Australian Journal of Basic and Applied Sciences, 5(7): 622-628, 2011
ISSN 1991-8178

Mitigation of Power Quality Problems with Series Active Filter

M. Najafi, M. Hoseynpoor, M. Davoodi, T. Karimi

Bushehr Branch, Islamic Azad University, Bushehr, Iran.

Abstract: Power quality is becoming an increasingly important topic in the performance of many industrial applications. There are numerous types of power quality issues and power problems such as voltage sags, voltage swells, interruptions, phase shifts, harmonics and transients. Control of power quality problems involves cooperation between network operator (utility), customer and equipment manufacturer. Series Active Filter injects three single phase AC voltages in series with the distribution feeder and in synchronism with the voltages of the distribution system. Series Active Filter establishes interface between utility and customer connected in series between the supply and load to mitigate the three major power quality problems, namely, the voltage sags, swells, and harmonics. In this paper, focus is given only on Series Active Filter system which will be simulated by using MATLAB software in order to mitigate voltage sags, swells, and harmonics. Mathematics model for calculation of voltage disturbances and injected voltage also described.

Key word: Power Quality, Series Active Filter, Voltage Sag, Voltage Swell.

INTRODUCTION

In recent years, the concentrating on power quality problems has revealed more than ever due to the increase in the growth of sensitive loads. A power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in failure or mis-operation of customers equipment. The increased concern has lead to measuring power quality variations, studying the characteristics of power disturbances and providing solutions to the power quality problems (Oliver *et al*, 2002) (Shin *et al*, 2006).

Series compensation is the most effective choice with a view to its technical and economic considerations for improving power quality (Ghosh and Ledwich, 2002),(Woodley *et al*, 1999). Series active filter is able to protect a sensitive load from the distortion in the supply side during fault or overloaded by injecting three phase ac output voltages in series and synchronism with the distribution feeder voltages (Ghosh and Ledwich, 2002). Fig.1 shows the structure and location of a typical Series active filter on the feeder of a sensitive load.

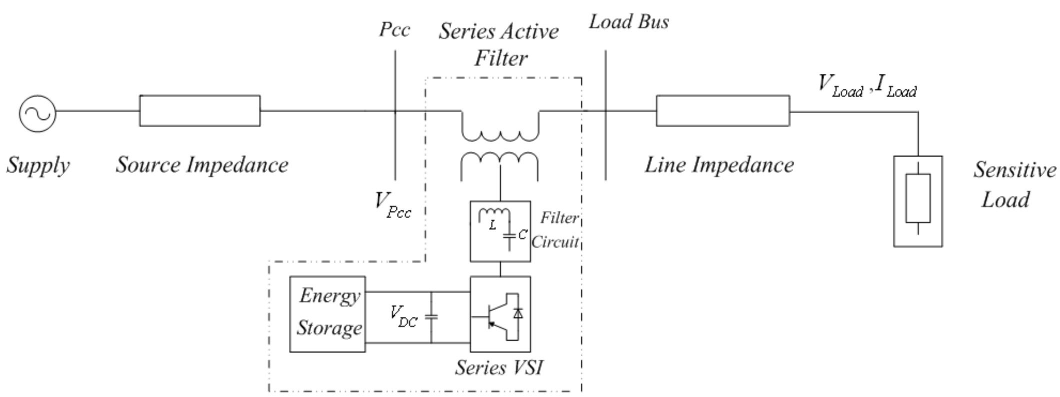


Fig. 1: Schematic diagram of a Series active filter.

As shown in Fig. 1, Series active filter consists of four major parts as follows (Ghosh and Ledwich, 2001):

Corresponding Author: M. Hoseynpoor, Bushehr Branch, Islamic Azad University, Bushehr, Iran.

