

Reactive Power Compensation In Distribution Systems Using SAPF

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Abstract— Traditionally when one imagine about power quality, images of classical waveforms comprising 3rd, 5th, 7th etc. harmonics come into picture .On this basis IEEE in team with industries and utilities and academia began to attack this problem in “power quality ” from the 80s. However in last few years the term power quality has grown in meaning form a simple power system harmonics. Since the growth of the industries is inevitable with more complex and sensitive equipments involving semiconductor etc. the power quality engulfed a whole new dimension of errors that appear in power system. These issues or anomalies are becoming more unavoidable and growing strongly and sensitive equipments will become even more sensitive due to the fierce market competition. Now, efficiency and cost are treated as peer parameters of equal importance. In such a situation Active Power Filters have emerged as the solution in which SAPF is employed for removal of load current harmonics and reactive power compensation .Active filters for power conditioning offer the following:

Reactive-power compensation, Harmonic compensation, harmonic isolation, harmonic damping, and harmonic termination, Negative sequence current/voltage compensation, Voltage regulation. The terminology *active filters* are often seen in different fields apart from power processing.

In this work both PI controller based and Hysteresis Band controller, three phases SAPF is used to compensate the reactive power that are elevated in the system due to inductive load to better the quality and is implemented on three phase wire system. The simulation of the results done through MATLAB program, and number of simulation results of the method are observed under steady conditions.

Index Terms— Reactive power compensation , SAPF , PI controller , MATLAB .

I. INTRODUCTION

A power quality problem is defined as any power problem that has relation with voltage, current and frequency deviation that results in failure of the system, damage to any equipment installed or mal operation . Power quality failures are categorized as :

- ✓ Disturbances in power frequency
- ✓ Transience in power system
- ✓ Electromagnetic interference
- ✓ Poor power factor
- ✓ Power system harmonics
- ✓ Electrostatic discharge

Almost all the power units operates with the loads that are inductive in nature , for example : arc furnaces , welding machine , elevators , power transformers , pumps, etc. Mostly , every severe power quality issues are encountered because of these inductive loads. The most feared power quality setbacks that are experienced in contemporary times are **Harmonics and Reduced Power Factor (Reactive Power)**.

Various problems that arises because of **reduced power factor** are :

- ✓ Poor voltage regulation
- ✓ Reduced efficiency
- ✓ Greater conductor size
- ✓ Increased load currents
- ✓ Large copper losses
- ✓ Reduction in life of equipments
- ✓ Large kVA ratings of the equipments

Therefore, it becomes mandatory to improve power factor. There are many compensation techniques available for reactive power compensation or say for the improvement of power factor , some of these techniques are listed below:

- ✓ Capacitor banks
- ✓ Static VAR compensators
- ✓ Synchronous Condenser
- ✓ Self Commutated VAR Compensators etc.

Majority of them have drawbacks/limitations as follows:

- ✓ In case of capacitor banks high transience are experienced while connecting and disconnecting the device.
- ✓ In case of Static VAR compensators, they adhere to high harmonic pollution.
- ✓ Synchronous machines have multiple disadvantages:

- It demands stringent foundation as they are not compact and result in undesirable bulky setup .
- They demand additional equipments for protection and starting the machine.

II. REACTIVE POWER AND NEED TO IMPROVE POWER FACTOR

Reactive power can be described as the quantity of un used power developed by reactive components such as inductor or capacitors in an AC circuit or systems . In DC circuit power is consumed in watts (V*A) by the circuit. In case of AC circuits containing reactive components the complexity increases as this product of Volt –Ampere changes with frequency. In an AC circuit the product of voltage and current is known as apparent power expressed as VA or kVA.

Power factor is actually the measure of how effective we use electricity. Power in an AC circuit can be classified as apparent , active and reactive power. The active power is also known as true or real power . this power is utilized by the equipments for heating, lighting etc. where as the loads like motors or ballast are inductive in nature and requires power to sustain a magnetic field for their operation. This non working power is called reactive power expressed as kVAR or kilo-Volt-Ampere-Reactive. Loads are usually both inductive and resistive . The ratio between these two forms of loads gain importance when we add more inductive equipments. Active and reactive power makes up apparent power which is expressed as kilo-volt-amperes. Power factor is the ratio of active power to apparent power :

$$PF = \frac{kW}{kVA}$$

A high power factor is beneficial for both consumers and utility and low power factor indicated poor utilization of electrical energy .

