International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 3 (2015) pp. 5971-5987

http://www.ripublication.com

Minimizing THD in a Non-Linear System by Hybrid Series Active Power Filter Using Cascaded Seven Level Inverter

C.Ramakrishnan[1] and S.Vijayan[2]

[1]Assistant Professor, Department of EEE, SNS College of Technology, Coimbatore, Tamilnadu, India
[2] Professor, Department of EEE, Surya Engineering College, Erode, Tamilnadu, India.
[1]ramramki.krishnan@gmail.com
[2]svijayansurya@gmail.com,

ABSTRACT

This paper focuses a design of hybrid series active filter to improve the power quality. An asymmetrical three phase seven level cascaded inverters along with the combination of LC connected in parallel with power lines acting as hybrid filter is considered for the analysis. The controller is designed to eliminate the source current harmonics. The control strategy is to eliminate the current harmonics is based on P-Q theory with phase locked loop for tracking the phase. Control strategies are based on extracting either source current harmonics or load voltage harmonics. Passive filters mitigate the load produced harmonics and the active filter helps to enhance filtering properties of passive filter. Series active filter is working as a voltage source to inject the voltage proportional to the current required for minimizing THD, thus it acts as harmonic isolator and further improves the filtering characteristics of passive filter. The validity of the control scheme is verified by simulation study with help of MATLAB/SIMULINK and comparative analysis is carried out with help of simulated values to obtain the harmonic values within standard values.

Keywords: Active filters, harmonics, harmonic distortion, PQ theory

1. INTRODUCTION

The increase in use of power electronic components in today's energy conversion system lead to the increasing power quality problems particularly power system harmonics. The harmonics introduces many malfunctions in equipments, overvoltage, heating and these cause harmonic impedance which affect system power quality. These harmonic current sources seems to be well identified, such as in industrial, commercial and residential facilities are exposed to well known patterns of waveform distortion. Non linear loads have been characterized into two types of harmonic sources as current source type and voltage source type harmonic sources. Their corresponding operating condition, features, applications issues, and adaptive harmonic sources of filters have been presented [F.Z.Peng., 1999].

Different non linear loads produce different harmonics but identifiable harmonic spectra. Various configurations of filters for elimination of harmonics produced by non linear load such as active and passive filters are discussed. These harmonics can be easily abated by use of filters such as passive filters which provides lower impedance to the tuned harmonic frequency than the source impedance to reduce harmonics flowing into the system. However it suffers from few disadvantages like parallel and series resonance and the effect of filtering characteristics get affected by supply impedance. They are also bulky, not suitable for variable loads and tuning frequency gets reduced with ageing, deterioration and temperature change.

This increasing austerity of harmonics in power system which made development of the equipment called as active filter which is also known as active power line conditioners. Several topologies of active filters are proposed [F.Z.Peng 1999 &2001], and they have been surveyed based upon the types of non linear loads[W.M.Grandy et al., 1990]. The active power line conditioners are classified as shunt and series, the use of these active filter for improvement of quality of power and their distinction is made [B. Singh et al., 1999]. Mostly shunt active filters have been implemented which compensates the harmonic current. Thus it acts as controlled current source for harmonic current produced due to non linear loads [Salem Rahmani et al., 2009]. However shunt active filters are expensive due to its large rating i.e. power capacity of filter increase with increase in load current to be compensated.

The emerging series filters can act as an active filter; this is capable of compensating voltage producing as well as current producing harmonics loads. The series active filter is better suited for harmonic voltage source such as diode rectifiers with dc smoothing capacitors [P. Salmeron et al., 2010]. The series active filter acts as sinusoidal current source in phase with mains of voltage was developed [Alexander Varschavsky et al., 2010]. This paper deals the filter used as hybrid i.e. in conjunction with passive filter.

The hybrid filter is used to mitigate source current harmonics as well as to regulate load voltage so as to compensate for abnormal utility voltages. Active filters can be implemented with Voltage Source Inverters [J.W.Dixon et al., 1997] but it possesses some disadvantages like high switching losses and high harmonic noise.

The cascaded H bridge multilevel inverter was used to implement the hybrid filter along with LC filter. Similar method of active filter is implemented [Alexander Varschavsky et al., 2010] which uses nine level topology with transformers. The use of nine level inverter which makes the control current circuit complex. The present technique overcomes advantages by eliminating the use of transformer and it uses a single DC source.

The multilevel inverter finds its own advantages [Mariusz Malinowkski et al., 2010] such as

1) Capability of producing cleaner voltage with low current distortion
2) It can operate with low switching frequency which drastically can reduce switching losses
3) Elimination of transformer by providing required voltage levels which results in faster response
4) Due to its simple structure it can be easily packed
5) In Multilevel inverter reduces voltage stress on power electronic devices

For higher number of inverter levels there is the more complicated problem of maintaining capacitor voltage balance while retaining good filtering performances.

To obtain efficient performance, it is important to obtain proper reference voltage generation. Major development in control strategy took place by [Akagi et.al.,1984] who introduces instantaneous power theory and another important technique by Synchronous Reference frame theory. There are several other techniques like hysteresis controller, digital deadbeat control, synchronous detection method and CRC theories, among all PQ theory is used in this paper. This method extracts its harmonic components of current but requires synchronization with grid voltage, under non sinusoidal supply voltage conditions.

2. SYSTEM DESCRPTION

2.1 System Configuration

The configuration of a hybrid filter connected into a non linear system is shown in **Fig.1**. In this a three phase source is connected to a non linear load which produces the voltage type harmonics. The hybrid filter consists of shunt passive filter connected to the load and series active filter in series and parallel to the load. The three phase cascaded seven level inverter acts as an active filter. A three single phase series connected transformer is not only to inject voltage into the system but also isolate the inverter from source side and also match the current and voltage of the inverter to the system specifications.

