

Simulation & Performance Analysis of Series APF for Voltage Harmonics Mitigation

Mrs. Ritika Chaudhary^{1*}, Dr. Mayank Mathur²

¹ Ph.D Scholar, Electrical Department, UOT, Jaipur, Rajasthan, India

² Professor, UOT, Jaipur, Rajasthan, India

Abstract - Recently, the use of non-linear loads has expanded and covered different fields of electricity. Bridge rectifiers, line converters, and switching mode power supplies are the most important used non-linear loads. Non-linear loads inject harmonic currents into the electrical grid. The grid currents and voltages become non-sinusoidal having different types of disturbances. Active power filters have been introduced as efficient devices for power quality improvement as like as reactive power compensation. In this work, harmonic problem are introduced and discussed. The different harmonic solutions are presented and discussed. The use of Series Active Power Filter for filtering the harmonics of the voltage is also discussed. The passive filters are used also for elimination of harmonic currents and voltages. The use of hybrid filters composed of parallel active power filter with passive filters, or series active power filter with passive filters is applied and studied. Different studied filters and topologies are implemented in MATLAB\Simulink. Simulation results are tabulated and discussed.

Keywords - Series APF, Harmonics, THD, Simulink, etc.

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INTRODUCTION

The increasing use of nonlinear loads which use switching elements has caused many power quality problems. The harmonic emission is increasing noticeably with the development of power electronics devices. The spread of harmonics into power grid causes many problems for the users of these power grids. It affects the normal function of the devices connected to the grid. Harmonic currents can cause the creation of harmonic voltages whose spread can be dangerous for the different users of the electrical power. Control systems, protection circuits, communication systems, and biomedical devices are the most affected devices by harmonic pollution. Different standards and regulations have been adopted by the international electrical committees like IEC and IEEE limiting the harmonic emission of the loads. Problems of system voltage unbalances and sudden changes in the grid voltages are an important issue in electrical engineering.

Many devices are designed to work under limited ranges of voltage and frequency. The sudden changes in the voltage can either affect the function

of the devices or even stop their function permanently. For that reason, the use of different types of voltage regulators and protection devices is an important precaution. These regulators can protect the connected devices from voltage variations by keeping the load side of the grid at a fixed voltage level. The main cause of voltage variations in power systems is the turning on and off of the electrical motors. These motors are absorbing high currents in the starting phase of function for a duration of many seconds. The simultaneous starting of many motors in the same time can cause huge variations in the grid voltage.

Active power filters are divided into different categories; some are used for voltage regulation and voltage harmonics mitigation. Other active filters can be used for filtering the currents and eliminating their harmonics. The third type can be used for simultaneous voltage regulation and harmonic currents cancelling. Series active power filters are used for voltage regulation. Shunt APF was proposed for current harmonics and reactive power compensation. The Unified Power Quality Filter or Conditioner combines the two types

Shunt and Series APF in one device responsible for the simultaneous compensation of voltage, current harmonics and reactive power. Different combinations of APFs with passive filters have been also used and proposed in the literary in the so-called Hybrid APFs (HAPFs). The combination between the simple and the modern in one HAPF has the aim of amelioration of different types of APF compensation performance, also the minimization of cost and complexity of compensation systems. It is considered to combine the advantages of old passive filter and the new APFs and reject the drawbacks related to each of them when used individually. Although there are different types of APF, the Shunt APF is still the most famous and used type APF. The main function of Shunt Active Power Filter is to cancel harmonic currents occurring in power grids. The principle of SAPF is to generate harmonic currents equal in magnitude and opposite in phase to those harmonics that circulate in the grid. The non-linear loads absorb non-sinusoidal currents from the grid.

LITERATURE SURVEY

Active power filters and power quality issues have been widely discussed in literary. Many aspects of active and passive filtering have been covered with a lot of researches. Some of the researchers have covered the analytical study of the power quality problems. Others have concentrated on the quantitative description of harmonics and their effects on the power losses and consumers. Other researches were pointed toward the study of different possibilities offered to treat the power quality problems. In other researches, the different control methods of active power filters were discussed and improved. While others discussed the structure of active filters itself and proposed new topologies for the different types of active filters. Concerning the topologies of active filters, the two level and three level power inverters were the main topologies used for active filtering. Multilevel filters were also discussed in literary but with less concentration due to their complex structure and difficulties of their control.