- Voltage source inverter (VSI)
- Energy storage
- Passive filters
- Injection transformers

The three phase voltage source inverter (VSI) is the main part of Series active filter which principally switched by pulse width modulation (PWM) pattern. Energy storage in Series active filter provides active power required for voltage compensation. Passive filters in Series active filter configuration are mostly series LC type and used to eliminate the harmonic distortions from output voltage of the inverter. Injection transformers consist of three single phase transformers that boost the output voltage of Series active filter to the nominal voltage of the compensated feeder (McGranaghan *et al*, 1993).

Early accomplished researches in the field of compensation strategies were based on synchronous reference frame (d-q transformation) to detect voltage distortions. By means of this detection technique, voltage distortions were improved with an adequate response and accuracy (Nielsen *et al*, 2001).

This paper presents a new control scheme for a Series active filter through computer simulation. In this control scheme, the transformation of a three phase system to d-q, two axis system is used through which real and reactive power can be controlled individually. The performance of the above said control scheme is tested by applying different distortions such as sag, swell and harmonic.

Principle of Operation of Series Active Filter:

The single line diagram of a system with the Active filter connected in series with the supply is shown in Fig. 2 (a). The Series active filter injects a voltage (V_c) in series with the terminal voltage (V_t) so that the load voltage (V_L) is always constant in magnitude. Fig. 2 (b) shows the phasor diagram of Series active filter when the terminal voltage is having sag (V_t) and swell (V_t') in the voltage.

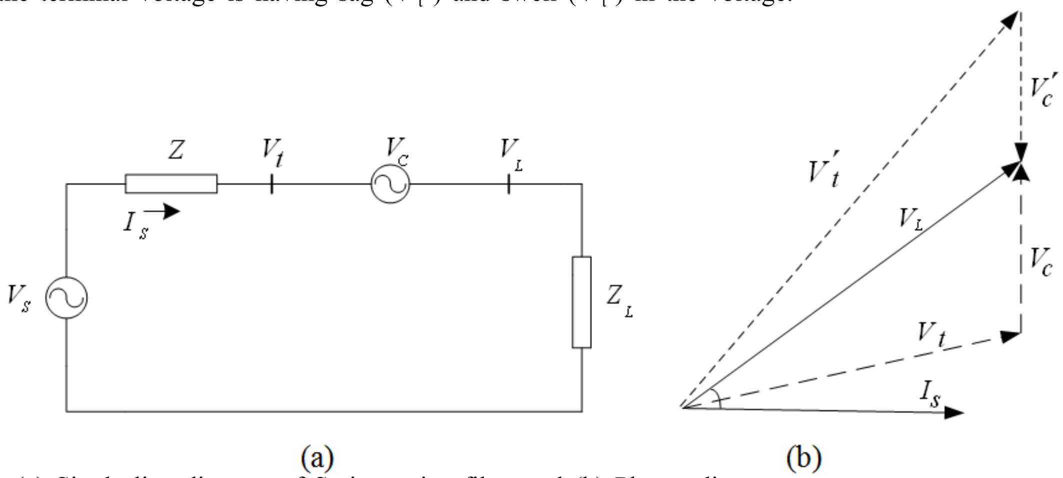


Fig. 2: (a) Single line diagram of Series active filter and (b) Phasor diagram.

The series inverter controls the magnitude and angle of the voltage injected in series with the line and this voltage injection is to influence the power flow on the line. The actual value of the injected voltage can be obtained in several ways such as Direct voltage injection mode, phase angle shifter emulation mode, line impedance emulation mode and automatic power flow control mode. In this paper, the series inverter operates in the direct voltage injection mode. The basic idea of a Series active filter is to inject the missing voltage cycles into the system through series injection transformer whenever voltage distortions are present in the system supply voltage. During normal operation, the capacitor receives energy from the main supply source. When voltage swells or sags are detected, the capacitor delivers dc supply to the inverter. The inverter ensures that only the missing voltage is injected to the transformer. A relatively small capacitor is present on dc side of the PWM solid state inverter, and the voltage over this capacitor is kept constant by exchanging energy with the energy storage reservoir. The required output voltage is obtained by using pulse-width modulation switching pattern.

