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Power Factor Importance in Modern Era

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We hope to give you an easy explanation of what power factor is, and to answerthe following most asked questions:

1: **What is Power Factor?**

2: What Causes Low Power Factor?

3: Why Should I Improve My Power Factor?

4: How Do I Correct (Improve) My Power Factor?

5: How Long Will It Take My Investment in Power Factor Correction to Pay for Itself?

6-Benefits of power factor improvement

1: What is Power Factor?

To understand power factor, we'll first start with the definition of some basic terms:

KW is Working Power (also called Actual Power or Active Power or Real Power).
It is the power that actually powers the equipment and performs usefulwork.

KVAR is Reactive Power.
It is the power that magnetic equipment (transformer, motor and relay)needs to produce the magnetizing flux.

KVA is Apparent Power.
It is the "vectorial summation" of KVAR and KW.

Let's look at a simple analogy in order to better understand these terms….

Let's say you are at the ballpark and it is a really hot day. You order up amug of your favorite brewsky. The thirst-quenching portion of your beeris represented by **KW** (Figure 1).

Unfortunately, life isn't perfect. Along with your ale comes a little bit of foam. (And let's face it…that foam just doesn't quench your thirst.) Thisfoam is represented by **KVAR.**

The total contents of your mug, **KVA**, is this summation of KW (the beer)and KVAR (the foam).

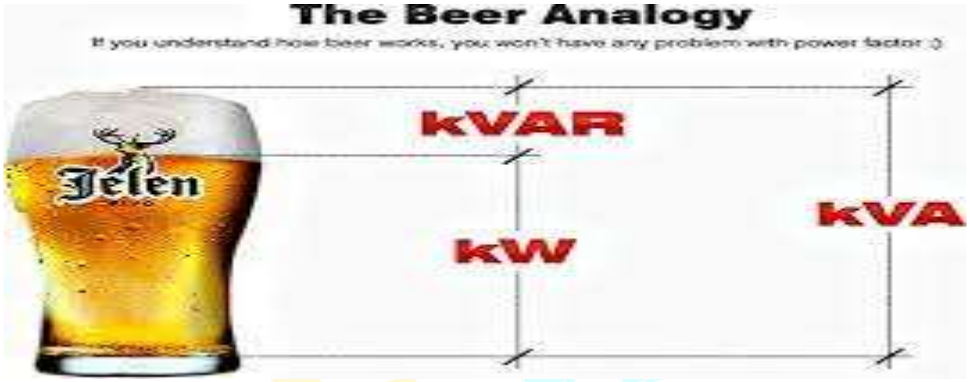


Figure 1

So, now that we understand some basic terms, we are ready to learn about power factor:

Power Factor (P.F.) is the ratio of Working Power to Apparent Power.

$$P.F. = \frac{KW}{KVA}$$

Looking at our beer mug analogy above, power factor would be the ratioof beer (KW) to beer plus foam (KVA).

$$P.F. = \frac{KW}{KW + KVAR}$$

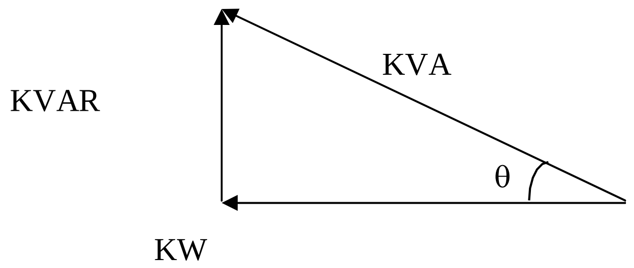
$$= \frac{Beer}{Beer + Foam}$$

Thus, for a given KVA:

- The more foam you have (the higher the percentage of KVAR), the lower your ratio of KW (beer) to KVA (beerplus foam). Thus, the lower your power factor.
- The less foam you have (the lower the percentage of KVAR), the higher your ratio of KW (beer) to KVA (beerplus foam). In fact, as your foam (or KVAR) approaches zero, your power factor approaches 1.0.

Our beer mug analogy is a bit simplistic. In reality, when we calculate KVA, we must determine the "vectorial summation" of KVAR and KW.Therefore, we must go one step further and look at the angle between these vectors.

