International Journal of Information and Technology (IJIT) – Volume 2 Issue 3, May-Jun 2016

RESEARCH ARTICLE OPEN ACCESS

Shunt Active Power Filter for Power Quality Improvement on Injection Transformer by using Fuzzy Controller

Mrs. M. Inba Arasi [1], S. Ranjitha [2]

ME Research Scholar [2], Assistant Professor [1]

Department of Electrical & Electronics Engineering

Mahendra College of Engineering, Salem

Tamil Nadu – India

ABSTRACT

Active filters are widely employed in distribution system to reduce the harmonics produced by non-linear loads. This project deals with improving the power quality of sensitive loads from voltage sags using injection transformer with an indirect current controlled shunt active power filter (APF) for improving power quality by reactive power compensation and harmonic filtering. The proposed APF is controlled by fuzzy controller and it is based on a voltage source inverter (VSI). The VSI is controlled by two loops, the voltage control loop and the current control loop. The voltage control loop regulates the DC link capacitor voltage and the current control loop uses hysteresis band control to shape the source current such that it is in-phase with and of the same shape as the input voltage. The proposed scheme has been verified through simulation investigations. This work presents and compares the performance of the PI controller with a fuzzy controller. The existing control strategies either mitigate the phase jump or improve the utilization of dc link energy by (i) reducing the amplitude of injected voltage, or (ii) optimizing the dc bus energy support. In this paper, an enhanced sag compensation strategy is proposed that mitigates the phase jump in the load voltage while improving the overall sag compensation time. This enhancement can also be seen as a considerable reduction in dc link capacitor size for new installation. The performance of proposed method is evaluated using simulation study and finally, verified experimentally on a scaled lab prototype.

Keywords:- Active power filter, Harmonic filtering, Hysteresis band control, Power quality

I. INTRODUCTION

In the industrial distribution systems, the grid voltage disturbances (voltage sags, swells, flicker and harmonics) are the most common power quality problems. Sag being the most frequent voltage disturbance, is typically caused by fault at remote bus and is always accompanied by a phase angle jump. The phase jump in the voltage can initiate transient current in the capacitors, transformers and motors. There has been a continuous rise of nonlinear loads over the years due to intensive use of power electronic control in industry as well as by domestic consumers of electrical energy. The utility supplying these nonlinear loads has to supply large vars. Moreover, the harmonics generated by the nonlinear loads pollute the utility. The basic requirements for compensation process involve precise and continuous var control with fast dynamic response and on-line elimination of harmonics. To satisfy these criterion, the traditional methods of var compensation using switched capacitor and thyristor controlled inductor coupled with passive filters are increasingly replaced by active power filters (APFs) and hybrid APFs The hybrid APFs improve the characteristics of passive filters with smaller rated APFs. The majority of the reported APFs and hybrid APFs use a var calculator to calculate the reactive current drawn by the load and accordingly a reference current is generated. The compensator current is made to follow the reference current for the required compensation. This method exhibits good current profile and fast dynamic response; however the generation of reference current is a complicated process. In the proposed indirect current controlled APF, the reference current is generated from the DC link capacitor voltage directly, without calculating the reactive current drawn by the the load, the compensation process is straight forward and simple as com-pared to the control techniques of conventional APFs.

For higher rated nonlinear loads; multilevel inverters (MLIs) can be used. To control the output voltage and reduce undesired harmonics of MLIs, sinusoidal PWM, selective harmonic elimination or programmed PWM and space vector modulation techniques have been conventionally used in MLIs. The major complexity associated with such methods is to solve the nonlinear transcendental equations characterizing the harmonics using iterative techniques such as Newton–Raphson method. However, this is not suitable in cases involving a large number of switching angles if good initial guess is not available. Another approach based on mathematical theory of resultant, wherein transcendental equations that describe the selective harmonic elimina-tion problem are converted into an equivalent set of polynomial equations and then mathematical theory of resultant is utilized to find all possible sets of solutions for the equivalent problem has also been reported. However, as the number of harmonics to be eliminated increases (up to five harmonics), the degrees of the polynomials in the equations become so large that solving them becomes very difficult. The evolutionary algorithm can be applied for computing the optimal switching angles of the MLI with the objective of optimizing the individual harmonics to allowable limits. It can also disturb the operation of commutated converters and may lead to glitch in the performance of thyristors based loads. It is therefore imperative to protect sensitive loads, especially from the voltage sags with phase jump. To protect sensitive loads from grid voltage sags, custom power devices (such as, SVC, D-STATCOM, DVR and UPQC) are being widely used. Among these devices.