***D - Q - 0 Control Strategy*:**

R.H.Park introduced the d-q-0 transformation. This paper presents operation of Series active filter using a control strategy which is based on d-q-0 axis control theory. This d-q-0 axis control system enables the

Series active filter to follow the changes in reference values like AC voltage, DC link voltage, real and reactive powers through the line. By implementing a d-q-0 axis controller it is possible to produce a relatively fast response and to reduce the interaction between real and reactive power flow. In this control system, the transformation of a three phase system to d-q-0 and d-q-0 to 3-phase quantities is done according to Park's transformation which real and reactive power can be controlled individually (Ooi *et al*, 1993).

Series Inverter Control Circuit:

The function of series inverter is to compensate the voltage disturbance in the source side, which is due to the fault in the distribution line. The series inverter control calculates the reference value to be injected by the series inverter as shown is Fig. 3.

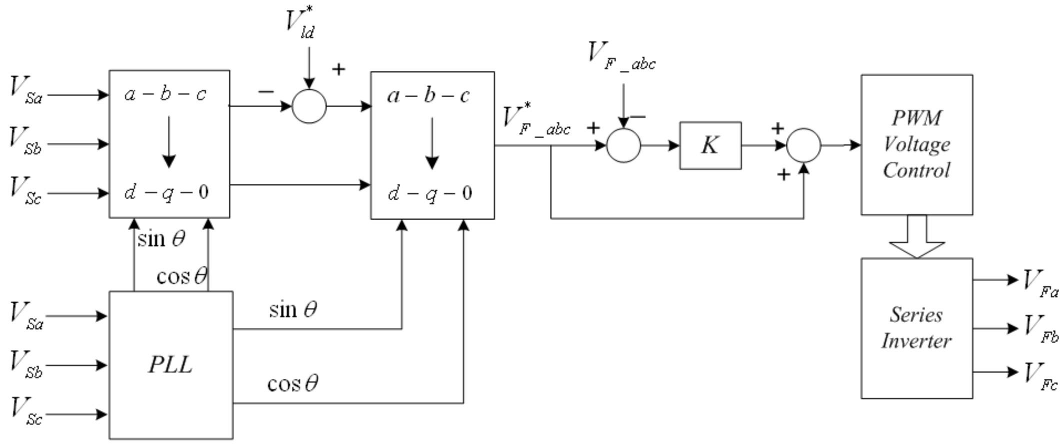


Fig. 3: Control block diagram of the series inverter.

The system voltages are detected and then transformed into synchronous d-q-0 reference frame using (1).

$$V_{sdq0} = T_{abc}^{dq0} V_{sabc} \tag{1}$$

$$T_{abc}^{dq0} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{2}$$

The load bus voltage should be kept sinusoidal with constant amplitude even if the voltage on system side is disturbed. So the expected load bus voltage in d-q-0 reference frame has only one value.

$$V_{ldq0}^{*} = T_{abc}^{dq0}.V_{labc}^{*} = \begin{bmatrix} V_m \\ 0 \\ 0 \end{bmatrix} \tag{3}$$

where

$$V_{labc}^{*} = \begin{bmatrix} V_m \cos(\omega t + \theta) \\ V_m \cos\left(\omega t + \theta - 120^\circ\right) \\ V_m \cos\left(\omega t + \theta + 120^\circ\right) \end{bmatrix} \tag{4}$$

Where V_m is peak value of desired load voltage, and θ is phase angle of load voltage which is determined by PLL (Phase Locked-Loop). This means d-axis of load reference voltage equals V_m while q-axis and zero axis of load reference voltage equals zero.

The compensation reference voltage is

$$V^*_{fdq0} = V^*_{ldq0} - V_{sdq0} \tag{5}$$

The compensation reference voltage in (5) is then inversely transformed into a-b-c reference frame. Comparing the compensation reference voltage with a triangular wave, the output compensation voltage of the series compensator can be obtained by PWM voltage control.