Example, If a load is running at 100kW(working power) and the meter records 125kVA(apparent power). Then the power factor will be 80% this means that only 80% of the incoming current does the useful and 20% is wasted.Thus higher the power factor the efficient is the distribution system . Improved power factors result in following :

- ✓ Reduced power loses
- ✓ Improved voltage to equipment
- ✓ Maximum current carrying capacity
- ✓ Reduction in cost of electricity
- ✓ Increase in available power

In this work SAPF is used employed for the removal of harmonics and compensating the reactive power and the power factor calculated in our system is close to unity . So it is clear that the apparent power can be classified as active power and non-active power . And this non-active power is further classified as the reactive power and the harmonic power . This is clearly shown in figure 1.1 . In figure 1.2 the phasor diagram is shown , in case of an ideal system the apparent power S is the resultant of active power P and reactive power Q . but because of the presence of non-linearities in the system the apparent power is slightly increased, as shown in figure 1.2

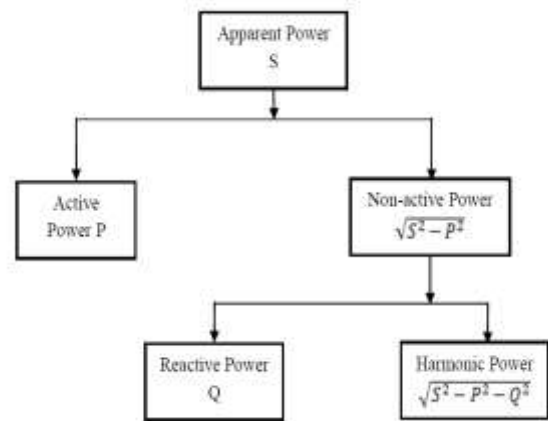


Figure 2.1 , Representing the active , reactive , harmonic and apparent power in power system

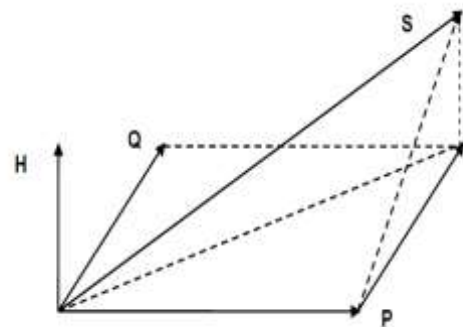


Figure 2.2 , Representing the deviation in apparent power due to harmonics (phasor)

III. CONTROL STRATEGIES

Hysteresis band PWM current control technique :

There are many types of PWM techniques available :

- ✓ Space Vector PWM
- ✓ Minimum ripple current PWM
- ✓ Hysteresis band current control PWM
- ✓ Sinusoidal PWM with instantaneous current control
- ✓ Selected harmonic elimination PWM
- ✓ Sinusoidal PWM
- ✓ Sigma Delta modulation

The hysteresis band current control is used in our work because of easy of implementation., fast transient response , direct limiting of device peak current and practical insensitivity of DC link voltage ripple that permits a lower filter capacitor. In HBPWM the actual current continuously follows the reference current within a given hysteresis band . The HBPWM is an instantaneous feedback current control method of pulse width modulation. The principle on which the working of HBPWM is based for a half bridge inverter is illustrated in the fig.

The actual phase current wave is compared to the reference sine current wave of expected magnitude and frequency .These sine reference current wave is generated by the current control circuit. As soon as the current exceeds a fixed boundary of hysteresis band the upper switch and lower switch is turned OFF and turned ON respectively. The current starts to diminish as the output voltage varies from +0.5Vd to -0.5Vd.

When the current trespasses the lower band limit the lower switch is turned OFF and the upper switch is turned ON. In

this way the actual current is forced to follow the reference wave within the hysteresis band by repeatedly switching the switch and lower switch. The input to the HBPWM controller are the difference in the three phase currents and the output are the switching signal for PWM inverter.

IV. 3- ϕ VOLTAGE SOURCE CONVERTER

The voltage source converters are used in majority of topologies of active power filter which normally uses capacitors as a storage device for energy. In the fig shown DC voltage is converted into AC voltage by properly turning on the switches. For the generation on AC Voltage, generally a single pulse for every half cycle can be applied for majority of functions that require dynamic performance of the filter but, the technique most commonly used, now a days is pulse width modulation technique. In pulse width modulation techniques the DC bus voltage is chopped for the generation of AC Voltage of an capricious waveform. Voltage source converters are subjected to pulse width modulation techniques. For the production of sinusoidal patterns or any other random patterns, plethora of pulse width modulation techniques are in use. The ac outcome of the voltage source converter can be controlled using pulse width modulation techniques.

