International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
Available at http://inpressco.com/category/ijcet

Research Article

Power Factor Correction using capacitor bank under Variable Load Condition

Abhay Pratap Singh* and Manish Kumar Srivastava

Electrical Engineering Department, SHUATS, Allahabad, India

Received 01 July 2018, Accepted 02 Sept 2018, Available online 06 Sept 2018, **Vol.8, No.5 (Sept/Oct 2018)**

Abstract

Wasted energy capacity, also known as poor power factor, is often overlooked. It can result in poor reliability, safety problems and higher energy costs. The lower your power factor, the less economically your system operates. The actual amount of power being used, or dissipated, in a circuit is called true power. Reactive loads such as inductors and capacitors make up what is called reactive power. The linear combination of true power and reactive power is called apparent power. Power system loads consist of resistive, inductive, and capacitive loads. Examples of resistive loads are incandescent lighting and electric heaters. Examples of inductive loads are induction motors, transformers, and reactors. Examples of capacitive loads are capacitors, variable or fixed capacitor banks, motor starting capacitors, generators, and synchronous motors. Power factor correction (PFC) is usually achieved by adding capacitive load to offset the inductive load present in the power system. The power factor of the power system is constantly changing due to variations in the size and number of the motors being used at one time. This makes it difficult to balance the inductive and capacitive loads continuously. There are many benefits to having power factor correction. As a customer the cost doesn't get passed on for having a low power factor. As a utility company, equipment has a much longer life span and maintenance costs remain low.

Keywords: *Wasted energy capacity, power factor etc.*

1. Introduction

Power factor is one of the factors that affect the efficiency of the power supply. Low power factor is one of the losses to the power supply company where supplying consumer with apparent power (volt-amperes), but bill them for real power (watt). At the same time, low power factor will cause high current to flow in the line, so the power losses will be increases because of proportional to the square of the current. In order to reduce the losses, the company needs to apply power factor correction.

Power factor correction can be divide into two which is active power factor correction and passive power factor correction. This project is developed in order to a design a system which corrects the power factor at distribution line near industry. It is because most of the industry use motor for their operating and this will cause low power factor due to the high inductive loads.

With the mining industry moving from traditional manual methods to the advanced mechanized mining, the focus is also shifting to the energy efficiency of the equipment and system being employed. Most of the equipment used in mining like shovel, drill, elevator, continues miner, conveyor, pumps etc. runs on electricity. Electric energy being the only form of energy which can be easily converted to any other form plays a vital role for the growth of any industry.

The Power Factor gives an idea about the efficiency of the system to do useful work out of the supplied electric power. A low value of power factor leads to increase is electric losses and also draws penalty by the utility. Significant savings in utility power costs can be realized by keeping up an average monthly power factor close to unity. The work carried out is concerned with developing power factor correction equipment based on embedded system which can automatically monitor the power factor in the mining electrical system and take care of the switching process to maintain a desired level of power factor which fulfils the standard norms.

The Automatic Power Factor Correction (APFC) device developed is based on embedded system having 89S52 microcontroller at its core. The voltage and current signal from the system is sampled and taken as input to measure the power factor and if it falls short of the specified value by utility, then the device

*Corresponding author **Abhay Pratap Singh (**ORCID ID: 0000-0003-2010-8740) is a Research Scholar and **Manish Kumar** Srivastava is working as Assistant Professor,
DOI: https://doi.org/10.14741/ijcet/v.8.5.2

automatically switch on the capacitor banks to compensate for the reactive power. After employing the correction equipment the targeted power factor of 0.95 is achieved and the increase in power factor varied from 9% to 19% based on the combination of load.

