Journal of Theoretical and Applied Information Technology
10th October 2014. Vol. 68 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

SIMPLIFIED FIVE LEVEL INVERTER AS SERIES ACTIVE POWER FILTER FOR MINIMIZING THD IN A NON-LINEAR SYSTEM

C.RAMAKRISHNAN[1], S.VIJAYAN[2], K.ARTHI[3]

[1]Assistant Professor, Department of EEE, SNS College of Technology, Coimbatore, India
[2]Professor, Department of EEE, Surya Engineering College, Erode, India
[3]PG Scholar, Department of EEE, SNS College of Technology, Coimbatore, India

E-mail: [1]ramramki.krishnan@gmail.com, svijayansurya@gmail.com, [2]arthidrives@gmail.com

ABSTRACT

A series hybrid Active Power Filter has been focused more in the area of power quality. The hybrid filter is implemented with three phase simplified asymmetrical five level inverter as active filter and LC filter connected in parallel with power lines acting as passive filter. The harmonics produced by the non linear loads are filtered out by the passive filters and the filtering property of it is improved by active filter. The multi level voltages are obtained from a simplified inverter, which operates at lower switching frequency intern reduces the switching losses compared to conventional cascaded five level inverter. The filter is developed to inject voltage in series and also for harmonic isolation. Current harmonics are eliminated by controlling the APF with the P-Q theory based control strategy developed for this simplified inverter. The system produces voltage of same amplitude but opposite to load harmonic voltage to nullify the harmonics injected into the system. For current harmonics, the system produces voltage proportional to the current and offers high impedance path to the current harmonics. 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, Harmonic Distortion, PQ theory, Multilevel Converters, Power Quality*

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 [1].

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 [1],[2], and

Journal of Theoretical and Applied Information Technology
10th October 2014. Vol. 68 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

they have been surveyed based upon the types of non linear loads [3]. The active power line conditioners are classified as shunt and series, the use of these active filters for improvement of quality of power and their distinction is made [4]. 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. 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 [5]. The series active filter acts as sinusoidal current source in phase with mains of voltage was developed [6]. 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 [7] but it possesses some disadvantages like high switching losses and high harmonic noise.

The multilevel inverter finds its own advantages [8] such as capability of producing cleaner voltage with low current distortion, operates with low switching frequency which drastically can reduce switching losses, Elimination of transformer by providing required voltage levels which results in faster response, simple structure and 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 [9] who introduces instantaneous power theory and another important technique by Synchronous Reference frame theory.

In this paper the simplified multilevel inverter was used to implement the hybrid filter along with LC filter. This inverter increases the number of output voltage level by using minimum number of power switches, driver circuits and dc voltage sources. Similar method of active filter is implemented [6] which uses nine level topology with transformers and nine level inverter which makes the control circuit complex to control eight switches. The present technique overcomes advantages by eliminating the use of transformer and it uses only six switches. The THD comparisons have made for with and without hybrid filters

There are several other techniques like hysteresis controller, digital deadbeat control, synchronous detection method and a CRC theory, 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.

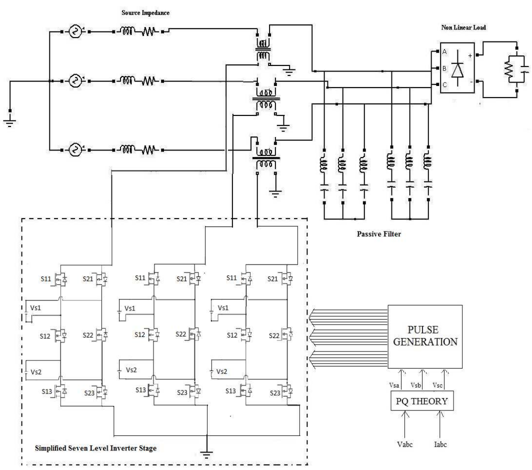


Figure 1: Hybrid Series Filter Configuration

The three phase simplified five 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.

