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A New Multilevel Inverter Based Shunt Active Power Filter to Improve Power Quality

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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.

I. INTRODUCTION

A multilevel inversion known by the power conversion approach diminishes the total harmonic distortion (THD) by getting the output voltage in steps and taking the output nearer to a sine wave [2]. Generating an estimated sinusoidal voltage from multiple stages of dc voltages, usually got from capacitor voltage sources is the general objective of multilevel inverters [1]. Using transformers, a multi-pulse inverter like 6-pulse or 12-pulse inverter accomplishes harmonic with reactive power (VAR) compensation through numerous voltage-source inverters interrelated in a crisscross manner [3]. A few power electronics applications are Flexible ac transmission systems, renewable energy sources, uninterruptible power supplies and active power filters; in which multilevel inverters are significant [4]. For power increase and harmonics reduction of AC waveform, Multi-level inverters (MLI) have materialized as a victorious and practical solution [19]. Non-linear loads like adjustable speed drives; electronically ballasted lighting and the power supplies of the electrical with equipment applied in present offices affect current harmonics in recent electrical allocation systems [5]. By these harmonic currents, Voltage alteration is generated as they unite with the impedance features of the supply systems [6]. Extra heating losses, shorter insulation lifetime, increased temperature and insulation stress, decreased power factor, decreased output, efficiency, ability and deficiency of plant system performance happen thus of a raise in the harmonic alteration component of the transformer [7].

To diminish the problem of harmonics, different methods have been recognized. A few examples are: 1) Specific Harmonic Elimination (SHE} [18] which is applied for abolition of discarded lower order harmonics and control of fundamental voltage in a square wave. 2) Harmonic elimination pulse width modulation (HEPWM) technique that has a number of advantages compared to traditional sinusoidal PWM (SPWM) for Voltage Source Inverters (VSI) [8]-[9]. Eradication of harmonics in nonlinear system is moreover attained by using a non-natural neural Network [10]. Lately, Shunt Active power filter is commonly utilized for eliminating harmonics and for improving power factor to eradication of the negative and zero series elements[11]. Intended for abolition of harmonics, an Active power filters are widely employed. The shunt compensator APF exterminates commotion in current, whereas the series compensator dynamic voltage Restorer (DVR) destroys turbulence in voltage. By avoiding generation or consumption of reactive power, the load harmonic currents can be effectively reimbursed with fundamental frequency components by planning the active filter controller to take out and insert load harmonic currents and maintain up a steady dc capacitor voltage [13].

Using pulse width modulation or by controlling the dc-link voltage, it has the prospective to change the amplitude of the synthesized ac voltage of the inverters. Solitary technique applied to recognize active filter current indications is by linking Lf and C_f on the AC and DC sides correspondingly and standards can be met and power rating of the APF can be reduced by employing choosey harmonics compensation.

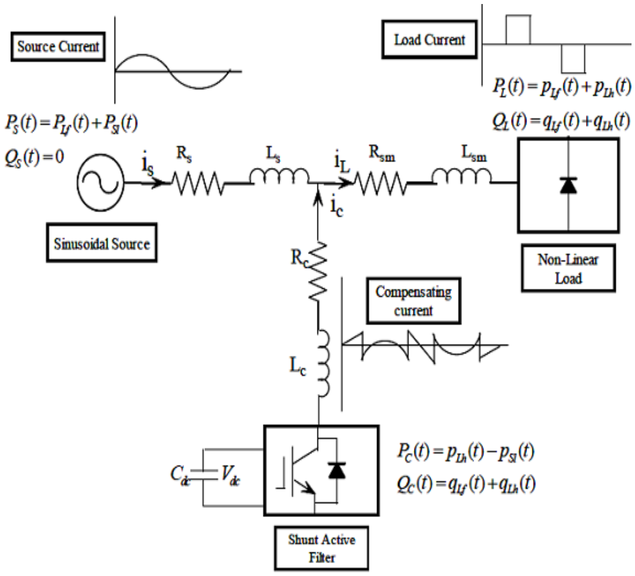

Fig.1. Operation of active power filter.

In this paper seven level cascaded multilevel inverter based shunt hybrid active power filter by Pulse Width Modulation technique as shown in Fig. 1. The proposed work attempts to analyze compensation the characteristics of cascaded multilevel inverter based shunt hybrid active power filter with a view to improve power quality are analyzed in this paper.

