# Simulation and Experimental Implementation of Single Phase Active Power Filters for Improving Power Quality

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**Abstract—**This paper presents single phase series and shunt active filters to improve power quality by reducing various power quality problems including current harmonics, voltage sag, voltage swell and voltage flicker. Voltage quality is improved by series active filter by injecting compensating voltage and current quality is improved by shunt active filter by injecting compensating current. Control strategy of series active filter contains two main loops, one is for output voltage control loop and another one is DC link voltage control loop. Control strategy of active filter should maintain constant voltage across DC side of the H Bridge and second objective is to maintain harmonic free sinusoidal source current in phase with source voltage. Simulation and experimental results are carried out for both filters to check the effectiveness of proposed control strategies.

**Keywords:** shunt active filter, series active filter, SPWM, Hysteresis PWM, power quality, flicker

## I. Introduction

Characteristics of the voltage and current in the power system are defined by power quality. Voltage imbalance, flickering, inter-harmonics, imbalance in voltage and currents, deviations in frequency, voltage and current are some of the power quality problems. These problems are increasing due to raise in power electronics based non linear loads [1]. Unbalance in three phase currents and increase in neutral current are main effects of single phase non linear loads which are changing continuously.

Power factor improvement and harmonics reduction have been done by using traditional passive LC filters. But due to their fixed compensation, problems in tuning, resonance and inability to work in dynamical conditions passive LC filters are not much preferred [2]. By replacing passive filters with active filters harmonics compensation, power factor improvement and hence increase in power quality can be effective and dynamic.

Active filters can be connected in series or in parallel. Series connection of active filter improves characteristics of voltage waveform; compensate voltage harmonics by injecting series voltage into line. Shunt connection of active filter improves current waveform; reduce current harmonics by injecting shunt current into line. Shunt current injected by shunt active filter is in opposite direction of load harmonic current to maintain sinusoidal harmonic free source current. Series active filters should be isolated from the power line to avoid short circuit paths. Isolation can be achieved by using series transformers [3,4].

Elimination of harmonics by active filters can be achieved by first detecting harmonics then after filtering them. Many authors discussed about importance of harmonics detection for performance of the filter [5], and proposed various closed loop controlling techniques which are having both detection and controlling of harmonics [6].

In studied literature several techniques can be found for detecting harmonics and controlling active filters. DQ frame control or synchronous frame control was proposed by many authors for controlling active power filters even during dynamic conditions [7,8]. Optimal control with pole placement technique using DQ control is proposed in [9]. Current source inverter is proposed in [10] for harmonic compensation with short circuit protection. As compared with voltage source converter, current source inverter is less in efficiency.

PQ control or instantaneous active and reactive theory based controlling for active filters proposed in [11]. Proportional and integral controllers or PID controllers with different tuning processes are proposed in [12]. Pulse width modulated technology based on P and PI controllers are used extensively but to get efficient harmonic compensation, gains should be tuned effectively for better dynamic response. Generalised integral PI control, integrator back stepping PI controller and iterative PI controller are proposed in [13] for improving dynamic behaviour of the active filters.

Artificial neural network are used in [14]. Using adaptive PI control and DRC improved dynamic response speed of active filters.

In single phase active filters, detected harmonics can be injected in opposite direction into power system for sinusoidal waveform at fundamental frequency in main line. Single phase active filter consists of a full bridge inverter with four switches and a DC link capacitor. DC link capacitor is a constant storage device connected to inverter for DC supply. Controlling algorithm for inverter should maintain constant voltage across DC capacitor for continuous supply for inverter. Instantaneous voltage of DC capacitor can be compared with a reference voltage and controller reduces the error between actual and reference value to maintain constant voltage across DC capacitor.

To increase accuracy and to improve performance of inverter and to get clean voltage and current in the line, self charging algorithm is proposed and compared with conventional method in [15]. This algorithm maintains DC voltage to be constant and dynamic with less ripples and noise. Self charging algorithm controls the charging and discharging of the capacitor by using energy conversion law.

In this paper proposing, an improved self charging algorithm for single phase series and shunt active filters. This algorithm improves performance of DC capacitor to maintain constant and ripple free voltage.