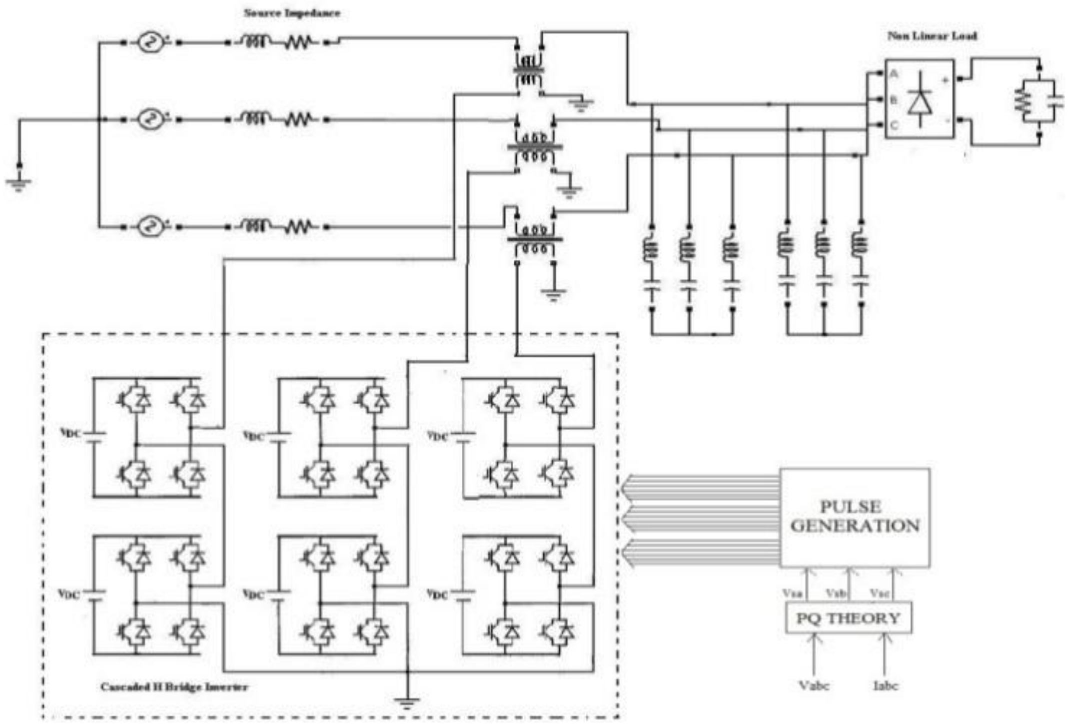

Fig.1. Hybrid Series Filter Configuration

2.2 Operation Principle

The operating principle of series active filter is different from shunt active filter. The series active filter is considered as controlled voltage source which generates compensation voltage for injection into the system. The active filter consists of three main circuits, namely control circuit for generation of compensation voltage, generation of gating pulse to the inverter and the inverter main circuit.

The first one produces reference voltage for the second part which produces gating pulses to the third part for compensation. **Fig. 2** shows the single phase equivalent circuit of series active filter, where v_s is the source voltage with source impedance z_s and current i_s is the source current. The voltage across load is denoted as v_l ; v_{af} denotes the compensated voltage by active filter.

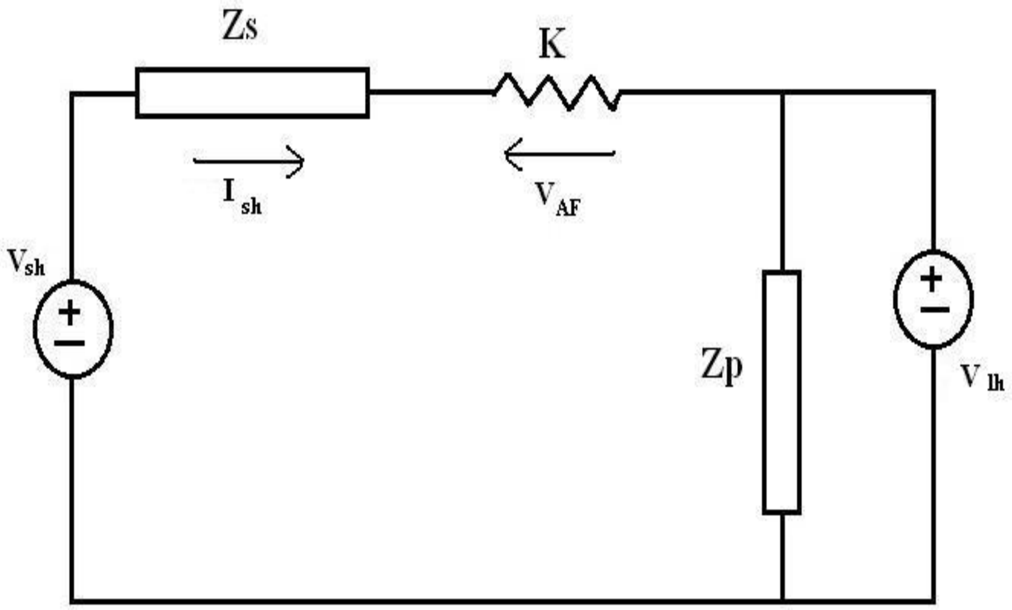

Fig.2. Single Phase Equivalent Circuit of Hybrid Filter

Current or Voltage signals contains fundamental as well as harmonic content which is denoted as: v_{sf} and v_{sh} is fundamental and harmonic content of source voltage respectively, i_{sf} and i_{sh} fundamental and harmonic content of source current respectively. Similarly the load voltage is described as v_{lf} and v_{lh} for its fundamental and harmonic content. Reference voltage is generated by detecting source current harmonics i_{sh}, and then form reference voltage which is k times proportional to source harmonic current (i.e. K. i_{sh}). Thus the series active filter is represented as resistor which has the value of K, the series active filter has value of zero for K, while it is K ohms for harmonic components. The reference voltage to each phase is

$$V_{af} = K^* i_{sh} + v_{aff} \quad (1)$$

From Fig 2 the harmonic current content is directly derived as

$$I_{sh}= \frac{V_{sh}-V_{lh}}{Z_s+K} \quad (2)$$

The series active filter offers high impedance path to the current harmonics and also acts as damping resistance, eliminating harmonic sinks problems which is an ingrained problem of shunt passive filter.