2. System Description and Modelling

A. Power factor correction

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 viable. 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. To reduce losses in the distribution system, and to reduce the electricity bill, power factor correction, usually in the form of capacitors, is added to neutralize as much of the magnetizing current as possible. Capacitors contained in most power factor correction equipment draw current that leads the voltage, thus producing a leading power factor. If capacitors are connected to a circuit that operates at a nominally lagging power factor, the extent that the circuit lags is reduced proportionately. Typically the corrected power factor will be 0.92 to 0.95. Some power distributors offer incentives for operating with a power factor of better than 0.9, for example, and some penalize consumers with a poor power factor. There are many ways that this is metered but the net result is that in order to reduce wasted energy in the distribution system, the consumer is encouraged to apply power factor correction. Most Network Operating companies now penalize for power factors below 0.95 or 0.9.

B. Type of Power Factor Correction

Power factor correction allows power distribution to operate at its maximum efficiency. Power factor correction can divide into three type which is Active Power Factor Correction (APFC), Passive Power Factor Correction (PPFC) and Hybrid power Factor (HPFC). The simple method to solve the low power factor is using a PPFC. However it is not as effective as Active Power Factor Correction, but it is much cheaper than the Active Power Factor Correction.

C. Passive Power Factor Correction

PPFC is known as an inductive filter, where it is simply used of an inductor in the input circuit. The inductor will stores sufficient energy to maintain the rectifiers in conduction throughout the whole of their half cycle and reduces the harmonic distortion caused by discontinuous conduction of these rectifiers if the inductor is sufficiently large. Practically a PPFC will reduce the harmonic currents and improves the power factor substantially but the problem does not eliminate completely. Figure 2 show the simplified block diagram of a PPFC circuit and Figure 3.13 show the typical input voltage and current waveforms of a PPFC. The circuit draws a lower distortion current than the non-corrected circuit but this will expense of higher (fundamental) reactive power consumption. Thus, there is a shift from distortion power factor to displacement power factor.

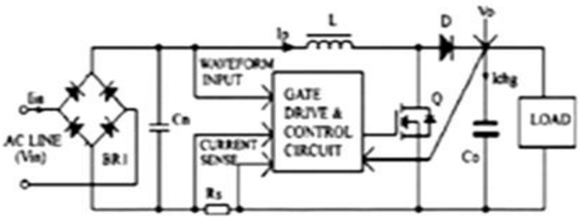

Fig 1: Block diagram of a PPFC circuit

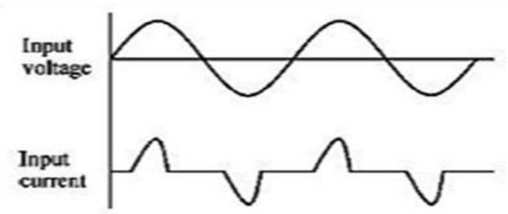

Fig 2: Input voltage and current waveform of a typical Passive Power Factor Correction circuit

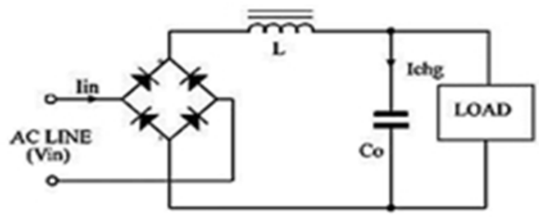

Fig 3: Block diagram of an Active Power Factor Correction circuit

D. Active Power Factor Correction

Another type of power factor correction is Active Power Factor Correction (APFC). Mostly, an APFC is a power electronic system which controls the amount of power drawn by the load in order to obtain a power factor closes to unity. Varieties topologies can be including are boost converter, buck converter and buck-boost converter Figure 3 show the block diagram of an Active Power Factor Correction circuit. A boost converter will produce an output voltage higher than its input. This enhances the energy storing function of the capacitor in Figure 3. A relatively stable output over a wide range of input voltages can be providing by a boost converter. A constantly high voltage will produce by the power factor correcting boost converter across its output capacitor, regardless of the input mains voltage. Thus, the holdup time becomes independent to the mains voltage. It will also make the equipment less susceptible to voltage dips.

