Comparison of Compensation Techniques using Multilevel Inverter based Active Power Filter in High Voltage Systems

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Abstract: ***In modern distribution systems the proliferation of non-linear loads results in a deterioration of the quality of voltage waveforms at the load end. Therefore, power-conditioning equipment is becoming more important for electric utilities and their customers. With the rapid development of semiconductor devices in power and control circuits, a new generation of equipment for power quality, the active power filters, has been developed. Implementation of multilevel inverter for active power filter in High Voltage system eliminates use of bulky and high cost transformer. The control of an active filter comprises two major parts: the reference current computation and the current control. In this paper three fundamental methods of generating the reference current: (i) PQ theory (ii)PLL Method (iii) Fuzzy Method are presented .In this paper comparison of control strategies using multilevel inverter based shunt active power filter is presented. This paper presents the modeling of cascaded type multi level inverter based active power filter for different control methods are presented. PQ method is used to obtain the fundamental mains by reference current generation. A PLL is used to obtain fundamental mains voltage and used to calculate average load power. A fuzzy controller is used to obtain fundamental mains voltage and to determine the THD. Carrier phase shifted pulse width modulation scheme is implemented to generate switching signals which reduces the individual device switching frequency. This system is modeled in MATLAB / SIMULINK environment. Simulation circuit is analyzed and results are compared for different control methods.***

Keywords: Multilevel inverter, Active Power filters (APF), Carrier phase shifted-Pulse width modulation, Total harmonic distortion (THD). Phase locked loop (PLL)

1. Introduction

In recent years power electronic converters are widely used in industrial as well as domestic applications for the control of power flow for automation and energy efficiency. Most of the time these converters draw harmonic current and reactive power from AC source and causes the power quality problems.

There are number of devices available to control harmonic distortion. Passive filters are used for harmonic mitigation due to their advantages of simplicity, low cost and easy maintenance. But disadvantages that these filters introduce are numerous such as; the filter can be overloaded, parallel resonance between the power system and the filter, de-tuning of harmonic frequency with aging of passive components, and the filtering characteristics are dependent on the source impedance which is not exactly known.

Active power filters are most effective for harmonic compensation. Different types, such as shunt and series active power filters are used effectively. It acts as a harmonic current source which injects an anti-phase but equal magnitude to the harmonic and reactive load current to eliminate the harmonic and reactive components of the supply current. These active filters have limitations in medium and high voltage application due to semiconductor's reverse voltage rating constraint, Use of transformer for high voltage applications, with active power filter requires high VA rating of transformer which results in high magnitude of current on low voltage side and causes more losses. The system becomes bulky and costly. Multilevel inverters are effective in high voltage applications as it provides high output voltages with same voltage rating of individual device and maintaining low individual device switching frequency. The use of multilevel inverter also eliminates the need of transformer to feed the power to HV system.

In this paper comparison of control strategies used for multilevel inverter based on active power filter is presented. These control strategies are implemented in High voltage system to eliminate bulky transformers. The P-Q theory, PLL method and Fuzzy control methods for reference current generation are simulated and performance is compared. Carrier phase shifted pulse width modulation (CPS- PWM) scheme is implemented to generate switching signals which reduces the individual device switching frequency.