The Power Triangle



$$P.F. = \frac{KW}{KVA} = \cos\theta$$

$$\frac{KVAR}{KVA} = \sin\theta$$

$$KVA = \sqrt{KW^2 + KVAR^2}$$

Note that…in an ideal world…looking at the beer mug analogy:

- KVAR would be very small (foam would be approaching zero)
- KW and KVA would be almost equal (more beer; less foam)

Similarly…in an ideal world…looking at Mac's heavy load analogy:

- KVAR would be very small (approaching zero)
- KW and KVA would be almost equal (Mac wouldn't have towaste any power along his body height)
- The angle □ (formed between KW and KVA) would approachzero
- Cosine □ would then approach one
- Power Factor would approach one

So….

In order to have an "efficient" system (whether it is the beer mug or Mac dragging A heavy load), we want power factor to be as close to 1.0 as possible.

Sometimes, however, our electrical distribution has a power factor much less than 1.0. Next, we'll see what causes this.

What Causes Low Power Factor?

Great. I now understand what power factor is. But I've been told mine is low. What did I do to cause this?

Since power factor is defined as the ratio of KW to KVA, we see that low powerfactor results when KW is small in relation to KVA. Remembering our beer mug analogy, this would occur when KVAR (foam, or Mac's shoulder height) is large.

What causes a large KVAR in a system? The answer is…**inductive loads.**

Inductive loads (which are sources of Reactive Power) include:

- **Transformers**
- **Induction motors**
- **Induction generators (wind mill generators)**
- **High intensity discharge (HID) lighting**

These inductive loads constitute a major portion of the power consumed inindustrial complexes.

Reactive power (KVAR) required by inductive loads increases the amount of apparent power (KVA) in your distribution system (Figure 4). This increase in reactive and apparent power results in a larger angle (measured between KW and KVA). Recallthat, as increases, cosine (or power factor) decreases.

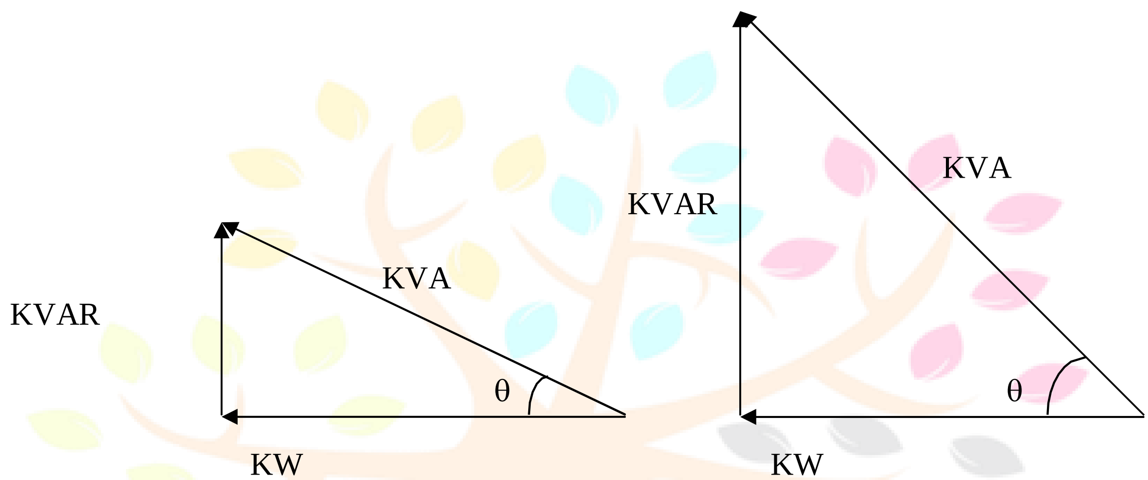


Figure 4

So, inductive loads (with large KVAR) result in low power factor.

Why Should I Improve My Power Factor?

Okay. So I've got inductive loads at my facility that are causing my power factorto be low. Why should I want to improve it?

You want to improve your power factor for several different reasons. Some of thebenefits of improving your power factor include:

1) **Lower utility fees** by:

   a. Reducing peak KW billing demand

      Recall that inductive loads, which require reactive power, causedyour low power factor. This increase in required reactive power (KVAR) causes an increase in required apparent power (KVA), which is what the utility is supplying.

      So, a facility's low power factor causes the utility to have to increase its generation and transmission capacity in order to handlethis extra demand.

