Power Quality Enhancement Using Shunt Active Power Filter Based on 5-Level Cascaded Multilevel Inverter for Controlled and Uncontrolled Converter Load

Seema Agrawal[1], Aditya Pandey[2], Mohammed Zaid Khan[3]
[1,2,3]*Electrical Engineering Department, Rajasthan Technical University, Akelgarh, Kota*

***Abstract* - Power electronic devices like cascaded multilevel inverter were developed to produce the required voltage and current waveform from many levels of DC voltages. Therefore, these inverters are striking topologies for their implementation in shunt active power filter to be used in medium and high-power application. So, this paper displays a five-level cascaded multilevel inverter working in a shunt active filter to eradicate current harmonics generated by different non-linear loads and compensates the reactive power. The system also includes PI controller for voltage regulation in SAPF in its DC side and for generating inverter switching pulses, triangular carrier current controller is worn. The control strategy used for production of reference compensation currents is unit impulse theory. So, main emphasis is on extenuation of harmonics from nonlinear loads with the support of PI controller for DC voltage regulation.**

***Index Terms* - Shunt Active Power Filter (SAPF), Multilevel Inverter (MLI), Pulse Width Modulation (PWM), Proportional Integral (PI).**

INTRODUCTION

In past few years, use of power electronic devices in electrical energy distribution system and consumer utility system have grown tremendously. These power electronic devices offer some very high non-linear characteristics, so are known as the non-linear loads[1] which produces some undesirable features like poor power factor, low system efficiency, interference in communication network, current/voltage harmonics and draws reactive power which causes numerous problems [2], [3]. So, in order to meet standard specification in terms of power quality and safety for grid connected system, phase angle and frequency of the grid voltage is very important aspect.

Normally, to reduce harmonics and to improve power factor passive LC filters are used, but these filters suffered with various problems like no voltage gain, no power gain, not flexible to use in different applications, larger in sizes, resonance and used inductors of higher value for lower frequencies [4]-[6]. In last couple of decades, for power quality issues like voltage regulation, reactive power compensation and mitigation of current harmonics new technique known as the active power filters had been considered. Different topologies of active power filter like series, shunt and hybrid have been introduced with shunt active power filter technique which is proven to be comparatively good for the use. It uses a three-phase voltage source inverter controlled by PWM having a capacitor working as an energy storage device connected to DC side. Harmonic compensation is achieved at the AC side of VSI through various filter control techniques like the active reactive power theory, synchronous reference theory and voltage reference method [7]-[10]. All these methods mentioned here have got their own merits and demerits when compared to each other and based on their degree of accuracy required and working state, appropriate method for reference current generation is selected. However, this paper discusses a new method for reference current generation known as the unit template method [11].

SAPF to work effectively, VSI must be a multilevel inverter which is an array of power semiconductors and capacitor voltage sources which generate stepped voltage waveform. These MLIs have several advantages like lower switching losses, very low harmonics and low distortion input current. They have 3 topologies namely Diode Clamped or neutral point clamped MLI, capacitor clamped or flying capacitor MLI and cascaded MLI [12]-[15]. Out of these, CMLI is one used in the work shown here because it has very simple structure, least switching losses, same circuit topology, easy to maintain and its reach to higher output levels. This makes us use MLI as a VSI working as a SAPF.

Here, in this paper unit template generation technique is used to generate reference current. This MLI based SAPF estimates compensating current instantly after the variation in load current and reduces harmonic. PWM pattern production is based on triangular carrier wave based current control to acquire switching signals for VSI. Simulation results are presented under steady state conditions using MATLAB/Simulink to show the efficiency of this paper.

II. SYSTEM CONFIGURATION

System revealed in Fig. 1 consists of three phase voltage sources connected to non-linear load and SAPF, where SAPF is used to alleviate current harmonics inoculated by non-linear loads. It is made by VSI which is actually a Cascaded MLI with DC link capacitor as a voltage source which is kept constant by flow of active power from point of common coupling (PCC). SAPF inserts compensating current at PCC which are although out of phase to the load harmonics but are equal in magnitude to it. This system uses unit impulse theory to generate fundamental component of load current to produce reference current for switching of MLI.