Control methods of active filters based on PQ theory and DQ theory were the most discussed methods. The use of PI controllers or fuzzy logic controllers were discussed widely also. Fuzzy logic control and sliding mode current control with sine multiplication theory was presented by (Sharmeela et al., 2007). Instantaneous active and reactive power method with hysteresis control was discussed in (Pei Ling, 2004). The function of APF with DC power generation was

proposed in (Cichowlas, 2004). In (Prusty, 2011), fuzzy logic and hysteresis control based on synchronous reference mode function was presented and discussed. In (Cheng, 2007), the use of PQ, synchronous reference method and sine multiplication theory was discussed. PI and hysteresis controllers were also used in this research. Sine multiplication theory with IP current controller was presented in (Chaoui et al., 2006). Fuzzy logic controller with sine multiplication method in single phase Active Power Filter has been presented in (Colak et al., 2010). In (Fei, Jingrong, and Yu, 2010), an adaptive fuzzy low pass filter for harmonic extraction has been proposed with shunt active power filter. Three phase active power filter based on DQ method and space vector pulse width modulation control was studied in (Li-ping, 2010). PQ theory, active and reactive currents theory performance was studied in (Xi et al., 2010). Study of PQ, DQ, constant active and reactive power theory, and unity power factor algorithm have been proposed in (El-Habrouk, 1998). Sliding mode based DC voltage controller for grid current's peak detection was proposed by (Singh et al., 1997). (Akagi, 1997) discussed the shunt active power filter and its best connection point. Different connections configuration were discussed and analyzed. In (Al-zamil et al., 2001) a passive series filter with shunt active power filter configuration was proposed and discussed. In (Tey et al., 2005) an adaptive topology of shunt active power filter was discussed. Neural network based control approach was proposed and discussed.

Three single phase shunt active power filters were designed for the compensation of a three phase four wire system harmonics was proposed by (Hou et al., 2010). Stationary reference frame based active power filter topology was proposed for the compensation of unbalanced system has been discussed in (Asadi et al., 2010). Fuzzy logic control of shunt active power filter using PQ theory and sine multiplication method was studied in (Georgios, 2010). A shunt active power filter connected to a photovoltaic array for harmonic and reactive power compensation has been presented in (Jian et al., 2011). (Jian et al., 2011). (Zheng et al., 1991) and (Bhattacharya et al., 1993) presented a hybrid topology composed of shunt passive and series active power filters. Hybrid series active filter was also discussed in (Bhattacharya et al., 1995). Hybrid series active power filter controlled using synchronous reference frame was discussed in (Bor-Ren & Yang, 2001). The series active power filter for harmonic currents

cancelling was proposed in (Bor-Ren et al., 2002). In (A Bakar, 2007), a hybrid active series parallel passive power filter was implemented for voltage and current harmonic elimination. Series active filter for the neutral was proposed for cancelling the third harmonic of a three phase four wire systems was proposed. Many other papers and researches have been written and discussed in the field of active and passive filtering. The subject of power quality and power filtering is a wide and developing subject that can expand continuously with the development of processing systems and power electronics.

POWER QUALITY ISSUES

Harmonics

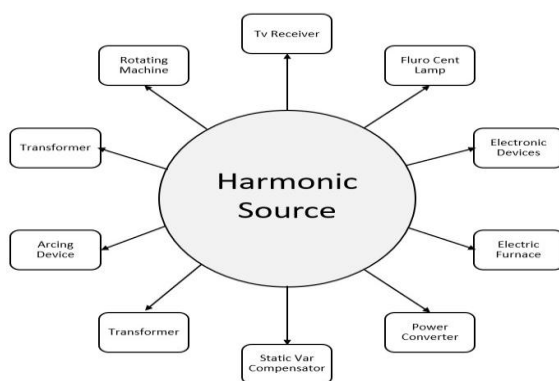


Figure 1: Harmonics source

Effects of Harmonics

- Problem caused by harmonics
- over loading of neutral
- Overheating of neutral
- nuisance tripping of circuit barker
- skin effect
- Overheating of induction motor

Therefore a pure voltage or current sine wave has no distortion and no harmonics and a non-sinusoidal wave has distortion and harmonics. In order to quantify the distortion, the term of Total Harmonics Distortion (THD) is used.