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

Journal of Theoretical and Applied Information Technology
10th October 2014. Vol. 68 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

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. 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

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

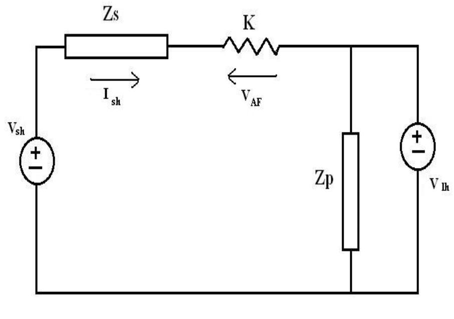


Figure 2: Single Phase Equivalent Circuit of Hybrid Filter[6]

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. [6]

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 [10]. The active filter which injects current to a radial distribution system at PCC [11] which determines the spectra of harmonics and location of injection by suitable method.

3. MULTILEVEL INVERTER

3.1 Simplified Multilevel Inverter Topology

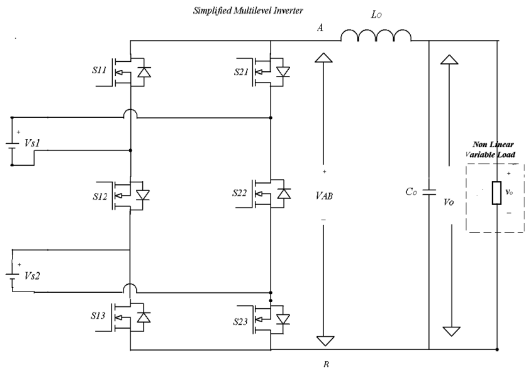


Figure 3: Basic Switching Circuitry of Five level Inverter

This topology used reduced number of switches than the conventional Cascaded H bridge inverter which is used drastically to reduce power circuit complexity with simple design. The basic circuitry of five level inverter with six switches is shown in Fig 3 [12]. The switching to the inverter is based on Phase Disposition PWM technique to produce five level output -2Vs to +2Vs. The strategy used two carriers and only one reference to produce the switching pulses.

The maximum positive voltage $(V_{s1}+V_{s2}) = 2V_s$ is obtained when the switches S_{12}, S_{21} and S_{23} are ON. The maximum negative output voltage $-(V_{s1}+V_{s2}) = -2V_s$ is obtained when the switches S_{11}, S_{13} and S_{22} are ON. The first levels of both positive and negative voltages are V_{s1} or V_{s2} and $-V_{s1}$ or $-V_{s2}$ are obtained when the switches S_{12}, S_{13} and S_{21} and S_{11}, S_{22} and S_{23} are ON. The zero voltage is obtained when all the switches from any one right or left leg are turned ON.

3.2 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.

Journal of Theoretical and Applied Information Technology
10th October 2014. Vol. 68 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Amplitude Modulation (m_a) = $\frac{A_m}{(m-1)A_c}$ (3)

Frequency Modulation (m_f) = $\frac{F_c}{F_m}$ (4)

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.

Table 1: Switching Sequence for Simplified five Level Inverter

Voltage levels	Switches					
	S11	S12	S13	S21	S22	S23
V_{s1}	0	1	1	1	0	0
V_{s2}	0	1	0	1	0	1
Zero	1	1	1	0	0	0
$-V_{s1}$	1	0	0	0	1	1
$-V_{s2}$	1	0	1	0	1	0

Table 1 lists the switching combination that generates the required five level output. The carrier and reference signal for pulse production is shown in Fig.4. The use of reduced number of switches naturally reduces switching losses and improves conversion efficiency.