The series active filter is mostly used as controlled voltage source which is operated with shunt passive filter to compensate voltage producing harmonics. The load current is made to circulate mainly through passive filter rather than power system. This technique is recommended for voltage unbalance and voltage sags from AC system and low power system. The filter is installed at PCC of the distribution line [Hirofumi Akagi, 1994]. The active filter which injects current to a radial distribution system at PCC [Tien-Ting Chang et al., 2000] which determines the spectra of harmonics and location of injection by suitable method.

3. MULTILEVEL INVERTER

3.1 Topology of Inverter

The multilevel inverter is alternative to traditional PWM inverter which eliminates the need of transformer. There are various topologies of multilevel inverter like diode clamped, cascaded and neutral point clamped used in various industrial applications [Mariusz Malinowkski et al., 2010]. The multilevel inverters are used in electric vehicle applications which are used as boost inverter [Zhong Du et al., 2009] and [Pereda et al., 2012] which eliminate the need of inductors. It dealt with a hybrid cascaded H-bridge multilevel motor drive DTC control scheme that has potential for Electric or Hybrid Electric Vehicles. The paper proposes control method which is very significant reduction in the torque ripple; sinusoidal output voltages and currents lower switching losses and a high performance torque and flux regulation [Khoucha et al., 2010]. In this paper a cascaded asymmetrical seven level inverter topology is used in which it has unequal A input voltages by DC link capacitors. Asymmetric inverter provides an increased number of voltage levels for the same cells than its symmetric counterpart. Cascaded MLI is series connection of H Bridge which is connected to its own DC source.

The general cascaded H Bridge multilevel inverter is shown in **Fig.3**. The unequal DC input voltages are used for this asymmetrical multilevel Inverter to obtain desired magnitude of output voltage.

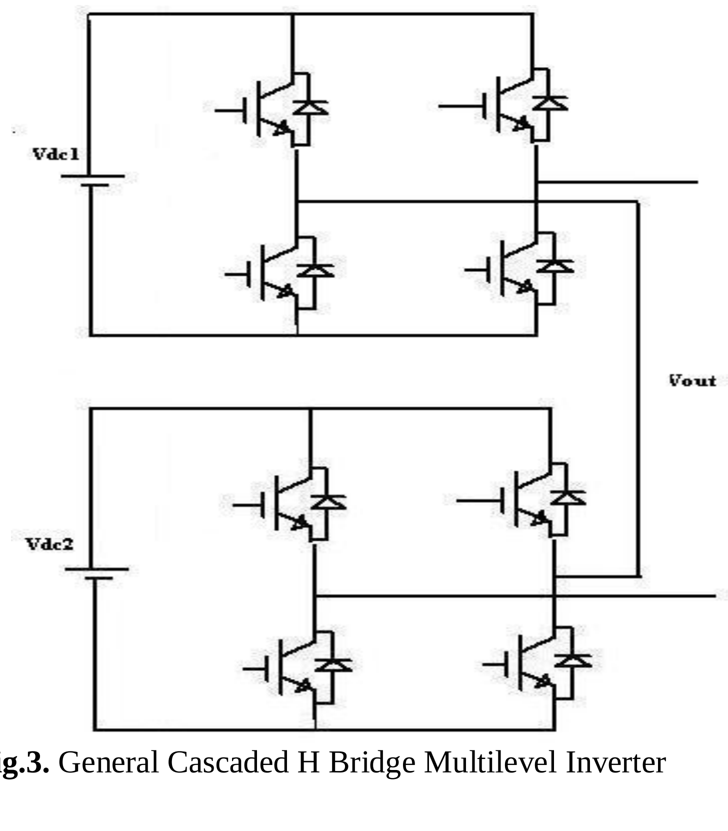

Fig.3. General Cascaded H Bridge Multilevel Inverter

The switching sequence of seven level inverter is given in **Table I**. Cascaded seven level MLI requires separate DC source for each of its H-Bridge which can be supplied by renewable energy sources.

Table I. Switching Sequence for Seven Level Inverter

Vout	S1	S2	S3	S4	S5	S6	S7	S8
Vdc1	1	0	0	1	1	0	0	1
Vdc2	0	1	0	1	1	0	0	1
Vdc1+ Vdc2	1	0	0	1	0	1	0	1
0	0	1	0	1	0	1	0	1
-Vdc1	0	1	1	0	0	1	0	1
-Vdc2	0	1	0	1	0	1	1	0
-Vdc1-Vdc2	0	1	1	0	0	1	1	0

3.2 Gate pulse generation for MLI

A Multicarrier sinusoidal pulse width modulation technique is employed to generate pulses for the seven level cascaded H bridge multi level inverter. There are various techniques for pulse generation are available such as carrier disposition method, phase shifted method, hybrid method, and trapezoidal modulation methods [Samir Kouro et al., 2008]. In carrier disposition method, the reference is sampled through number of carrier frequency displaced by contiguous increments of the reference waveform amplitude where no harmonics occur at carrier frequency. The carrier and reference voltage for gate pulse generation of seven level inverter is shown in **Fig.4** .In this technique six carrier signals were used for seven level output generation.

Phase shifted multicarrier PWM method uses m-1 carrier signals of the same amplitude and frequency which are phase shifted by 90 degrees to one another to generate the multi level inverter output voltages the gate signals for the cascaded inverter can be derived directly from the PWM signals.

