Simulation of Three Phase Transformer-less Shunt Active Power Filter for Harmonic Compensation in Grid Connected Applications

[1]Palak Hariyaliyan, [2]Mr. Mihir K. Patel, [3]Mr. Kiran A. Patel

[1] *PG Scholar, Electrical Department, KITRC-Kalol, Gujarat, India*
[2, 3] *Assistant Professor, Electrical Department, KITRC-Kalol, Gujarat, India*

ABSTRACT

Shunt active power filter is the preeminent solution against nonlinear loads, current harmonics and power quality problems. APF topologies for harmonic compensation use numerous high-power rating components and are therefore disadvantageous. Hybrid topologies combining low-power rating APF with passive filters are used to reduce the power rating of voltage source inverter. Hybrid APF topologies for high-power rating systems use a transformer with large numbers of passive components. In this Paper a novel four-switch two-leg VSI topology for a three-phase SAPF is proposed for reducing the system cost and size. The proposed topology comprises a two-arm bridge structure, four switches, coupling inductors, and sets of LC PFs. The third leg of the three-phase VSI is removed by eliminating the set of power switching devices, thereby directly connecting the phase with the negative terminals of the dc-link capacitor. The proposed topology enhances the harmonic compensation capability and provides complete reactive power compensation compared with conventional APF topologies. The simulation and analysis of 3-phase transformer less SAPF is carried out using Matlab-Simulink.

Keywords:- SAPF, VSI, APF, LC-Filters, Harmonics, etc.

INTRODUCTION

Most of the power quality issues created in the power system are due to the nonlinear characteristics and fast switching of power electronic equipment. The application of power electronics devices such as arc furnaces, adjustable speed drives, Computer power supplies, etc. are some typical non-linear characteristic loads used in most of the industrial applications. The use of the above power electronic devices in power distribution system gives rise to harmonics and reactive power disturbances. The harmonics and reactive power cause a number of undesirable effects like heating, equipment damage and Electromagnetic Interference effects in the power system. The conventional method to mitigate the harmonics and reactive power compensation is by using passive LC filters.

Over the past few years, the enormous increase in the use of non-linear loads, arises many power quality issues like high current harmonics, voltage distortion and low power factor etc. on electrical grid [1]. Hence the proliferation of non-linear load in system generates harmonic currents injecting into the AC power lines. This distorted supply voltage and current causes malfunction of some protection devices, burning of transformers and motors, overheating of cables. Hence it is most important to install compensating devices for the compensation of harmonic currents and voltages produced due to nonlinear load. Traditionally, passive power filters have been used as a compensating device, to compensate distortion generated by constant non-linear loads. Henceforth, to avoid these drawbacks of active filter, a combined system of passive filter and active filter. Among all the topology of Shunt Active Power Filter (SAPF) system is suitable for compensation of both voltage as well as current harmonics and also for compensation of reactive power. SAPF is also gives better performance for both type of non-linear load such as voltage-type harmonic load and current-type harmonic load.

Voltage-type of harmonic load is defined as a 3-phase full bridge diode rectifier, consists of a dc capacitor of larger value is in parallel with the resistor in DC side. Current-type harmonic load is built up by 3-phase diode bridge rectifier, with inductor in series with the resistor in output side. The performance of Transformer less Shunt Active Power Filter (SAPF) system is developed by choosing a proper reference compensating voltage. This research article employed pq-theory for reference generation process. This theory is applied for the generation of compensating voltage. Performance of proposed Transformer less SAPF with p-q control approach is found feasible for both current-type harmonic load and voltage type harmonic load. This reference voltage is directly depends on load voltages and source currents. Hysteresis voltage controller is used for switching pattern generation because it is easy in computational intensive and fast in implementation.

Modern active filters are superior in filtering performance, smaller in physical size, and more flexible in application, compared to traditional passive filters using capacitors, inductors and/or resistors. However, the active filters are slightly inferior in cost and operating loss, compared to the passive filters, even at present. Active filters intended for power conditioning are also referred to as “active power filters,” “active power line conditioners,” “active power quality conditioners,” “self-commutated SVCs (static var compensators),” etc. The term “power conditioning” used in this has much broader meanings than the term “harmonic filtering.” In other words, the power conditioning is not confined to harmonic filtering, but it contains harmonic damping, harmonic isolation, harmonic termination, reactive-power control for power factor correction and voltage regulation, load balancing, voltage flicker reduction, and/or their combinations.

Active filters can be divided into

- Single-phase active filters and
- Three-phase active filters.

However, single-phase active filters would attract much less attention than three-phase active filters because single-phase versions are limited to low-power applications except for electric traction or rolling stock.

Moreover, the active filters can be classified into

- Series active filters,
- Shunt active filter and
- Hybrid active filters in terms of their circuit configuration.

Most pure active filters can use as their power circuit either a voltage-source pulse width-modulated (PWM) converter equipped with a dc capacitor or a current-source PWM converter equipped with a dc inductor. At present, the voltage-source converter is more favorable than the current source converter in terms of cost, physical size and efficiency. Hybrid active filters consist of single or multiple voltage source PWM converters and passive components such as capacitors, inductors and/or resistors. The hybrid filters are more attractive in harmonic filtering than the pure filters from both viability and economical points of view, particularly for high power applications. Both pure and hybrid active filters, along with traditional passive filters. These pure and hybrid filters have a wide range of spectrum, ranging from those available in the market to those under research and development. They are based on leading-edge power electronics technology that includes power conversion circuits, power semiconductor devices, analog/digital signal processing, voltage/current sensors, and control theory. In addition, active filters act as a powerful bridge between power electronics and power engineering in electrical engineering.

ACTIVE FILTERS FOR POWER CONDITIONING

Pure active filters can be classified into shunt (parallel) active filters and series active filters from their circuit configurations.

Circuit configurations of shunt and series active filters

Figure-1 shows a system configuration of a single-phase or three-phase shunt active filter for harmonic-current filtering of a single-phase or three-phase diode rectifier with a capacitive dc load. This active filter is one of the most fundamental system configurations among various types of pure and hybrid active filters. The dc load may be considered as an A.C motor driven by a voltage-source PWM inverter in many cases. This active filter with or without a transformer is connected in parallel with the harmonic-producing load. The active filter can be controlled on the basis of the following “feed forward” manner:

– The controller detects the instantaneous load current *IL*.

– It extracts the harmonic current *iLh* from the detected load current by means of digital signal processing.

– The active filter draws the compensating current *iAF* (= *iLh*) from the utility supply voltage *vs*., so as to cancel out the harmonic current *iLh*.

Note that the ac inductor *Lac* that is installed at the ac de of the diode rectifier plays an important role in operating the active filter stably and properly.

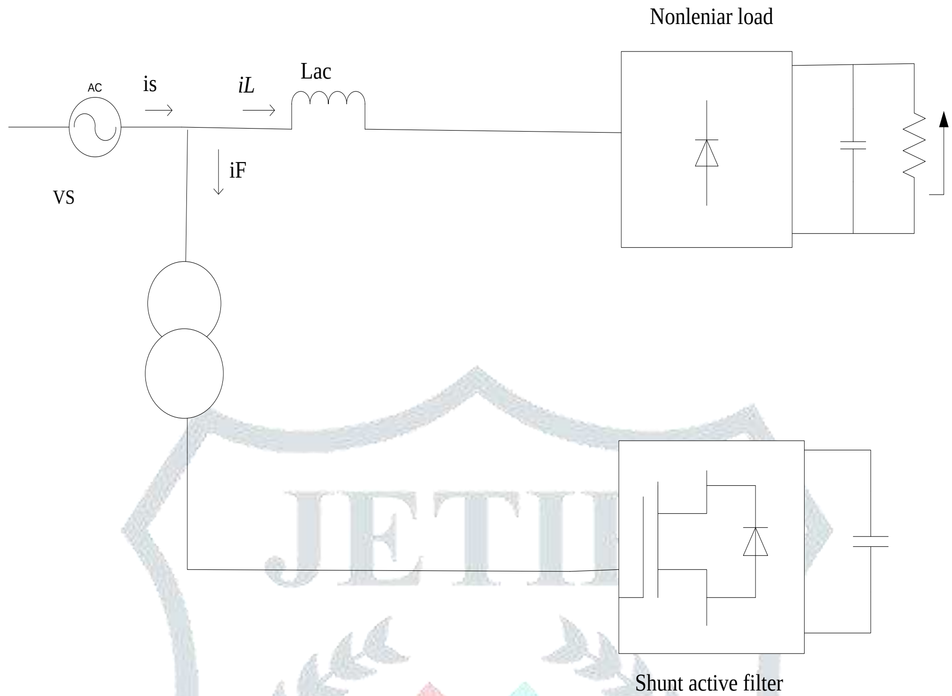

Fig. 1 Single-phase or three-phase shunt active filter

Figure-2 shows a system configuration of a single-phase or three-phase series active filter for harmonic-voltage filtering of a single-phase or three-phase diode rectifier with a capacitive dc load. The series active filter is connected in series with the utility supply voltage through a three-phase transformer or three single-phase transformers. Unlike the shunt active filter, the series active filter is controlled on the basis of the following "feedback" manner:

– The controller detects the instantaneous supply current *is*.

– It extracts the harmonic current *iSh* from the detected supply current by means of digital signal processing,

– The active filter applies the compensating voltage *vAF* (= *KiSh*) across the primary of the transformer. This results in significantly reducing the supply harmonic current *iSh* when the feedback gain *K* is set to be enough high.

The above considerations suggest that "dual" relationships exist in some items between the shunt active filter and the series active filter.