      By raising your power factor, you use less KVAR. This results inless KW, which equates to a dollar savings from the utility.

b. Eliminating the power factor penalty

Utilities usually charge customers an additional fee when their power factor is less than 0.95. (In fact, some utilities are not obligated to deliver electricity to their customer at any time the customer's power factor falls below 0.85.) Thus, you can avoidthis additional fee by increasing your power factor.

2) **Increased system capacity** and **reduced system losses** in your electricalsystem

By adding capacitors (KVAR generators) to the system, the powerfactor is improved and the KW capacity of the system is increased.

For example, a 1,000 KVA transformer with an 80% power factorprovides 800 KW (600 KVAR) of power to the main bus.

$$1000\ KVA = \sqrt{(800\ KW)^2 + (?\ \ KVAR)^2}$$

KVAR = 600

By increasing the power factor to 90%, more KW can be suppliedfor the same amount of KVA.

$$1000\ KVA = \sqrt{(900\ KW)^2 + (?\ \ KVAR)^2}$$

KVAR = 436

The KW capacity of the system increases to 900 KW and theutility supplies only 436 KVAR.

Uncorrected power factor causes power system losses in your distribution system. By improving your power factor, these lossescan be reduced. With the current rise in the cost of energy, increased facility efficiency is very desirable. And with lower system losses, you are also able to add additional load to your system.

3) **Increased voltage level** in your electrical system and **cooler, more efficientmotors**

As mentioned above, uncorrected power factor causes power system losses in your distribution system. As power losses increase, you may experience voltage drops. Excessive voltage drops can cause overheating and premature failure of motors and other inductive equipment.

So, by raising your power factor, you will minimize these voltage drops along feeder cables and avoid related problems. Your motors will run cooler and be more efficient, with a slight increasein capacity and starting torque.

How Do I Correct (Improve) My Power Factor?

All right. You've convinced me. I sure would like to save some money on mypower bill and extend the life of my motors. But how do I go about improving (i.e., increasing) my power factor?

We have seen that **sources of Reactive Power** (inductive loads) <u>decrease</u> powerfactor:

- **Transformers**
- **Induction motors**
- **Induction generators (wind mill generators)**

- **High intensity discharge (HID) lighting**

Similarly, **consumers of Reactive Power** increase power factor:

- **Capacitors**
- **Synchronous generators (utility and emergency)**
- **Synchronous motors**

Thus, it comes as no surprise that one way to increase power factor is to add capacitors to the system. This--and other ways of increasing power factor--are listedbelow:

1) Installing capacitors (KVAR Generators)

Installing capacitors decreases the magnitude of reactive power (KVAR orfoam), thus increasing your power factor.

Here is how it works (Figure 5)…

Reactive power (KVARS), caused by inductive loads, always acts at a 90-degree angle to working power (KW).

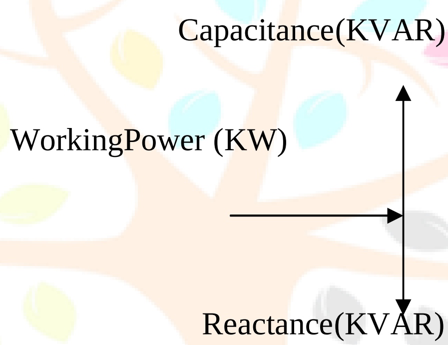


Figure 5

Inductance and capacitance react 180 degrees to each other.Capacitors store KVARS and release energy opposing the reactive energy caused by the inductor.

The presence of both a capacitor and inductor in the samecircuit results in the continuous alternating transfer of energy between the two.

Thus, when the circuit is balanced, all the energy releasedby the inductor is absorbed by the capacitor.

Following is an example of how a capacitor cancels out the effect of aninductive load….

2) Minimizing operation of idling or lightly loaded motors.

We already talked about the fact that low power factor is caused by the presence of induction motors. But, more specifically, low power factor iscaused by running induction motors lightly loaded.

3) Avoiding operation of equipment above its rated voltage.

4) Replacing standard motors as they burn out with energy-efficient motors.

Even with energy-efficient motors, power factor is significantly affectedby variations in load. A motor must be operated near its rated load in order to realize the benefits of a high power factor design

How Long Will It Take my Investment in Power FactorCorrection to Pay for Itself?

Super, I've learned that by installing capacitors at my facility, I can improve my power factor. But buying capacitors costs money. How long will it take for the reduction in mypower bill to pay for the cost of the capacitors?