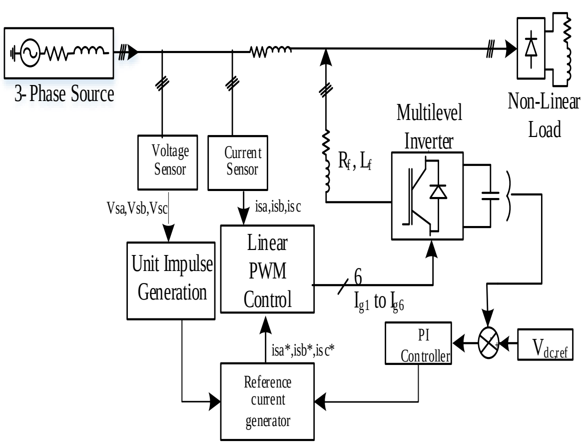


Fig. 1. Block diagram of Cascaded MLI based SAPF.

The main circuit which makes up SAPF is multilevel inverter and following Fig. 2 shows a 3-phase, 5-level Cascaded H-bridge MLI which is constructed up of two H-bridges connected in series per phase which consists of double parallel legs having two IGBT/Diode switches in one leg working as a switching device. Its construction is such that here m=5 (m is the number of output level of MLI) and it requires four triangular shaped carrier waves to generate gating signal for inverter switches which is result of current controller because for every phase it has unvarying switching strain. In each phase of the MLI, two capacitors are connected to DC side of H-bridge, where 'i' is referred to as the three phases (a, b, c) of inverter.

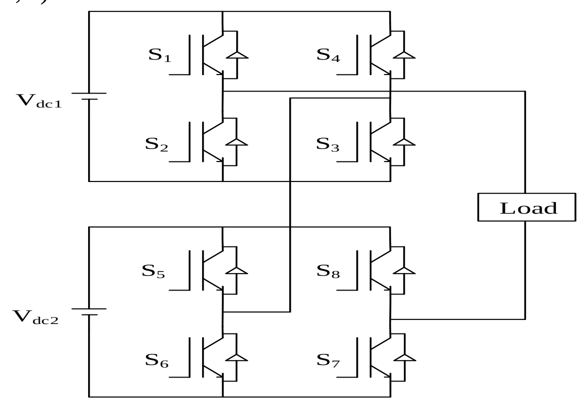


Fig. 2. Cascaded Multilevel Inverter.

Projected control strategy which consists of unit impulse theory uses a PI controller and PWM controller with triangular current carrier. Unit impulse reference current is generated by dividing peak magnitude of the source voltage with the magnitude resulting in a perfect sinusoidal wave with magnitude of 1. Fig.3 shows block diagram of PI controller scheme. Voltage of DC side capacitor is identified and equated with the reference value.

The output of the unit impulse waveform is as shown below:

$$U_{sa} = \sin(\omega t) \quad (1)$$

$$U_{sb} = \sin(\omega t + \frac{2\pi}{3}) \quad (2)$$

$$U_{sc} = \sin(\omega t - \frac{2\pi}{3}) \quad (3)$$

So, the reference currents are given as shown in the equation below:

$$i_a^* = U_{sa} \times i_p = i_p \sin(\omega t) \quad (4)$$

$$i_b^* = U_{sa} \times i_p = i_p \sin(\omega t + \frac{2\pi}{3}) \quad (5)$$

$$i_c^* = U_{sc} \times i_p = i_p \sin(\omega t - \frac{2\pi}{3}) \quad (6)$$

Here, i_p is the maximum magnitude of the desired current.