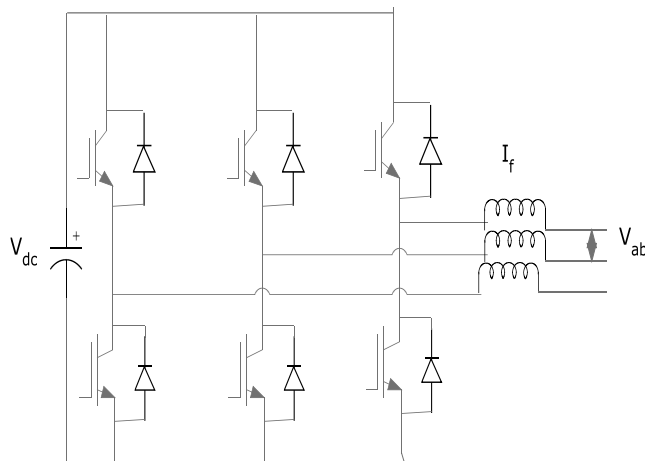


figure 4.1, representing voltage source converter.

In the Figure, represents the working of pulse width modulation process by employing the triangular carrier technique which is one of the most basic and commonly used technique. It compels the voltage V_o over a switching cycle to be at par with the average amplitude of the modulating waveform, V_o (reference), governed by time period of $V_{carrier}$ (Triangular wave). Some unwanted harmonic components will be present in the resultant voltage waveform along with the fundamental component of sine wave. The undesired components that are present in the resultant waveform components can be decreased using a carrier wave high in frequency. Although, this frequency relies upon the IGBT's highest frequency (switching). Triangular carrier wave is used in the modulation strategy illustrated in figure. There are many control strategies available now a days for the control of power inverters, triangular carrier wave technique is amongst them

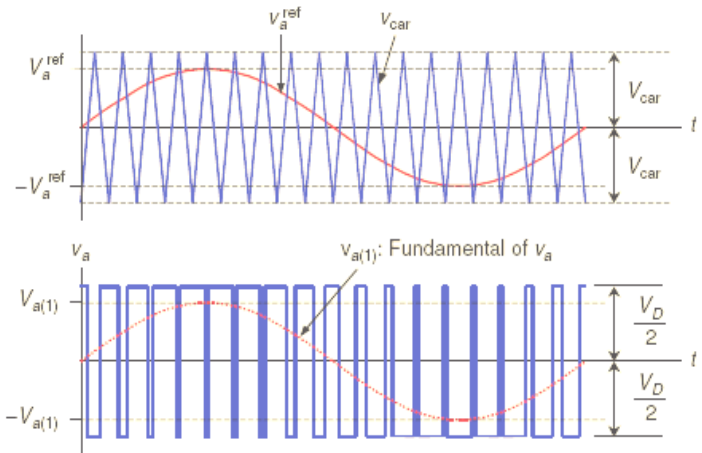


Figure 4.2, Representing PWM (triangular carrier technique)

V. BASIC COMPENSATION PRINCIPLE

Below given figure depicts the principle of Basic Compensation of a shunt active power filter. SAPF is regulated to cancel the current harmonics on the AC side by either drawing or supplying a compensating current from or to the system. The curve 1,2 and 3 depicts the waveform of load current (curve 1), desired current (curve 2) and the compensating current (curve 3) which is introduced in the system by the active filter. This compensating current displayed in curve 3 is the one which turns the main current sinusoidal containing all the harmonics. The mitigation of current harmonics and the compensation of reactive power can be achieved using SAPF.

