International Journal of
Scientific Engineering and Technology Research

ISSN 2319-8885
Vol.03,Issue.15
July-2014,
Pages:3191-3195

www.semargroup.org,
www.ijsetr.com

Power Factor Improvement for Industrial Load by using Shunt Capacitor Bank

AYE AYE MON[1], SOE WIN NAING[2]
[1]Dept of Electrical Power, Mandalay Technological University, Mandalay, Myanmar, Email: ayeayemon.aam23@gmail.com.
[2]Dept of Electrical Power, Mandalay Technological University, Mandalay, Myanmar.

Abstract: Most industrial loads such as induction motors operate at moderately low power factors. Around 60% of the utility load consists of motors and hence the overall power factor of the power system is low. Depending on the level of the load, these motors are inherently low power factor devices. The power factor of these motors varies from 0.30 to 0.95, depending on the size of the motor and other operating conditions. Therefore, the power factor level is always a concern for industrial power systems, utilities, and the user. The system performance can be improved by correcting the power factor. Since the number of power electronic based devices is increasing, it leads to designing more and more capacitor bank. Shunt capacitor banks are used to improve the quality of the electrical supply and the operation of the power system. . In industrial systems, power factor correction capacitor units are utilized for group or individual loads.

Keywords: Capacitors, Industrial Loads, Power Factor, Power Factor Correction, Shunt Capacitor Bank.

I. INTRODUCTION

Most plant loads are inductive and require a magnetic field to operate motors transformers and florescent lighting. The magnetic field is necessary, but produces no useful work. The utility must supply the power to produce the useful work. These two types of current are active and reactive. Shunt capacitor banks are mainly installed to provide capacitive reactive compensation/power factor correction. The use of SCBs has increased because they are relatively inexpensive, easy and quick to install. Its installation has other beneficial effects on the system such as: improvement of the voltage at the load, better voltage regulation, reduction of losses and reduction or postponement of investment in transmission. Power factor capacitors are static equipment without any rotating parts and require less maintenance. Therefore, shunt capacitors are widely used in power factor correction applications. The shunt capacitors provide kVAR at leading power factor and hence the overall power factor is improved.[1]

II. POWER FACTOR

The current required by motors, lights, and computers is made up of real and reactive components. This concept of a two component current is helpful in understanding the capacitor current. Loads such as a heater require the supply of only the real component of current. Some loads, such as an induction motor, require both real and reactive currents. The real current is that component that is converted by the equipment into useful work such as production of heat through a heater element. The unit of measurement of this current is ampere (A) and of power (voltage_real current) is watts (W). The reactive current is that component that is required to produce the flux necessary for the functioning of induction devices. The current is measured in ampere (A) and the reactive power in VARs.

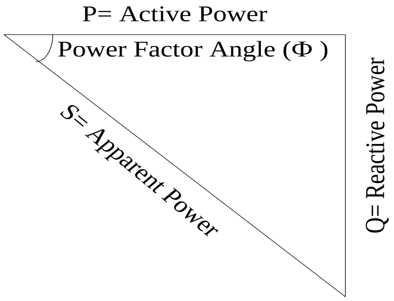
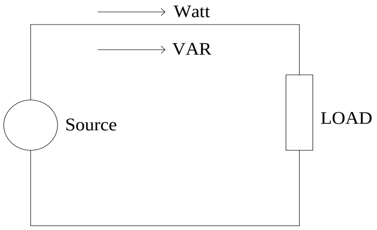


Figure1. Power triangle [1].

Power factor is the ratio of working power to apparent power or kW/kVAR. Power factor values can carry from 0 to 1.00. Typically, values range from 0.80 to 0.98. A power factor below 0.80 is considered low.

A. Lagging Power Factor

Consider an inductive load as shown in Figure 3.2. In this circuit, both watts and VARs are delivered from the source. The corresponding phasor diagram is shown in Figure 3.2. The power factor angle in this case is negative, and therefore the power factor is lagging.