Simulation Results:

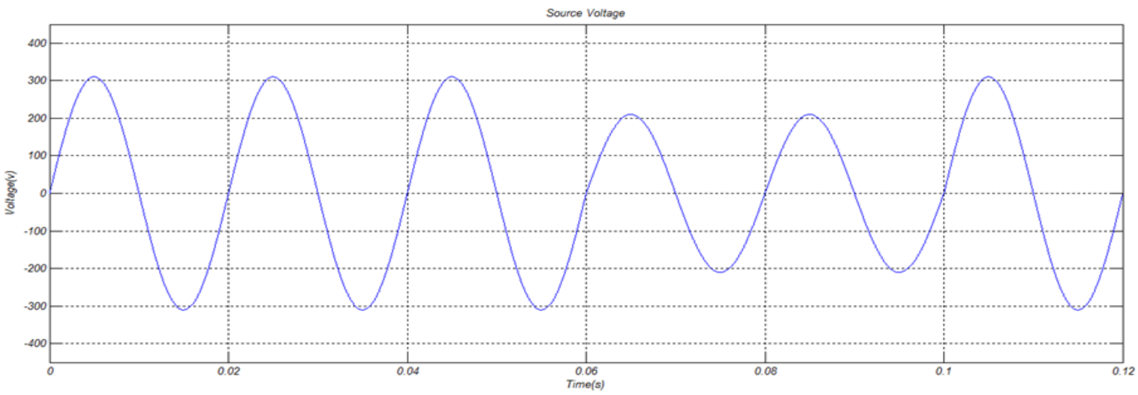
The simulation is done in MATLAB environment. In this software, all required parameters are considered. The parameter values of the system are shown in Table 1.

Table 1: The parameter values of the system.

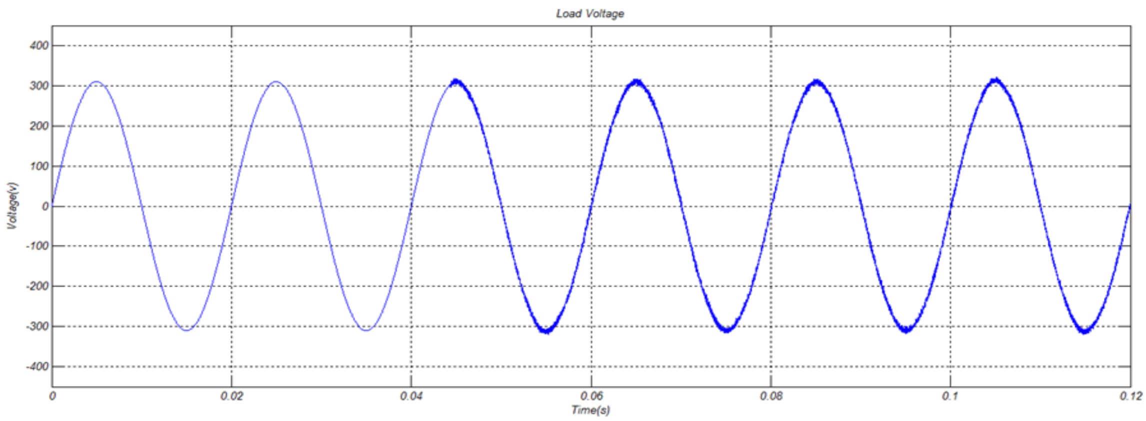
Parameters	Values
Source phase voltage	220v/50Hz
Source inductance	0.01 mH
Source resistance	0.01Ω
Line inductance	5 mH
Inverter output inductance	3 mH
Inverter output capacitance	60 µF
Inverter output resistance	10 Ω
Switching frequency	2kHz

Voltage Sag:

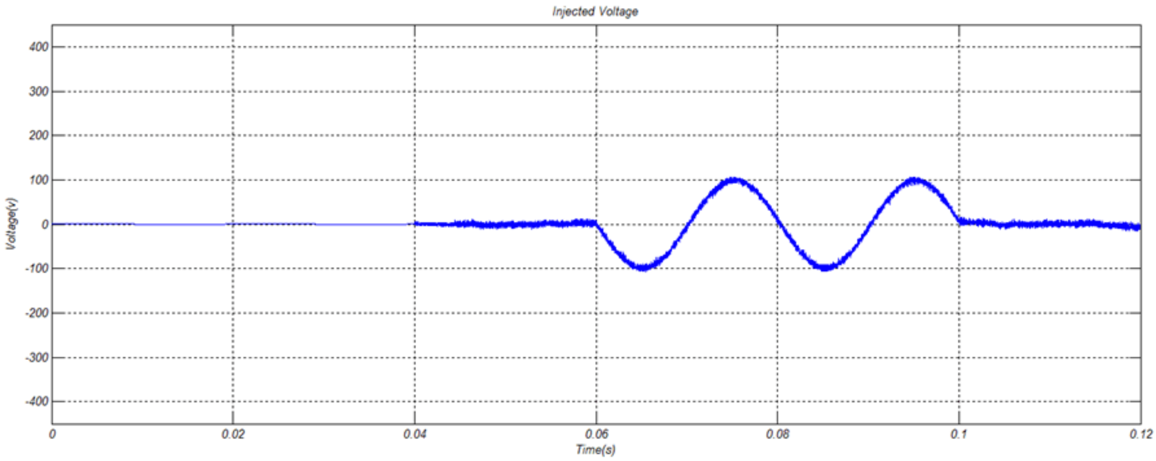
In this section, voltage sag is applied and the results are studied. A voltage sag with peak amplitude of 100v is applied from t=0.06sec to t=0.1sec. In t=0.04sec series inverter starts compensation. The source and load voltage are shown in fig. 4. (a) and fig. 4.(b). It is seen that the series inverter has modified load voltage correctly and also In fig. 4. (c) the injected voltage by series inverter is showen.



(a)



(b)

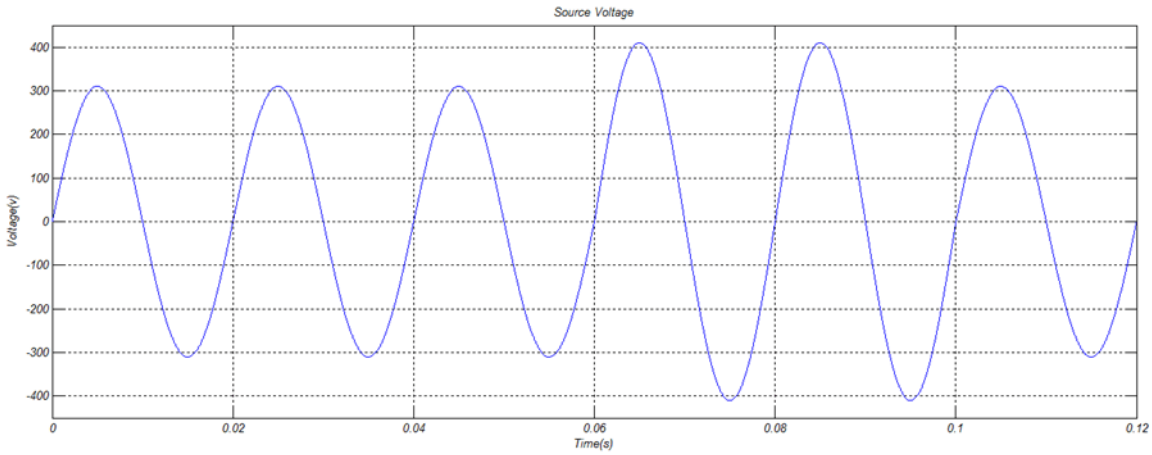


(c)

