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PERFORMANCE EVALUATION OF MULTILEVEL INVERTER FED PMSM DRIVE USING HYSTERESIS CURRENT CONTROLLER

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ABSTRACT: This project presents adaptive hysteresis current controller to control the inverter. Hysteresis current controller is used in many industrial applications because it has many advantages as fast, high dynamic performance and doesn't require any information about load parameters. The drawback of this current controller is varying switching frequency. It is used to reduce the ripple, total harmonic distortion and improvement the switching frequency through design of PI current controller. The modified hysteresis current controller is compared to conventional hysteresis controller under steady state and transient conditions with fixed load, sudden applied and sudden removal load and reversing load to show the effectiveness of this modification. A permanent magnet synchronous motor is a synchronous motor, in which the rotor winding are replaced by high resistive permanent magnet. The dynamic performance of VSI (voltage source inverter) fed PMSM drive system largely depends on the applied control strategy. the modeling and analysis of multilevel inverter fed PMSM (Permanent Magnet Synchronous Motor) drive. The concept of hysteresis is applies to produce the controlled switching pulses to multilevel inverter and the concept of vector control is applied in PMSM to obtain linear dynamics similar to DC motor. Multilevel structure of inverter produces high power and high voltage output without requiring higher ratings of individual devices, so the power rating of the converter can exceed the limit imposed by the individual switching devices. The performance of the PMSM drive system due to improvement in the hysteresis current controller is simulated through the MATLAB / Simulink.

KEYWORDS- Multilevel converter, permanent magnet synchronous motor, cascaded H-bridge inverter, nine level inverter, level shifted and phase shifted PWM technique.

I. INTRODUCTION

PM synchronous motors are widely used in low and mid power applications robotics adjustable speed drives attractive solution for servo drive in k-w the range industrial applications. The high-quality permanent magnet materials have high flux density, high coercively. Samarium - cobalt (SmCo), neodymium iron-boron (NdFeB) magnates used for their low cost. The concept of multilevel converters has been introduced

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since 1975. A multilevel converter can operate at both fundamental switching frequency and high switching frequency PWM. A multilevel inverter is a power-electronic system that generates a desired output voltage by several PWM techniques. Here we use phase shifted PWM, level shifted PWM. In level shifted PWM i) Phase disposition(PD), ii) Alternative Phase Opposition Disposition(APOD) iii) Phase Opposition Disposition(POD). The advancement in power electronics technology has made it possible to vary the frequency of the voltage. Thus, it made more extensive use in variable speed drive applications and the control of PM motor has become easier and cost effective, with the possibility of operating the motor over a wide range of speeds and still retains a good efficiency.

(2) SYSTEM CONFIGURATION AND PRINCIPLE OF OPERATION

A 1.5 KW, 4000 rpm, 4 poles, 50 Hz vector controlled PMSM is used to emulate the performance of five level cascaded inverter fed PMSM drive. Fig. 1 shows the block diagram of hysteresis controlled five level inverter fed PMSM drive. The actual current flowing through the PMSM are sensed using two Hall Effect sensors and the third phase current is estimated by considering the sum of two phase current is zero. The rotor speed is compared with reference speed which generates speed error. The speed error is processed in the PI speed controller, which generates reference torque. The reference torque produced q-axis current and d-axis current is kept zero. Both the d and q axis component of stator current generates three phase reference current. The actual and reference currents are compared and current error are fed to the hysteresis current controller, which generates switching SCEECS 2014 pulses for MLI by force the error current within the hysteresis tolerance band h.

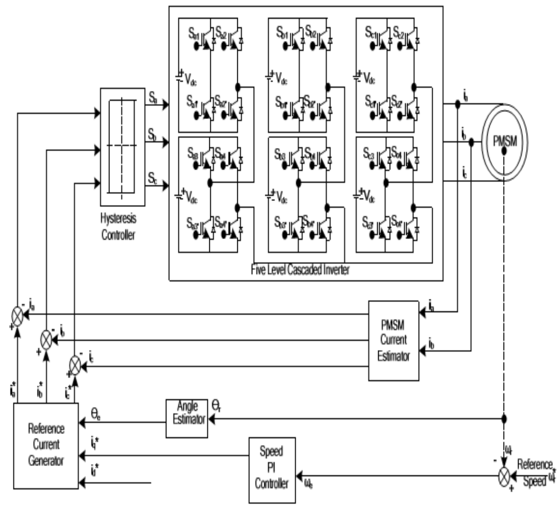

Fig. 1. Schematic block diagram of hysteresis current controlled five levels CHB inverter fed PMSM drive.