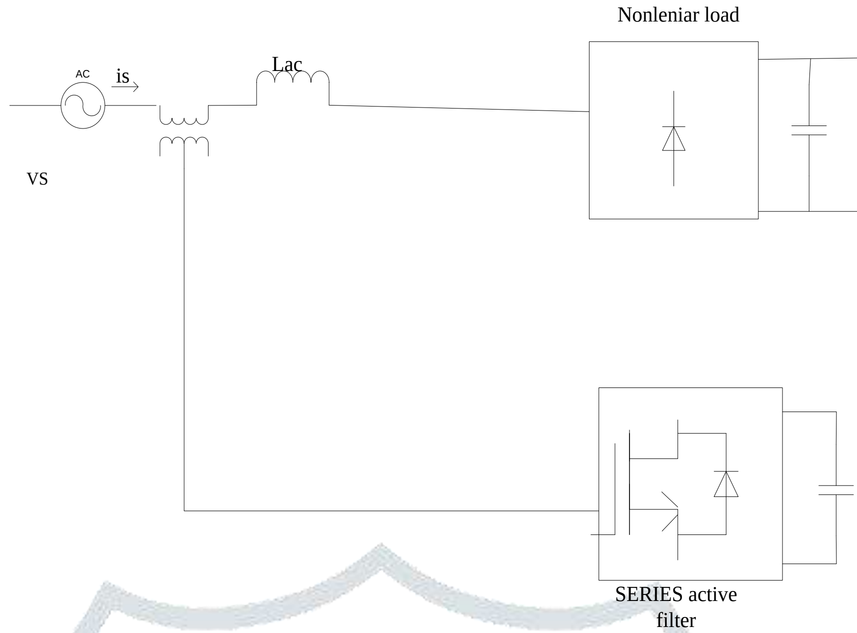

Fig.2 Single-phase or three-phase series active filter

Hybrid active filters for harmonic-current filtering

Circuit configurations

Two types of hybrid active filters for harmonic-current filtering of nonlinear loads were proposed in 1988 and in 1990, respectively. Figure 4.5 and 4.6 show the simplified circuit configurations of the hybrid active filters. The proposal of the two hybrid filters has encouraged power electronics researchers/engineers to do further research on various hybrids active filters, concentrating on their practical use.

The two hybrid filters are based on combinations of an active filter, a three-phase transformer (or three single-phase transformers), and a passive filter consisting of two single tuned filters to the 5th- and 7th-harmonic frequencies and a second-order high-pass filter tuned around the 11th-harmonic frequency.

Although these hybrid filters are slightly different in circuit configuration, they are almost the same in operating principle and filtering performance. Such a combination with the passive filter makes it possible to significantly reduce the rating of the active filter. The task of the active filter is not to compensate for harmonic currents produced by the thyristor rectifier, but to achieve "harmonic isolation" between the supply and the load. As a result, no harmonic resonance occurs, and no harmonic current flows in the supply.

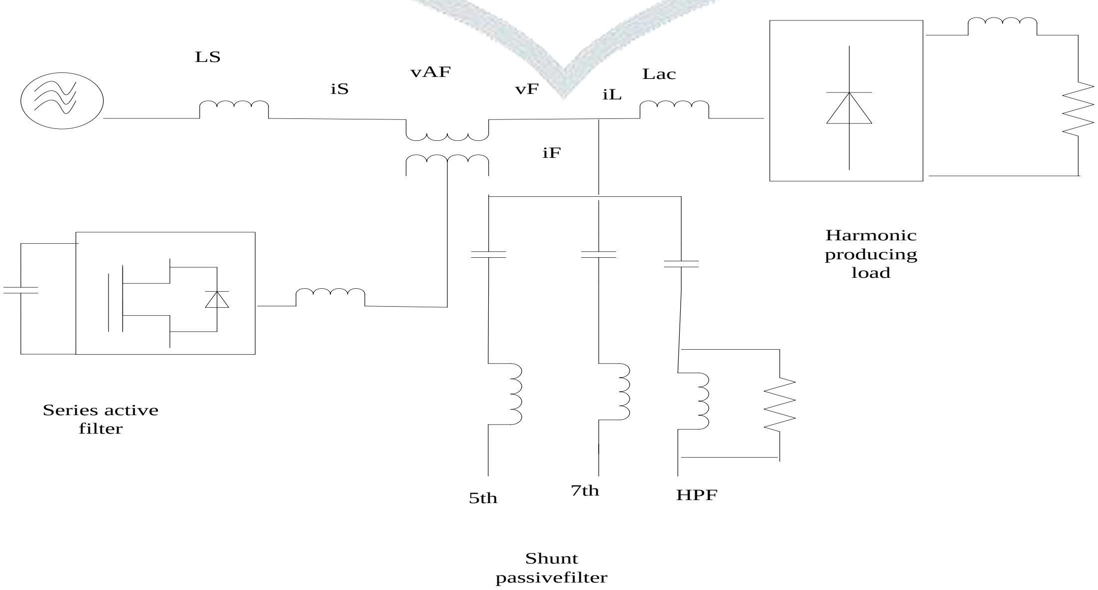

Fig.3 Combination of a series active filter and a shunt passive filter

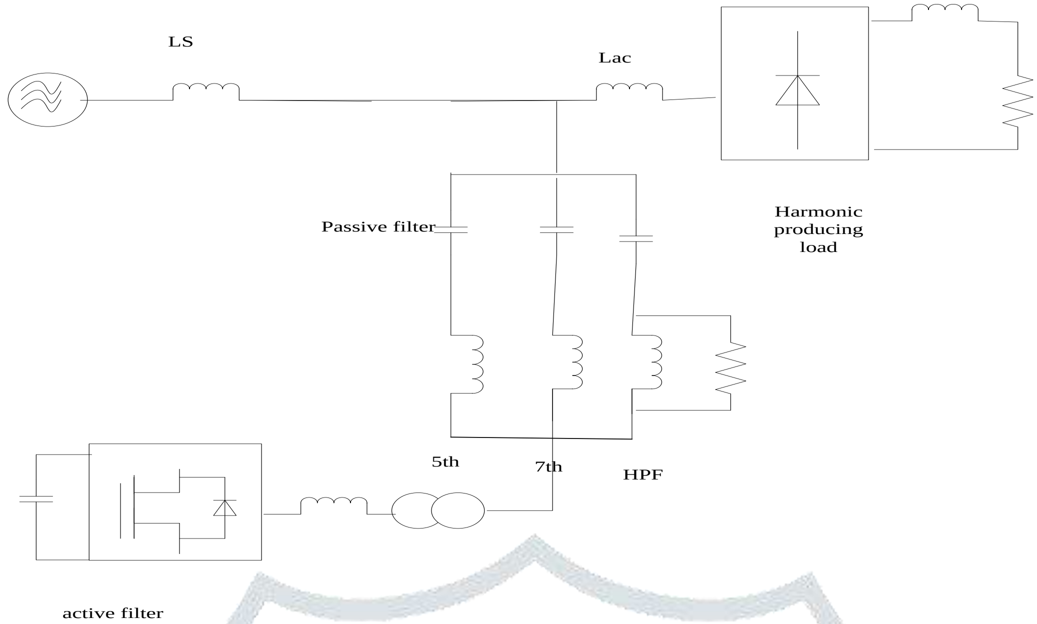

Fig.4. Series connection of an active filter and a passive filter

PROPOSED TRANSFORMER LESS SAPF

A typical APF consists of a voltage source inverter (VSI) of a three-leg bridge structure with a dc-link capacitor. Conventional APF topologies require a matching transformer and a large number of active switching devices, such as the insulated gate bipolar transistor (IGBT); thus, these topologies are disadvantageous [4]. These considerations result in heavy weight and costly system and are therefore undesirable. A transformer-less three-phase pure SAPF is integrated with diode rectifier nonlinear load. The SAPF is connected through the coupling inductor at the point of common coupling (PCC) in the shunt position with the power distribution system. This topology is composed of a six-switch three-leg full-bridge VSI with a dc-link capacitor and coupling inductors. The designed ac inductors are implemented to shape the input current and compensate the current harmonics. A transformer-less HAPF for overcoming the limitation of high-power rating inverters is presented in [8]. This topology consists of a three-phase six-switch bridge inverter connected in series with a passive filter (PF). The low-power rating inverter compensates the current harmonics at the PCC flowing into the utility source and improves the filtering characteristic of the series LC PF. On the other hand, a reduced switch count transformer-less HAPF is illustrated in [9, 10]. The new design uses four switches to test the two-leg bridge inverter by connecting the removed leg with the negative terminal of the dc-bus.

Besides reducing cost, it offers less complex structure, high reliable filtering compensation, and controlled balanced dc-link voltage. In the present Paper, a transformer-less SAPF topology based on a four-switch two-leg structure is presented. Unlike other existing topologies, the new circuit is derived from the six-switch full-bridge inverter. The new model enhances harmonic filtering and reactive power compensation comparable to conventional full-bridge topologies.

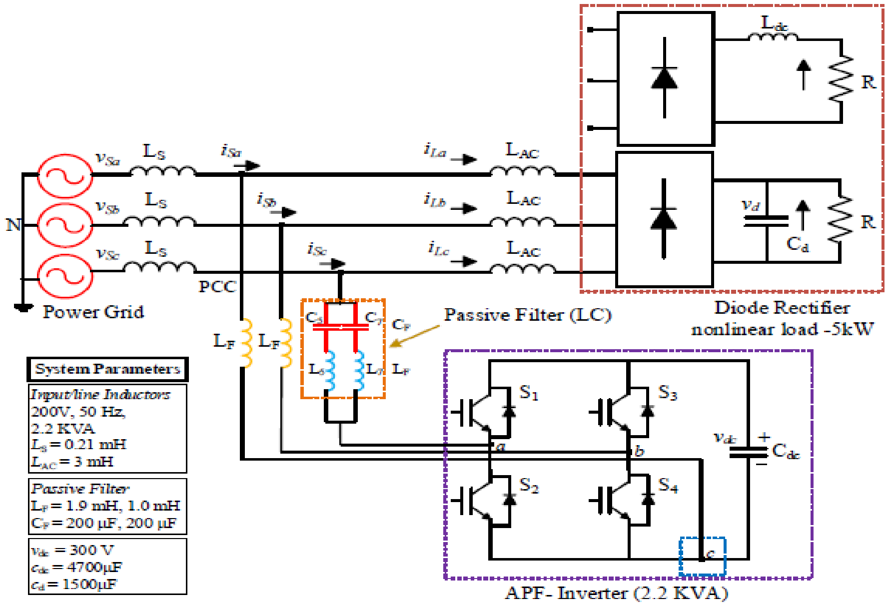

Fig. 5 Proposed transformer less APF system

The proposed design mainly aims to provide superior compensation capability and less complex structure without increasing the number of power switching devices for three-phase applications. The series ac-coupling inductors overcome the fixed reactive power compensation by limiting the use of PFs. The new topology provides superior overall performance as compare to the dc-bus midpoint connection configuration in terms of harmonic compensation capability owing to the balanced current and voltage.