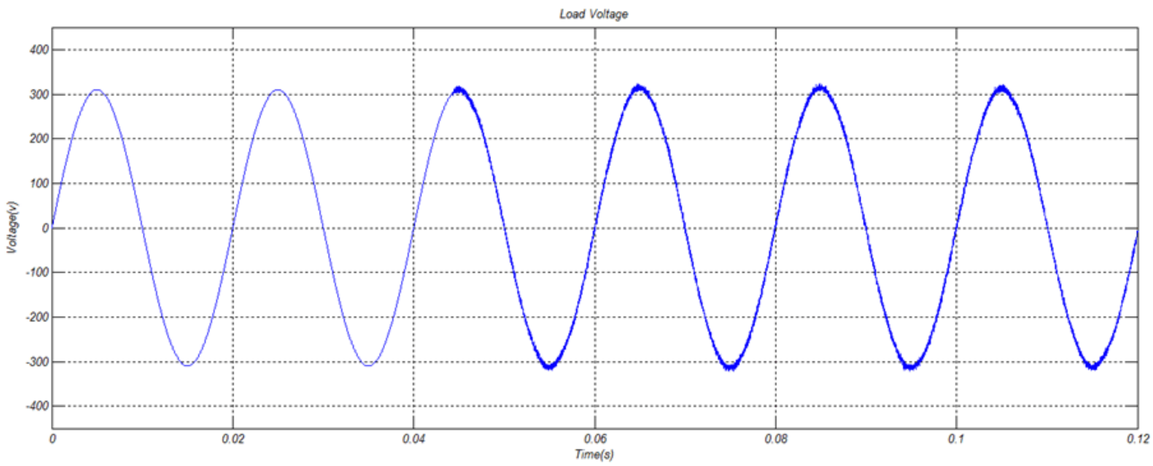
Fig. 4: (a). Source voltage. (b). Load voltage. (c). Injected voltage.

Voltage Swell:

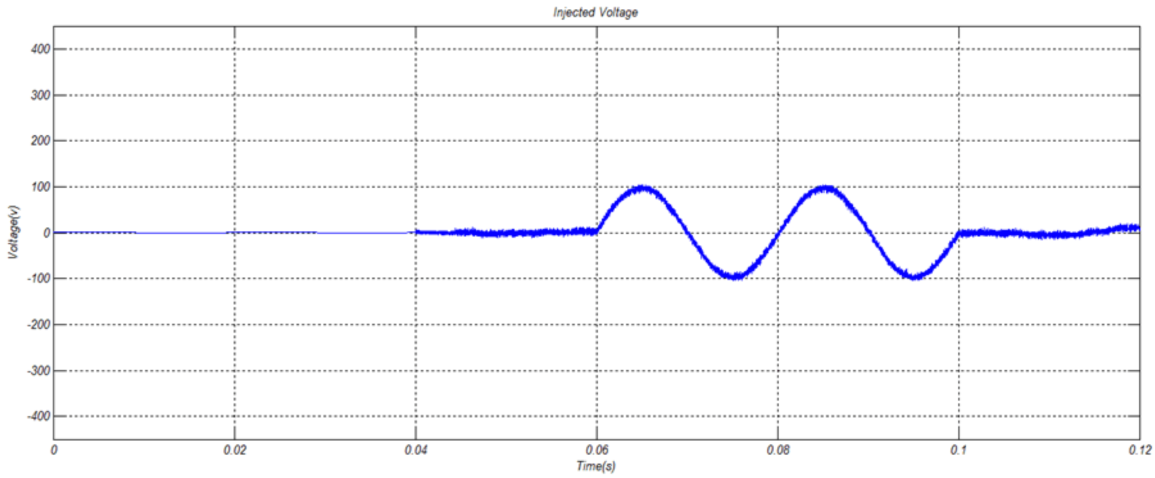
Voltage swell is studied in this section. A voltage swell with peak amplitude of 100v is applied from t=0.06sec to t=0.1sec. Compensation starts from t=0.04sec. The source voltage is shown in fig. 5. (a). Fig. 5.(b). Shows that load voltage modified correctly and the injected voltage by series inverter is showen in fig. 5. (c).



