# Series Active Power Filter for Power Quality Improvement

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**Abstract -** *Commercial buildings embrace the workplace buildings of IT corporations, instructional establishments, apartments, airports, etc. the everyday masses in these industrial buildings comprise of the many single- section and three section masses which has non-linear load like electronic and magnetic ballasts, switched mode power provides (SMPS), air-conditioning systems, lifts, pumps, server, IT instrumentality, printers, tiny and enormous UPS, refrigerators, copier machines, workplace automation accessories, fire- Fighting systems.*

*These loads square measure sensitive for any input variations in voltage. The performance of the electrical instrumentality gets worsened if they're furnished with contaminated or distorted voltage.*

*A number of solutions square measure accessible within the gift day apply like power issue correction system with detuned filter, electrical device banks and series reactors to mitigate harmonics, improve power issue, avoid electrical resonance. much passive filters square measure still used although they need mounted compensation and also the threat of resonance.*

*Solutions to those issues is of 2 ways- one is to alter the planning of the systems in order that the matter gets reduced and also the different is to search out a remedy for the prevailing system. the various masses square measure classified in step with the issues raised by them and to focus on the assorted sensible solutions that may solve them to a good extent.*

*This paper focuses on modeling and analysis of Custom Series Active Power Device (SAPF). MATLAB/Simulink primarily based models for Series Active Power filter (SAPF) is bestowed. Among numerous PWM techniques, physical phenomenon band voltage management PWM is popularly used attributable to its simplicity of implementation. This legendary technique doesn't want any data concerning system parameters. The SAPF is simulated for various voltage variations at input generated by the 3 section programmable supply and also the results square measure bestowed.*

***Key Words***: Series Active Power Fault (SAPF), Power quality improvement

## 1. INTRODUCTION

Power quality phenomena embody all doable things within which the wave form of the availability voltage (voltage quality) or load current (current quality) deviate from the curving wave form at rated frequency with amplitude like the rated rms worth for all 3 phases of a three-phase system [1]. The wide selection of power quality disturbances covers unexpected, short length variations, e.g. impulsive and periodical transients, voltage sags, short interruptions, furthermore as steady state deviations, like harmonics and flicker. One also can distinguish, supported the cause, between disturbances associated with the standard of the availability voltage and people associated with the standard of this taken by the load [2].

To the primary category covers voltage dips and interruptions, largely caused by faults within the power grid. These disturbances could cause tripping of "sensitive" electronic equipment with unfortunate consequences in industrial plants wherever tripping of essential instrumentality will bear the stoppage of the total production with high prices associated. One can say that in this case it is the source that disturbs the load. To avoid consistent money losses, industrial customers often decide to install mitigation equipment to protect their plants from such disturbances.

The second category covers phenomena as a result of caliber of this drawn by the load. during this case, it's the load that disturbs the supply. A typical example is current harmonics drawn by perturbing hundreds like diode rectifiers, or unbalanced currents drawn by unbalanced hundreds. Customers don't expertise any direct production loss associated with the prevalence of those power quality phenomena. However poor quality of this taken by many shoppers along can ultimately end in caliber of the ability delivered to alternative customers [3]. Each harmonics and unbalanced currents ultimately cause distortion and severally, unbalance within the voltage furthermore.

Therefore, correct standards are issued to limit the number of harmonic currents, unbalance and/or flicker that a load might introduce. To accommodates limits set by standards, customers usually have to be compelled to install mitigation instrumentality. In recent years, each industrial and industrial customers of utilities have rumored a flood tide of misadventures associated with power quality. the difficulty stems from the multiplied refinement of today's machine-driven instrumentality, whether or not variable speed drives or robots, machine-driven production lines or machine tools, programmable logic controllers or power provides in computers. They and also their like ar so much liable to disturbances on the utility system than were the previous generation of mechanical device instrumentality and the previous less machine-driven production and data systems. A growing range of hundreds is sensitive to customers' vital processes that have pricey consequences if disturbed by either poor power quality or power interruption.

For the explanations represented on top of, there's a growing interest in instrumentation for mitigation of power quality disturbances, particularly in newer devices supported power physics known as "custom power devices" ready to deliver custom-built solutions to power quality issues.

