Reactive Power Compensation and Harmonic Filter using SAPF in MATLAB

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Abstract— This project work presents a shunt active power filter method for harmonic filtration and reactive power compensation. Due to wide use of non-linear single phase power electronic devices in low voltage side has increased harmonic pollution in the power system to the larger extent. The presence of harmonics in electrical systems means that current and voltage are distorted and deviate from sinusoidal waveforms which can cause many different problems in the electrical system and sometimes also leads to the faults in the system. Reactive power makes the generation and distribution of electrical power very inefficient so this is very important to neglect harmonics and reactive power from the system. Improving power quality has become the biggest challenge for electrical engineers. A shunt active power filter was modeled in MATLAB/SIMULINK to reduce harmonics and reactive power. Simulation results are presented to demonstrate performance of shunt active power filter during presence of non-linear load.

Keywords: Pollution, Electronic Devices, MATLAB, Faults, Harmonics

I. INTRODUCTION

Power quality improvement has become a major research topic in modern power distribution system. Nearly twenty years ago most of the loads used by the industries and consumers were passive and linear in nature, with a lesser number of non-linear loads thus having less impact on the power system. With the arrival of semiconductor and power electronic devices and their easier controllability have caused wide use of non-linear loads such as chopper, inverter switched mode power supply, rectifier, etc. The power handled by modern power electronics devices like Silicon Controlled Rectifier (SCR), Insulated Gate Bipolar Transistor (IGBT),power diode, Metal Oxide Semiconductor Field Effect Transistor (MOSFET) are very large, which promotes their industrial as well as domestic applications. With addition to that various power electronic devices are used to increase the efficiencies and power factor of wind, solar, and other non-conventional sources of energy. While the advantages of using above devices are certainly good but there are some demerits of such excessive use of power electronic devices. The use of above semiconductor devices is responsible for harmonic and reactive power disturbances. The harmonics and reactive power are the cause various problem which includes overheating of transformers, excessive neutral current, distortion of feeder voltage, low power factor, damages to power electronic devices and malfunction of sensitive equipment[9].

If nonlinear single-phase and/or three-phase loads are present, or the three-phase load is unbalanced, line currents are unbalanced and neutral currents flow. These neutral currents contain both fundamental and harmonic components[10]. In extreme cases, the neutral currents are potentially damaging to both the connected neutral conductor and the transformer. To eliminate the harmonics in the power system, active power filters (APF) are installed at Point of Common Coupling (PCC). Active Power Filter injects compensating current at PCC to cancel out the harmonics and to make source current sinusoidal. By installation of APF, harmonic pollution as well as low power factor in the power system can be improved. Though APFs are widely used in three phase system, by little modification in the control strategy it can be implemented in the single phase system, thus harmonic pollution can be reduced at low voltage system [9].

Reactive power can best be described as the quantity of "unused" power that is developed by reactive components in an AC circuit or system. Reactive Power (sometimes referred to as imaginary power) is expressed in a unit called "volt-amperes reactive", (VAR), symbol Q and is given by the equation:

$$Q = VI \sin\Phi$$

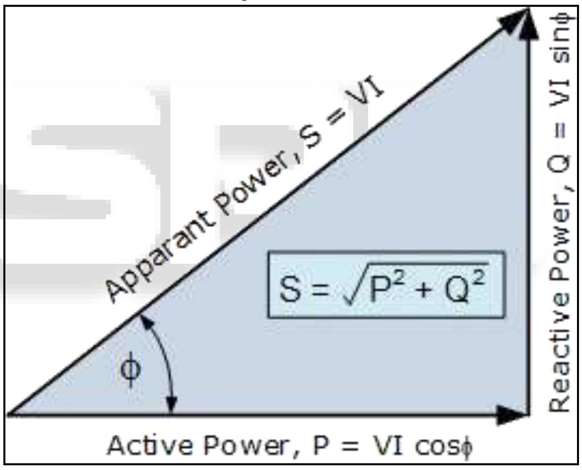

Fig. 1: Power Triangle

$$\text{Active Power,}(P) = \text{Apparant Power,}(S) \times \text{Power Factor,}(pf)$$

$$\text{Power Factor, }(pf) = \frac{\text{Active Power, }(P)\text{ in Watts}}{\text{Apparant Power, }(S)\text{ in volt} - \text{amps}}$$

From the above power triangle we can see that AC circuits supply or consume two kinds of power: active power and reactive power. Also, active power is never negative, whereas reactive power can be either positive or negative in value so it is always advantageous to reduce reactive power in order to improve system efficiency.