Therefore, less complex structure and straightforward connection between the transmission line and the terminal of the dc-bus reduce the constraint of voltage balancing across the dc-link capacitor. This configuration also eliminates the need of extra controller and transformer in between the LC PF and the filter inverter for preventing magnetic saturation. As a result, the design configuration presents less cost, volumetric size, and lightweight structure. In this Paper, a novel four-switch two-leg VSI topology for a three-phase SAPF is proposed for reducing the system cost and size. The proposed SAPF is composed of the three-phase two-leg bridge version of the four-switch inverter, as shown in Fig. 5.7. It comprises a two-arm bridge structure, four switches, coupling inductors and sets of LC PFs. The adopted modulation strategy in this study is the sinusoidal PWM (SPWM) for a proper switching scheme. The carrier signal is compared with the comparators with single modification to pattern the reference signals. The proposed system mainly aims to provide superior compensation capability and less complex structure without increasing the number of power switching devices for three-phase applications. The series ac coupling inductors overcome the fixed reactive power compensation by the LC PF, the two ac inductors are coupled to the two phases of VSI. The reduced leg terminal is linked through the sets of LC filters, including the inductor and capacitor set. In the reduced leg, the direct connection between the utility power line and the dc-link terminal divides the dc voltage and shifts it to the output voltage of the power converter. Therefore, the PFs are used to reduce the power and voltage requirement against the utility fundamental component at the output of the inverter (*phase c*). In addition, the inductors are used as a filter against the switching ripple generated from the switching converter. The capacitor of the PF provides the fundamental reactive power demand to the load and reduces the dc current circulation and also dc voltage.

