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A Review of Three Level Voltage Source Inverter Based Shunt Active Power Filter

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Abstract— In this paper various reference current prediction methods and current control methods are reviewed for shunt active power filter applications. The Active Power Filter (APF) can be implemented with current controlled Voltage Source Inverter (VSI). Three level voltage source inverter can be used for the shunt active power filter. Three level inverter can be used for high power & high voltage application. Various reference current generation techniques compared in this paper. It is found that FFT method is best among all other methods. FFT method has been discussed in the paper. FFT algorithm can give three reference current generations. It is input for current control strategies. In this paper two current control methods discussed as per literature refereed. PI based current control & Vector Based Hysteresis current controls are discussed in this paper.

Keywords: Shunt Active Power Filter, Three Level Inverter, Fast Fourier Transform, PI Based Current Control Method, Space Vector Hysteresis Current Control Method.

I. INTRODUCTION

Maximum pollution issues created in power systems are due to the non-linear characteristics and fast switching of power electronic equipment. Power quality issues are becoming stronger because sensitive equipment may be damaged. Active power filters have been developed over the years to solve these problems to improve power quality.

The multilevel converter and shunt active power filter are topics of great interest in power electronics and electrical industry. The multilevel converter structure allows synthesizing a sinusoidal waveform from several voltage levels which are obtained from capacitors banks or dc sources. Several topologies of multilevel inverters have been reviewed in the power stage of active power filters for single-phase or three-phase applications, where the main objectives of control are tracking a reference signal (current harmonics or voltage harmonics) and maintain regulated the dc voltages. Dead time effect is bad on output voltage of VSI. Due to deviation in output voltage of inverter, output current is also distorted in drive and Shunt Active Power Filter (SAPF). In this paper how dead time affect to the performance of VSI is reviewed. Pulse based dead time compensation method is also discussed for the performance improvement of the inverter. PBDTC is previously used in induction motor drive application. This paper includes discussion about review of literature for SAPF.

Literature review consists of shunt active power filter related research papers that includes different power topologies, control schemes, mathematical modelling, simulation and experiments results.

Jose Rodriguez *et al.* [1] described about the most important topologies like diode-clamped inverter (neutral-point clamped), capacitor-clamped (flying capacitor), and cascaded multi cell with separate dc sources. The active filter can compensate current harmonics and reactive power in medium voltage distribution systems using NPC three-level voltage source inverter[2]. Multi level inverter can be used for shunt active power filter for medium voltage distribution.

NPC power topology has disadvantage of capacitor voltage unbalancing. Sun Hui *et al.* [3] discuss for The NPC three-level converter with self- voltage balancing through clamping switching and clamping diodes used for active power filter. By simulation result, the three-multilevel diode-clamping-converter may work without active control of the clamping-capacitor-voltage. Space vector PWM method can be used for three level NPC voltage source inverter and using redundant vector capacitors voltage to be balanced[4].
Space vector current control with two coordinate system has been used for two level and three level VSI with simulation and hardware results[5]. FFT algorithm is also used for reference current generation of active power filter.J. W. Cooley and J. W. Tukey[6] have described about FFT algorithm for machine calculation of complex Fourier series. FFT algorithm is modification of DFT algorithm. FFT algorithm is fast than DFT algorithm. S.D. Round and D.M.E. Ingram [7] discuss about various techniques (p-q Theory, Synchronous (d-q) reference frame, Sine Subtraction and FFT) used for reference current generation and their comparisons. FFT algorithm performance is good for Steady-state condition and unbalanced load. Lucian Asiminoaei et al.[8] also describe the reference current generation methods evaluations for active power filter.

The open-loop structure which predicts the reference currents from the load currents and the closed-loop structure which predicts the reference currents from the grid currents using Fourier series [9]. PSIM simulation can be used for the FFT and pq theory based shunt active power filter[10]. Mansour Mohseni, and Syed M. Islam[11] discuss about conventional and vector based hysteresis current control schemes used for VSI with simulation results. Space vector based current controllers are used for two level PWM inverters [12]. The pulse based dead time compensation(PBDTC) method has been used for three level inverter fed induction motor drive with experimental results on 45 kW (60 HP) induction motor[13]. PBDTC method can be used for shunt active power filter. Carlos Henrique da Silva et al.[14] has discussed about the Fast Feedback Loop dead time compensation method for shunt active power filter using two level VSI with experimental results. The direct pulse dead-time compensation method can be used for APF with SVPWM control [15]. Pulse-based dead-time compensator method has been proposed for two level PWM voltage source inverter [16]. PBDTC method is software intensive method and cheaper.