The input full wave rectified line voltage wave shape, the magnitude of the input voltage average and the output voltage will be monitoring by the circuit. The three input signals are combined to modulate the average input current waveform in accordance with the rectified line voltage, while regulating the output voltage for line and load variations. By modulating the boost regulator's MOSFET drive, for the power factor correction, the boost regulator's input current is forced to be proportional to the input voltage waveform. In order to control the input current, peak current mode control or average current mode control may be used. Current sensing could be done in many ways. This could even be a resistor as shown in Figure 3.

E. Hybrid Power Factor Corrector

Hybrid Power Factor Correction (HPFC) is combination between PPFC with APFC. HPFC can improve the compensation characteristics of the PPFC and avoiding the possibility if the generation of series or parallel resonance. Figure 4 show the diagram of hybrid APFC circuit. In this scheme, if the passive filters are not connected, the series active power filter can compensate only voltage regulation, and voltage unbalance.

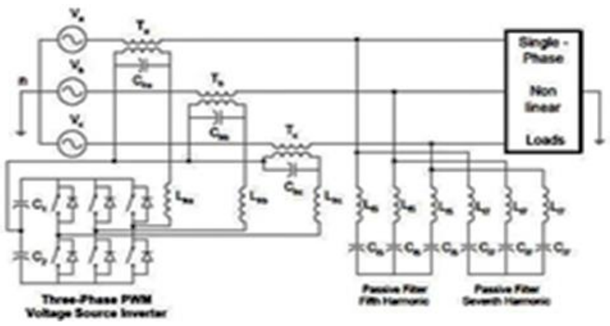

Fig 4: Series active power filter topology

Figure 5 shows another possible of combine the compensation characteristics APFC and PPFC is by connecting the active and passive power factor corrector in series with the passive one. By this way, the compensation characteristic of the PPFC is significantly improved. Since the active scheme generated voltage harmonic components across the terminal of the primary windings of the series transformer, forcing current harmonics generated by the load to circulate through the passive filter instead of the power distribution system.

Many features of the direct-drive modular PM generator are useful for a promising variable speed generator. In addition, variable- speed operation removes the need for special synchronizing equipment and for damping both of which have been found to be difficult and costly to implement. Therefore, modifying the direct-coupled, modular PM generator for variable-speed operation should provide an attractive machine for the wind energy industry. The new variable-speed generator will require an efficient power electronic interface that provides high quality power.

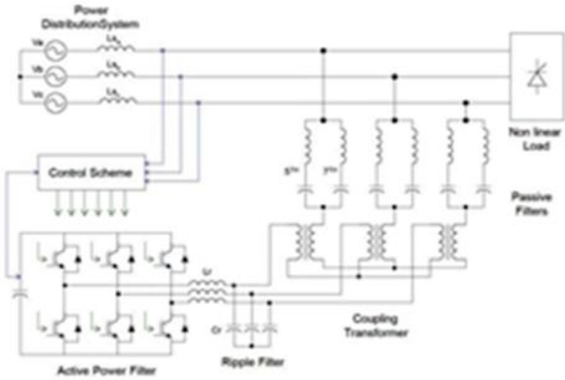

Fig 5: Block diagram of a hybrid Active Power Factor Correction

F. Basic Design of Variable Power Factor Correction

To fix the power factor automate, variable power factor correction was created. The term variable mean that the system can correct power factor automatically as the load varies. In order to correct the power factor automatically, the system must have a sensor to measure or calculate the power factor of the system and correct it by turning on and off the certain number of capacitors. In term of measure the power factor, the system is design to calculate the power factor from real power, P and also reactive power, Q. Base on the theories; the design can be divided into several parts which are:

1) Current measure
2) Voltage measure
3) Power factor detection
4) Switching Control
5) Capacitor counter