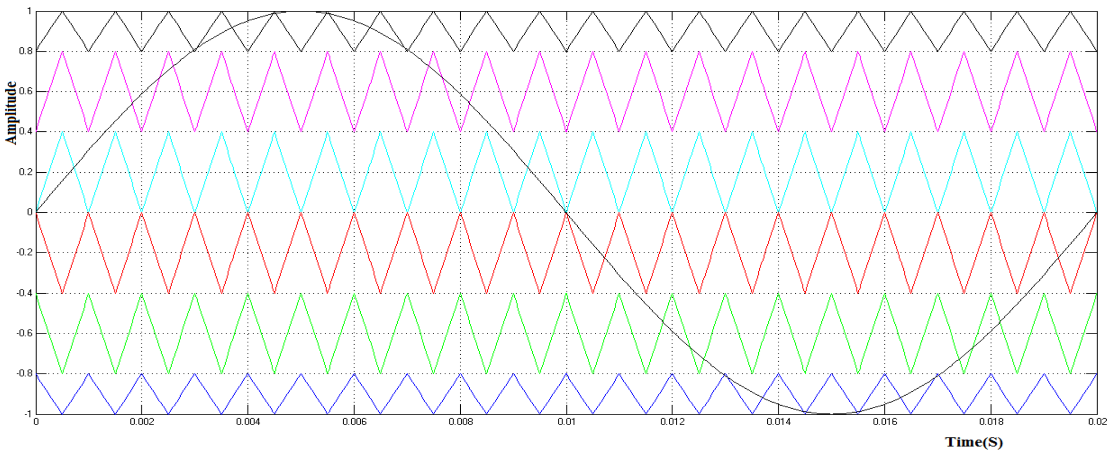

Fig.4. Carrier and Reference Voltage for Gate Pulse Generation of Seven Level Inverter

3.3 Harmonic Elimination
Output voltage V(t) of MLI can be expressed in Fourier series as

$$V(t) = \sum_{n=1}^{\infty}(A_n \sin n\alpha + B_n \cos n\alpha) \quad (4)$$

Due to the quarter wave symmetry of output voltage the even harmonics are absent (B_n=0) and only odd harmonics are present [Wanmin Fei et al., 2009].

The amplitude of n^{th} harmonic A_n is expressed only with first quadrant switching angle $\alpha_1,\alpha_2,\ldots\ldots\alpha_n$

$$A_n=\frac{4Vdc}{n\pi}\sum_{k=1}^{\infty}\cos n\alpha k \quad (5)$$

For any odd harmonics A_n can be expressed up to k^{th} term. Multilevel inverters are mainly employed in three-phase medium and high-voltage systems in which all the triplen harmonics are absent in output voltage because triplen harmonics can be automatically cancelled in line-line voltages for a balanced three phase system. The low order non triplen harmonics in the line-to-neutral voltages are to be eliminated.

3.4 Modulation Strategy
In general, inverters are modulated by pulse width modulation or pulses are generated by comparison of a modulated signal with carrier. The index of modulation is represented in two indices signal.

$$\text{Amplitude Modulation } (m_a) = \frac{A_m}{(m-1)A_c} \quad (6)$$

$$\text{Frequency Modulation } (m_f) = \frac{F_c}{F_m} \quad (7)$$

The carrier signals are defined with same frequency F_c and amplitude A_c. The index of modulation is shown in (6) and index of frequency is shown in (7) which is ratio of frequency of carrier with respect to the modulator. This is always greater than one.

4 CONTROL SCHEME
The reference voltage generator and controller circuit are mainly used in harmonic elimination PQ theory is employed for the purpose of generation of reference voltage. The controller for reference voltage generation is shown in **Fig.5** which is based on PQ theory discussed in following section.

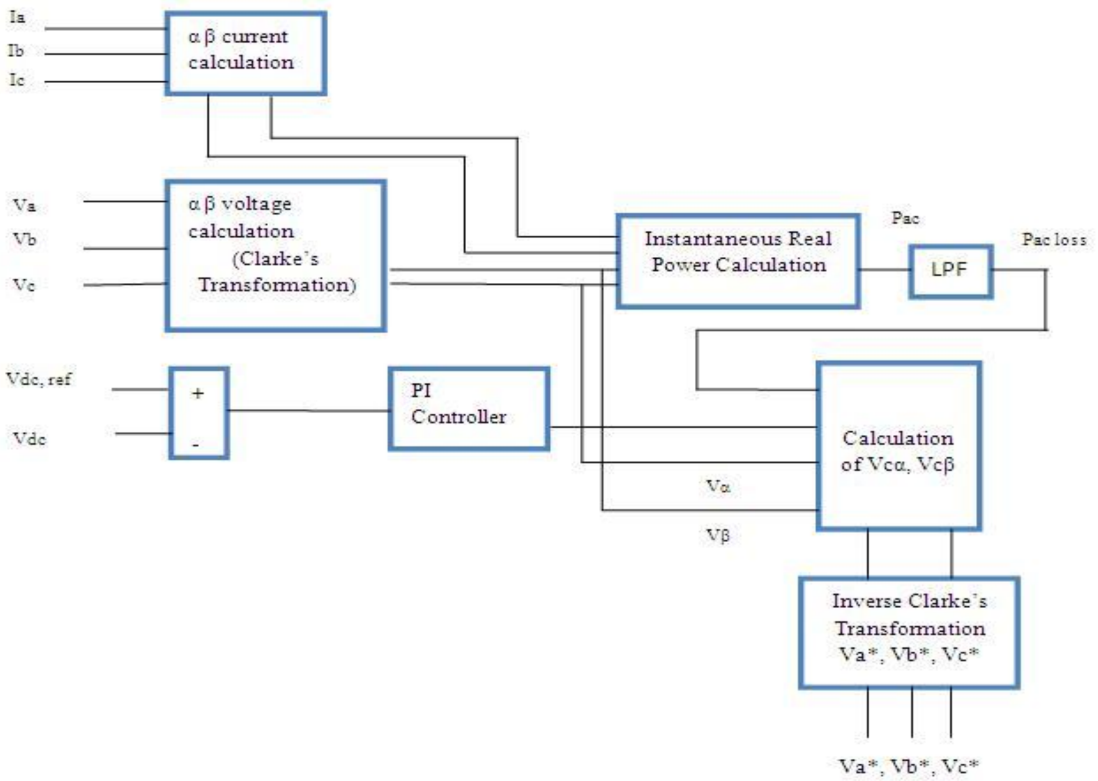

Fig.5. Controller for Reference Voltage Generation

4.1 Instantaneous power theory

The appropriate voltage is used as reference by use of generalised instantaneous power theory [H.Akagi., 1984]also called as PQ theory. The PI controller is used to maintain constant DC voltage across the dc link capacitor.