Reducing reactive power to help improve the power factor and system efficiency is a good thing, one of the disadvantages of reactive power is that a sufficient quantity of it is required to control the voltage and overcome the losses in a transmission network. This is because if the electrical network voltage is not high enough, active power cannot be supplied. But having too much reactive power flowing around in the network can cause excess heating (I^2*R losses) and undesirable voltage drops and loss of power along the transmission lines.

A. Power Factor Correction of Reactive Power

One way to avoid reactive power charges, is to install power factor correction capacitors. Normally residential customers are charged only for the active power consumed in kilo-watt hours (kWhr) because nearly all residential and single phase power factor values are essentially the same due to power factor correction capacitors being built into most domestic appliances by the manufacturer.

Industrial customers, on the other hand, which use 3-phase supplies have widely different power factors, and for this reason, the electrical utility may have to take the power factors of these industrial customers into account paying a penalty if their power factor drops below a prescribed value because it costs the utility companies more to supply industrial customers since larger conductors, larger transformers, larger switchgear, etc, is required to handle the larger currents.

Generally, for a load with a power factor of less than 0.95 more reactive power is required. For a load with a power factor value higher than 0.95 is considered good as the power is being consumed more effectively, and a load with a power factor of 1.0 or unity is considered perfect and does not use any reactive power.[8]

Filters are electronic circuits that allow certain frequency components and / or reject some other. They are passive and are the electric circuits or networks that consist of passive elements like resistor, capacitor, and (or) an inductor.

There are two types of filters used-
1) Active Filters.
2) Passive Filters.

1) Active Filters

Active filters are the electronic circuits, which consist of active element like op-amp(s) along with passive elements like resistor(s) and capacitor(s).

Active filters are mostly and widely used in electrical system for filtration purposes than the passive filters. This is because active filters has many advantages over the passive filters.

Advantages of active filters-
1) Active filters are having low cost because the OP-AMPS are very cheap and easily available.
2) The components used in active filters are very small in size as compared to the passive filters.
3) Active filters are very easy to tune so easy frequency adjustments are possible.
4) OP-AMPS has high input resistance and low output resistance therefore active filters using OP-AMPS do not load the input source.

There are three types of active filter-
1) Shunt active filter.
2) Hybrid active filter.
3) Series active filter.

Here in the project the shunt active power filters method is used to compensate reactive power and harmonic filter. A shunt active power filter was modeled in MATLAB/SIMULINK to reduce harmonics and reactive power.

B. Shunt Active Power Filter

SAPFs are widely used in the power system to compensate reactive power and current harmonics. It can also play the role of static VAR generator in the power system for improving and stabilizing the voltage profile. Shunt active power filter compensate current harmonic by injecting complementary current that of produced by non-linear load. Shunt active power filter(SAPF) acts as a current source by introducing the harmonic components created by the load but phase shift by 180.Consequently, the current harmonic component present in the load current got cancelled and the source current remain sinusoidal and in phase with the respective phase to neutral voltage. By the use of proper control scheme, APF can also improve system power factor. Thus, by the effect of active power filter, voltage sources see the non-linear load simply as resistor.

However the performances of SAPF largely depend on the control strategy which is responsible for generating complementary harmonic current to cancel out the current harmonics present in the load current.

The features Shunt Active Power Filter are:
1) Parallel in the circuit, even its failure would not cause the entire system can not be used, just the function is no use.
2) Be able to compensate for multiple harmonics, rather than tuning a particular harmonic; also be compensation for a select number of harmonics.
3) Compensation effect is unchangeable with the size of the load rate of change, always be able to achieve satisfactory results.
4) If necessary, can also be carried out on the displacement factor compensation.
5) There is no danger of overload, a maximum current is running under the limit mode.