The proposed indirect current controlled shunt APF is shown in Fig. 1. It has two control loops, the voltage control loop and the current control loop. The voltage control loop regulates the average value of the DC link capacitor voltage (V_c). The sensed DC link capacitor voltage is sent to a low pass filter (LPF) to remove the ripples present in it. The voltage thus obtained is compared with a reference DC voltage ($V_{c,ref}$) and the error is fed to a PI controller. The output of the PI controller is the amplitude (k) of the current, which is used to derive the reference current. The derived reference current is compared with the source current in the cur-rent control loop for generating gate signals for the switches of the voltage source inverter (VSI) of the APF. Hysteresis band control has been used in the current control loop of the proposed APF. Indirect current controlled APF.

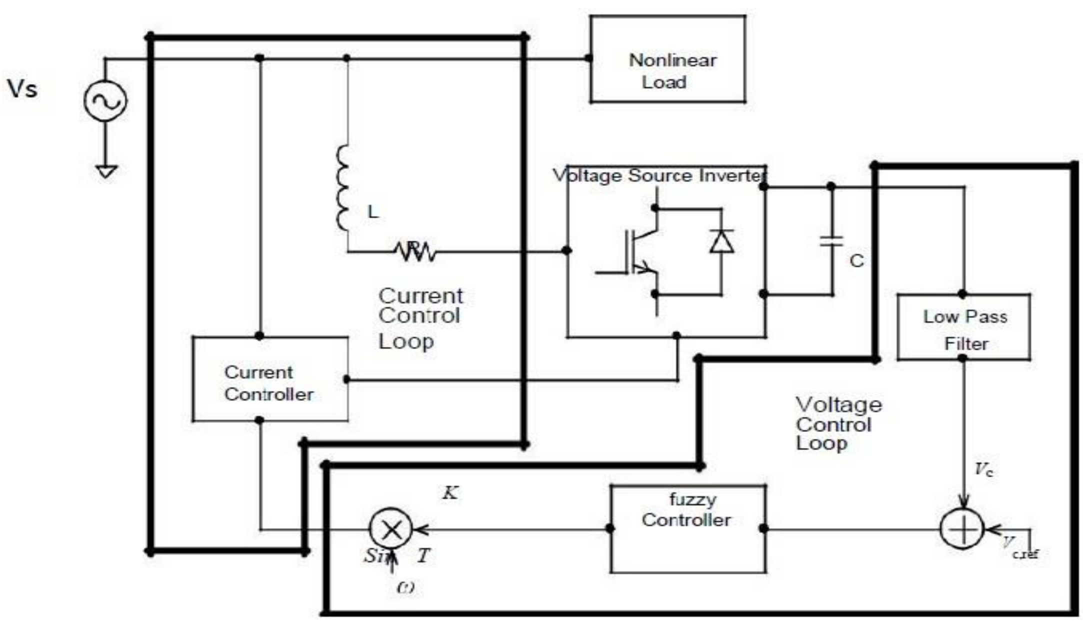

Fig. 1.Indirect Current Controlled Shunt APF.

II. INDIRECT CURRENT CONTROLLED APF

The VSI of a single-phase indirect current controlled shunt APF is shown in Fig. 2. The VSI is controlled to produce a fundamental terminal voltage in-phase with the AC system voltage. When the fundamental inverter terminal voltage is more than the RMS value of AC system voltage V_s, a leading current is drawn from the AC system and when the inverter terminal voltage is less than V_s, a lagging current is drawn from the AC system. The magnitude of the inverter terminal voltage depends on the DC link c apacitor voltage V_c.

By controlling the gate signals of the switches, the inverter terminal voltage can be made to lag or lead the AC system voltage, so that real power flows into or out of the inverter circuit When $V_{comp1} > V_{s,}$ leading current (with respect to V_s) will be drawn and the inverter supplies lagging vars to the system. When $V_{comp1} < V_{s,}$ the inverter draws lagging current and it sup-plies leading vars to the system. When V_{comp1} ¼ $V_{s,}$ no current will flow into or out of the system. The var supplied by the APF is given by

$$Q \quad = \quad \frac{Vs\,|\,Vcomp1Vs\,|}{\sqrt{\omega 2L2 + R2}} \qquad (1)$$

where L is the inductor in series with the APF, R is the resistance of inductor L and x is the supply frequency. By controlling V_{comp1}, the reactive power can be controlled.

III. CONTROL PRINCIPLE

The switches S_1, S_2, S_3 and S_4 (Fig. 2) are operated in such a way that total current drawn from the source is of the same shape as that of the source voltage V_s. This gives where i_{comp} is the compensation current of the APF and V_c is the DC link capacitor voltage.

s = 1, if the switches S_1 and S_4 conduct; s = 1, if the switches S_2 and S_3 conduct and s = 0.

$$\frac{dicomp}{dt} = \frac{Vs - R\,icomp - sVc}{L} \qquad (2)$$

IV. VOLTAGE SOURCE INVERTER

The Voltage Source Inverter is controlled to produce a fundamental terminal voltage in-phase with the AC system voltage

When the fundamental inverter terminal voltage is more than the RMS value of AC system voltage V_s, a leading current is drawn from the AC system and when the inverter terminal voltage is less than V_s, a lagging current is drawn from the AC system.