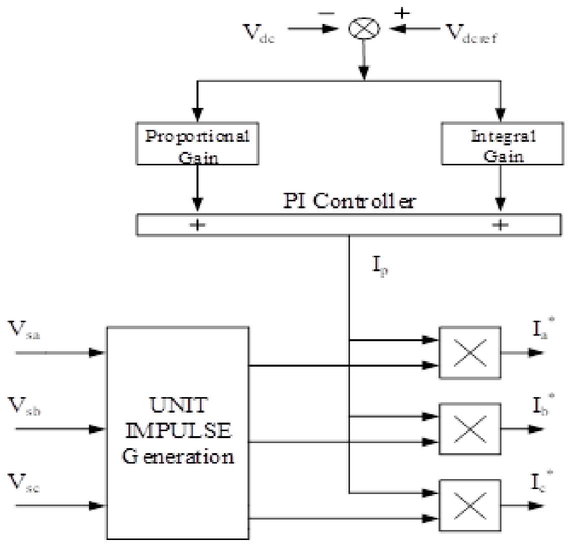


Fig. 3 Block diagram of PI controller

The working of SAPF is based on error generation by comparing reference currents with actual load currents. The produced error is then utilized as modulating signal and is further compared with carrier signals to produce required gating pulses for inverter switches exhibited in Fig.4.

$$S = \begin{Bmatrix} 0 \rightarrow if \quad V_{cr} > V_{ref} \\ 1 \rightarrow if \quad V_{cr} \leq V_{ref} \end{Bmatrix} \qquad (7)$$

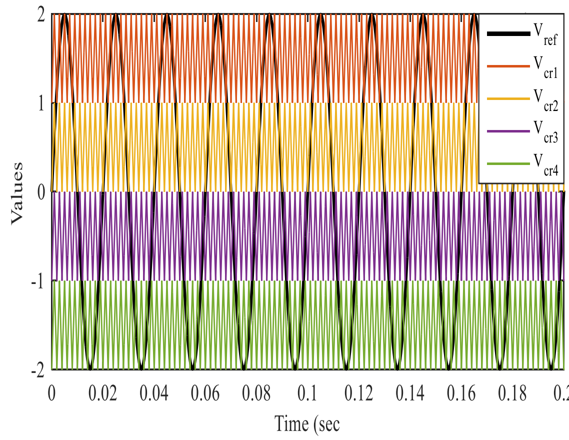


Fig. 4 Constant switching frequency PWM

III. SIMULATION RESULTS

MATLAB/Simulink is used for simulation to evaluate the performance. Controlled and uncontrolled converter with R-L load is used here under balanced condition. Modelling parameters are shown in Table 1 and simulation time is T_S = 0 to 0.2 sec.

TABLE 1. Modelling Parameters

Source	Fundamental Supply Voltage: 400 (RMS line voltage) Source Frequency = 50Hz R_s = 1Ω L_s = 0.5mH
SAPF	DC Link Capacitor, C_{dc} = 2000μF Reference DC Link Voltage: V_{dc} = 300V Filter Inductor, L_f = 4mH, R_f = 0.3Ω DC Link PI Controller gain, K_p = 0.2 and K_i = 1.5
Controlled Converter with R-L Load	Controlled Converter with L_l = 100mH and R_l = 20Ω
Uncontrolled Converter with R-L Load	Uncontrolled Converter with L_l = 20mH and R_l = 50Ω

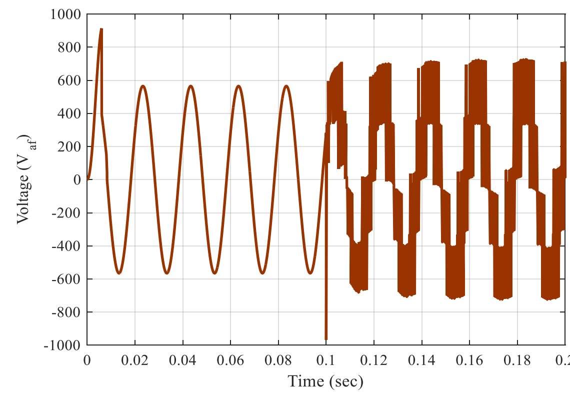


Fig. 5 Output of Phase A of 5 Level Cascaded Multilevel Inverter

The above shown Fig. 5 is the output voltage of 5-level cascaded multilevel inverter. It is a 3-phase cascaded MLI but waveform shown is of phase-A.