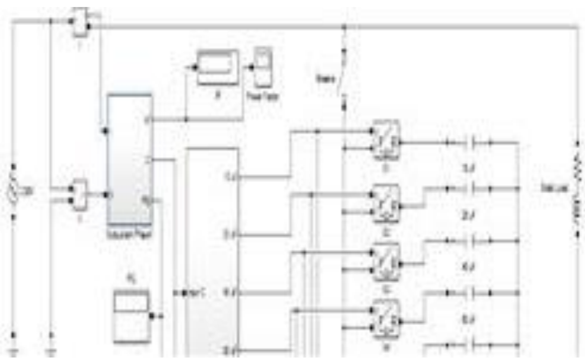

Fig 6: Position of current measurement, voltage measurement and power factor detection

Figure 6 show how the voltage and current measurement blocks were connected in the design system. The voltage measurement block measures the instantaneous voltage at the supply source where the current measurement block measures the instantaneous current flow through the load. The current and the voltage measure value will used to calculate the active and reactive power at the power factor detection subsystem block. All the calculation in the power factor detection block was using the formula power factor.

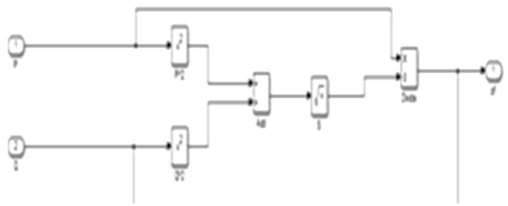

Fig 7: Power factor measure from active and reactive power

After the power factor of the system have been identified, the system start compensate the low power factor which is small than 0.9. In order to do so, the capacitor bank is installing in the design system. Normally, the inductive load will supply positive reactive power such as motor which produce high reactive power. For example, if the load produces 100 MVar, the power factor of the system is equal to 0.71 lagging. The capacitor needs to generate negative reactive power in order to improve the low power factor, for example -70 MVar. The neat power factor is equal to 0.96 lagging, which mean that the power factor for the overall system has been improved. A control system needs to be design in order to control the number of capacitor on to produce the negative reactive power need to generated by capacitor used to improve the power factor. The switch ON, OFF the capacitors as show on Figure 7 is control by the control system. A control system needs to create to control the operation of the capacitors at each phase.

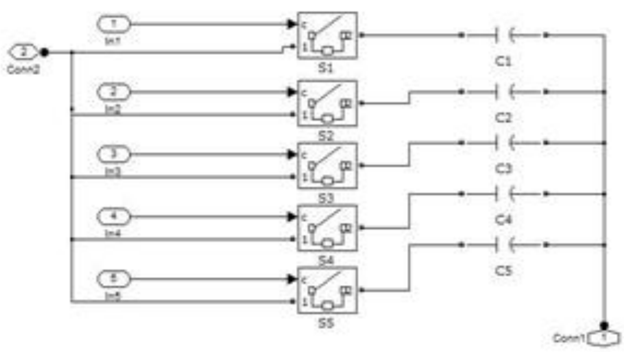

Fig 8: Switching

G. The Control System

The control system will start determine the value of capacitor need to replace in order to improve the lower power factor. The system will monitor the power factor of the system from time to time, when the power factor is small than 0.9, the system will start to determine the capacitor value used to generate negative reactive power to compensate the low power factor. In order to improve the power factor closed to unity, we assume that reactive power supply by the inductive load need to be replaced by the same value of reactive power (For example, if the load produces 100MVar, the power factor of the system is equal to 0.71 lagging. So the capacitor needs to generate negative reactive power in order to improve the low power factor same as 100MVar so that the value of power factor is closed to utility. The value of capacitor used to improve the low power factor is calculated in the power factor detection block which is show in Figure 9.