Bhim Singh et al. [17] describe about dc link voltage balancing algorithm and modeling of active power filter with hardware results. Three-Phase Four- Wire System has been used for Shunt Active Power Filter [18]. Three phase four wire system of Shunt Active Power Filter can be used for distribution system. Switching lag (dead) time can distort the voltage wave form of PWM voltage source inverter [19]. Voltage gain and loss will result in current distortion in induction motor drive. S. G. Jeong and M. H. Park [20] dead time effects and compensation describe in PWM inverters. voltage distortion has been operate with low output voltage in PWM inverters[21]. For open-loop PWM-VSI drives, On-line dead-time compensation technique has been used [22]. L. Ben-Brahim [23] has discussed about dead time effects and compensation for three phase PWM inverters. Theoretical analysis and simulation have been used to verify the zero crossing phenomenon.
Hirofumi Akagi and Takaaki Hatada[24] describe about the capacitor Voltage balancing control for NPC topology characterized by superimposing a sixth harmonic zero-sequence voltage on the active filter voltage reference in each phase is introduced to the three-level converter with triangle carrier modulation.

II. THREE LEVEL VSI BASED SHUNT ACTIVE POWER FILTER

Fig.1 shows the configuration of the standard neutral point-clamped three-level VSI for the SAPF application. Fig. 2 shows Basic block diagram of shunt active filter illustrating the hardware modules required. It can be implemented using DSP TMS320F28335 as a controller. Size of ripple filter can be decreased Using three level inverter based shunt active power filter.

Classification based on Power Topologies,

- Two Level VSI
- Three Level VSI
- Multilevel VSI

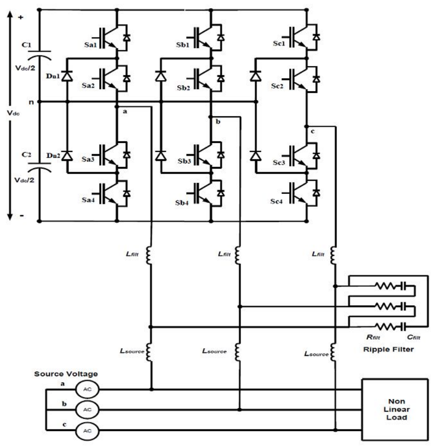

Fig.1. Two and three-level VSIs for the SAPF

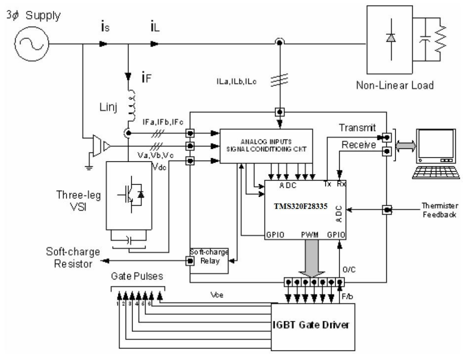

Fig. 2. Basic block diagram of shunt active filter illustrating the hardware modules required

III. COMPENSATION BASED CLASSIFICATION

For reference current prediction of shunt active power filter following methods have been reported in literatures.
In frequency domain,

- Fast Fourier Method(FFT) method

In time domain,

- Instantaneous reactive power (p-q) Theory
- Synchronous (d-q) reference frame theory
- Sinusoidal subtraction

Here in this paper all methods compared and FFT method is discussed in detail.

A. FFT method

The Fast Fourier Transform (FFT) algorithm takes the sampled load current for one period and calculates the magnitude and phase of the frequency components[6]. Figure 3(a) shows the time domain sample used as the input to the FFT and Figure 3(b) shows the FFT output.

Each element in the frequency plot is a harmonic since the spacing is 50 Hz. The numbers of harmonics that can be resolved are given by half the number of samples used. Therefore the higher the number of samples in each cycles of current, the higher the value of f_{max}.