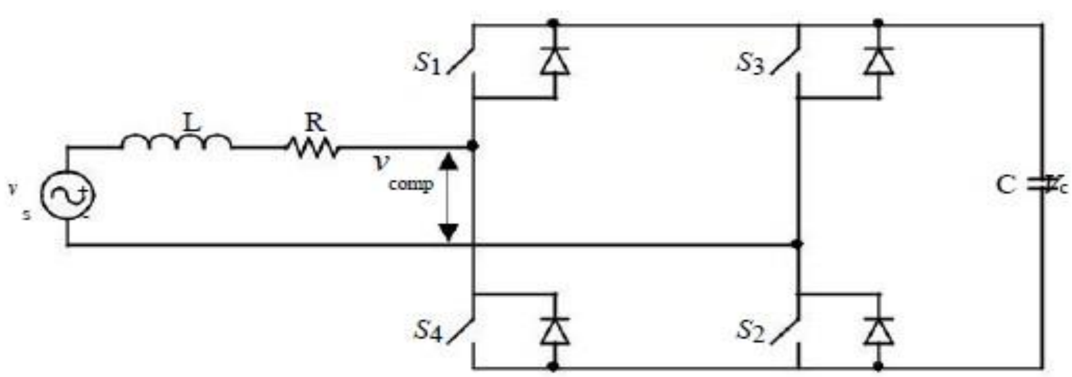

Fig. 2. Voltage source inverter

The APF forces the source current to become same in shape as the source voltage V_s. The source current i_s can be expressed in terms of compensation current of the APF, By controlling the switching function s, (4) can be controlled. V_c is maintained at a voltage higher than V_s. This is done by the volt-age control loop. The dynamic stability of the indirect current con-trolled APF depends on its ability to keep the DC link capacitor voltage close to a reference value. The capacitor voltage control loop assumes that the active power supplied by the source is the sum of the power drawn by the load and the losses in the inverter. During the sudden increase in load power demand, capacitor volt-age decreases because the energy stored in the capacitor supplies power to the load. This results into an increase in the capacitor error voltage, which ultimately increases the magnitude of the reference current. The increase in reference current recharges the capacitor to the reference value.

V. DESIGN OF DC LINK CAPACITOR

The DC link capacitor supplies or absorbs energy, whenever there is a sudden change in the active power demand of the loads.In such conditions, the capacitor supports the load demand for the half period of the supply frequency. The DC link capacitor value is calculated from the energy balance principle. The energy stored in capacitor is equal to the energy demand of the load during the transient period. This assumption after simplification gives the expression for calculating the value of DC link capacitor, C as $V_{c,min}$ is the desired minimum capacitor voltage. In practice, a slightly higher capacitance value is selected to take care of the capacitor losses. The reference value of the capacitor voltage $V_{dc\ ref}$ is selected mainly on the basis of reactive power compensation capability. For satisfactory operation the magnitude of $V_{dc\ ref}$ should be higher than the magnitude of the source voltage V_S.

By suitable operation of switches a voltage V_S having fundamental component V_{C1} is generated at the ac side of the inverter.This results in flow of fundamental frequency component I_{s1}, as shown in Figure 3.3. The phasor diagram for $V_{c1}>V_S$ representing the reactive power flow is also shown in this Figure.3.4.In this, I_{s1} represent fundamental component.

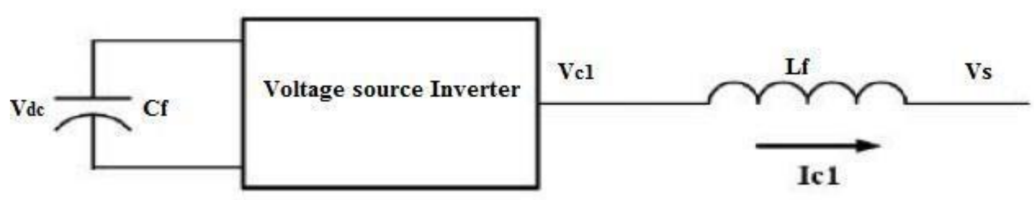

Figure 3. Single line diagram for SHAF

The dynamic stability of the indirect current controlled APF depends on its ability to keep the DC link capacitor voltage close to a reference value. The capacitor voltage control loop assumes that the active power supplied by the source is the sum of the power drawn by the load and the losses in the inverter.

During the sudden increase in load power demand, capacitor voltage decreases because the energy stored in the capacitor supplies power to the load. This results into an increase in the capacitor error.

VI. DESIGN OF FILTER INDUCTOR

The reference cur-rent is expressed as

$$i_{ref}=k\sin\omega t. \qquad (3)$$

$$\max(di_{ref}/dt)=k\omega \qquad (4)$$

The maximum di_{ref}/dt of the reference current is determined for each harmonic component based on its amplitude and frequency.The overall maximum di_{ref}/dt of the reference current is the highest individual di/dt.The harmonic giving the highest third harmonic for the single-phase and fifth harmonic for the three-phase nonlinear loads.