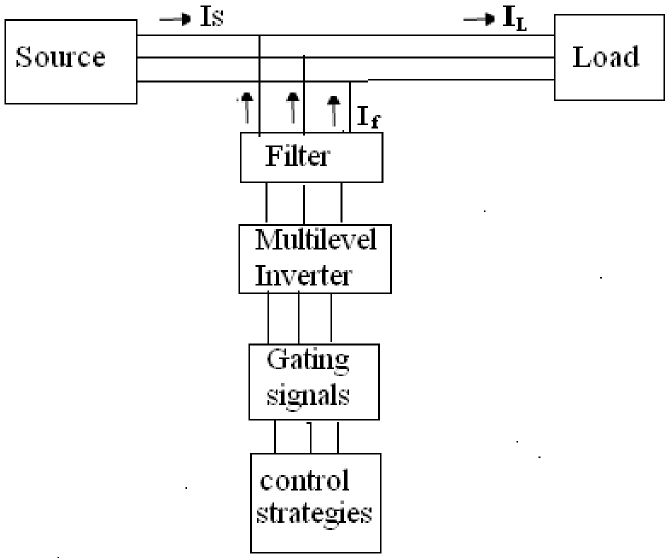

Figure 1: Block Diagram of Multilevel Inverter Based On Active Power Filter

2. Topologies of Multilevel Inverter

Cascade multilevel inverters are increasingly regarded in high power applications due to its direct high voltage output with no need of transformer. 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 increases. It can solve the size-and-weight problems of conventional transformer-based multi pulse inverters and the component- counts problems of multilevel diode-clamped and flying- capacitor inverters

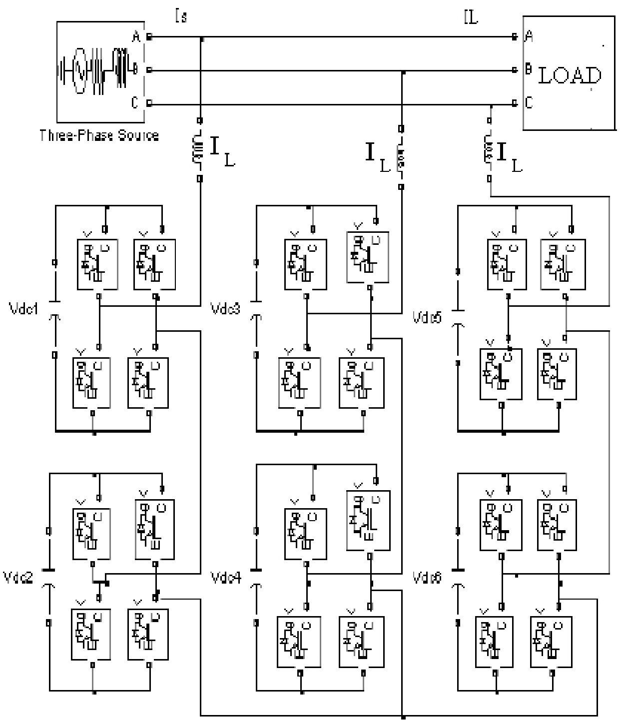

Figure 2: Multilevel Inverter Based APF

Fig.2 shows the three phase multilevel inverter used for current; IL is load current where three phase diode rectifier with R-L load is used as load, IL is the compensated current from APF.

In operation of APF, the harmonic component of load current is derived through harmonic detection circuit and reverses it as the reference compensated current. Then switching signals for multilevel inverter are generated such that AC side output current of APF correctly trace reference current and provides the harmonic current of the load so that source current will be free from harmonics and approaches towards pure sinusoidal

In this application there is no need of active power output from the inverter. So, separate dc source for each converter bridge is not required. The APF will draw small power from source to compensate the switching losses and capacitor losses in the inverter. DC voltage of each converter should be balanced and to achieve it, the capacitor voltages are sensed and compared with reference and the error is fed to PI controller to generate loss component of APF.

3. Reference Current Generation using P-Q Theory

Estimation of compensating signal is the important part of the active filter control. It has great impact on compensation objectives, rating of active filter and its transient as well as steady state performance. p-q theory is used to calculate instantaneous real and imaginary reactive power components. The 'p-q' theory is based on the αβ transformation which transforms three phase voltages and currents into the αβ stationary reference frame. The three phase voltages and

$$\begin{bmatrix} vp \\ vq \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 0 & -1/2 & -1/2 \\ 1 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} va \\ vb \\ vc \end{bmatrix}$$

and

$$\begin{bmatrix} ip \\ iq \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 0 & -1/2 & -1/2 \\ 1 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix}$$

