Modelling And Simulation Of A Hysteresis Band Pulse Width Modulated Current Controller Applied To A Three Phase Voltage Source Inverter By Using Mat lab

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ABSTRACT: In This Paper It has been designed a hysteresis band PWM (HBPWM) current controller for a three level voltage source inverter (VSI) .The HBPWM approach has been selected for the research, since it has the potential to provide an improved method of deriving non-linear models which is complementary to conventional techniques. To illustrate the validity of this approach, an indirect vector controlled induction motor (IVCIM) drive has been considered as its application. The induction motor (IM) is modelled using *d-q* transform called Park's transformation as it adequately simulates the transient performance. Network acquires the features of an HBPWM controller. The simulation model of an IVCIM drive employing HBPWM current controller is developed in SIMULINK/MATLAB environment. The performance of the proposed method is compared with conventional PWM current control scheme. HBPWM current controller is more efficient in terms of fault tolerance, switching loss and total harmonic distortion thus improving the performance of the drive.

 Keywords: Hysteresis band pulse width modulated controller (HPWM) ,Indirect vector control of Induction Motor(IVCIM), Voltage source Inverter(VSI)

I.INTRODUCTION

   The effective way of varying speed of an Induction Motor (IM) drive is to supply with three phase Inverter of variable frequency and variable voltage. It can be obtained through a dc voltage link via a current controlled inverter. In order to maintain the proper magnetic conditions in the core the applied voltage /frequency ratio must be constant

        The various methods for the control of output voltage [6] of inverters are (i) External control of ac output voltage. (ii)External control of dc input voltage. If the available voltage is dc, then the dc voltage input to the inverter is controlled by means of chopper. This method is not much used as it involves more losses, reduced efficiency, high cost and complexity.(iii) Internal control of inverter control within the inverter itself. The most efficient method of doing this is by Pulse Width Modulation (PWM) control used within the inverter. PWM inverters are quiet popular and most widely used in all industrial applications. In the present paper the output voltage of inverter is controlled by using HBPWM control

        The PWM principle, different methods of PWM techniques and HBPWM controller is discussed in detail and description of modeling of HBPWM controller in SIMULINK/MATLAB. Simulation block diagram of IVCIM using HBPWM current controller for the inverter is presented and   the simulation results are shown.

II. PWM CONTROL

        In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. Inverters employing PWM principle are called PWM inverters. PWM techniques are characterized by constant amplitude pulses. The width of these pulses is modulated to obtain inverter output voltage control and to reduce its harmonic content. The advantages possessed by PWM technique

are [8](i)The output voltage control with this method can be obtained without any   additional components.(ii)With this method, lower order harmonics can be eliminated or minimized along   with its output voltage control. As higher order harmonics can be filtered easily, the filtering requirements are minimized.[1]

The main disadvantage of this method is that the SCRs are expensive as they must possess low turn on and turn off times. This is the most popular method of controlling the output voltage of an inverter in industrial applications. [2]

III.TYPES OF PWM TECHNIQUES

There are several types of PWM techniques [4] Sinusoidal PWM (SPWM),Selected harmonic elimination (SHE) PWM, Minimum ripple current PWM, Space vector PWM, Hysteresis band current control PWM (HBPWM),Sinusoidal PWM with instantaneous current control, Sigma-delta modulation .

The hysteresis band current control PWM has been used because of its simple implementation, fast transient response, direct limiting of device peak current and practical insensitivity of dc link voltage ripple that permits a lower filter capacitor.

IV.HBPWM CURRENT CONTROL

The HBPWM is basically an instantaneous feedback current control method of PWM where the actual current continually tracks the command current within a specified hysteresis band. [3]
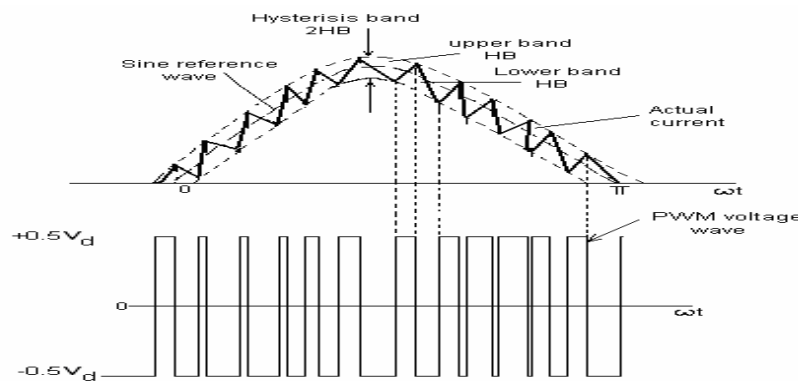

