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Power quality enhancement using cascaded multilevel inverter based shunt hybrid active power filter

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Abstract

This paper investigates mitigation of current harmonics using different configuration of cascaded multilevel inverter based shunt hybrid active power filter (SHAPF) and to improve power quality of the system. The main objective of this paper is to develop and analyze the compensation characteristics of cascaded multilevel inverter based shunt hybrid active power filter by employing indirect current control algorithm. The indirect current control algorithm is employed to generate reference current and phase disposition pulse width modulation technique is incorporated to generate gating signal for shunt hybrid active power filter strategy. The nonlinear loads are connected to distort the source current to 21% of harmonics distortion, as per IEEE 519 allowable current harmonic distortion is 5%. To mitigate harmonic distortion, cascaded multilevel inverter based shunt hybrid active power filter is proposed and after compensation the source current harmonic distortion is reduced to 2.93%. The simulation analysis is carried out using SIMPOWERSYSTEMS block set of MATLAB/SIMULINK to determine which of the inverter topology based shunt hybrid active power filter strategy perform better on compensating source current harmonic distortion.

Keywords: Cascaded Multilevel Inverter, Multicarrier PWM technique, power factor correction, shunt hybrid active power filter.

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1. Introduction

Recently, power quality has been given attention due to wide application of power converters for controlling and converting ac power to feed electrical loads. These converters are used at different power levels, ranging from large adjustable speed drives (ASDs) to low power household appliances, office equipment and computer. The large amount of power pollution produced from these power converters or non-linear load will causes a low power factor efficiency of the power system, implies to voltage distortion, and increases losses in the transmission and distribution line (Singh et al., 1998). The conventional compensation, approaches is done using passive LC filters to eliminate line current harmonics and improve the system power factor. These passive filters have the disadvantage of large size, resonance and fixed compensation (Singh et al., 1999). In the last couple of decades, the concept of active power filter has been introduced and many publications have appeared on this subject. A comprehensive review of active power filter (APF) configuration, control strategies, selection of components and other related issues is given in El-Harouk et al. (2000). But the initial and operational costs of this filter are too high. Combining the advantage of both passive and active filters, hybrid filter topologies are developed (Senini and Wolfs, 2000; Karthik, and Quaicoe, 2000; Yuwen et al., 2000; Jacobs et al., 2001; Liqiao et al., 2004). Hybrid filters effectively mitigate the problems of a passive and an active filter and provide cost-effective harmonic compensation, particularly for high-power nonlinear loads. A parallel hybrid power filter system consists of a small-rating active filter in series with a tuned passive filter. This eliminates the possibility of series and parallel resonances. Correspondingly, Pulse Width Modulation (PWM) inverter (with 10 kHz of high switching frequency) has been used for harmonic and reactive power compensation. However, the high initial and running cost have been hindering their practical use in power distribution systems. In addition it is difficult for PWM-inverter based active filters to comply with electromagnetic interference (EMI) requirements. A cascaded multilevel inverter has been proposed for both harmonics and reactive power compensation. This inverter generates almost sinusoidal staircase voltage with only one time switching per line cycle. When cascaded inverter is applied to line conditioning and active power filtering of a distribution system, it is expected that the initial and running costs and the EMI will be dramatically reduced below that of the traditional PWM inverter (Liqiao et al., 2004; Miranda et al., 2004). The various topology for multilevel inverter based shunt active power filter strategy for compensation of power quality problems are reported in literature survey (Rodriguez et al., 2002; Holmes and McGrath, 2001). The application of shunt active power filter is applied to distribution generator is discussed in Cirrincione et al. (2008). The artificial intelligence based active filter strategy and other techniques used to mitigate current harmonic in distribution system is discussed (Bhattacharya, and Divan, 1995; Park et al., 2000a, b; Dixon et al., 1999; Rahmani et al., 2003).

In this paper five level, seven level and nine level cascaded multilevel inverter based shunt hybrid active power filter by employing indirect current control algorithm technique with phase disposition Pulse Width Modulation were presented. The proposed work attempts to analyze compensation the characteristics of cascaded multilevel inverter based shunt hybrid active power filter by employing indirect current control algorithm with a view to improve power quality is analyzed in this paper. The paper also discusses a comparative analysis of different configuration of cascaded multilevel inverter based shunt hybrid active power filter with respect to source current and its harmonic spectrum and reactive power compensation are to be analyzed and compared. The simulation is carried out in MATLAB/SIMULINK environment.

2. Basic Compensation Principle

The basic compensation principle of active power filter is illustrated in figure 1.

