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PERUSAL OF POWER FACTOR AND ITS EFFECTS

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Abstract:
The electrical power system is involved in power generation, transmission and distribution. Therefore, the power factor quickly comes into the consideration. Most of the loads (like induction motors, Arc lamps) are inductive in nature and hence have very low lagging power factor. This is not desirable as it causes an increase in current, resulting in additional ohmic power losses in all elements of power system from power station generator down to the utilization devices. In order to secure most economical conditions for a supply system from engineering point of view, it is must to have power factor close to unity. Thus, perusal of power factor and its effects are considered.

Keywords: Active power, Volt-ampere reactive (VAR), Inductance, consumed, Shunt capacitor.

Introduction:

In power system, a load with low power factor draws more current than a load with a high power factor for the same amount of power transferred. The higher currents increase the ohmic loss in the distribution system, and require larger conductors and other accessories. Due to larger accessories cost and wasted power, electrical utilities will charge a higher cost to all commercial customers where there is a low power factor (cosΦ). The cosine of the phase angle between voltage (V) and current (I) is known as power factor. The term cosΦ is called the power factor of the circuit [5]. In case of Inductance, the current lags behind the voltage and the power factor is referred to as lagging. But in a capacitive circuit, current leads the voltage and power factor is leading. Considering an inductive circuit taking a lagging current (I) from supply voltage (V), lagging angle is Φ. The phasor diagram is shown below
The circuit current can be resolved as:

- I cosΦ (active component) is in same phase with V.
- I sinΦ (reactive component) is 90 degree out of phase with V.

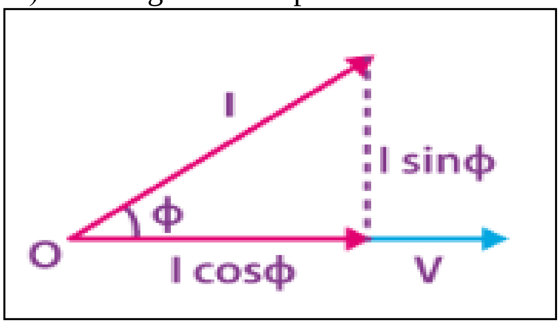

Fig1: Phasor diagram for inductive circuit

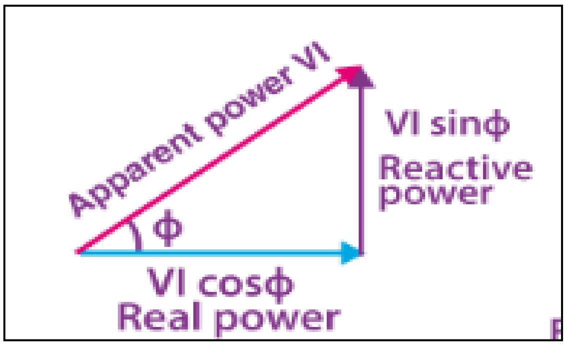

Fig2: Power Triangle

The following points may be noted from the power triangle (Fig.2)

(i) The apparent power in an a.c. circuit has two components i.e., active and reactive power at right angles to each other.

$OB^2 = AB^2 + AB^2$

Or (apparent power) ^{2} = (active power)^2 + (reactive power)^2

Or (kVA) ^{2} = (kW) ^{2} +(kVAR)^2

(ii) Power factor, CosΦ= OA/OB =active power/apparent power =kW/kVA

Thus the power factor of a circuit is defined as the "ratio of active power to apparent power".

(iii) The lagging reactive VAR is responsible for the low power factor. It is seen from the power triangle (Fig.2) that the smaller the reactive power component, the higher will be the power factor.

(iv) For capacitive circuit, the power triangle becomes opposite. If a device taking leading VARs (e.g. capacitor) is connected in parallel with the load, then the lagging VARs of the load will be partly neutralized, thus improves the power factor of the load [1].

