

An Improved Dynamic Response of Voltage Source Inverter using Novel Hysteresis Dead Band Current Controller

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Abstract- Due to high dynamic response, current-controlled pulse width modulated (PWM) voltage source inverters (VSI) are widely used in high performance AC drive system for Industrial applications. The main objective of current controller is to force the load current vector to follow the reference trajectory in the three-phase load. There are three types of current controllers used in voltage source inverters such as, ramp comparator current controller, hysteresis current controller and predictive current controller etc. This paper mainly focused on novel hysteresis current controller for PWM voltage source inverter using square type hysteresis dead band. This controller provides excellent dynamic response. The study was undertaken by the MATLAB/ Simulink environment in order to validate the results. Fast Fourier transform technique is used to find the THD levels of the three-phase load current waveforms.

Index Terms – Dynamic response, High performance AC drives, Hysteresis current controller, Voltage source inverter (VSI).

1 INTRODUCTION

Due to quick response and accurate control, the current controlled PWM voltage source inverters are usually preferred for high performance AC drive system and continuous ac power supplies where we need to produce a sinusoidal ac output. The main task of the current regulated PWM voltage source inverters is to force the current vector in the three phase load according to a reference trajectory. The performance of the converter system largely depends on the applied current control technique. When current control is used, the inverter output currents are measured and compared with reference signals, the errors being used as an input to the PWM modulator, which provides the inverter switching signals. As per available literature survey, a lot of research work has proposed besides current control techniques for PWM voltage source inverters because an advantage in eliminating the dynamics in non-linear load system [1]. Therefore, current control technique plays an important role in modern power electronics industry. The main features of current controller are 1) control of instantaneous current waveform and high accuracy; 2) peak current protection; 3) overload rejection; 4) extremely good dynamics; 5) compensation of effects due to load parameter changes (resistance and reactance); 6) compensation of the semiconductor voltage drop and dead times of the converter; 7) compensation of the dc-link and ac-side voltage changes [2]-[5].

There are three types of current controllers used in voltage source inverters such as ramp- comparator current controller, hysteresis current controller, and predictive current controller. The ramp-comparator controller compares the error current signal to a carrier waveform to generate the inverter firing pulses [3]. The main advantage of the ramp comparison technique is that the inverter switching is usually limited to the frequency of the career waveform, and the produced harmonics are defined at a fixed frequency. However, the system response is purely depends on load parameters and it is

affected by the stability requirements of the feedback loop, Thus, inherent phase and amplitude errors arise during steady-state condition. Predictive current controllers calculate the voltage of the inverter which forcing the load current vector to follow the reference current trajectory. Thus, it gives optimum performance of converter in terms of both response time and accuracy. But one of the problem of predictive current controller is, it takes more calculations and requires a good knowledge of the load parameters [6]. In a hysteresis current controller, the hysteresis comparators are used to impose a dead band or hysteresis around the reference current. Among all current control techniques, the hysteresis controller is used widely because of its simplicity of implementation, fast response current loop and this method does not need any knowledge of the load parameters. However, the main disadvantage is the variation of switching frequency during load parameter (resistance and reactance) variation of fundamental period [7]. From the above information, the characteristics required from the current controlled PWM inverter are a quick current response during transient conditions and a low harmonic current content during steady state conditions. However, these two requirements contradict each other, so the decision to use a specified type of current controller depends on the nature of the application. This paper mainly focused on novel hysteresis current controller for PWM voltage source inverter using square type hysteresis dead band. The basic implementation of hysteresis current control is based on deriving switching signals from the comparison of the error current with a fixed tolerance band. This control is based on the comparison of the actual current error with tolerance band around the reference current associated with that phase. This type of band control is negatively affected by the phase current interactions mainly due to interference between commutations of three phases, since each phase current not only depends

on the corresponding phase voltage but also affected by other two phase voltages, resulting in irregular inverter operation. This controller provides excellent dynamic response. The study was undertaken by the MATLAB/Simulink environment in order to validate the results. Fast Fourier transform technique is used to find the THD levels of the three-phase load current waveforms.