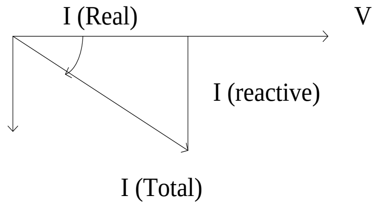


Figure2. The concept of lagging power factor [1]

B. Leading Power Factor

Consider a capacitive load as shown in Figure 3.3. In this circuit, the watts are delivered from the source. The reactive power (VARs) is delivered from the load to the source. The corresponding phasor diagram is shown in Figure 3.3. The power factor angle in this case is positive, and therefore the power factor is leading.

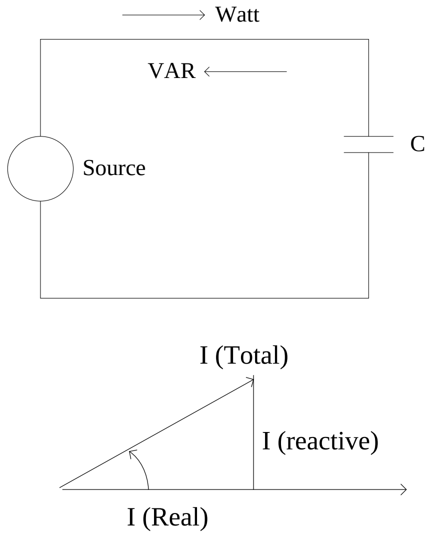


Figure3. The concept of leading power factory.

III. POWER FACTOR IMPROVEMENT

Most industrial loads such as induction motors operate at moderately low power factors. Around 60% of the utility load consists of motors and hence the overall power factor of the power system is low. Depending on the level of the load, these motors are inherently low power factor devices. The power factor of these motors varies from 0.30 to 0.95, depending on the size of the motor and other operating conditions. Therefore, the power factor level is always a concern for industrial power systems, utilities, and the user. The system performance can be improved by correcting the power factor. The system power factor is given by:

$$\textbf{Power Factor} = \textbf{P/kVA} \qquad (1)$$

Where P and kVA are the real and apparent power, respectively. The relation between the power factor and the Q/P ratio is shown in Table1. From Table 1, it can be seen that even at 90% power factor, the reactive power requirement is 48% of the real power. At low power factors, the reactive power demand is much higher. Therefore, some form of power factor correction is required in all the industrial facilities.

The power factor of any operating system can be lagging or leading. The direction of active and reactive power can be used to determine the nature of the power factor. If both the real and reactive power flow are in the same direction, then the power factor is lagging. If the reactive power flows in the direction opposite to that of the real power, then the power factor is leading. A typical lagging power factor load is an induction motor. A typical leading power factor load is a capacitor. Generally, power factor improvement can be made for three reasons in industrial plant. [2]

Table I. Power Factor and Q/P Ratio [2]

Power Factor %	Angle Degree	Q/P Ratio
100	0	0.00
95	11.4	0.20
90	26.8	0.48
85	31.8	0.62
80	36.8	0.75
70.7	45.0	1.00
60	53.1	1.33
50	60.0	1.73

A. Reduce electricity consumption in a plant

Power factor improvement in plant, by adopting any one of the aforementioned options, will generally compensate for the losses and reduce current loadings on supply equipment, i.e.; cables, switchgear, transformers, generating plant, etc. That means power factor corrections – whenever there is scope for correction- will reduce electricity consumption in the plant and in turn the electricity cost. Many of these losses are not properly monitored in many industries and hence the savings are not quantified. This may be one of the reasons for the argument that PF improvement reduces only electricity costs in case the power utility is offering a tariff where a reactive power demand charge are part of the monthly electricity bill. Power factor improvement will lead to reduction in electricity consumption, when it is done at the equipment level or at the Control Centre level. (A case study is given to demonstrate the savings in both these cases) But it will not lead to reduction in electricity consumption if the plant, receiving power from a common grid, carries out the correction at the supply voltage/incoming voltage level, just to compensate for the reactive power drawn from the grid. If the plant does the above correction in their own self-generating grid supply, there will be a saving in cost (either in terms of electricity cost or in fuel cost) due to reduction in generator losses.

