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SHUNT ACTIVE FILTER USING TRANSISTOR CLAMPED MULTILEVEL INVERTER

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ABSTRACT

Inverter is a power electronic circuit that converts DC supply into AC supply of desired frequency and voltage. Based on the voltage levels at the output, inverters are classified as two level voltage source inverter and multilevel inverter. Advantages of multilevel inverters over two level inverters are less harmonic distortion and reduced electromagnetic interference. Because of these advantages, multilevel inverters are widely employed for active power filtering, reactive power compensation and speed control of electrical machine drives. Apart from this multilevel inverters are also used to interface renewable energy sources with the electrical energy source. Active power filters are generally used for reactive power compensation to improve power quality. By reactive power compensation losses are reduced which results in energy saving. In this work a shunt active filter using transistor clamped multilevel inverter is proposed. The proposed shunt active filter is simulated using MATLAB/SIMULINK. The results are compared with the shunt active filter using two level inverter which shows the superiority of the proposed method.

INTRODUCTION

When inverters are used to feed AC loads, it is required that output voltage of desired magnitude and frequency be achieved. To obtain a variable output voltage either external control or internal control is employed for the inverter. The internal control method makes use of Pulse Width Modulation (PWM) to vary the output voltage of the inverter. In a shunt active filter, the voltage and the current feedback from the line is processed to calculate the filter current to compensate for the harmonic content in the line current. Synchronous reference frame theory can be used for reactive power compensation. The speed of the system which determines the reference frame determines the capability of the active filter to eliminate harmonics and is independent of its position (Kasimvali and SrinivasaRao, 2012; S.Jain et.al., 2003; Akagi H, 2005; Akagi H, 1996). Instantaneous reactive power theory is employed for power conditioning (H. Akagi et.al., 2007). A new algorithm is propsed in the literature that results in unity power factor and sinusoidal source current (Karuppanan and Kamala KantaMahapatra 2010; Ambrish Chandra et.al., 2000). Compensating the reactive power without using energy storage components to minimize losses is also carried out in the literature (Akagi H et.al., 1984).

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Better power quality is achieved by using a five level transistor clamped H bridge power cell using a PWM method with multicarrier phase shift. Such methods apart from usage in medium power drive applications, can also be employed for applications requiring high quality output (NasrudinAbd. et al., 2013). Also the performance of various control techniques that can be used for active filters are compared in the literature (Meo S, Perfetto A; 2002). This new transistor clamped H-bridge (TCHB) 5-level inverter has less distortion of the output voltage compare to both the old TCHB and CHB cascaded 5-level inverter. In comparison with diode clamped and the flying capacitor topologies for same number of level in output voltage waveform there is a great reduction in the diodes and the capacitors used (Prakash et al., 2012). FPGA is used for generating control signals for a hybrid multilevel inverter based on PWM technique and digital technique (Thongprasri, 2011; Sebasthi Rani Kathalingam and Porkumaran Karantharaj, 2012). By using multiple carrier level shifted PWM techniques, the shunt active filter performance is improved. This method results in reduced harmonic distortion both in source voltage and current. A three phase diode bridge rectifier is used as a nonlinear load for verifying the performance of the PWM technique employed. For high power applications there are certain limitations that restricts the use of two level inverters. For such applications, multilevel inverters can be employed. A shunt active power filter with multilevel inverter shows a better performance with improved waveform of supply current and low switching losses (Alexander Varschavsky et al., 2010; J.Rodriguez et.al., 2002). The proposed work makes use of five level transistor clamped H bridge inverter which is simulated in MATLAB/SIMULINK and the results are compared with the performance of shunt active filter using two level inverter. Shunt Active Power Filter Modelling Harmonic currents that are generated by the shunt active filter cancel out the load current harmonics. By using a reactor, the Voltage Source Inverter is connected to the electrical energy source. The active filter is connected across the load which needs compensation. Therefore it is known as shunt active filter. This shunt active filter injects harmonic current into the electrical source of same magnitude as the load current but is phase shifted by 180˚.