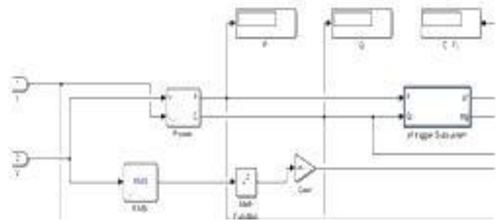

Fig 9: Determination of capacitor Block diagram

After the value of capacitor is determine by the circuit, the switch control block will going to identify the number of capacitor to be ON. Output 1, output 2, output 3, output 4 and output 5 will switch on capacitor 10 µf , 20 µf , 40 µf, 80 µf and 160 µf respectively. For example when the capacitor value is 180 µf, the output 2 and output 5 will be on, so the total capacitor one is 180 µf . On the other hand, if the capacitor value is 184 , the number of output switch is same as the 180 µf . Where each level of different switch will be on is 10 µf which show in Appendix A.

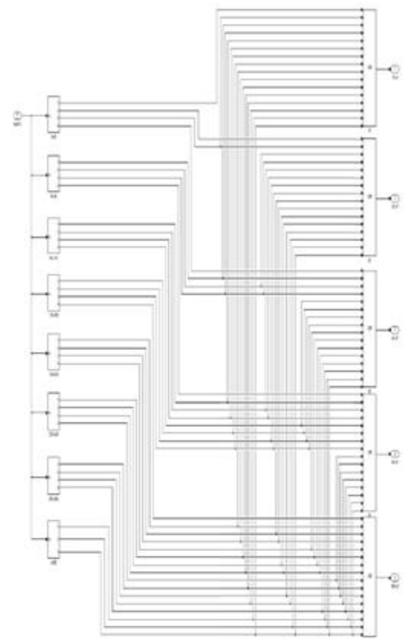

Fig 10: Switching Control Circuit

Figure 10 show the circuit of how the control circuit is connects to switch on and off the capacitor. Figure 9 is show the comparator to identify the number of output to turn on and off. The range for each level is 10 µf, which mean that if the capacitor value is 10 so the range of the capacitor is 5. And if the value of capacitor is 201 µf, so the range is between 195 µf. And the maximum of the capacitor value can be support by the system is less 310 µf. If the system requires capacitance greater or equal than 310 µf, the system will be supplying 310 µf

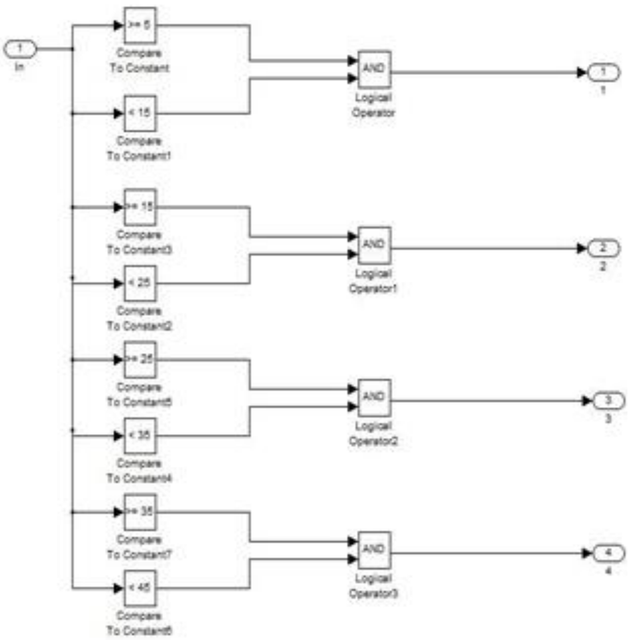

Fig 11: Switching Capacitor

3. Simulation Results

The result performance and the simulation of the system will be displayed and discussed in this chapter. In this project, the three phase system and the power factor of the system will be correct by using capacitor bank, which is connected in parallel near to the load and control by using PPFC. The load used in this system will be at a balance load. The value of the power factor is show in the figure and the value of capacitor used to improve the power factor also show in the figure. Table 4.1 shows the value of the load connects to the system and the power factor before the correct using capacitor bank and after correct. The table also show the value of the capacitor used for the different value of the power factor to improve the low power factor.