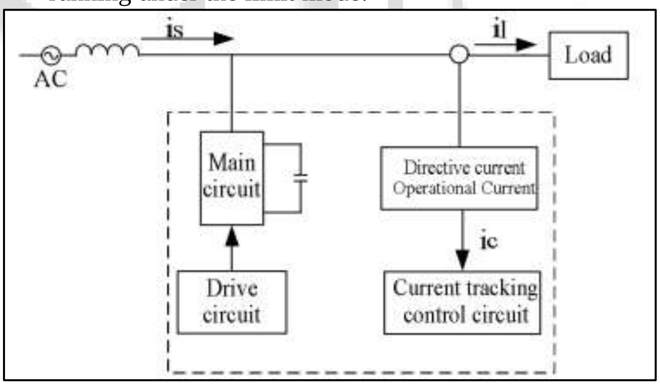

Fig. 3: Shunt active power filter system consisting of schematic diagram.[11]

Shunt active power filter is widely used due to its simpler construction and robustness. A brief idea about shunt active power filter and its control schemes.

C. Passive Filter

The passive filter requires resistors, inductors, and capacitors and they do not depend upon any type of external power source. By proper selection of L and C, they are tuned to bypass a particular harmonic component. Multiple numbers of passive filters are connected in parallel to nullify higher order of harmonics as shown in Fig.3 Though passive filters were widely used as harmonic improvement and reactive power compensation devices in the power distribution system, their performances is not satisfactory due to following reasons:

Reasons-

1) A separate filter is necessary for each harmonic frequency.
2) Passive filter must be designed in considering with current provided by nonlinear load.
3) Source impedance affects the compensation characteristics of LC filters.
4) When the content of harmonics in the AC line increases, the filter will be loaded.

Frequency variation of AC source and tolerances in the filter components will affect the compensation characteristics of LC filters. If the system frequency varies in wide range, components required for attaining tuned frequency become impracticable.

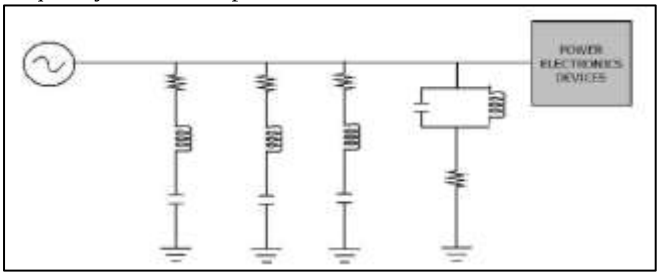

Fig. 4: Block diagram for passive filter connected power system.

With the above mentioned disadvantages the passive filter are less frequently used compared to active power filter. The practice of using the active power filter is the future trend of harmonic improvement in power distribution system because of its excellent dynamic characteristics. A flexible and handy solution to harmonic problem is provided by active power filters. Presently they are based on PWM converters and connected to low and medium voltage distribution system either in shunt or series.[9]