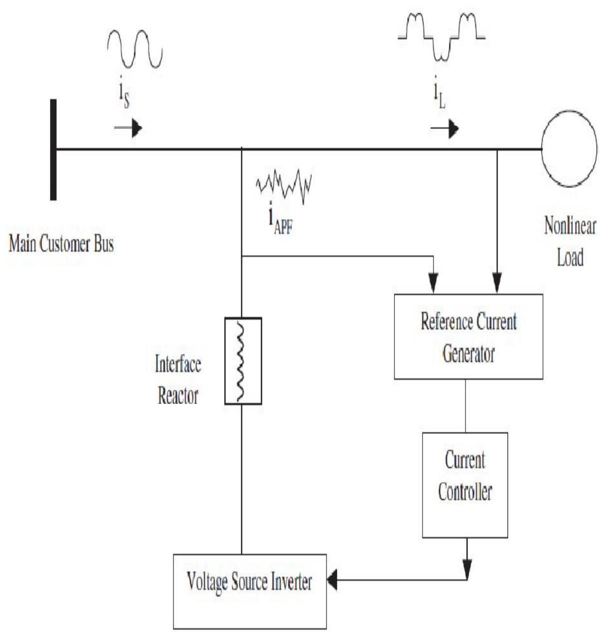

Fig. 1. Generalized block diagram of Shunt Active power filter

Multilevel Inverters

The new emerging inverters with the concept of reduced number of switches and with these new switching configurations the new inverters can be used for active filter controllers. Normally a 3-level and 5- level inverters are widespread for many applications like drives, conditioners and compensators. With an advantage of fundamental switching frequency they can produce more number of voltage levels, by which the harmonic content produced due to the active filter can be reduced. They can draw input current with low distortion and also reduce their voltage and current ratings. The main disadvantage of Cascaded H-Bridge is that separate dc voltage sources for each level. To overcome this disadvantage a new proposed inverter is designed which uses single DC source for single phase.

Fig.2 shows the circuit configuration of a Transistor Clamped H Bridge Five level Inverter based on five main switches (M11, M21, M31, M41, M51) in which M11 acts a bidirectional switch. In traditional Five level Cascaded H Bridge Inverter having 8 main switches (Ma11, Ma12, Ma13, Ma14, Ma21, Ma22, Ma23, Ma24). This inverter has five level inverter which has ±2Vdc, ±Vdc, 0. The carrier wave signal with a switching frequency of 10 kHz and the filter current harmonics is inserted at the point of common coupling with equivalent and conflicting current with respect to the harmonic current. The switching table is exposed in table 1 and the circuit diagram of Transistor Clamped H-Bridge is shown Fig.2

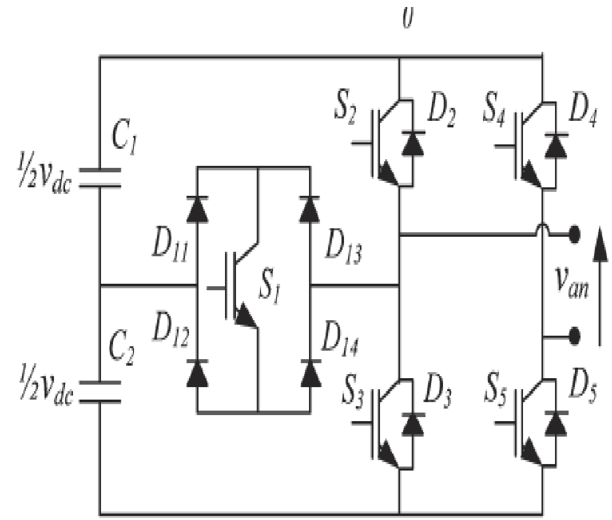

Fig.2. Single Phase T-CHB Inverter

Table 1. Switching Table for proposed T-CHB Inverter

S_1	S_2	S_3	S_4	S_5	v_{an}
0	1	0	0	1	v_{dc}
1	0	0	0	1	$\frac{1}{2}v_{dc}$
0	0 or 1	1 or 0	0 or 1	1 or 0	0
1	0	0	1	0	$-\frac{1}{2}v_{dc}$
0	0	1	1	0	$-v_{dc}$

(Switch ON = 1, Switch OFF = 0)

Synchronous Reference Frame (SRF) Theory

The synchronous reference frame detection method is used to recognize and extract harmonic distortions. In this method, the three phase currents ia, ib and ic are transformed to two phase stationary reference frame currents iα and iβ.