The term Custom Power describes the added power that electrical utilities and different service suppliers can supply their customers within the future. The improved level of reliableness of this power, in terms of reduced interruptions and fewer variation, can stem from associate degree integrated answer to gift issues, of that a outstanding feature are the applying of power electronic controllers to the utility distribution systems and/or at the availability and of the many industrial and industrial customers and industrial parks.

The compensating devices square measure used for active filtering; load reconciliation, power issue correction and voltage regulation. The active power filters, that eliminate the harmonics, may be connected in each shunt and series. Shunt active power filter will perform power issue correction, harmonic filtering once connected at the load terminals. The harmonic filtering approach relies on the principle of injecting harmonic current into the AC system, of an equivalent amplitude and reverse part thereto of the load current harmonics.

Dynamic Voltage Restorer (DVR) may be a series connected device. The most purpose of this device is to shield sensitive hundreds from sag/swell interruptions within the offer aspect. This can be accomplished by speedy series voltage injection to make amends for the drop/rise within the offer voltage. Since this can be a series device, it may also be used as a series active power filter.

Unified Power Quality Conditioner (UPQC) [4-8] may be a terribly versatile device that may inject current in shunt and voltage asynchronous at the same time during a twin management mode. So it will perform each the functions of load compensation and voltage management at an equivalent time.

## 2. POWER FILTER TECHNOLOGY

Depending on the particular application or electrical problem to be solved, active power filters can be implemented as shunt type, series type, or a combination of shunt and series active filters (shunt-series type). These filters can also be combined with passive filters to create hybrid power filters.

The shunt-connected active power filter as shown in Fig. 2.3, with a self-controlled dc bus, has a topology similar to that of a static compensator (STATCOM) used for reactive power compensation in power transmission systems. Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180°.

Series active power filters as shown in Fig. 2.4 were introduced by the end of the 1980's and operates mainly as a voltage regulator and as a harmonic isolator between the nonlinear load and the utility system. The series-connected filter protects the consumer from an inadequate supply voltage quality. This type of approach is especially recommended for compensation of voltage unbalances and voltage sags from the ac supply and for low-power applications and represents an economically attractive alternative to UPS, since no energy storage (battery) is necessary and the overall rating of the components is smaller.

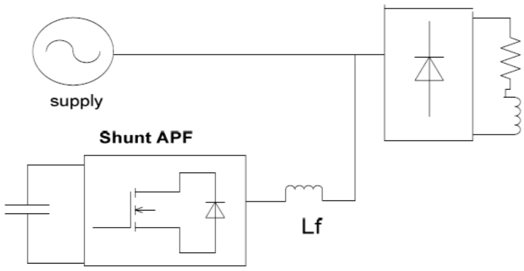


**Fig-1:** Block Diagram of Shunt APF

The series active filter injects a voltage component in series with the supply voltage and therefore can be regarded as a controlled voltage source, compensating voltage sags and swells on the load side. In many cases, series active filters work as hybrid topologies with passive LC filters. If passive LC filters are connected in parallel to the load, the series active power filter operates as a harmonic isolator, forcing the load current harmonics to circulate mainly through the passive filter rather than the power distribution system.

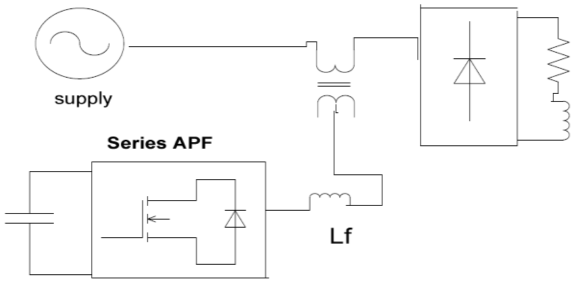


**Fig -2:** Block Diagram of Series APF

The main advantage of this scheme is that the rated power of the series active filter is a small fraction of the load kVA rating, typically 5%. However, the apparent power rating of the series active power filter may increase in case of voltage compensation.

The series-shunt active filter is a combination of the series active filter and the shunt active filter. The shunt active filter is located at the load side and can be used to compensate for the load harmonics. On the other hand, the series portion is at the source side and can act as a harmonic blocking filter. This topology has been called the Unified Power Quality conditioner. The series portion compensates for supply voltage harmonics and voltage unbalances, acts as a harmonic blocking filter, and damps power system oscillations. The shunt portion compensates load current harmonics, reactive power, and load current unbalances. In addition, it regulates the dc link capacitor voltage. The power supplied or absorbed by the shunt portion is the power required by the series compensator and the power required to cover losses.