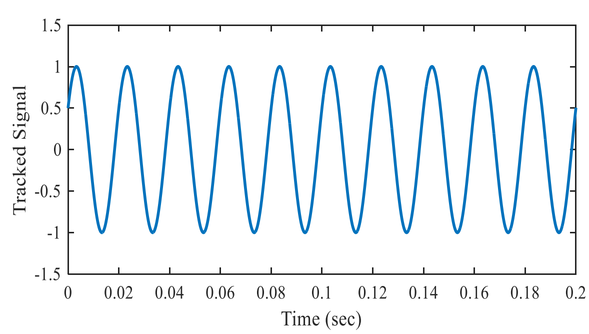


Fig. 6 Tracked Signal for Phase-A

Tracked signal or the unit impulse generated for phase- A is shown in Fig. 6.

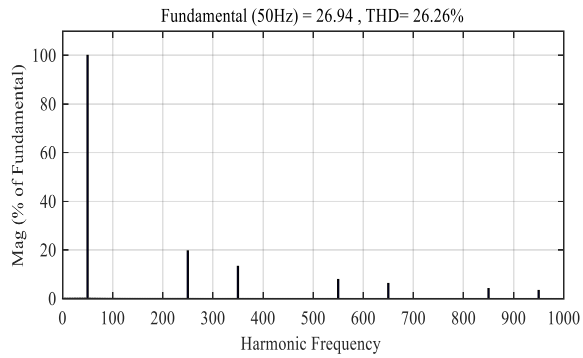


Fig.7 FFT analysis of source current before compensation for controlled converter with R-L load

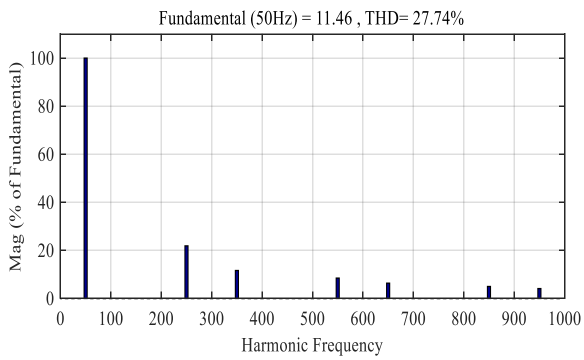


Fig. 8 FFT analysis of source current before compensation for uncontrolled converter with R-L load

The above Fig. 7 and Fig. 8 shows the FFT analysis of current waveform of the controlled and uncontrolled converter with R-L load. It clearly shows that without compensation %THD for the above-mentioned loads is 26.26% and 27.74% respectively.

Fig. 9 is the simulation result of the cascaded multilevel inverter-based shunt active power filter connected to controlled converter with R-L load and Fig. 10 is the simulation result when the filter is connected to the uncontrolled converter with R-L load. For both the cases, the first waveform corresponds to the voltage source (V_{sabc}) followed by source current (I_{sabc}), compensating current (I_{habc}), compensated source current (I_{cabc}), DC link voltage (Vdc)and FFT analysis after compensation.