SIMULATION AND RESULTS

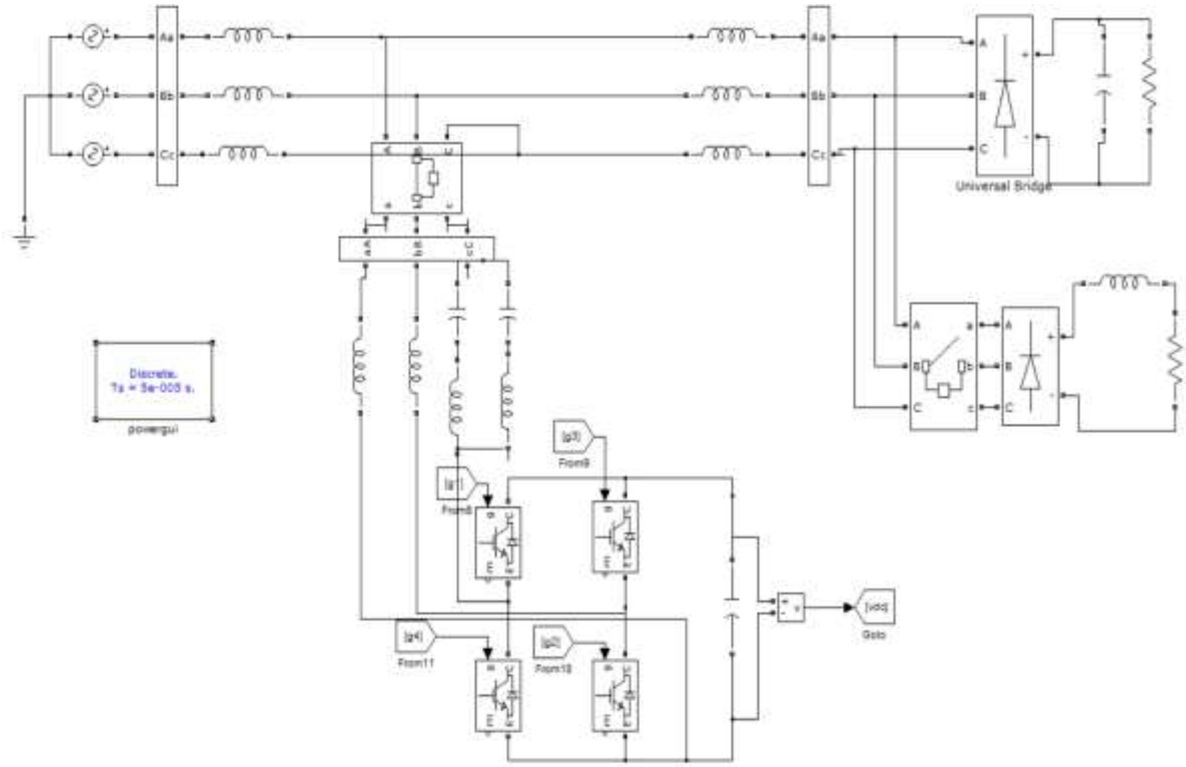

Fig 6- Matlab simulation of Transformer less SAPF

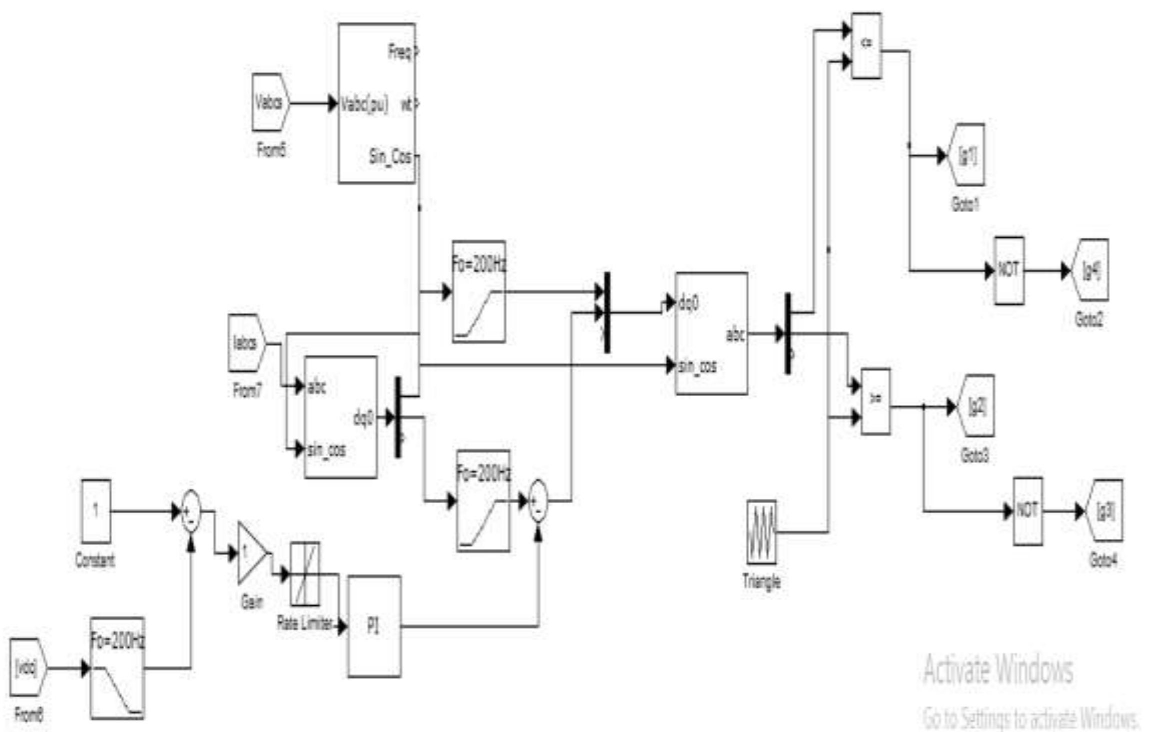

Fig 7- Matlab simulation of Transformer less SAPF control system

SIMULATION RESULTS OF TRANSFORMERLESS SAPF

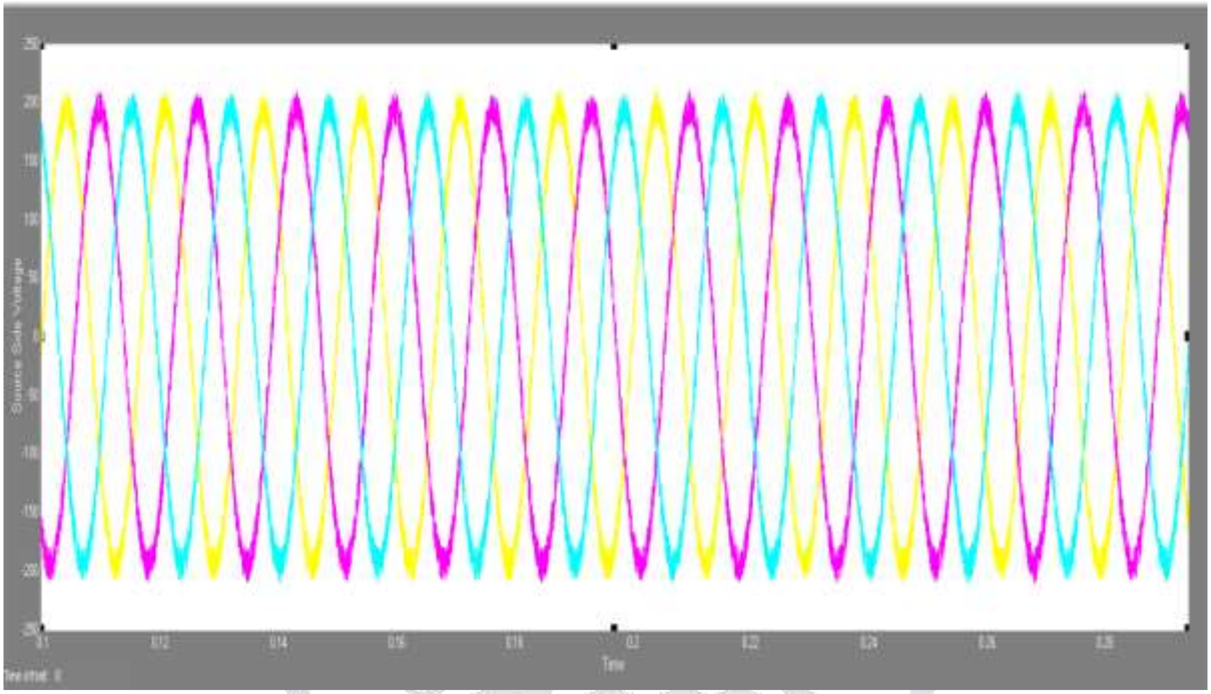

Fig.8- Source Side Voltage Waveform

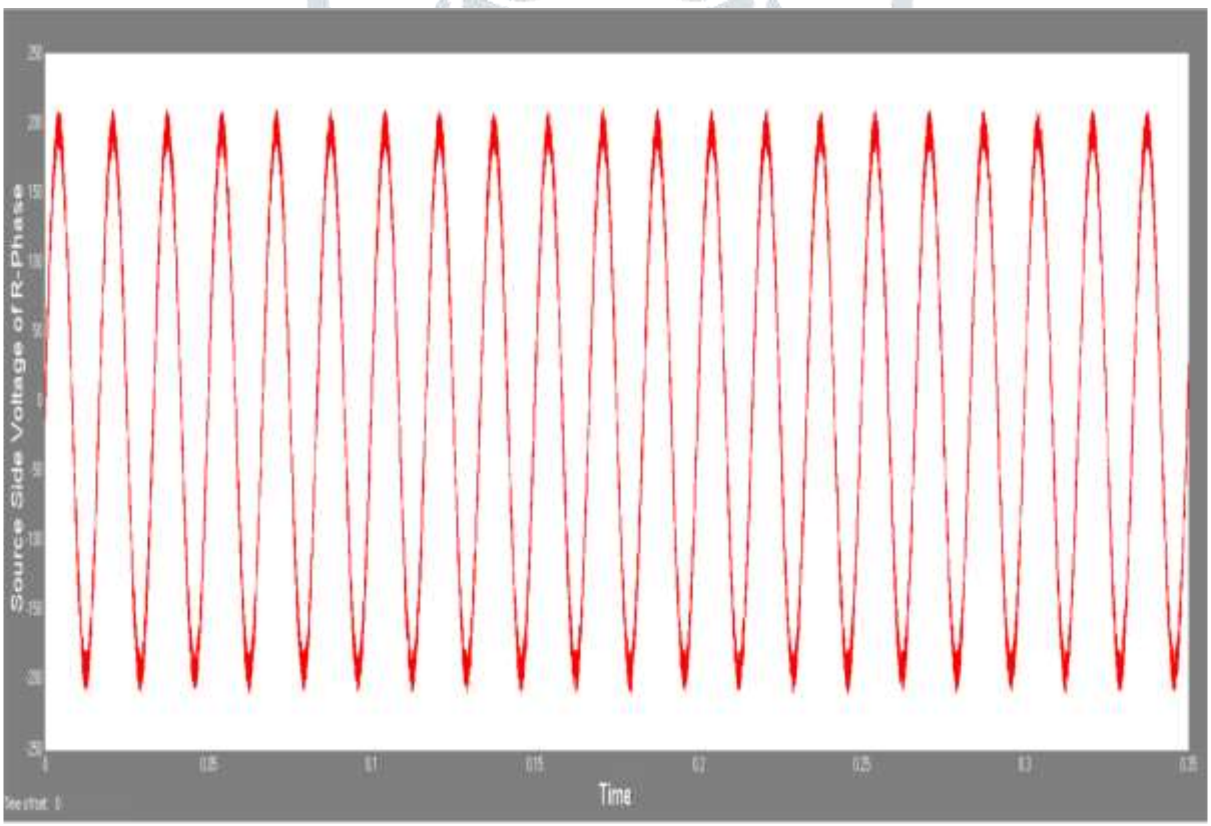

Fig.9- Source Side Voltage Waveform Phase-R

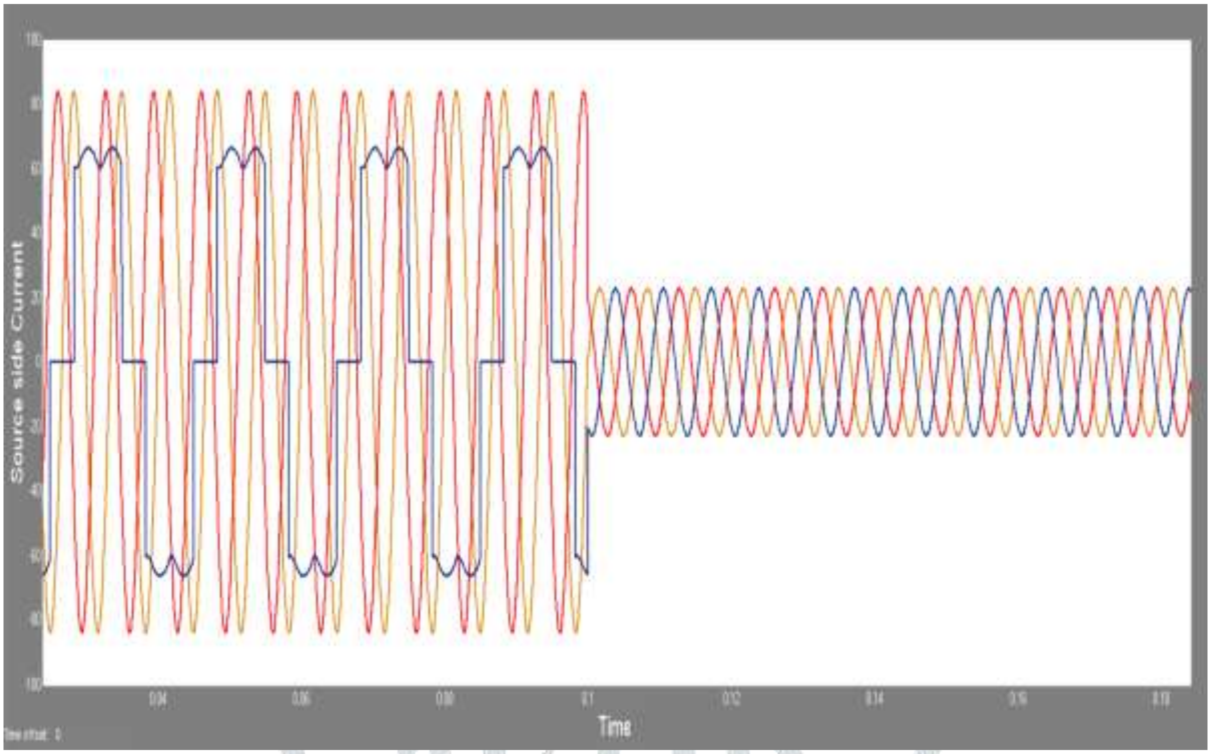

Fig.10- Source Side Current Waveform

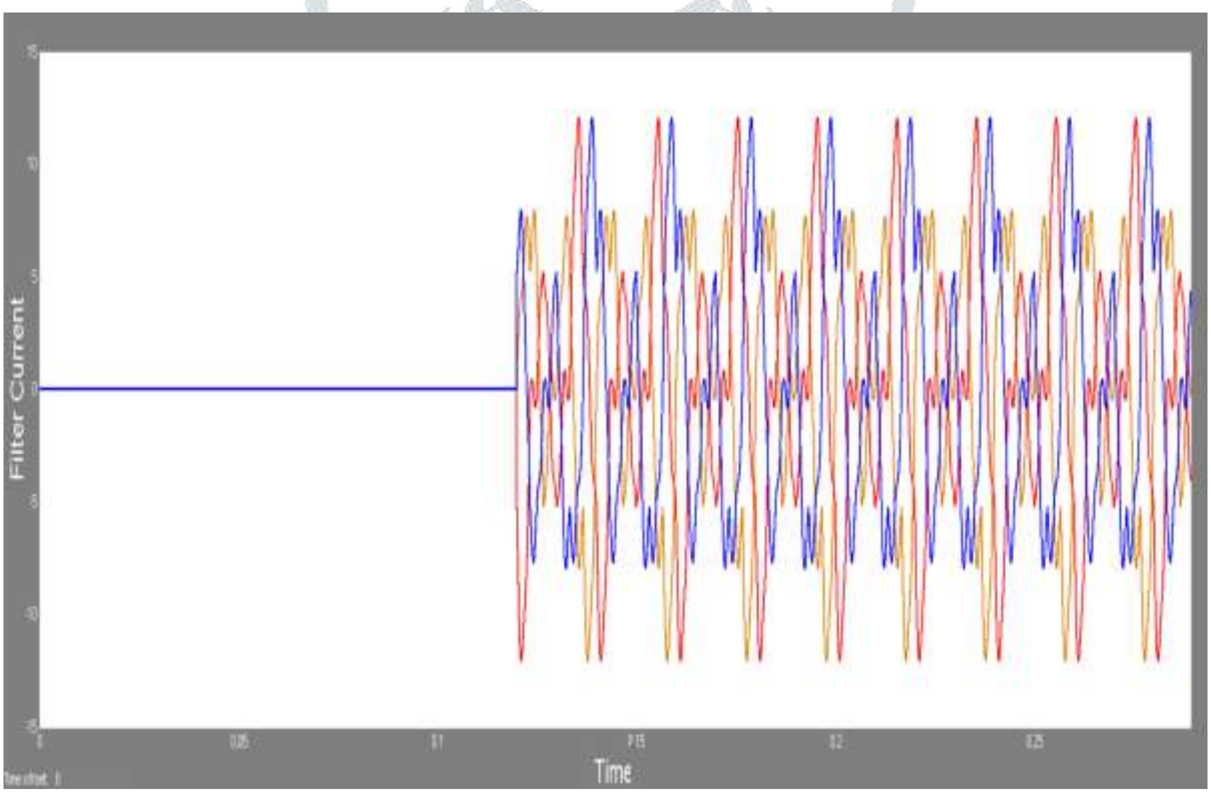

Fig.11- Filter Side Current Waveform

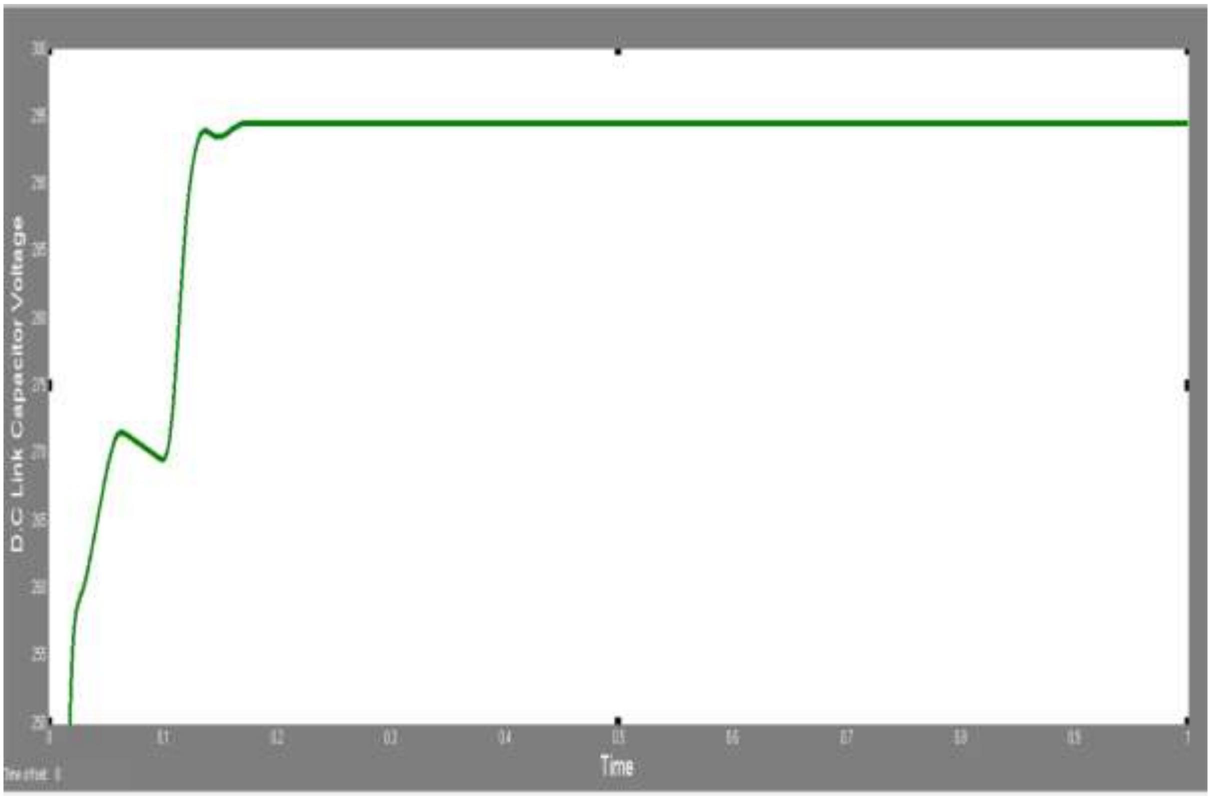