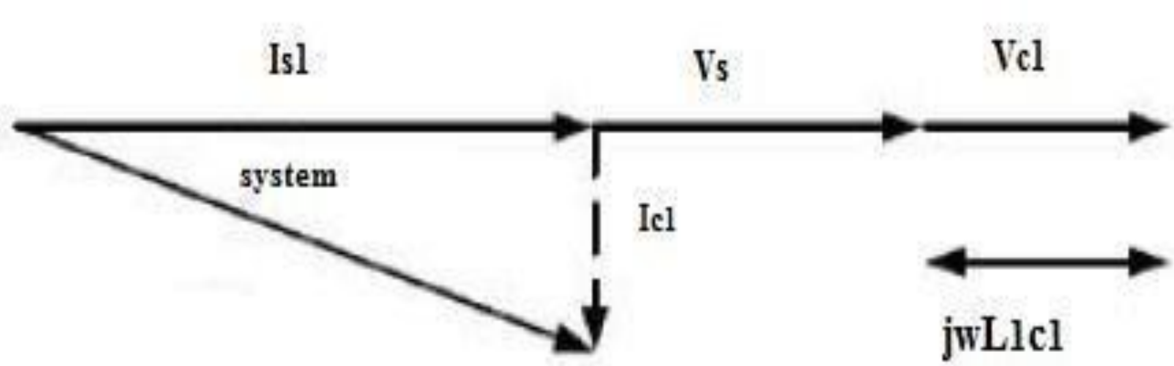

Figure 4. Vector diagram of SHAF

VII. HYSTERESIS BAND CONTROL

The maximum inductance possible is used in the inverter to give the lowest average switching frequency. This in turn reduces the electromagnetic interference and switching losses.

Analysis of the above equation shows that the required capacitance of the DC capacitor is

Proportional to the line inductance and inversely proportional to the specified DC voltage fluctuation. The value of the DC-link capacitor can also be designed in order to supply active power to the load during a pre-defined time interval in case of AC source absence. Thus, knowing the AC connecting inductance, the nominal DC voltage and the allowed voltage fluctuation, the DC capacitor value can be obtained.

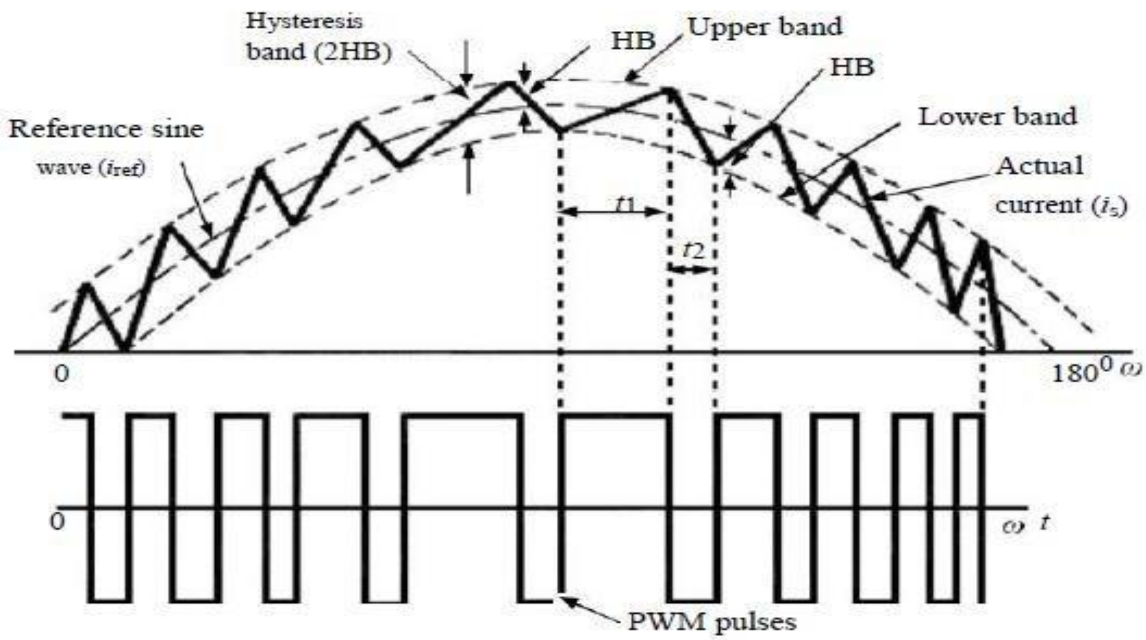

Figure 5. Basic Principle of Hysteresis Current Controller

It is used for controlling the voltage source inverter so that the output current is generated from the filter will follow the reference current waveform is shown in Figure 3.5The hysteresis control, limit bands are set on either side of a signal representing the desired output waveform .The inverter switches are operated as the generated signals within limits. The control circuit generates the sine reference signal wave of desired magnitude and frequency, and it is compared with the actual signal The hysteresis control, limit bands are set on either side of a signal representing the desired output waveform .The inverter switches are operated as the generated signals within limits. The control circuit generates the sine reference signal wave of desired magnitude and frequency, and it is compared with the actual signal. As the signal exceeds a prescribed hysteresis band, the upper switch in the half-bridge is turned OFF and the lower switch is turned ON. As the signal crosses the lower limit, the lower switch is turned OFF and the upper switch is turned ON .The actual signal wave is thus forced to track the sine reference wave within the hysteresis band limits.