(a)



(b)

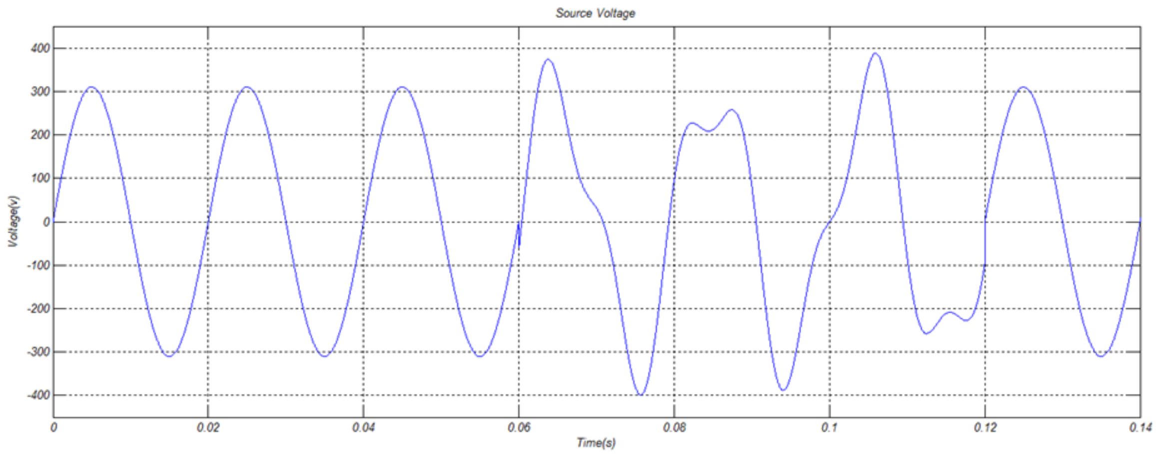


(c)

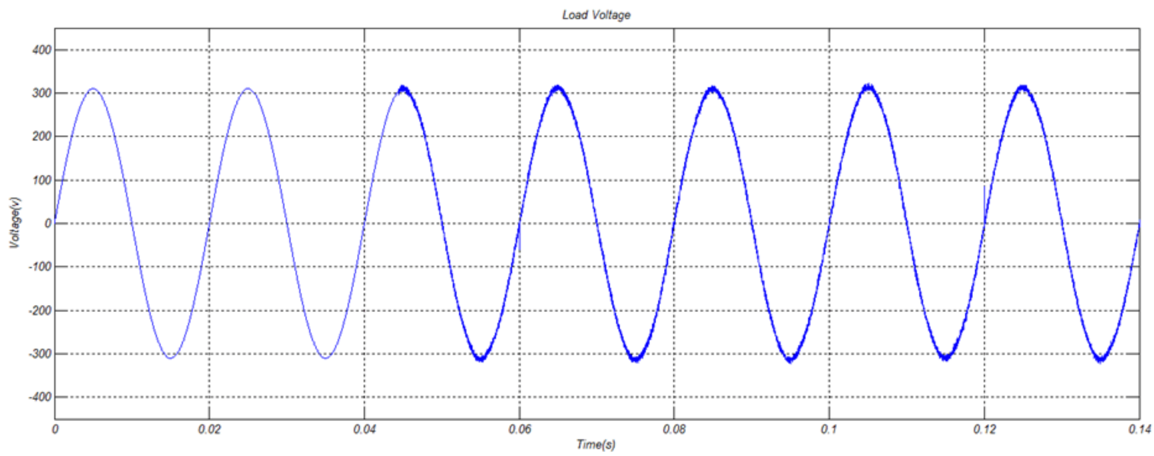
Fig. 5: (a). Source voltage. (b). Load voltage. (c). Injected voltage.