According to this theory three phase sinusoidal source voltages and distorted line currents are considered for reference generation. Instantaneous quantities of voltages are V_a, V_b, V_c and the currents are i_a, i_b, i_c of a three phase system are considered. The a-b-c co-ordinates are to be transformed into α-β coordinates as orthogonal system by Clarke's transformation as follows

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\tfrac{2}{3}}.\begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}.\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{8}$$

Similarly the current co ordinates expressed as

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}.\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{9}$$

The conventional instantaneous power (P_{ac}) on the three phase circuit can be defined as follows:

$$P_{ac}=V_a i_a+V_b i_b+V_c i_c$$

$$=V_{\alpha}.i_{\alpha}+V_{\beta}.i_{\beta} \qquad (11)$$

Instantaneous real power is passed through second order butterworth filter (50Hz Low Pass Filter) which eliminates higher order thereby permitting only fundamental component which is denoted by P_{ac} loss

The conventional instantaneous reactive power on the three phase circuit is

$$Q=V_{\alpha}*i_{\alpha}+V_{\beta}*i_{\beta} \qquad (12)$$

The power components P and Q are related to the same α-β voltages and currents, they can be written as

$$\begin{bmatrix} P \\ Q \end{bmatrix}=\begin{bmatrix} V_{\alpha} & V_{\beta} \\ -V_{\beta} & V_{\alpha} \end{bmatrix}.\begin{bmatrix} i_{\alpha} \\ i_{\beta} \end{bmatrix} \qquad (13)$$

The instantaneous real power is calculated from AC component of real power loss P_{acloss} and DC power loss which is denoted by $P_{dc\ loss}$

The DC power component is obtained by comparing dc link capacitor voltage of H bridge inverter and reference voltage. The PI controller determines the dynamic response and settling time of dc capacitor

$$P_{dc}=[V_{dc,ref}-V_{dc}]\ kp+ki/s] \qquad (14)$$

Instantaneous voltage on α-β divided into real power loss and reactive power loss. The proposed controller computes only real power loss and reactive power loss is taken as zero

The reference voltage generation

$$\begin{bmatrix} V_{c\alpha} \\ V_{c\beta} \end{bmatrix} = \frac{1}{i^2\alpha+i^2\beta}\begin{bmatrix} i_{\alpha} & -i_{\beta} \\ i_{\beta} & i_{\alpha} \end{bmatrix}.\begin{bmatrix} P_{dc}+P_0+P_{acloss} \\ 0 \end{bmatrix} \qquad (15)$$

Where

P_{dc} is average component of instantaneous real power

P_0 is zero sequence power

P_{acloss} is power loss in the system.

The reference voltage generation for compensation in a-b-c coordinates can be obtained by inverse Clarke's transformation

$$\begin{bmatrix} V_{ca}* \\ V_{cb}* \\ V_{cc}* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Vc\alpha \\ Vc\beta \\ Vc0 \end{bmatrix} \quad (16)$$

$$Vc_0 = -V_o \quad (17)$$

The use of PQ theory for harmonic elimination is used as reference for the MLI to generate pulse based on phase disposition method. The generated gate pulses for seven level inverter are shown in **Fig 6.** The instantaneous real and reactive power theory has several advantages such as it can be inherently applied to a three phase system which can be balanced or unbalanced, with or without harmonics in case of both current and voltage. The system with PQ controller has very good dynamic response. This includes only algebraic expressions which are relatively simple.

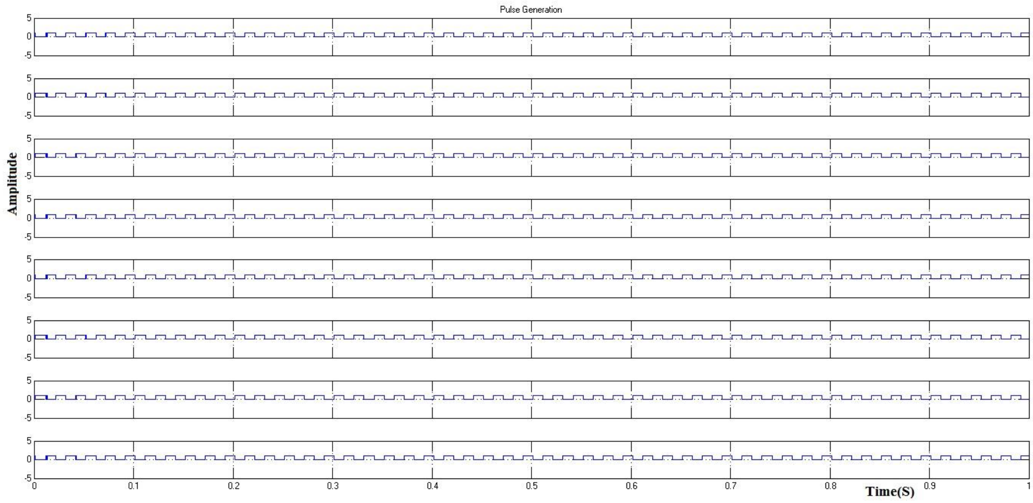

Fig.6. Gate Pulses for Seven Level Inverter

5 SIMULATION RESULTS

The proposed hybrid filter is implemented using MATLAB/SIMULINK for 2 kVA, 440V and 50Hz system using multilevel inverter as series active filter. From the above discussed equations the compensating voltage is obtained by taking the source current and voltage. Hybrid filter simulation model is tested for compensating voltage source producing harmonic load. Since the power supply is a voltage source, the series active filter tries to control the load voltage. But the load current depends on it terminal voltages. The voltage that the series instantaneous active filter wishes to inject depends on the current of the load, and the current of the load depends on its voltage.

The non linear diode rectifier with R-C load acts as voltage producing harmonic load and the cascaded MLI as active filter in series at PCC for injection of anti harmonics. Elimination of harmonics in the system is done by computing load voltage and source current. The series active filter is more suitable for voltage harmonics non linear loads such as diode rectifiers with smoothing capacitors and

SMPS. The harmonic spectra and THD for load voltage and source current are analyzed. It uses system with no filter, with passive filter and with hybrid filter are analyzed for the source current and load voltage of a three phase system in this section. The compensated voltage is injected into the system with help of three single phase matching transformers. **Fig.7** shows the simulated output response source voltage and source current waveforms of the system when there is no compensation for the harmonics is made.