Table 1 Power factor before and after correction

Load Value	Power Factor		Capacitor Value
	Before	After	
10.00 + j 134 Ω	0.431	0.939	10 µF
5.56 + j 104.7 Ω	0.253	0.983	30 µF
2.32 + j 62.8 Ω	0.124	0.957	50 µF

A. Uncompensated System Performance

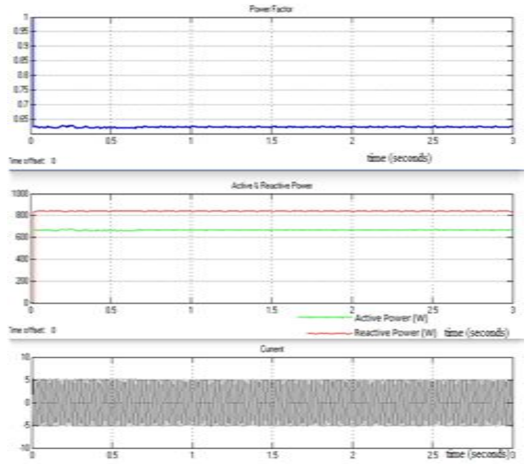

Fig 11: Scope output for power factor, Active & Reactive Power and Line Current for uncompensated system

Figure 11 shows system performance when power factor, active and reactive power and line current for an uncompensated system. Since the load takes reactive component from source thus active power falls below reactive power hence power factor nearly below 0.65.

B. Compensated System Performance

Figure 12 show the simulation result for the compensated balance system of this project. From the simulation, the capacitance select by the system have slightly different compare to the calculation value. Where the system only could provide 10 µF as smallest capacitance value and followed by 20 µF, 30 µF, 40 µF, 50 µF until 310 µF. For the value which between 10 µF and 20 µF is not provide in the system. For example 11 µF is not provided by the system and the system will only give 10 µF in order to improve the power factor. When the resistance of the system is very small, the 1 µF which could not provide by the system will give big effect to the system.

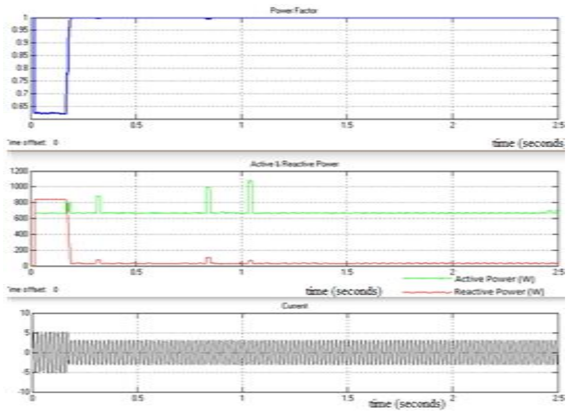

Fig 12: Scope output for power factor, Active & Reactive Power and Line Current for Compensated System

And this system could only function between 10 μF to 310 μF, for load which need higher than 310 μF the system only supply the 310 μF.

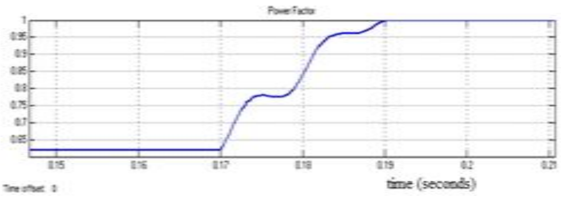

Fig 13: Magnified Scope output for power factor

Figure 11 to Figure 13 shows the change of the active power and reactive power of the system from uncompensated to compensate. The reactive power is very low could be neglect compare to the active power. Figure 11 to Figure 13 shows the power factor for the system. For the 1st 0.15 second, the system start to determine the power factor of the system and the system start to identify the value of capacitor used to improve the power factor in the next 0.02 second. After system has identified the value capacitor value, the system start improves the power factor of the system at 0.17 second. The system takes 0.02 second to improve the power factor. The system will reach steady-state on 0.19 second and the power factor of the system is improved.