(3) CONTROL SCHEME

The basic building blocks of multilevel inverter fed PMSM drive system are shown in Fig.1. The drive used vector control to obtained linear dynamics of PMSM similar to that of DC motor and hysteresis current control to produce the controlled switching pulses to multilevel inverter respectively. The controlled system variable is compared against hysteresis band(s) to create the switching commands for the inverter. The basic control algorithm and equations for the different blocks, which include PMSM current estimator, speed PI controller, reference current generator, hysteresis controller, multilevel inverter and permanent

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magnet synchronous motor are given as follows,

3.1 Estimation of PMSM Current

The three phase PMSM current is obtained by sensing two phases currents i_a and i_b, the third phase current is estimated by considering the sum of instantaneous three phase current is zero as,

$$i_a + i_b + i_c = 0 \tag{1}$$

3.2 Speed PI Controller

The input to the PI speed controller is the speed error ωe(k), between the reference speed ω*r(k) and the actual sensed motor speed ωr(k) .This error is estimated at the kth sampling instant given as,

$$\omega_{e(k)} = \omega^*_{r(k)} - \omega_{r(k)} \tag{2}$$

The error is processed in the PI speed controller and the output of controller is given by the reference torque T*, the reference torque is divided by the motor torque constant to give the reference quadrature axis current i_q^*. The reference i_q^* quadrature at Kth sampling instant is given as,

$$i^*_{q(k)} = i^*_{q(k-1)} + K_P\{\omega_{e(k)} - \omega_{e(k-1)}\} + K_I\omega_{e(k)} \tag{3}$$

Where $i^*_{q(k)}$ and $i^*_{q\,(k-1)}$ are the output of speed PI controller in the kth and (k-1)th sampling instant and KP and KI are the proportional and integral gains of the PI controller respectively. The direct component of current i_d^* can be defined as,

$$i_d^* = 0 \tag{4}$$

3.3 Reference Current Generation

The d-axis and q-axis component of reference stator currents ($i_d^*$and i_q^*), generate three phase reference currents (i_a^*, i_b^* and i_c^*) by using Park's transformation. The transformation angle for the estimation of PMSM phase current is obtained as,

$$\theta_e = (p/2) * \theta_r \tag{5}$$

Where θ_r is the rotor angular position in electrical rad/sec produced by angle estimator.

The three phase reference currents for the stator winding can be represented as,

$$i_a^* = i_d^* \cos\theta_r - i_q^* \sin\theta_r \tag{6}$$

$$i_b^* = i_d^* \cos(\theta_r - 2\pi/3) - i_q^* \sin(\theta_r - 2\pi/3) \tag{7}$$

$$i_c^* = i_d^* \cos(\theta_r + 2\pi/3) - i_q^* \sin(\theta_r + 2\pi/3) \tag{8}$$

These reference currents (i_a^*, i_b^* and i_c^*) are compared with sensed winding currents (i_a, i_b, and i_c) of the PMSM and the errors are fed the to hysteresis current controller.

3.4 Design of Hysteresis Current Controller

Hysteresis current control is basically an instantaneous feedback current control method where the actual load current tracks the reference current within a specific hysteresis band h [2]. The error current are produced by the comparison of actual PMSM current i_{abc} with reference current i^*_{abc} of desired

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magnitude and frequency. The error current is fed to hysteresis controllers which consist of tolerance band (h). For five level inverter four hysteresis bands are built is shown in fig. 4.2. If the error current exceeds the upper limit of the hysteresis band, the next higher voltage level should be selected to attempt to force the current error towards zero. However, the new inverter voltage level may not be sufficient to return the current error to zero and inverter should switch to next higher voltage level until the correct voltage level is selected. As a result, the current gets back into the hysteresis band.