## 3. MODELING OF SERIES ACTIVE POWER FILTER

### 3.1. Principal of operation

Active power filter could be a terribly useful gizmo to enhance the ability quality of electrical distribution network. the most perform of a series active power filter is that the protection of sensitive masses from offer voltage sags, swells and harmonics. The series filter is connected between the provision and cargo terminals exploitation 3 single section transformers. the first windings of those transformers area unit star connected and therefore the secondary windings area unit connected serial with the three-phase offer. additionally to injecting the voltage, these transformers area unit wont to filter the switch ripple of the series active filter. A little capability rated RC filter [1] is connected across the secondary of every series electrical device to eliminate the high switch ripple content within the series active filter injected voltage. The voltage supply inverters for both the active filters area unit enforced with IGBTs (Insulated Gate Bipolar Transistors).

The general structure of active power filter below study is given in Fig. 3. Series active power filter consists of 3-phase voltage supply device, Lf, Cf filter to suppress switch ripples and series transformers that inject the compensating voltage to the road.

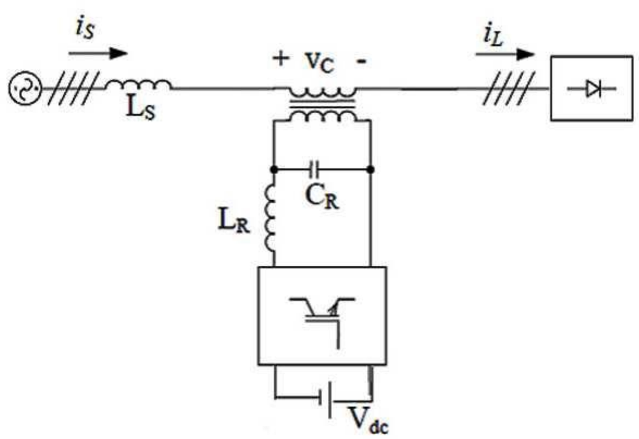


**Fig -3:** Schematic diagram of series active filter

The Series Active Power Filter performances can rely primarily on the dynamics of the modulation technique accustomed management the switches and on the strategy accustomed confirm active filter voltage references. The management theme of series active power filter consists of 2 main blocks: the disturbance identification block and also the voltage management. For identification of voltage references, a strong PLL system is employed during this paper.

Among varied PWM techniques, physical phenomenon band current or voltage management PWM is popularly used thanks to its simplicity of implementation. This legendary technique doesn't would like any data concerning system parameters.

### 3.2. Control scheme of series filter

A simple algorithm is developed to control the series and shunt filters. The series filter is controlled such that it injects voltages (*Vca, Vcb, Vcc*) which cancel out the distortions and/or unbalance present in the supply voltages **(** *Vsa, Vsb, Vsc***)** thus making the voltages at the PCC ( *Vla, Vlb, Vlc* ) perfectly balanced and sinusoidal with the desired amplitude. In other words, the sum of the supply voltage and the injected series filter voltage makes the desired voltage at the load terminals. The control strategy for the series AF is shown in Fig. 4.

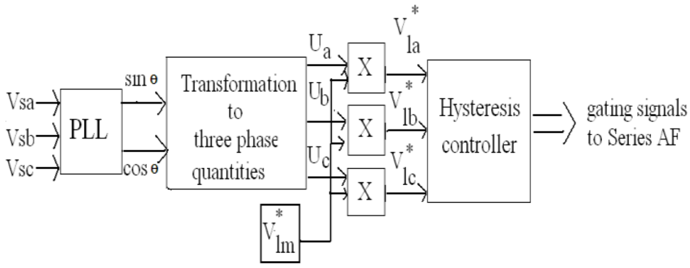


**Fig-4**: Control Scheme of Series APF.

### 3.3. Reference voltage generation & Hysteresis voltage controller

Since the supply voltage is unbalanced and or distorted, a phase locked loop (PLL) is used to achieve synchronization with the supply. This PLL converts the distorted input voltage into pure three phase sinusoidal supply of RMS value of each phase equal to that of the fundamental (1 p.u). Three phase distorted/unbalanced supply voltages are sensed and given to the PLL which generates two quadrature unit vectors (*Sin*q ,*Cos*q ) **.** The sensed supply voltage is multiplied with a suitable value of gain before being given as an input to the PLL. The in-phase sine and cosine outputs from the PLL are used to compute the supply in phase, 1200 displaced three unit vectors