A calculation can be run to determine when this payoff will be. As an example, assume that a portion of your facility can be modeled as in Figure 6 below. Your currentpower factor is 0.65.

Following are the parameters for your original system:

- 163 KW load
- 730 hours per month
- 480 Volt, 3 phase service
- 5% system losses
- Load PF = 65%
- PSE Rate Schedule:
  - Energy Rate = 4.08 per KWH
  - Demand Charge = 2.16 per KW
  - PF Penalty = 0.15 per KVARH

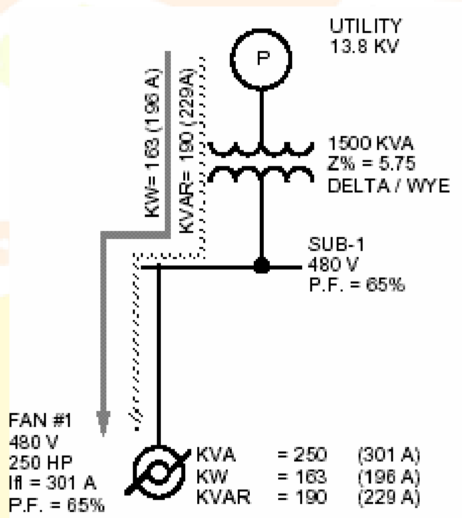


Figure 6

We'll calculate the total amount the utility charges you every month as follows: First, we'll calculate your **energy usage:**

163 KW X 730 Hours/Month X 4.08/KWH = 4,854.79/MonthNext, we'll calculate your **demand charge:**

163 KW X 2.16/KW = 352.08/Month

Finally, we'll calculate your **Power Factor Penalty:**

190 KVAR X 730 Hours/Month X 0.15/KVARH = 208/Month

Now, let's say that you decide to install a capacitor bank (Figure 7). The 190 KVAR from the capacitor cancels out the 190 KVAR from the inductive motor. Yourpower factor is now 1.0.

Following are your parameters for your system with capacitors:

- Corrected PF = 1.0

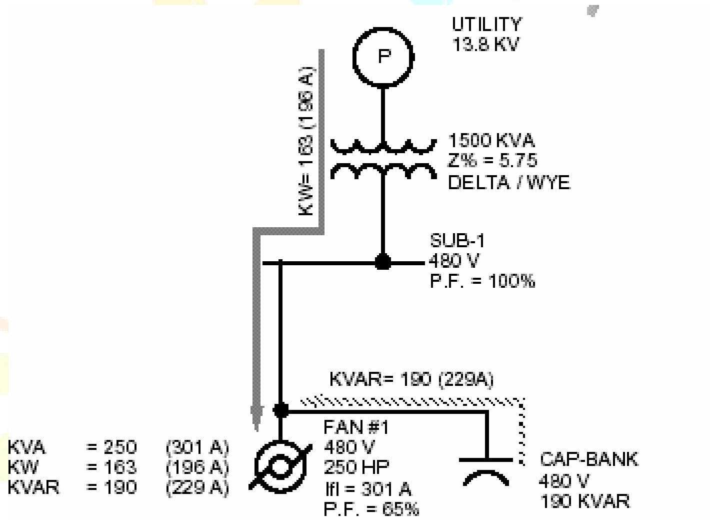


Figure 7

You can calculate your loss reduction:

Loss Reduction = $1-(0.65^2 / 1.00^2) = 0.58$ Therefore, your system

loss reduction will be as follows:

0.58 X 0.05 (losses) = 0.029 System Loss ReductionYour total KW load

will be reduced as follows:

163 KW X 0.029 = 4.7 KW

Now we can calculate your savings in **energy usage:**

4.7 KW X 730 Hours/Month X 4.08/KWH = 141.00/MonthNext, we'll calculate

your savings in **demand charge:**

4.7 KW X 2.16/KW = 10.15/Month

Finally, remember that your **Power Factor Penalty** is zero.

Let's calculate how long it will take for this capacitor bank to pay for itself.

- Capacitor Cost = 30.00/KVARYour savings per

month are as follows:

141.00	Energy Usage
10.15	Demand Charge
208.00	PF Penalty Charge
359.15	Total

Your payback will be at the following time:

$30.00/KVAR X 190 KVAR/$359/Month = 16 MonthsInstallation of your

capacitors will pay for themselves in 16 months.