2 CURRENT CONTROL SCHEME OF VOLTAGE SOURCE INVERTER

The operation of current-controlled voltage source inverter can be studied by considering the circuit shown in fig (1). With advances in modern power semiconductor technology fast switching devices such as IGBT's and IGCT's are widely used as switches in inverter circuits. In this circuit three phase R-L load is connecting to the three phase PWM inverter. The load currents are compared with the reference currents, and error signals are passes through hysteresis band to generate the firing pulses, which are operated to produce output voltage in manner to reduce the current error. The inverter conduction state is represented by logics NA, NB, NC. A logic "1" means T₁ is conducting logic "0" means T₄ conducting. The conduction modes of the inverter are given in Table I. Fig (2) shows the voltage vectors corresponding to the six active states. Each vector has an amplitude of 2V_{dc}/3. The magnitude of the voltage vectors u₀ and u₇ corresponding to the freewheeling states, which equal to zero. The magnitude of voltage u₀ is zero when the upper switches T₁,T₃,T₅ are OFF and lower switches T₄,T₆,T₂ are ON. Similarly, the magnitude of the voltage vector u₇ is zero when the upper switches T₁,T₃,T₅ are ON and lower switches T₄,T₆,T₂ are OFF. It means no voltage is applied to load.

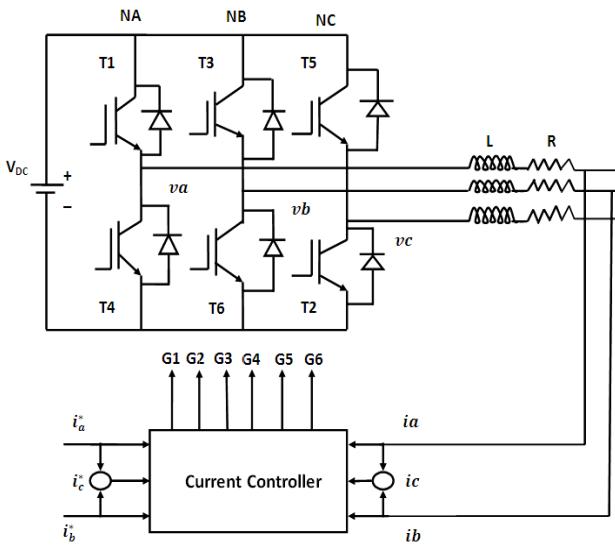


Fig .1. System diagram for current controlled Voltage source inverter

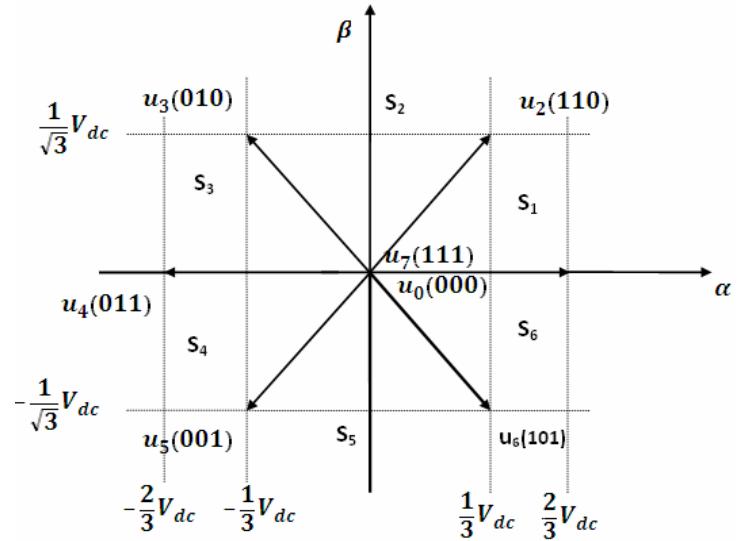


Fig .2. Inverter voltage vectors

2.1 Limitation of DC-Bus voltage and Inverter Switching Frequency

Switching frequency of inverter in hysteresis current controller depends on several factors. To determine this factor, let us consider one phase of the load be described by the following differential equation as:

$$\frac{di_a}{dt} = \frac{v_a}{L} - \frac{R}{L}i_a \quad (1)$$

An idealized PWM inverter is switched between $\pm V_B$ and generates switching current waveform shown in fig(3). Δi_a is the peak –to –peak current ripple, T is the cycle period , and Δt_1 and Δt_2 are the times at which inverter voltage is switched between $+ V_B$ and $-V_B$ respectively. The time $\Delta t(\Delta t_1 + \Delta t_2)$ in which the line current will increase by Δi_a can be found as:

$$\Delta t = L\Delta i_a / (v_a - Ri_a) \quad (2)$$

$$f = 1/\Delta t. \quad (3)$$

Above equation gives the inverter switching frequency. The switching frequency is affected by several factors, such as load inductance and dc-bus voltage as well as magnitude of the load current and its ripple contents. The fundamental line- to - neutral voltages vary periodically. Therefore either the inverter switching frequency and/or the current ripple will vary over a fundamental inverter period.