## II. Active Filters

### a). Series Active Filter

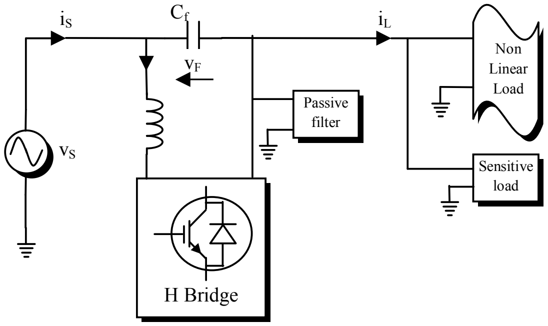

Fig.1. Single phase series active filter

Series active filter with an H bridge in series with load and source shown in fig1. Capacitor (Cf) in parallel with series active filter is for creating low impedance path for current harmonics. During voltage sags and swells power injected into line can be drawn from DC storage capacitor connected across DC side of the H Bridge. This configuration not used any costly and bulky series transformers and it is capable of reducing voltage distortions and hence current harmonics. Comparing with other series compensators this series active filter is cost effective because of its transformer less configuration. Passive filter connected is optimised for 5th, 7th and higher harmonics.

Supply voltage can be described in terms of fundamental component and distortion component as

$$V_s = V_1 + V_h - V_{non}$$

$V_s$ is the sum of fundamental component and harmonic distortions. $V_h$ is harmonic voltages present and $V_{non}$ represents nonlinear voltages present due to nonlinear currents. For the load voltage to be harmonic free and regulated series active filter should inject $V_1$ that eliminated or reduces harmonic voltages $V_h$ and nonlinear voltages $V_{non}$.

Control strategy of series active filter contains two main loops, one is for output voltage control loop and another one is DC link voltage control loop. Fundamental component $V_1$ of source voltage $V_s$ can be extracted by a low pass filter $F_1$. By subtracting $V_1$ from $V_s$ harmonic content of PCC voltage can be found.

$$V_h = V_s - V_1$$

$V_h$ is the one component of voltage to be maintained at series active filter. Another component $V_{cd}$, should maintain constant voltage across DC side of series active filter. Hence DC link voltage control loop is used to generate $V_{cd}$. Input of DC voltage control loop is $V_{err}$ where

$$V_{err} = V_{refdc} - V_{dc}$$

$$V_{cd} = V_1 V_{con}$$

$V_{con}$ is the output of the controller used in DC voltage control loop. Then reference voltage required for output voltage control loop is the sum of harmonic content extracted and voltage component required to maintain constant voltage across DC side of series active filter.

$$V_{ref} = V_{cd} + V_h$$

In output voltage control loop, $V_{ref}$ is compared with actual voltage across series active filter using a controller and pulses are generated by SPWM from output of the controller. In both control loops PI controllers are used for better regulation and tuned by using trial and error. Control strategy of series active filter is shown in fig.3.