Hysteresis current control is a method of controlling a voltage source inverter so that an output current is generated which follows a reference current waveform. This method controls the switches in an inverter asynchronously to ramp the current through an inductor up and down so that it tracks a reference current signal. Hysteresis current control is the easiest control method to implement.

The respective equation for switching intervals t_1 and t_2 can be written as

$$(di_s^+/dt)-(di_{ref}/dt)t_1=2HB \qquad (5)$$

$$(di_s^-/dt)-(di_{ref}/dt)t_2=2HB \qquad (6)$$

- lowerband $\leq i_{ref} - i_s$ upper band,none of the switches are ON.
- $I_{ref} - i_s$ > upper band,$S_1$and S_2 are ON.
- $I_{ref} - i_s$ < lower band,S_3 and S_4 are ON.

The realation between t_1 and t_2 can be written in terms of switching frequency of the hysteresis band,ω_s as

$$t1+t2=2\pi/\omega s \quad (7)$$

The expression of hysteresis band,HB can be expressed as

Wherei_{ref}=ksinωt. (8)

The maximum switching frequency $\omega_{s,max}$ for a specified hysteresis band can be expressed as

$$\omega_{s,max}=0.5\pi V_c/HB.L \quad (9)$$

VIII. SWITCHING PULSE

The magnitude of the inverter terminal voltage depends on the DC link capacitor voltage V_c. By controlling the gate signals of the switches, the inverter terminal voltage can be made to lag or lead the AC system voltage, so that real power flows into or out of the inverter.

By suitable operation of the switches, a voltage V_{comp} having a fundamental component V_{comp1} is generated at the output of the inverter. When $V_{comp1} > V_s$, leading current (with respect to V_s) and the inverter supplies lagging vars to the system.

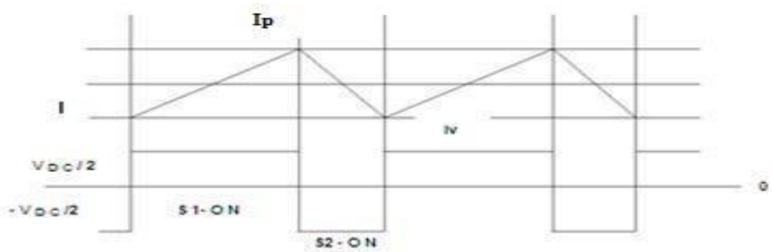

Figure 6. Switching pulse of the inverter

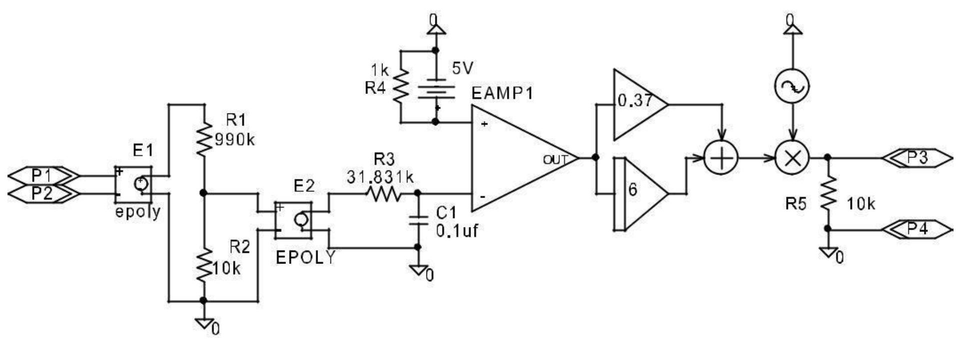

Figure 7. Voltage control loop of APF (HB1).

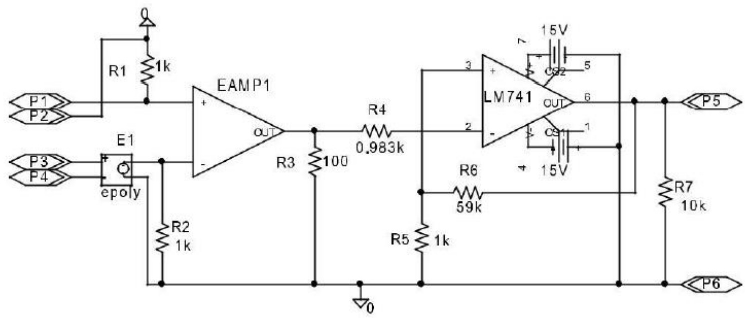

Fig. 8. Current control loop of APF (HB2).