TABLE 1
LOGIC OPERATION OF VSI UNDER CURRENT CONTROL

State	T ₁	T ₄	T ₃	T ₆	T ₅	T ₂	Operation mode	Voltage vector
0	0	1	0	1	0	1	freewheeling	u ₀
1	1	0	0	1	0	1	active	u ₁
2	0	1	1	0	0	1	active	u ₂
3	1	0	1	0	0	1	active	u ₃
4	0	1	0	1	1	0	active	u ₄
5	1	0	0	1	1	0	active	u ₅
6	0	1	1	0	1	0	active	u ₆
7	1	0	1	0	1	0	freewheeling	u ₇

3 ANALYSIS OF HYSTERESIS CURRENT CONTROLLER

The operation of the hysteresis current controller is explained by circuit shown in fig (3) the load current components i_{α}, i_{β} are sensed and compared with the respective command current components $i_{\alpha}^*, i_{\beta}^*$ using two independent hysteresis comparators having hysteresis band H. The output error currents of comparator are used to active the inverter powers switches. The advantage of this controller lies its simplicity and its providing of excellent dynamic performance. Thus, it has most extensively used. On the other hand, the disadvantage is that the switching frequency varies during fundamental period, resulting in irregular operation of the inverter. As a result the switching losses are increased. Varies strategies have been proposed in the literature to control or minimize the switching frequency variation. There are two tolerance bands for α and β current components. Therefore the hysteresis surface is a tolerance square for the current error which shown in fig (5). When the current error vector touches the border of the surface, another voltage vector is applied to force it back with in the square. The square tolerance band moves together with the reference current such that the current vector points always in the center of the square. For this purpose two hysteresis comparators are employed. A simple consideration makes it possible to control the current without any knowledge of load inner voltage. If the current reaches the border of the vector has to be applied. In this case regardless of the position of the load inner voltage, the α component of the voltage across the load inductance and therefore the current deviation in direction of the α can be reversed.

The complex (α, β) plane can be divided into different sectors as defined by the dotted lines in fig(2). In α – axis it is possible to apply four different voltage levels of $u_k (\frac{2}{3}V_{dc}, \frac{1}{3}V_{dc}, -\frac{1}{3}V_{dc} \text{ and } -\frac{2}{3}V_{dc})$. In β -axis there are three voltages of $u_k (\frac{1}{\sqrt{3}}V_{dc}, 0, -\frac{1}{\sqrt{3}}V_{dc})$. The exact selection of the appropriate voltage vector u_k is

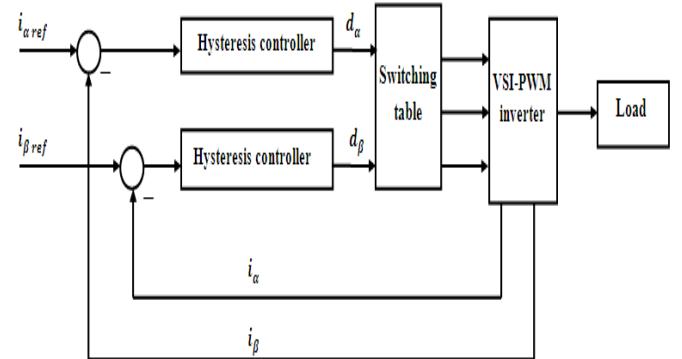


Fig. 3. Block diagram of the used method for Current vector control

determined by structure of the α and β hysteresis comparators and corresponding switching table (table2). Hysteresis comparators are shown in fig (4), for α comparator, level 0 to level $\frac{-2}{3}V_{dc}$, 1 to $\frac{-1}{3}V_{dc}$, 2 to $\frac{1}{3}V_{dc}$ and 3 to $\frac{2}{3}V_{dc}$. For β comparator level 0 corresponds to $\frac{-1}{\sqrt{3}}V_{dc}$, level 1 to 0 and level 2 to $\frac{1}{\sqrt{3}}V_{dc}$. The control scheme uses four level hysteresis comparator for α component and three level hysteresis comparator for β component of the error current vector.tolerance square, then other voltage vector of smaller α component then actual. The outputs of the comparators (d_{α}, d_{β}) select the state of the inverter switches S_a, S_b, S_c using the switching table 2.

