Improvement of Power Factor for Industrial Plant with Automatic Capacitor Bank

Marlar Thein Oo, Ei Ei Cho

Abstract—This paper is intended to uplift the technological standard of industrial plants. The overall power factor of modern industries is very poor because of inductive loads absorbing reactive power. Especially, industrial plant with variable load conditions has large inductive loads and its power factor is very poor. These industries benefit most from automatic capacitor banks. This bank provides improved power factor, increased voltage level on the load and reduced electric utility bills. Besides, automatic capacitor banks may be able to eliminate kVAR energized at light-load periods and undesirable over-voltages. In most cases, the main reason why a customer installs a capacitor bank is to avoid penalization in the electricity bill. This inappropriate installation without enough study gives rise to a great variety of technical problems. Therefore, the fact that capacitor banks are designed for long-term use should be considered.

Keywords—industrial plants, poor power factor, automatic capacitor bank, long term

I. INTRODUCTION

In most industrial and commercial facilities, a majority of the electrical equipment is inductive loads such as AC induction motors, induction finances, transformers and ballast-type lighting. Problems of power quality in industrial plants are growing due to the increasing number of rectifier controlled motors and the overall increase of harmonics and interharmonics. These loads cause poor power factor in industrial plants. A poor power factor indicates ineffective utilization of electricity and affects total energy costs. These problems are aggravated by the proper selection, sizing and installation of capacitors.

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FUNDAMENTAL OF POWER FACTOR

Power factor is a measure of how effectively electrical power is being used by a system. To understand power factor, we first have to know that power has three components: working, reactive and apparent power. Working power is the current and voltage actually consumed. It performs the actual work, such as creating heat, light and motion. Working power is expressed in kilowatts (kW), which register as kilowatt-hour on electric meter. Reactive is not useful work, but it is needed to sustain the electromagnetic field associated with many commercial/industrial loads. It is measured in kilovolt-amperes-reactive, or kVAR. The total required capacity, including working and reactive power, is known as apparent power. It is expressed in kilovolt-amperes or KVA.
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.

II. INDUCTIVE LOADS CONTRIBUTING TO POOR POWER FACTOR

If the plant inductive loads, which require the use of a magnetizing current to create a magnetic field, Power factor corrections are required. Inductive characteristics are more pronounced in motors and transformers and are found more often in commercial and industrial facilities. One of the worst offenders is a lightly loaded induction motor, often found in "cycle processes"—for example, in the operation of saws, conveyors, and grinders—where the motor must be sized for the heaviest load. Other sources include: induction furnaces, standard stamping machines, weaving machines, single stroke presses, automated machine tools, welders and certain fluorescent lamp ballasts. Table 1 shows incorrect power factor of some industrial plants.

### Table 1

**Typical Low Power Factor Industries**

<table>
<thead>
<tr>
<th>Industry</th>
<th>Uncorrected Power factor</th>
</tr>
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<tbody>
<tr>
<td>Saw Milk</td>
<td>45% - 60%</td>
</tr>
<tr>
<td>Plastic</td>
<td>55% - 70%</td>
</tr>
<tr>
<td>Machine Tools, Stamping</td>
<td>60% - 70%</td>
</tr>
<tr>
<td>Planting, Textile, Chemicals</td>
<td>65% - 75%</td>
</tr>
<tr>
<td>Hospitals, Foundries</td>
<td>70% - 80%</td>
</tr>
</tbody>
</table>

III. POWER FACTOR CORRECTION

If the power factor of the plant is low, it uses more power than it needs to do the work. Poor power factor should be corrected as it substantially increases costs. Capacitors generally are the most economical means to improve power factors.

Power factor correction is the term given to a technology that has been used since the turn of the 20th century to restore the power factor to as close to unity as is economically stable. This is normally achieved by the addition of capacitors to the electrical network which compensate for the reactive power demand of the inductive load and thus reduce the burden on the supply. There should be no effect on the operation of the equipment.

A sample analogy for power factor is to relate it to a garden hose. Circumstances, if you need 10 liters of water per minute to come out at the end of the hose, the tap should be turned on to deliver that amount of water. But if your hose leaks, is squashed between rocks, or is kinked because it is cheap, you will experience a drop in pressure. To achieve your target of 10 liters per minute, therefore, you need to turn up the tap and force more water through the hose. That is Power Factor Correction.

IV. BENEFITS OF POWER FACTOR CORRECTION

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

1. Environmental benefit—reduction of power consumption due to improved energy efficiency. Reduced power consumption means less greenhouse gas emissions and fossil fuel depletion by power stations.
2. Reduction of electricity bills.
3. Extra kVA available from the existing supply.
4. Reduction of I^2R losses in transformers and distribution equipment.
5. Reduction of voltage drop in long cables.
6. Extended equipment life—reduced electrical burden on cables and electrical components.

V. METHODS OF CAPACITOR INSTALLATIONS
We need to choose the optimum type, size and number of capacitors for the plant. There are four methods of capacitor installations:

**Method 1:** Capacitor at load

Installed a single capacitor at each sizeable motor and energize it whenever the motor is in operation. This method usually offer the greatest advantage of all, and the capacitors could be connected either in location (A) as (B) in Figure below.