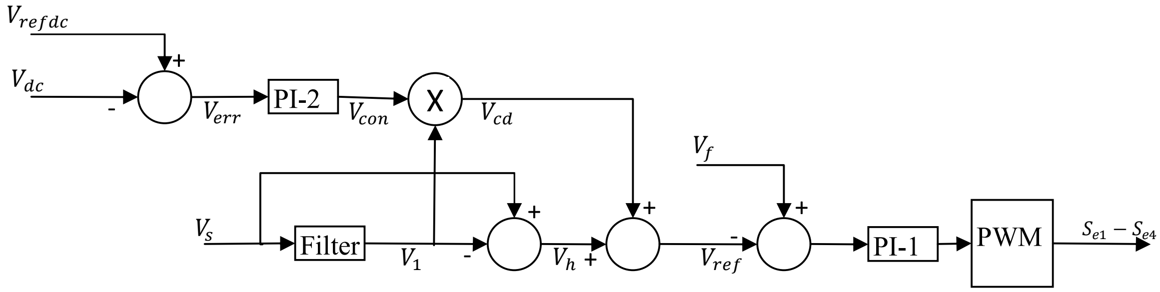

Fig.3. Control Strategy of Series Active Filter

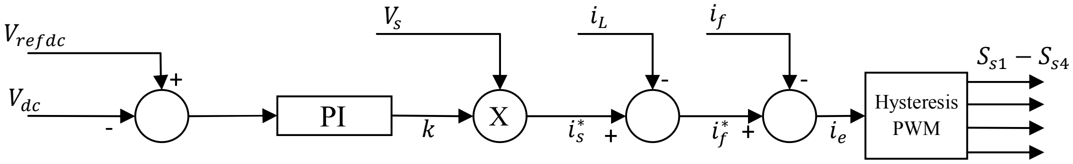

Fig.4. Control Strategy of Shunt Active Filter

**b). Shunt Active Filter**

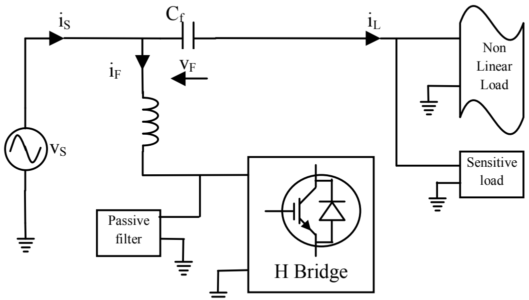

Fig.2. Single phase shunt active filter

Shunt active filter with H Bridge in parallel with source, nonlinear load and passive filter is shown in fig.2. Non linear load is supplied by source. H Bridge consists of four switching devices and should be operated to inject compensating current into PCC to eliminate or reduce harmonics injected by nonlinear load into line. In ideal operation of shunt active filter source current should be in same shape with source voltage and in same phase with it.

$$L\frac{di_f}{dt} + di_f = V_s - V_i$$

$$C\frac{dV_f}{dt} = Vi_f$$

$V_s$ is the source voltage, $V_i$ is input voltage of the active filter, $V_f$ is the capacitor voltage.

The control strategy of active filter should achieve two main objectives. The first objective is to maintain constant voltage across DC side of the H Bridge and second objective is to maintain harmonic free sinusoidal source current in phase with source voltage. Second objective can be achieved by inner current loop to force source current to trace the reference current.

$$i_s^* = kV_s$$

Where $k$ is the time dependent scaling factor which value is based on power requirement by nonlinear load. The value of $k$ is output of the PI controller based outer voltage control loop.

$$k = K_P(V_{dc}^* - V_{dc}) + K_I \int (V_{dc}^* - V_{dc})\, dt$$

$V_{dc}^*$ is the reference capacitor voltage at DC side of H Bridge. $K_P$ and $K_I$ are gains of PI controller and tuned by trial and error method.

To achieve first objective, that is to force source current to track reference current hysteresis current control based PWM can be used. Input of the hysteresis current control is error between actual filter current and reference filter current.

$$i_e = i_f - i_f^*$$
$$i_f^* = i_s^* - i_L$$

Then the control law of hysteresis PWM can be described as

$$u = \begin{cases} +1\, for\, i_e > 0 \\ -1\, for\, i_e < 0 \end{cases}$$

This control law generates very high switching frequency pulses to the H Bridge due to which switching losses can be increased. To rectify this disadvantage hysteresis band is used to generate the pulses.

Control signals for switching transistors in H Bridge are generated from hysteresis function in such a way that $S_{S1}$ and $S_{S4}$ are switched on and of simultaneously. $S_{S2}$ and $S_{S3}$ are also switched on or off simultaneously as these two are complement of $S_{S1}$ and $S_{S4}$.

$$S_{s1} and\ S_{s4} = \begin{cases} on\ when\ i_f > i_f^* + h \\ on\ when\ i_f < i_f^* - h \end{cases}$$

Where h is the hysteresis band.

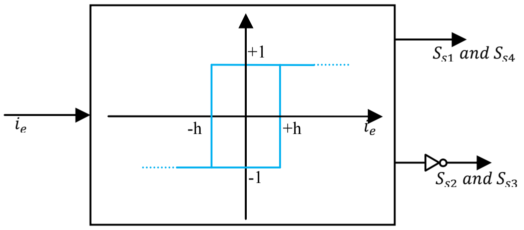

Fig.5. Hysteresis Band

## III. Simulation Results

Simulation results are carried out using MATLAB/SIMULINK to check effectiveness of proposed controlling strategies on shunt and series active filters. Parameters of the system and both the filters are given in Table1.