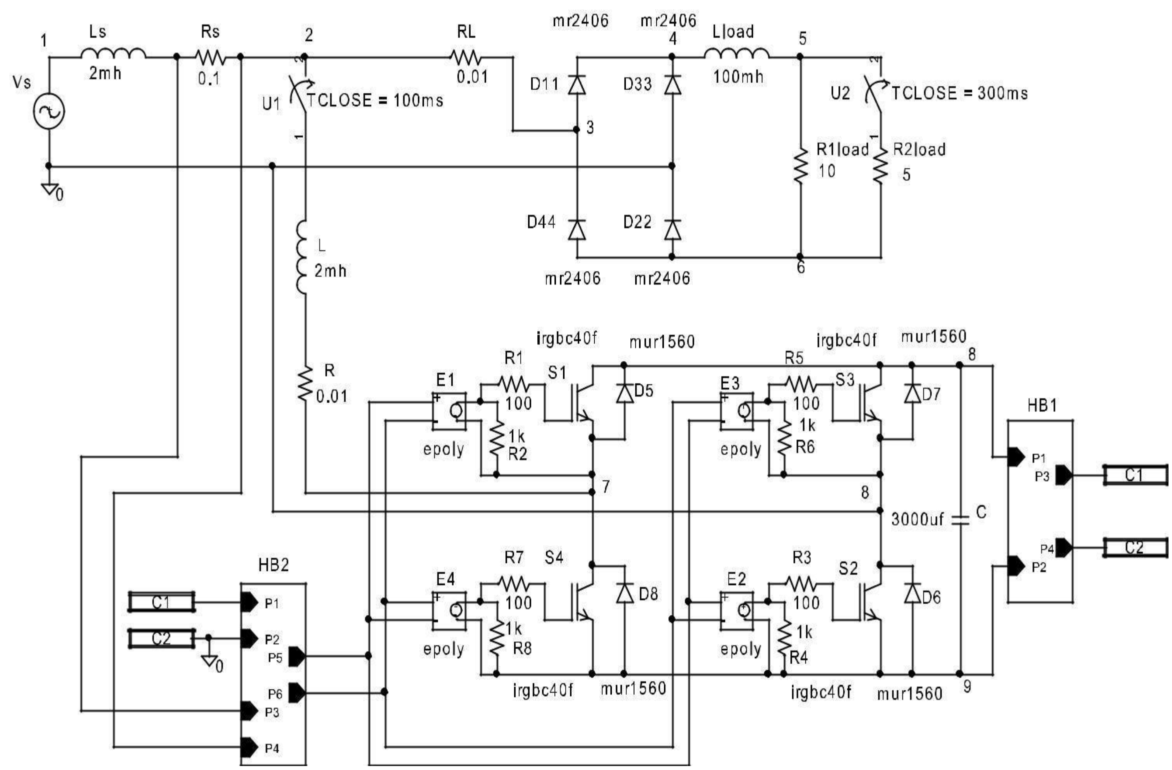

Fig. 9. Simulation circuit of single-phase shunt APF with diode rectifier feeding an RL load

The simulated waveforms of single phase sunt active power filter with diode rectifier feeding an RL load with fuzzy controller are shown below.The (a) load current I(RL), (b) source current I(Ls)and voltage at node 1 V(1),(c) current supplied by APF I(L) and (d) DC link capacitor voltage V(C:1)–V(C:2).