Fig 1. Principle of Hysteresis Band current control

The Fig 1 explains the operation principle of HBPWM for a half bridge inverter. The control circuit generates the sine reference current wave of desired magnitude and frequency, and it is compared with the actual phase current wave. As the current   exceeds a prescribed hysteresis band, the upper switch in the half-bridge is turned off and   the lower switch is turned on. As a result the output voltage transitions from $+0.5V_d$ to $-0.5V_d$, and the current starts to decay. As the current crosses the lower band limit, the lower switch is turned off and the upper switch is turned on. The actual current wave is thus forced to track the sine reference wave within the hysteresis band by back- and-forth switching of the upper and lower switches. The inverter then essentially becomes a current source with peak to peak current ripple, which is controlled within the hysteresis band irrespective of V_d fluctuation. The peak-to peak current ripple and the switching frequency are related to the width of the hysteresis band. The HBPWM inverter control method is shown in the Fig 2. The inputs to the HBPWM controller are three phase current errors and the outputs are the switching patterns to the PWM inverter. k in the figure represents the normalization factor and is used for the purpose of scaling the current error input to the HBPWM controller. PS is the pulse separation circuit for the separation of pulses to the IGBTs in the upper and lower leg of the inverter.[4]
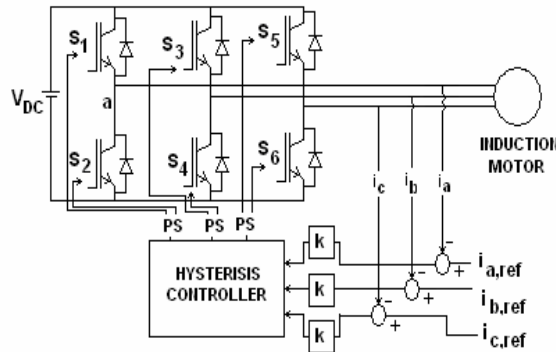
Fig.2Conventional HBPWM Inverter Control method

The hysteresis current controller gives output pulses to the inverter according to this   rule [7]

$|i_{m,ref} - i_m| < \varepsilon$ keeps the output pulse at the same state $i_{m,ref} - i_m > \varepsilon$ let output pulse =1(high)

$i_{m,ref} - i_m < -\varepsilon$ let output pulse =0(low)Where m=a, b, c phases and ε is the hysteresis band

The algorithm for this scheme is:

$$i_{m,ref}(t) = I_{m,ref}\sin(wt)$$

Upper band $i_u = i_{m,ref}(t) + \Delta i$ (1)

Lower band $i_l = i_{m,ref}(t) - \Delta i$ (2)

Where Δi =hysteresis band limit

If $i_m > i_u$, $V_{mo} = -V_{dc}/2$ (3)

If $i_m < i_l$, $V_{mo} = V_{dc}/2$ (4)

Else, maintain the same state. Where m=a, b, c phases i is load current and V_{dc} is the dc link voltage of the inverter.[3]
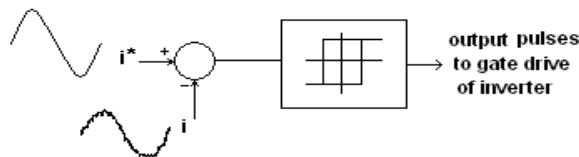

Fig 3 Control block diagram for HBPWM

The main drawback of this method is that the PWM frequency is not constant   and, as a result non optimum harmonics will result.