(v) The power factor of a circuit can be defined as

- **Power factor = Resistance(R)/Impedance(Z)**
- **Cosine of the phase angle i.e., CosΦ**
- **CosΦ=Active Power(P)/Apparent Power(S)**

Disadvantages of Low Power Factor:

The power factor plays a vital role in a.c. circuits, since power consumed depends upon this factor. As we know that

$P = VICos\Phi$ **(For single phase supply)**

$P = \sqrt{3}VICos\Phi$ **(for 3-phase supply)**

Now It is seen that for a fixed power and voltage, the current is inversely proportional to the power factor. Lower the power factor (cos*Φ*), higher is the load current (I) and vice versa. A power factor less than unity results in the following disadvantages [2].

1. Large power rating and size of Electrical Machine:

As we know, most of the Electrical Machines (i.e., Alternators, Switchgears, transformers etc) are rated in kVA. But, Power factor is inversely proportional to the kVA rating of electrical machines. (i.e., **KVA = kW/ CosΦ).** Thus, for low Power factor, larger will be the kVA rating of Machines and other equipments makes them **costly and heavier in size.**

2. Effect on Transmission line conductors (Bigger conductor size and larger cost):

At low power factor, for transmitting a fixed amount of power at constant voltage, the conductor will have to carry more current. As the current carrying capacity of the conductor is directly proportional to the cross-sectional area (a) of the conductor. To transmit high current, bigger sized conductors are

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required.
it is seen that if an electrical motor works at a lower power factor (**CosΦ**) of 0.8 then it draws more line current (I) than at unity power factor. Hence, bigger sized conductor at low power factor is required. This increases the conductor cost.

3. Large Copper Losses and poor Efficiency:

As the copper losses (I^2R losses) become directly proportional to the square of line current. Also, the line current is inversely proportional to circuit power factor (CosΦ). Hence by combining these relations, we concluded that copper losses (Cu-losses) will be inversely proportional to the square of power factor (i.e., $Cos^2Φ$). So due to low power factor, line current (I) will be higher as well as copper losses (I^2R loss) will be higher. This results in poor efficiency of power system.

4. Poor voltage regulation (High voltage drop):

Since, low power factor causes large line current to be drawn by the electrical equipments. So large current at low lagging power factor (CosΦ) causes a higher voltage drop in generators, 3-Φ transformers, transmission lines, etc. This reduces the voltage available at the supply end of equipment and hence the poor voltage regulation. So in order to improve voltage regulation, it is needed to install extra regulation equipment (i.e., Voltage regulators).

5. A Penalty from Electrical power Supply Company:

A Penalty from Electrical power Supply Company imposes to the consumer in electricity bill because of maintaining power factor below a required level (i.e., poor CosΦ).

Reasons of Low Power Factor:

The prime reasons of low power factor are because of the inductive load. In the case of inductive load, the current lags behind the voltage (I lags V). Therefore power factor becomes lagging in nature.
Following are the main Causes for Low power factor.

1. Inductive Load:

- 90% of the industrial load consists of induction motors (1-ϕ and 3-ϕ). Such electrical motors draw magnetizing current to set up the magnetic flux (Φ) for its proper working and hence work at low power factor.
- For induction motors,the power factor is usually low (0.2 to 0.3) at light loading conditions and rises to 0.8 to 0.9 at full load.
- The current drawn by inductive loads are lagging which results in poor power factor [3].
- Other inductive machines such as transformers, generators, arc lamps, electric heating furnaces, electric discharge lamps, etc also work at low power factor [3].

2. Variations in power system loading:

- A modern power system is the interconnected electrical power system. So according to the different session and time, power system loading is not always constant. Actually It varies time to time during the entire day. It is on maximum during the morning and evening (Peak load) but less during the rest time period.
- When the system is loaded lightly, voltage increases which increase the magnetization current demand of the machines. This results in Poor power factor.