Fig.12- Common D.C Link Capacitor Voltage Waveform

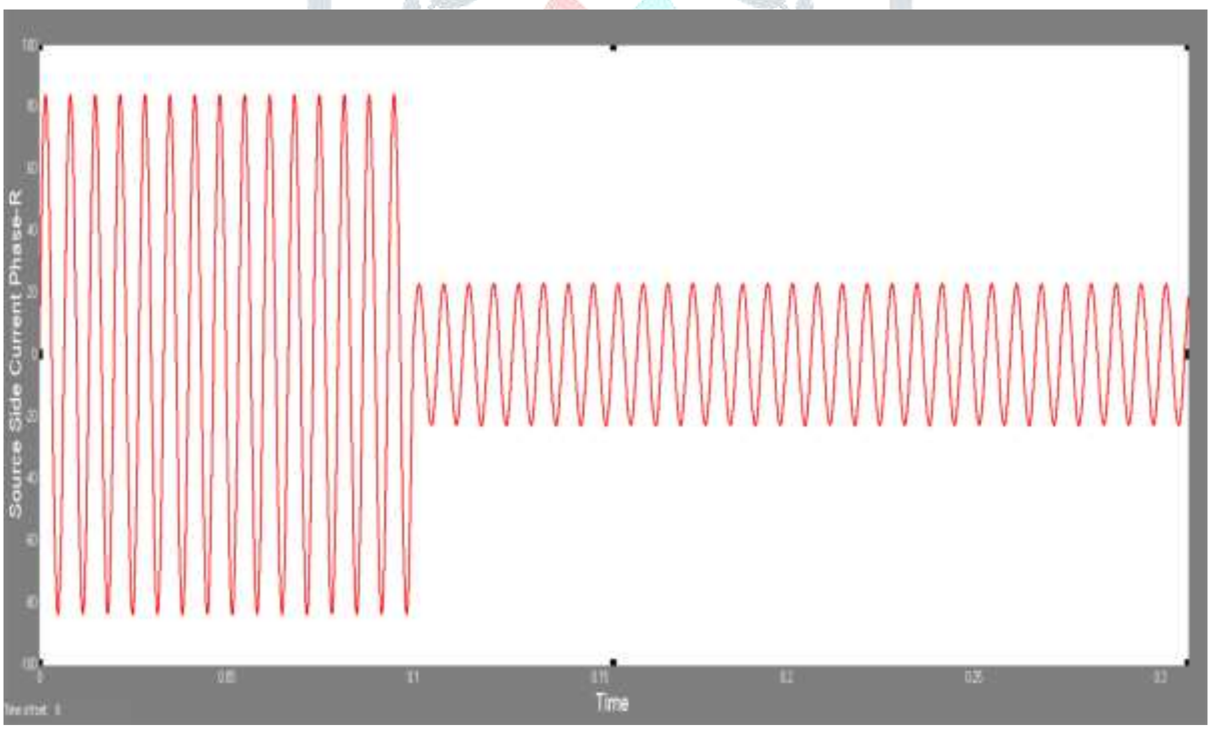

Fig.13- Source Side Current Waveform Phase-R

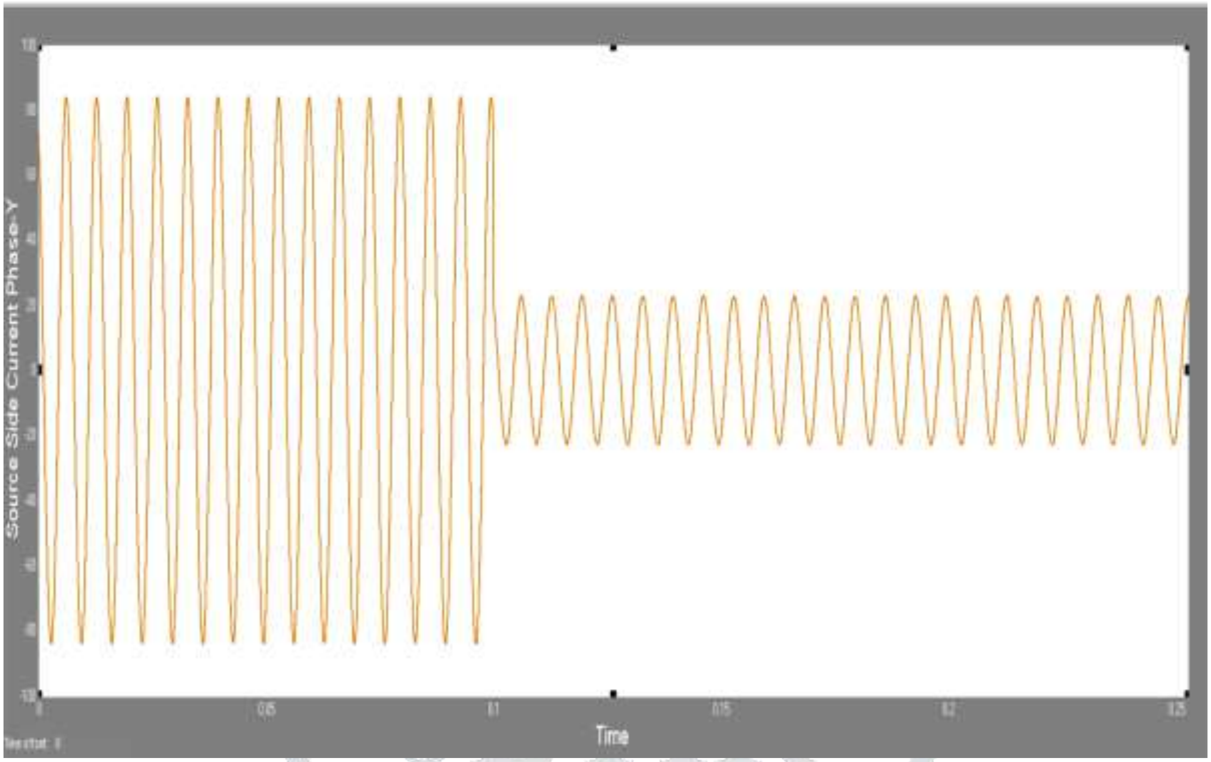

Fig.14- Source Side Current Waveform Phase-Y

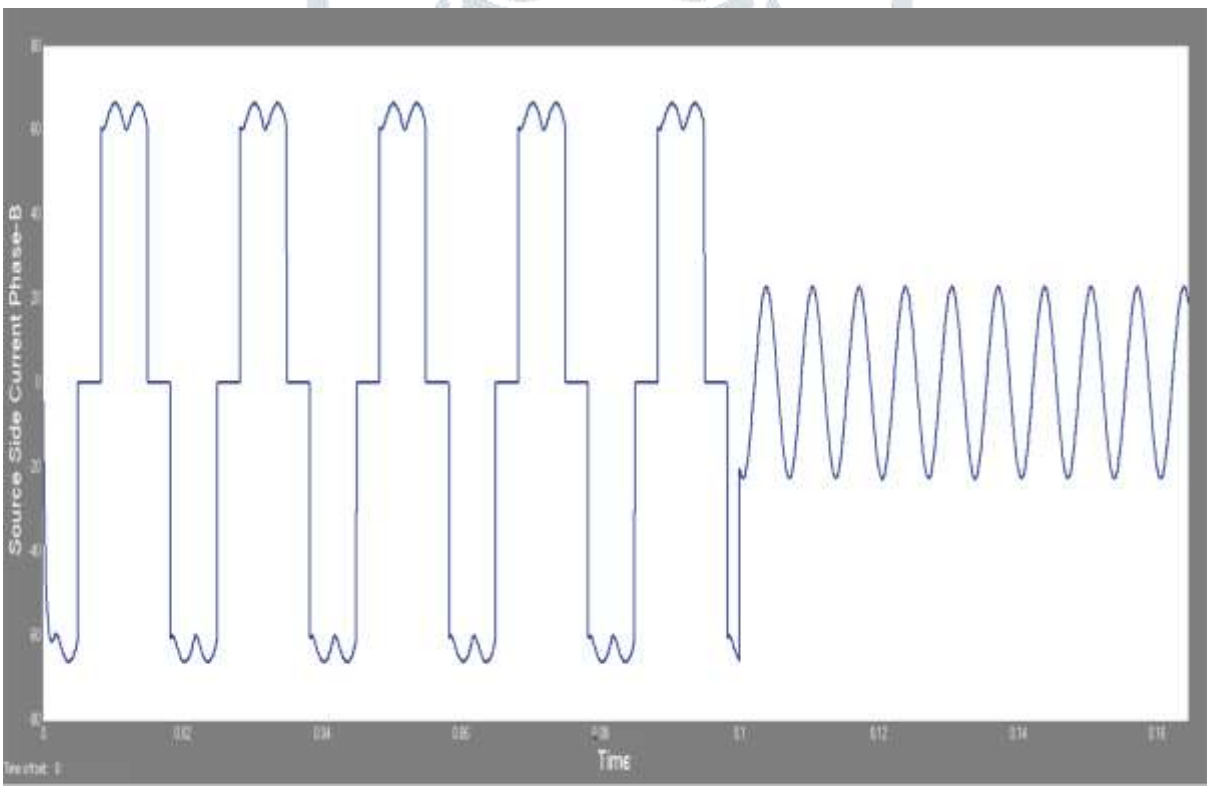

Fig.15- Source Side Current Waveform Phase-B

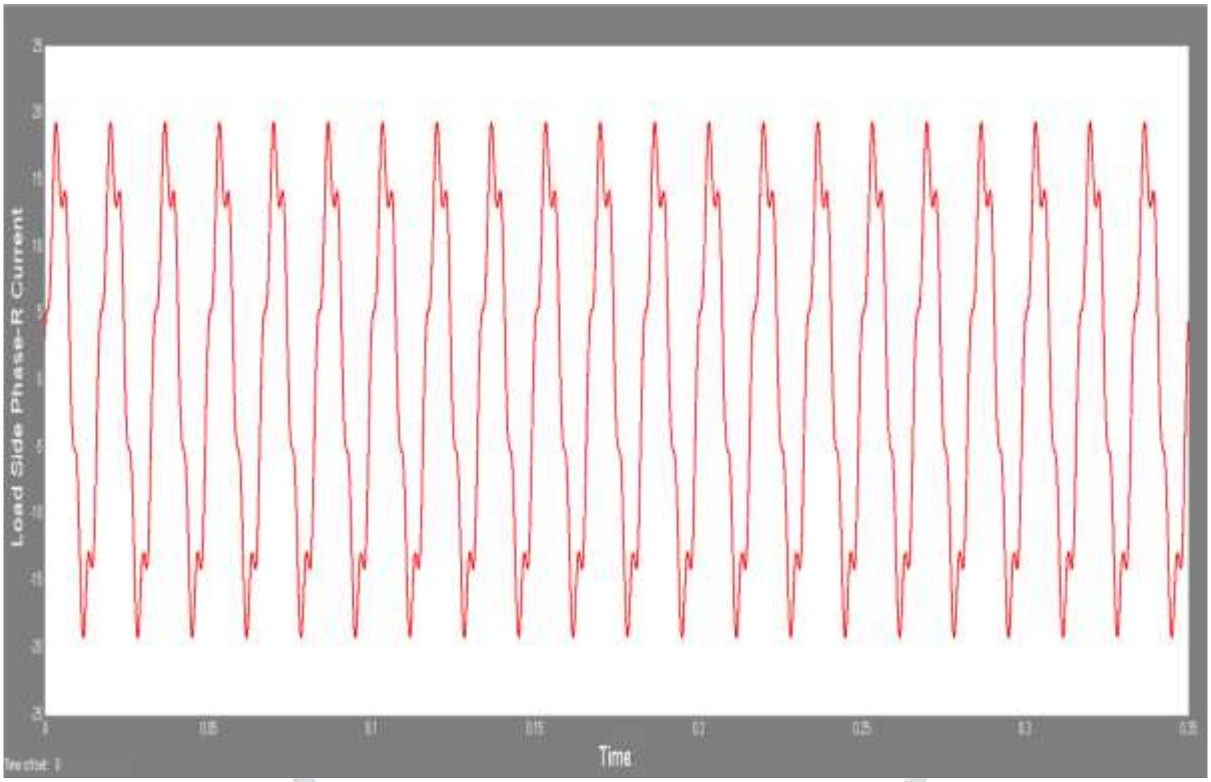

Fig.16- Load Side Current Waveform Phase-R

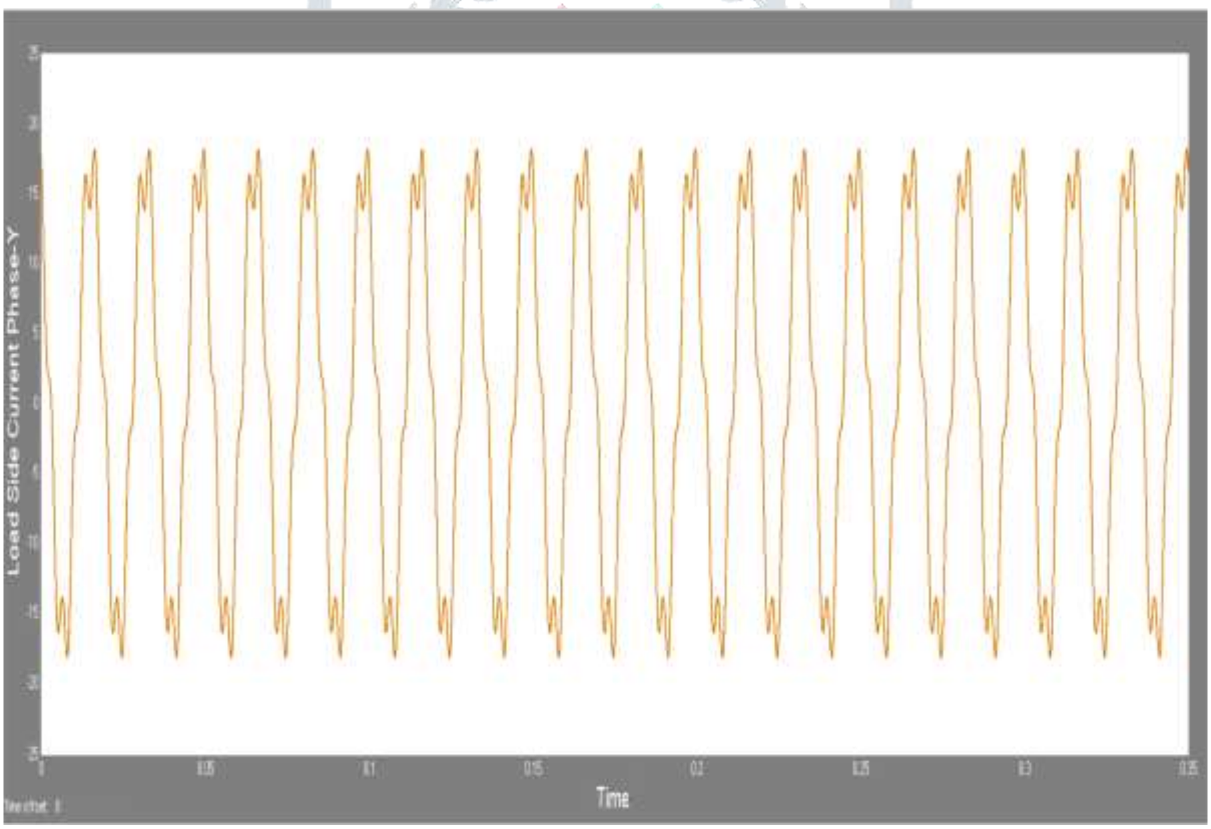

Fig.17- Load Side Current Waveform Phase-Y

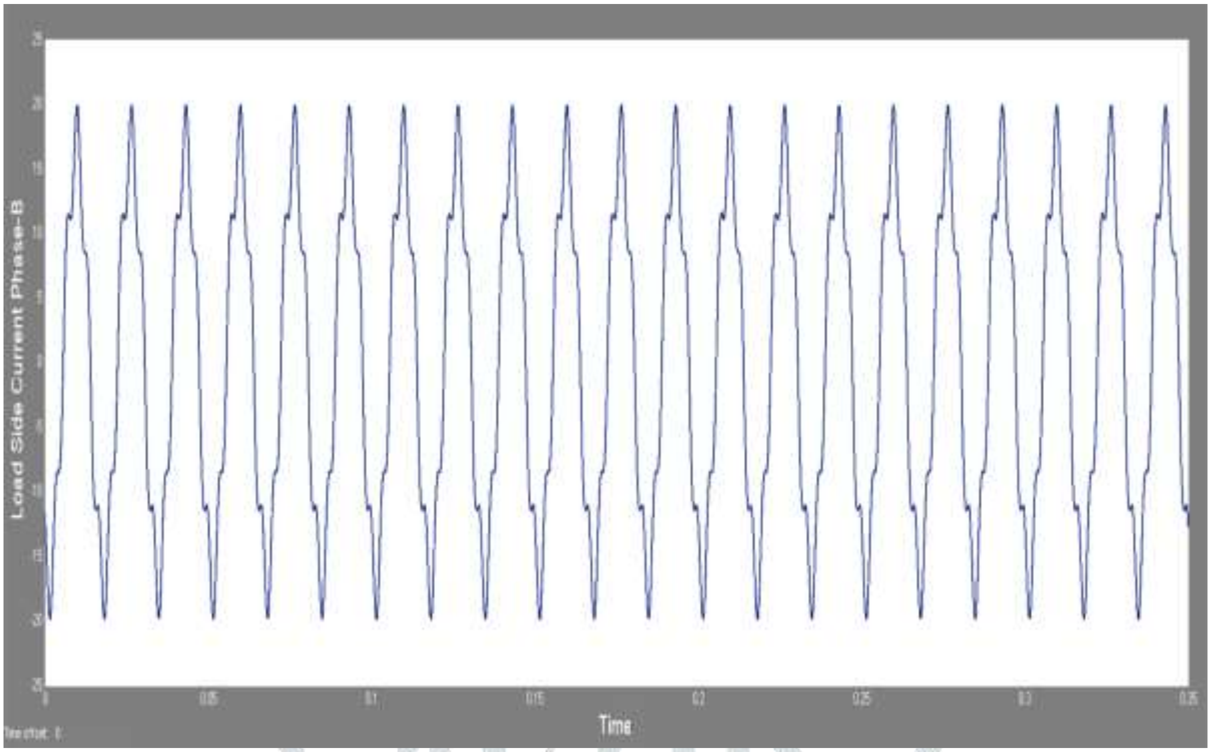

Fig.18- Load Side Current Waveform Phase-B

MATLAB SIMULATION OF SAPF USING FUZZY LOGIC CONTROL

To verify the effectiveness of SAPF with the proposed controller, simulation studies are realized at MATLAB/Simulink environment. Electrical parameters of SAPF used in simulation studies are given this section. Two scenarios for steady state and transient state conditions are considered in simulation studies and Matlab/Simulink Model of SAPF is given in Fig.19. In these scenarios, the same conditions are provided for Fuzzy Logic Control. The first scenario is carried out under fixed load in order to test the performance of SAPF structure with two controllers. Waveform obtained from both controllers is given in Figs. below.