V.SIMULINK MODELOF HBPWM CURRENT CONTROLLER

The HBPWM current controller block diagram using SIMULINK/MATLAB is shown below in Fig 4. Current errors for the three phases are determined and a hysteresis block is employed for each phase. The outputs of HBPWM controller, which are pulses, are given to inverter feeding the 3-ø IM. The hysteresis block is available in SIMULINK library in discontinuities and fixed point block set
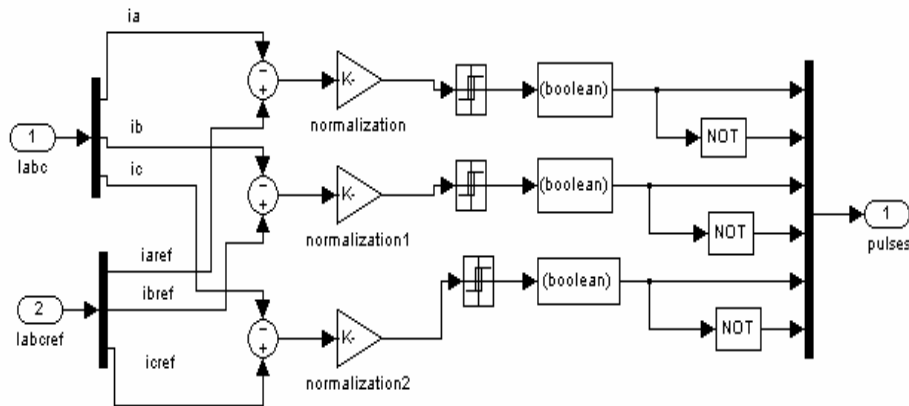
Fig 4 Block diagram of HBPWM current controller

VI. SIMULINK MODEL OF IVCIM DRIVE USING HBPWM CONTROLLER

To illustrate the operation of HBPWM current controller the simulation model of an IVCIM drive using HBPWM current controller is developed and simulated. The model is shown in Fig 5. The IM block is available in the SIMULINK library in Sim Power Systems block set. The motor specifications can be specified by double clicking the block. The IM is squirrel cage type and the synchronous reference frame is selected. The motor block is internally d-q modeled.[5]
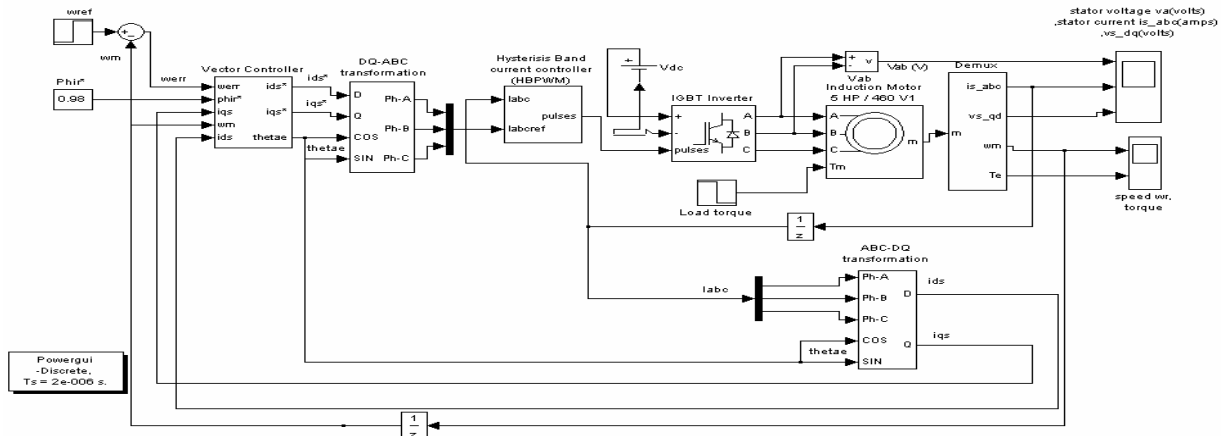
Fig 5 Block diagram of IVCIM drive using HBPWM current controller.

The reference inputs to the system are the reference speed (ω_{ref}) in radians per second, the flux linkages (flux*) and the load torque (Load torque) The required outputs are the developed electromagnetic torque (T_e) and the rotor speed (ω_m).

