

Hysteresis Controller and Delta Modulator- Two Viable Schemes for Current Controlled Voltage Source Inverter

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Abstract: Current-controlled pulse width modulated voltage source inverters are most widely used in high performance AC drive systems, because they provides high dynamic response. This paper presents a comparative study between the hysteresis and delta modulated current controllers for three-phase voltage source inverter. The hysteresis controller provides excellent dynamic performance because it acts quickly. The integrator in the delta modulated PWM inverters acts as a low-pass filter for harmonics. Delta modulation technique have ability to optimize (harmonic minimization) pulse width modulated (PWM) inverter waveforms on-line without conventional optimization processes, like selective harmonic elimination or harmonic weighting techniques. A comparison has been made in terms of THD level at the three-phase load current, current error minimization and switching frequency. The simulation study has been carried out with the help of MATLAB Simulink environment and the performance of such controllers has been observed during load variations.

Index terms – hysteresis current controller, delta modulator, voltage source inverter (VSI), total harmonic distortion (THD), pulse width modulation (PWM), switching frequency.

I. INTRODUCTION

Current controlled PWM inverters are widely used in high-performance AC drives because they offer substantial advantages in eliminating stator dynamics in those systems. A basic PWM voltage source inverter with current control is shown in fig.1. The main objective of current controller is to force the load current vector according to reference current trajectory. The performance of converter system is mainly depends on type of current control technique. In current controller load currents are measured and compared with reference currents, the errors are used as an input to the PWM modulator, which provides inverter switching signals. This paper presents the comparative study between hysteresis current control and delta modulated current control. In a hysteresis controller, the hysteresis comparators are used to impose hysteresis or hysteresis around the reference current. Among all current control techniques, the hysteresis controller is widely used because of its simplicity of implementation; fast response Current loop and this method do not need any knowledge of load parameters. However, the main disadvantage is the variation of switching frequency during load parameter variation of fundamental period. In delta modulated current control integrator performs the function of input signal estimation from the output signal by low pass filtering process. The estimated signal is compared with actual input signal to generate error signal, which is in turn to produce modulated signal. The main advantage of

the delta modulator is easy to on-line harmonic minimization; however, at very high frequency such modulators experience instability. These limitations restrict wide application of double integrator delta modulator in inverter operations. From the above information, the characteristics required for current controlled PWM inverter are a quick current response during transient condition and a low harmonic content during steady state conditions. However, these two requirements contradict each other, so decision to use a specified type of current control depends on nature of application. The simulation study has been carried out with the help of MATLAB Simulink environment and the performance of such controllers has been observed during load variations.

I. BASIC SCHEME FOR CC-PWM INVERTER

A VSI current controller controls the load current by controlling the switching of a voltage source across the load. The operation of current-controlled voltage source inverter can be studied by considering the circuit shown in fig.1. For analysis done here load is considered to be RL-load which can be represented by combination of inductance L_s and resistance R_s . Sinusoidal command currents (i_a^* , i_b^* , i_c^*) are compared with the respective machine phase currents (i_a , i_b , i_c) and the resulting errors through hysteresis-band current controllers command the transistor base drives. 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 RL-load is connect to three phase PWM inverter. The concept of the voltage (current) vector is utilized because it is a very convenient representation of a set of three-phase voltages (or currents). The voltage vector is defined by the following expression:

$$\vec{v} = \frac{2}{3} [v_a + av_b + a^2v_c] \quad (1)$$

Where

$$a = e^{j2\pi/3}$$

Which defines a two-dimensional vector (or complex number) associated with the three-phase voltages. The actual voltages

can be recovered from v and the zero sequence component v_0 using the equations

$$\begin{aligned} v_a &= |v| \cos \theta + v_0 \\ v_b &= |v| \cos\left(\theta - \frac{2\pi}{3}\right) + v_0 \\ v_c &= |v| \cos\left(\theta + \frac{2\pi}{3}\right) + v_0 \end{aligned} \quad (2)$$

Where θ is the angle between the voltage vector and real axis. The inverter operates in one of eight conduction modes to produce one of six nonzero voltage vectors or a zero voltage vector as illustrated in Fig. 3. The line-to-ground voltages: V_{ag} , V_{bg} , and V_{cg} are uniquely specified by the inverter with the line-to-neutral voltages equal to the line-to-ground voltages if the neutral is connected to the dc bus midpoint. Otherwise, the line-to-neutral voltages sum to zero, and the inverter cannot apply a zero sequence voltage across the load.