**Table 1**

| | |
|---|---|
| Source Voltage | 100 V |
| Frequency | 50 Hz |
| Non Linear Load | 10 Ω, 50 mH |
| Linear Load | 5 Ω |
| Capacitive Filter Cf | 10 µF |
| Inductive Filter Lf | 5 mH |
| Capacitance Cdc | 100 µF |
| Hysteresis Bandwidth | ±0.1 |

### a). Series active filter

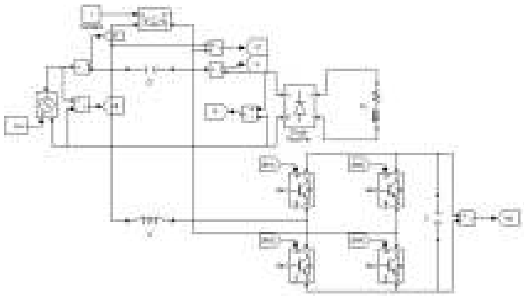

Fig.6. Simulation of series active filter

### 1. Voltage Sag

Simulation of series active filter is shown in fig.6. Using a controlled of voltage source 20% sag is created at source side between 0.1-0.2 sec as shown in fig.7a. Control strategy of series active filter is designed in simulink as shown in fig 3. Voltage injected by sereis active filter into line (Vf) will maintain load voltage (VL) to be constant. VL is shown in fig.7b. and Vf is shown in fig.7c. DC voltage of series active filter is shown in fig.8.

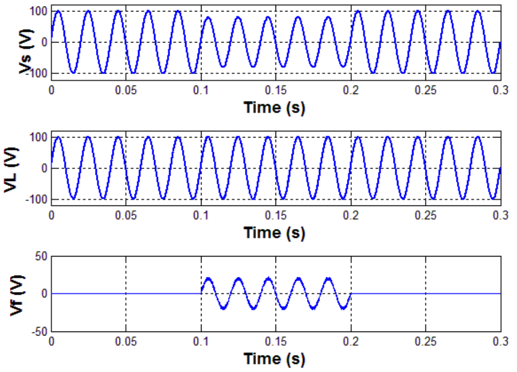

Fig.7. Source voltage Vs, load voltage VL and series active filter injected voltage Vf during sag

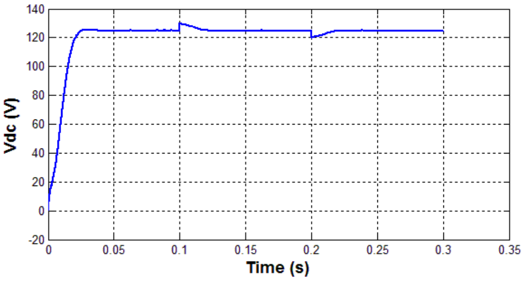

Fig.8. DC voltage across the capacitor of series active filter during voltage sag.

### 2. Voltage Swell

20% of voltage swell is created at source side to check effectiveness of series active filter during swell. Source voltage with swell is shown in fig.9a. Injected voltage by active filter (Vf) makes load (VL) to be constant. VL and Vf are shown in fig.9b. and fig9. DC voltage is shown in fig.10.

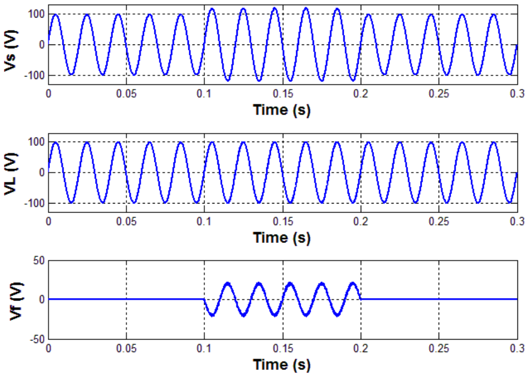

Fig.9. Source voltage Vs, load voltage VL and series active filter injected voltage Vf during swell