The instantaneous active and reactive power in p-q coordinates are calculated by following expressions

$$p(t) = V_p i_p + V_q i_q$$
$$q(t) = -V_p i_q + V_q i_q$$

The fundamental active power component is extracted by using low pass filter. APF loss component obtained by controlling CDC capacitor voltages are added to fundamental active power. The compensating currents in p-q plane are;

$$\begin{bmatrix} ip* \\ iq* \end{bmatrix} = 1/\left(vp^2+vq^2\right)\begin{bmatrix} vp & vq \\ vq & vp \end{bmatrix}\begin{bmatrix} p \\ q \end{bmatrix}$$

Then three phase currents are obtained by following two phase to three phase transformation

$$\begin{bmatrix} ia* \\ ib* \\ ic* \end{bmatrix} = \sqrt{2}/3\begin{bmatrix} 0 & 1 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} ip* \\ iq* \end{bmatrix}$$

These currents are compared with source currents and error is processed through PI controller to generate reference currents for APF. The block diagram of the control scheme of shunt active power filter using p-q theory is shown in Fig.2. The advantage of p-q theory is that real and reactive powers associated with fundamental components are dc quantities. These quantities can be extracted with low pass filter. Since the signal to be extracted is dc filtering α-β reference frame is insensitive to any phase shift errors introduced by low pass filter, improving compensation characteristics of the active power filter. The limitation of this theory is the requirement of pure sinusoidal supply voltages. In most industrial power system mains voltages are often unbalanced and distorted.

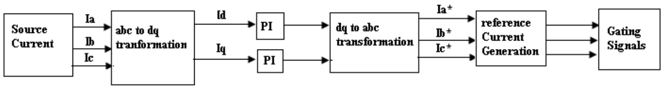

Figure 3: Block diagram for reference current generation using P-Q theory

4. Reference current generation using PLL method

The average power method gives accurate results even the supply voltage is distorted. A PLL method is used to obtain fundamental component of mains voltage. Block diagram shown in the figure deals with extraction of fundamental components of main voltage. The mains voltage contains fundamental and distorted component.

The reference currents are compared with triangle carriers to generate switching signals. The frequency of triangular carriers decides the switching frequency of individual device. The block diagram for the generation of reference current is shown in figure 4.

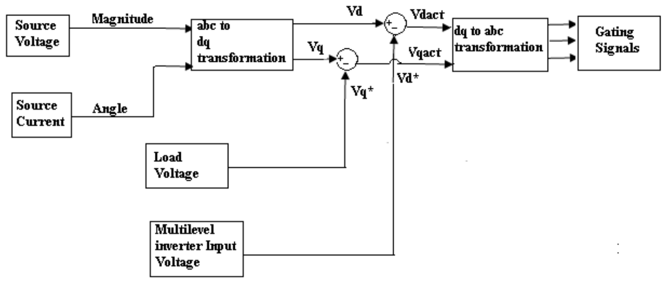

Figure 4: Block diagram for PLL method

This PLL based SIMULINK model is designed in MATLAB / SIMULINK as shown in Fig4. The reference supply currents are derived from the sensed load voltages, supply currents and dc bus voltage. The output of the PI controller used for the control of dc bus voltage is added with the direct axis component of current. Similarly, the output of the PI controller used for the control of the amplitude of the load voltage is added with the quadrature axis component of the supply current. A pulse width modulation (PWM) technique is used over the error between reference supply currents and sensed supply currents to generate gating signals for the IGBT's (insulated gate bipolar transistors).

5. Reference Current Generation Using Fuzzy Controller

Fuzzy controllers are used to control consumer products, Fuzzy control is a control method based on fuzzy logic. Just as fuzzy logic can be described simply as 'computing with words rather than numbers'', fuzzy control can be described simply as ''control with sentences rather than equations''.

A Fuzzy Controller is used to obtain distortion less mains voltage, it rectifies the harmonic content and determined the THD which is less than PLL.