II. H-BRIDGE MULTILEVEL INVERTER

The traditional two or three levels inverter does not completely eliminate the unwanted harmonics in the output waveform. Therefore, using the multilevel inverter as an alternative to traditional PWM inverters is investigated. In this topology the number of phase voltage levels at the converter terminals is 2N+1, where N is the number of cells or dc link voltages. In this topology, each cell has separate dc link capacitor and the voltage across the capacitor might differ among the cells. So, each power circuit needs just one dc voltage source as shown in Fig. 2. The number of dc link capacitors is proportional to the number of phase voltage levels. Each H-bridge cell may have positive, negative or zero voltage. Final output voltage is the sum of all H-bridge cell voltages and is symmetric with respect to neutral point, so the number of voltage levels is odd. Cascaded H-bridge multilevel inverters typically use IGBT switches. These switches have low block voltage and high switching frequency. The cascaded H-bridges multilevel inverter introduces the idea of using Separate DC Sources (SDCSs) to produce an AC voltage waveform as shown in Fig. 3. Each H-bridge inverter is connected to its own DC source V_{dc}. By cascading the AC outputs of each H-bridge inverter, an AC voltage waveform is produced. By closing the appropriate switches, each H-bridge inverter can produce three different voltages: $+V_{dc}$, 0 and $-V_{dc}$.

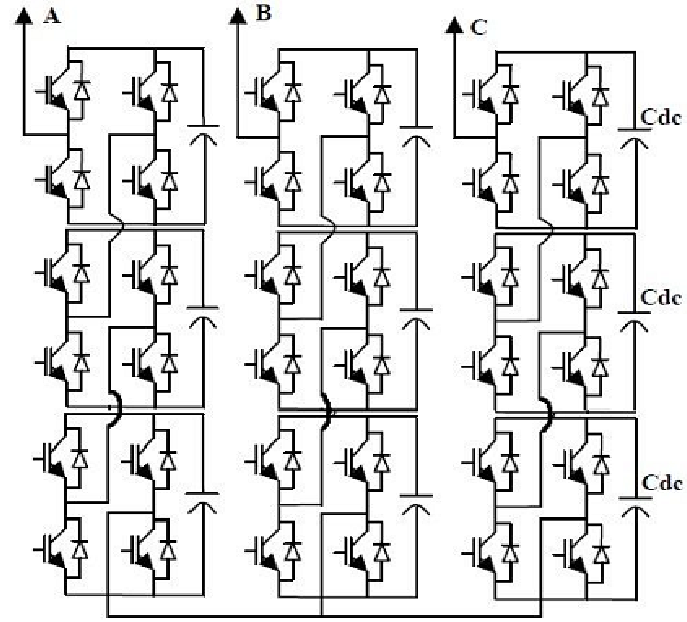

Fig.2. schematic diagram of five level three phase inverter.

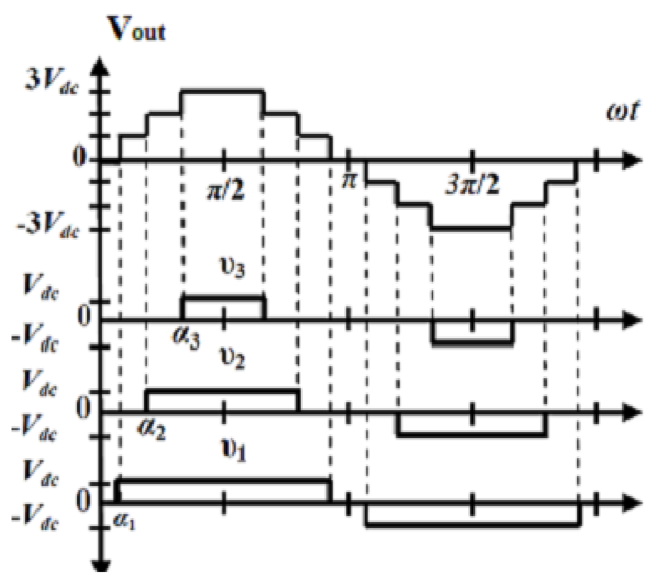

Fig.3. Output Voltage of cascaded H-bridge seven level inverter.