B. Reduce electricity costs only

Power factor correction will reduce electricity cost only, when the plant receiving power from a common grid carries out the correction at the supply voltage/incoming voltage level, just to compensate for the reactive power drawn from the grid. But, even this improvement in PF may not always reduce the electricity cost as the contract demand in a plant is very often fixed on a fictitious consumption in the plant. On many occasions contract demand is fixed based on the future expansion plans, and based on the high diversity factor taken during design stages. In most of the cases the Utilities charge for a minimum contract demand irrespective of the consumption and a reduction in kVA may not produce any benefit as long as the contract demand is re-fixed to actual value. Generally, PF is improved to 0.95-0.98, as improving PF further to unity may lead to higher payback periods.

C. Reduce both electricity cost and electricity consumption

In all other cases other than the above mentioned exception, whenever improvement of power factor is carried out, it will eventually lead to reduction in electricity consumption and hence electricity cost. However, payback on investment due to power factor correction depends on the type of installation and various other factors like power tariff, loading pattern of equipment, method of power generation/utilization, operating philosophy of the plant etc.

D. Advantages of Power Factor Correction

The advantages that can be achieved by applying the correct power factor correction are

1. Reduced system losses, and the losses in the cables, lines, and feeder circuits and hence lower sizes could be opted.
2. Improved system voltages, thus enable maintaining rated voltage to motors, pumps and other equipment. The voltage drop in supply conductors is a resistive loss, and wastes power heating the conductors. A 5% drop in voltage means that 5% of your power is wasted as heat before it even reaches the motor. Improving the power factor, especially at the motor terminals, can improve your efficiency by reducing the line current and the line losses.
3. Improved voltage regulation.
4. Increased system capacity, by release of kVA capacity of transformers and cables for the same kW, thus permitting additional loading without immediate augmentation.

IV. FUNDAMENTALS OF SHUNT CAPACITOR BANK

Economical operation of modern power systems requires more distributed voltage support than ever before. Load and distributed generation characteristics have both changed to require increased VAR support throughout the power system. Capacitor banks are the most economical form of adding VARs to the system. The shunt capacitor banks can be installed at distribution systems, loads, feeders, high voltage systems, or extra-high voltage systems. Loads, feeders, high voltage systems, or extra-high voltage systems. Further, the capacitor banks can be applied on individual loads, branch locations, or at the group load. Furthermore, the banks can be fixed or switched. There are various methods available for switching these capacitor banks. The shunt capacitor installations are used in distribution and high voltage systems, where significant reactive power is supplied to the power system. Also, if a capacitor unit fails, then the voltage of the good capacitor units increases. These voltages have to be kept within acceptable limits. The capacitor units are manufactured, tested, and used in power factor correction applications. Proper specification of the applicable parameters is important for safe and efficient operation. Some of the specifications applicable to these units are voltage, frequency, insulation class, momentary ratings, nominal kVAR rating, and allowable operating service conditions. In order to compensate for the reactive power, the shunt capacitors are used at the motor terminals. [3]

V. LOCATION OF SHUNT CAPACITORS

Power factor correction capacitors can be installed at high voltage bus, distribution, or at the load. The following power factor correction approaches are commonly used.

A. Group Capacitor Bank

A group capacitor bank installation is shown in figure 4. In this approach, the power factor correction is applied to a group of loads at one location. This technique is suitable for utility or industrial customers with distributed load.