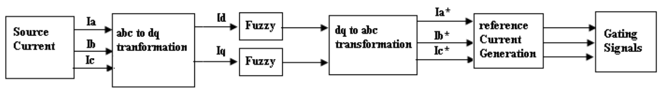

Figure 5: Block diagram for fuzzy controller

6. MATLAB / SIMULINK Model

6.1 SIMULINK Model of H-Bridge Multilevel Inverter

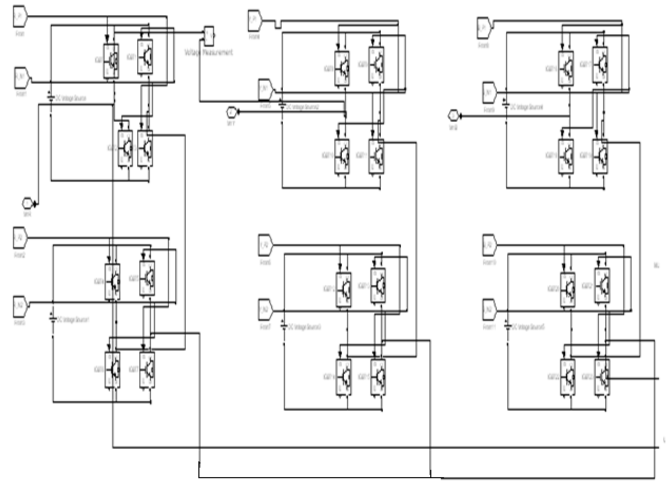

Figure 6: Simulink Model of H-Bridge Multilevel Inverter

6.2. Simulink Model of Reactive Power Compensation

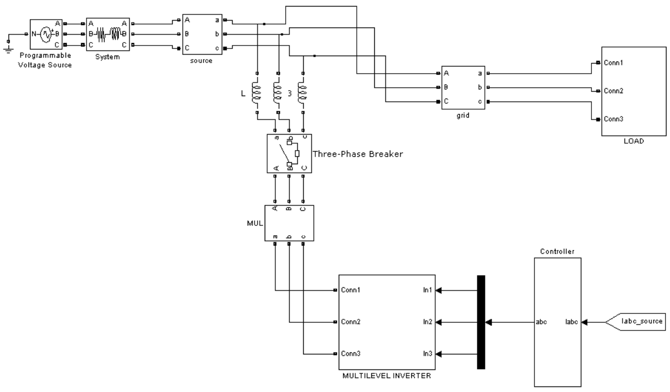

Figure 7: Simulink Model of Reactive Power Compensation

7. Results and Discussions

The simulated results of the output voltages for different compensation techniques are

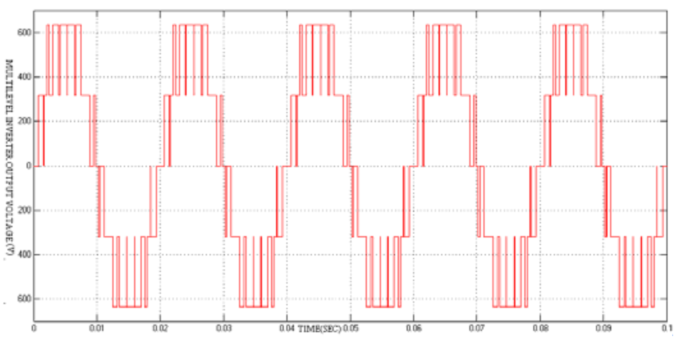

Figure 8: Multilevel Inverter Output Voltage

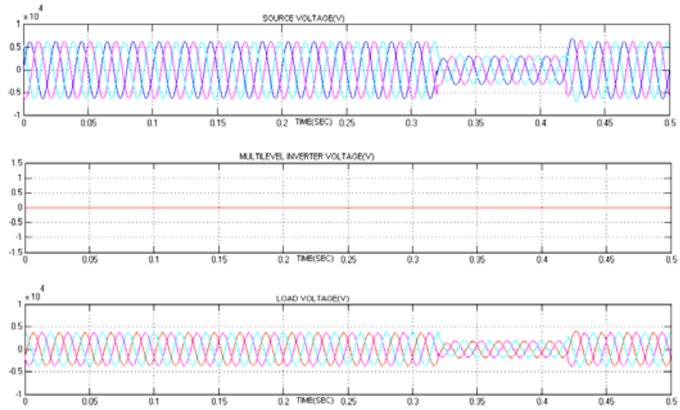

Figure 9: Waveforms of Source Voltage, Multilevel Inverter Voltage, Load Voltage at Transient Period of (0.32 to 0.42S) Without Controller