A. Effect of DC Voltage Limit

For a current controller to operate properly there must be sufficient voltage to force the line currents in the desired direction. For loads with low counter EMF the dc bus voltage is not critical, but as the counter EMF is increased, a point is reached where the current controller is not able to command the desired current. This condition is reached when the line-to-neutral Voltages approach a six-step quasi-square wave. In the following sections it is assumed that there is sufficient voltage to command the line currents.

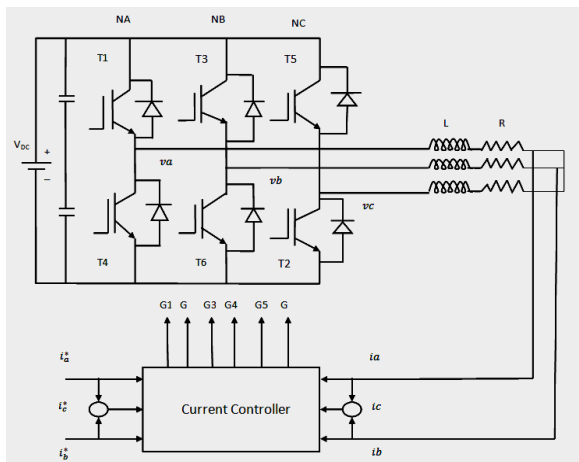


Figure.1. Basic circuit of Current Controlled Voltage Source Inverter

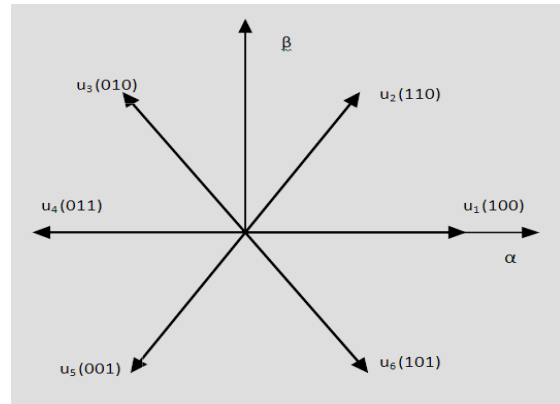


Figure.2. Voltage Vector of VSI

II. ANALYSIS OF CURRENT CONTROLLERS

A. Hysteresis controller

The operation of the hysteresis current control is explained by circuit shown in fig.3 (a). The purpose of the current controller is to control the load current by forcing it to follow a reference one. The load currents are sensed and compared with the respective reference currents, the error signal passes through three independent hysteresis comparators having hysteresis band H. the output error currents of comparator are used to active the inverter power switches. Based on band, there are two types of current controllers, namely, fixed band hysteresis current controller and sinusoidal band hysteresis current controller. Here we are concentrating on fixed band current controller.

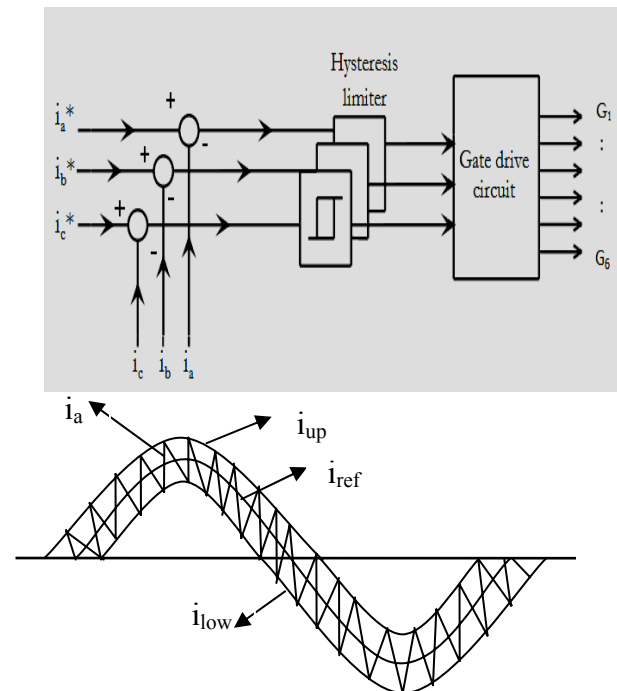


Figure.3.(a) basic circuit diagram of hysteresis controller (b) hysteresis controller control structure

