Power factor measurement and correction techniques

C.S. Prasanna Kumar a, S.P. Sabberwal b, A.K. Mukharji b

a National Physical Laboratory, New Delhi 110012, India
b Centre for Energy Studies, Indian Institute of Technology, New Delhi 110060, India

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Abstract

The prevailing method of power factor measurement is debatable. Certain methods are suggested in this paper with hints to improve power factor measurement and correction.

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1. Introduction

Both small- and medium-size industries in India face the power factor penalty which is being levied by the supply authorities for violation of statutory limits. From the power system point of view this sector of industry is badly organized due to financial constraints. Such industries run one or two shifts of eight hours each daily. Generally, the power input is 11 kV three phase, which is stepped down to 440 V three phase through a delta–wye transformer of rating between 300 and 1000 kVA. The supply authorities instal a kWh meter and a kVAh meter incorporating a kVA MD indicator. In this country a minimum power factor of 0.85 is mandatory on the HT side. Various aspects of determination of the power factor, degree of accuracy of the meters on varying loads with varying power factors, and the legality of the penalty imposed on the industries are discussed in this paper. Some practical hints on the improvement of the power factor are also discussed.

2. State of the problem

The power factor is defined as the cosine of the angle between the voltage and the current. It is an instantaneous value. Further, the above is true only if both the signals, i.e. voltage and current, are sinusoidal. In India, most of the loads become non-linear when operated at voltages above the rated value. Additionally, all discharge lamps such as fluorescent tubes, sodium and mercury lamps, thyristor controlled devices, reconditioned motors, normal motors working at low loads, induction and arc furnaces, saturated reactors and welding loads are inherently non-linear loads. Non-linearity causes harmonics and improvement of the power factor becomes a difficult task in the presence of harmonics.

In most rolling mills and furnaces, the loading is never constant and varies between wide limits. For rolling mills, the current level in motors can be as high as the short-circuit level whenever the rollers get stuck. Even during normal peak production times, three out of six passes working, high current levels are experienced. The waveshapes of the ensuing currents are non-sinusoidal and create a lot of impediments to power factor improvement.

Additionally, voltage variations and surges accentuate the difficulties encountered owing to the increased level of harmonics in currents with comparatively little increase in delivered power. Hence, the overall power factor decreases.

Generally, it is seen that on national holidays, weekends and at night the voltage level increases. Typically, a 10% increase is quite common. This has the effect of increasing the magnetizing currents and operating the system at a low power factor. Correction devices which have been installed tend to fail due to prolonged overvoltage. During undervoltage operation, the current levels increase significantly and so do the losses, thereby resulting in an improvement in the power factor.

In thyristor controlled devices, phase angle control is most common. Invariably, the equipment is operated at 0.4–0.7 times the full load level. The angle of delay is quite large, causing truncation of the current sine wave. Consequently, the harmonic level becomes comparable with that of the fundamental. The effect of chokes in
series also becomes significant as the impedance is dependent upon the frequency. The power factor in establishments using such devices is normally low, about 0.4–0.6. The penalty attracted is high, and normal correction methods become defunct.

3. Power factor measurement

The supply authorities take the cumulative monthly readings of the kWh and kVAh meters.

Let the kWh reading be \( x \), the kVAh reading be \( h \), and the kVArh reading be \( y \) (if any). The power factor (taken over a month) is given by

\[
p.f. = \frac{(x_2 - x_1)}{(h_2 - h_1)}
\]

It is generally seen that

\[H^2 \neq x^2 + y^2\]

The industries which have attracted penalties have raised doubts about the method of determination of the power factor. The various methods suggested for the measurement of the power factor, they argue, could be any one of the following:

(a) \( p.f. = \sum p.f.,/n \)

(b) \( 1/p.f. = (1/n) \sum (1/p.f.,) \)

(c) \( p.f. = \frac{x_2 - x_1}{[(x_2 - x_1)^2 + (y_2 - y_1)^2]^{1/2}} \)

The question that arises, therefore, is how to arrive at a justifiable value of the power factor.

4. Some practical situations

Referring to Fig. 1(a), it is tacitly assumed here that the power factor over a period of time from \( t_1 \) to \( t_2 \) has remained constant at all loads. In this case,

\[ p.f. = AB/AC \]

Referring to Fig. 1(b), over the period of time from \( t_1 \) to \( t_2 \) the power factor of the load is varying. AB indicates the recorded kWh, AD the recorded kVAh, and BC the recorded kVArh. AC is the kVAh based on kWh and kVArh. It is also assumed here that the energy consumed per unit time is constant. Then,

\[ p.f. = AB/AD \]

The power factor determined by the supply authorities is a stretched hypotenuse, i.e. the scalar addition of the instantaneous kVAh values. The above value of the power factor could at times go below the mandatory statutory limit of 0.85, thereby attracting a penalty.

