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OVERVIEW OF POWER FACTOR IMPROVEMENT TECHNIQUES

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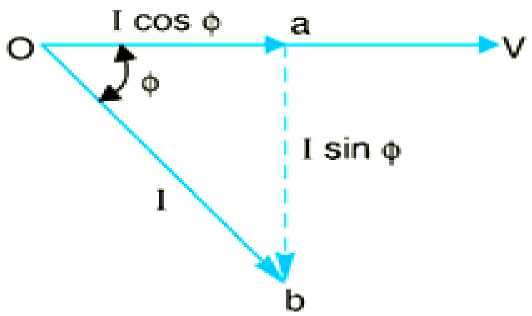
Abstract: The electrical energy is almost exclusively generated,transmitted and distributed in the form of alternating current. Therefore, the question of power factor immediately comes into picture. Most of the loads(e.g. induction motors, arc lamps) are inductive in nature and hence have low lagging power factor. The low power factor is highly undesirable as it causes an increase in current, resulting in additional losses of active power in all elements of power system from power station generator down to the utilisation devices[1-3]. In order to ensure most favourable conditions for a supply system from engineering and economical standpoint, it is important to have power factor as close to unity as possible. In this paper various power factor improvement techniques will be discussed.

Keywords: energy, distributed, inductive, utilisation,active.

I. Introduction

The cosine of angle between voltage and current in an ac circuit is known as power factor. In an a.c. circuit, there is generally a phase difference between voltage and current. The term cosΦ is called the power factor of the circuit. If the circuit is inductive, 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 said to be leading. Consider an inductive circuit taking a lagging current I from supply voltage V; the angle of lag being Φ[1-2]. The phasor diagram of the circuit is shown in figure 1. The circuit current can be resolved into perpendicular components, namely:

(a) IcosΦ in phase with V known as active or wattful component.
(b) IsinΦ 90° out of phase with V is called reactive ot wattless component.



(c)
(d) Fig 1 Phasor Diagram for Lagging Circuit

The reactive component is a measure of the power factor. If the reactive component is small, the phase angle Φ is small and hence power factor cos Φ will be high. Therefore a circuit having small reactive current(i.e. , IsinΦ) will have high power factor and vice-versa.

A. Power triangle

The analysis of power factor can be made in terms of power drawn by the ac circuit. If each side of the current traingle oab of figure 1 is multiplied by voltage V, then we get the power triangle oab shown in figure 2.

Where

OA = VICosΦ and represent the active power in watts or kW

AB = VISinΦ and represent the reactive power in VAR or KVAR

OB = VI and represent the apparent power in VA or KVA

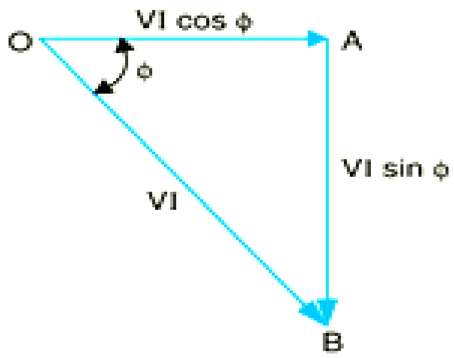


Fig 2 Power Triangle

The following points may be noted from the power triangle

(i) The apparent power in an a.c. circuit has two components viz., 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

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

(ii) Power factor, CosΦ $= \frac{OA}{OB} = \frac{active\ \ power}{apparent\ \ power} = \frac{kW}{kVA}$

Thus the power factor of a circuit may also be defined as the ratio of active power to apparent power.

(iii) The lagging reactive power is responsible for the low power factor. It is clear from the power triangle that smaller the reactive power component, the higher is the power factor of the circuit[3-5].

$$kVAR = kVASin\Phi = \frac{kWSin\Phi}{Cos\Phi}$$

$$kVAR = kWtan\Phi$$

(iv) For leading currents, the power triangle becomes reversed. This fact provides a key to the power factor improvement. If a dev ice taking leading reactive power (e.g. capacitor) is connected in parallel with the load, then the lagging reactive power of the load will c partly neutralized, thus improving the power factor of the load[5].