II. LITERATURE REVIEW/SURVEY

1) Longfu Lu et.al(2014)[1] demonstrated new method for harmonic suppression and reactive power compensation which is integrated with converter transformer is proposed to deal with the oversize problems of transformer and harmonic filter system in the cases where physical space is of limit based on the presented non-orthogonal decoupling mechanism, the integrated filter is designed and constructed. In this paper authors demonstrated studies on the decoupling effect, the inductor winding linearity, inductance computation, the harmonic reduction and reactive power compensation performance of the described integrated filter. Simulation and experimental verifications of an integration converter transformer prototype was provided.
2) W.R.N Santos et.al(2014)[2] presented a universal active filter for harmonic and reactive power compensation for single-phase systems applications. The proposed system was a combination of parallel and series active filters without transformer. It is suitable for applications where size and weight are critical factors. The model of the system was derived and it was shown that the circulating current observed in the proposed active filter was an important quantity that must be controlled. A complete control system, including pulse-width modulation (PWM) technique was developed. Comparisons between the structures were made from weighted total harmonic distortion (WTHD). The steady-state analysis was also presented in order to demonstrate the possibility to obtain an optimum voltage angle reducing the current amplitude of both series and parallel converters and, consequently, the total losses of the system. Simulated and experimental results validate the theoretical considerations.
3) Maheswar Prasad Behera et.al(2015) [3] presented a single phase grid integration of a shunt connected Photovoltaic (PV) generator. The objective of the proposed system was to provide uninterrupted power supply to the load during both strong sunlight as well as at night or at cloudy conditions. The interface between the grid and the PV was carried out through a Voltage Source Inverter (VSI), eliminating the current harmonics and compensating the load reactive power. The DC voltage control of the DC bus capacitor was employed in order to maintain unit power factor operation of the system, irrespective of changes in solar radiation level or due to change in load. The control scheme implemented was based upon single phase p-q theory.
4) Mohit Bajaj et.al(2015) [4]presented a modified id-iq based control algorithm for time varying active and reactive power control and load harmonics compensation by D-STATCOM under load fluctuations. The proposed scheme of control algorithm had been introduced for enhancing steady-state performances in addition to useful elimination of power quality disturbances. Employing a preexisting D-STATCOM to attain these added control purposes can advantage system handling operators to maximize complete response of the system. For regulating the time varying active and reactive power control, an extra current control loop system was provided and consequently comprised in the control block. To validate its application, a 200-V electricity feeder with a 3-phase rectifier as a non-linear load was simulated. Results obtained proved that addition of an extra control loop of current component of reactive power can regulate active as well as reactive power drawn on controlled feeder completely under the fluctuations of load reactive power control time varying active power control load harmonics compensation load fluctuations control algorithm steady-state performance power quality disturbances.
5) Md Abdullah et.al(2016) [5] presented a control method for hybrid active power filter using Space Vector Pulse Width Modulation (SVPWM). In the proposed control method, the Active Power Filter (APF) reference voltage vector was generated instead of the reference current, and the desired APF output voltage is generated by SVPWM. A MATLAB code was developed to generate the SVPWM switching pulses fed to the two-level inverter topology. The entire power system block set model of the proposed scheme had been developed in MATLAB environment. The developed control algorithm was simple. The APF based on the proposed method can

eliminate harmonics, compensate reactive power and balance load asymmetry. Simulation results show the feasibility of the APF with the proposed control method.

6) Sasawat Kumar et.al(2016) [6] presented a three-phase APF for power line conditioning (PLC) system to improve the power quality in the point of common coupling (PCC). It also consisted of a controller to control the APF. The hysteresis current controller (HCC) was used to generate the switching pulses for the voltage source inverter. VHDL is used to design a digital controller as it is independent of process technology. To generate the reference current synchronous reference frame (SRF) theory was used. The PI current algorithm and the HCC are designed using VHDL codes and implemented on FPGA for hardware. The three phase APF was modeled, tested and investigated under different unbalanced non linear conditions using MATLAB/SIMULINK environment. The simulation results justify that the APF is compensating the harmonics and reactive power at the PCC.
7) Anand Panchbhai et.al(2017)[7] presented decadence of power quality issue of electrical society. In practice, utility of switching device is increased in industrial as well as in domestic applications. Non-linearity causes adverse effects on system efficiency, utility of the power supply, power factor, etc. As reduction in power factor increases reactive power which does not have any contribution in energy transfer so its compensation is needed. So efforts are made to upgrade power quality, concept of Filter is in demand. In contrast to passive filter, active filters are popular due to its smaller size and weight. In the paper, work was done on shunt active power filter (SAPF) using P-Q theory for current harmonic mitigation and reactive power compensation. The simulation as well as its parameters, with or without active filter was well presented. The paper was commenced with power quality issues then better understanding of PQ theory, simulation circuits, results, comparison and finally ended with conclusion. An effort was made to achieve THD value of source current below 5% to meet the required IEEE standards.

III. OBJECTIVES

- To compensate reactive power from the system to make it more efficient.
- To reduce harmonics from the system.
- To reduce the disturbances in the system caused by harmonics.
- To improve/correct the power factor.
- To improve the power quality.