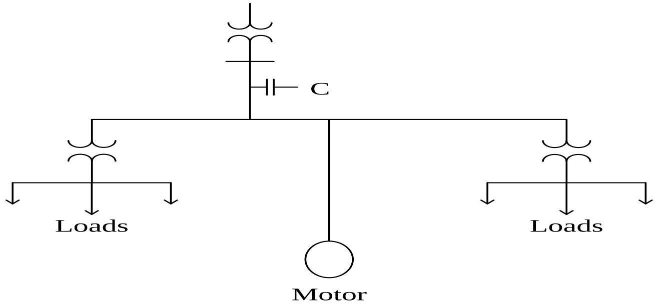


Figure4. Group capacitor bank [3]

If the entire load comes on or off together, then it is reasonable to switch the capacitor bank in this manner. If part of the load is switched on and off on a regular basis, then this type of reactive compensation is not appropriate. It is economical to have a large capacitor bank for reactive compensation rather than several smaller banks.

B. Branch Capacitor Bank

In certain industrial applications, the load is switched on and off based on shifts. Such a load group can be related to individual feeders or branch circuits. Therefore, it is advantageous to switch the capacitor banks along with the specific branches. An example of branch capacitor bank scheme is shown in Figure 4.4. This type of capacitor bank will not help reduce the losses in the primary circuit.

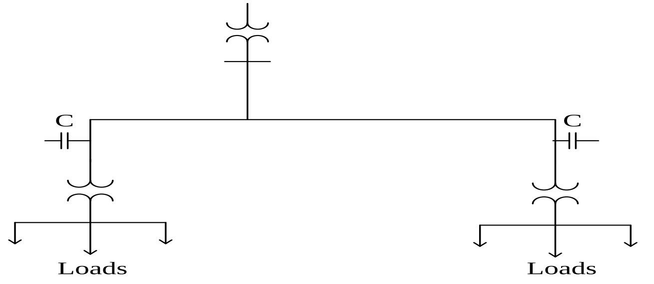


Figure5. Branch capacitor bank [3].

C. Local Capacitor Bank

An example of local capacitor bank application for the power factor correction is shown in Figure 4.5. In this scheme, the individual loads are provided with separate capacitor banks. This type of reactive compensation is mainly suitable for industrial loads. The localized power factor correction can be expensive.

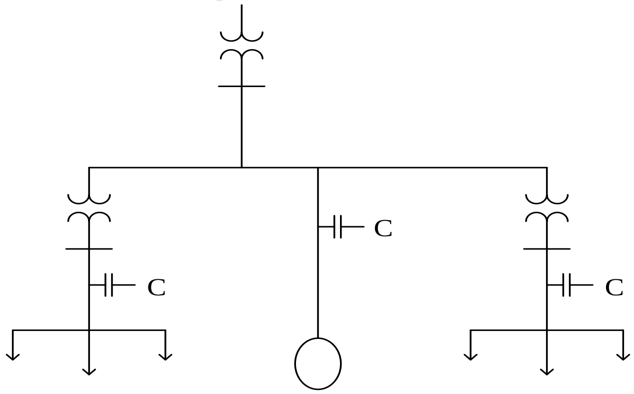


Figure6. Local capacitor bank [3]

VI. BENEFITS OF USING SHUNT CAPACITOR BANKS

Using shunt capacitors to supply the leading currents required by the load relieves the generator from supplying that part of the inductive current. The system benefits due to the application of shunt capacitors include;

- Reactive power support
- Voltage profile improvements
- Line and transformer loss reductions
- Release of power system capacity
- Savings due to increased energy loss

These benefits apply for both distribution and transmission systems.

A. Reactive Power Support

In distribution systems, the voltage at the load end tends to get lower due to the lack of reactive power. In such cases, local VAR support is offered using shunt capacitors. In the case of long transmission lines, the reactive power available at the end of the line during peak load conditions is small and hence needs to be supplied using shunt capacitors. The reactive power drawn from the supply is substantially less, and the kVA and the current flows are less. The power factor at the load is improved.