Voltage Harmonic Compensation:

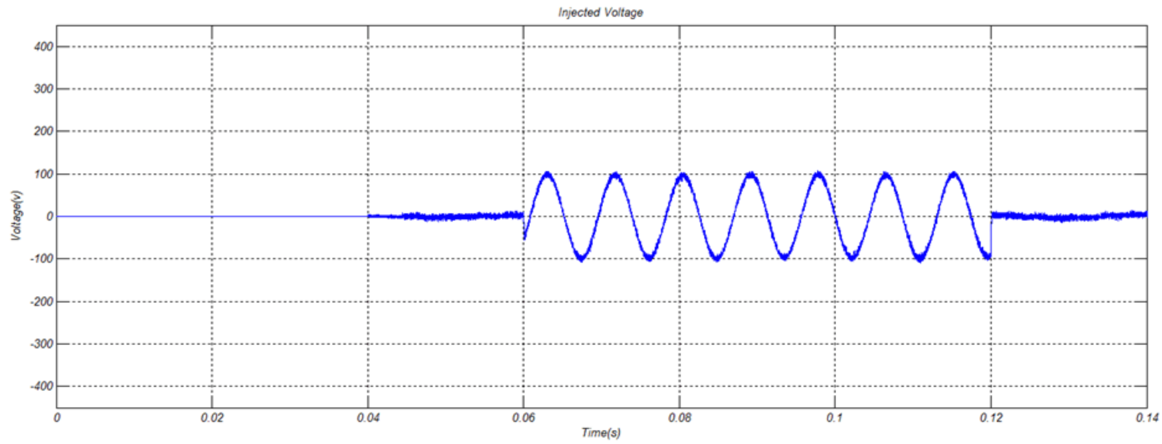
In this section, harmonic voltage is applied and the results are studied. A harmonic voltage is applied from t=0.06sec to t=0.12sec. The source voltage is shown in fig. 6. (a). Fig. 6. (b). Shows that load voltage modified correctly and the injected voltage by series inverter is showen in fig. 6. ©.



(a)



(b)



(c)

Fig. 6: (a). Source voltage. (b). Load voltage. (c). Injected voltage.

Conclusion:

The Series active filter is a promising and effective device for power quality enhancement due to its quick response and high reliability. The conclusion is that the Series active filter is an effective apparatus to protect sensitive loads from short duration voltage distortions. The role of a Series active filter in mitigating the power quality problems in terms of voltage sag, swell and interruptions is explained. By applying d-q-0 control strategy, good transient response can be obtained. Simulation results show that the Series active filter has very good performance in mitigation of power quality problems.

REFERENCES

Ghosh, A. and G. Ledwich, 2002. Compensation of distribution system voltage using DVR, IEEE Transactions on Power Delivery, 17(4): 1030-1036.

Ghosh, A. and G. Ledwich, 2002. Power Quality Enhancement Using Custom Power Devices, Kluwer Academic Publishers.

Ghosh, A. and G. Ledwich, 2001. Structures and Control of a Dynamic Voltage Regulator DVR, IEEE Power Engineering Society, 3: 1027-1032.

McGranaghan, M.F., D.R. Mueller and M.J. Samotyj, 1993. Voltage Sags in Industrial Systems, IEEE Transactions on Industry Applications, 2: 397-403.

Nielsen, J.G., F. Blaabjerge and N. Mohan, 2001. Control Strategies for Dynamic Voltage Restorer Compensating Voltage Sags with Phase Jump, 16th Annual IEEE Conference on Applied Power Electronics, APEC, 2: 1267-1273.

Oliver, J.A., R. Lawrence and B.B. Banerjee, 2002. How to specify power-quality-tolerant process equipment, IEEE Ind. Appl. Magazine, 8: 21-30.

Ooi, B.T., S.Z. Dai and F.D. Galiana, 1993. A solid state PWM phase-shifter. IEEE Transaction on Power Delivery, 8(2): 573-579.

Shin, Y.J., E.J. Powers, M. Grady and A. Arapostathis, 2006. Power quality indices for transient disturbances, IEEE Power Delivery, 21: 253-261.

Woodley, N.H., L. Morgan and A. Sundaram, 1999. Experience with an inverter based dynamic voltage restorer, IEEE Transactions on Power Delivery, 14(3): 1181-1186.