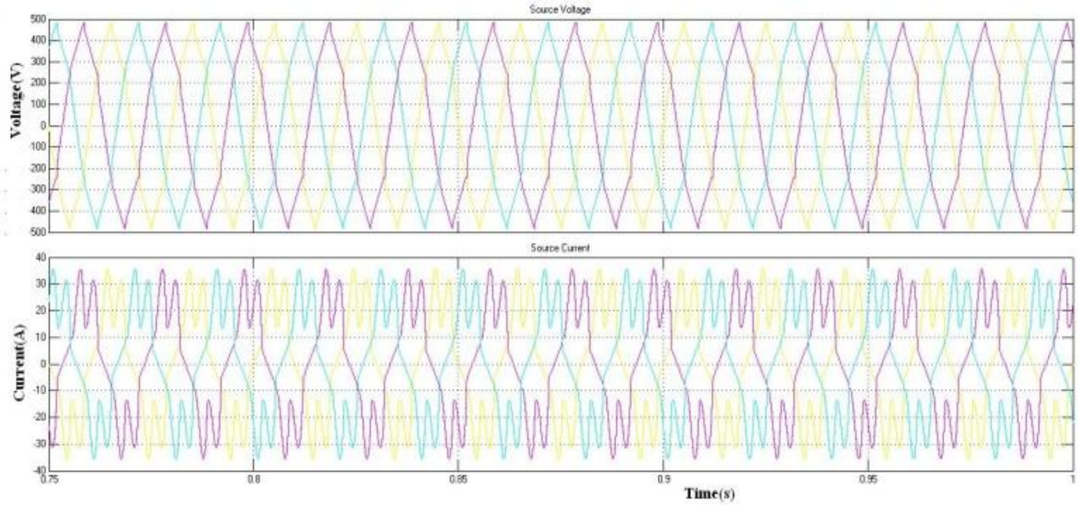

Fig.7. Simulated Output Response of a Three Phase Uncompensated System, (a) Source Voltage (b) Source Current

The harmonic spectra of the system with presence of harmonic contents are shown in **Fig.8**. These distorted components have to be compensated rather than isolating by use of filters.

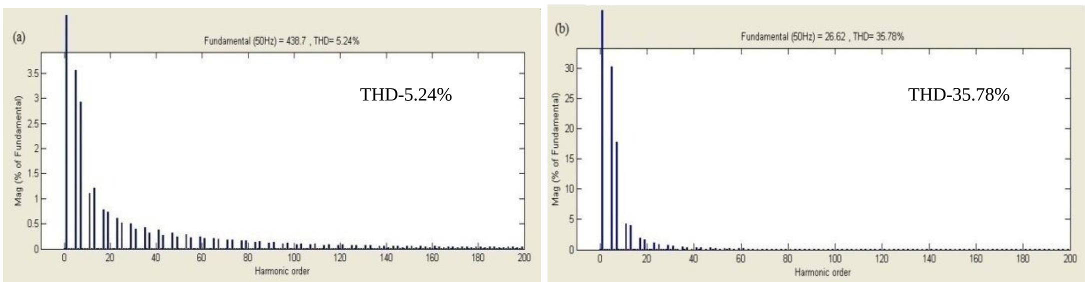

Fig.8. Harmonic Spectra of Uncompensated System (a) Source Voltage (b) Source Current

When the active filter is offline it does not inject the compensating voltage into the system instead it shows anticipated waveforms. The shunt passive filters reduces the harmonic level to certain extent further reduction in harmonics will introduce resonance problems with increase in component value. The Simulated Output Response of a Three Phase System with Passive Filter Compensation is shown in **Fig**.**9** and their harmonic spectra is shown in **Fig**.**10**

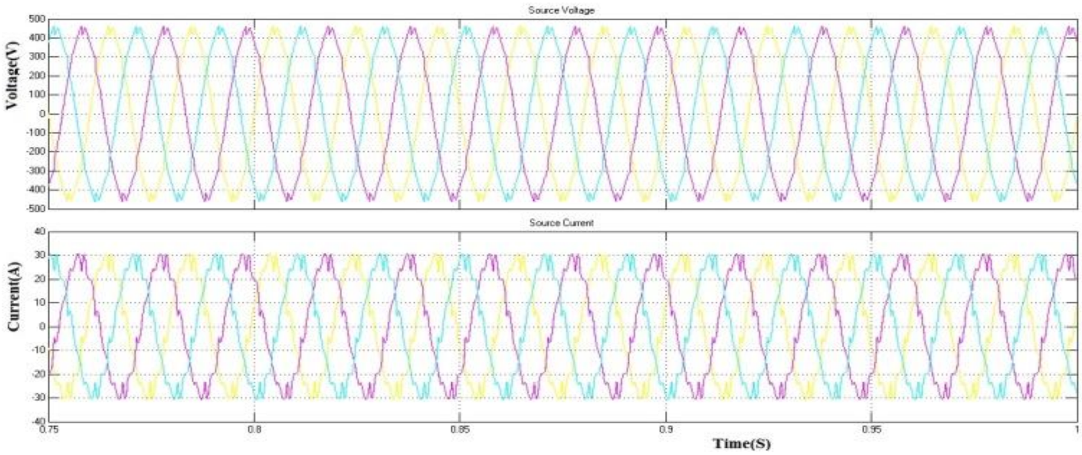

Fig.9. Simulated Output Response of a Three Phase System with Passive Filter Compensation, (a) Source Voltage (b) Source Current

