 microns to 24 microns depending upon the voltage level of the system. The thickness of the aluminum foil is in the order of 7 microns. For low voltage applications, there may be one layer of impregnated paper of suitable thickness between the foils but for higher voltage applications more than one layer of impregnated papers are placed between the aluminum foil to avoid unwanted circulation of short circuit current between the foil due to presence of conducting matters in the papers. The capacitor sections are wound into rolls there after they are flattened out,compressed into packs, enclosed in multiple layers of heavy paper insulations and inserted into the containers. When the lid had been welded to the container, the capacitor unit is dried and integrated in large autoclaves by a combination of heat and vacuum. After the paper is completely dried and all gases removed from the insulation the capacitor tank is filled with impregnant degassed at the same vacuum. In the early stages of development, it was generally mineral insulating oil which was used as impregnant. This has now been replaced by most of the manufacturers with synthetic liquids of chlorinated group bearing different trade names. Mineral insulating oil has very low electric conductivity and very high dielectric strength. But it has however some drawbacks such as,

1. It has low dielectric constant.
2. The voltage distribution in the mineral oil is not uniform.
3. It is very inflammable.
4. It is subjected to oxidation.

With the synthetic impregnant it is quite possible to manufacture smaller capacitor unit with higher voltage rating. The voltage rating of the capacitor unit is restricted within certain limits because on low voltage the cost per kilo VAR goes high. For high voltage applications, numbers of capacitor units are connected in series and parallel combination to form a capacitor bank for required voltage and Kilo VAR ratings. For example when 5.1 Mega VAR capacitor bank is to be commissioned in an 11 KV system, each unit of the bank is made of 11 KV rated. In this installation, per phase requirement of Mega VAR is 5.1/3=1.7. In this installation, there should be only one capacitor unit connected in series and 17 of such units are connected in parallel to meet up the mega VAR requirement of one phase. For three phase system three such groups of capacitor unit are connected together in star or delta form. Let’s show another example for better understanding. When a bank of 5.4 Mega VAR is to be installed at 33 KV 3 phase system. There shall be three capacitor units connected in series and six of such series combinations are connected in parallel to meet up 1.8 Mega VAR demand of per phase. The same capacitor units can be used for 132 KV systems too. For that Series and parallel combinations of the basic capacitor units will be assembled as per mega VAR requirement.



5.4 MVAR-33 kV Bank

Important Questions:

1. Prove the power loss due to load currents in the conductors of the 2-phase, 3 wire lateral with multi-grounded neutral is approximately 1.64 times larger than the one in the equivalent 3-phase lateral.
2. Discuss the effect of shunt compensation on distribution system.
3. How economic power factor arrived at for a given distribution system with different loads?
4. Explain in detail the economic justification for capacitor location?
5. Discuss the methods of improving power factor with necessary phasor diagrams?
6. Give the step by step Procedure for Economic Justification of Best Capacitor Location?
7. Discuss the importance of improving power factor for both consumers and Generating stations? List the various causes of low power factor.