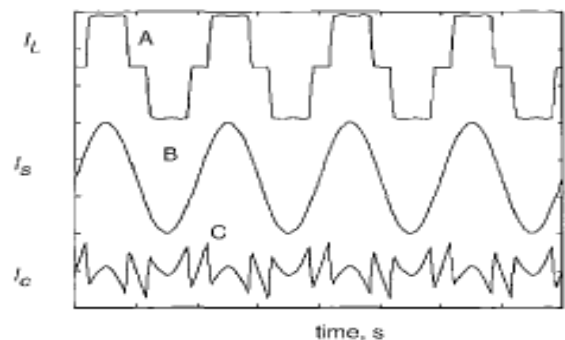
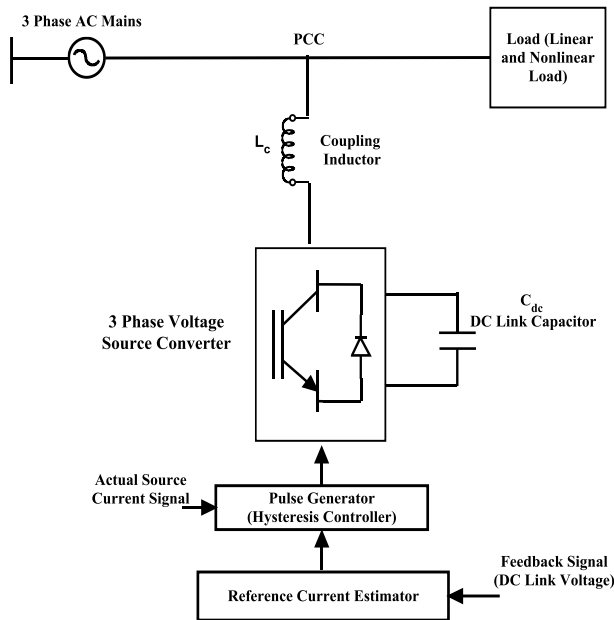


Figure 5.1, Representing shape of load current, source current and compensating current.



In this system two control loops are employed, that are voltage and current loop. A PLL block (phase locked loop) is used to generate the sine vectors that are synchronized with the source voltage. This unit sine vectors are multiplied with the maximum value of source current which is the output of PI controller. In PI controller the actual DC link capacitor voltage is sensed and compared to the set DC reference value. The error output is processed in the PI controller. By multiplying the output of PI controller with the sine vectors generated the three phase sinusoidal source current is generated, displaced by 120 degrees from each other. These three phase reference source currents are compared with the actual source currents in a hysteresis controller, to produce the required gate pulses for the inverter.

VI. SIMULATION RESULTS

A Discrete Rms value block is connected to measure the rms value of current and a display is connected at its output. A combination of Linear and Non-linear load is connected to the system. Through a three phase breaker as shown in figure --- a step input is connected to the breaker. Load is changed at 0.4 seconds from $P = 2\text{kW}$ and $Q = 2\text{kVAR}$ to $P = 2\text{kW}$ and $Q = 5\text{kVAR}$.

That is the reactive load is increased, or can say the reactive power demand of load is increased after 0.4 seconds and this will be compensated by active power filter and therefore the rms value of current supplied by the source will not change as the source is used to supply only active power. Figure 6.1 and 6.4 shows the waveform for load active and reactive power separately. It is clear in the figure that the active power demand of load is 2kW and is not increased with the increase in load as after 0.4 seconds we have increased only the reactive power demand by increasing the reactive inductance in the load. On the other hand, Load reactive power demand is increased from 2 kVAR to 5kVAR after 0.4 seconds. We have increased the reactive power demand keeping the active power demand same to clearly show that the increase in reactive power after 0.4 seconds is taken care of by the shunt active power filter.