III. PHASE LOCKED LOOP

Many methods have been proposed for the reference current generation for SAPF like Instantaneous Reactive Power Theory (p-q Theory) [5]-[7], Synchronous Reference Frame Theory [8], DFT analysis [9], notch filtering [10] etc. This paper introduces a novel signal processing system for extraction of harmonic and reactive current components for their use in SAPF by making use of Enhanced Phase Locked Loop (EPLL). Basically EPLL is a non-linear adaptive notch filter. Hence it can be used as an alternative method to DFT analysis which requires a large amount of computations and hence time, as against the case of PLL, it can lock and track certain frequency in minimum time as long as the input frequency is in the capture range of the PLL. Few advantages of PLL are- stability, robustness and convergence rate [10].

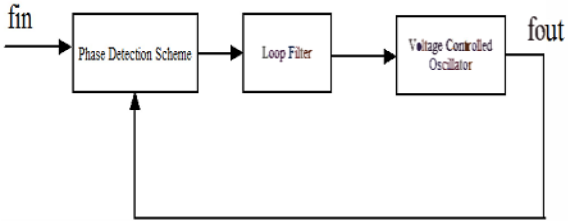

Fig.4. Block diagram of PLL.

Phase-Locked Loop (PLL) has a feedback loop which locks two waveforms with the same frequency but shifted in phase. The fundamental use of this loop is in comparing frequencies of two waveforms and then adjusting the frequency of the waveform in the loop to match the input waveform frequency. A block diagram of the PLL is shown in Fig.4. It is basically a feedback control system that controls the frequency of a voltage controlled oscillator (VCO). The input signal is applied to one of the inputs of a phase detector. The other input is connected to the output of a divide by N counter. Normally the frequencies of both signals will be nearly the same. The output of the phase detector is a voltage proportional to the phase difference between the two inputs. This signal is applied to the loop filter. It is the loop filter that determines the dynamic characteristics of the PLL. The filtered signal controls the VCO. Note that the output of the VCO is at a frequency that is N times the input supplied to the frequency reference input. This output signal is sent back to the phase detector via the divide by N counter.

A. EPLL-Based System

In this paper, EPLL (Enhanced Phase Locked Loop) is used for extracting the fundamental component of the load current which is then used for the purpose of reference current generation for SAPF (Shunt Active Power Filter). The basic components of EPLL are same as those of PLL. The block diagram of EPLL is shown in Fig5. But the main difference between PLL and EPLL is that in PLL, the phase difference between the input signal and the VCO output signal is constant, whereas that can be made and maintained zero in case of EPLL. Also EPLL is an amplitude locked PLL unlike a PLL. Let the inputs to the multiplier of EPLL be vim sin(wit) that is the input signal and v_{om}cos(wot + 0(t)) which is output of VCO which is then 90° phase shifted. Then the output voltage v_p is

$$v_p = v_{im}\sin(\omega_i t) \times v_{om}\cos(\omega_o t + \emptyset(t))$$

$$= \frac{v_{im}v_{om}}{2}\left(\sin\left((\omega_i - \omega_o)t - \emptyset(t)\right) + \sin\left((\omega_i + \omega_o)t + \emptyset(t)\right)\right) \quad \textbf{(1)}$$

This output v_p is passed through a low-pass filter and if the two frequencies W_i and W_o are c1ose together then the output of the filter is a function of the phase difference between the two input waveforms given by

$$v_{olp} = \frac{v_{im}v_{om}}{2}\left(\sin\left((\omega_i - \omega_o)t - \emptyset(t)\right)\right) \quad \textbf{(2)}$$

The output v_{Olp} is a function of the instantaneous phase difference (wit-(w_ot+Ø(t))) between the two waveforms. The EPLL is inherently adaptive and follows variations in amplitude, phase angle and frequency of the input signal. The EPLL is capable of accurately estimating the fundamental component of a polluted signal. This feature of EPLL is made use of in the proposed method of reference current generation for SAPF. The structure of the EPLL is simple and this makes it suitable for real-time embedded applications for software or hardware implementation. Also its structure is in sensitive with respect to the variations of internal parameters which constitutes to the robustness.