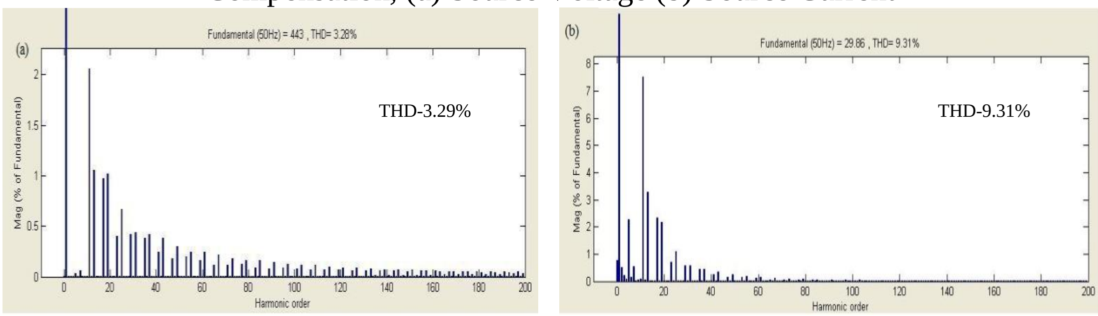

Fig.10. Harmonic Spectra of System with Passive filters (a) Source Voltage (b) Source current

However smaller harmonic distortion still remains at source current due to presence of distorted components in the system voltage. The use of passive filters will eliminate harmonic content in the source voltage from 5.24% to 3.29% and source current from 35.78% to 9.31%. The Values of Inductance, Capacitors as passive filters used in the system are shown in **Table II**. The voltage that the series active filter injects depends on the current of the load, and the current of the load depends on its voltage. The use of active filter will eliminate the oscillating component of the real power.

Table. II. Values of Inductance, Capacitors as Passive Filters

Frequency	C(μF)	L(mH)
250Hz	32.88	12.32
350Hz	32.88	6.29

The controller used is based on PQ theory by producing voltage reference to produce gate pulses. The voltage source injects the voltage into eliminate the harmonics. The compensated voltage injected by the active filter into the system through series transformer is shown in **Fig.11**. As considerable amount of fundamental voltage appears across the terminals of the active filter, which is due to resistive loss at AC side of the filter transformers. By introducing hybrid filter the line current becomes sinusoidal than the expected outcome compared to the use of LC filter alone.

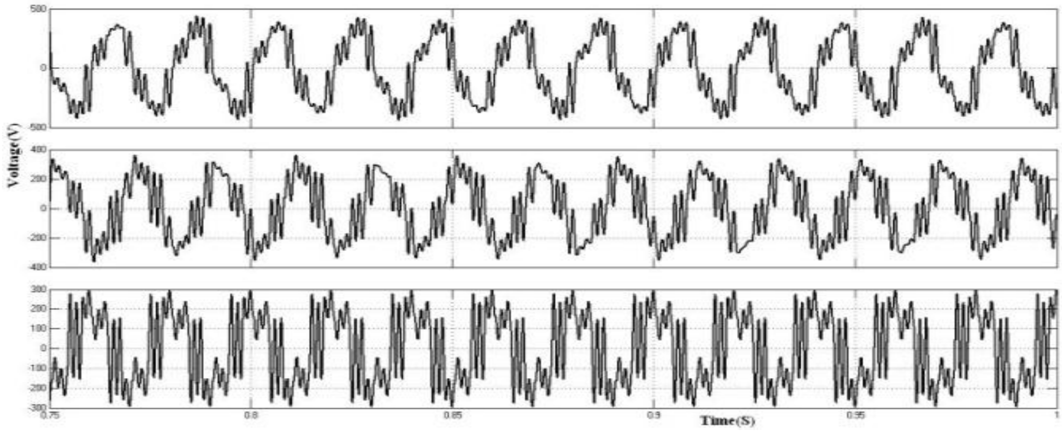

Fig.11. Compensated Voltage Injected by Active Filter in to the System

The use of MLI as active filter compensates harmonics produced in the system due to non linear loads. The smooth waveform is produced and Simulated Output Response of a Three Phase System with Hybrid filter is shown in **Fig.12**. The level of THD by use of hybrid filter with seven level inverter as active filter is reduced when compared to the use of nine level inverter with transformer and the harmonic spectra is shown in **Fig.13.** The line current THD is drastically improved by use of hybrid filters from 9.31% to 0.53% and also the source voltage is reduced from 3.29% to 0.13% where almost all the harmonics goes to zero level. This is due to the presence of transformer which introduces inductance when connected.

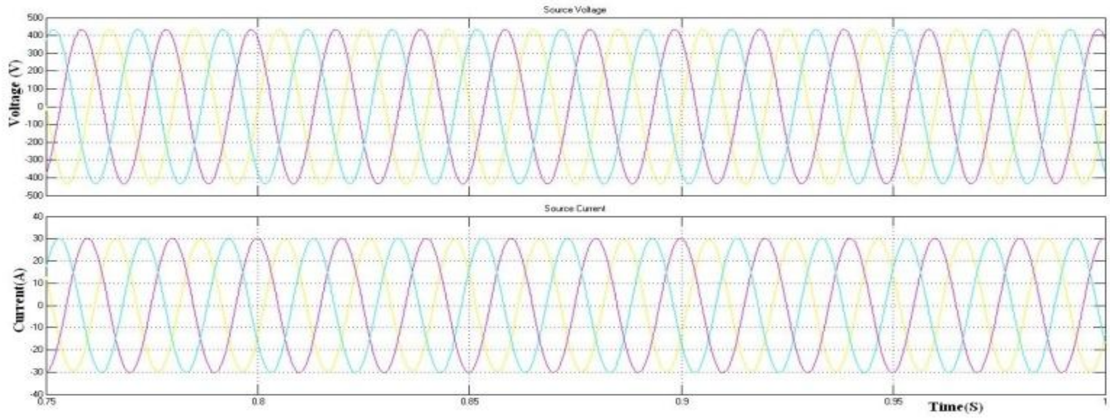

Fig.12. Simulated Output Response of a Three Phase System with Hybrid filter (a) Source voltage (b) Source Current