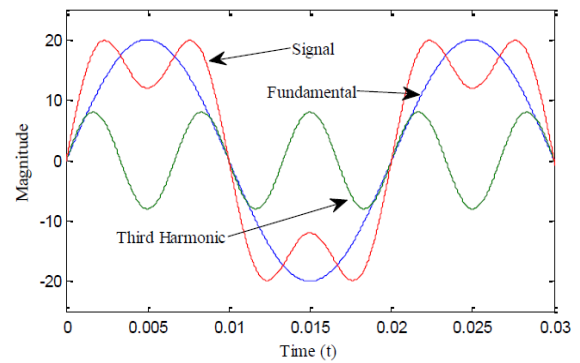


Figure 2: Harmonic components of a non-sinusoidal signal

Total Harmonic Distortion

The THD is a measure of the effective value of the harmonic components of a distorted waveform. That is, it is the potential heating value of the harmonics relative to the fundamental. This index can be calculated for either voltage or current:

$$THD = \frac{\sqrt{\sum_{h=2}^{h_{max}} M_h^2}}{M_1} \quad (1)$$

Where M_h is the rms value of harmonic component h of the quantity M . The rms value of a distorted waveform is the square root of the sum of the squares as shown in Eq. (1) and (2). The THD is related to the rms value of the waveform as follows:

$$RMS = \sqrt{\sum_{h=1}^{h_{max}} M_h^2} = M_1 \sqrt{1 + THD^2} \quad (2)$$

The THD is a very useful quantity for many applications, but its limitations must be realized. It can provide a good idea of how much extra heat will be realized when a distorted voltage is applied across a resistive load. Likewise, it can give an indication of the additional losses caused by the current flowing through a conductor.

Effects of harmonics

Harmonic currents rush in the grids and can cause a number of problems. They can be trapped by power factor correction capacitors and overload them or cause resonant with them causing their failure. They can also cause problems in computers, telephone lines, motors, and power

supplies, and may even cause transformer failures due to eddy current losses. The harmonic currents can be cancelled by using series capacitive inductive filters designed for the harmonic frequency. Such filters provide low impedance to the harmonic frequencies compared to the grid impedance. Good experience says that multiple resonant filters must be installed first at the lowest harmonic frequency of interest and then at the higher-frequencies (Sueker, 2005).

The effect of harmonic currents or voltages is a function of different loads sensitivity; some loads are more sensitive for harmonics where as other loads are slightly sensitive. The least sensitive loads are heating equipments of all types. The most sensitive kinds of equipments are the electronic devices which have been designed expecting an ideal sinusoidal voltage or current waveforms. Electric motors are the most popular loads which are situated between these two categories.

Treatment of Harmonic Problems

The purification of the currents and voltage in the electric systems is a very important issue for the users and the distributors of electrical power. The increasing use of harmonic emitting non-linear loads has implied the existence of more interest of finding solutions of harmonic problems. The harmonics are causing annual losses in all countries because of their effects on the grids in addition to the noise applied on the communication systems. International committees limit the acceptable harmonic emission that can be produced by different loads. Producers of electrical equipments try to produce equipments that meet the limitations and standards of these international committees. Users of electric grids are also encouraged continuously to use different means of filtering currents and voltages and improving power factor of their systems. Batteries of harmonic elimination and reactive power compensation are used to reduce the pollution levels and increase the efficiency of electric systems.