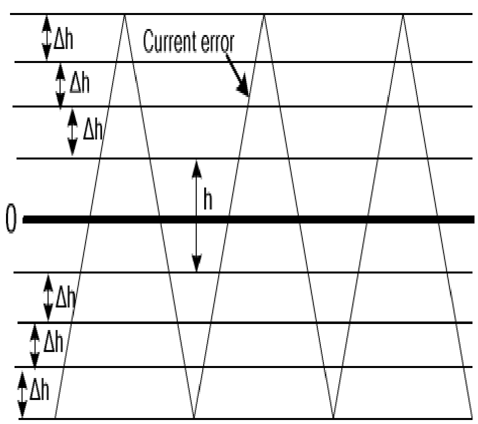

Fig. 2. Hysteresis band of five level inverter

3.5 Design of Five Level Cascaded Inverter

The five level cascaded inverter is developed it consist of series connection of single-phase inverters with separate DC sources. It consists of 24 IGBT and six DC voltage sources, where eight IGBTs and two voltage sources are used for each phase leg. The switching state of a cascaded inverter can be determined as [16],

$$S_w = 3^m \tag{9}$$

3.6 Modeling *of PMSM*

The mathematical model of PMSM is derived from the synchronous motor under the assumption that the armature emf is induced by the permanent magnets in place of DC excitation. Assuming that the induced emf is sinusoidal and eddy current and hysteresis losses are negligible. The stator voltage equations in the rotor reference frame are given as [1],

$$V_q = R_s\, i_q + p\varphi_q + \omega_r\, \varphi_d \tag{10}$$

$$V_d = R_s\, i_d + p\varphi_d - \omega_r\, \varphi_q \tag{11}$$

$$\varphi_q = L_q i_q \tag{12}$$

$$\varphi_d = L_d i_d + \varphi_f \tag{13}$$

Where:

Vq,Vd :d, q axis stator voltages, iq, id :d,q axis stator currents, Lq, Ld :d,q axis inductances, φf :stator flux linkages produced by permanent magnets, Rs :stator winding resistance per phase, ωr :rotor speed in rad/sec (electrical).

$$T_e = (3/2)\,(P/2)\,\{\varphi_d\, i_q - \varphi_q\, i_d\} \tag{14}$$

Where, P is the number of poles. The electromagnetic torque is balanced by the load torque, accelerating torque and damping torque of the system and can be expressed in electromechanical equation as:

$$T_e = T_L + B\omega_r + Jp\omega_r \tag{15}$$

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The model equations of PMSM can be rearranged in the form of following first order differential equations as:

$$p\, i_d = (v_d - R_s\, i_d + \omega_r\, L_q\, i_q) / L_d \qquad (16)$$

$$p\, i_q = (v_q - R_s\, i_q - \omega_r\, L_d\, i_d - \omega_r\, \varphi_f) / L_q \qquad (17)$$

$$p\, \omega_r = (T_e - T_L - B\, \omega_r) / J \qquad (18)$$

$$p\theta_r = \omega_r \qquad (19)$$

4. Induction Motor Drive

Induction Machines, the most widely used motor in industry, have been traditionally used in open-loop control applications, for reasons of cost, size, reliability, ruggedness, simplicity, efficiency, less maintenance, ease of manufacture and its ability to operate in dirty or explosive conditions. However, because the induction machine requires more complex control methods, the dc machine has predominated in high performance applications. With developments in micro-processors/DSPs, power electronics and control theory, the induction machine can now be used in high performance variable-speed applications.

Applications:

- Heating,
- Ventilation,
- Air Conditioning Systems,
- Waste Water Treatment Plants,
- Blowers,
- Fans,
- Textile Mills,
- Rolling Mills, Etc.