( $u_a, u_b, u_c$ ) using eqn.(1) as

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \times \begin{bmatrix} \sin\theta \\ \cos\theta \end{bmatrix}$$ ……………………………..(1)

The computed three in-phase unit vectors are then multiplied with the desired peak value of the PCC phase voltage ( $V_{lm}^*$ ) , which becomes the three-phase reference PCC voltages as

$$\begin{pmatrix} V_{la}^* \\ V_{lb}^* \\ V_{lc}^* \end{pmatrix}$$ ……………………………………………………………………….(2)

The desired peak value of the PCC phase voltage is considered to be 338V = $\frac{415*\sqrt{2}}{\sqrt{3}}$.

The computed voltages from eqn. (2) are then given to the hysteresis controller along with the sensed three-phase PCC voltages. The output of the hysteresis controller is switching signals to the six switches of the VSI of the series AF. The hysteresis controller generates the switching signals such that the voltage at the PCC becomes the desired sinusoidal reference voltage. Therefore, the injected voltage across the series transformer through the ripple filter cancels out the harmonics and unbalance present in the supply voltage. The MATLAB/Simulink model of the control scheme for series active filter is shown in Fig. 5.

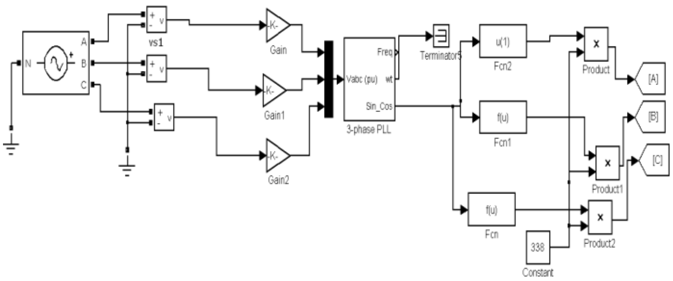


**Fig-5**: Reference voltage generator

### 3.4. Proposed Series Active Power Filter

The series active power filter is used to compensate the source side disturbances such as voltage sags, swells and also harmonic distortions. In this configuration, the filter is connected in series with the line being compensated.

Therefore the configurations are often referred to as a series active filter. The approach is based on the principle of injecting voltage in series with the line through the injection transformer to cancel the source side voltage disturbances and thus it makes the load side voltage sinusoidal.

Fig. 6 shows the MATLAB/ Simulink model of designed system.

The main components of the below system are as follows.

· Mains supply

· Nonlinear load

· Active Power Filter

o Voltage source inverter

o Interface reactor

o Reference voltage generator

o Hysteresis voltage controller

## 4. MATLAB SIMULATION MODEL & RESULTS

### 4.1. Case 1

Fig. 7 shows the source voltage in which rated 1 p.u voltage is created from 0 to 0.1 seconds , 0.8 p.u sag from 0.1 to 0.15 seconds,1 p.u voltage from 0.15 to 0.2 seconds, 1.2 p.u swell from 0.2 to 0.25 seconds , 0.4 p.u sag from 0.25 to 0.3 seconds, 0.9 sag from 0.3 to 0.4 seconds and 1p.u voltage from 0.4 to 0.5 seconds.