It is generally seen that there is an initial high power factor operation with reduced power factor at the end of the day. This usually occurs in medium-size industries where one or two shifts are operating. When the load in the third shift is less, the power factor is low. Even under such situations the power factor determined by the supply authorities is questionable.

It can therefore be concluded that the best way to determine the power factor is as follows:

\[ p.f. = x/(x^2 + y^2)^{1/2} \]

In other words, the power factor should only be related to the amount of reactive kVA supplied (received) by the supply authorities per unit kW of load over a specified time. It is therefore very important to take the readings on exact specified dates to arrive at an unquestionable value of the power factor for any industry.

It is therefore obvious that supply authorities should only instal two meters, a kWh and a kVArh meter. If trivector meters are used the power factor should only be determined by the kWh and kVArh meters; the kVAh meter should only serve the purpose of obtaining the kVA MD.

5. Power factor correction techniques

Generally speaking, if the machines of a factory run on full load, its power factor is best. The method of connecting capacitors on the main line and hoping for the best is basically unscientific for varying load conditions.

All phase correction devices should be connected on the load itself with the axiom 'load on, capacitor on'.

5.1. Motors

It is best to correct the power factor of any motor at no-load/dead-load conditions. The power factor at load will be looked after by itself. The reason for this technique lies in the fact that magnetizing current causes low power factor, whereas the load part of the current has essentially a high power factor.

In star–delta starters, phase correction devices have to be connected on the star side so that initially a lower voltage is impressed and the initial current jerk is low, thereby reducing the chances of damage to capacitors.

Fig. 1. Measurement of the power factor where (a) the power factor is constant at all loads between \( t_1 \) and \( t_2 \) and (b) it is varying.
In inching applications, a time delay is incorporated so that the correction device is connected only when the electrical conditions have reached the steady-state values, otherwise the possibility of damage is increased. Electrical resonance conditions must be avoided to prolong the life of the equipment.

Typical power factor figures at 0.5, 0.75, and 1.00 per unit dead load on motor are 0.5, 0.6, 0.7–0.8, and 0.8–0.9, respectively. If correction is achieved on dead load, the corresponding power factor readings become 0.95, 0.96, 0.98, and 0.98 (leading). Where a group of motors run simultaneously, the phase correction device may be connected in the vicinity of the largest possible motor with an adequate time delay incorporated in the circuit.

The above argument is different from the philosophy espoused in the technical literature.

5.2. Discharge lamps

Correction at each load point has to be made. The capacitor chosen must have a low dielectric loss factor owing to the presence of large harmonics.

In India, where the operating voltage is 240 V, there are some limitations in the use of discharge lamps, which have a voltage drop of about 100 V across them [1]. The best operating voltage is around 160 V, with the use of a three-phase delta–wye transformer separately for lighting circuits. This has the effect of improving the power factor, reducing line currents and reducing distribution losses.

By and large, energy conservation can also be achieved by the use of L–C ballasts [2,3] operating on line voltage at line frequency.

5.3. Thyristor controlled devices

Better power factor can be achieved by incorporating a suitable triplen harmonic trap between supply and load. The damage normally done by harmonics is thus minimized. However, the fifth and seventh harmonics still play a significant adverse role.

Alternatively, all thyristor devices should incorporate gate turn-off thyristors with adequate clipping of the waveform effected at suitable leading and trailing edges. The authors have tried this technique on a laboratory scale and the results are encouraging. This basically involves going into the motor control circuitry. Only a daring factory owner will allow such an upheaval.

5.4. Welding equipment

Connecting a suitable capacitor in series helps only to some extent in power factor improvement. Where a large part of the load is due to welding, power factor correction can be quite a task.

5.5. Induction furnace

Correction is needed during patching only as the power factor is quite high during most of the melting operation. Permanent correction during patching has negligible effect during the melting time.

The auxiliary transformer in an induction furnace shop is normally operated at a low power factor. Its correction leads to a substantial improvement in power factor values, especially where only single-shift working is involved.

5.6. Transformers

Some industries shut off their activities in winter, e.g., ice factories. Others operate at a reduced load, e.g., cold storages. Such installations suffer from low power factor because the transformer is unloaded most of the time. Shunt capacitors do not improve the power factor because of the distortion in no-load current. One of the successful methods is to reduce the tap on the high-voltage side, thereby reducing the operating flux density.

4. Conclusions

The present method of determining the power factor by the supply authorities in India is misleading, faulty and can lead to legal complications. An exact method of determining the power factor is described, with a new definition of power factor.

Some techniques for power factor correction are described here. Detailed calculations can be made only after taking adequate spot readings of electrical parameters. The normal practice of linking the rating of a kVar capacitor bank with h.p./load (kW) is rather misleading, as it is applicable only to newly installed motors. Conditions on the ground are quite different. Power factor correction is possible for all types of loads.

Some companies install automatic switching control panels. These are ineffective for direct current, widely varying loads and transient conditions.

References

[1] C.S. Prasanna Kumar et al., Some limitations in the use of discharge lamps. Accepted for publication in Energy Conversion and Management, Texas.