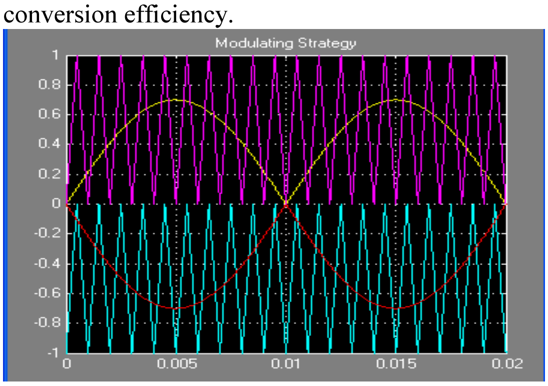


Figure 4: Comparison of Carrier and Reference signals

3.3 Harmonic Elimination

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

$$V(t) = \sum_{n=1}^{\infty}(A_n \sin n\alpha + B_n \cos n\alpha) \quad (5)$$

Due to the quarter wave symmetry of output voltage the even harmonics are absent (B_n=0) and only odd harmonics are present [13].The amplitude of n^{th} harmonic A_n is expressed only with first quadrant switching angle α1, α2,……αn

$$A_n = \frac{4V_{dc}}{n\pi}\sum_{k=1}^{\infty}\cos n\alpha k \quad (6)$$

For any odd harmonics An 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.

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.

4.1 Instantaneous power theory

The appropriate voltage is used as reference by use of generalized instantaneous power theory [9] 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

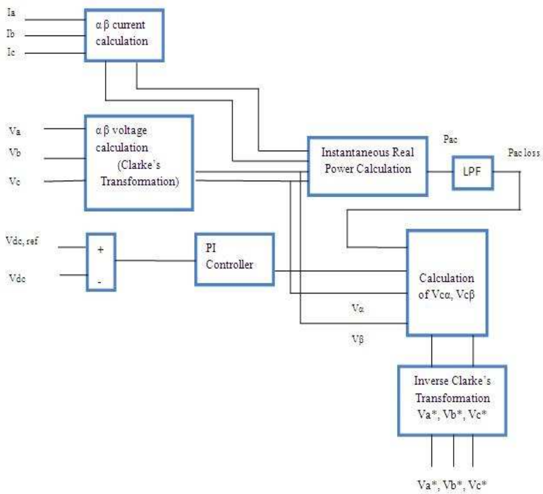


Figure 5: Reference Voltage Generation

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\tfrac{2}{3}} \cdot \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\tfrac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (8)$$

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

$$P_{ac}=V_a i_a+V_b i_b+V_c i_c$$
$$=V_{\alpha} . i_\alpha+V_\beta . i_\beta \quad (9)$$

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_{acloss}

The conventional instantaneous reactive power on the three phase circuit is

$$Q=V_\alpha * i_\alpha+V_\beta * i_\beta \quad (10)$$

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

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (11)$$

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

$$P_{dc}=[V_{dc,ref}-V_{dc}]\ kp+ki/s \quad (12)$$

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

$$\begin{bmatrix} V_{c\alpha} \\ V_{c\beta} \end{bmatrix} = \frac{1}{i^2\alpha+i^2\beta} \begin{bmatrix} i_\alpha & -i_\beta \\ i_\beta & i_\alpha \end{bmatrix} \cdot \begin{bmatrix} P_{dc}+P_0+P_{acloss} \\ 0 \end{bmatrix} \quad (13)$$

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

$$\begin{bmatrix} V_{ca}* \\ V_{cb}* \\ V_{cc}* \end{bmatrix} = \sqrt{\tfrac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Vc\alpha \\ Vc\beta \\ Vc0 \end{bmatrix} \quad (14)$$

$$Vc0= -Vo \quad (15)$$

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.

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.

As per the PWM strategy, PWM signals for the six power switches are generated and shown in Fig.6. It is noted that one active switch from both the legs are operated at fundamental frequency

Journal of Theoretical and Applied Information Technology
10th October 2014. Vol. 68 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

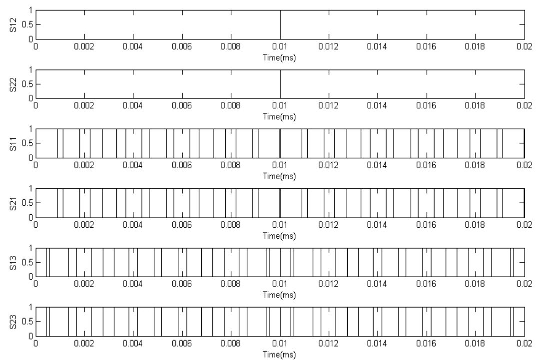


Figure 6: Simulated switching signals for the proposed inverter switches.