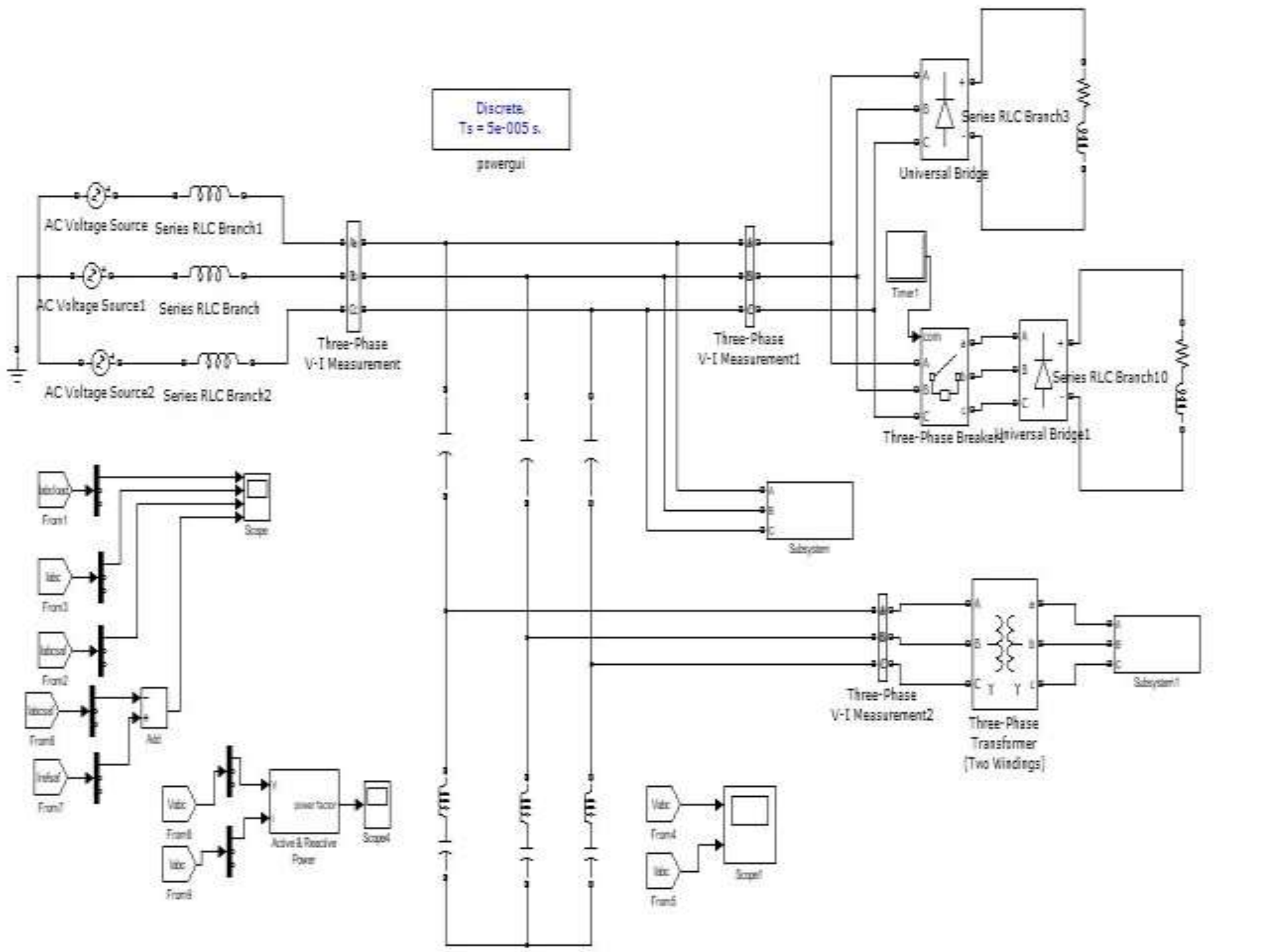

Fig.19- Proposed system of SAPF using FLC controlling

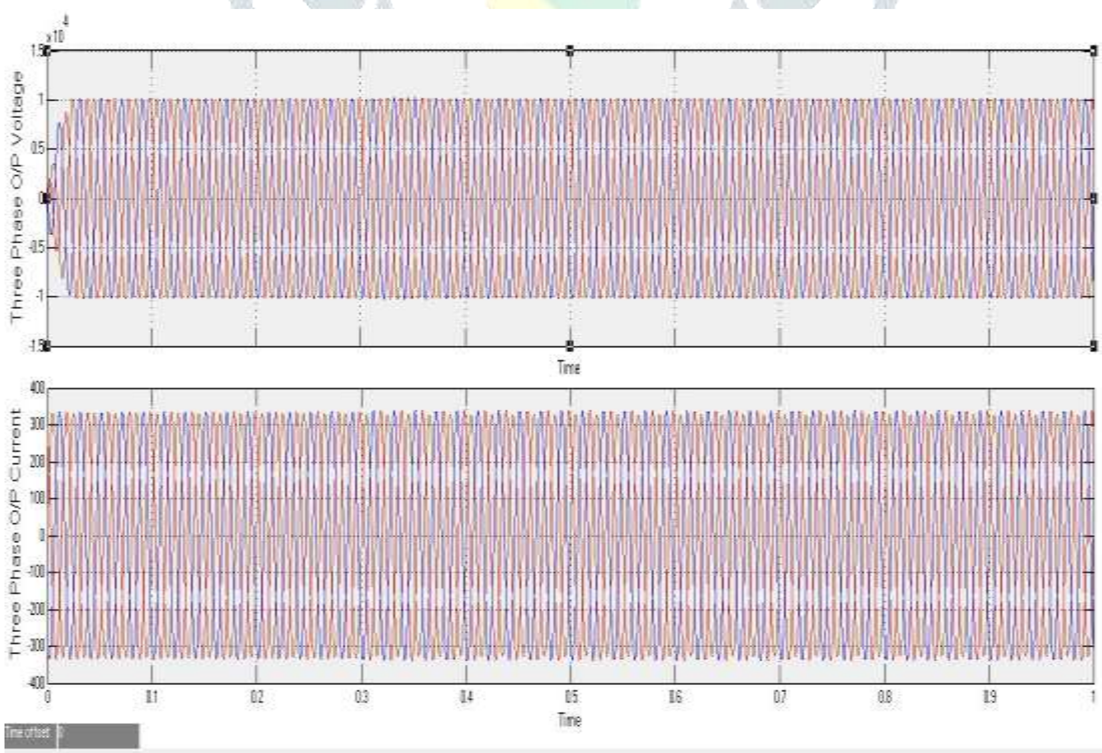

Fig.20- Three phase output voltage and current waveform

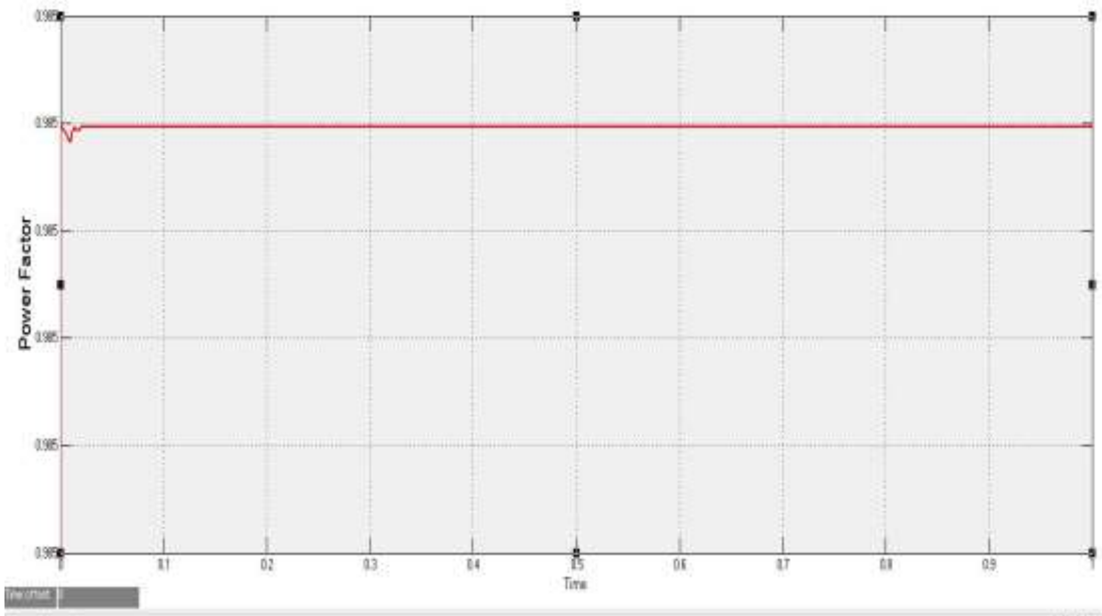

Fig.21- Power factor improvement

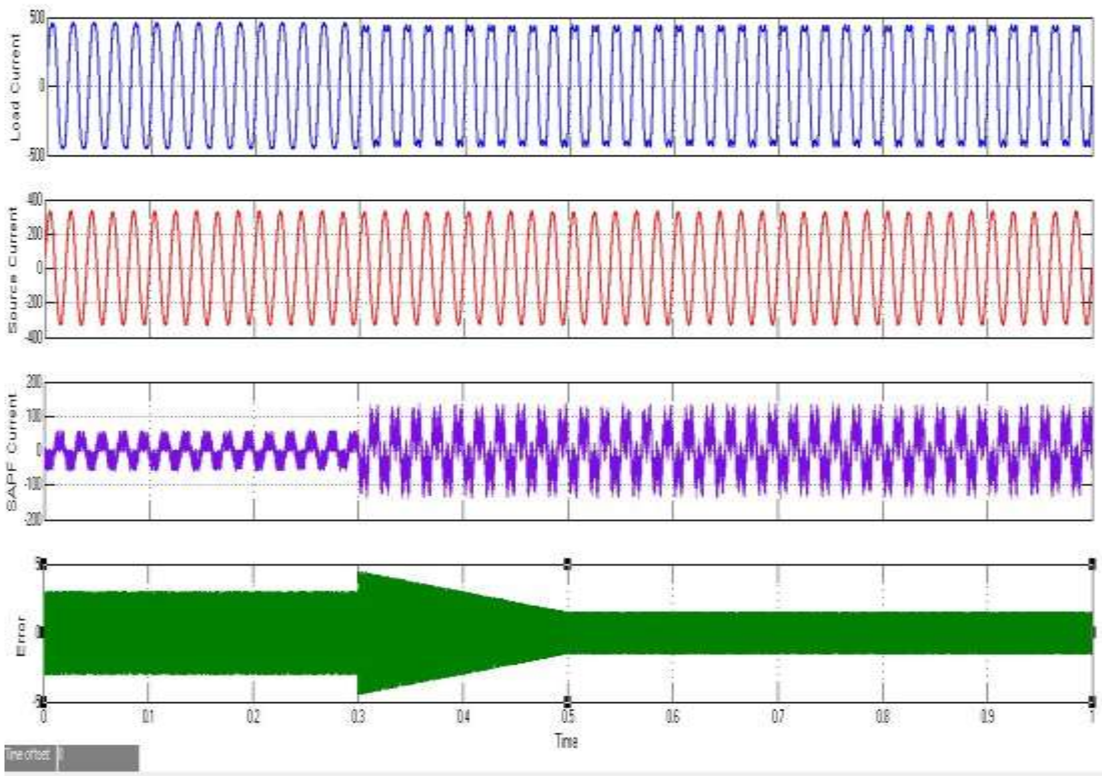

Fig.22- SAPF different current controlling signals

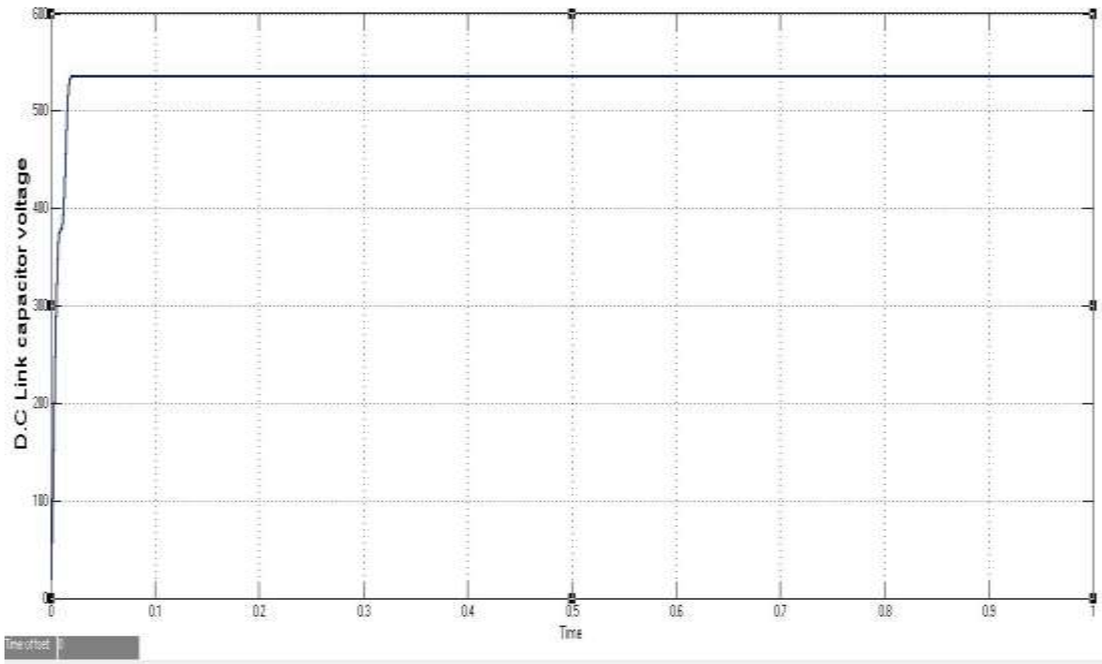

Fig.23- D.C link capacitor voltage

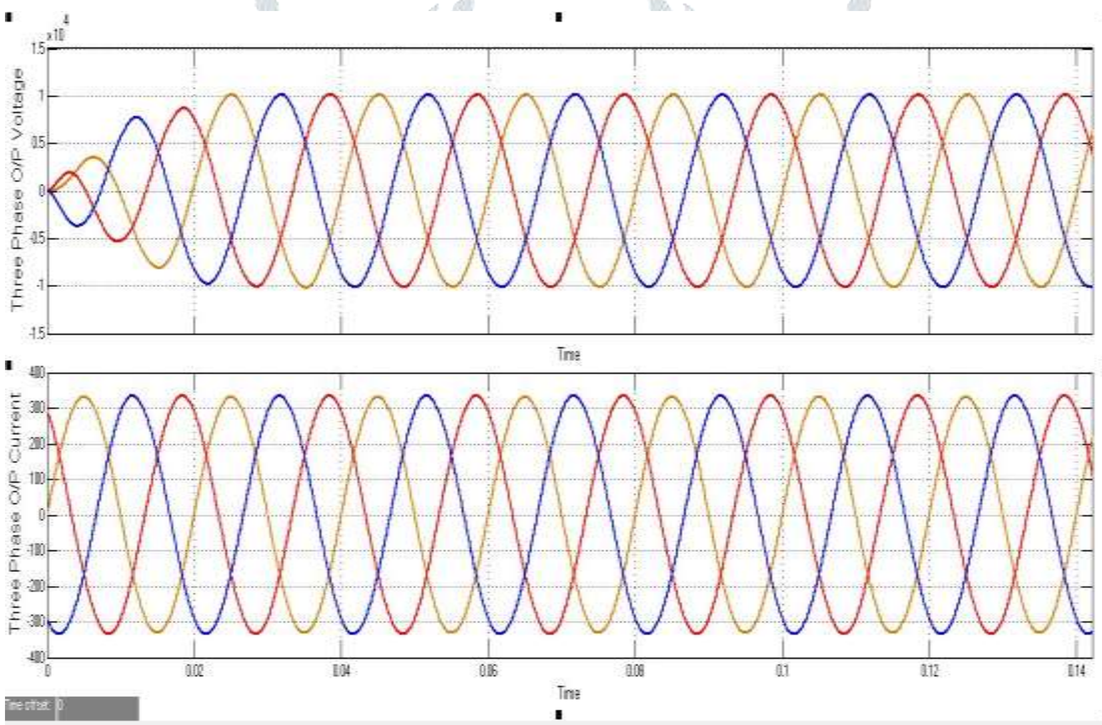

Fig.24- three phase output voltage and current improvement

CONCLUSION

The effectiveness of the proposed SAF to provide harmonic compensation has also been observed with but balanced supply system. Series active power filters are intended mainly as a voltage regulator and acts as a harmonic isolator between the nonlinear load and the utility system. In addition, it has capability of voltage imbalance compensation, voltage regulation and harmonic compensation at the utility consumer point of common coupling. In detail study about our topic we can conclude that the increased use of static power converter and static power capacitors can set up system condition to cause power quality problems like harmonics in power system. In detail study about our topic we can conclude that the increased use of static power converter and static power capacitors can set up system condition to cause power quality problems like harmonics in power system. The proposed filter can compensate source currents and also adjust itself to compensate for variations in non-linear load currents, maintain dc link voltage at steady state and helps in the correction of power factor of the supply side adjacent to unity.

REFERENCES

1. Wajahat Ullah Khan Tareen, and Saad Mekhielf , “Three-Phase Transformer less Shunt Active Power Filter with Reduced Switch Count for Harmonic Compensation in Grid-Connected Applications ” IEEE Transactions on Power Electronics , 2017 IEEE.
2. Medha Pandey, Anirban Sinha Ray and Avik Bhattacharya, “Transformerless Dual Inverter Based Series Injected Shunt Active Power Filter”, 3rd International Conference on Advances in Electrical Engineering 17-19 December, 2015, Dhaka, Bangladesh, 2015 IEEE