Since the mid of the 20th century, many classic and new solutions for harmonics elimination and power quality improvement were proposed in literary. These methods varies between the investigation in the load to reduce the harmonic emission amounts while the others impose the use of external special constructed filtering equipments that stop the expansion of harmonics toward the electric grids (Kmail, 2012). The main methods of harmonic limiting are the use of special connections of three phase power transformers that prevent the harmonic of defined

orders from circulation through the neutral to the grid. The use of line reactors which prevent higher frequency harmonic from being spread into the grid is also another classic solution for the reduction of harmonics. More efficient solutions include the use of combination of passive elements connected to the distorted systems and calculated in concordance with defined levels of harmonics. These elements trap the harmonics before being spread to the grids. Many types of these filters have been proposed in the literary. These types include resonant, high pass, and resonant high pass filters in addition to other combinations of passive filters. The use of especially constructed active filters has been introduced into literary by the beginning of the 80th of the last century. These active filters include shunt, series, and shunt series combination filter. The use of hybrid active and reactive filters has been considered as a useful solution for power quality problems.

Active Power Filters

The purpose of the active power filters (APF) is to produce harmonic currents or voltages in an approach such that the grid current or voltage waves preserve the sinusoidal structure. The APFs can be connected to the grid in series (Series APF), parallel (PAPF) to compensate voltage harmonics or current harmonics correspondingly. Or can be connected with passive filters to build the hybrid filters (HAPF). Active filters are fairly new types of devices for eliminating harmonics. This kind of filter is based on power electronic devices and is much more costly than passive filters. They have the individual advantage that they do not resonate with the power system and they work autonomously with respect to the system impedance. They are used in difficult circumstances where passive filters can't work effectively because of resonance problems and they don't have any intervention with other elements installed anywhere in the power system (Javadi, 2009).

Series active power filter (SAPF)

The intend of the series APF is to locally modify the grid impedance. It is considered as a source of harmonic voltages that withdraw the voltage harmonics coming from the grid or those twisted by the circulation of the harmonic currents into the grid. However, series APFs can't balance the harmonic currents produced by the loads.

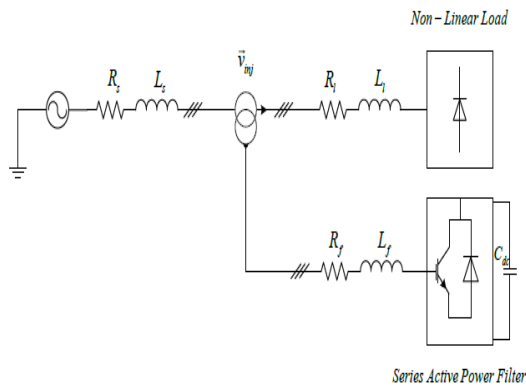


Figure 3: Series active power filter connected to the grid

Series active power filters are connected to the power grids by means of coupling transformers in series with the grid. Voltages are then injected to the grid such that it compensates for the voltages harmonics and perturbations. Series active power filters were introduced in the 80s of the last century; they operate mainly as voltage regulators and separate the loads from power source. The series filter protects the consumer from unexpected supply voltage faults such as high voltages or low voltage sequences. This type of filtering is recommended for compensation of voltage unbalances and sags from the supply. Series compensators inject voltages in series with the supply voltage; that is, they can be considered as controlled voltage regulators (Kantaria, 2012).

Parallel active power filter (PAPF)

The PAPFs are associated in parallel with the harmonic emitting loads. They are anticipated to introduce in real time the harmonic currents absorbed by the pollutant loads. Thus, the mains currents will happen to being sinusoidal.