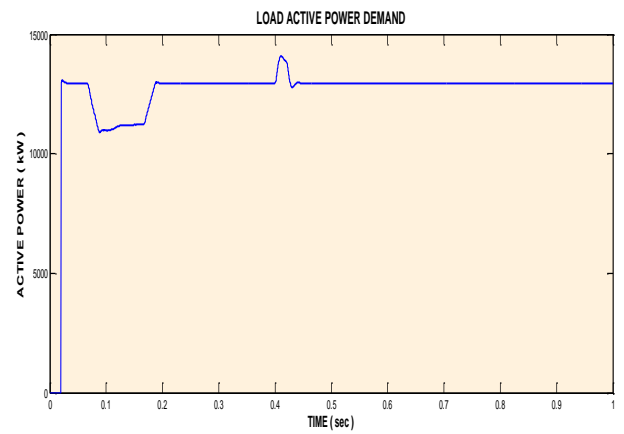


Figure 6.1, represents the active power demand of load

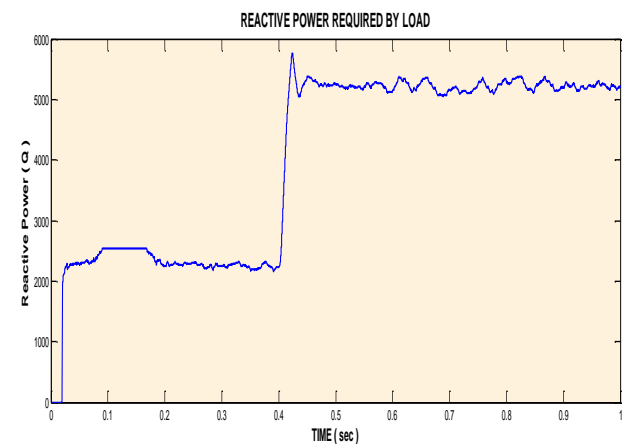


Figure 6.2 represents the reactive power demand of load

Figure 6.3 and 6.4 shows the active and reactive power supplied by the source in the absence of filter respectively. In the absence of filter the source have to supply the increase in power demand by the load which is only the reactive power demand increase. It is clearly seen in figure 7.16 that there is an increase in the reactive power supplied by source in accordance with the increase in the reactive power demand. And when the filter is operated or say is connected to the system, there is no change in the active power supplied by the source, even if the demand is increased as this increase in reactive power is taken care of by the shunt active power filter, which works as a reactive power compensator, whereby compensating the reactive power requirement.

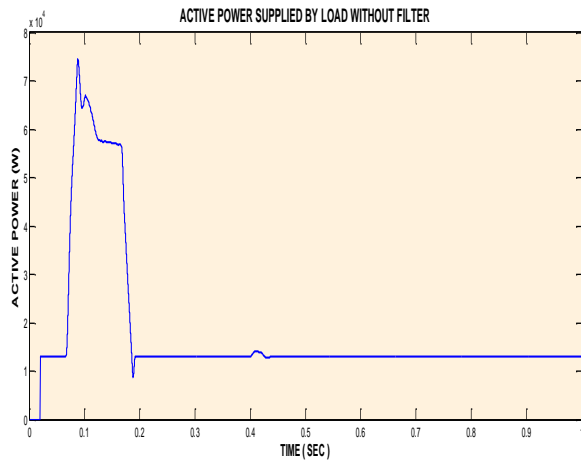


Figure 6.3 , shows the active power supplied when the filter was not connected.

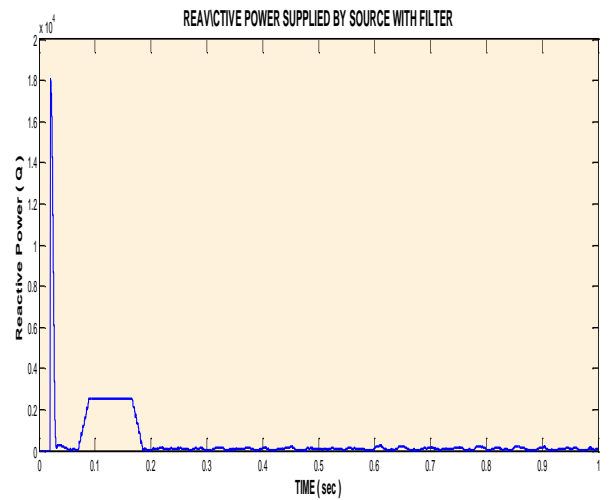


Figure 6.6 , Shows the Reactive power supplied by source when the filter is connected. . It is very clear in the figure that source does not have to supply the reactive power demand of load .

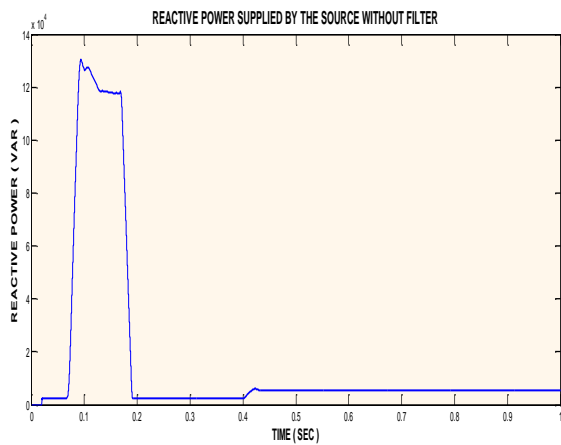


Figure 6.7 and 6.8 , shows the compensating active and reactive power provided by the shunt active power filter. The shunt active power filter does not supply any active power to the load , and it only supplies the reactive power to the load. It is also seen in the figure that the reactive power supplied by the compensator increases as the load reactive power demand gets increased.

Figure 6.4 , shows the Reactive power supplied , when the filter was not connected.