3. Harmonic Current:

- The presence of harmonic current in the system also reduces the power factor of the system.
- In some cases, due to improper wiring or electrical accidents in which 3- phase power imbalance occurs. This results in low power factor too. [3]

Significance of Power Factor Improvement:

- Reduction in Electricity bill
- Reduction in copper losses of transformers and distribution equipment which increases the efficiency of the system.
- Reduction in voltage drop which increases voltage regulation.

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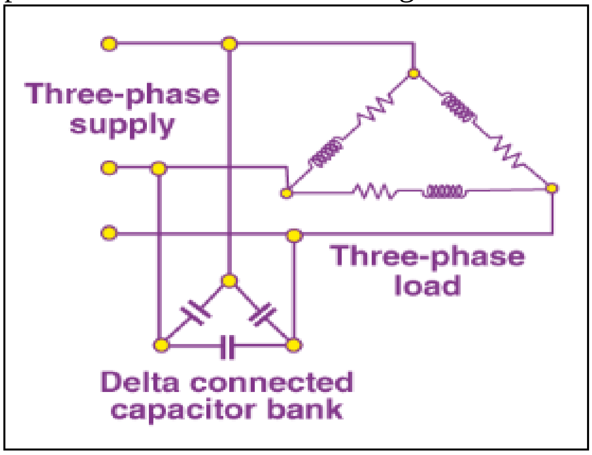
- It reduces the line current which decreases the burden on cables and also increases the life of the equipment.

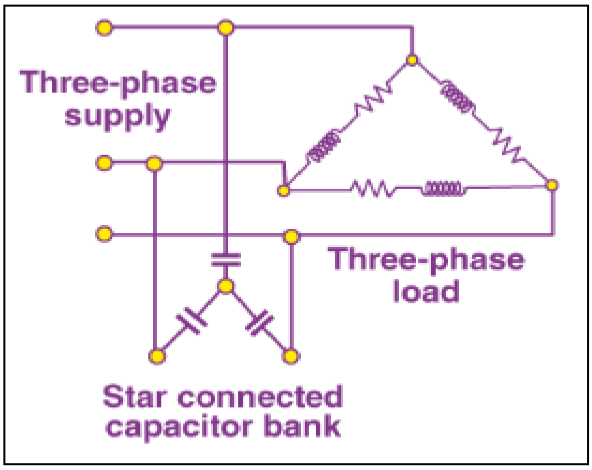
Power Factor Improvement Methods:
The different methods of improvement of Power-factor (CosΦ) are as under:
1. By using static capacitor bank
2. By using synchronous condenser
3. By using phase advancer

1. By using Static capacitor bank:

In this method, A capacitor bank is connected in parallel with the load. Since the capacitor takes leading reactive power (VARs), overall reactive power taken from the source decreases. Hence the system power factor improves. A system is provided to control and monitor the power factor of the system and switches the capacitor bank "ON" and "OFF" as per the need.
Star and Delta connected capacitor bank is shown in the Fig.3



(a)Delta connected Capacitor



(b) Star connected Capacitor Bank
Fig3: Capacitor Bank

Both the connections improve the system power factor. But a delta connected capacitor bank is generally used for the improvement of power factor (CosΦ). Because in delta connected system the capacitor value required per phase becomes one-third times (small in delta) of star-connected system.

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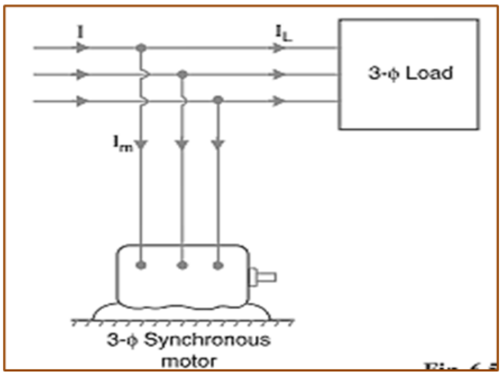
Advantages:
Low losses.
Low maintenance.
Light weight.
No foundation required. Hence easy to install.