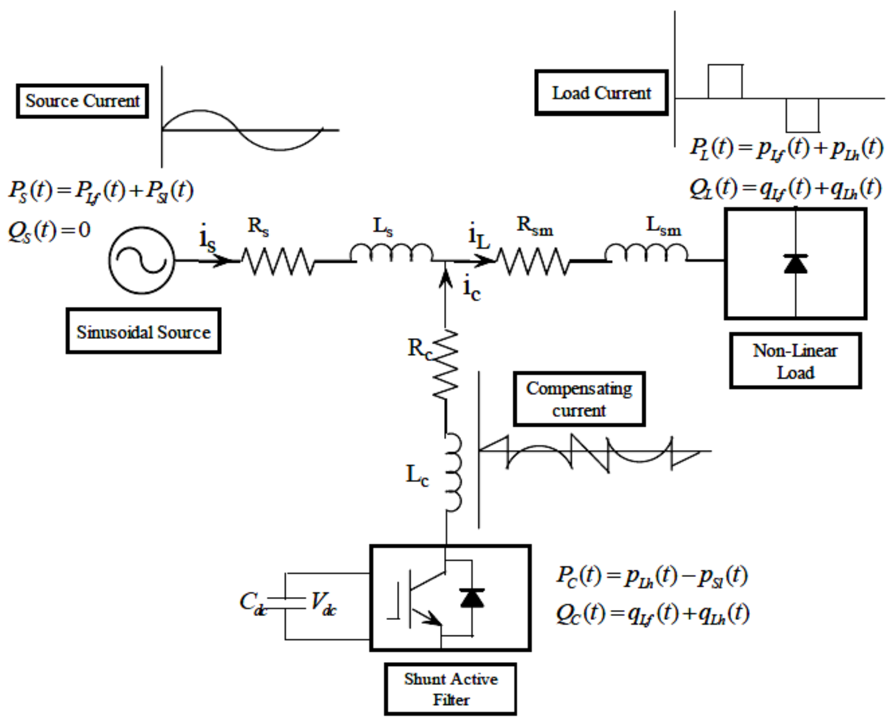

Figure 1. Operation of active power filter.

The instantaneous nonlinear load current is as follows

$$i_L(t) = \sum_{h=1}^{\infty} I_h \sin(h\omega t + \Phi h) = I_1 \sin(\omega t + \Phi_1) + \sum_{h=L}^{\infty} I_h \sin(h\omega t + \Phi h) \quad (1)$$

The instantaneous load power as been formulated as

$$P_L(t) = V_s(t) i_L(t)$$

$$= V_m I_1 \sin^2(\omega t)\cos(\Phi_1) + V_m I_1 \sin(\omega t)\cos(\omega t)\sin(\Phi_1) + V_m \sin(\omega t)\sum_{h=2}^{\infty} I_h \sin(h\omega t + \Phi_h) \tag{2}$$

$$= P_{Lf}(t) + P_{Lq}(t) + P_{Lh}(t)$$

Where, I_1 is the peak value of the fundamental load current, I_h is the peak value of the harmonic load current Φ_1 and Φ_{h_h} are the phase angle of the fundamental and harmonic component of the load currents, respectively. In (2) the instantaneous power of nonlinear load is divided into three terms. The first term $P_{Lf}(t)$ is the instantaneous load fundamental power. The second term $P_{Lq}(t)$ is instantaneous load fundamental quadrature (reactive) power and the third term $P_{Lh}(t)$ is the instantaneous load harmonic power. A shunt APF is designed to be connected in parallel with the load, to detect its harmonic and reactive current and to inject into the system a compensating current, identical with the load harmonic and reactive current. Therefore, instantaneous supply current I_s having only fundamental component which is in-phase with source voltage $V_s(t)$.

3. Proposed Cascaded Multilevel Inverter Based Shunt Active Power Filter

Cascade Multilevel Inverters (MLI) is increasingly used in high power applications. Cascade multilevel inverter uses multiple H-bridge power cells connected in a series to produce high ac output voltages [11-12]. An m-level cascade multilevel inverter consists of (m-1)/2 single-phase full bridges in which each bridge has its own separate dc source. This inverter can generate almost sinusoidal waveform voltage with only one time switching per cycle as the number of levels increase. In Fig.2 nine level cascade multilevel inverter is shown. It consists of four single phase full bridges connected in series in each leg. In this configuration if S= no of full bridge cells, then the number of output levels is (2S+1). With S=4 there will be nine levels in phase voltage and peak magnitude is SVdc. In Fig.2. Is is the AC source current, IL is load current, Ic is the compensated current from APF then