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

The currents expressions *id* and *iq*in (*d* −*q*) reference frame are given by

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \sin(\theta) & -\cos(\theta) \\ \cos(\theta) & \sin(\theta) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

By using a low pass filter the DC quantities and all other harmonics are transformed to non DC quantities

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \bar{i}_d & + & i_d \\ \bar{i}_q & + & i_q \end{bmatrix}$$

The expression of the reference current iα-ref and iβ-ref are given by

$$\begin{bmatrix} i_{\alpha-ref} \\ i_{\beta-ref} \end{bmatrix} = \begin{bmatrix} \sin(\theta) & -\cos(\theta) \\ \cos(\theta) & \sin(\theta) \end{bmatrix}^{-1} \begin{bmatrix} \bar{i}_d + i_{dc} \\ \bar{i}_q \end{bmatrix}$$

The reference currents i.e the compensating currents in the (*abc*) frame are given by

$$\begin{bmatrix} i_{a-ref} \\ i_{b-ref} \\ i_{c-ref} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{\alpha-ref} \\ i_{\beta-ref} \end{bmatrix}$$

Design of Current Controller - Hysteresis Controller

A band is set above and below the generated error signal. Whenever this signal crosses the upper band, the output voltage changes so as to decrease the input current and whenever the signal crosses the lower band, the output voltage changes to increase the input current which is shown in Fig.3. However, variable switching frequency and high ripple content are the main disadvantages of hysteresis current control. It can be realized with high accuracy and fast response. The Simulink model for hysteresis current controller is shown in Fig.4.