(v) The power factor of a circuit can be defined in one of the following three ways:

(a) Power factor = CosΦ = cosine of angle between V and I

(b) Power factor = $\frac{R}{Z} = \frac{Resistance}{Impedance}$

(c) Power factor = $\frac{VICos\Phi}{VI} = \frac{Active\ \ power}{Apparent\ \ Power}$

(vi) The reactive power is neither consumed in the circuit nor it does any useful work. It merely flows back and forth in both directions in the circuit. A wattmeter does not measure reactive power[5-7].

II. Problem Formulation

(a) Disadvantages of Low Power Factor

The power factor plays an important role in a.c. circuits since power consumed depends upon this factor

$$P = VICos\Phi \quad \text{(For single phase supply)}$$

therefore $I = \frac{P}{VCos\Phi}$

$$P = \sqrt{3}VICos\Phi \quad \text{(for 3phase supply)}$$

$$I = \frac{P}{\sqrt{3VCos\Phi}}$$

It is clear from above that for fixed power and voltage, the load current is inversely proportional to the power factor. Lower the power factor, higher is the load current and vice versa. A power factor less than unity results in the following disadvantages[6-7]:

(i) *Large KVA Rating of equipment:* the electrical machinery (e.g. alternators, transformers, switchgear) is always rated in KVA

As

$kVA = \frac{kW}{Cos\Phi}$

It is clear that KVA rating of the equipment is inversely proportional to power factor. The smaller the power factor, the larger is the KVA rating. Therefore at low power factor, the KVA rating of the equipment has to be made more, making the equipment larger and expensive.

(ii) *Greater Conductor size*: To transmit or a fixed amount of power at constant voltage, the conductor will have to carry more current at low power factor. This necessitates large conductor size.

(iii) *Large copper losses*: the large current at low power factor causes more I^2R losses in all the elements of the supply system. This results in poor efficiency.

(iv) *Poor voltage regulation*: The large current at low lagging power factor causes greater voltage drops in alternators, transformers, transmission lines and distributors. This results in the decreased voltage available at the supply end, thus impairing the performance of utilizing devices. In order to keep the receiving end voltage within permissible limits, extra equipment (i.e., voltage regulator) is required.

(v) Reduced handling capacity of system: The lagging power factor reduces the handling capacity of all the elements of the system. It is because the reactive component of current prevents the full utilization of installed capacity.

(b) Causes Of Low Power Factor

Low power factor is undesirable from economic point of view. Normally, the power factor of the whole load on the supply system is lower than 0.8. The following are the causes of low power factor [6]:

(i) Most of the ac motors are of induction type (1phase and 3 phase induction motors) which have low lagging power factor. These motors work at a power factor which is extremely small on light load (0.2 to 0.3) and rise to 0.8 or 0.9 at full load.

(ii) Arc lamps, electric discharge lamps and industrial heating furnaces operate at low lagging power factor.

(iii) The load on the power system is varying; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetization current. This results in the decreased power factor.

III. Importance Of Power Factor Improvement

The improvement of power factor is very important for both consumers and generating stations as discussed below[3]:

(i) ***For consumers:*** A consumer has to pay electricity charges for his maximum demand in KVA plus the units consumed. If the consumer improves the power factor, then there is a reduction in his maximum KVA demand and consequently there will be annual saving due to maximum demand charges. Although power factor improvement involves extra annual expenditure on account of power factor correction equipment, yet improvement of p.f. to a proper value results in the net annual saving for the consumer.

(ii) ***For generating stations:*** A generating station is as much concerned with power factor improvements as the consumer. The generators in a power station are rated in KVA but the useful output depends upon KW output.

As station output is: $kw = kVACos\Phi$

Therefore number of units supplied by it depends upon the power factor. The greater the power factor of the generating station, the higher is the KWh it delivers to the system. This leads to the conclusion that improved power factor increases the earning capacity of the power station

IV. Power Factor Correction Calculation

In Power factor calculation, the source voltage and current drawn can be measured using a voltmeter and ammeter respectively. A wattmeter is used to get the active power[3].

As $P = VICos\Phi \;\; watt$

Or $Cos\Phi = \frac{P}{VI} = \frac{Wattmeter\ \ reading}{voltmeter\ \ reading\ \ X\ \ Ammeter\ \ reading}$

Now calculate the reactive power Q = VI SinΦ VAR.

This reactive power can now be supplied from the capacitor installed in parallel with load in local. Value of capacitor is calculated as per following formula:

$$Q = \frac{V^2}{Xc}$$

$$C = \frac{Q}{2\pi f V^2} \quad \text{farad}$$

V. Power Factor Improvement Methods

Normally, the power factor of the whole load on a large generating station is in the region of 0.8 to 0.9. However, sometimes it is lower and in such cases it is generally desirable to take special steps to improve the

power factor. This can be achieved by the using: Static capacitors, Synchronous condensers, Phase advancers[3-4].