![Location of the capacitor connections](image)

**Location A:** Normally used for most motor applications.

**Location B:** Used when motors are jogged, plugged, reversed; for multi-speed motors, as reduced voltage start motors.

**Method 2:** Fixed capacitor bank

Installed a fixed quality of kVar electrically connected at one or more locations in the plant’s electrical distribution systems, and energized at all times. This method is often used when the facility has few motors of any sizeable horsepower to which capacitors can economically be added. When the system is lightly loaded, and the amount of kVar energized is too large, the voltage can be so great that motors, lamps, and controls can burn out.

It is a important fact to remember that kVar equal to 20% of the transformer kVA is the maximum size of a fixed kVar bank. Valued greater than this can result in a large resonant current, which is potentially harmful to the system.

**Method 3:** Automatic capacitor bank

It is installed at the motor control centre at the service entrance. This bank will closely maintain a pre-selected value of power factor. This is accomplished by taming a controller switch steps of kVar on, as off, as needed. Automatic switching ensures exact amount of power factor correction, eliminates over capacitance and resulting over voltages.

**Method 4:** Combination of methods

Since no two electrical distribution systems are identical, each must be carefully analyzed to arrive at the most cost-effective solution, using are or more of the method.

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Individual Capacitors</td>
<td>Most technically efficient, most flexible</td>
<td>Higher installation and maintenance cost</td>
</tr>
<tr>
<td>Fixed Bank</td>
<td>Most economical, fewer installations</td>
<td>Less flexible, requires switches and/or circuit breakers</td>
</tr>
<tr>
<td>Automatic Bank</td>
<td>Best for variable loads, prevents over voltages, low installation cost</td>
<td>Higher equipment cost</td>
</tr>
<tr>
<td>Combination</td>
<td>Most practical for larger numbers of motors</td>
<td>Least flexible</td>
</tr>
</tbody>
</table>

**VI. PARTICULAR NEEDS OF THE PLANT**

When deciding which type of capacitor installation best meets weight the advantages and disadvantages of each and consider several plant variables, including load type, load constancy, load capacity, motor starting method.

**A. Load type**

If the plant consist of many large motors, 50 Hp and above, it is usually economical to install one capacitor per motor and switch the capacitor and motor together. If the plant has many small motors, ½ to 25 hp, group motors and install one capacitor at a control point in the distribution system. The best solution per plants with large and small motor is to used both types of capacitor installation.

**B. Load Size**

Facilities with large loads benefit from a combination of individual load, group load and banks of fixed and automatically-switched capacitor units. A small facility may need only one capacitor as the control board.

Sometimes, only an isolated trouble spot requires power factor correction. This may be the case if the plant has welding machines, induction heaters or dc drives. If a particular feeder serving s low power factor load is connected, it may raise...
overall plant power factor enough that additional capacitors are unnecessary.

C. Load Constancy

If the plant operates around the clock and has a constant load demand, fixed capacitors offer the greatest economy. If lead is determined by eight-hour shift five day a week, switched units are wanted more to decrease capacitance during times of reduced load.

D. Load capacity

If the feeder or transformers are overloaded, or if additional load is added to already load lines, correction needs at the load if the facility has surplus amperage, the capacitor banks are installed at main feeders. If load varied a great deal, automatic switching is probably the solution.

VII. METHODOLOGY FOR POWER FACTOR BILLING ADJUSTMENT

Assume a 400 kW load with a power factor of 70 percent. To improve power factor to 90 percent, the total kVar added to your plant (rating of capacity bank) is 200kVar.

Total annual kWh = 2, 400, 000
Average kWh charge = 50 kyats
Annual charge = 120, 000, 000 kyats
Power factor adjustment is 0.06 percent or each percentage point below or above 85 percent.

Power factor adjustment for 70 percent (penalty value)

\[ 85 - 70 \]
\[ = 15 \times 0.06\% \]
\[ = 0.9\% \times 120, 000, 000 \]
\[ = 1, 080, 000\text{ kyats} \]

Power factor adjustment for 90 percent (credit value)

\[ 90 - 85 \]
\[ = 5 \times 0.06\% \]
\[ = 0.3\% \times 120, 000, 000 \]

Net gain (Annual saving)

\[ = 1, 080, 000 + 360, 00 \]
\[ = 1, 440, 000\text{ kyats} \]

Therefore, annual saving is 1.2 percent of annual charge.

This is to illustrate a hypothetical annual estimate. Single line diagram and control circuit diagram of 200 kVAR automatic capacitor bank are designed in appendix.

The linear payback period of this installation is described below.

Total cost of installation (survey cost, advice, capacitance and labour) is 3, 2000, 00 kyats.

Annual saving is 1, 440, 000 kyats.

Therefore, the payback period is 2 years and 3 months.

VIII. DISCUSSIONS AND CONCLUSION

The most frequent case at industrial plants is to compensate the reactive power at low voltage. To do this, there are on the market a large no. of manufacturers that offer standardized products with power ratings up to and even exceeding 1000 kVar. This is a very well known and widespread product and, as a result, on many occasions it is installed without enough study.

Therefore, the effects of disturbances are suffered mostly by the owner of the capacitor bank. Please ensure that installation meet your requirements, manufacturers, installations and all applicable codes, standards and regulations.

IX. RECOMMENDATIONS

- Size electric motors to match mechanical loads to increase the overall p.f.
- Use capacitor banks at motor control centre or service entrances to facilitate switching for varying load.
- Install conditions as harmonic filters to avoid harmonic resonance problems and excessive voltage distortion levels.

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REFERENCES


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Fig. 7 Single Line Diagram of 200 kVAR Automatic Capacitor Bank
Fig. 8 Control Circuit Diagram of 200 kVAR Automatic Capacitor Bank