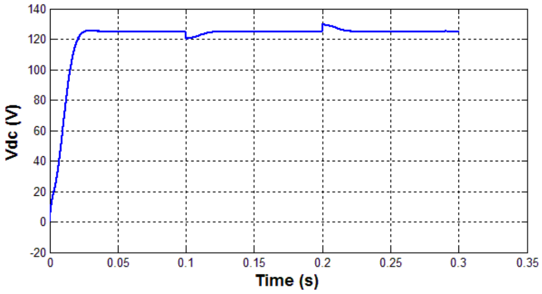

Fig.10. DC voltage across the capacitor of series active filter during voltage swell

### 3. Voltage Flicker

Voltage flickers are introduced at source side using controllable voltage source.fig.11a. is showing source voltage with flickering. These disturbbances in source can be eliminated by active filter by injecting compensating voltage shown in fig.11b. constant load voltage is shown in fig.11b.

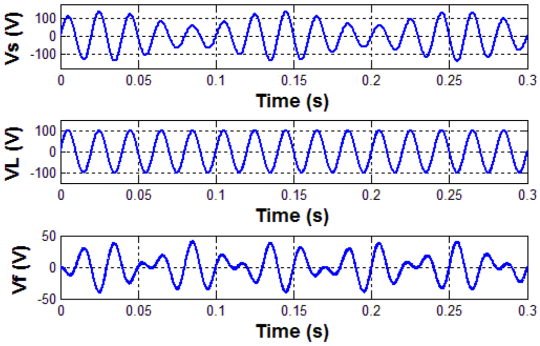

Fig.11. Source voltage Vs, load voltage VL and series active filter injected voltage Vf during flicker

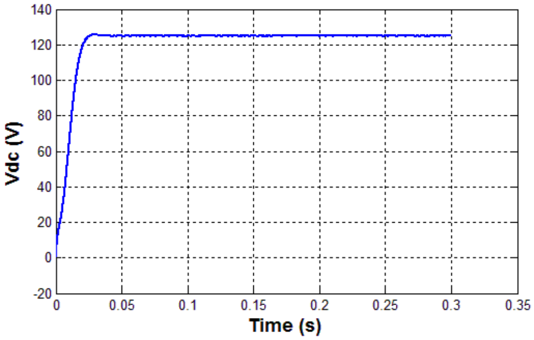

Fig.12. DC voltage across the capacitor of series active filter during voltage flicker

### b). Shunt Active Filter

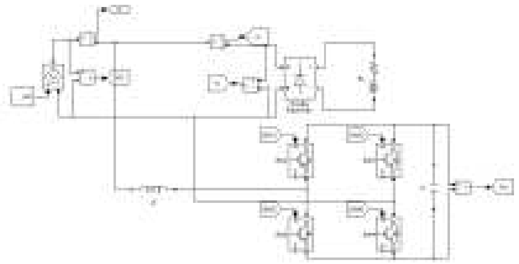

Fig.13. Simulation of series active filter

Single phase H Bridge is connected in parallel to improve current waveform. A diode bridge rectifier is connected which acts as non linear load. Control strategy of shunt active filter is designed in simulink as shown in fig 4. At 0.15 sec load is increased. Load current is shown in fig. THD of load current is 42.74%. Due to current injected by shunt active filter (If) into line, load current harmonics can be reduced and THD in source current can be improved to 1.04%. Filter current and source current are shown in fig.14. and fig.15.