Figure 6.5 and 6.6 shows the active power and reactive power supplied by the source in presence of shunt active power filter , or say when the filter is connected to the system. The active power supplied by the source will not change and the increase in reactive power demand is now supplied by compensator and so the reactive power supplied by the source is not increased. That is now the increase in reactive power demand of the load is provided by the compensator and not the source.

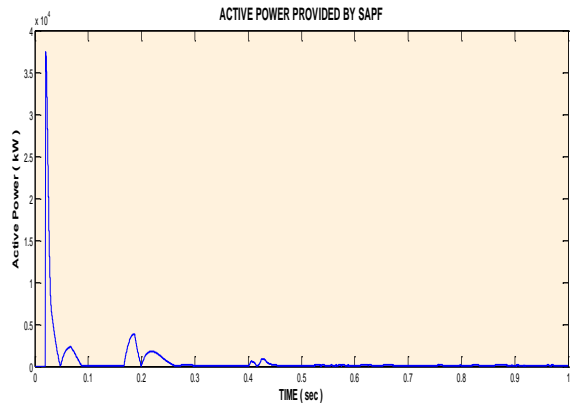


Figure 6.7 Shows the active power supplied by the filter

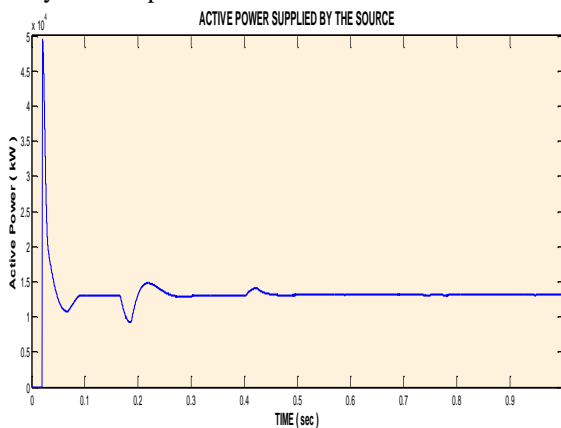


Figure 6.5 , shows the active power supplied when the filter is connected

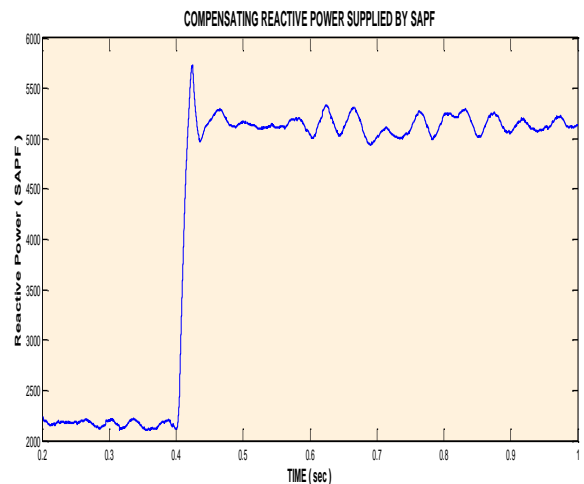


Figure 6.8 shows the Reactive power (Compensating) supplied by the filter .

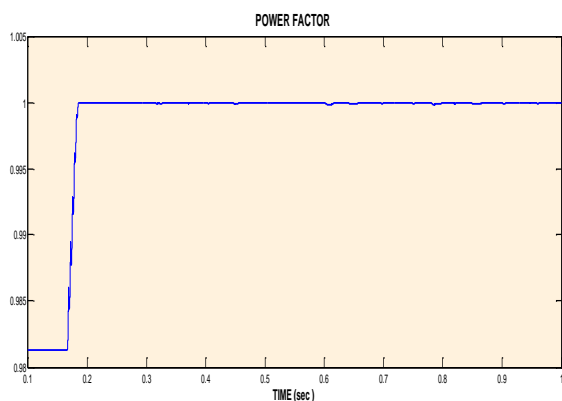


Figure 6.9 , Shows the power factor of the system . And it is clear from the waveform that the power factor is approximately unity.

VII. CONCLUSION

A complete filter is designed for the compensation of reactive power in the system. Various simulations are carried out and the results shown in the paper represents the effectiveness of the filter for the compensation of reactive power demand of load. A model has been developed in Matlab Simulink and the model is simulated for the verification of results. The filter designed is capable of compensating all the reactive power demand also the power factor of the system is almost unity when the filter was connected to the system.

VIII. REFERENCES

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