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Reactive Power Management Practices and their Comprehensive Evaluation for a Short Circuit Test Plant

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A vast majority of electrical loads in short circuit testing plants are inductive rapidly varying in nature. Typical examples are motors, transformers, drives etc. Such loads consume high reactive power in short durations. Load requirement of the short circuit plant is intermittent in nature due to varieties of customer tests. Hence controlling of reactive power of these types of loads is a challenge. It is therefore necessary to reduce and manage the flow of reactive power to achieve higher efficiency of the short circuit plant and reduction in cost of electricity consumed. An improvement of the reactive power management of an installation presents several technical and economic advantages, notably in the reduction of electricity charges. This paper discusses a cost effective method of reducing and managing reactive power. It has been shown that the installed reactive power compensating devices captured both the technical and economic aspects of short circuit plant operation in competitive electricity markets. Also it has been shown that traditional techniques are economically viable if they are used in a judicious manner.

Keywords: *Displacement P.F., Distortion P.F., Energy conservation and Reactive power management.*

1.0 INTRODUCTION

Energy Conservation is an important issue and is a major part of Energy Management. The high cost and less availability of energy has compelled the operating personnel to rethink to run the plant and equipment in an energy efficient manner [3]. The conservation of energy, therefore, is using less more wisely than before.

Energy conservation is really the cheapest of energy 'resources' at least until its potential is exhausted. Energy conservation promises to fill the gap between supply and demand. Several measures for conservation of energy are very important for consideration. One of the ways is by following reactive power management practices.

High reactive power results low power factor, it requires an increase in the electric utility's generation and transmission capacity to handle the reactive power component caused by inductive loads [1]. Utilities usually charge a penalty fee to customers with power factors less than 0.9. One can avoid this additional fee by improving the power factor to near unity.

Load requirements of the CPRI is intermittent in nature due to varieties of equipment and power required for different tests. Hence controlling of reactive power of these types of loads is always crucial one.

The supply of reactive power from the system results in reduced installation efficiency [2].

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One of the objective is to follow reactive power management practices is to minimize the monthly electricity charge and improve capacity. The traditional techniques are also economically viable than automatic power factor controller (APFC) if they are used in a judicious manner.

2.0 ENERGY CONSERVATION BY OPTIMUM POWER FACTOR

Power factor ranges from near unity, to near zero. Incandescent lighting loads are resistive and result in a power factor of 1.0. The power factor ratio becomes less than unity when loads draw reactive and or harmonic currents in addition to the current that does real work. Power factor is a measurement of how efficiently a facility uses electrical energy [8]. As the power factor drops the system becomes less efficient. Commercial, industrial, and institutional establishments that pay demand charges, which use relatively large amounts of electricity, or that have electrically powered systems with potential for power factor problems may be able to reduce demand charges by improving power factor [1, 8].

2.1 Displacement and Distortion Power Factors

There are two types or sources of reduced power factor, Displacement Power Factor and Distortion Power Factor.

Displacement Power Factor is caused by a reactive component in the load. If there is an inductive component in the load, then there will be an inductive current flowing in addition to the resistive current. The inductive current follows the voltage waveform by 90°. The displacement power factor value is the cosine of the angle between the voltage waveform and the resultant current waveform. Displacement power factor is typically decreased (made worse) by inductive loads such as induction motors, transformers and lighting ballasts.

Traditionally, power factor is based on the 50 Hz fundamental frequency. Harmonic currents drawn by VFDs (Variable Frequency Drives), PCS, PLCs, and electronic office equipment are increasing in the modern facility. As a result, power factor now must be viewed in reference to harmonic frequencies of the 50 Hz fundamental.

Distortion power factor, on the other hand, takes into account the harmonic currents that do not contribute to the real work produced by the load. Distortion power factor is defined as the ratio of the fundamental component of the line current to the total line current. The composite power factor is thus a combination of both displacement and distortion power factors.

2.2 Types of Compensation Methods

The methodology followed to achieve a consistently high power factor under modern application conditions involves proper selection and uses the following two most common types of devices used for power factor correction are capacitors and tuned harmonic filters.