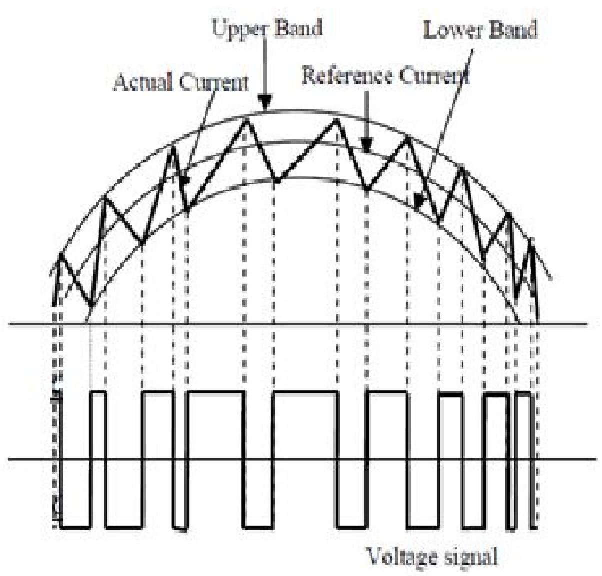

Fig.3. Hysteresis Controller

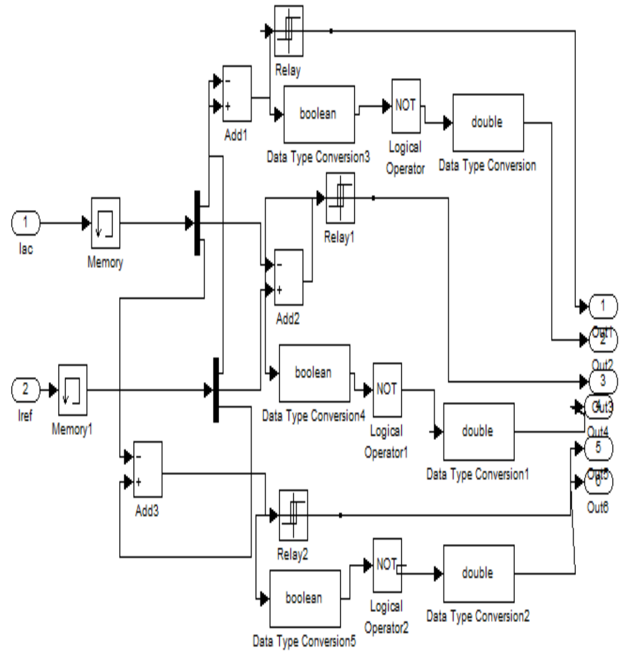

Fig. 4. Simulink Model of Hysteresis Controller

Design of PI Controller for DC link Capacitor Voltage Control

For proper working of APF, the dc-link capacitor voltage must remain constant and there should not be fluctuations in the voltage as the APF should not exchange active power with the supply. The filter transfers a small amount of active power from ac to the inverter dc for compensating the variations in voltage. To achieve this a sinusoidal voltage signal in phase with line current is generated. The active power transferred is the product of the above signals. As the three inverters share dc capacitors the output

C(s) = Kp*(1+1/Ti*s)

The transfer function of a closed loop control of dc link is

$$\frac{\Delta Vdc}{\Delta Vref} = \frac{KpKIs\ cos\emptyset\sqrt{3}/CVdc\ .s + KpKIs\ cos\emptyset\sqrt{3}/TiCVdc}{s^2 + KpKIs\ cos\emptyset\sqrt{3}/CVdc\ .s + KpKIs\ cos\emptyset\sqrt{3}/TiCVdc}$$

Simulation Parameters

SL.NO	*SYSTEM PARAMETERS*	*VALUES*
[1]	Source voltage	415 V
[2]	Non-linear load	R=40Ω , L=1e-6H
[3]	Interface Reactor	L=2e-3 F
[4]	Capacitor voltage of multilevel inverter	C=150e-2 F
[5]	Initial capacitor voltage	300 V
[6]	Multilevel inverter load	R=1500Ω , L=0.0001H
[7]	3 Phase Source X/R Ratio	0.7
[8]	System frequency	50 Hz

Simulation Result

Shunt active power filter using two level inverter and transistor clamped multilevel inverter are considered. For simulation, balanced nonlinear load is considered. In this work, a three phase diode bridge rectifier with RL load is used as the nonlinear load.

Source Current and its THD without Shunt Active Filter

Fig. 5 shows the source current and its without active filter connected to the line.

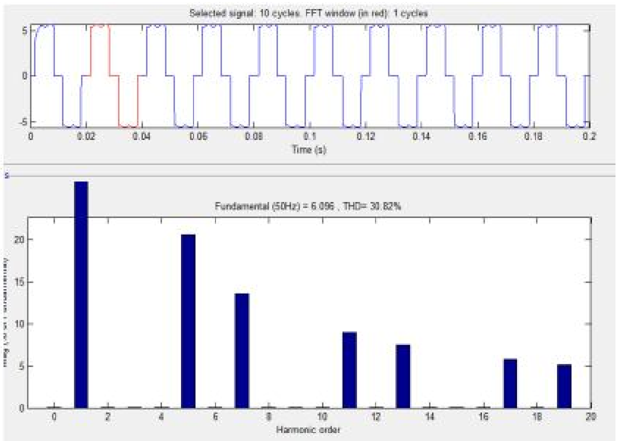

Fig.5. Spectrum of source current without filter

THD of the source current is 30.82% without active filter.

Active Filter using two level VSI

Fig. 6 shows the simulation model of SAF using two level inverter in MATLAB/SIMULINK.