Benefits of power factor improvement

Most benefits provided by a power factor improvement system from the reductionof reactive power in the system. This may result in

A) Lower purchased-power cost if the utility enforces a power-factor clause
B) Release of system electrical capacity
C) Voltage improvement and
D) Lower system losses

Maximum benefits are obtained when capacitors are located at low power-factor levels. Although reducing the power bill is still primary reason for improving the power factor, and it is becoming more important because of conservation of energy, the function of releasing system capacity is sometimes the decisive factor.

2. POWER-FACTOR FUNDAMENTALS:

Causes of Low Power Factor.

Most utilization devices require two components of current.

a) The power producing current or working current is that current which is converted by the equipment into useful work, usually in the form of heat, light or mechanical power. The unit of measurement of power is WATT.

b) Magnetizing current, also known as Watt-less, reactive or non-working current, is the current required to produce the flux necessary for the operation of electromagnetic devices. Without magnetizing current, energy could not flow through the core of transformer. The unit of measurement of reactive power is VAR.

The normal relationship of these two components of current to each other, to the total current, and to the system voltage is explained in Fig-1. It shows that the active current and reactive current add vectorially to form the total current whichcan be determined from the expression,

Total current = I = $\sqrt{(I\cos\Phi)^2 + (I\sin\Phi)^2}$

3. DEFINITION OF POWER-FACTOR:

The power factor is defined as the ratio of active power to apparent power in acircuit. It varies from one to zero but is generally given as below:

Power factor = Active power in KW / Apparent power KVA

Power Factor = cosine of angle between active power and apparent power = Cos Φ

Active Power = Apparent power × Power Factor
= (KVA). (PF)

4. LEADING AND LAGGING POWER FACTOR:

The power factor may be lagging or leading depending on the direction of both the active and reactive power flows. If these flows are in same direction, the power factor at that point of reference is lagging. If either power component flow is in an opposite direction, the power factor at that point of reference is leading. Since the capacitors are a source of reactive power only, their power factor is always leading. An induction motor or transformer has a lagging power factor as it required both active and reactive power into in the motor or transformer.(same direction)

5. BASIC POWER FACTOR ECONOMICS:

High plant power factors can yield direct savings. Some, such as reduced power bills and release of system capacity, are quite visible; others, such asdecreased I2R losses (copper loss) are also visible. The cost of improving the power factor in existing plants, and of maintaining proper levels as load is added, depends on the power factor value selected and upon the equipment chosen to supply the compensating reactive power. In general, medium voltage capacitors costless per kilovar than low-voltage capacitors.

The combination of reduced power billing and released system capacity by improving the power factor is very attractive economically.

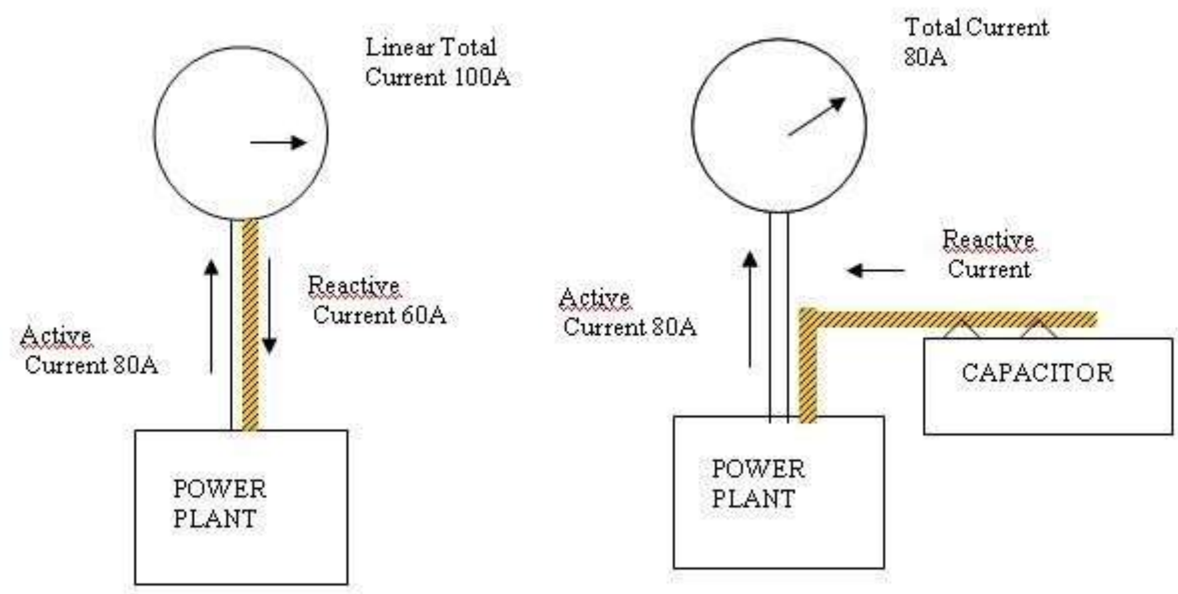
On comparing the installation cost of power factor improving capacitors and installed cost per KVA of power distribution equipment, it is achieved that the economic power factor would be 0.95