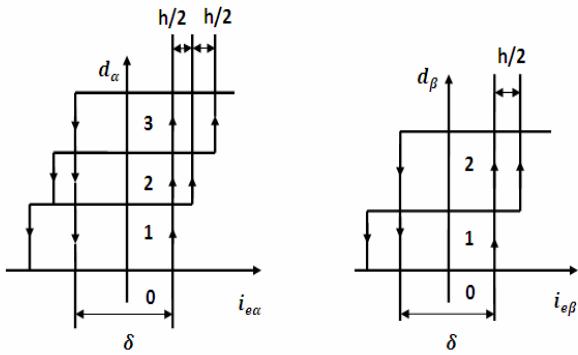
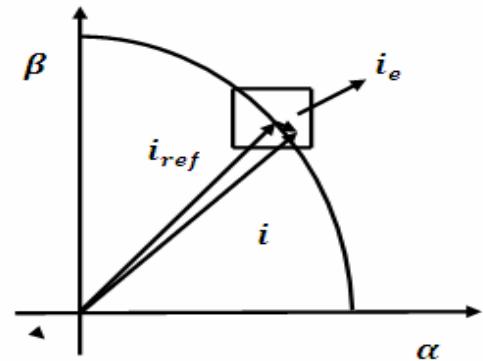
Fig 4. Hysteresis comparators for α and β components

Fig. 5. Square hysteresis area

4 SIMULATION RESULTS

The performance of the current controller has been studied by using MATLAB/Simulink environment.. The values of load and other parameters are given as follows:

Resistance: 3Ω ; Inductance: 5mH ;

Dc voltage: 350V ;

Reference current: 7.071A ;

Hysteresis Band: ± 0.2 of reference current

Fig 5.1(b).shows the sinusoidal reference current of fed to the hysteresis current controller. This reference current will be compared with actual load current waveform. Fig 5.1(a) depicts the actual three-phase load current waveforms. The magnetite of the error could be analyzed by the Fig. 5.2. The current error is limited in between hysteresis bands. Some of the higher order harmonics has significant magnitude. Ripple content in output waveform can be decreased by decrease in hysteresis band. The harmonic spectrum of load current is analyzed using the Fast Fourier transform (FFT) and it was shown in Fig. 5.3 which satisfies the IEEE 519-1992 standard.

We could observe that the error in the switching transition varies between $+0.2$ to -0.2 (with in dead band) in the Fig.5.2. with in $0.1\mu\text{sec}$.So the controller acts quickly and the current reaches the desired set point at very fast. But, when the load parameters are changes the switching frequency is also getting changed. This could be obtained from the table 3. It shows the variation of switching frequency for different load parameters along with THD level for three-phase load currents. So the Hysteresis controller is very sensitivity to load parameter changes as well as load changes.

TABLE 2
SWITCHING LOGIC TABLE FOR SQUARE HYSTERESIS CONTROL

α, β levels	0	1	2	3
0	u_5	u_5	u_6	u_6
1	u_4	$u_{0,7}$	$u_{0,7}$	u_1
2	u_3	u_3	u_2	u_2