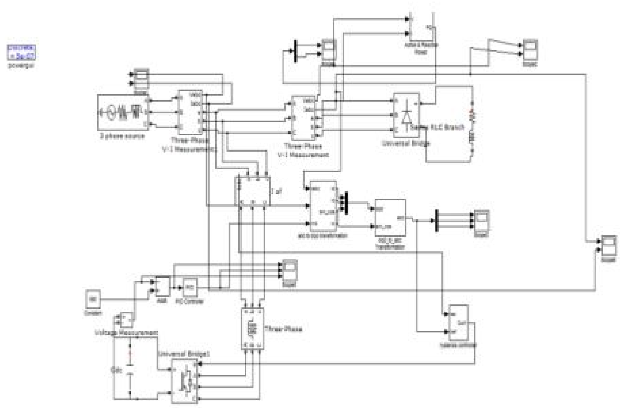

Fig.6. Simulation model of SAF using VSI

The filter current, the source current and its THD are shown in Fig.7 and Fig.8.

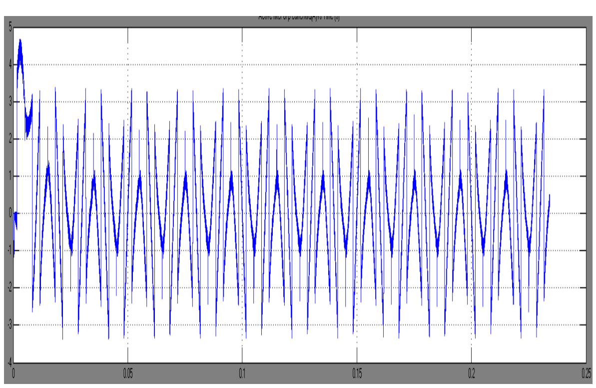

Fig.7. Active filter current

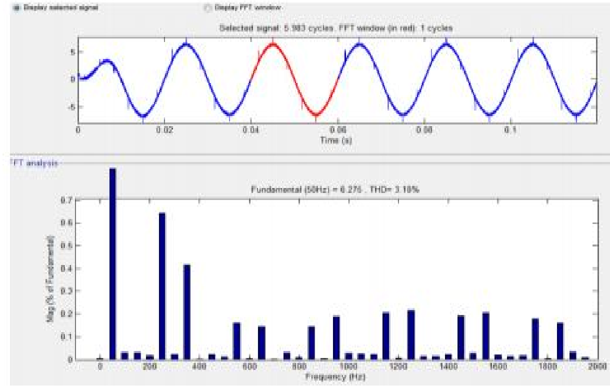

Fig.8.Source current and its spectrum

For a SAF using two level VSI, THD is found to be equal to 3.28%.

SAF using Transistor Clamped H bridge Inverter

Transistor Clamped H bridge Inverter is simulated in SIMULINK and the output voltage waveforms are shown in Fig.9

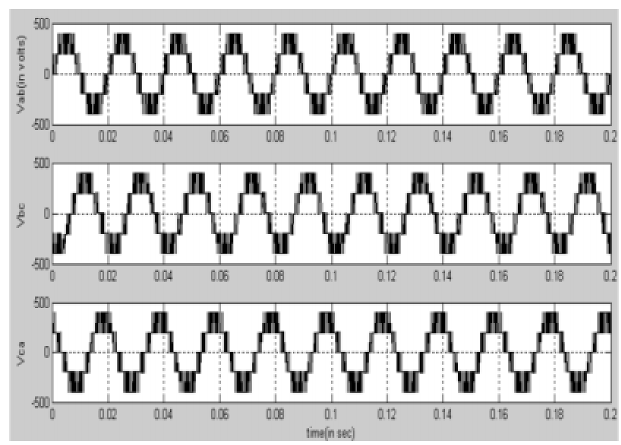

Fig.9. Output voltage of Transistor Clamped H bridge Inverter

MATLAB/SIMULINK model of SAF using multilevel inverter is shown in Fig.10.