$$I_s = I_L + I_c \tag{3}$$

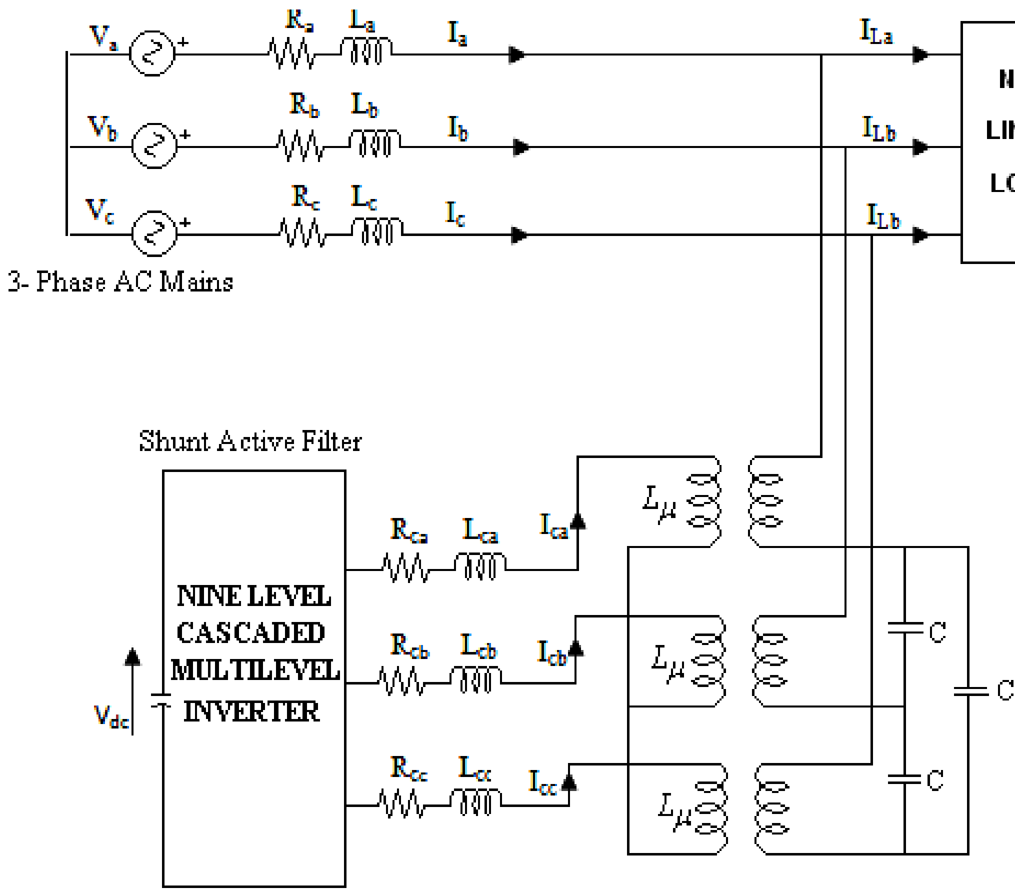

Figure 2. Nine level Cascaded Multilevel Inverter based SHAPF.

Shunt active filter acts a current source injecting equal but opposite harmonic and quadrature components of load current at the point of common coupling. In effect the system views non linear load together with active filter as an ideal resistor. A PWM voltage source inverter operating as a current controller device can be used as Shunt active Power filter. Latest researches include the use on multilevel inverter for high power energy conversion. The advantage of multilevel inverter will enable the circuit to operate with less output voltage harmonics and less electromagnetic interference. Because of the stepped output voltage, multilevel inverters have fewer ripples in its line current. There is individual capacitor for each H-bridge module. The APF will adopt small power from source to compensate the switching losses and capacitor losses and for that purpose, the capacitor voltages are sensed and compared with reference and fed to PI controller to generate loss component of APF. As compared with five levels and seven levels output voltage waveform is improved in nine levels multilevel inverter.

3. Reference Current Signal Generation

The indirect current control technique using a PI controller in shown in Fig. 3. The shunt hybrid active power filter bus voltage V_{dc} is sensed and compared with its reference V_{dc}^*, the error is fed to the controller, the output of the controller estimate the peak line current I_{sm}^*, it take care of the active power demand of the load and losses in the active power filter circuit[14-15]. The instantaneous reference supplies current (I_{sa}^*, I_{sb}^*, I_{sc}*) are evaluated by multiplying the peak line current by three unity voltage vectors. The shunt active power filter is used to compensate for reactive current absorbed by non-linear load, the unbalanced current and maintain the dc link voltage at constant level. In this control algorithm, the desired mains current is assumed to be the product of the magnitude and a unit amplitude sinusoidal wave in phase with the mains voltage. The mains is required to supply only the active portion of the load current as the shunt hybrid active power filter is expected to provide compensation for the harmonic and reactive portion of the three phase load current, and also for any imbalance in the three-phase load currents. Hence, only balanced current will be drawn from the mains which will be purely sinusoidal and in phase with the mains voltages. The reference compensation currents for the shunt hybrid active filter are thereby deduced as the difference between the actual load current and the desired source current in each phase can be represented as follows

$$i_{a(comp)} = i_{La} - i_{sa(ref)} \tag{4}$$

$$i_{b(comp)} = i_{Lb} - i_{sb(ref)} \tag{5}$$

$$i_{c(comp)} = i_{Lc} - i_{sc(ref)} \tag{6}$$

Where the desired (reference) source currents in the three phases are given as,

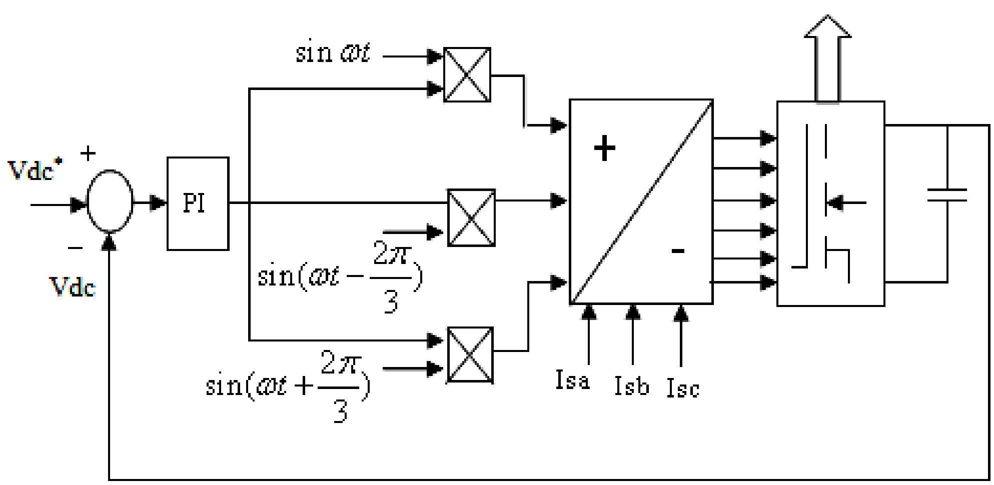

Figure 3. Indirect current control algorithm for SHAPF

$$i_{sa(ref)} = \left|i_{s(ref)}\right| \text{ x } V_a = \left|i_{s(ref)}\right| . \sin \omega t \tag{7}$$