The induction motor speed variation can be easily achieved for a short range by either stator voltage control or rotor resistance control. But both of these schemes result in very low efficiencies at lower speeds. The most efficient scheme for speed control of induction motor is by varying supply frequency. This not only results in scheme with wide speed range but also improves the starting performance.If the machine is operating at speed below base speed, then v/f ratio is to be kept constant so that flux remains constant. This retains the torque capability of the machine at the same value. But at lower frequencies, the torque capability decrease and this drop in torque has to be compensated for increasing the applied voltage.

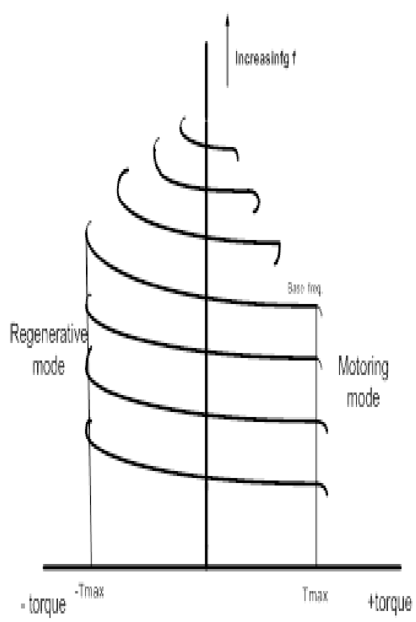

Fig.3 (a). Speed Torque Characteristics of Induction Motor with frequency variation

The above curve suggests that the speed control and braking operation are available from nearly zero speed to above synchronous speed.

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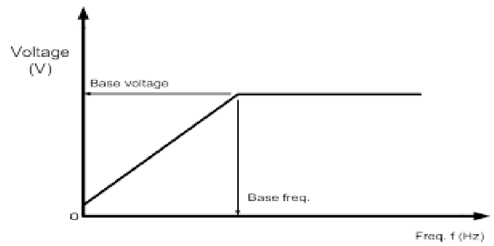

Fig.3 (b).voltage and frequency variation in VSI fed Induction motor

In Fig.3 (b) it is noted that V is kept constant above base speed and freq. is increasing. The variable frequency control provides good running and transient performance because of the following features:

(a) Speed control and braking operation are possible from zero to above base speed.

(b) During transients (starting, braking and speed reversal), the operation can be carried out at the maximum torque with reduced current giving good dynamic response.

© Copper losses are reduced, efficiency and power factor are high as the operation is in between synch. Speed and max. torque point at all frequencies.

(d) Drop in speed from no load to full load is small.

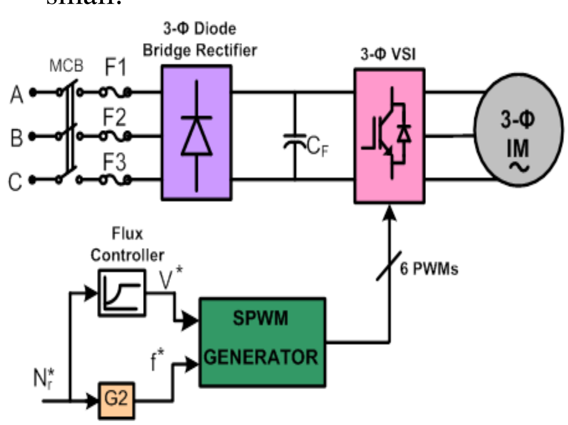

Fig:3 ©. Block Diagram Schematic of V/f control of VSI fed 3-phase Induction Motor drive

Fig.3.1 © shows the block diagram of a V/f control of VSI fed three phase induction motor drive. In this according to the reference speed input command (N_r^*) the reference frequency (f^*) and reference voltage (V^*) commands are calculated such that V/f ratio maintained to be constant. The reference commands V^* and f^* are given to the SPWM generator to generate 6-PWM pulses to the three-phase voltage source inverter which drives the three-phase induction motor.