VII. VECTOR CONTROLLER

The inputs to the vector controller are rotor reference flux (flux*) and difference in reference speed and actual motor speed (ω_{err}). Flux* is used to generate i_{ds}^*. i_{ds}^* is the control current to control i_{ds}, where i_{ds} is the d-axes component of stator current. The Fig 6 shows the vector controller for the IM drive.
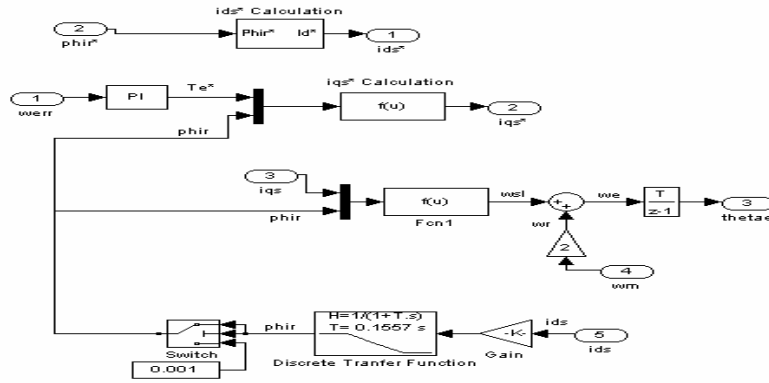
Fig 6 Vector Controller block diagram

$$\Psi_r = L_m i_{ds}^* \qquad (5)$$

$$i_{ds}^* = \frac{\Psi_r}{L_m} \qquad (6)$$

i_{qs}^* is the control current to control i_{qs}, where i_{qs} is the q-axes component of stator current. ω_{err} is used to calculate i_{qs}^* using algorithm. A PI controller is used to generate the reference torque T_e^* from $\omega_{err.}$ The gain constants K_P and K_I of the PI controller chosen are 16 and 32 and are selected by performance. The Rotor flux is calculated from the equation (5)

$$\Psi_r = L_m i_{ds} \left/ \left[\frac{L_r}{r_r} s + 1 \right] \right. \qquad (7)$$

The dynamic part of the flux is omitted while calculating the reference rotor flux. This is because the rotor flux is constant in steady state. The i_{qs}^* is calculated using T_e^* and flux*.

$$T_e^* = \frac{3}{2} \frac{P}{2} \frac{L_m}{L_r} \Psi_r I_{qs}^* \qquad (8)$$

$$i_{qs}^* = \frac{2}{3} \frac{2}{P} \frac{L_r}{L_m} \frac{1}{\Psi_r} T_e^* \qquad (9)$$

Slip speed denoted by ω_{sl} in rad/sec is calculated using Phir (rotor flux) and i_{qs} (q-axes component of stator current) from the following equation 4.

$$\omega_{sl} = (\omega_e - \omega_r) = L_m \frac{r_r'}{L_r} \frac{i_{qs}}{\hat{\Psi} r} \qquad (10)$$

The synchronous speed ω_e and therefore theta are calculated using the equations 5 and 6 respectively.

$$\omega_e = \omega_r + \omega_{sl} \qquad (11)$$

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl} \qquad (12)$$

VIII.(ABC-DQ) TRASNFORMATION

The a-b-c to d-q transformation can be implemented by the SIMULINK model shown in the Fig 7.
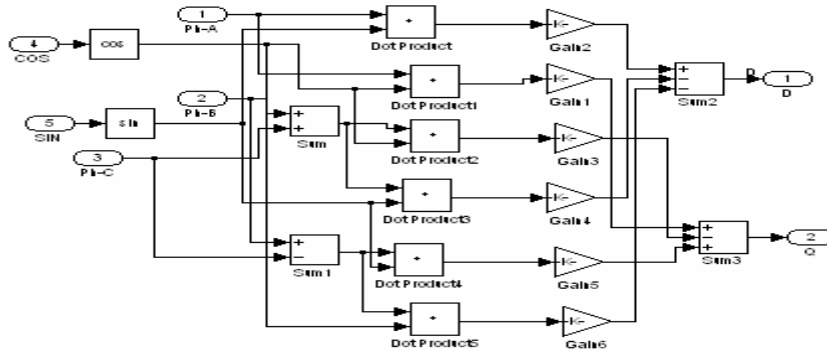