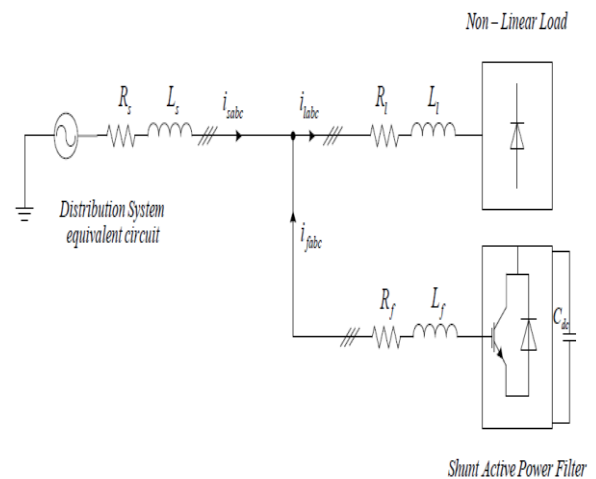


Figure 4: Shunt APF connected in parallel with non-linear load

Hybrid filters

Hybrid filter is a filter topology that combines the rewards of the passive and active filters. For this reason, it is considered as the finest solution to take away the harmonic currents from the grids. The prime motivation for the use of hybrid filters is the progress of the power semiconductors like MOSFETs and IGBTs. Over more, from an economical point of view, the hybrid power filters permit dropping the cost.

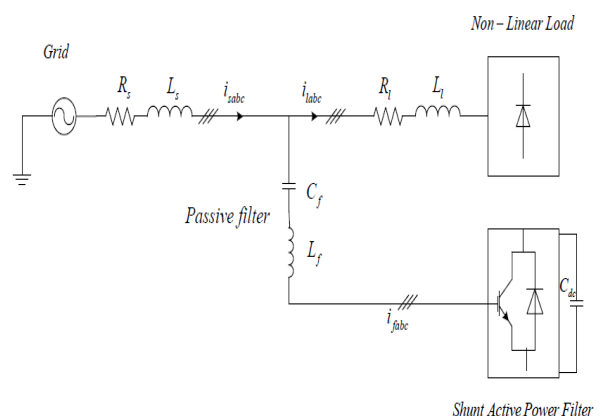


Figure 5: Hybrid APF connected with non-linear load

SIMULATION AND RESULTS

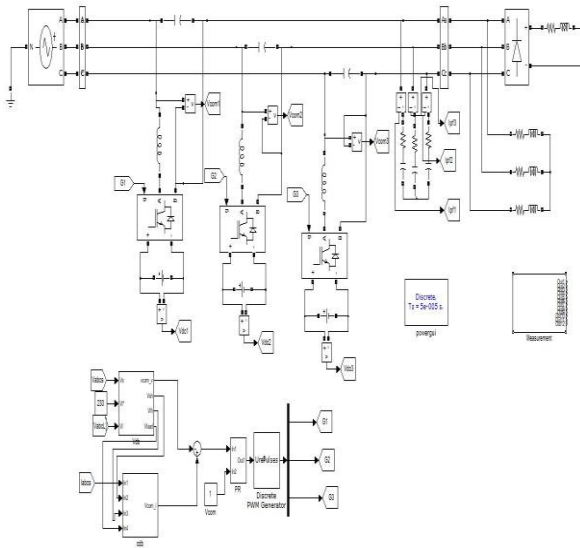


Figure 6: Matlab Model of The proposed three-phase THSeAF connected ahead of load PCC

The THSeAF is connected in series in order to inject the compensating voltage. On the DC side of the compensator, auxiliary dc-link energy storage components are installed.