6. HOW THE POWER FACTOR IS IMPROVED:

When the reactive power component in a circuit is reduced, the total current is reduced. If the active power component does not change, as is usually true, the power factor will improve as the reactive power component becomes zero, the power factor will be unit or 100 percent.

Suppose a transformer load (in the power plant used in DOT) takes an active loadof 80A and a reactive load of 60A from the mains, the total or line current will be of v802 + 1002 = 100 Amps. If a capacitor is installed so that it will supply the reactive current of 60A, then the supply needs to deliver only 80A to the exactly same load of the transformer. The supply circuit is now carrying only active power, hence the system capacity is not wasted in carrying reactive power.

Fig. 2



Now, if we increase the capacity of capacitor further to increase the reactive current, the excess reactive current tends to flow towards the mains, causing the leading power-factor, which is also not advisable in the view of Electricity authorities.

Calculation of methods of power-factor improvement.

From the right triangle relationship shown in Fig.1, the simple and useful mathematical expressions may be written.

$$\text{Cos } \Phi = \frac{\text{Active Power}}{\text{Apparent Power}} = \frac{\text{KW}}{\text{KVA}}$$

$$\text{Tan } \Phi = \frac{\text{Reactive Power}}{\text{Active power}} = \frac{\text{Kvar}}{\text{KW}}$$

$$\text{Sin } \Phi = \frac{\text{Reactive power}}{\text{Apparent power}} = \frac{\text{Kvar}}{\text{KVA}}$$

Because the active power component usually remains constant and the apparent power and reactive power components change with the power factor, the

expression involving the active power component is the most convenient one toanalyse. This expression may be written as

$$\text{Reactive Power} = \text{Active power} \times \text{Tan } \Phi$$

$$\text{Kvar} = (\text{KW}).\ \text{Tan } \Phi$$

Where Tan Φ corresponds to the power factor angle.

For example, assume that it is necessary to determine the Capacitor rating toimprove the load power factor:

Reactive power at Original power factor = Active power × Tan Φ_1
= (KW).(TanΦ_1)

Reactive power at Improved power factor = Active power × Tan Φ_2
= (KW).(Tan Φ_2)

Where the Φ_1= angle of original power factorΦ_2= angle of improved power factor

Therefore the capacitor rating required to improve the power factor is

Reactive power of capacitor = Active power × (Tan Φ_1 - Tan Φ_2)'

Kvar ' Rating of the capacitor

$$=(KW). (\tan \Phi_1 - \tan \Phi_2)$$

Example: Find the capacitor rating required to improve the power factor of a 50KW loadfrom 0.76 to 0.93

$$Kvar = KW. (\tan \Phi_1 - \tan \Phi_2)$$

Cos Φ_1 = 0.76; Φ_1 = 40° 54' : Tan Φ_1 = 0.8662Cos Φ_2 =0.93; Φ_2 =21° 38' : Tan Φ_2 =0.3966 Tan Φ_1 - Tan Φ_2 = 0.4676

Now Kvar = 50 (0.4696)

=23.48

25 Kvar

Capacitor rating = 25 Kvar

7. LOCATION OF REACTIVE POWER SUPPLY:

The benefits obtained by installing capacitors for power factor improvement resultfrom the reduction of reactive power in the system. They should, in general, be installed as close to the load as possible. It is in common practice to connect the capacitors ahead of individual plants. This provides power factor improvement at the load and permits switching the capacitor and the plant as a unit as shown in location C1 of fig.3.

Power factor improvement for small loads or for those units that for some otherreason may not lend themselves to have capacitors directly associated with theload, may be accomplished by connecting capacitors at a substation at location C2. Large plants with extensive primary distribution systems often install capacitors atthe primary voltage bus at location C3 when the utility billing encourages the userto improve the power factor.