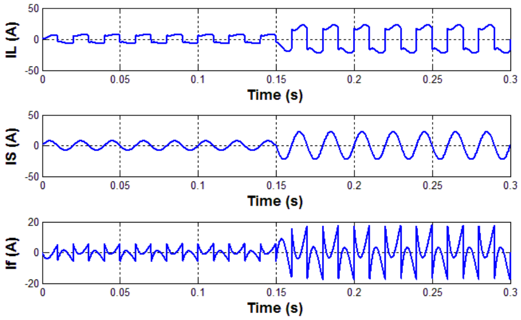

Fig.14. Load Current IL, Source Current IS and shunt active filter injected current If during load increase

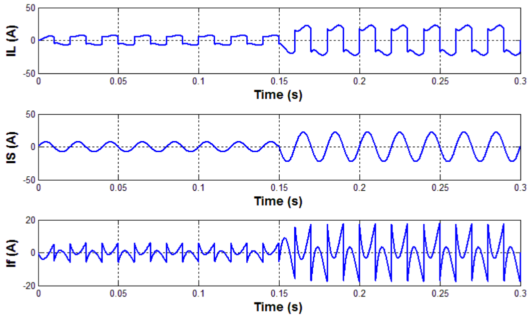

Fig.15. Load Current IL, Source Current IS and shunt active filter injected current If during load decrease

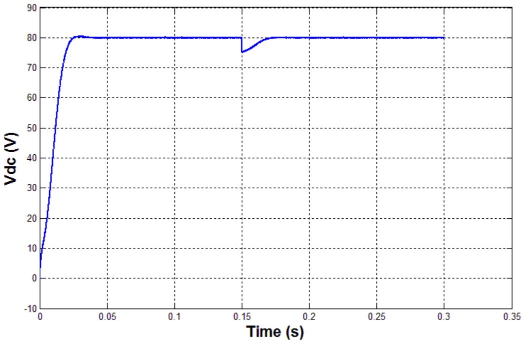

Fig.16. DC voltage across the capacitor of shunt active filter during load increase

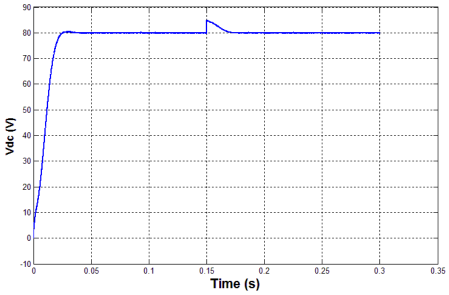

Fig.17. DC voltage across the capacitor of shunt active filter during load decrease

## IV. Experimental Results

Experimental setup for single phase active filter is shown in fig.18. and fig.19. Parameters of experimental setup shown in table 2.

Hysteresis bandwidth based PWM was developed for IGBT gating signals. The transistor can be switched when error between reference signal and actual signal exceeds fixed band. Switching frequency is limited to 20KHz, for effective performance of IGBTs.

**Table 2**

| | |
|---|---|
| Source Voltage | 100 V |
| Frequency | 50 Hz |
| Non Linear Load | 10 Ω, 50 mH |
| Linear Load | 5 Ω |
| Capacitive Filter Cf | 10 µF |
| Inductive Filter Lf | 5 mH |
| Capacitance Cdc | 100 µF |
| Hysteresis Bandwidth | ±0.1 |

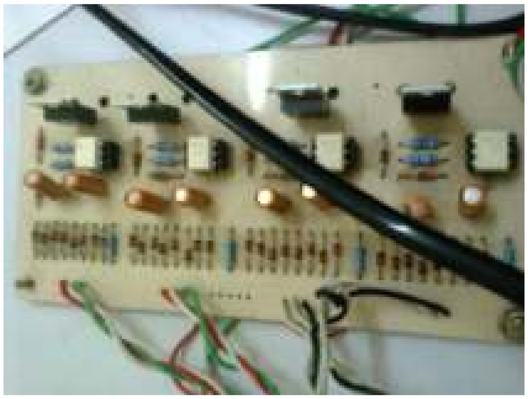

Fig.18. Hardware of H Bridge for Active Filter

Fig.19. Active Filter with Non Linear Load

### a). Series active filter

Experiment results are presented for series active filter.