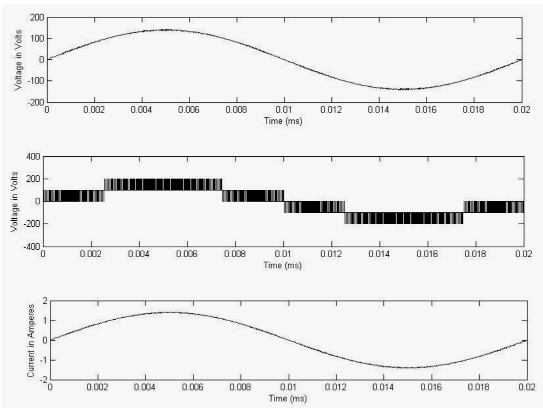


Figure 7: Simulated output phase voltage with filter, without filter and current waveforms of the proposed inverter.(single phase)

and the memory switches are operated at the frequency of carrier signal. Hence the switching stresses for the switches are considerably reduced and the inverter efficiency is improved.

The magnitude of this output voltage from the inverter is varied by varying the input magnitude to the inverter. It is noticed that the voltage across the switches operating at higher frequencies are equal to any one input voltage source V_{s1}or V_{s2}.But the voltage across the switches operating at supply frequencies are equal to the addition of two input source voltages $V_{s1}+V_{s2}$.Hence the switching stresses for the switches are considerably reduced and the inverter efficiency is improved.

The output voltage obtained from the inverter is not a sinusoidal one. Hence suitable filter is designed and used as an output filer to improve the shape of the wave form. The output voltage with filter, without filter and the current through a linear load is shown in the Fig.7.

The compensated voltage is injected into the system with help of three single phase matching transformers. Fig.8 shows the source voltage and source current waveforms of the system when there is no compensation for the harmonics is made.

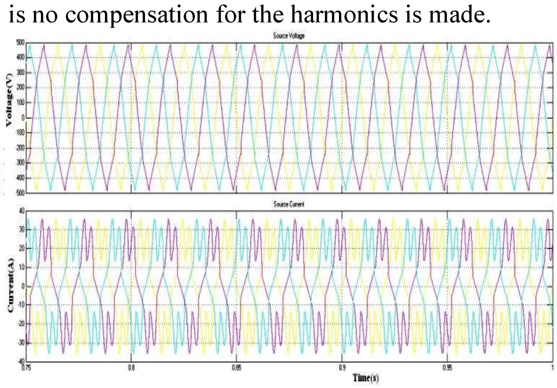


Figure 8: Simulated output for three phase Uncompensated System, (a) Source Voltage (b) Source Current

The harmonic spectra of the system with presence of harmonic contents are shown in Fig.9. These distorted components have to be compensated rather than isolating by use of filters.

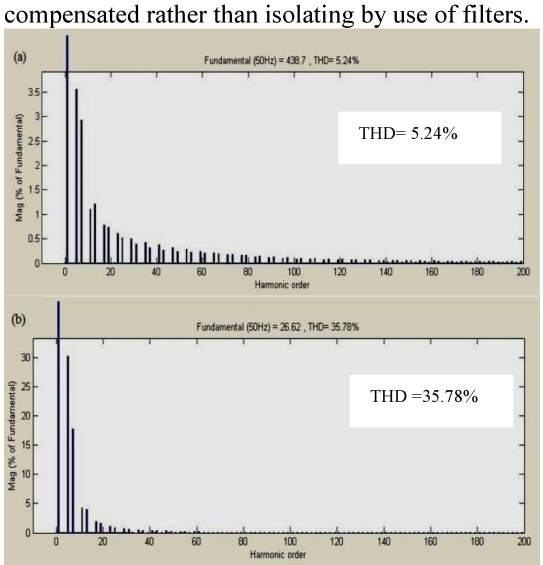


Figure 9: Harmonic Spectra of Uncompensated System (a) Source Voltage (b) Source Current

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 system with the use of passive filter can mitigate the harmonic to the level which is shown in Fig.10 and their harmonic content is shown in Fig.11.