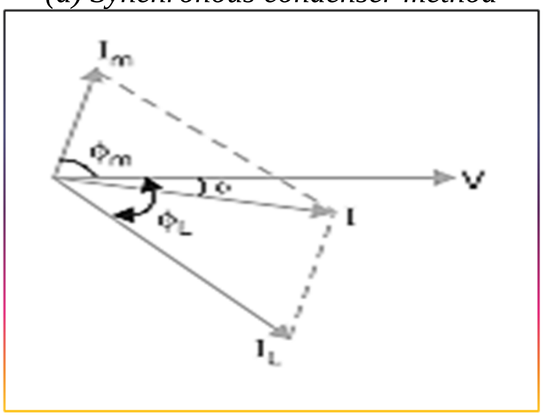
Disadvantages:
- Capacitors get easily damaged due to overvoltage
- Short life (Approx 9 years)
- Once damaged, the repair of system is costlier and not economical.

Due to switching, voltage surges and 3rd harmonics may be produce

Synchronous capacitors or condensers:
A synchronous motor takes a leading current (IM) if it is in overexcited mode and therefore, behaves like a capacitor. An overexcited synchronous motor running without load is known as synchronous condenser (i.e., generates leading VARs). When such a machine is connected in shunt with the supply then it takes a leading current (IM) which neutralizes the lagging reactive component of current (IL) of the load. Thus the power factor is improved. Fig.4 (a) shows the power factor improvement by synchronous condenser method.
From Fig.4 (b), The 3 phase load takes current IL at low lagging power factor CosΦL. The synchronous condenser takes a leading current of IM ampere which leads the voltage (V). The resultant current (I) is the phasor sum of IM and IL and lags behind the voltage (V) by an angle Φ. It is seen that Φ is less than ΦL so that CosΦ becomes greater than CosΦL. Thus, the power factor (CosΦ) is improved from CosΦL to CosΦ. This method is generally used at major bulk supply substations for power factor improvement. [4]



(a) Synchronous condenser method



(b) Related Phasor Diagram

Fig 4: Synchronous capacitors or condensers

Advantages:

- **Reliable and long life span (almost 25 years)**
- **Flexible and continuous control of power factor.**
- **Not affected by harmonics.**
- **No switching required hence free from switching surges.**

Disadvantages:

- It has more losses as compared to a capacitor bank.
- High maintenance cost.
- It produces Noise pollution.
- It has slow response due to the large time constant of its field circuit whereas the capacitor bank offers a fast response.
- A synchronous condenser can be installed only at one place whereas the capacitor bank can be distributed at many places hence due to this the capacitor bank is more effective in controlling reactive power flow and voltage profile [3].
- Uneconomical for below 500 kVA.

3. Phase advancer Method:

It can be used only for Induction Motors. Since the stator winding of the induction motor draws lagging current from the mains supply. Hence, to improve the power factor of Induction motor, we have to supply this lagging current from an alternative source [3]. Therefore this alternative source is called the phase advancer.

A phase advancer is an AC exciter, which is always mounted on the same shaft of the main motor (whose power factor (CosΦ) is to be improved) and connected in the rotor circuit. It supplies exciting ampere turns (i.e., mmf) to the rotor circuit of induction motor at a slip frequency. So the power factor of the induction machine can be improved. Another important property of phase advancer is that when we supply more amp-turns (i.e., mmf) than needed, the motor will operate in an overexcited mode (i.e., at leading PF).

Advantages Of Power Factor Improvement:

- Reduced Demand Charges
- Increased Load Carrying Capabilities in Existing Circuits
- Improved Voltage
- Reduced Power System Losses
- Improve system Stability
- Reduced alternator size

Conclusion:

The low power factor is not desirable because it produces an increment in current, resulting in additional ohmic losses (i.e., I^2R) of active power in all the elements of power system from power station generator to the distribution/utilisation devices. In order to ensure most valuable and appropriate conditions for a supply system from engineering and economical point of view, it is important to have power factor as close to unity (i.e., 1) as possible.

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