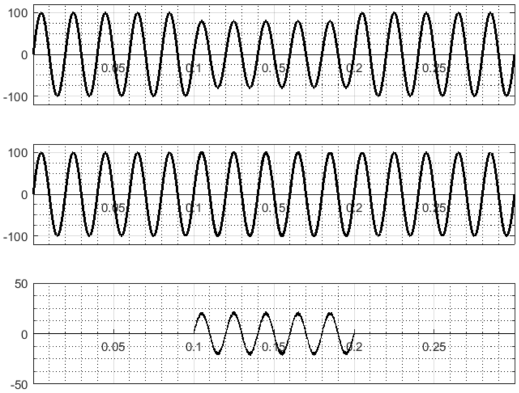

Fig.20. Source voltage Vs, load voltage VL and series active filter injected voltage Vf during sag

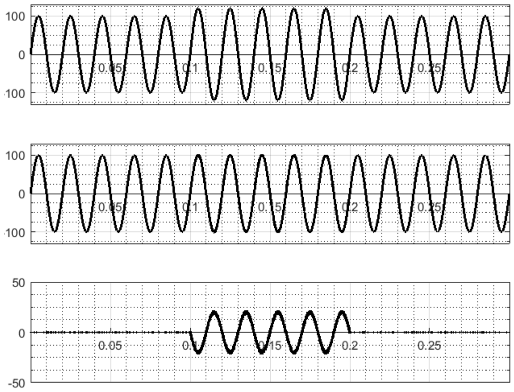

Fig.21. Source voltage Vs, load voltage VL and series active filter injected voltage Vf during swell

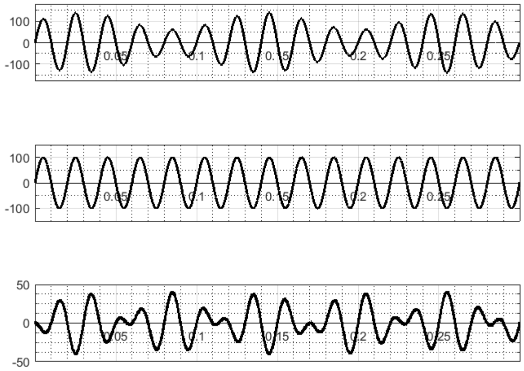

Fig.22. Source voltage Vs, load voltage VL and series active filter injected voltage Vf during flicker

**b). Shunt active filter**

Experimental results of shunt active filter are shown in fig.23. and fig24. For load increase and decrease respectively.

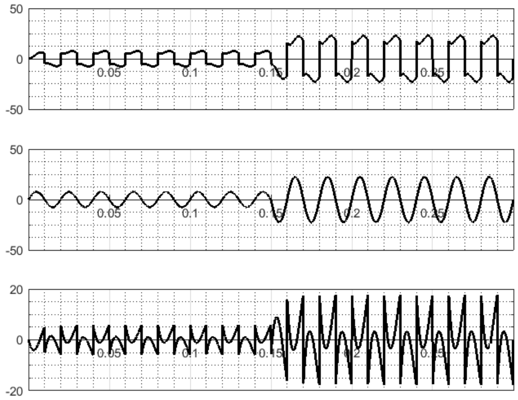

Fig.23. Load Current IL, Source Current IS and shunt active filter injected current If during load increase

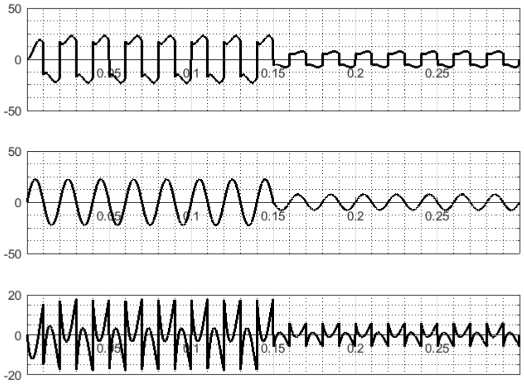

Fig.24. Load Current IL, Source Current IS and shunt active filter injected current If during load decrease

## V. Conclusion

Active power filters can improve power quality by reducing various power quality problems like sag, swell, flicker and current harmonics. In this paper series and shunt active filters are designed to improve power quality in a single phase distribution system. Main objectives for control strategy of series active filter is maintain constant DC voltage and regulating load side voltage. Shunt active filter control strategy should reduce current harmonics injected by non linear load into source side. SPWM is used for generating pulses for series active filter and hysteresis PWM is used for shunt active filter. Simulation and experimental results are carried out for both filters to check effectiveness of control strategies.

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