The most cost effective method of reducing and managing Reactive power is by power factor improvement through well designed fast acting power capacitors. Power factor correction requirements determine the total amount of capacitors required at low voltage buses. Capacitors can be applied easily and commonly an are used in industrial and commercial facilities which have minimum amount of harmonics. Both single-value banks and automatically switched variable banks are available. Overheating problems with capacitor banks are becoming more common as harmonic current levels increase. Furthermore, switched capacitor banks, without appropriate design precautions, also can cause high-voltage switching surges as capacitors are switched in and out of service.

Harmonic currents can be significantly reduced in an electrical system by using harmonic filters. In its basic form, a filter consists of a capacitor connected in series with a reactor tuned to a specific harmonic frequency. In theory, the impedance of the filter is zero at the tuning frequency; therefore, the harmonic current is absorbed by the filter. This, together with the natural resistance of the circuit, means that only a small level of harmonic current will flow in the network [6].

A filter for the 7th harmonic creates a parallel resonance in the vicinity of the 5th harmonic with magnification of the existing 5th harmonic. Therefore, a 7th harmonic filter requires a 5th harmonic filter. Consequently, it is often necessary to use a multiple filter design where each filter is tuned to a different frequency [6–7]. Experience is extremely important in the design of filters to ensure the most efficient and costs effective solution is selected and no adverse inter action between the system and the filter.

With the advent of IEEE 519-92 "Recommended Practices and Requirements for Harmonic Control in Electric Power Systems," the increasing demand by utilities for power factor improvement and the proliferation of non-linear loads in industrial power distribution systems, specification of harmonic mitigation has become common. The recommended limits for voltage distortion in IEEE 519 are presently 5% for general applications.

3.0 LOAD DETAILS AND CAUSES OF LOW P.F. OF CPRI, BHOPAL

Figure 1 shows the complete load distribution of CPRI, Bhopal [2]. Institute is having a contract demand of 1765 kVA with Madhya Pradesh Electricity Board. CPRI has installed two short circuit generators of rating 1500 MVA. Out of these two short circuit generators is rotating with the help of prime mover which is an induction motor of rating 1600 kW and the other one is having a static excitation system. There are auxiliary motors and pumps and are connected to each of the short circuit generator to support short circuit generator while running. The total capacity of the connected auxiliaries is around 450 HP to each generator. It is one of the major loads of the Institute.

Another two major loads are 25,000 A and 10,000 A temperature rise test labs. These laboratories consume more reactive power as they installed with higher capacity electrical devices for testing of various electrical equipments.

CPRI being in the field of Testing and Research, hence load variation is very high. Most of the testing activities are involved with highly inductive loads. Whether it may be short circuit test, temperature rise test or losses measurement of a transformer. Ultimately these loads are absorbing reactive kVAr which are feeding from supply. This is one of the causes to have low power factor displacement power factor. Institute also have some electronic equipment, hence there is a possibility of harmonics. Hence there is a presence of distortion power factor. The electronic equipments which are coming now a day are produces very less harmonics, as they are manufacturing as per standards.

It has been made all the efforts to maintain good power factor, but due to testing of various electrical equipments like Transformers, Circuit Breakers, MCB's, MCCB's, and Bus Duct etc. load is completely depending on rating of the test equipment and type of test i.e. temperature rise test, internal arc fault test, short circuit withstand test etc.

If rating of the test object is small then consumption of reactive power is low and if rating of the test objects is high obviously it draws more reactive power. Consumption of reactive power is also depending on the various types of tests. Hence consumption of reactive power in a short circuit plant influences many factors. And all the factors which are not in the hands of short circuit plant operator. So, we are unable to connect capacitor banks permanently to the system because power factor may goes more than unity and leading when there is no testing activities in the institute. The situation of this is very dangerous than having low power factor.