Conclusion

Power factor is a critical problem in electrical power supply. The quality of the overall power system might be affected by the low power factor at certain area. This project is conducted in order to overcome the low power factor for industry area by applying the variable power factor correction, using capacitor bank. By using the automatically switching on the capacitor, it helps to improve the power factor and decrease the current flow in the cable. At the same time, the power losses in the cable will be reduced. In this project, the role of the Passive Power Factor system has been studied. The function of Passive Power Factor system is used to improve the low power factor automatically for the power system. An automation power factor correction system improves the low power factor when the power factor of the system is lower than the set value. By improving the low power factor, a good power quality can be obtained.

A computer model for three phase PPFC system has been developed by using MATLAB R2014b. This system has been developed in close loop system, which has a feedback system to monitor the output signal from time to time. Close loop system also able to compensate and correct for any disturbances that add to the system. The supplier set the lowest power factor accepted is 0.90. In terms of that, this design tried to achieve as high as 0.95 power factor using the designed circuit and it works. Based on the simulation results, the overall power factor of the system is corrected and achieve a 0.95 power factor. In conclusion, a computer model of PPFC system for variable balance load in three phase system was design and meets the objective of this project. From the evaluation, the power factor was maintained at 0.9 for the variable load by switching on and off the capacitor automatically by the system.

References

Joshi. A and Mishra M.K. (Apr. 2003), Control schemes for equalization of capacitor voltages in neutral clamped shunt compensator, *IEEE Trans. Power Del.*, Vol. 18, No. 2, pp. 538-544.

Jones L. ,Blackwell .D,(1983), Energy Saver Power Factor Controller for Synchronous Motors, *IEEE Transactions on Power Apparatus and Systems*, Volume: 5, Issue: 5, Pages: 1391-1394.

Keith. Harker (1998), Power System Commissioning and Maintenance practice. London: Institution of Electrical Engineers

Nalbant. M.K, (1990), *Power Factor Calculations and Measurement, IEEE Conferences on Applied Power Electronics*, PP.453-553.

Marlar.Thein, Ei.Cho, (Jan2008), Proceedings of World Academy of Science, *Engineering and Technology,* ISSN, Volume 32, PP.2070-3740.

Onar O C, Uzunoglu M, Alam M.S, Dynamic Modeling, Design and Simulation of A Wind/Fuel Cell/Ultra-Capacitor-Based Hybrid Power Generation System, *Journal of Power Sources* 161 PP.707-722, 2006.

Rakendu Mandal, Sanjoy Kumar Basu, Asim Kar, Syama Pada, (1994), A Microcomputer Based Power Factor Controller, *IEEE Transaction on Industrial Electronics,* Volume 41,PP.361-671.

Rao U M,Vijaya M A, Venakata S S, Williams T J, Butter N G,(1998), An Adapative Power Factor Controller For 3 Phase Induction Generations, *IEEE Transaction on Power Apparatus and Systems,* Volume PAS 104,PP.1825-1831.

R J Sinha (Jul 2013) ,Power Factor Improvement of Induction Motor by Using Capacitors, *International Journal of Engineering Trends and Technology (IJETT)* - Volume 4 Issue 7.

Sharkawi E l,Chen M A, Vandari S V, Fisser G W, Butter N G, Vinger R J, (1985), An Adaptive Power Factor Controller for Three Phase Induction Generator, *IEEE Transaction on Power Apparatus and Systems,*,Volume PAS 104,PP.1825-1831.

Stephen, J. C. (1999). Electric Machinery and Power System Fundamentals. 3rd.ed. United State of America: McGraw-Hill Companies, Inc.

Suman Maiti , Chandan Chakraborty, (2010),A New Instantaneous Reactive Power Based MRAS For Sensorless Induction Motor Drive, PP 1314–1326.

T.J.E.Miller, (1982), *Reactive Power Control in Electric Systems* by John Wiley & Sons Inc.