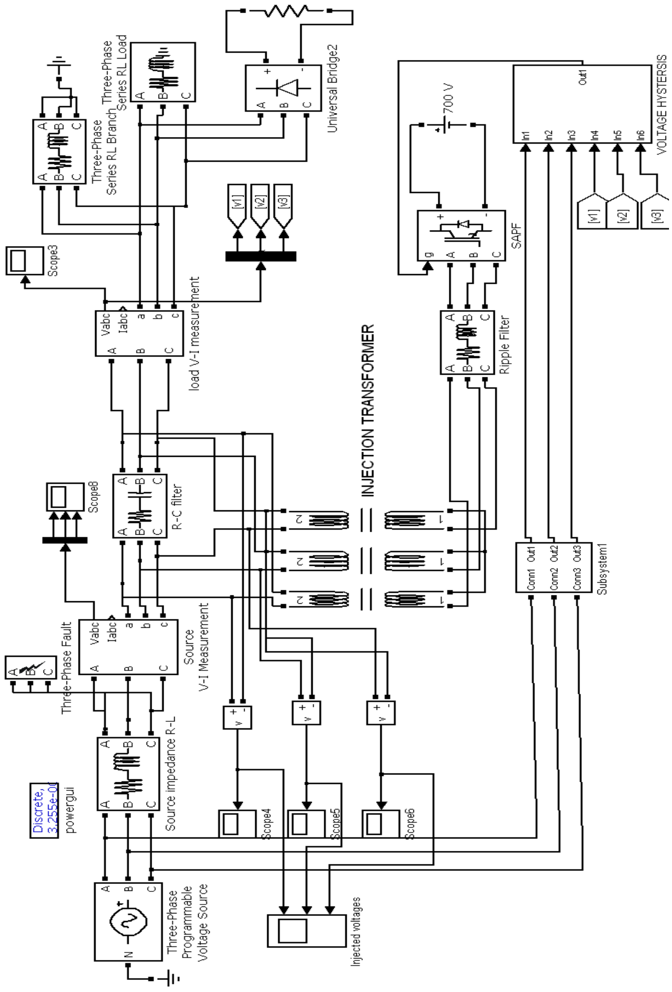


**Fig-6**: MATLAB/Simulink model of proposed Series active power filter

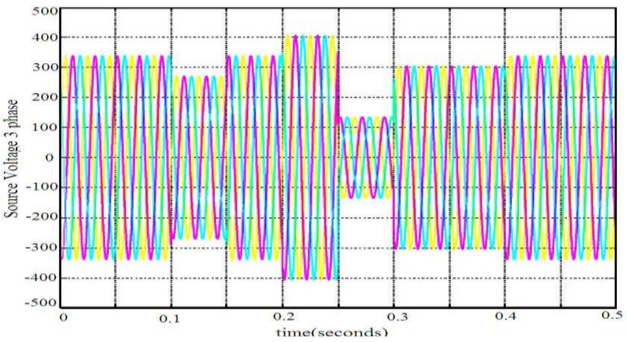


**Fig-7**: 3-Phase Source voltage (Line-Ground)

Due to the injection of the above voltages through the injection transformer in series with the line the load voltage is sinusoidal as shown in Fig. 8.

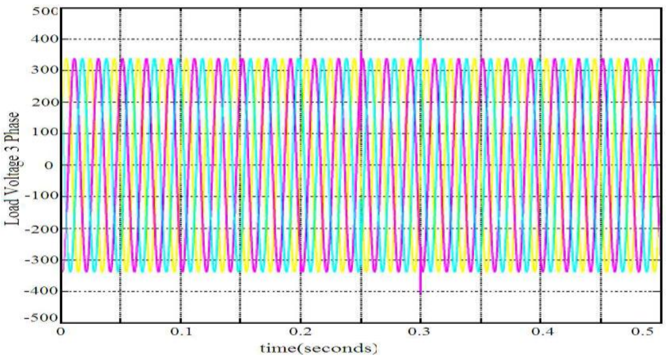


Fig-8: Phase Load voltage (Line-Ground)

The Total harmonic distortion of source voltage is 1.64% and load voltage is 0.04 % as shown in Fig. 9 & Fig. 10 respectively.