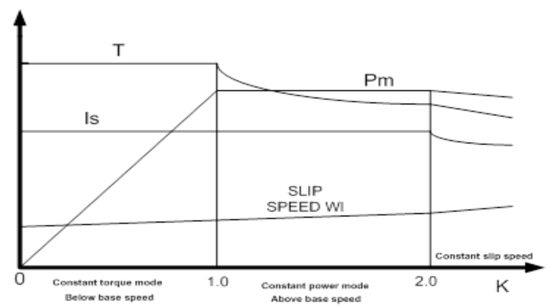

Fig.3 (d). Modes of operation and variation of is, ωsl,, T and Pm with per unit frequency K

5. MATLAB/SIMULINK RESULTS

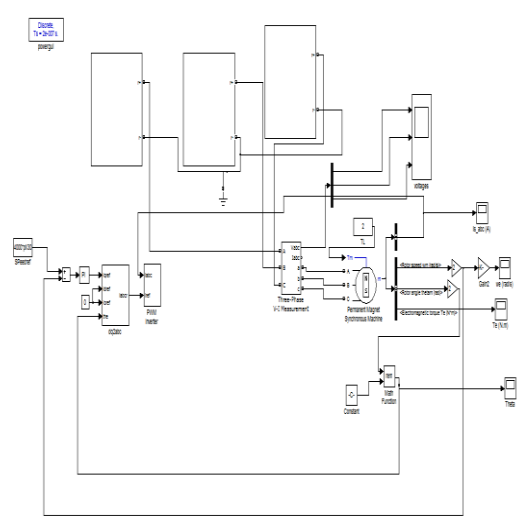

Fig.4 Mat lab/Simulink model of Hysteresis current controlled five level CHB inverter fed PMSM drive

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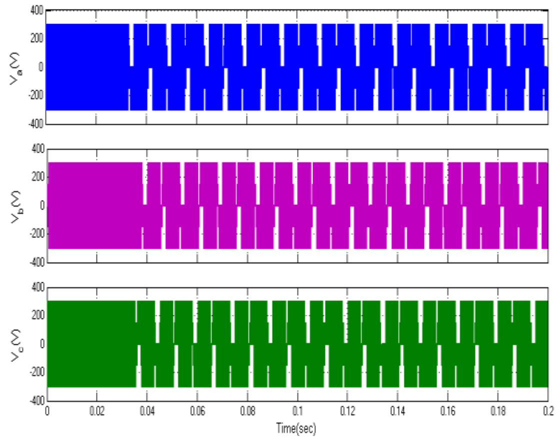

Fig.5 Starting Performance of Hysteresis current controlled five level CHB inverter voltage waveforms

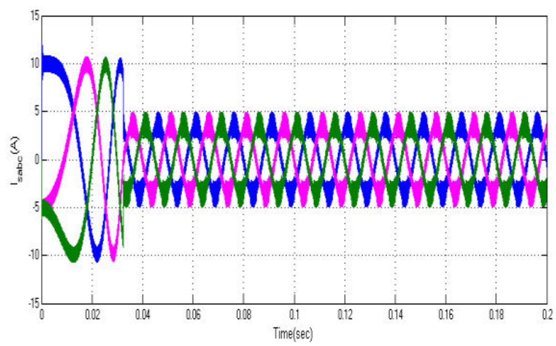

Fig.6 Starting Performance of Hysteresis current controlled five level CHB inverter current wave forms

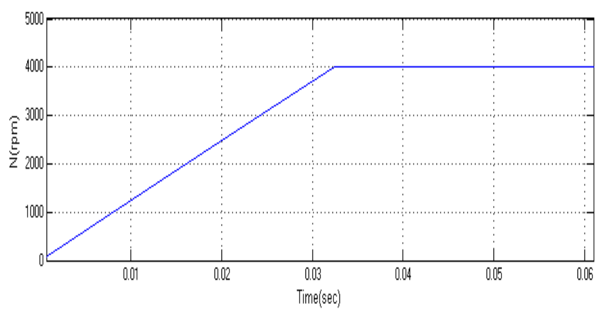

Fig.7 Starting Performance of Hysteresis current controlled five level CHB inverter speed characteristics