Fig 7   Block diagram for a-b-c to d-q Transformation

Transformation matrix used for a-b-c to d-q transformation is given by the following equation 13.

$$\left[T_{qd0}(\theta)\right] = \frac{2}{3}\begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin(\theta) & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{13}$$

IX.(DQ-ABC) TRANSFORMATION

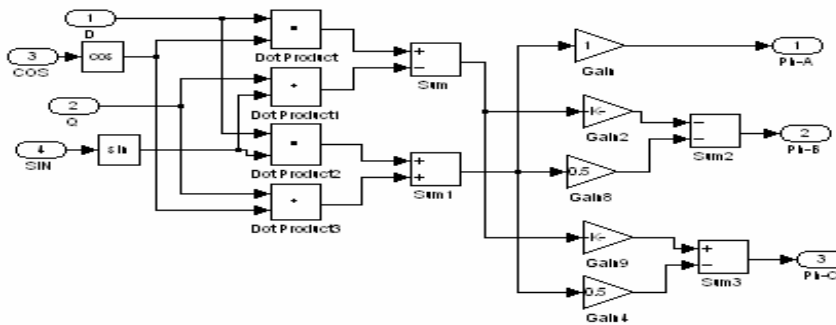The d-q to a-b-c transformation can be implemented by the SIMULINK model shown in the Fig 8.

Fig.8 Block diagram for d-q to a-b-c Transformation

Transformation matrix used for d-q to a-b-c transformation is given by the equation (14).

$$\left[T_{qd0}(\theta)\right]^{-1} = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 1 \\ \cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & 1 \\ \cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \tag{14}$$

X. SIMULATION RESULTS AND DISCUSSIONS

The simulation results of the IVCIM drive employing HBPWM controller with an inverter and an IM with the following specifications are considered.

Inverter: DC link voltage (V_{dc}) = 428.76V

The dc link voltage V_{dc} should be around $1.453V_L$ where V_L is R.M.S value of line voltage.

Sampling time (T_s): 1.8μs,Hysterisis Band width of HBPWM current controller is 0.03.

Induction motor: 3 phase, 6 hp, 440 V, 4-pole Frequency: 50 Hz Stator resistance (r_s): 0.007 ohm. Rotor resistance (r_rL) ecnatcudni egakaeL rotatS .mho 820.0 :($'_{ls}$): 0.8 mH. Rotor Leakage inductance (L_{lr} gnizitengaM .Hm 8.0 :(' inductance (L_m):34.7 mH
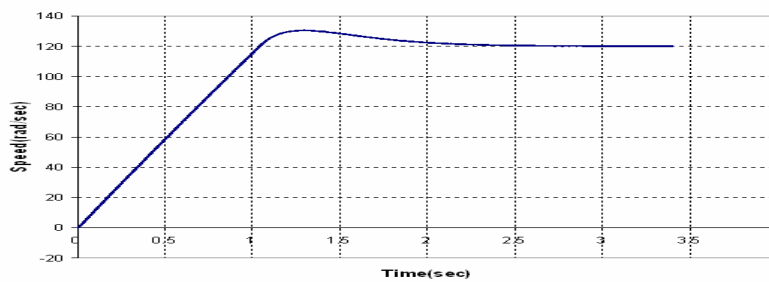

Fig 9 Speed response of IVCIM using HBPWM controller without any disturbance

The motor has high starting torque of about 10 to 12 times the load torque. But in the graph the starting torque is seen to be constant at three times the load torque. In the vector controller circuit for i_{qs}^* generation where a PI controller is used to generate the reference torque, a saturation limit of three times the load torque is set.
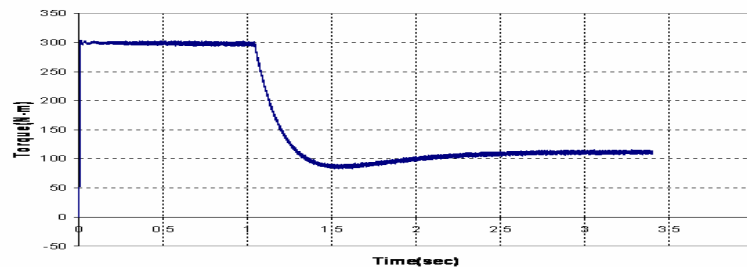