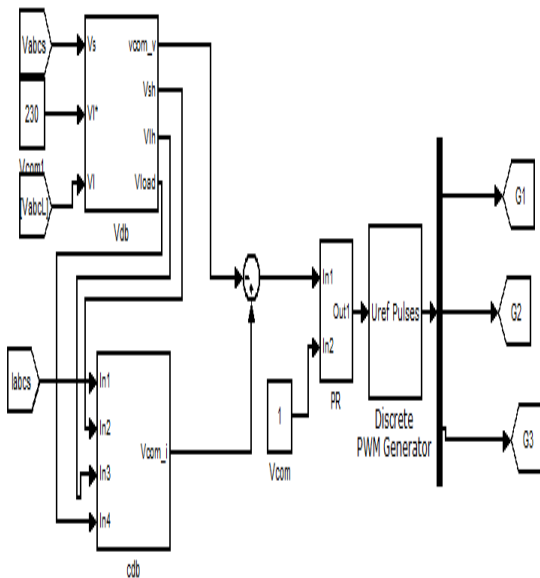


Figure 7: Matlab Model of Controller scheme

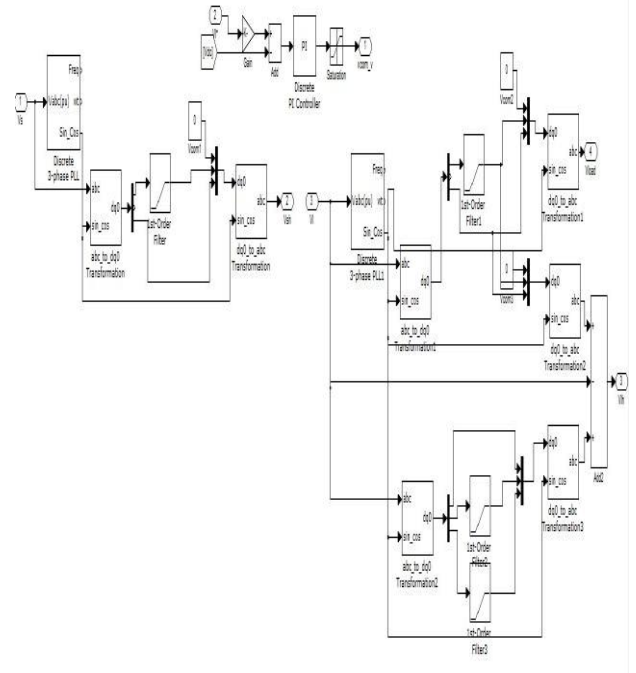


Figure 8: Matlab Model of Voltage control system

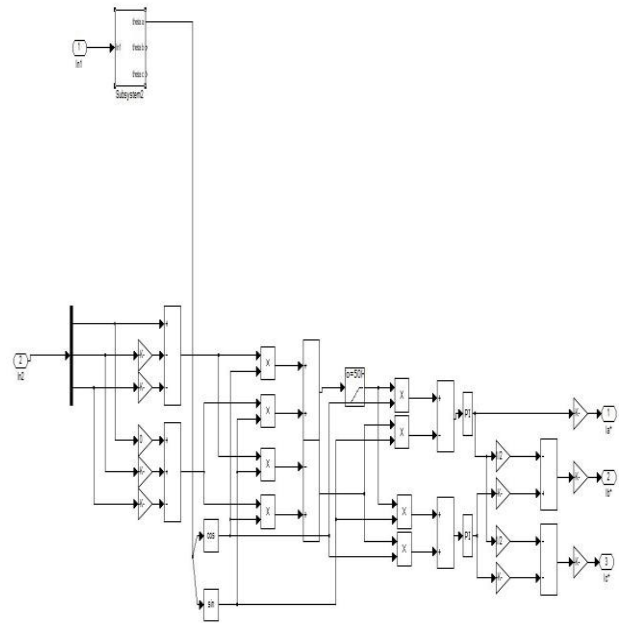


Figure 9: Current Control subsystem

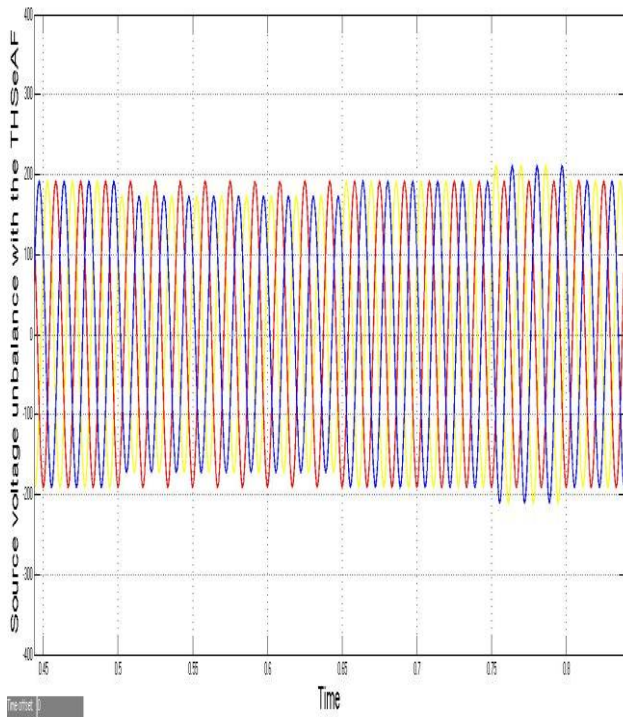


Figure 10: Source Voltage during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