$$i_{sb(ref)} = \left|i_{s(ref)}\right| \text{ x } V_b = \left|i_{s(ref)}\right| . \sin(\omega t - 120^\circ) \tag{8}$$

$$i_{sc(ref)} = \left|i_{s(ref)}\right| \times V_c = \left|i_{s(ref)}\right| . \sin(\omega t + 120^{\circ}) \tag{9}$$

V_a, V_b and V_c are the unit amplitude templates of the phase to ground source voltages in the three phases respectively.

$$V_a = 1. \sin(\omega t) \tag{10}$$

$$V_b = 1. \sin(\omega t - 120^{\circ}) \tag{11}$$

$$V_c = 1. \sin(\omega t + 120^{\circ}) \tag{12}$$

The magnitude of the desired source current $\left|i_{s(ref)}\right|$ can be expressed as the average of the magnitude of the real components of the fundamental load currents in the three phases

$$\begin{aligned} \left|i_{s(ref)}\right| &= \frac{\left|\mathrm{Re}(i_{La})\right| + \left|\mathrm{Re}(i_{Lb})\right| + \left|\mathrm{Re}(i_{Lb})\right|}{3} \\ &= \frac{\left|i_{La}\right| . \cos\phi_a + \left|i_{Lb}\right| . \cos\phi_b + \left|i_{Lc}\right| . \cos\phi_c}{3} \end{aligned} \tag{13}$$

To generate firing pulse for shunt hybrid active power filter, Phase disposition (PD) Pulse Width Modulation technique is used. This is basic sub harmonic PWM technique, in which all the carrier triangles are in phase [18]. The number of carriers is one less than the number of levels. In this technique, significant harmonic energy is concentrated at the carrier frequency f_c, because it is co-phasal components, it does not appear in the line voltage. It should be noted that the other harmonic components are centered around the carrier frequency as sidebands.Fig.4. shows the arrangement of carrier for phase disposition PWM technique.

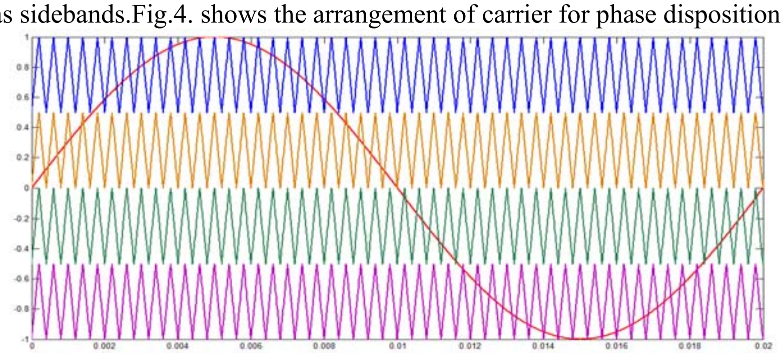

Figure 4. Arrangement of carriers-PD.

5. Simulation Results and Analysis

In this section, simulation results of three-phase shunt hybrid active power filter based on five level, seven level and nine level cascaded multilevel and its comparative analysis are presented. The goal of the simulation is to examine harmonic and reactive power compensation under balanced system. The system consist of a three-phase network feeds a three-phase diode bridge rectifier with a resistor R and inductor L in series at its dc output. Simulation investigation was carried on using MATLAB/SIMULINK simulation software in power system block set toolbox. The system parameters used in these simulations are shown in Table.4.1

5.1 Harmonic and reactive power compensation under balanced ac source and load by 5-Level cascaded MLI:

Fig.6. demonstrates the steady state response of source voltage, source current, compensation current, load current and output V_{dc} voltage under balanced source and balanced load is clearly depicted. The harmonic spectrum of source current before and after compensation is shown in Fig.5. and Fig.7. From the obtained results, the total harmonic distortion (THD) of source current is observed to be reduced from 21.03% before compensation to 4.56% after compensation.

Table.4.1 Simulation Parameters

System Parameter	Values
Sending end voltage (Line to Line) V	415 V (RMS)
Supply frequency F	50Hz
Line impedance L_s	1.2mH
Line impedance R_L,L_L	20Ω,8mH
Active filter parameter R_{dc},L_{dc},C_{dc}	0.5mH,0.1Ω,2400μF
Carrier Frequency for PWM circuit	10KHz
Passive filter parameter L_μ,C_p	7mH,40 μF

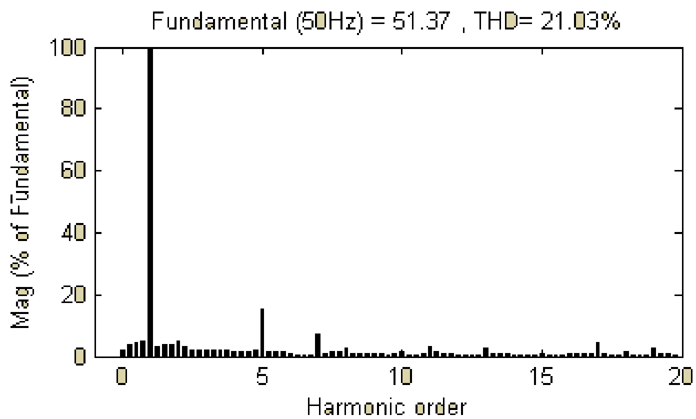

Figure 5. Harmonic Spectrum of Source current before compensation.