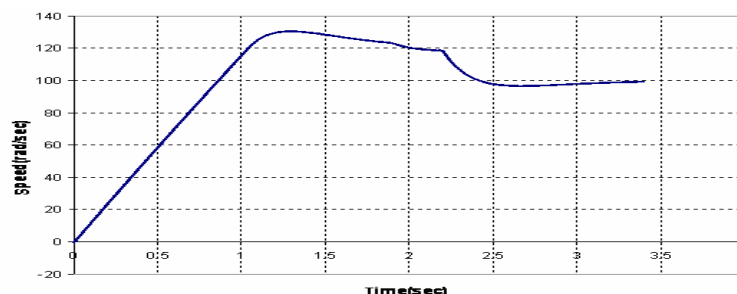Fig 10 Torque response of IVCIM using HBPWM controller without any disturbance

Fig 11 Speed response of IVCIM using HBPWM controller with step disturbance

It can be seen from the graph that the disturbance in load is given even before the drive reached the post disturbance speed 160 rad/sec. Now if the drive is left as such without any further disturbance, it stabilizes at around 3.277 sec. But the step disturbance of 50 rad/sec in speed given at 2.2 sec causes the drive to stabilize at around 3.5 sec.
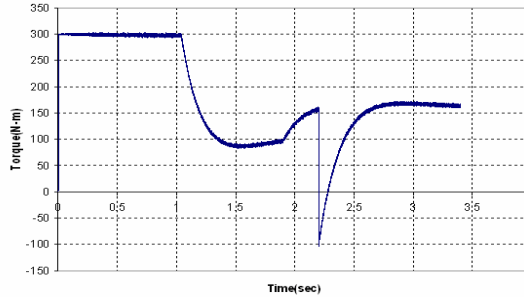
Fig 12 Torque response of IVCIM using HBPWM controller with step disturbance

HBPWM controller, when there is a step disturbance in load torque and speed at 1.9 sec and 2.2 sec respectively. Pre and post disturbance values of load torque are 100 N-m and 150 N-m respectively.. This dip can be reduced by proper selection of gain constants of the PI controller generating the reference torque T_e^*. As the speed of motor reaches the reference value of 100 rad/sec, the developed torque reaches a final value of   170 N-m.
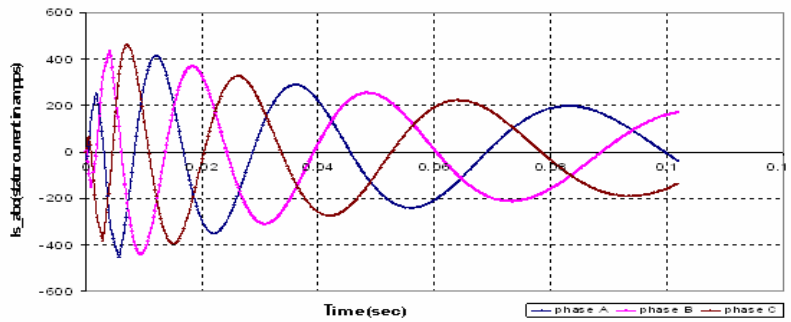

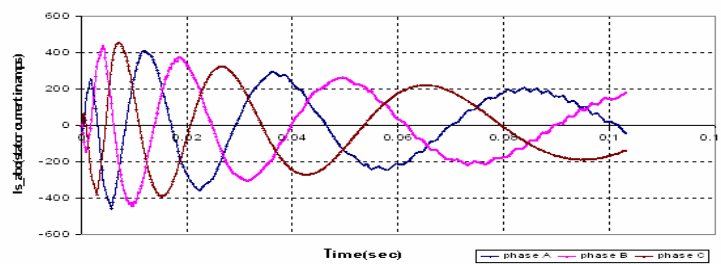Fig 13 Stator current of IVCIM using HBPWM controller with normalization factor k=1