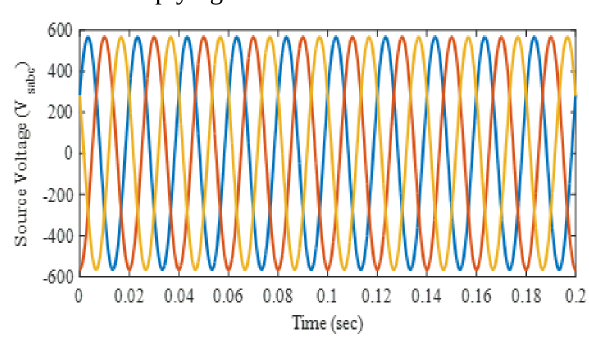
To calculate magnitude of harmonic content in the system, Fourier analysis is performed. Above discussed technique is applied for harmonic compensation and to make source current sinusoidal. Spectral analysis of compensated source current shown in Fig. 9 and Fig. 10, before and after compensation. This clearly shows that total harmonic distortion (THD) before compensation when controlled converter with R-L load was used is 26.26% with magnitude of fundamental to be 26.81 ampere while after compensation, THD is reduced to 4.96% with magnitude of fundamental to be 31.27 ampere. When uncontrolled converter with R-L load is connected, total harmonic distortion (THD) before compensation was 27.74% with magnitude of fundamental to be 11.46 ampere while after compensation, THD is reduced to 4.66% with magnitude of fundamental to be 12.97 ampere.

TABLE I1. Comparative Performance Analysis

Parameter	Controlled Converter with R-L Load	Uncontrolled Converter with R-L Load
Load current THD	26.26%	27.74%
Source current THD (after filtering)	4.96%	4.66%

IV-CONCLUSION

In this work, cascaded MLI based SAPF along with PI controller is developed. MLI here offers a good compensating current for removing harmonic content from fundamental with the use of PI controller to maintain DC side capacitor voltage almost constant and settled. In this system SAPF is connected to AC mains in shunt to non-linear load which are controlled converter with R-L load and uncontrolled converter with R-L load. PI controller with unit impulse generating technique is used for generation of reference current leading to switching signals from linear PWM controller. Steady state of the system is achieved in short time and so a fast convergence is possible with proposed topology resulting THD to be 4.96% and 4.66% respectively with balanced load condition complying to the IEEE 519 standards.