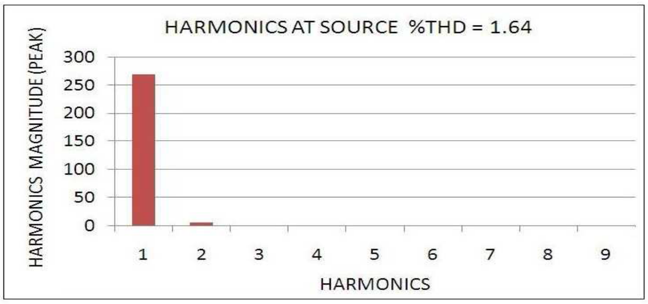


**Fig-9**: Source voltage harmonic spectrum

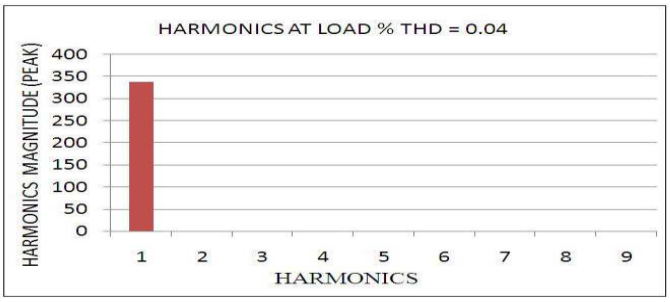


**Fig-10**: Load voltage harmonic spectrum

### 4.2. Case 2

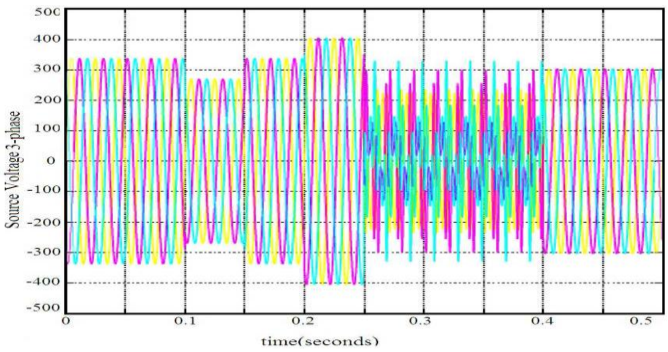


**Fig-11**: 3-Phase Source voltage (Line-Ground)

Fig. 11 shows the source voltage in which rated 1 p.u voltage is created from 0 to 0.1 seconds , 0.8 p.u sag from 0.1 to 0.15 seconds,1 p.u voltage from 0.15 to 0.2 seconds, 1.2 p.u swell from 0.2 to 0.25 seconds , 5th order harmonics of 0.4 p.u and 7th order harmonics of 0.2 p.u from 0.25 to 0.4 seconds , 0.9 sag from 0.4 to 0.5 seconds . the load is R=50Ω and L=10 mH.

Due to the injection of the above voltages through the injection transformer in series with the line the load voltage is sinusoidal as shown in the Fig. 12.

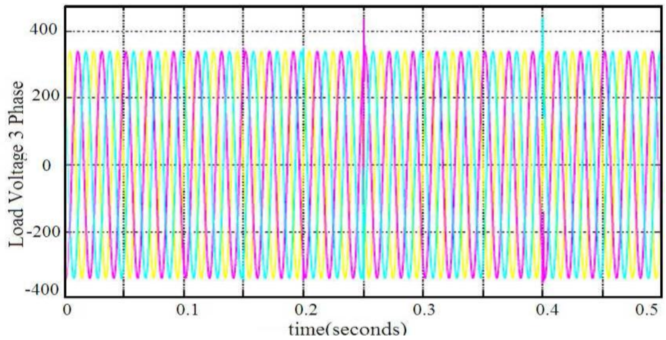


**Fig-12**: 3-Phase Load Voltage (Line-Ground)

The Total harmonic distortion of source voltage is 64.37% and load voltage is 0.72 % as shown in Fig. 13 & Fig. 14 respectively.