IV. FACILITIES REQUIRED

1) Software required-MATLAB/SIMULINK
2) Hardware required-PC or Laptop

V. SPECIFICATIONS

Voltage source-Three phase zero impedance voltage source.
Amplitude-=380
Frequency-50Hz
3 phase VI measurement
3 phase parallel RLC branch-
Type-Inductive
Inductance-0.1e^-3
U_B&I_B- To send signals.
Scope-To show graphical output representation.
UDC-Ideal voltage measurement.
IDC-Ideal current measurement.
L3-Parallel Inductance
Type-Capacitive
Capacitance-1e^-5
L2-Inductor
Value-e^-3
Universal Bridge-
Snubber Resistance-1e^6
No. of bridge arms-3

VI. RESULT

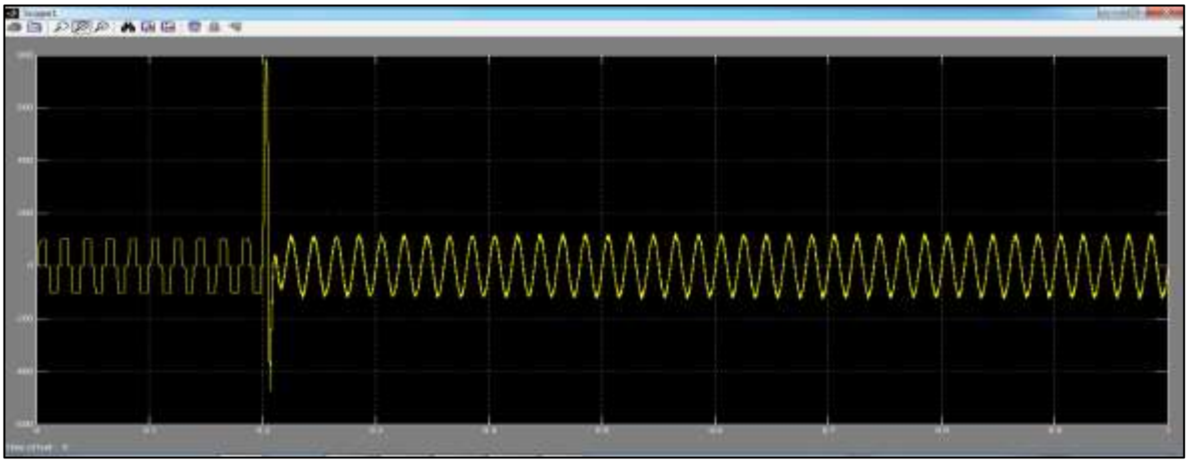

Fig. 5: Source Current

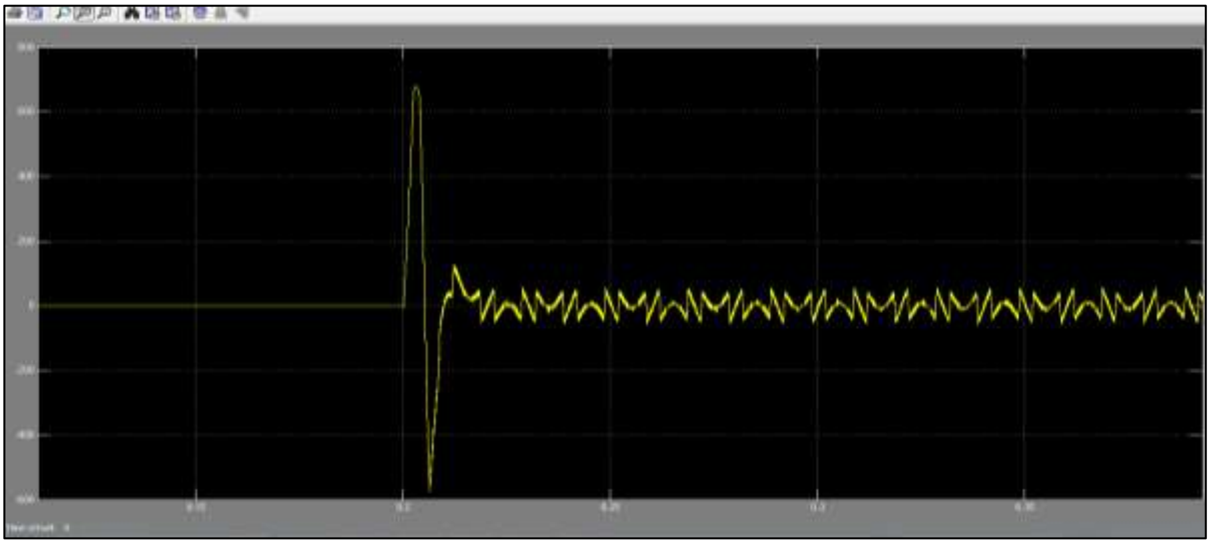

Fig. 6: Injected Current

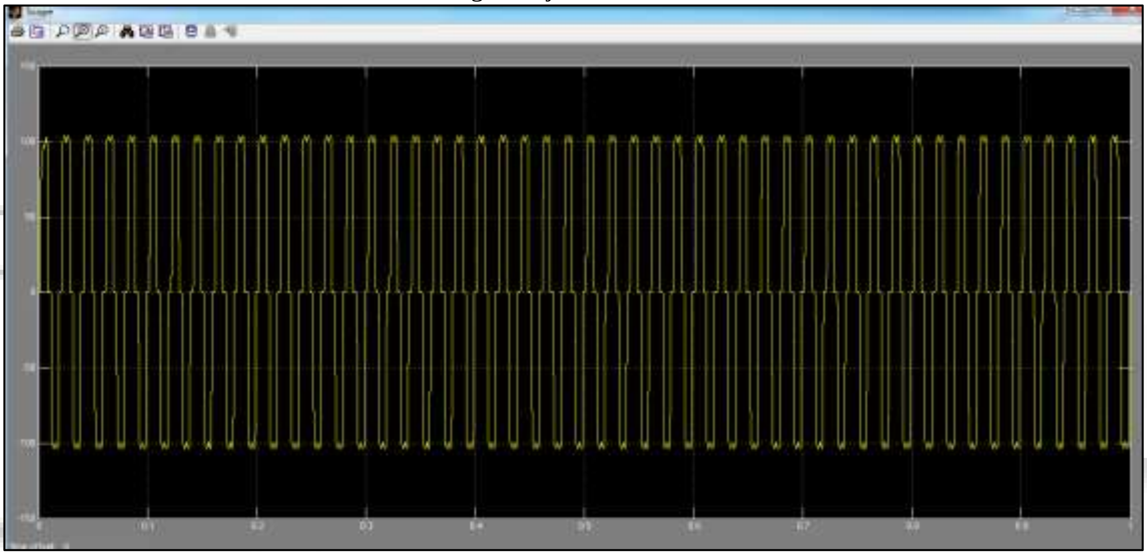

Fig. 7: Load Current

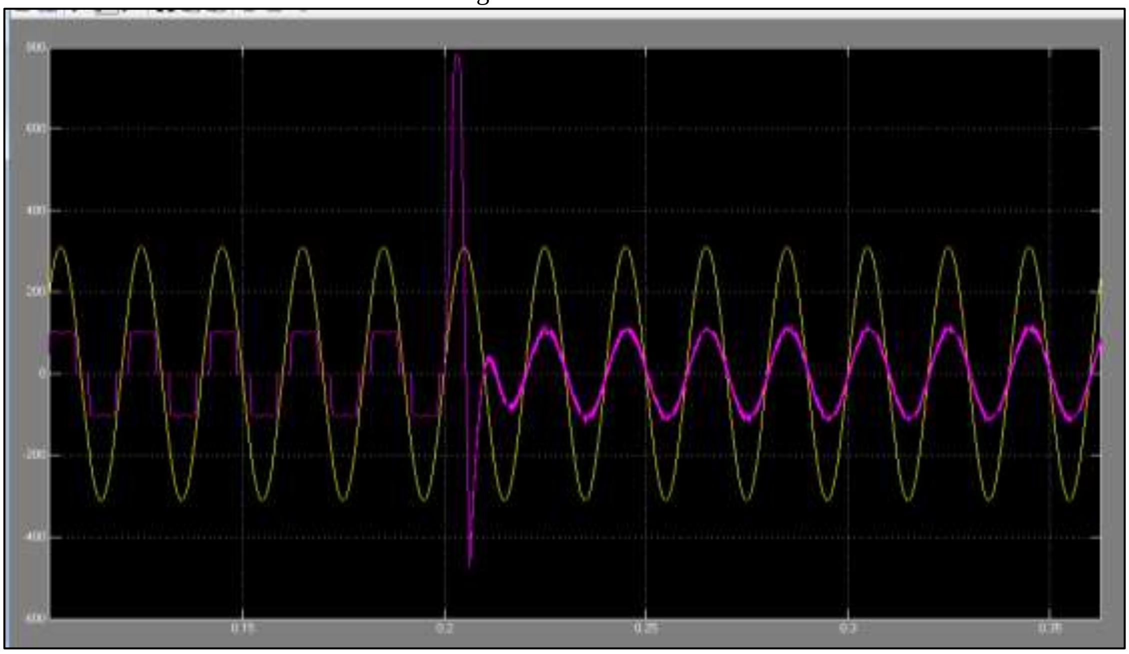

Fig. 8: Power factor correction

VII. CONCLUSION

The simulation of shunt active power filter has been carried out with non-linear load and the results obtained from the simulations shows that this technique improves the power quality ie THD and the power factor. The power factor correction helps to improve the reactive power usage and make the system more efficient. The THD is reduced using this method which helps in improving the quality of power. The hardware implementation of shunt active power filter has been conducted using real time workshop in the MATLAB Simulink environment.