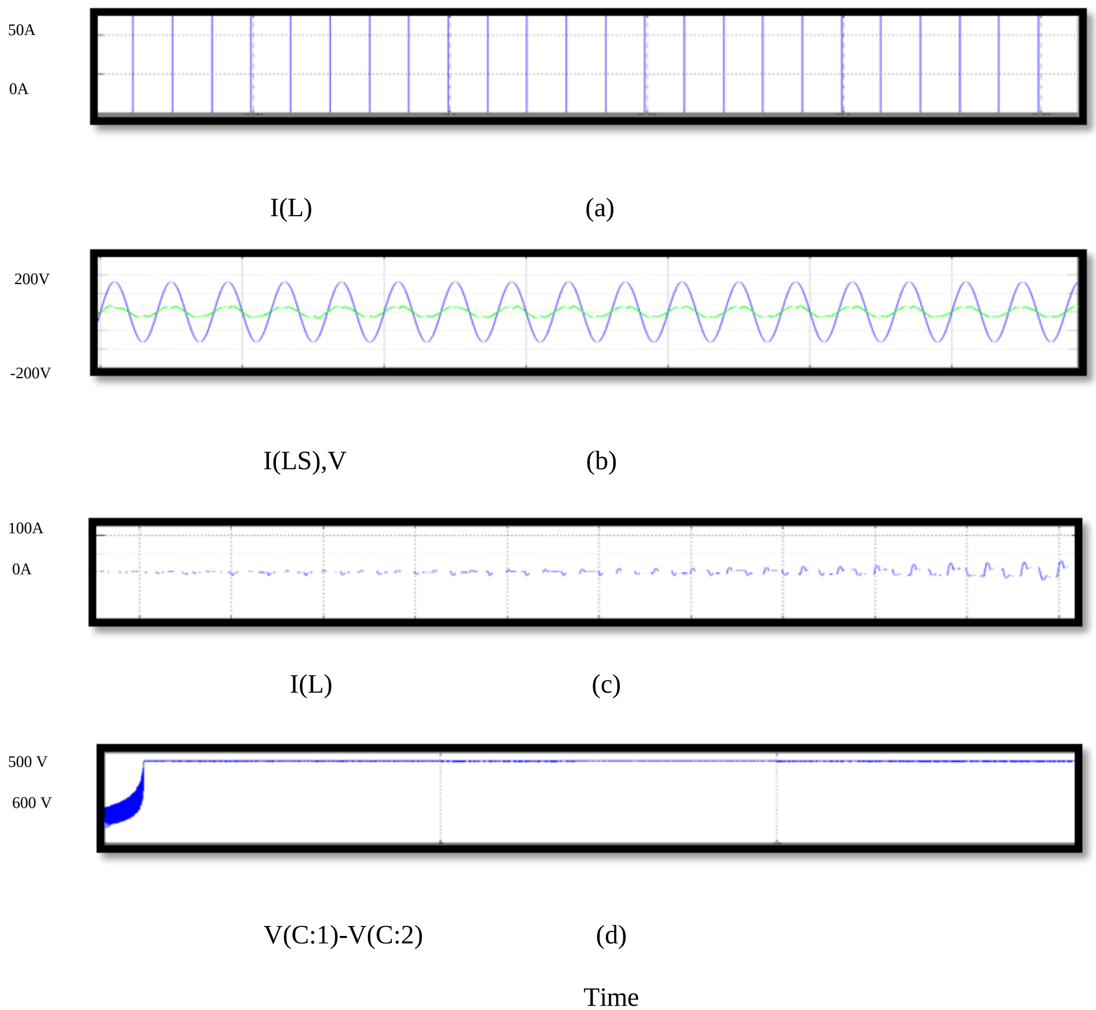

Fig. 10. Simulated waveforms of single-phase shunt APF with diode rectifier feeding an RL load in fuzzy controller.

(a) Load current I (RL),

(b) Source current I (Ls) and voltage at node 1 V(1)

(c) Current supplied by APF I (L)

(d) DC link capacitor voltage V(C: 1)–V(C: 2).

IX. SIMULATION RESULTS

The proposed indirect current controlled shunt APF has been simulated using Pspice for a 230 V, 50 Hz AC sys tem for the cases: (1) single-phase shunt APF with diode rectifier feeding an RLload with PI controller, (2) single-phase shunt APF with diode rectifier feeding an RL load with fuzzy controller.

7.1Single-phase shunt APF with diode rectifier feeding an RL load

The simulation circuit of single-phase shunt APF with diode rectifier feeding an RL load is shown in Fig. 9(R1load = 10 X, R2load = 5 X and L load = 100 mH). The control loops HB1 and HB2 are same as that. The simulated waveforms of I (RL), I(Ls), V(1), I(L) and V(C:1)–V(C:2) are shown in Figs.8 & 9(a)–(d). The harmonic spectra of I (RL) and I(Ls) after step change in load at 300 ms are shown in Figs. 4(a) and (b).

X. DISCUSSIONS ON SIMULATION RESULTS

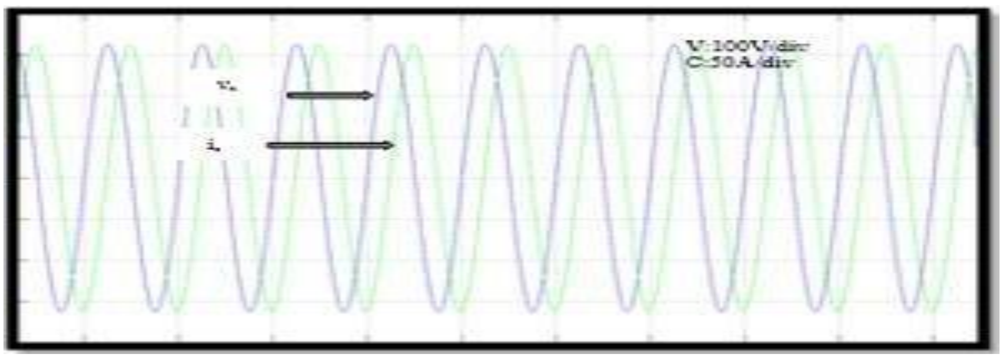

Fig.11.Simulated Waveform Of Source Voltage Vs. And Source Current Is Waveforms before Connecting Of Apf In Fuzzy Controller