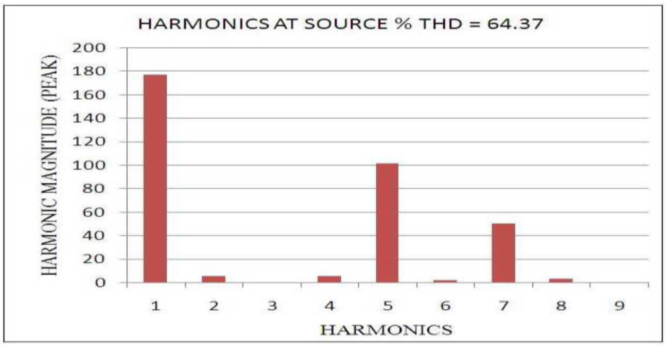


**Fig-13**: Source voltage harmonic spectrum

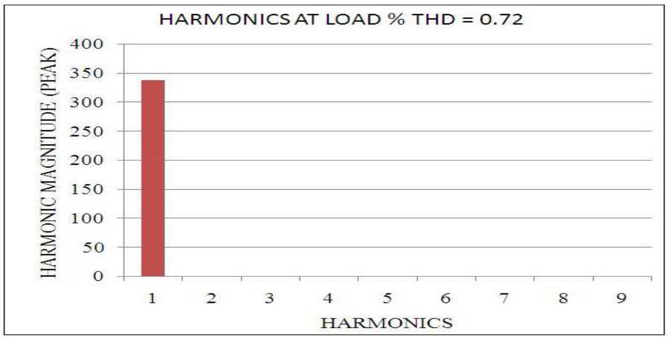


**Fig-14**: Load voltage harmonic spectrum

### 4.3. Case 3

The source voltage in which rated 1 p.u voltage is created from 0 to 0.1 seconds , 0.8 p.u sag from 0.1 to 0.15 seconds,1 p.u voltage from 0.15 to 0.2 seconds, 1.2 p.u swell from 0.2 to 0.25 seconds , 0.8 p.u sag from 0.25 to 0.4 seconds , 1 p.u voltage from 0.4 to 0.5 seconds . A L-G fault occurs in phase A from 0 to 0.2 seconds .The load is R=10 Ω and L=1mH, a three phase diode rectifier bridge ,an inductive load of power factor (p.f) 0.894 lag (active power =1000W and reactive power = 500W).

Due to the injection of the above voltages through the injection transformer in series with the line the load voltage is sinusoidal as shown in the Fig. 16.

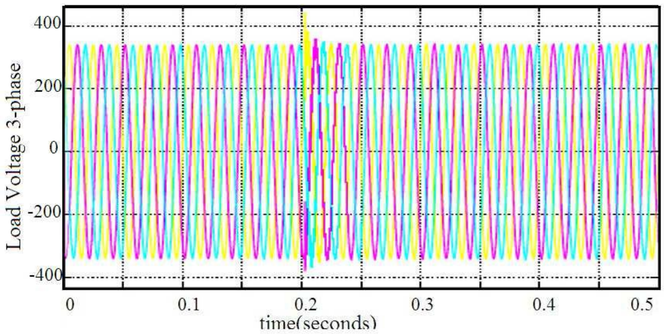


**Fig-16**: 3-Phase load voltage (Line-Ground)

The Total harmonic distortion of source voltage is 3.52% and load voltage is 1.09 % as shown in Fig. 17 & Fig. 18 respectively.

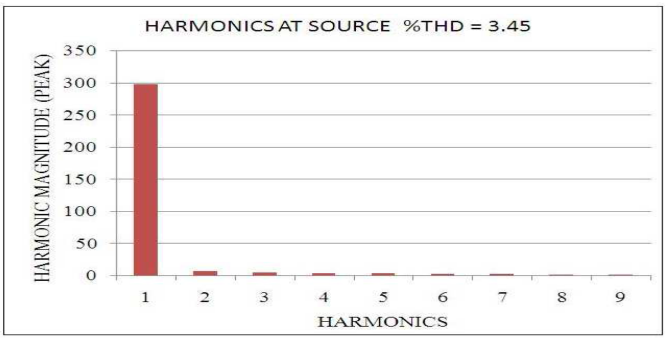


**Fig-17**: Source voltage harmonic spectrum

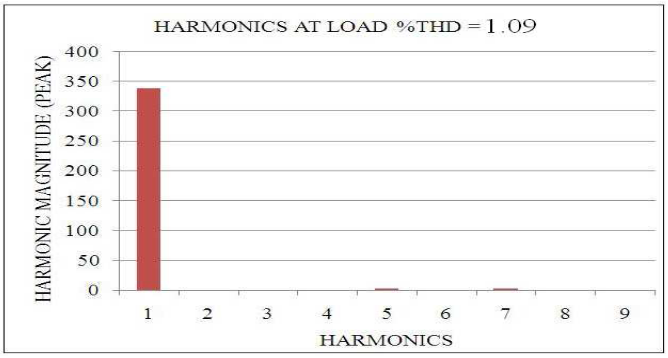


**Fig-18**: load voltage harmonic spectrum

### 4.4. Case 4

The source voltage with 1p.u voltage in phase A from 0 to 0.5 seconds ( no distortion) , Line to Line Fault in phase B & C from 0.1 to 0.25 secconds, the rest is free from distortions. Due to this fault the Line to Line voltage between B&C lines is zero The load is R=10 ohms and L=1 mH, a three phase diode rectifier bridge ,an inductive load of 0.894 lag (active power =1000W and reactive power = 500W).