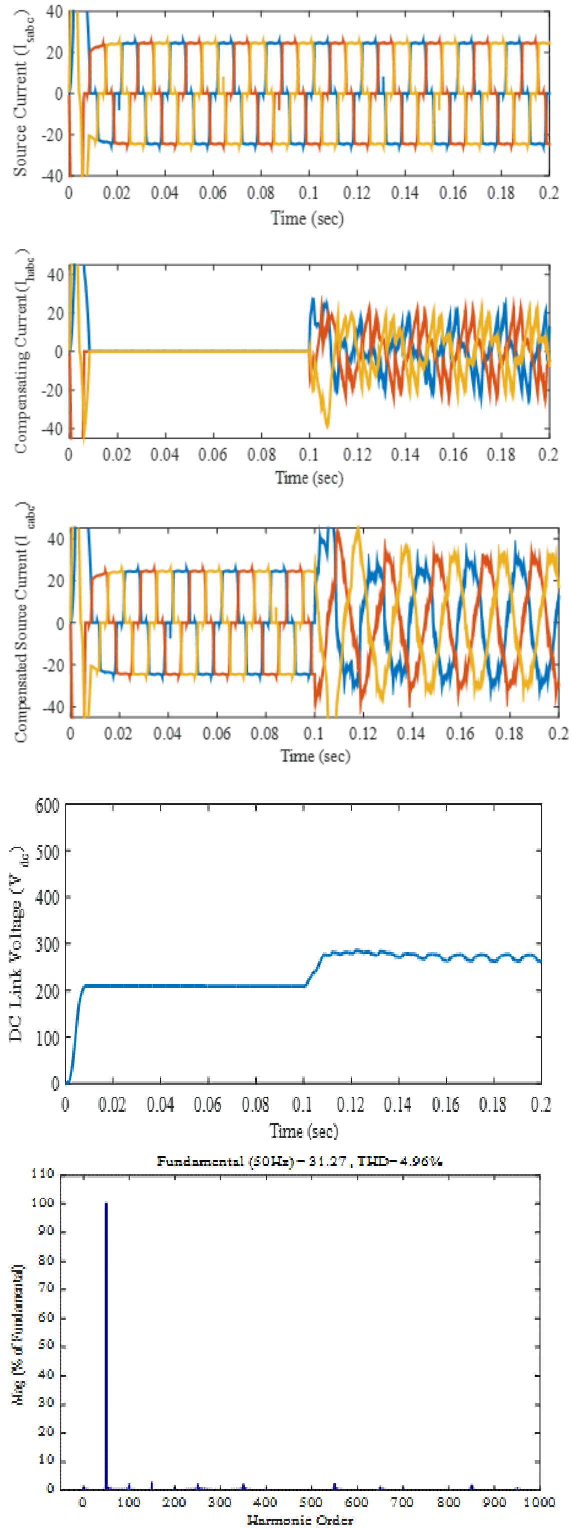


Fig. 9 Simulation Results of Cascaded Multilevel Inverter based Shunt Active Power Filter with Controlled Converter with R-L Load.

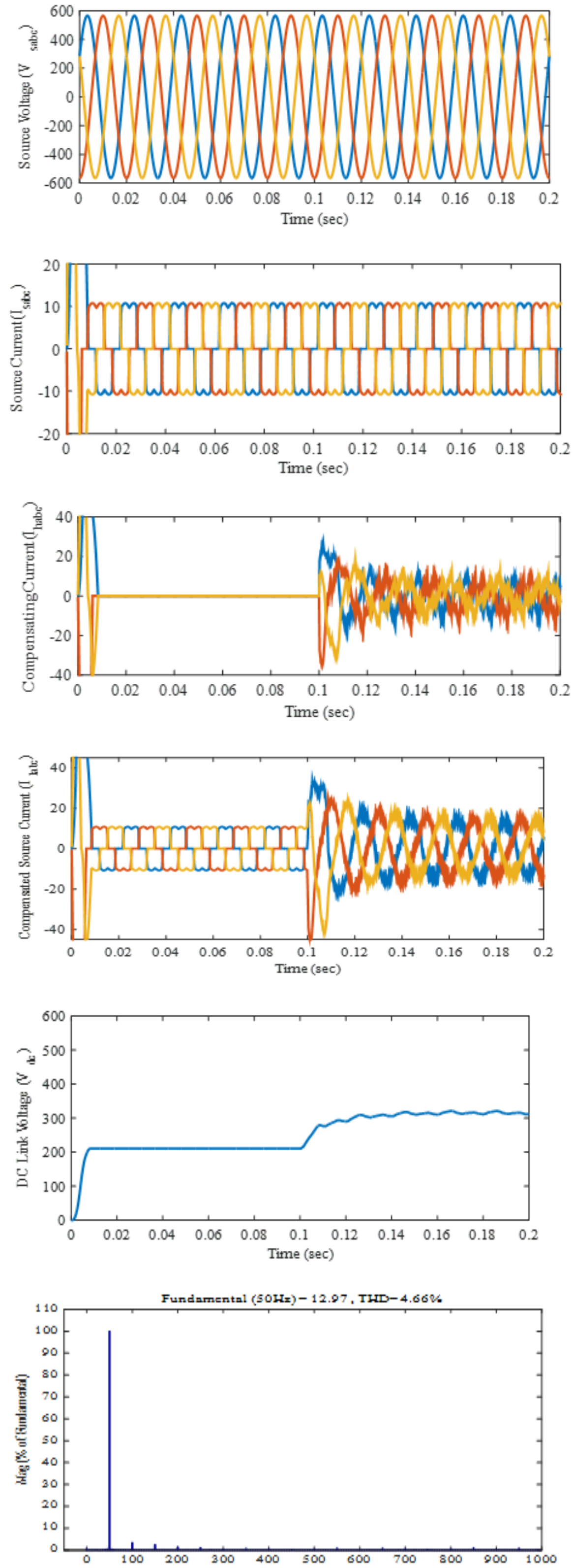


Fig. 10 Performance of Cascaded Multilevel Inverter based Shunt Active Power Filter with Uncontrolled Converter with R-L Load

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