(a) *Static Capacitor:* The power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor. The capacitor (generally known as static capacitor) draws a leading current and partly or completely neutralizes the lagging reactive component of load current. This raises the power factor of the load. For three phase loads, the capacitor can be connected in delta or star as shown in figure 3. Static capacitors are invariably used for power factor improvement in factories. Table 1shows advantages and disadvantages of using Static Capacitor.

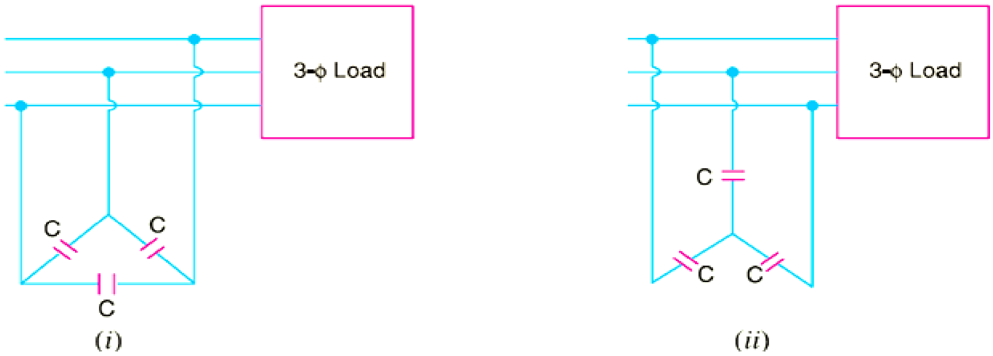


Fig 3 Static Capacitor connected in parallel with the load

Table 1: Advantages and disadvantages of using Static Capacitor

Advantages	**Disadvantages**
low losses.	Have short service life ranging from 8 to 10 years.
require little maintenance as there are no rotating parts.	Easily damaged if the voltage exceeds the rated value.
Can be easily installed as they are light and require no foundation.	Once the capacitors are damaged, their repair is uneconomical.
Can work under normal atmospheric conditions	

(b) *Synchronous Condensors:* A synchronous motor takes a leading current when over-excited and therefore, bhaves as a capacitor. An over -excited synchronous motor running on no load is known as synchronous condenser. Whwn such a machine is connected in parallel with the supply, it takes a leading currennt which partly neutralises the lagging reactive component of the load. Thus the poor factor is improved. Figure no 4 shows the power factor improvement by synchronous condenser method. The 3 phase load takes current I_L at low lagging power factor $Cos\Phi_L$. The synchronous condenser takes a current I_m which leads the voltage by an angle Φ_m. The resultant current I is the phasor sum of I_m and I_L and lags behind the voltage by an angle Φ. It is clear that Φ is less than Φ_L so that CosΦ is greater than $Cos\Phi_L$. Thus the power factor is increased from $Cos\Phi_L$ to CosΦ. This method is generally used at major bulk supply substations for power factor improvement. Table 2 shows advantages and disadvantages of using Synchronous condenser method