Journal of Theoretical and Applied Information Technology
10th October 2014. Vol. 68 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

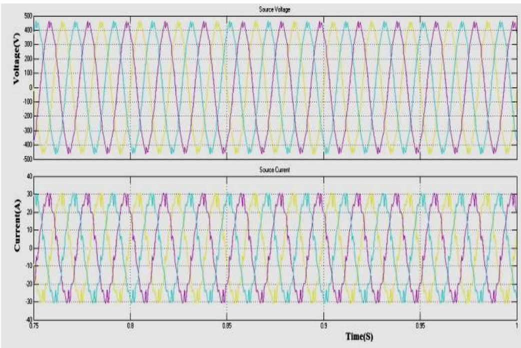


Figure 10: Simulated output for three phase System with passive filter (a) Source Voltage (b) Source Current

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 passive filters used in the system are shown in Table 2. 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 2: List of Passive Filters

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

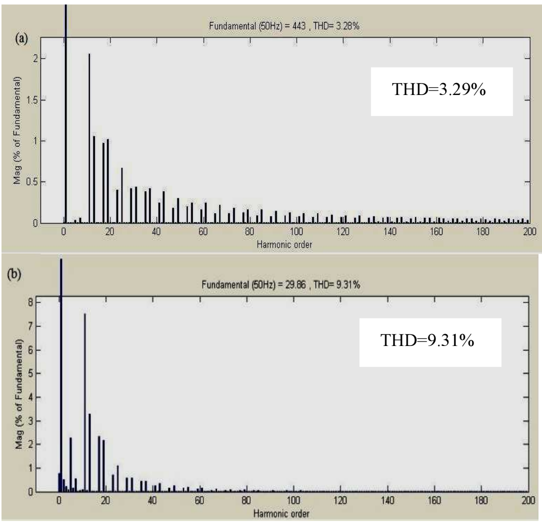


Figure 11: Harmonic Spectra of System with Passive filters (a) Source Voltage (b) Source current

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 is to be injected into the system through series transformer is shown in Fig.12. 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.

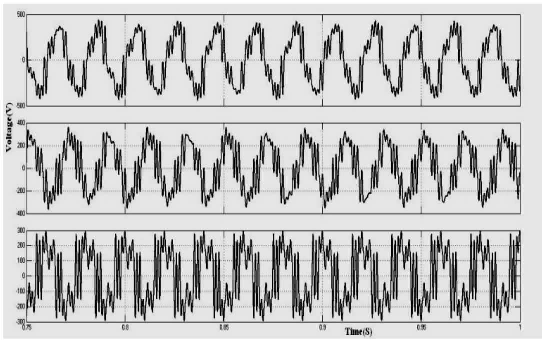


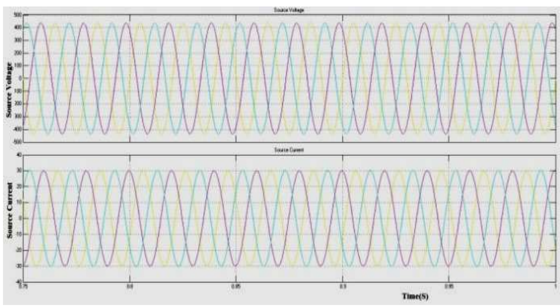
Figure12: Active filter Voltage for Three Phase System

5.1 Simplified Multilevel Inverter as active filter

The simplified five level inverter as active filter injects the required amount of injection voltage into the system for harmonic elimination and the source becomes purely sinusoidal as shown in Fig.13. The line current THD is drastically improved by use of hybrid filters from 9.31% to 0.53% which is shown in Fig.14 and also the source voltage is reduced from 3.29% to 0.13% where almost all the harmonics goes to zero level.

The level of harmonics further reduces the source voltage harmonics and hence all harmonics go to zero with less harmonic content. Table **3** shows performance of THD of source current and source voltage of the system before compensation and series hybrid filter connected to it.