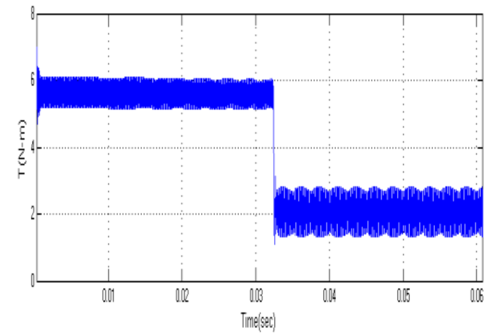

Fig.8 Starting Performance of Hysteresis current controlled five level CHB inverter fed torque characteristics

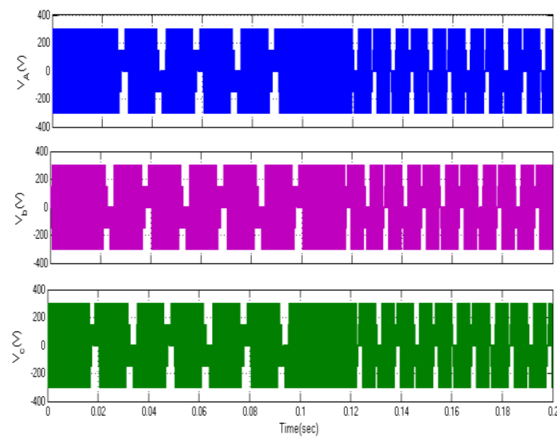

Fig.9 Transient Performance of Hysteresis current controlled five level CHB inverter fed voltage waveforms

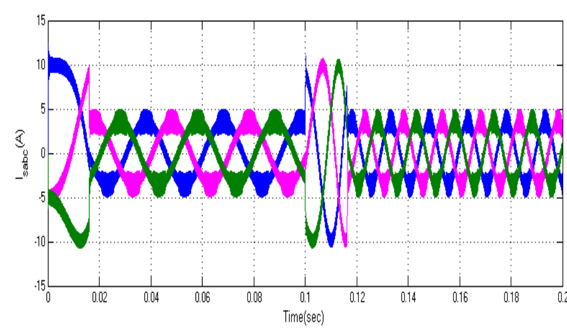

Fig.10 Transient Performance of Hysteresis current controlled five level CHB inverter fed current wave forms

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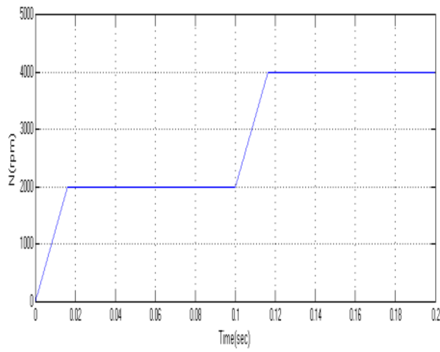

Fig.11 Transient Performance of Hysteresis current controlled five level CHB inverter fed speed characteristics

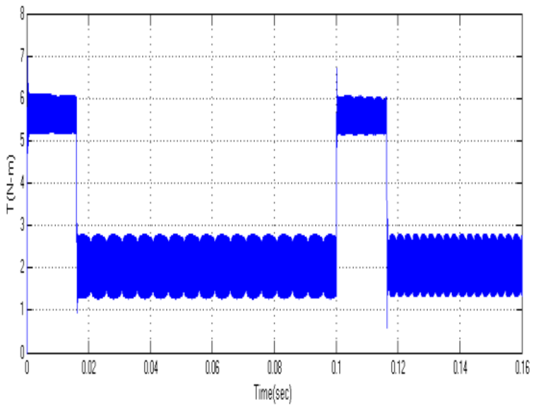

Fig.12 Transient Performance of Hysteresis current controlled five level CHB inverter fed torque characteristics

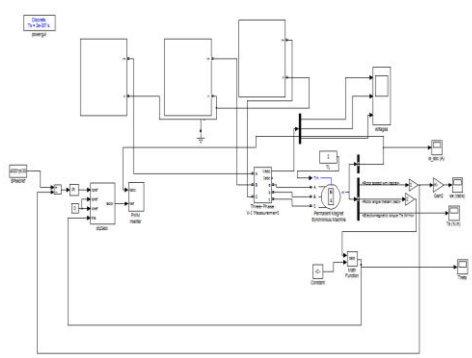

Fig.13 Matlab/simulink model of Hysteresis current controlled Nine level CHB inverter fed PMSM drive