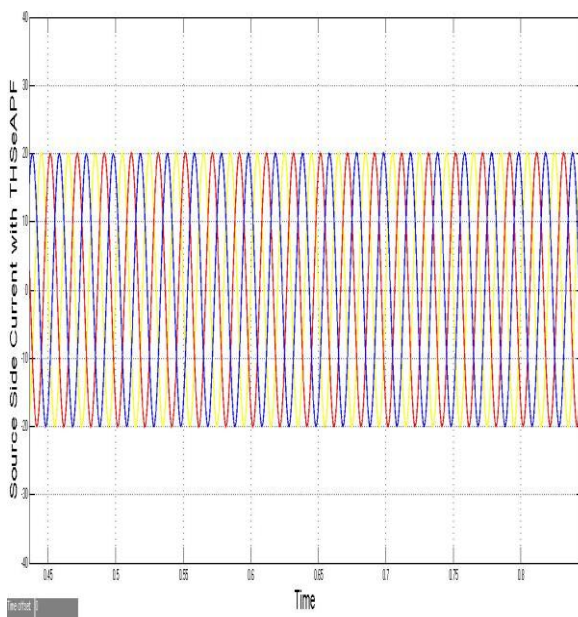


Figure 11: Source Current during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

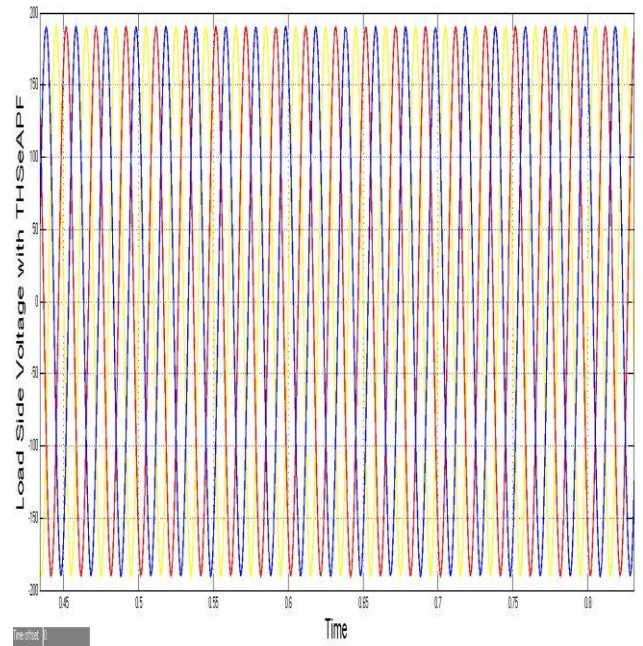


Figure 12: Load Voltage during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

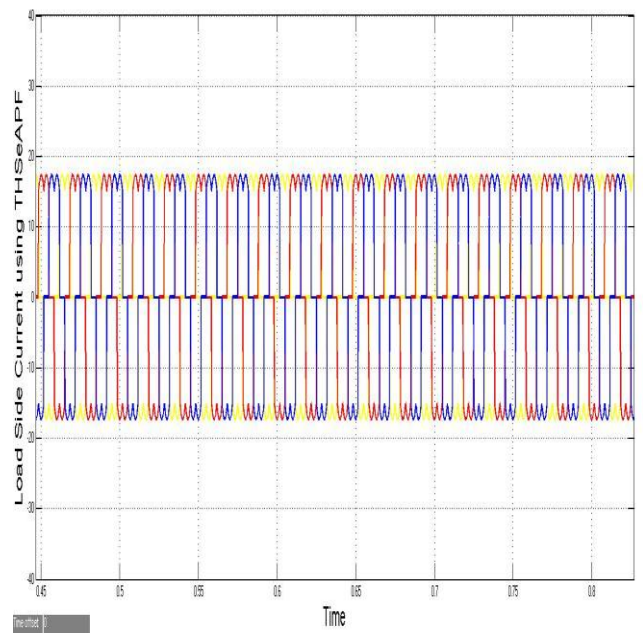


Figure 13: Load Current during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