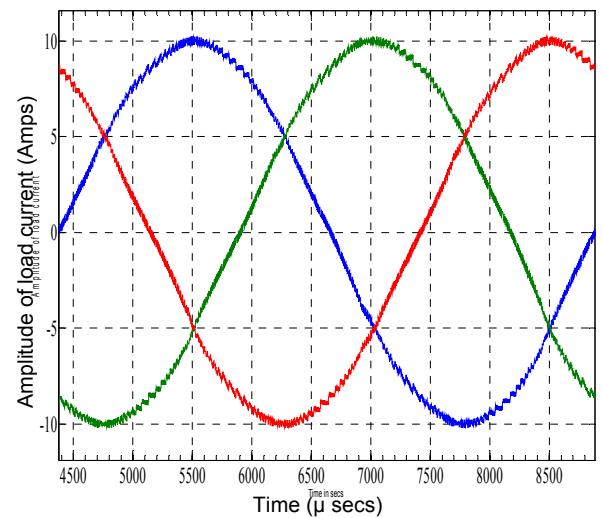


Fig .5.1(a). Actual load current waveforms

TABLE 3
SWITCHING FREQUENCY VARIATION DUE TO PARAMETER CHANGES AND PERCENTAGE OF THD

Variation in the Switching frequency	1.38kHz	1.11kHz	1.24kHz	1.04kHz
Load	R=3ohm,L=5mH	R=3ohm,L=4mH	R=2ohm,L=3mH	R=2ohm,L=2.5mH
Harmonic order	Magnitude of Harmonic content			
1	7.041	7.041	7.046	7.043
3	0.001362	0.000759	2.512e-8	0.002835
5	0.02367	0.02453	0.02102	0.02073
7	0.007178	0.00777	0.006911	0.004747
9	0.00223	0.001898	1.208e-8	0.002576
11	0.001036	0.00236	0.002426	0.002871
13	0.001825	0.00323	0.005603	0.001818
15	0.00208	0.001441	9.008e-9	0.003259
17	0.00152	0.003238	0.004329	0.001929
19	0.00338	0.003096	0.003471	0.0008766
21	0.001277	0.001024	1.496e-8	0.003031
23	0.00352	0.00285	0.005616	0.003407
25	0.001971	0.002088	0.003493	0.0005191
THD for I_{load}	12.06 %	12.44 %	11.67 %	11.76 %

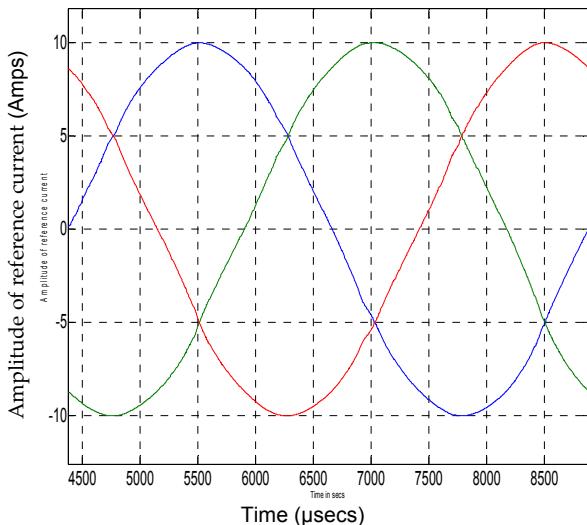


Fig .5.1(b). Reference current waveforms

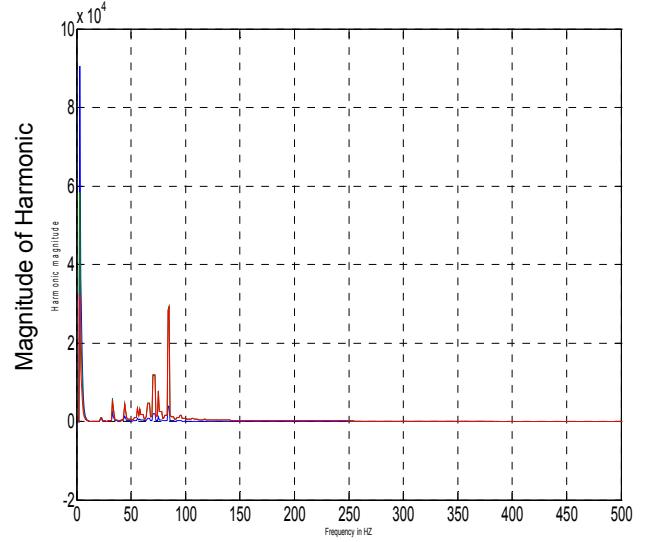


Fig .5.3. Harmonic spectrum of load current waveforms

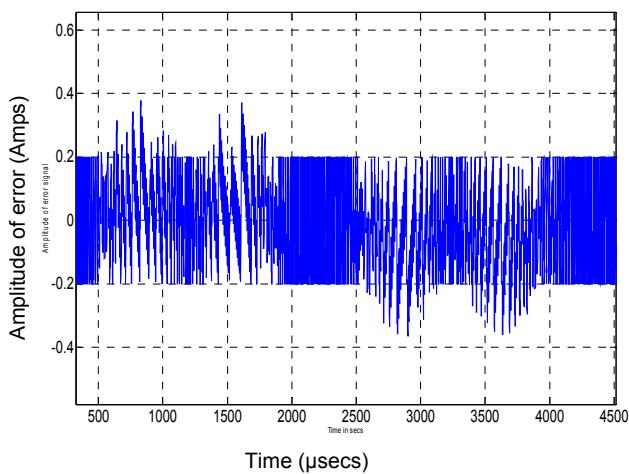


Fig .5.2. Error signal

5 CONCLUSION

This paper presents the performance of the square hysteresis current controller for a voltage source inverter. This technique uses the advantages of both Hysteresis and Space Vector PWM. This scheme shows an excellent dynamic behavior, this is very suited for low power high dynamic requirements, especially servo drives. But we observed that switching frequency of PWM voltage source inverter could de vary due to variation of load parameters. This problem can be overcome by employing Delta modulator with Sample and Hold circuit. This will be focused on the next paper with experimental validation.

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