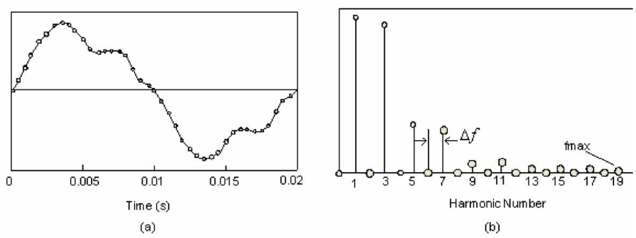

Fig. 3. (a) Input waveform of load current with 40 samples within one cycle.(b) Harmonic spectrum of the input waveform as in (a)

Removal of the fundamental from the input current is easily performed by setting the frequency component for 50 Hz to zero and then performing the inverse fast Fourier transform (IFFT). The IFFT recreates a time domain signal based on the magnitude and phase information of each harmonic. These calculations are performed on each cycle of mains current. It is important to ensure that a FFT is calculated on a complete cycle to prevent distortion due to spectral leakage. Any changes in the load current that distort the waveform will cause errors in the output of the FFT and this leads to an incorrect compensating current signal for a short time.

The algorithm used for performing the FFT based harmonic detection detects step changes in load current and generates a zero compensating current for one cycle. This prevents the injection of erroneous compensating currents.

A frequency domain based harmonic isolation method has some advantages. The magnitude of the load harmonics is known from the FFT and this allows selective harmonic cancellation to be performed. By manipulating the harmonic magnitudes it is possible to prevent the cancellation of certain harmonics or reduce the level of cancellation of selected harmonics.

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TABLE I
COMPARISON OF REFERENCE CURRENT PREDICTION METHODS FOR SHUNT ACTIVE FILTER

Operation	p-q Theory	d-q Frame	Sine Subtraction	FFT
Steady-state Quality	Poor	Good	Excellent	*Excellent*
Transient Response Quality	Good	Good	Poor	Poor
Requires Voltages	Yes	No	No	*No*
Requires Balanced three phase	Yes	Yes	No	*No*

Comparison of different reference current prediction methods for shunt active filter is shown in Table I. From comparison FFT method is better for SAPF. But complexities of programming are increased for FFT method.

B. Operating Principle of FFT

Fast Fourier Transform can be used as harmonic reference generation instead of p-q Theory. The principle of FFT implementation for shunt active filter is illustrated in Figure 4.

This method assumes that the grid current is predictable and can be represented by a discrete frequency spectrum, which is a function of the time [9]. Each grid period, the measured current time spectrum is acquired (1). This time spectrum is the set of the measured current samples over the grid period. From this time spectrum, the frequency spectrum is computed using the Fast Fourier Transform algorithm (FFT) (2a). The FFT algorithm is an optimized method to compute the Fourier series with a minimum of operations.

It suits well to the implementation of Fourier series or Fourier Transform on DSPs. The AF reference current is easily obtained from the frequency representation of the measured current.

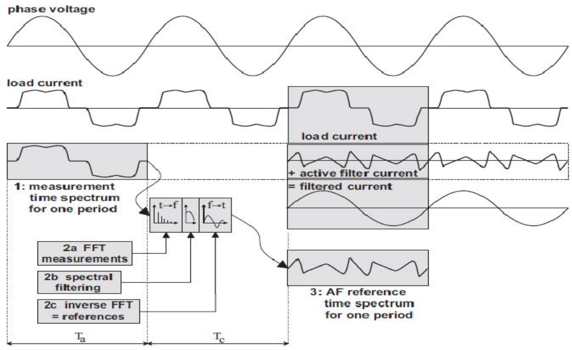

Fig. 4. Execution sequence of the harmonic reference predictor, (1) acquisition of time spectrum, (2) calculation of reference in the frequency domain, (3) current control with the computed reference in the time domain.

An approximate method to obtain the reference spectrum from the load current spectrum is to remove the fundamental from it (the fundamental is the first order harmonic), and to take the opposite of the remaining spectrum (2b). The reference time spectrum is computed using the inverse FFT (2c). During the next grid period, at each sampling instant the current controller will take his actual reference from this time spectrum (3). The sequence of these operations is performed in 3 grid periods [10].

C. Flow chart for FFT implementation

The fast Fourier transform algorithm is complex and not easy to implement without DSP. The steps for implementing the fast Fourier transform for shunt active filter is shown below in figure 5.