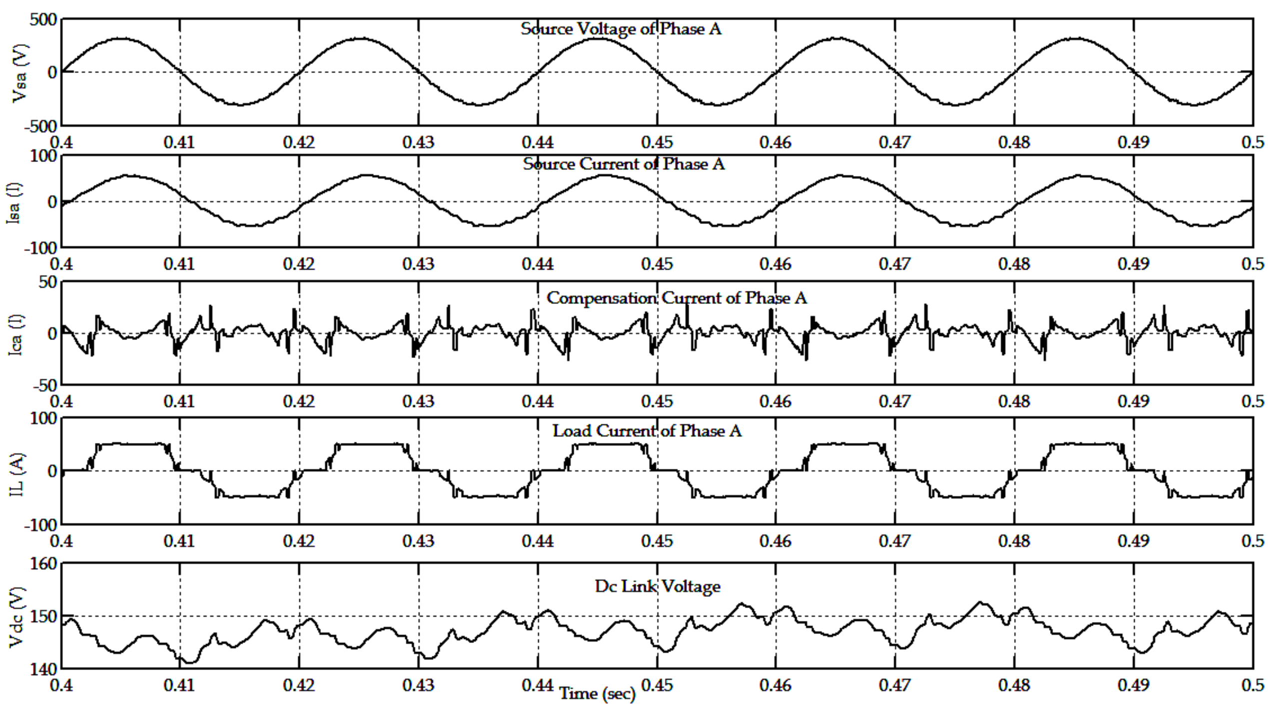

Figure 6. Steady State Response of 5-level Cascaded MLI based SHAPF

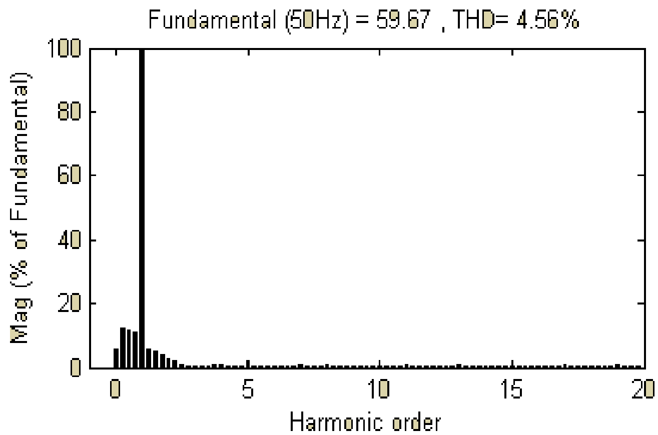

Figure 7. Harmonic Spectrum of Source current after compensation.