Improvement of voltage source harmonic depends upon utility stiffness if is the system is



ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Figure13: Simulated output for Three phase system with Hybrid filter (SFLI) (a) Source voltage (b) Source Current

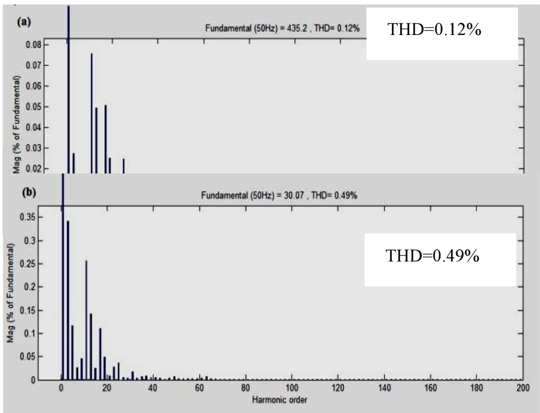


Figure 14: Harmonic spectra of System with Hybrid Filter (SFLI)(a)Source Voltage (b) Source Current

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.

Table 3: Source Voltage and Source Current Harmonic Content

SL.No	Description	Type of Compensator	%THD
1	Source Voltage	Without Filter	5.24
		With Passive Filter	3.29
		With Hybrid Filter(SFLI)	0.12
2	Source Current	Without Filter	35.78
		With Passive Filter	9.31
		With Hybrid Filter(SFLI)	0.49

6 CONCLUSION

Thus series active filter not acts as harmonic compensator rather as harmonic isolator. A hybrid series active power filter based on five 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.

REFERENCES:

[1].Fang Zeng Peng, “Application issues of Active Filter” IEEE Ind. Appl Mag. vol 4, No 5, pp 21-30, sept/oct 1999.

[2].F.Z.Peng ,“ Harmonic Sources and filtering Approaches,” IEEE Ind.Appl. Mag., vol 7, no.4 pp. 18-25, Jul/Aug.2001.

[3].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

[4].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.

[5].P. Salmeron, 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

[6].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, pp 2761-2767, Aug. 2010.

[7].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.

[8].Mariusz Malinowkski, K.Gopakumar, Jose Rodriguez and Marcelo A.Perez “A Survey on Cascaded Multilevel Inverters” IEEE Transon Indus. Electronics, Vol.57, No7, pp.2197-2205, July-2010

[9].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.

[10].Hirofumi Akagi, “Trends in Active Power Line Conditioners”, IEEE Trans on Power Electronics, Vol.9, No.3, May-1994

[11].Tien-Ting Chang, Hong-Chan Chang “An Efficient Approach for Reducing Harmonic

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Voltage Distortion in Distribution Systemswith Active Power Line Conditioners ", IEEE Trans on Power Delivery,Vol.15, No.3, pp.990 995, 2000

[12].Yi-Hung Liao, Ching-Ming Lai "Newly Constructed Simplified Single-Phase Multistring Multilevel InverterTopology for Distributed Energy Resources", IEEE Trans.pow. Electron., vol. 26, pp. 2386,2391 Sept. 2011

[13].Wanmin Fei,,Xinbo Ruan, Bin Wu "A Generalized Formulation of Quarter-Wave Symmetry SHE-PWM Problems for Multilevel Inverters" IEEE Trans. Power Electron., vol.24,no.7, pp.1758-1766 July 2009.

[14].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.

[15].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

[16].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

[17].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

[18].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.

[19]. Zhong Du, Ozpineci, B,Tolbert, L.M."DC–AC Cascaded H-Bridge Multilevel Boost Inverter with No Inductors for Electric/Hybrid Electric Vehicle Applications" IEEE Trans.Ind.Appl., Vol45 No.3 pp. 963-970,Jun 2009.

[20].JeyrajSelvaraj and Nasrudin A. Rahim, "Multilevel Inverter for Grid-Connected PV System Employing Digital PI Controller" *IEEE Transactions on Industrial Electronics*, Vol. 56, No. 1, pp. 149-158, January 2009.