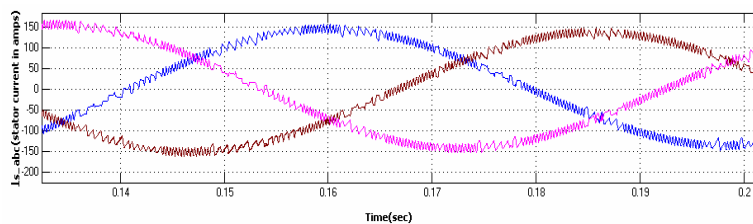Fig 14(a) Stator current of IVCIM using HBPWM controller with k=0.003

Fig 14(b) Zoomed portion of stator current of IVCIM using HBPWM controller with k=0.003

It can be observed from the graphs shown in Figs 13 and 14(a) that when the current error input to the HBPWM controller is not normalized i.e. k=1, the input current to the stator of IM is smooth but with the normalization factor k=0.003 the input current to the stator of IM is distorted and there is an increase in torque pulsations in the developed torque. The Fig 3.14(b) shows the zoomed portion of the stator current in the in the Fig 3.14 (a). Further normalization causes further distortion of input current and increase in the pulsations in the torque waveform.
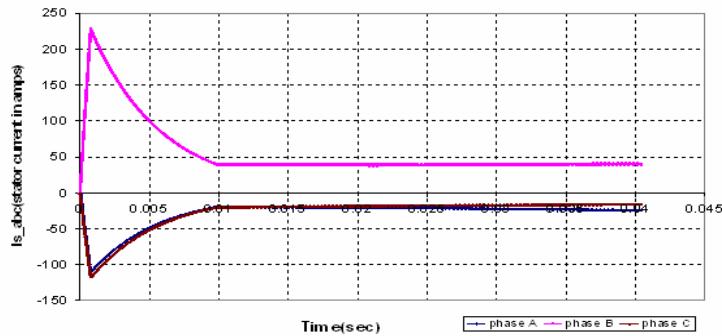

Fig. 15 Stator current of IVCIM with HBPWM when A-phase current error is zero

If any one of the inputs to the HBPWM current controller is zero the IM drive ceases to work as the input current to the IM motor becomes zero. The graph in the   Fig 15 shows current input to the motor when A-phase current error input to the HBPWM current controller is zero.

The switching loss of the inverter using HBPWM controller in the IVCIM drive is calculated by defining a ratio α as follows:

$$\alpha = \frac{\text{number of actual device switchings}}{\text{number of possible switchings}}$$

Reduction of α decreases the inverter switching loss .The values of α calculated for different values k is given below:

α for k=1 is   0.26
α for k=0.1 is   0.64
α for k=0.003 is   0.96

Total Harmonic Distortion:

The total harmonic distortion (THD) is a measure of closeness in shape between a waveform and its fundamental

component and is defined as $\text{THD} = \dfrac{\left[\sum\limits_{n=2,3,\ldots}^{\infty}\left(\dfrac{I_n^2}{n}\right)^2\right]^{1/2}}{I_1} = \dfrac{1}{I_1}\left(I^2 - I_1^2\right)^{1/2}$

where, I_n = RMS value of the nth harmonic component of the current I_1 = RMS value of the fundamental component of the current . I = RMS value of the total current. The % total harmonic distortion (%THD) of the input current to the stator of the IVCIM using HBPWM controller for hysteresis band widths of 0.02 and 0.5 are shown in the Table 1:

XI.CONCLUSIONS

In this Paper the working principle of HBPWM current controller and its modeling in SIMULINK for an inverter control is discussed. As its application, an IVCIM drive is modeled and the results are shown. The hysteresis band width of the HBPWM current controller is 0.02. The speed, torque responses, stator current waveforms, inverter switching losses and %THD of the stator current of the IVCIM.

Table 1: %THD

Hysteresis Band Width	%THD of stator current (phase-A) of IVCIM using HBPWM controller
0.02	3.679
0.5	4.210

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