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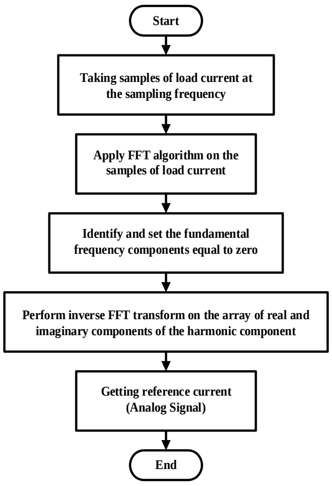

Fig.5. Flow chart of calculation of frequency components of input waveform using Fast Fourier transform

IV. CURRENT CONTROL METHODS

This paper discusses current control methods for shunt active power filter. Reference current is predicted from the FFT algorithm. That reference current is used for current control methods. Following methods are reported in literature for current control of shunt active power filter.

- PI based current control (Carrier based current control)
- Space Vector Hysteresis Current Control (Carrier less current control)

A. PI based current control

However, parameters of PI controllers must be carefully tuned with a tradeoff between maintaining the system stability over the whole operation range and achieving an adequate dynamic response during transients. This can result in degraded transient performance, which in turn, hinders the application of PI current controller in high-demanding situations, such as active power filters [11]. This method is also called Sine Pulse Width Modulation method for shunt active power filter with triangular carrier wave. It can limit switching frequency of inverter. It will degraded transient performance of filter.

B. Space Vector Hysteresis Current Control for Three-Level VSI

Fig. 6. Shows the Space Vector current control, in stationary αβ-coordinates based on the five-level hysteresis comparator.

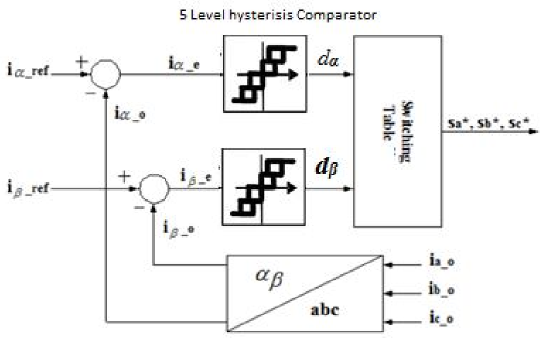

Fig.6. Five level Hysteresis comparator for three-level VSI

Based on current error five-level hysteresis comparators will give values of d_α and d_β. The switching states of the three level inverter can be represented in the αβ -coordinates, as shown in Fig. 7. Based on the values of d_α and d_β, the appropriate voltage vectors are selected, from switching Table II.

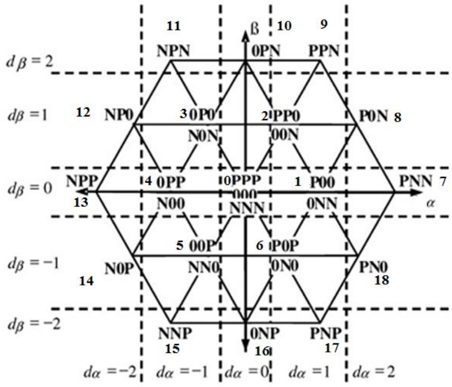

Fig.7. Space-vector diagram for three-level inverter

TABLE II
SWITCHING TABLE, DEPENDENT UPON d_α & d_β

d_β / d_α	-2	-1	0	1	2
-2	vector=9; PPN	vector=8; P0N	vector=7; PNN	vector=18; PN0	vector=17; PNP
-1	vector=9; PPN	vector=2; PP0/00N	vector=1; P00/0NN	vector=6; P0P/0N0	vector=17; PNP
0	vector=10; 0PN	vector=2; PP0/00N	vector=0; PPP/000/NNN	vector=6; P0P/0N0	vector=16; 0NP
1	vector=11; NPN	vector=3; 0P0/N0N	vector=4; 0PP/N00	vector=5; 00P/NN0	vector=15; NNP
2	vector=11; NPN	vector=12; NP0	vector=13; NPP	vector=14; N0P	vector=15; NNP

From this survey it is concluded that PI based current control methods can limit the switching frequency of inverter. Space vector based current control method cannot limit the switching frequency. Space vector based current control method is complex for three level inverter based shunt active power filter.

V. CONCLUSIONS

A review of shunt active power filter is discussed to understand various topologies, reference current prediction methods, current control methods and dead time compensation methods. All control methods for shunt active power filters have been compared from the research papers. It is concluded that three level inverter based shunt active power filter with FFT algorithm for reference current prediction will give better performance. PI based current control method can limit switching frequency but degrade transient performance. SVHCC method is robust to grid parameter variations and load changes. It is considered that this review will be useful to researcher and professionals working in this area.

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