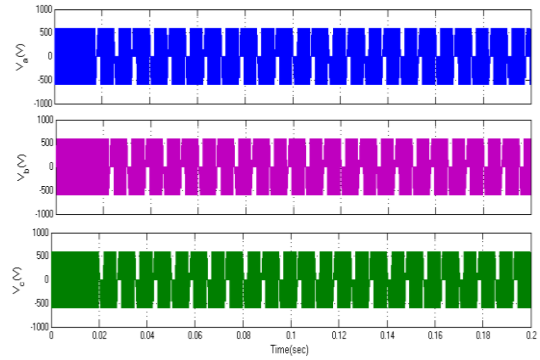

Fig.14 Starting Performance of Hysteresis current controlled Nine level CHB inverter voltage waveforms

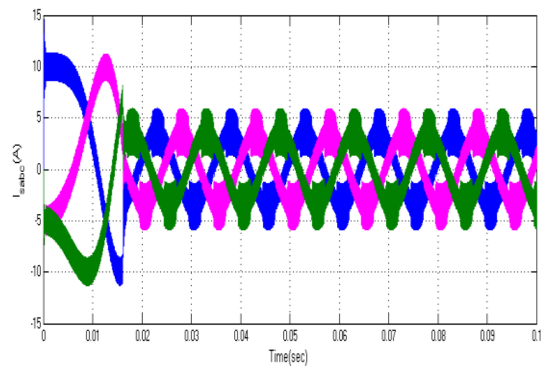

Fig.15 Starting Performance of Hysteresis current controlled Nine level CHB inverter current wave forms

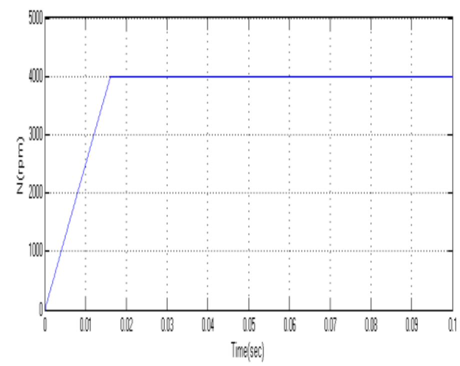

Fig.16 Starting Performance of Hysteresis current controlled Nine level CHB inverter speed characteristics

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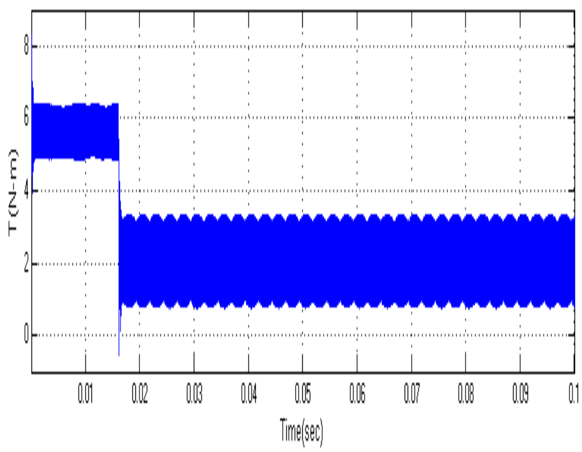

Fig.17 Starting Performance of Hysteresis current controlled Nine level CHB inverter fed torque characteristics

6.CONCLUSION

The modeling and analysis of five level cascaded inverter fed PMSM drive has presented under wide operating conditions. Hysteresis current controllers have a variable switching frequency that depends on the hysteresis band and if the bandwidth is very small it may imply high switching frequency, which affect the device switching capability and increased switching losses. However, the simulation with hysteresis current controller allows faster simulations with reduced time and computational resources. The obtained simulation results of Nine level inverter fed drive shows faster response and the quality of voltage and current waveforms is improved as compare to Five level hysteresis controlled drive.

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