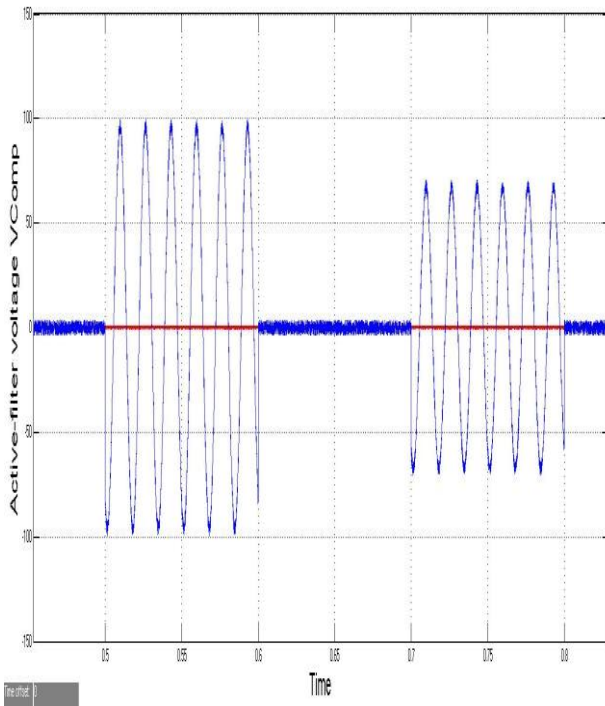


Figure 14: Active Filter Voltage VComp during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

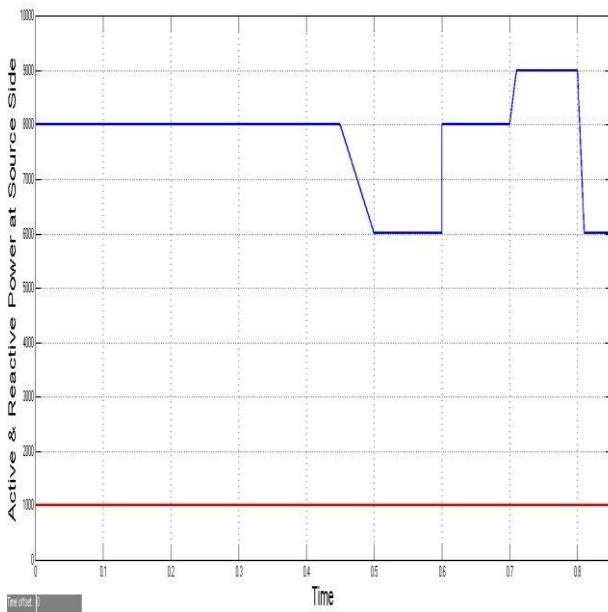


Figure 15: Source Side Active and Reactive Power during voltage unbalance with the THSeAF delivering a regulated and balanced supply to the load PCC

CONCLUSION

This paper presents Active filters were proposed recently for current and voltage harmonics cancelling. They are composed of instantly controlled elements that can offer variable impedance for

different types of harmonics. These harmonics will then flow to the filter instead of spreading into grid. Two types of active filters were discussed in this work, these are the parallel active and series active power filter. The parallel active filters are the mostly used types of filters and deals with current harmonics. The series active power filters are interested more in voltage problems. Both passive and series active power filters were used also in hybrid combinations with passive filters to offer better efficiency and to reduce the stresses on the active filter. Hybrid filters are said to be more efficient than the separated active or passive filters.

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Corresponding Author

Mrs. Ritika Chaudhary*

Ph.D Scholar, Electrical Department, UOT, Jaipur,
Rajasthan, India