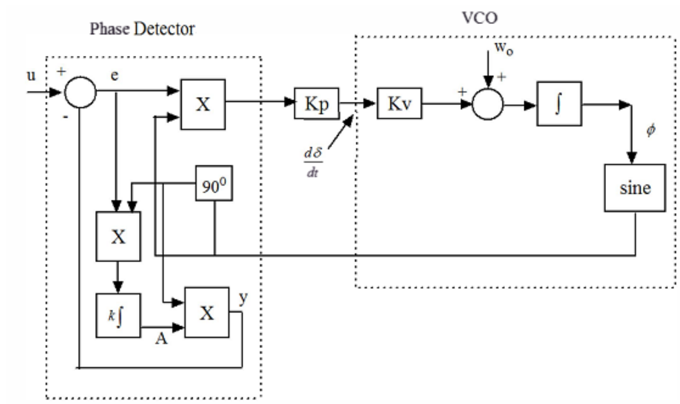

Fig.5. Block diagram of EPLL.

Rate of convergence of EPLL is increased by increasing the values of K and K_p, K_v thereby controlling the transient as well as the steady state behaviour of the filter. One of the main features of EPLL is that as K increases, the speed of response increases but at the same time oscillations are increased .i.e. there is a trade-off between the speed and accuracy of the response. Decreasing K and K_p, K_v makes the system robust to the noise in input signal. Hence it is suitable for the extraction of the peak value of fundamental component of the input signal (load current in the proposed case) in real time, which further is used for reference current generation for SAPF.

IV. MATLAB/SIMULINK RESULTS

Fig. 6 shows the MATLAB/Simulink diagram for a SAPF with EPLL used in order to extract the fundamental component of the load current and the frequency which are then used for reference current generation to control the switching of VSI used in SAPF. The power supplied to the inverter used in SAPF is through the DC link capacitor and the current required to charge this capacitor is taken from the source itself. This current is termed as loss current which is then added to the fundamental current computed by EPLL to find the total current to be compensated. The three phase template currents are generated with this amplitude and are synchronized with the source voltage. These currents are subtracted from the load current and the output is compared with hysteresis current controller to generate reference current signals as shown in Figs.6 to 17.

Case 1: 4- leg VSI based SAPF for balanced load

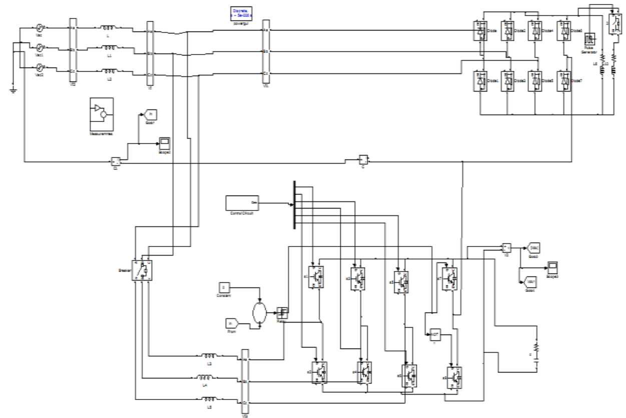

Fig.6.Simulink circuit for SAPF for balanced load.

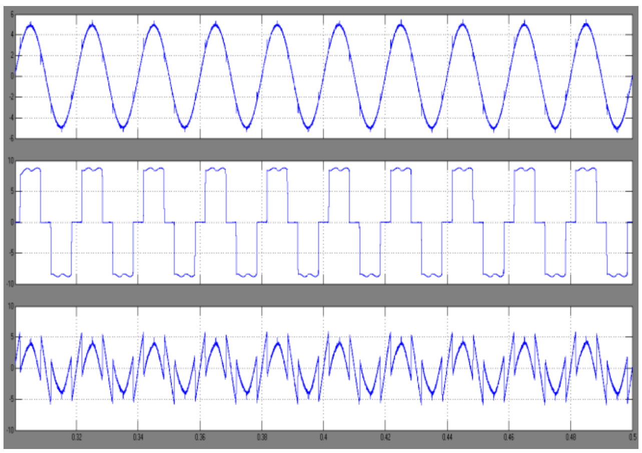

Fig.7.Simulation results for source current, load current and compensation current.

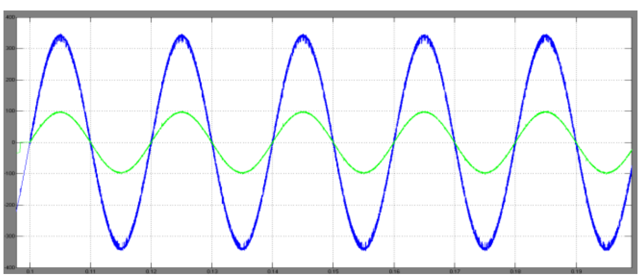

Fig.8.Simulation results for source power factor.