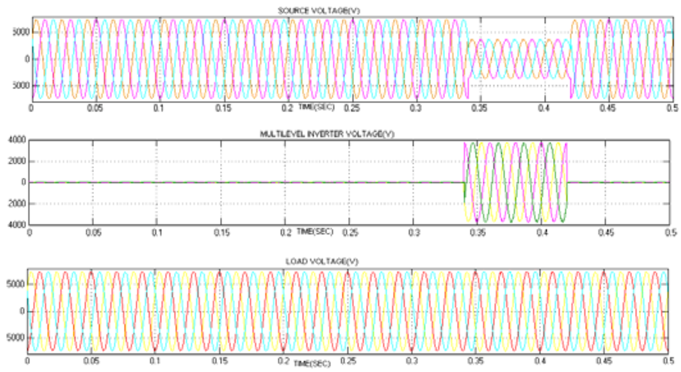

Figure 10: Waveforms of Source Voltage, Multilevel Inverter Voltage, Load Voltage at Transient Period of (0.32 to 0.42S) using P-Q theory

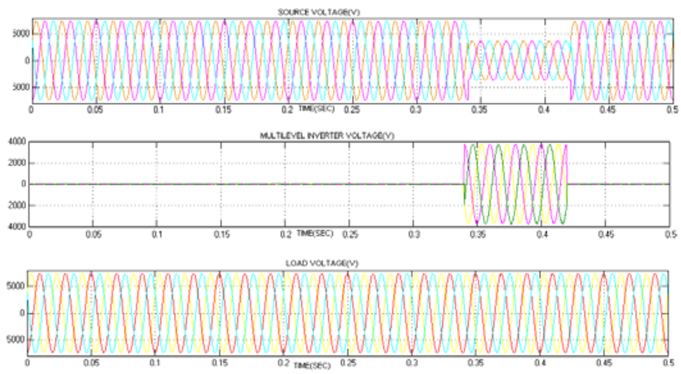

Figure 11: Waveforms of Source Voltage, Multilevel Inverter

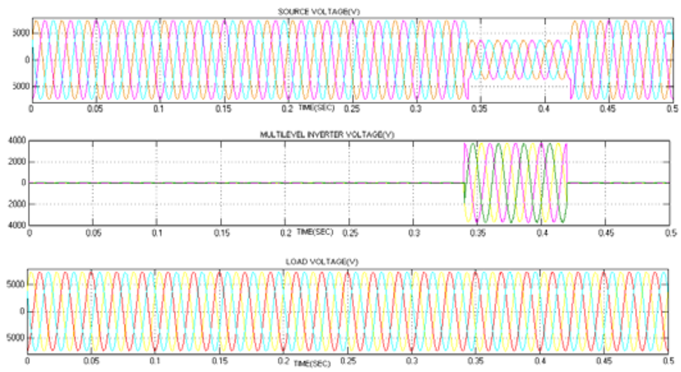

Figure 12: Waveforms of Source Voltage, Multilevel Inverter Voltage, Load Voltage at Transient Period of

(0.32 to 0.42S) using Fuzzy logic.