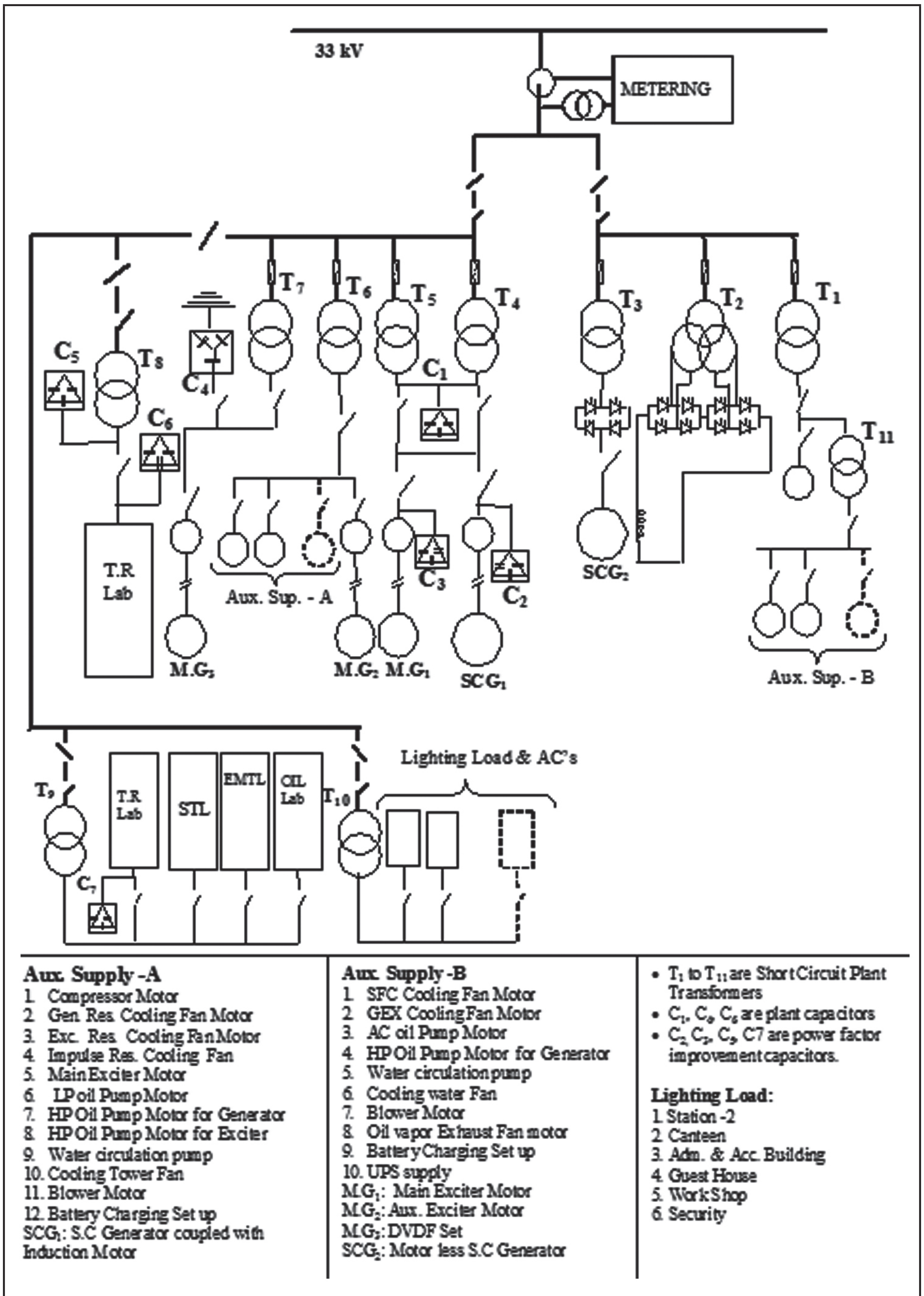

FIG. 1 OVER VIEW OF LOAD DISTRIBUTION OF CPRI, BHOPAL.