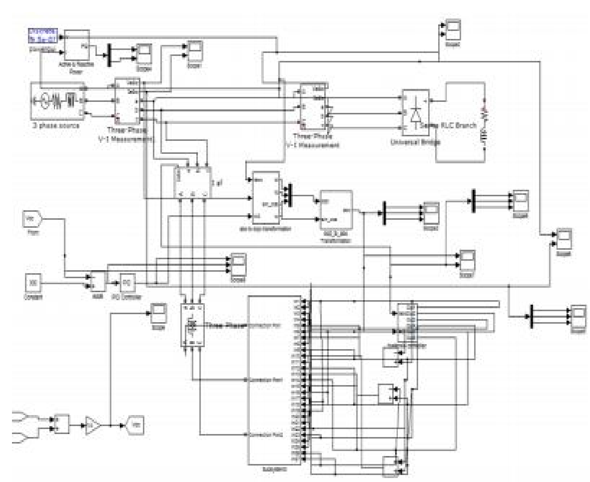

Fig.10.Simulation model of SAF using Transistor Clamped H bridge Inverter

After simulation, the filter current, source current and THD are shown in Fig.11 and Fig.12

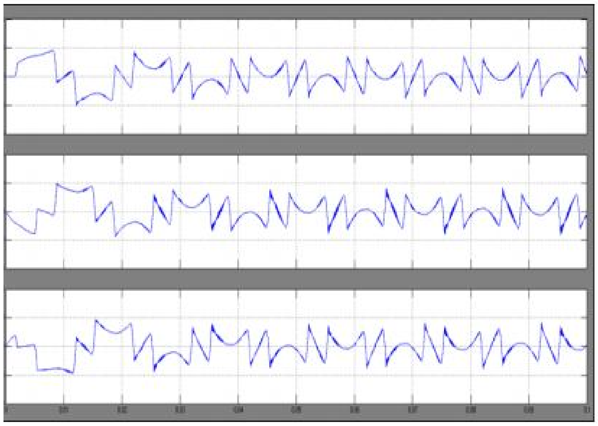

Fig.11. Filter current

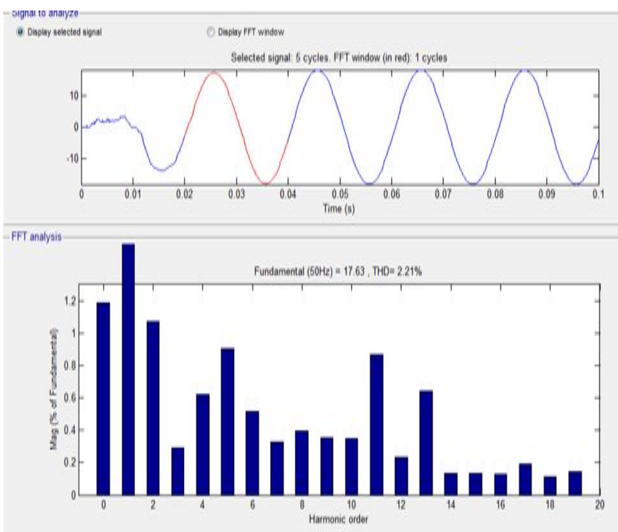

Fig.12.Source current and its spectrum

THD of the source current for the proposed method is 2.21%. This is less when compared to the SAF using two level inverter. Thus the proposed SAF has better reactive power compensation.

Comparison Result

The results are compared in Table.2. The proposed method gives better result.

Table 2.Comparison Result of Total harmonic distortion

Performance Parameter	Without compensation	With SAF using two level inverter	With SAF using TCHB Inverter
THD	30.82%	3.28%	2.21%

Conclusion

The shunt active power filter for three phase three wire system was modeled in MATLAB/SIMULINK and the simulations were carried out. The results achieved were satisfactory and within the permissible limits in accordance to IEEE standards. Similarly, the simulations for five level inverter were performed and the stepped output voltages were obtained. Proper control strategies for switching of the multilevel inverters were used .Care must be taken while implementing the switching strategies for it is vital in the desired operation of the inverters .The harmonic distortions present in the load current and voltage waveforms were observed and calculated through FFT analysis tool in MATLAB/SIMULINK.

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