B. Voltage Profile Improvement

The shunt capacitors reduce the amount of inductive current in an electric circuit. The reduction in the line current decreases the IR and IX voltage drops, thereby improving the voltage level of the system from the capacitor location back to the source. In both the distribution and transmission systems, there is a need to maintain a voltage in the range 0.95–1.05 P.U. A lower system voltage will cause induction motors to operate with a larger than nominal current. With lower voltages, the recovery voltages after fault clearing will be slow. Therefore, maintaining acceptable voltage levels in the power system is an important objective.

C. Line and Transformer Loss Reduction

When shunt capacitors are installed for power factor correction, the line current magnitude is decreased. Therefore, both I^2R and I^2X losses are reduced. In industrial power systems, the I2R losses vary from 3–8% of the rated load current depending on the hours of full load operation, conductor size, length of the feeder circuit, and the transformer impedance. The load on most electric circuits will vary depending on the time of the day.

D. Release of Power System Capacity

Power factor correction capacitors provide the reactive current requirements locally and reduce the line current. Reduced line current means less kVA for transformers and feeder circuits. Thus, the shunt capacitor compensation helps to reduce the thermal overloads on transformers, transmission lines, generator, and cables.

E. Release of Generator Capacity

The synchronous generator has kW limit as well as kVA limit. The kVA limit of the generator may correspond to unity power factor operation. If the load is a low power factor apparatus, then the generator has to deliver a kW at a lower power factor. But the generator output cannot exceed the nominal kVA rating. The power factor correction at the generator terminals can release the kVA capability.

VII. DESIGN CALCULATION OF SHUNT CAPACITOR BANK FOR INDUSTRIAL PLANT

The following data are obtained from Sin Min-1 Cement Factory to design shunt capacitor bank for power factor correction. Induction motors are mostly used in that factory. In this design calculation, suitable size of shunt capacitor bank for one induction motor used in cement mill is calculated.

Present load = 800 kW
Present kVA = 1143 kVA
Present kVAR = 816 kVAR
Present Power Factor = 0.7
Desired Power Factor = 0.95
Transformer Rating = 4000 kVA
Voltage = 6000 V
If power factor is raised to 85%,
Desired kVA Demand = Present load/ Desired power factor
= 800/0.85
= 941 kVA

The size of the capacitor required to accomplish this is determined from the Kvar at the two values of power factor as follows:

$$\text{kVAR} = \sqrt{(\text{kVA}^2 - \text{kW}^2)}$$

$$\text{kVAR}_1 \text{ at } 70\% \text{ power factor} = \sqrt{(\text{kVA}_1^2 - \text{kW}^2)} = \sqrt{(1143^2 - 800^2)} = 816 \text{ kVAR}$$

$$\text{kVAR}_2 \text{ at } 85\% \text{ power factor} = \sqrt{(\text{kVA}_1^2 - \text{kW}^2)} = \sqrt{(941^2 - 800^2)} = 495 \text{ kVAR}$$

$$\text{Capacitor rating} = \text{kVAR}_1(\text{Uncorrected}) - \text{kVAR}_2(\text{Corrected}) = 816 - 495 = 321 \text{ kVAR}$$

% Line Current Reduction =100 [1−(Present pf/Improved pf)]
= 100 [1− (0.7/0.85)]
= 17.65 %

% Loss Reduction = 100 [1− $(\text{Present pf}/\text{Improved pf})^2$]
= 100 [1− $(0.7/0.85)^2$]
= 32.2 %

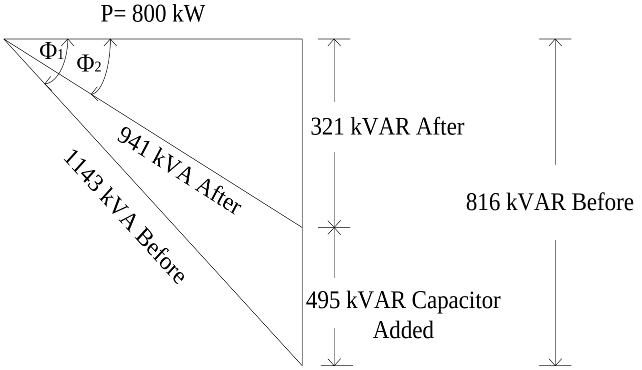


Figure7. Required Apparent Power before and after Adding Capacitors (At 0.85 Power Factor).