REFERENCES

[1] L. Luo, C. Liang, Y. Li, W. Liao and Q. Qi, "A new method highly integrated with converter transformer for harmonic suppression and reactive power compensation," *2014 International Conference on Power System Technology*, Chengdu, 2014.

[2] W. R. N. Santos, E.R.C. da Silva, C.B. Jacobina *et al.*, "The Transformer less Single-Phase Universal Active Power Filter for Harmonic and Reactive Power Compensation," in *IEEE Transactions on Power Electronics*, July 2014.

[3] M. P. Behera and P. K. Ray, "Single-phase grid integrated Photovoltaic inverter for harmonic and reactive power compensation," *2015 Annual IEEE India Conference (INDICON)*, New Delhi, 2015.

[4] M. Bajaj, M. Pushkarna, A. S. Rana and M. T. Khan, "A modified algorithm for time varying reactive power control and harmonics compensation by D-STATCOM," *2015 Annual IEEE India Conference (INDICON)*, New Delhi, 2015.

[5] M. A. K. Aziz Biabani, Md. Abdullah, P. K. Joshi and M. Imran, "Harmonic compensation and reactive power control of distribution system by using shunt active power filter," 2016 International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES), Paralakhemundi, 2016.

[6] S. K. Ram and B. B. Das, "Digital controller design for three phase active power filter for harmonic and reactive power compensation using FPGA and system generator," *2016 International Conference on Inventive Computation Technologies (ICICT)*, Coimbatore, 2016.

[7] A. Panchbhai, S. Parmar and N. Prajapati, "Shunt active filter for harmonic and reactive power compensation using p-q theory," *2017 International Conference on Power and Embedded Drive Control (ICPEDC)*, Chennai, 2017.

[8] Tutorials, E. (n.d.). *AC Circuits / Reactive Power*. Retrieved December 9, 2020, from Electronics tutorials: https://www.electronics-tutorials.ws/accircuits/reactive-power.html

[9] Jena, Shyamsundar (2014) *MATLAB simulation of single phase shunt active power filter and development of experimental set up.*

[10] S. Po-Ngam, "The simplified control of three-phase four-leg shunt active power filter for harmonics mitigation, load balancing and reactive power compensation," *2014 11th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, Nakhon Ratchasima, 2014

[11] J. Zhao, W. Dai and K. Wang, "Shunt Active Power Filter and Its Application," *2010 International Conference on Challenges in Environmental Science and Computer Engineering*, Wuhan, 2010.