The expression, release of capacity means that as the power factor is improved, the current in the existing system will be readuced, permitting additional load tobe served by the same system.

If a plant has a load of 100KVA at 70 percent power factor and 48 Kvar of capacitors are added, the system electric capacity is released by 28 percent approximately, that the system can carry 28 percent more load without exceeding the apparent power rating. The final power factor of the original load plus the additional load will be 0.9 (90 percent) approximately.

8. VOLTAGE IMPROVEMENT

Although capacitors raise a circuit voltage, it is rarely economical to apply them in industrial plants for that reason alone. The following approximate expression showsthe importance of reducing the reactive power component of a current in order to reduce the voltage drop.

$$\Delta V \approx RI \cos \Phi \pm XI \sin \Phi$$

$$\Delta V = (R) X [\text{Active power current}] \pm (X) [\text{Reactive power current}]$$

Where ΔV is the voltage change, which may be a drop or rise in voltage;

R and X are in ohms; I in amperes; Φ is the power factor angle. Plus is used when the power is lagging and minus when it is leading.

Typically, reactive power flow produces a voltage drop. Since the power factor actsdirectly to reduce reactive power flow, it is most effective in reducing voltage drop.

9. POWER SYSTEM LOSSES:

Although the financial return from conductor loss reduction is seldom sufficient tojustify the installation of capacitors, it is an attractive additional benefit. System conductor losses are proportional to current squared, and since current is reduced in direct proportion to power factor improvement, the losses are inversely porportional to the square of the power factor.

Percentage loss reduction = 100 [1 – (Original PF / Improved PF)^2]

<u>Case Study of Usage of Capacitor banks for Improving PF - TEHarbour</u>

1. When all the capacitors are switched OFF,
   PF : 0.787 KVA : 414.3 KW : 326.1

2. KVAR required to improve the PF to 0.9 = 326.1 x 0.292 (MF) = 95.22
   = 95 KVAR

3. KVAR required to improve the PF to 1.0 = 326.1 x 0.776 (MF)

4. = 253 KVAR

5. Additional KVAR required to improve the PF from 0.9 to 1.0
   = 253-95 =158 KVAR

6. Capital Investment for installing Capacitors:

- Cost of capacitor with MS compartment & switch gearsPer KVAR = Rs.1500
  Total amount for 158 KVAR = 158 x 1500 = Rs.2,37,000 (A)

- Watt loss of the capacitor = 0.5 W per KVAR
  For 158 KVAR , the total watt loss = 0.5 x 158 = 79 W

  Expenditure on electricity charges
  Per month @ Rs. 5 /Unit = $\frac{79 \times 24 \times 5 \times 30}{1000}$ =Rs.284 (B)

Sl No	Bill period from 4/2004 to 9/2004	Actual Maximum Demand	Actual Power Factor	No. of units consumed
1	April	568.9	0.99	320,620
2	May	602.0	1.0	312,230
3	June	554.7	1.0	306,910
4	July	542.8	0.99	264,550
5	August	482.3	0.99	240,210
6	September	551.9	0.98	223,330
	Average /Month	**550**		**2,77,925**

Contract demand : 700 KVA

- <u>Electricity Charges for a month if PF = 0.9</u>

Unit Charges @ Rs.5/unit = 2,77,925 x 5 = 13,89,625
MD charges @ Rs. 300 /KVA = 630 x 300 = 1,89,000

15,78,625

- Electricity Charges for a month if PF = 1.0

Unit Charges @ Rs.5/unit = 2,77,925 x 5 = 13,89,625
MD charges @ Rs. 300 /KVA = 630 x 300 = 1,89,000

15,78,625

Rebate @ 2.5 % 39,466

15,39,159
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5. Rate of return of cost of Capacitors

Month	Interest on the investment made@ 5 % PA	Expenditure dueto watt loss of capacitor	Return of cost due to incentive	Balance amt. tobe recovered
0	0	0	0	237,000
1	995	284	39,466	198,813
2	835	284	39,466	160,466
3	674	284	39,466	121,958
4	512	284	39,466	83,289
5	350	284	39,466	44,456
6	187	284	39,466	5,461

❖ Approximately in 6 months time the cost of capacitors are paidback by means of incentive.