If power factor is raised to 90%,
Desired kVA Demand =Present load/ Desired power factor
Desired kVA Demand = 800/0.9
= 889 kVA

$kVAR_2$ at 90% power factor = $\sqrt{(kVA_1^2 - kW^2)}$
= $\sqrt{(889^2 - 800^2)}$
= 388 kVAR

Capacitor rating = $kVAR_1$(Uncorrected)-$kVAR_2$(Corrected)
=816 − 388
= 428 kVAR

% Line Current Reduction =100 [1−(Present pf/Improved pf)]
= 100 [1− (0.7/0.9)]
= 22.2 %

% Loss Reduction = 100 [1− $(\text{Present pf}/\text{Improved pf})^2$]
= 100 [1− $(0.7/0.85)^2$]
= 39.5 %

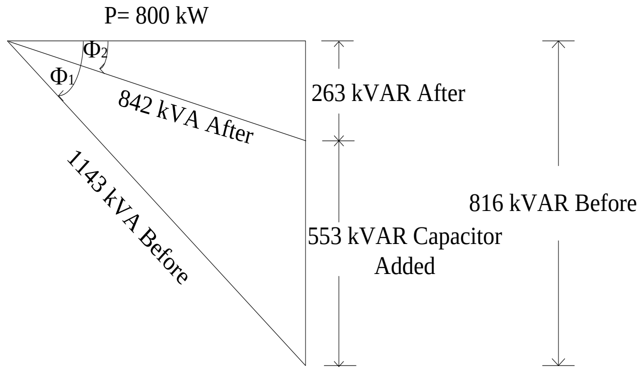


Figure8. Required Apparent Power before and after Adding Capacitors (At 0.95 Power Factor).

If power factor is raised to 95%,
Desired kVA Demand = Present load/ Desired power factor
= 800/0.95
= 842 kVA

$kVAR_2$ at 95% power factor = $\sqrt{(kVA_1^2 - kW^2)}$
= $\sqrt{(842^2 - 800^2)}$
= 263 kVAR

Capacitor rating = $kVAR_1$(Uncorrected)-$kVAR_2$(Corrected)
=816 − 263
= 553 kVAR

% Line Current Reduction =100 [1−(Present pf/Improved pf)]
= 100 [1− (0.7/0.95)]
= 26.32 %

% Loss Reduction = 100 [1− $(\text{Present pf}/\text{Improved pf})^2$]
= 100 [1− $(0.7/0.95)^2$]
= 45.7 %

VIII. CONCLUSION

The modern tendency in industry is to produce as cheaply and quickly as is economically possible and the advantages which can be derived from the use of electricity have led to a steady increase in the amount of electrical apparatus used for industrial purpose. Therefore, some form of power factor correction is required in all the industrial facilities. Shunt capacitors are widely used in power factor correction applications. The shunt capacitors provide kVAR at leading power factor and hence the overall power factor is improved. This paper illustrated the basis issues related to power factor improvement by using shunt capacitor banks for industrial loads.

IX. REFERENCES

[1] Hadi Saadat, International Edition, WCB 1999, Power System Analysis, Milwaukee School of Engineering, McGraw-Hill.

[2] Marija LLic, 2000, Handbook of Electric Power Calculations, McGraw-Hill,Inc.

[3]G.Brunello, B.Kasztenny ,C.Wester, 2003 Shunt Capacitor Bank Fundamentals and Protection, Conference for Protective Relay Engineers -Texas A&M University.