5.2 Harmonic and reactive power compensation under balanced ac source and load by 7-Level cascaded MLI:

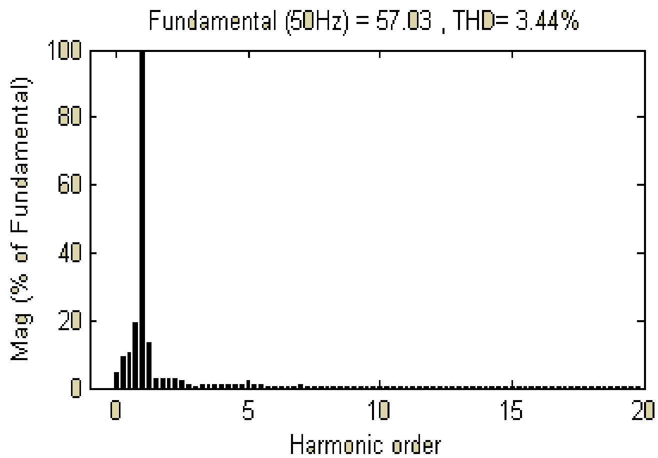

Figure 8. Harmonic Spectrum of Source current after compensation.

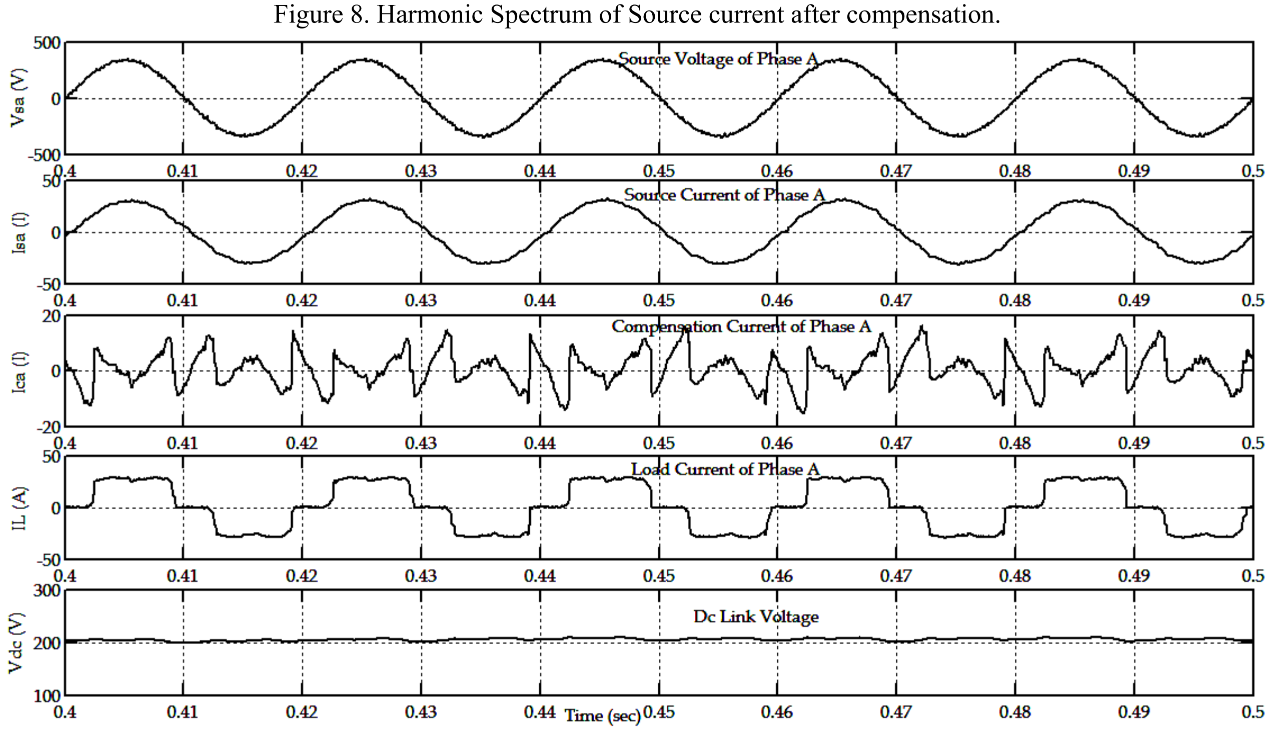

Figure 9. Steady State Response of 7-level Cascaded MLI based SHAPF

The harmonic spectrum of source current after compensation is shown in Fig.8. The steady state response of source voltage, source current, compensation current, load current and output V_{dc} voltage under balanced source and balanced load is clearly depicted revealed in Fig.9. It shows the supply mains currents in the three phases after compensation are expected to be sinusoidal and in phase with the mains, this shows shunt compensation has been achieved fairly. For before compensation, nonlinear load distorted the source current to 21.03% of harmonic distortion whereas after compensation using 7-level Cascaded MLI based SHAPF harmonic distortion is minimized to 3.44%. This demonstration proves that 7-level Cascaded MLI based SHAPF is better on mitigating current harmonics compared to 3-level Cascaded MLI based SHAPF.

5.3 Harmonic and reactive power compensation under balanced ac source and load by 9-Level cascaded MLI

The steady state response of source voltage, source current, compensation current, load current and output V_{dc} voltage under balanced source and balanced load is highlighted in Fig.10. It shows the supply mains currents in the three phases after compensation are expected to be sinusoidal and in phase with the mains, this shows shunt compensation has been achieved fairly. The harmonic spectrum of source current before and after compensation is shown in Fig.5 and Fig.11. Before compensation, the total harmonic distortion (THD) of source current is found to be 21.03% while after compensation using 9-level Cascaded MLI based SHAPF source current harmonic distortion is reduced to 2.93%.