4.0 INDUCTION OF QUICK AND COST EFFECTIVE REACTIVE POWER MANAGEMENT PRACTICES

A very low power factor was recorded in the year 2008. It was also observed that the monthly energy charges were above the normal amount due to low power factor. Hence it is decided to induce the reactive power management practices, such a way that they should be very quick and cost effective methods. These methods successfully followed and achieved the main objective i.e bringing the monthly energy charges to normal value with the help of controlling reactive power during the operation of short circuit plant. The methods which are followed are putting capacitor banks in the plant. The appropriate values of the capacitor banks are calculated by keeping in view of the following parameters.

i. Average monthly consumption of reactive power in the years 2007 and 2008.

ii. By considering the test equipment rating.

iii. By considering the type of test.

iv. By considering the installed equipment rating.

The details of all the capacitor banks have been shown in Figure 1. There are some capacitor banks are permanently connected to the system which feeds the reactive power to the supply continuously to compensate the reactive power consumed due to lighting load and some of the station transformers of the organization. There are some capacitors banks are connected to the system temporarily and these capacitor banks will be switched on just before starting of the testing activities in their laboratories. Some of the capacitor banks may not be switched on if the rating of the testing equipment is too low.

After implementing all the necessary steps for having better management of reactive power i.e good power factor, institute is having average power factor 0.9 and 0.91 for the year 2010 and 2011. Steps have been already taken to improve it further.

Table 1 gives the average energy consumed details of last three years [4]. Table 1 clearly indicates when there is an improvement in power factor, it reduces the average demand per month and also simultaneously there is a decrease in consumed average kWh per month. There is an appreciable improvement in reactive power regulation after inducing the quick and cost effective methods in short circuit plant which is having so many parameters to control the reactive power.

TABLE 1

ENERGY CONSUMPTION DETAILS OF LAST THREE YEARS

Year	Avg. demand per month	Avg. consumption kWh per month	Avg. P.F.
2009	1736	125216	0.87
2010	1681	121012	0.90
2011	1574	114550	0.91

5.0 COMPREHENSIVE EVALUATION OF ENERGY CONSERVATION MEASURES

5.1 Evaluation in Terms of Saved Energy

For evaluating energy savings it has been taken two parameters one is average demand per month and another one is average consumption in kWh per month. The saved details of energy after improving power factor shown in Figure 2 [2], these are calculated with reference to the year 2008. Figure 2 shows that huge amount of energy has been saved by following reactive power management practices strictly.

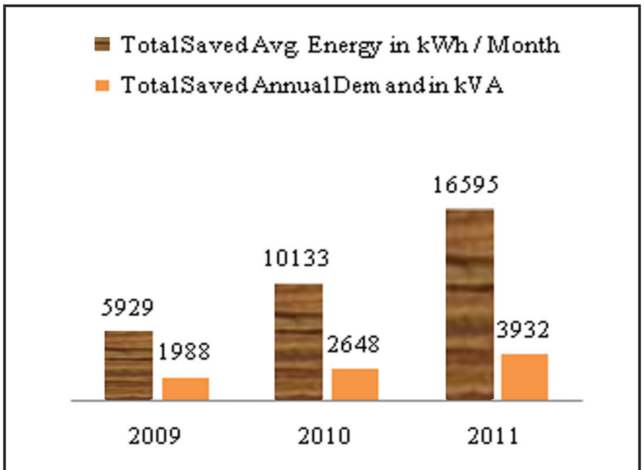

FIG. 2 SAVED ENERGY DETAILS AFTER IMPROVING POWER FACTOR.

5.2 Evaluation in Terms of Financial Savings

As the institute comes under HV tariff schedule, it has two types of charges one is fixed charges for the consumed demand and another one is energy charges to the consumed energy. Average billing demand kVA has been considered during the evaluation of savings in fixed charges. The billing demand for the month shall be the actual maximum kVA demand of the consumer during the month or 90% of the contract demand, whichever is higher [5]. Savings in fixed and energy charges are also shown in Figure 3.