7.1 The Results

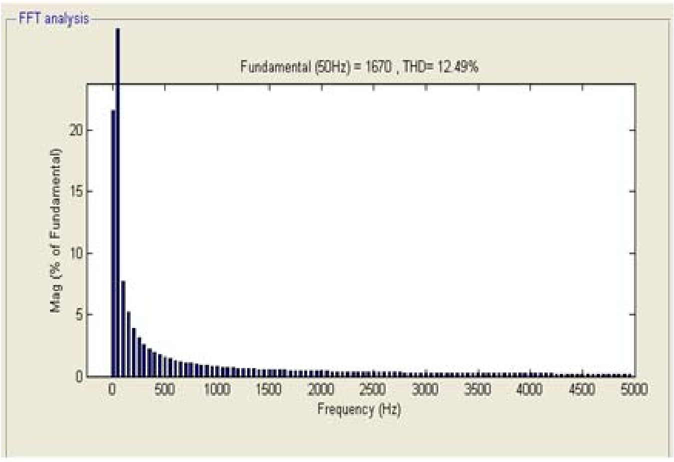

Figure 13: Spectrum of Load current without Controller

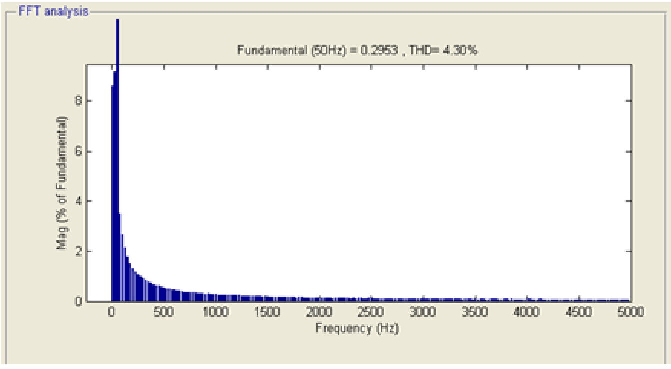

Figure 14: Spectrum of Load current with P-Q Theory

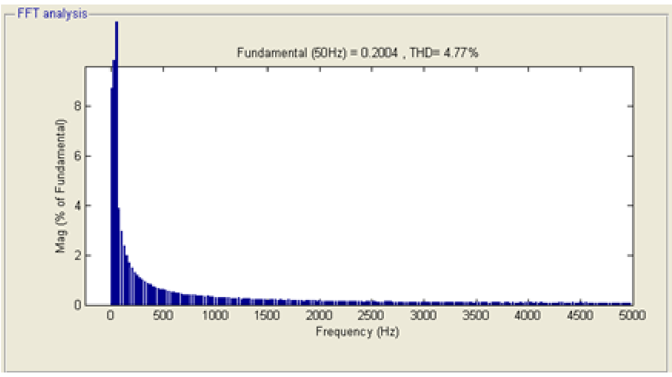

Figure 15: Spectrum of Load current with PLL Method

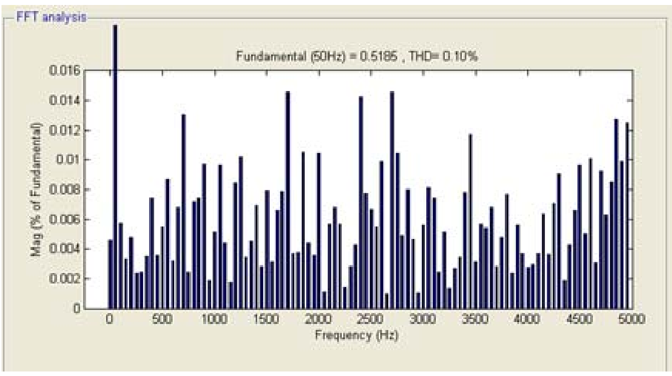

Figure 16: Spectrum of Load current with Fuzzy Method

The THD levels for different control strategies are compared:

	PERCENTAGE THD		
	P-Q Method	**PLL Method**	**Fuzzy Method**
Load voltage	4.30	4.77	0.10
Source voltage	11.78	11.74	8.56
Load current	4.30	4.77	0.10

It is observed that from the total harmonic distortion is reduced better in fuzzy method when compared with the remaining two methods.

8. Conclusion

In this paper a novel cascade multilevel H-bridge inverter with Fuzzy logic control based Active Power Filter is implemented in high voltage system. This eliminates need of high cost transformer with Active Power Filter in high voltage systems. PQ method is used to obtain the fundamental mains by reference current generation. A PLL is used to obtain fundamental mains voltage and used to calculate average load power. A fuzzy controller is used to obtain fundamental mains voltage and to determine the THD. The carrier phase shifted Pulse width modulation method reduces individual device switching frequency despite high frequency output of the converter. Simulated results validates that the cascaded multi-level inverter based Active Power Filter can compensate harmonics without use of transformer in high voltage system and also it works satisfactory in transient conditions and in distorted mains voltage.

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