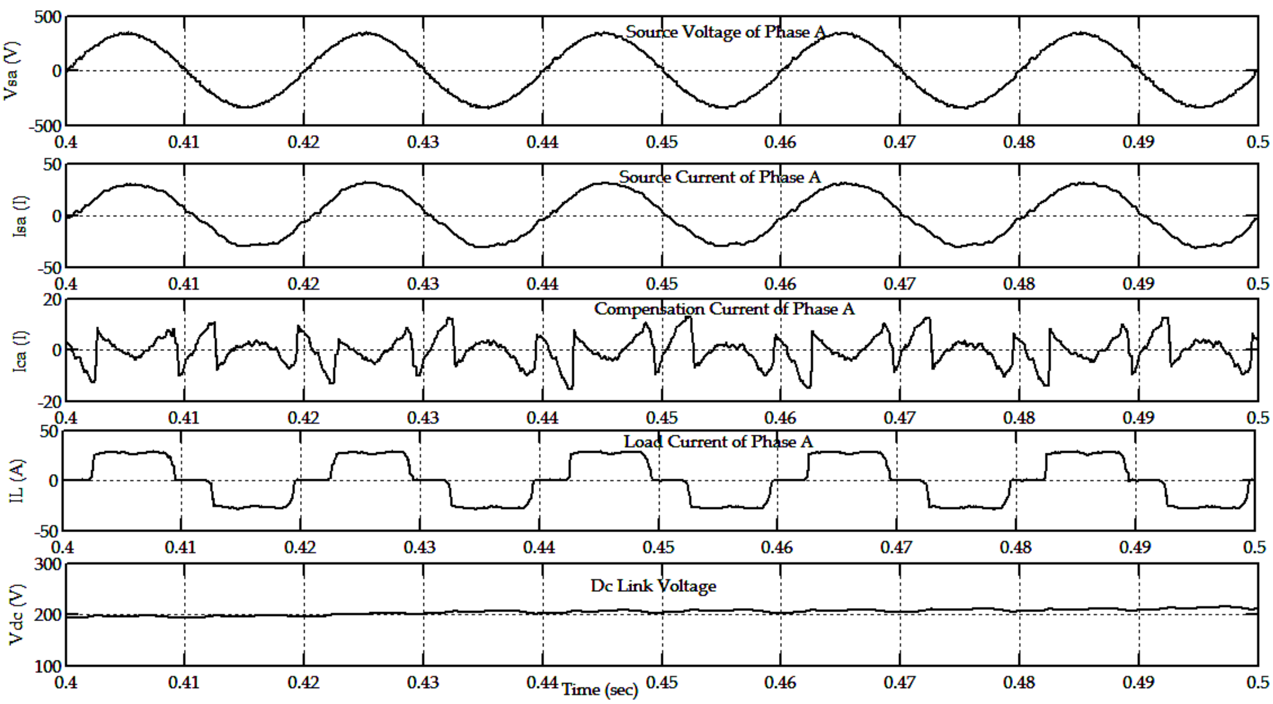

Figure 10. Steady State Response of 9-level Cascaded MLI based SHAPF

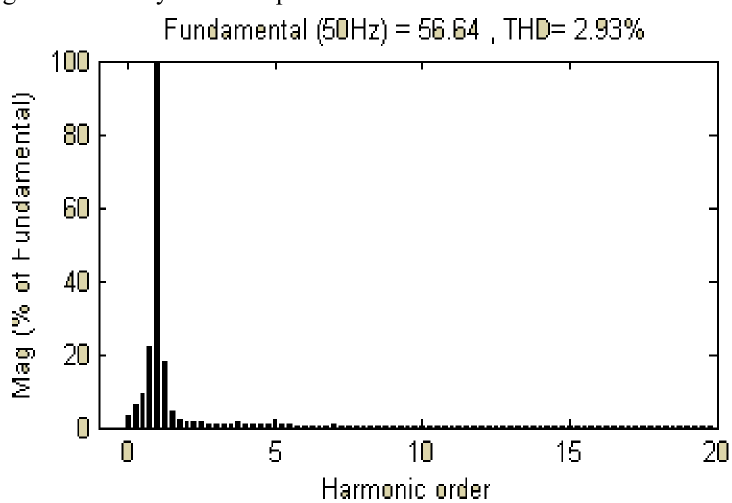

Figure 11. Harmonic Spectrum of Source current after compensation.

Table 5.2 shows the comparison of results obtained from under harmonic and reactive power compensation under balanced ac source and load. The harmonic spectrum of source current after compensation is clearly indicated in the table5.3. The overall investigations, proved that the 9-level Cascaded MLI based SHAPF has found to be better compensation capability compared to 7 and 5-level Cascaded MLI based SHAPF and three phase voltage source inverter based shunt hybrid active power filter.

Table 5.2 Comparison of 5-Level, 7-Level Cascaded Multilevel Inverter based Shunt hybrid Active Power Filter

Different Configuration	**Before Compensation**	**After Compensation**
Five Level Cascaded Multilevel Inverter based SHAPF	21.03%	4.56%
Seven Level Cascaded Multilevel Inverter based SHAPF	21.03%	3.44%
Nine Level Cascaded Multilevel Inverter based SHAPF	21.03%	2.93%

Table 5.3 Individual harmonic content under non-liner load condition.