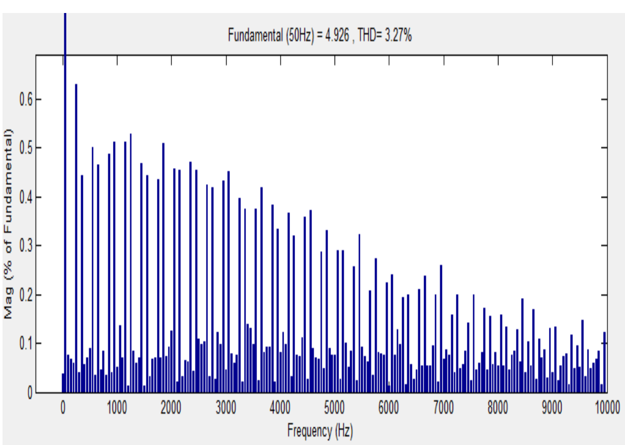

Fig.9.FFT analysis for source current.

Case 2: 4- leg VSI based SAPF for Unbalanced Load

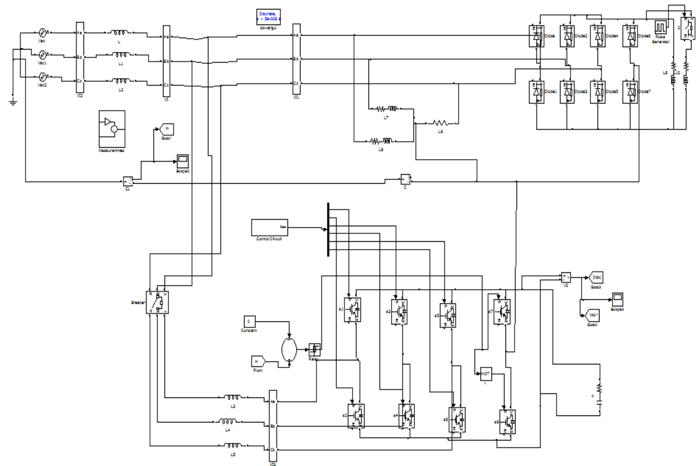

Fig.10.Simulink circuit for unbalanced load.

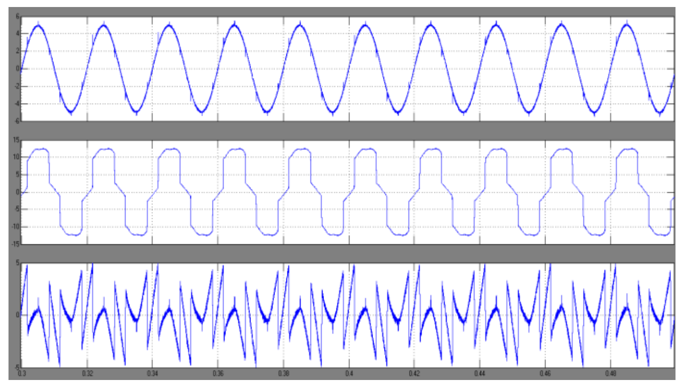

Fig.11.Simulation results for source current, load current and compensation current.

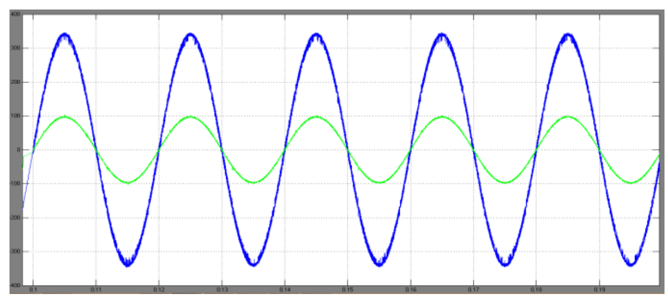

Fig.12.Simulation results for source power factor.

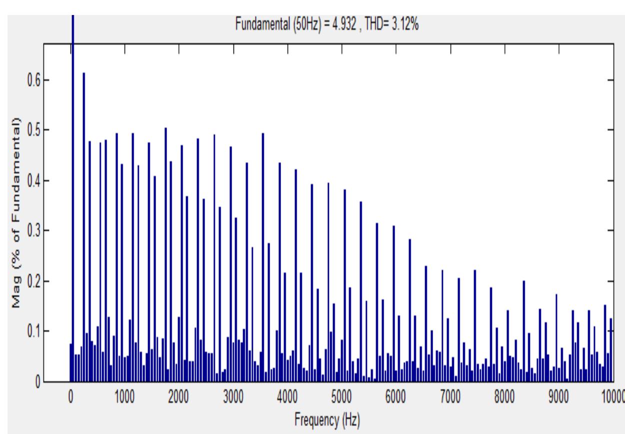

Fig.13.FFT analysis for source current.