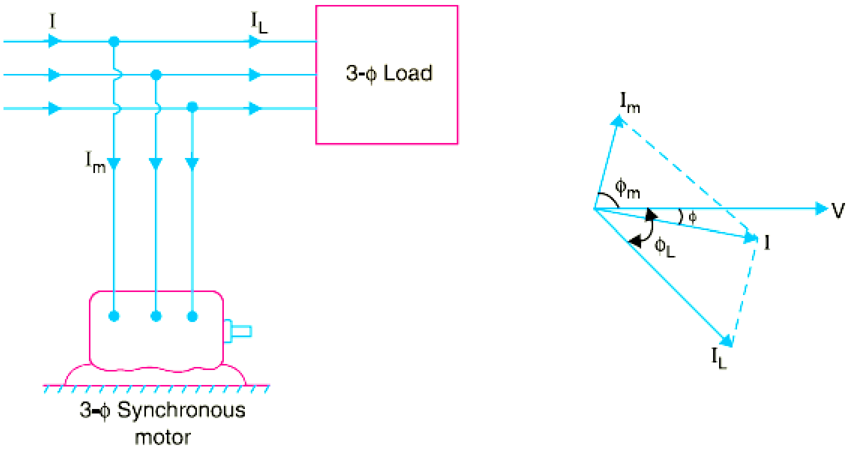


Fig 4 Synchronous condenser method

Table 2: Advantages and disadvantages of using Synchronous condenser method

Advantages	**Disadvantages**
Finer control can be achieved y varying the field excitation.	The cost is higher than static capacitors.
Possibility of overloading a synchronous condenser for short periods.	Higher maintenance and operating cost.
System stability is improved.	Lower efficiency due to losses in rotating parts and heat losses and noise.
The faults can be easily removed	Increase of short-circuit currents when the fault occurs near the synchronous condenser
	Except in sizes above 500kVA, the cost is greater than that of capacitor method.
	An additional equipment is required to start the synchronous motor, as they has no self-starting torque

(c) *Phase advancers:* This method is used to improve the power factor of induction motors. In induction motor, the stator winding draws exciting current which lags behind the supply voltage by 90°. It leads to low power factor in induction motors. If the excitation is provided from some other source, then the stator winding will be relieved of exciting current. So the power factor of the induction motor can be increased. This additional excitation is done by phase advancers. It is simply known as ac exciter. It is mounted on the same shaft as the main motor and is connected in the rotor circuit of the motor. It provides the exciting ampere turns to the rotor circuit at slip frequency. By providing more ampere turns than required, the induction motor can be made to operate on leading power factor like an over-excited synchronous motor. Table 3 shows Advantages and disadvantages of using Phase advancers

Table 3: Advantages and disadvantages of using Phase advancers

Advantages	**Disadvantages**
Lagging KVAR drawn by the motor is drastically reduced due to supply of exciting ampere-turns at slip frequency	This method is conveniently used where the use of synchronous condensers are not possible
This method is conveniently used where the use of synchronous condensers are not possible	

VI. Benefits Of Power Factor Correction

There are numerous benefits to be gained through power factor correction. These benefits range from reduced demand charges on your power system to increased load carrying capabilities in your existing circuits and overall reduced power system loses. And the benefits of power factor correction aren't just limited to the balance sheet; there are also huge environmental benefits associated with power factor correction [5-6].

(i) Reduced Demand Charges: Most electric utility companies charge for maximum metered demand based on either the highest registered demand in kilowatts (KW meter), or a percentage of the highest registered demand in KVA (KVA meter), whichever is greater. If the power factor is low, the percentage of the measured KVA will be significantly greater than the KW demand. Improving the power factor through power factor correction will therefore lower the demand charge, helping to reduce the electricity bill.

(ii) Increased Load Carrying Capabilities in Existing Circuits: Loads drawing reactive power also demand reactive current. Installing power factor correction capacitors at the end of existing circuits near the inductive loads reduces the current carried by each circuit. The reduction in current flow resulting from improved power factor may allow the circuit to carry new loads, saving the cost of upgrading the distribution network when extra capacity is required for additional machinery or equipment, saving thousands of dollars in unnecessary upgrade costs. In addition, the reduced current flow reduces resistive losses in the circuit.

(iii) *Improved Voltage:* A lower power factor causes a higher current flow for a given load. As the line current increases, the voltage drop in the conductor increases, which may result in a lower voltage at the equipment. With an improved power factor, the voltage drop in the conductor is reduced, improving the voltage at the equipment.

(iv) Reduced Power System Losses: Although the financial return from conductor loss reduction alone is seldom sufficient to justify the installation of capacitors, it is sometimes an attractive additional benefit; especially in older plants with long feeders or in field pumping operations. System conductor losses are proportional to the current squared and, since the current is reduced in direct proportion to the power factor improvement, the losses are inversely proportional to the square of the power factor.

(v) Reduced Carbon Footprint: By reducing the power system's demand charge through power factor correction, the utility is putting less strain on the electricity grid, therefore reducing its carbon footprint. Over time, this lowered demand on the electricity grid can account for hundreds of tons of reduced carbon production, all thanks to the improvement of power system's electrical efficiency via power factor correction.

VII. Conclusions

By observing all aspects of the power factor it is clear that power factor is the most significant part for the utility company as well as for the consumer. Utility company rid of from the power losses while the consumer free from low power factor penalty charges. By installing suitably sized power capacitors into the circuit the power factor is improved and improving the efficiency of a plant [3].

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