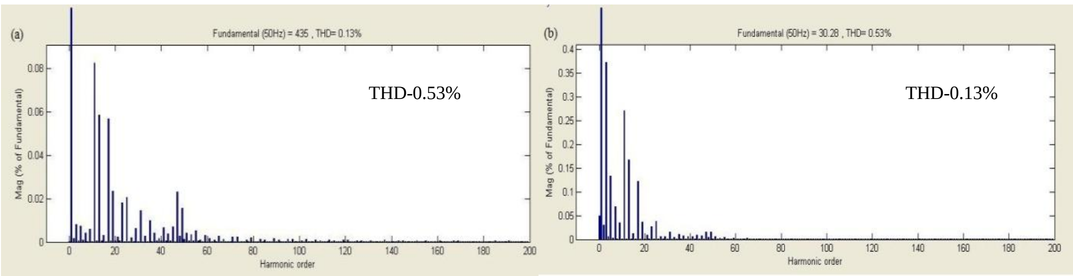

Fig.13. Harmonic Spectra of System with Hybrid Filter (a) Source Voltage (b) Source Current

The level of harmonics further reduces the source voltage harmonics and hence all harmonics go to zero with less harmonic content. **Table III** shows performance of THD of source current and source voltage of the system before compensation and after compensation when series hybrid filter connected to it. Improvement of voltage source harmonic depends upon utility stiffness if is the system is strong voltage is not affected by harmonic currents flowing from loads and action of APF cannot be seen clearly. Alternatively if the system is weak, line currents affect the source voltage and performance of APF can be understood clearly. From the above discussions, the FFT analysis of the hybrid filter indicates that the THD of source current is brought less than 5% as compliance of standards such as IEEE 516, IEC 61000-3.

6 CONCLUSION

Thus series active filter not acts as harmonic compensator rather as harmonic isolator. A hybrid series active power filter based on seven level inverter acting as high impedance path for voltage producing harmonic loads. It was developed with no active power consumption as good power line conditioning. The control strategy is to obtain almost sinusoidal voltages and currents. The effect nonlinear loads on the power quality of power delivered is analyzed and rectified. The controller used in this paper for compensation of harmonics. The proposed filter compensates harmonic voltage source generated by contaminating loads. The performance of the system is studied by comparing the harmonic profile with and without filter.

Table. III. Performance Comparison of THD of Source

SL.No	Description	Type of compensator	%THD
1	Source Voltage	Without Filter	5.24
		With Passive Filter	3.29
		With Hybrid Filter	0.13
2	Source Current	Without Filter	35.78
		With Passive Filter	9.31
		With Hybrid Filter	0.53

REFERENCES

1. Alexander Varschavsky, Juan Dixon, Mauricio Luis Moran, “Cascaded Nine Level Inverter for Hybrid Series Active Power Filter using Industrial Controller” IEEE Trans Ind.Electron, vol.57, no. 8, pp2761-2767, Aug. 2010
2. B.Singh, K. Al-Haddad and A.Chandra, “A Review of active filters for power quality Improvement,” IEEE Trans.Ind. Electron., vol.46, no.5, pp. 960-971, oct,1999.
3. F.Z.Peng, H.Akagi and A.Nabe, “A new approach to harmonic compensation in power systems-A combined system of shunt passive and series active filters,” IEEE Trans.Ind.Appl., vol.26, no.6, pp 983-990, Nov/Dec.1990.
4. Fang Zeng Peng, “Application issues of Active Filter” IEEE Ind. Appl Mag. vol 4, No 5, pp 21-30, sept/oct 1999.
5. F.Z.Peng, “Harmonic Sources and filtering Approaches,” IEEE Ind.Appl. Mag., vol 7, no.4 pp. 18-25, Jul/Aug.2001.
6. H.Akagi, Y.Kanazawa ,A.Nabe, “ Instantaneous Reactive Power compensators comprising devices without Energy storage Components”, IEEE Trans.Ind.Appl., vol.IA-20, no 3,pp 625 -630,May 1984.
7. Hirofumi Akagi, “Trends in Active Power Line Conditioners”, IEEE Trans on Power Electronics, Vol.9, No.3, May-1994
8. J.W.Dixon, G.Venegas and L.A.Moran, “A Series active filter based on a sinusoidal current- Controlled voltage- source inverter,” IEEE Trans Ind. Electron. vol.44, no. 5, pp. 612- 620, oct.1997.
9. Khoucha, F., Lagoun, S.M., Marouani, K., Kheloui, A. El Hachemi Benbouzid, M., “Hybrid Cascaded H-Bridge Multilevel-Inverter Induction-Motor-Drive Direct Torque Control for Automotive Applications”, IEEE Trans.Ind. Electron., Vol.57 No.3, pp.892-899, Mar 2010
10. P. Salmerón, S. P. Litrán, “Improvement of the Electric Power Quality Using Series Active and Shunt Passive Filters” IEEE Trans on Power Delivery.Vol.25, No.2,pp 1058- 1067,Apr.,2010
11. Peng, F.Z., Adams, D.J. “Harmonic sources and filtering approaches-series/parallel, active/passive, and their combined power filters” IEEE Industry Applications Conference, 1999. Thirty-Fourth IAS Annual Meeting. Conference Record of the 1999., vol 01 pp 448 -455
12. Pereda, J., Dixon, J. “23-Level Inverter for Electric Vehicles Using a Single Battery Pack and Series Active Filters”, IEEE Trans vehic Tech., Vol.61 No.3 pp 1043 -1051, Mar.2012
13. Salem Rahmani, Abdelhamid Hamadi, Nassar Mendalek and Kamal Al-Haddad, “A New Control Technique for Three-Phase Shunt Hybrid Power Filter” IEEE Trans. Ind. Electron. vol.56, no.8, Aug. 2009.
14. Samir Kouro, Pablo Lezana, Mauricio Angulo, Jose Rodriguez, “Multicarrier PWM with DC-Link Ripple Feed forward Compensation for Multilevel Inverters”, IEEE Transactions on power electronics, vol. 23, no. 1, January 2008.pp 52-59.

15. Tien-Ting Chang, Hong-Chan Chang “An Efficient Approach for Reducing Harmonic Voltage Distortion in Distribution Systemswith Active Power Line Conditioners ”, IEEE Trans on Power Delivery,Vol.15, No.3, pp.990 995, 2000
16. W.M.Grady, M.J.Samotyj, A.H.Noyola “Survey of Active Power Line Conditioning Methodologies” IEEE Trans on Power Delivery,Vol.5, No.3, pp.1536-1542, July-1990
17. 516-2009 - IEEE Guide for Maintenance Methods on Energized Power Lines