Harmonic Order	**Compensation with five level cascaded MLI (%)**	**Compensation with seven level cascaded MLI (%)**	**Compensation with nine level cascaded MLI (%)**
180Hz(h3)	0.93	0.33	0.25
300Hz(h5)	1.90	1.52	1.05
420Hz(h7)	1.62	0.82	0.67
540Hz(h9)	0.29	0.24	0.14
660Hz(h11)	0.89	0.31	0.31
780Hz(h13)	0.66	0.31	0.20

6. Conclusion

The paper has investigated the comparative analysis of five level, seven level and nine level cascaded multilevel inverter based shunt hybrid active power filter for compensation of current harmonics and reactive power compensation are presented. The test results bring out the advantage of cascaded multilevel inverter based shunt hybrid active power filter for power quality enhancement. The total harmonic distortion of source current has been reduced from a high value to an allowable limit and to meet the IEEE 519 standard. The simulation results clearly shows that reduction in THD is better in nine level inverter as compared with seven level and five level inverter based shunt hybrid active power filter. The indirect current control algorithm with phase disposition pulse width modulation method provides better computation efficiency for generating reference current. The proposed shunt active filter topology realized an acceptable power factor profile and compensates the wide range of power quality problems.

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References

Bhattacharya S., and Divan D., 1995. Synchronous frame based controller implementation for a hybrid series active filter system. *Conf. Rec. IEEE-IAS Annu. Meeting*, pp. 2531–2540.

Cirrincione M., Pucci M., and Vitale G., 2008. A single-phase DG generation unit with shunt active power filter capability by adaptive neural filtering, *IEEE Trans. Ind. Electron.*, Vol. 55, No. 5, pp. 2093–2110.

Dixon J.W., Contardo J.M., Morlan L.A, 1999. A fuzzy controlled, active front end rectifier with current harmonic filtering characteristics and minimum sensing variable, *IEEE Trans. Power Electron*., Vol. 14, No. 4, pp.724-729.

El-Harouk M., Darwish M.L., and Mehta P., 2000. Active power filters- A review, *Proc. IEE-Elect. Power Application*, Vol. 147, No. 5, pp. 403-413.

Holmes D. G., McGrath B. P., 2001. Opportunities for harmonic cancellation with carrier-based PWM for two-level and multilevel cascaded inverters, *IEEE Trans. Ind. Applicat.*, Vol. 37, No. 2, pp. 574-582.

Jacobs J., Detien D., Doncker R., 2001. A new hybrid filter versus a shunt power filters, *Proc. European Con. On Power Electronics and Applications (EPE 2001)*, Graz, Australia.

Karthik K., and Quaicoe J.E., 2000. Voltage compensation and harmonic suppression using series active and shunt passive filters, *Proc. IEEE Canadian Conf. on Electrical and Computer Engineering*, pp. 582–586.

Liqiao W., Ping L., Zhongchao Z. 2004. Study on shunt active power filter based on cascade multilevel converters, *35th Annual IEEE power electronics Specialists Conference*, pp.3512- 3516.

Liqiao W., Shireen W., Packebush P. and Pitel I., 2004. Analysis, design of a new active power filters to cancel neutral current harmonics in three-phase four-wire electric distribution systems, *Conf. Record IEEE-IAS Annual Meeting*, pp. 939–946.

Miranda H., Cardens V., Perez J., 2004. A hybrid multilevel inverter for shunt active filter using space vector control, *35th Annual IEEE power electronics Specialists Conference*, pp 3541-3546.

Park S., Han S.B., Jung, Choi S.H., and Jeong H.G., 2000a. A current control scheme based on multiple synchronous reference frames for parallel hybrid active filter. *Proc. 3rd Int. Conf. on Power Electronics and Motion Control (PIEMC)*, pp. 218.

Park S., Han S.B., Jung, Choi S.H., and Jeong H.G., 2000b. A current control scheme based on multiple synchronous reference frames for parallel hybrid active filter. *Proc. 3rd Int. Conf. on Power Electronics and Motion Control (PIEMC)*, pp. 218–223.

Rahmani S., Al-Haddad K., Fnaiech F.. 2003. Bipolar reference for PWM control of a single phase shunt hybrid power filter. *IEEE ISIE2003*, pp. 401–406.

Rodriguez J., Lai S., Peng F.Z. 2002. Multilevel inverters: a survey of topologies, controls, and applications, *IEEE Trans. On Ind. Electronics*, Vol.49, No 4, pp. 724-738.

Senini S. and Wolfs P.J., 2000. Hybrid active filter for harmonically unbalanced three phase three wire railway traction loads, *IEEE Trans. on Power Electronics,* pp. 702 -710.

Singh B., Al-Haddad K. and Chandra A., 1998. A new control approach to three phase harmonics and reactive power compensation, *IEEE Trans. on Power Systems*, Vol. 13, No 1, pp. 133-138.

Singh B., Al-Haddad K., and Chandra A., 1999. A review of active filter for power quality improvement, *IEEE Trans. Ind Electron*, Vol.46, pp-960-971.

Yuwen B., Jiang X., and Zhu D., 2000. Study on the performance of the combined power filter with unsymmetrical condition. *Proc. 3rd Int. Conf. Power Electronics and Motion Control (PIEMC)*, pp. 365–370.

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