3. W. U. Tareen, S. Mekhilef, M. Seyedmahmoudian, and B. Horan, "Active power filter (APF) for mitigation of power quality issues in grid integration of wind and photovoltaic energy conversion system," *Renewable and Sustainable Energy Reviews,* vol. 70, pp. 635-655, 4// 2017.
4. J. Solanki, N. Fröhleke, and J. Böcker, "Implementation of Hybrid Filter for 12-Pulse Thyristor Rectifier Supplying High-Current Variable-Voltage DC Load," *IEEE Transactions on Industrial Electronics,* vol. 62, pp. 4691-4701, 2015.
5. L. Asiminoaei, C. Lascu, F. Blaabjerg, and I. Boldea, "Performance Improvement of Shunt Active Power Filter With Dual Parallel Topology," *IEEE Transactions on Power Electronics,* vol. 22, pp. 247-259, 2007.
6. T. L. Lee and S. H. Hu, "An Active Filter With Resonant Current Control to Suppress Harmonic Resonance in a Distribution Power System," *IEEE Journal of Emerging and Selected Topics in Power Electronics,* vol. 4, pp. 198-209, 2016.
7. S. Rahmani, A. Hamadi, K. Al-Haddad, and L. A. Dessaint, "A Combination of Shunt Hybrid Power Filter and Thyristor-Controlled Reactor for Power Quality," *IEEE Transactions on Industrial Electronics,* vol. 61, pp. 2152-2164, 2014.
8. R. Inzunza and H. Akagi, "A 6.6-kV transformerless shunt hybrid active filter for installation on a power distribution system," *IEEE Transactions on Power Electronics,* vol. 20, pp. 893-900, 2005.
9. L. R. Limongi, L. R. d. S. Filho, L. G. B. Genu, F. Bradaschia, and M. C. Cavalcanti, "Transformerless Hybrid Power Filter Based on a Six-Switch Two-Leg Inverter for Improved Harmonic Compensation Performance," *IEEE Transactions on Industrial Electronics,* vol. 62, pp. 40-51, 2015.
10. J. C. Wu, H. L. Jou, Y. T. Feng, W. P. Hsu, M. S. Huang, and W. J. Hou, "Novel Circuit Topology for Three-Phase Active Power Filter," *IEEE Transactions on Power Delivery,* vol. 22, pp. 444-449, 2007.
11. Z. Luo, M. Su, Y. Sun, W. Zhang, and Z. Lin, "Analysis and control of a reduced switch hybrid active power filter," *IET Power Electronics,* vol. 9, pp. 1416-1425, 2016.
12. R. L. d. A. Ribeiro, T. d. O. A. Rocha, R. M. d. Sousa, E. C. d. Santos, and A. M. N. Lima, "A Robust DC-Link Voltage Control Strategy to Enhance the Performance of Shunt Active Power Filters Without Harmonic Detection Schemes," *IEEE Transactions on Industrial Electronics,* vol. 62, pp. 803-813, 2015.