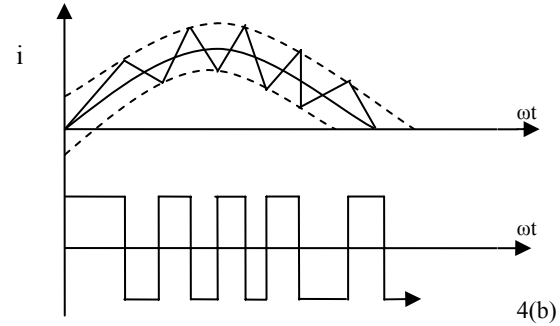
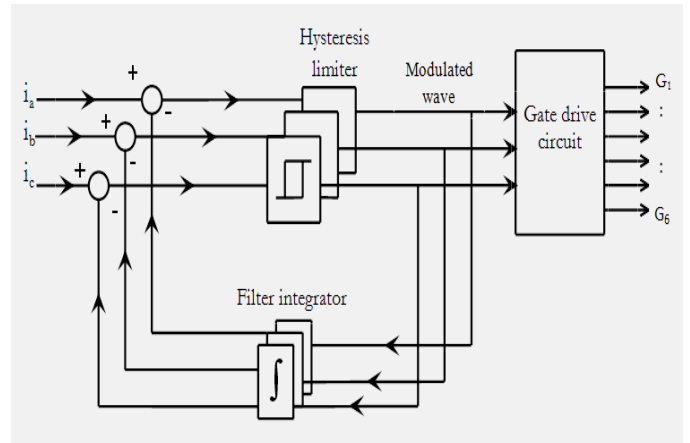
The waveform of fixed band hysteresis current controller is shown in fig.3 (b). In the fixed band scheme, the hysteresis band is fixed over the fundamental period. The mathematical equations for fixed band control is given as

$$i_{ref} = I_{max} \sin \omega t \quad (3)$$

$$i_{up} = i_{ref} + H \quad (4)$$

$$i_{lo} = i_{ref} - H \quad (5)$$

Where i_{up} is the upper band, i_{lo} is the lower band, and H is the hysteresis band limit. From fig.5, if $i_a > i_{up}$, then $NA=0$, which means that inverter output is negative in order to reduce line current. Similarly if $i_a < i_{lo}$, then $NA=1$, where the inverter voltage is positive, in order to increase the load current. The same sequence is followed to other to sequences. The advantage of this controller lies in 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. Various strategies have been proposed in the literature to control or minimize the switching frequency variation. The load current waveforms are, thus, obtained and simulation results have been carried out.



A. Delta modulated current controller

The basic circuit for rectangular delta modulated current controller is shown in fig.4(a). In rectangular delta modulation scheme for inverters, the input signal to controller is sine wave and output is the modulated waveform. The feedback path consists of an integrator filter and the forward path consists of a hysteresis quantizer. The input signal and the signal derived from the modulator output by low pass filtering of the integrator are compared to produce error signal. The quantizer determines this error signal to produce the modulated wave in such manner that error is minimized and kept between certain levels. The integrator shown in fig.4(c), when used in the feedback path of the modulator output low pass filtering having fixed cut off frequency determined by the following transfer function:

$$\frac{e_o(s)}{e_i(s)} = \frac{K}{\tau s + 1} \quad (6)$$

Where k is the gain of the filter = $-R_2/R_1$ and τ = time constant of the filter = $R_2 C$.

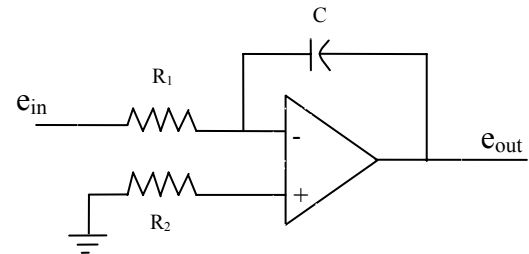


Figure.4. (a) block diagram of simple delta modulator (b) waveforms (c) integrator filter.

Since the above filter has a fixed cutoff frequency f_c , the harmonic contents in the output currents of the modulator can be changed by changing the time constant of the integrator or cutoff frequency. The delta modulation offers an opportunity of on-line harmonic minimization of pulse width modulated inverter without conventional optimization processes, like selective harmonic elimination or harmonic weighting techniques. At very high frequency operation of double integrator modulators experience instability. These limitations restrict the wide application of double integrator delta modulator in inverter operations.