Due to the injection of the above voltages through the injection transformer in series with the line the load voltage is sinusoidal as shown in the Fig. 19

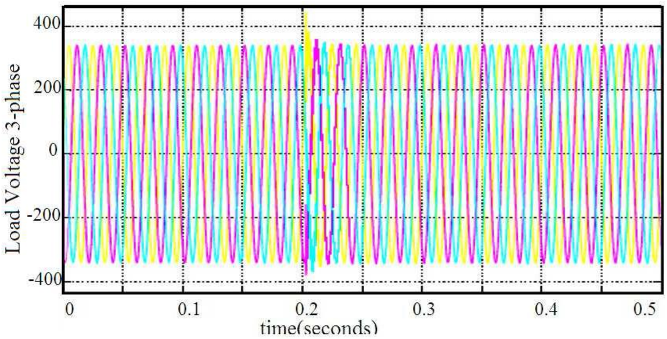


**Fig-19**: 3-Phase load voltage (Line-Ground)

The Total harmonic distortion of source voltage is 1.32% and load voltage is 0.66 % as shown in Fig. 20 & Fig. 21 respectively.

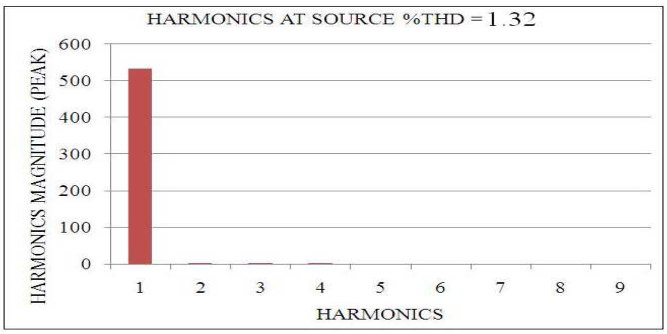


**Fig-20**: Source voltage harmonic spectrum

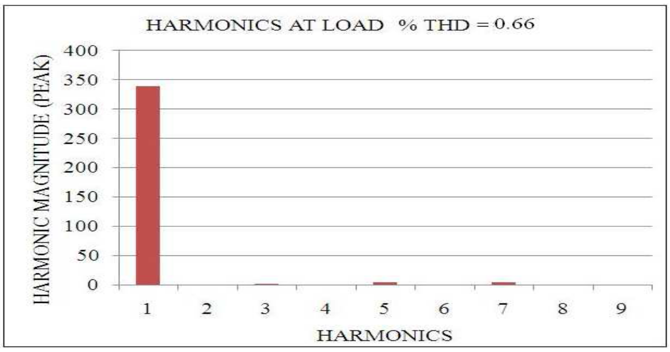


**Fig-21**: load voltage harmonic spectrum

## 5. CONCLUSION

A Series active power filter has been investigated for power quality improvement. Various simulations are carried out to analyze the performance of the system. Hysteresis controller based Series active power filter is implemented for harmonic and voltage distortion compensation of the non-linear load. The Simulation is even extended for abnormal faults occurring on the power system like L-G & L-L faults.

The simulation results of series active power filter has shown the ability to compensate voltage sag, swell and harmonics present at input source side. With these functions, the proposed SAPF is suitable for connecting at the PCC of industrial drives which are most sensitive to Sags, Swells and harmonics. The THD of the load voltage is below 5%, the harmonics limit imposed by IEEE standard.

## 6. FUTURE SCOPE

Fuzzy logic and neural network techniques are now being increasingly applied to power electronics. The integration of fuzzy logic with neural networks and genetic algorithms is now making automated cognitive systems a reality in many disciplines.

The power of fuzzy systems when integrated with learning capabilities of neural networks and genetic algorithms is responsible for new commercial products and processes that are effective cognitive systems. The performance of the above mentioned Hysteresis controller based Series active filter can be improved by fuzzy logic controller.

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