Case 3: CHB based SAPF

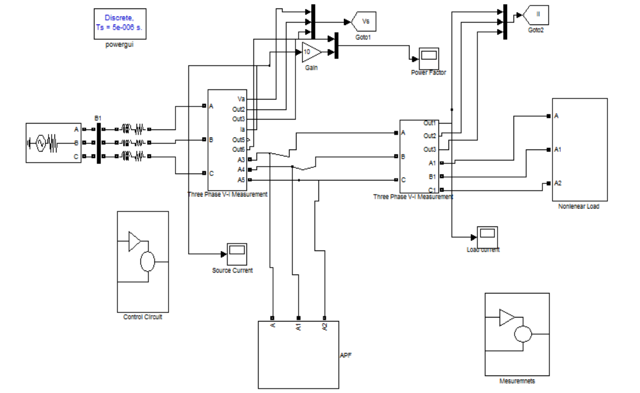

Fig.14.Simulink circuit for CHB based SAPF.

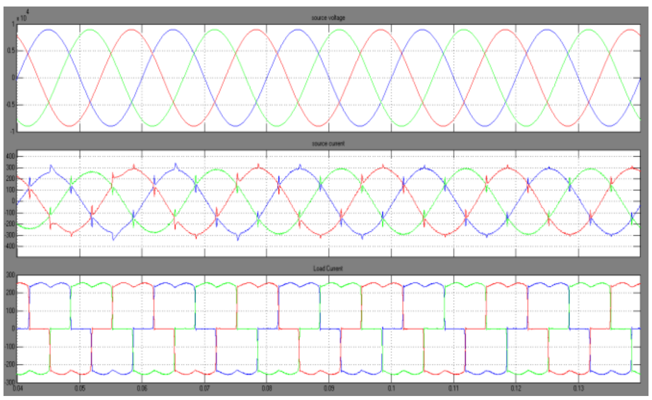

Fig.15.Simulation results for source current, load current and compensation current.

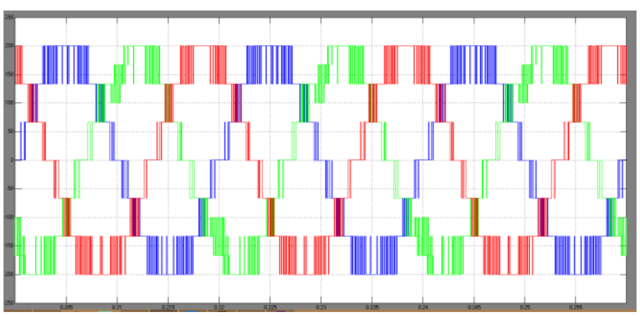

Fig.16.Simulation results for 7level output voltage of CHB.

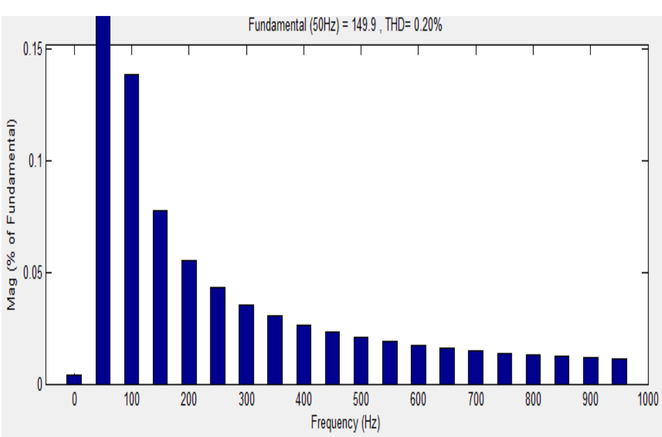

Fig.17.FFT analysis for source current.

V. CONCLUSION

The paper has investigated the analysis of seven 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 low value to an allowable limit and to meet the IEEE 519 standard. The simulation results clearly shows that reduction in THD is better in seven level inverter. 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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