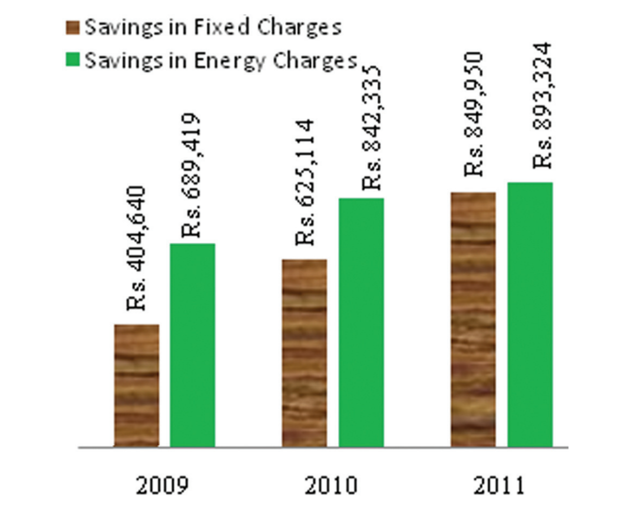

FIG. 3 SAVED FIXED AND ENERGY CHARGES DETAILS AFTER IMPROVING POWER FACTOR.

5.2.1 Evaluation of Savings in Fixed Charges

Table 2 gives the calculated values of savings in fixed charges per annum. It clearly shows that a huge amount has been saved only in terms of fixed charges. The following factors [5] have been taken while calculating savings in fixed charges per annum.

i. Fixed charges at 1.3 times the normal charges for excess demand when the recorded maximum demand is beyond 105% of the contract demand.

ii. Fixed charges for demand from the recorded maximum demand to 105% of the contract demand.

5.2.2 Evaluation of Savings in Energy Charges

Table 3 gives the calculated values of savings in energy charges. Energy charges savings are calculated based on the following four parameters [5] are

i. Energy charges at 1.3 times the normal tariff for consumed energy during excess demand (beyond 105% of the contract demand).

ii. Electricity duty at 15% on saved energy charges amount.

iii. Fuel cost adjustment charges at 10%on saved energy units.

iv. Low power factor adjustment charges (for P.F. < 0.9) at 1%, for each one percent fall on total amount of bill under the head of "Energy charges".

6.0 CONCLUSION

Controlling of reactive power of short circuit plant is always a challenging job as these plants face loads which are intermittent and transient in nature. Also the rating of test equipment is highly variable in the nature. But ultimately, reactive power has to compensate to get high power factor for getting maximum benefits.

For consumers like CPRI with large intermittent and transient loads whose applicable tariffs include maximum demand charges, the power

TABLE 2

DETAILS OF SAVINGS IN FIXED CHARGES OF LAST THREE YEARS

Year	Total saved annual billing demand in kVA	Saved fixed charges for excess demand when the recorded maximum demand is beyond 105% of the contract demand in Rs.	Saved fixed charges for excess demand from the recorded maximum demand to 105% of the contract demand in Rs.	Total fixed charges savings in Rs.
2009	1842	162240	242400	404640
2010	2611	180898	444216	625114
2011	3120	208478	641472	849950

TABLE 3

DETAILS OF SAVINGS IN ENERGY CHARGES OF LAST THREE YEARS

Year	Total saved avg. energy in kWh / month	Saved energy charges for consumed energy during excess demand in Rs.	Savings on electricity duty on saved energy at 15% in Rs.	Fuel cost adj. charges on saved energy at 10% in Rs.	Savings due to low p.f adj. charges in Rs.	Total energy charges savings in Rs.
2009	5929	245718	46958	7115	389628	689419
2010	10133	245718	80253	12160	504204	842335
2011	16595	245718	131432	19914	496260	893324

factor improvement shall be able to reduce their energy demand as well as consumption and thus shall benefit from both the reduced cost of energy and reduced consumption of electricity. The same has been shown by following reactive power management practices strictly.

It has been observed that the payback period for the amount invested for reactive power compensating devices is around ten to twelve months.

7.0 FURTHER SCOPE OF WORK

The objective is to maintain power factor greater than 0.95 or around unity. This objective can be achievable with the help of fast transient automatic power factor correction unit. An automatic power factor correction unit consists of a number of capacitors that are switched by means of contactors. These contactors are controlled by a regulator that measures power factor in an electrical network. Depending on the load and power factor of the network, the power factor controller will switch the necessary blocks of capacitors in steps to make sure the power factor stays above a selected value. The Institute can expect a payback period of less than one to one and half year when automatic power factor correction system is implemented.

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