III. SIMULATION RESULTS

The performance of the current controllers 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: 10A ;
- Hysteresis band: ± 0.5 of reference current.

The performance of two current controllers is studied at same load conditions. The harmonic spectrum of load current waveform is analyzed using the Fast Fourier transform (FFT) and measure the THD of load current for different values of R, L which is shown in Table 1. Fig. 5 shows the reference current waveform, load current waveform, error signal and corresponding harmonic spectrum along with THD in percentage of load current for a hysteresis current controller (for load values $R=3\text{ohm}$, $L=5\text{mH}$). Fig. 6 shows the load current waveform, error signal and corresponding harmonic spectrum along with THD in percentage of load current for a delta modulated current controller (for load values $R=3\text{ohm}$, $L=5\text{mH}$). THD of delta modulator is less compared to that of hysteresis current controller. Load current of delta modulator reaches steady state after one and half cycle, it is only quarter cycle for hysteresis current controller which is shown in figures 5, 6. From this point we can say that dynamic response of hysteresis current controller is good compared to that of delta modulator, because time constant of the integrator filter which is used in delta modulator. This integrator filter takes some time to reach the steady state and which provides phase lag (phase delay) in the steady state this can be clearly observed in load current waveform of fig 6. In hysteresis current controller while increase in load values, THD also increases but higher order harmonics are decreases and lower order harmonics increases this is due to time constant of RL-load. The increase of THD values from load 1 to load 4 in hysteresis current controller is more this is because variation of switching frequency with load variations. The increase in THD value in delta modulator is proportion load varies. Hysteresis band which taken here (HB is 10% of load current magnitude) compromise between switching frequency and THD of load current. While decreases hysteresis band switching frequency will increases which leads to more switching losses and increase in hysteresis band load current waveform is distorted which leads to more THD.

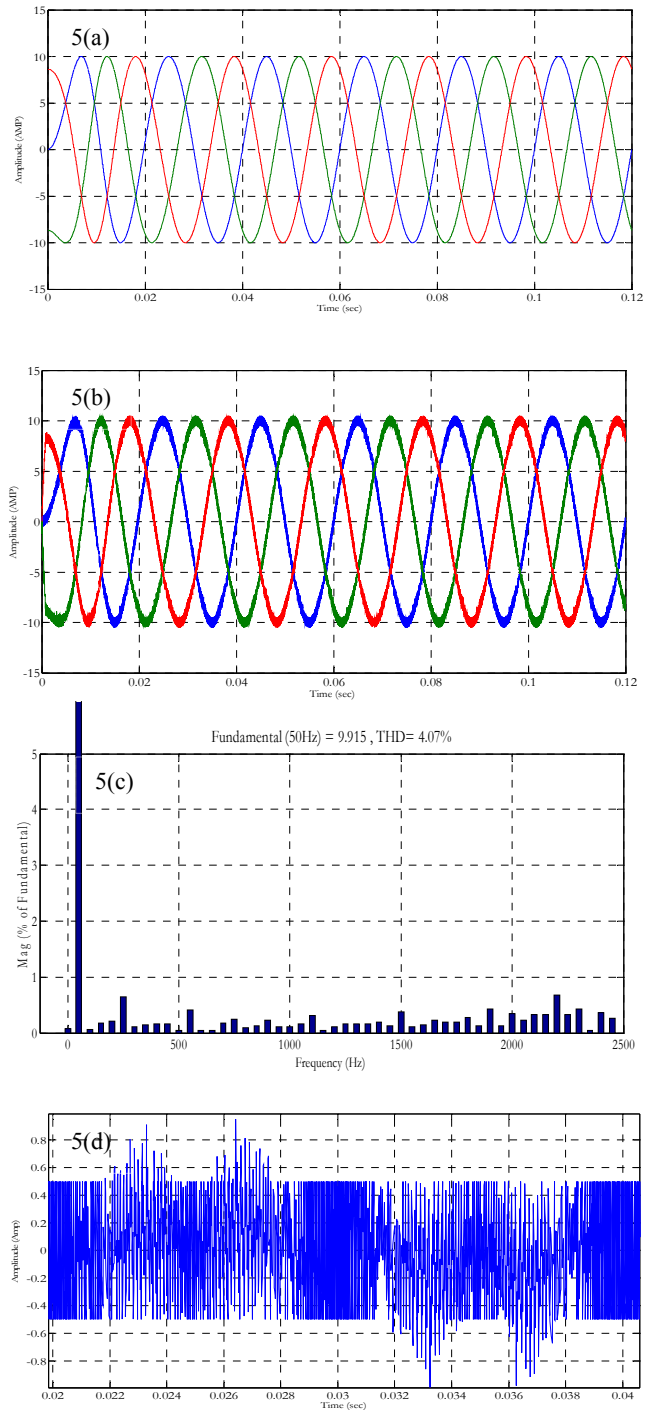


Figure. 5. For hysteresis current controller (a) Reference current waveform (b) Load current waveform (c) harmonic spectrum of load current (d) Error current signal