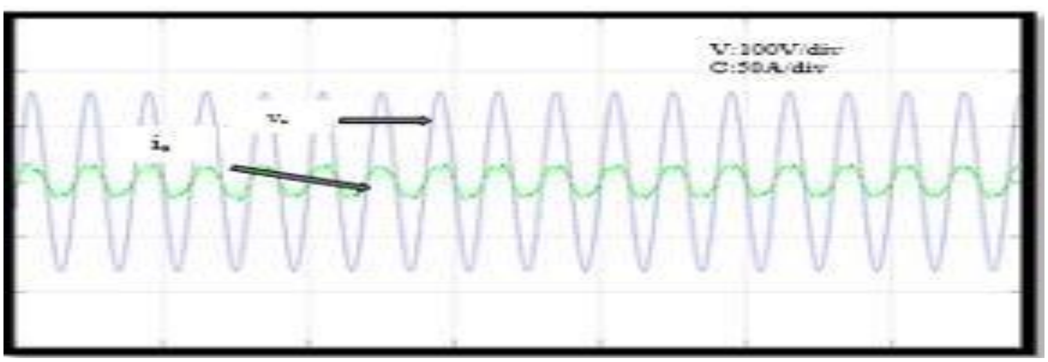

Fig.12.Simulated waveform of source voltage vs. and source current is waveforms after connecting of APF in fuzzy controller.

The individual harmonic components in load current I(RL), source current I(Ls) and % total harmonic distortion (THD) for the cases discussed. THD (%) of the source currents for all the two cases are well below 5%, the harmonic standards defined in IEEE Standard 519–1992. It may be observed from the simulation studies that the source current and voltage at the point of common coupling is distorted at the instant of connecting the APF. However, it does not affect the performance of APF and the source current becomes sinusoidal after connecting the APF in PI and fuzzy controller.

It may be noticed from the simulation results that the dynamic response time of the proposed indirect current controlled shunt APF is two cycles. The reason behind this is that a LPF is used to eliminate the ripple from the sensed DC link voltage. Inclusion of a LPF introduces a finite delay in the control process. In addition, the DC link capacitor takes some time to respond to the change in load conditions.

XI.CONCLUSION

An indirect current is controlled by shunt APF has been proposed for improving power quality and harmonic filtering. The mathematical background of the indirect current will be controlled shunt APF using of the hysteresis band control has been used.
Simulations have been carried out using Pspice for single-phase indirect current controlled by shunt APFs. And it is for different types of nonlinear loads. A single-phase indirect current controlled shunt APF prototype has been tested and developed in the laboratory to analyzed some of the simulation results. As the reference current in the proposed APF in fuzzy controller has been generated by regulating the DC link capacitor voltage using fuzzy controller. Without calculating the reactive current drawn by the load, the compensation process is straight forward and simple as compared to conventional APFs. After compensation, the source current is sinusoidal and it is phase with the supply voltage. It compensates both harmonics and reactive power simultaneously. Finally, the simulation results of with and without filter has been compared.

REFERENCES

[1] Gyugyi L. Reactive power generation and control by thyristor circuits. IEEETrans Ind Appl 1979;15(5):521–32.

[2] Gyugyi L, Taylor Jr ER. Characteristics of static, thyristor-controlled shuntcompensators for power transmission system applications. IEEE Trans PowerApparatus Syst 1980;99(5):1795–804.

[3] Jin H, Goós G, Lopes L. An efficient switched-reactor-based static varcompensator. IEEE Trans Ind Appl 1994;30(4):998–1005.

[4] Karymov RR, Ebadian M. Comparison of magnetically controlled reactor (MCR)and thyristor controlled reactor (TCR) from harmonics point of view. Int JElectr Power Energy Syst 2007;29(3):191–8.

[5] Mahanty R. Large value AC capacitor for harmonic filtering and reactive powercompensation. IET Gen Transm Distrib 2008;2(6):876–91.

[6] Mahanty R. Modified static VAR compensator using a large value AC capacitor.Elect Power Syst Res 2010;80(2):240–7.

[7] Abdusalam M, Poure P, Karimi S, Saadate S. New digital reference currentgeneration for shunt active power filter under distorted voltage conditions.Elect Power Syst Res 2009;79(5):759–65.

[8] Vardar K, Akpinar E, Sürgevil T. Evaluation of reference current extractionmethods for DSP implementation in active power filters. Elect Power Syst Res2009;79(10):1342–52.

[9] Singh GK, Singh AK, Mitra R. A simple fuzzy logic based robust active powerfilter for harmonics minimization under random load variation. Elect PowerSyst Res 2007;77(8):1101–11.

[10] EL-Kholy EE, EL-Sabbe A, El-Hefnawy A, Mharous HM. Three-phase activepower filter based on current controlled voltage source inverter. Int J ElectrPower Energy Syst 2006;28(8):537–47.