TABLE: 3
THD LEVEL OF DIFFERENT LOAD CONDITION WITH DELTA AND MODIFIED RAMP TYPE CURRENT CONTROLLERS

Different Loads	Hysteresis current controller	Delta modulator
R=3 ohm, L=5 mH	THD = 4.07%	3.91%
R=3 ohm, L=4 mH	THD = 4.20%	3.98%
R=2 ohm, L=3 mH	THD = 4.23%	4.03%
R=2 ohm, L=2.5 mH	THD = 4.30%	4.13%

IV. CONCLUSION

This paper discussed the performance of hysteresis current controller and delta modulated current controller for a voltage source inverter. From the observed results, the switching frequency of PWM voltage source inverter in hysteresis controller is varying due to variation in load parameters. This problem can overcome by delta modulator with filter integrator time constant. The switching frequency is fixed at cutoff frequency of the integrator. This switching frequency can be varied by varying time constant of integrator or cutoff frequency. The harmonic content in the delta modulated current controller is less compared to the hysteresis current controller. These two techniques will be employed in grid connected distributed power generating system in order to reduce the THD of grid current and well as for good dynamic response in the next paper.

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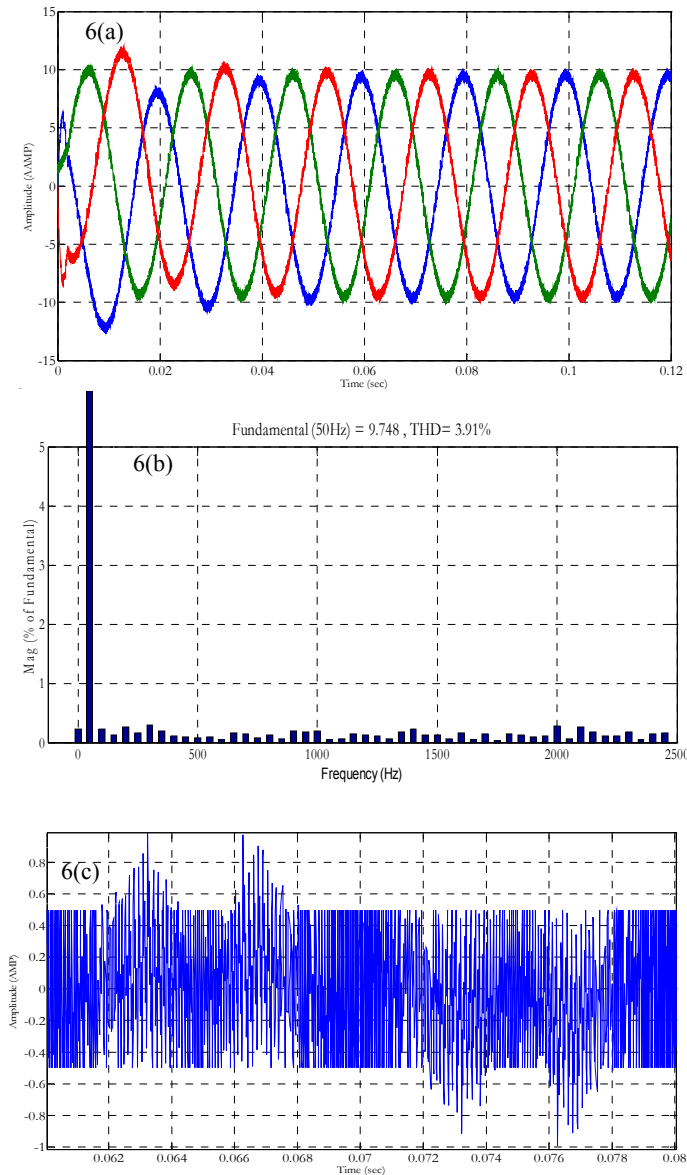


Figure.6. For Delta modulator (a) Load current (b) Harmonic spectrum of load current (c) Error current signal