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SPEED CONTROL OF PMS MOTOR USING VECTOR-BASED HYSTERESIS CONTROL TECHNIQUE

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Abstract: This paper deals with the field oriented based on the Hysteresis current controller for permanent magnet synchronous motor (PMSM). Permanent magnet synchronous motor drivers are widely used for high performance applications like robotics, Electric Vehicles and in industries. The vector control of PMSM drives compared to induction motor drives is simple and effective in implementation in high-speed drives. In this paper, the field orientated control of PMSM in use of hysteresis current controller with PI controller to achieve optimized variations due to the effect of direct and quadrature axis of stator currents with the help of Park and Clarke reference frame transformation. This PAPER presents the comparative analysis of various conditions of PMSM drive and performance through simulation using MATLAB/Simulink.

***Index Terms* - PMSM, FOC, vector control, Hysteresis current control, park and Clarke, PI controller.**

I. INTRODUCTION

Now a days the permanent magnet synchronous motors are giving good competition to IM drive due to its high efficiency, high torque to weight ratio. Many schemes have been proposed to motor drives to improve its reliability and performance. There are many advantages of PMSM over other rotating machines which are used for AC servo applications. Typical PMSM systems includes 3 controlling loops (1) Position loop (2) Speed loop (3) Current loop.

In this paper, Simulation work is carried out for speed and current loop system performance. Vector control performance can be improved by the use of robust and dynamic controllers. These controllers can be used for speed, torque and position control of the drive.

Vector control makes it possible to control the AC analogous to DC motor drive. The field-oriented control (FOC) of the PMSM is one widely used control technique to obtain the ripple less and precise operation. The main aim of FOC of PMSM is to control the vector of magnetic flux, current and voltage. In context with this the decoupled control of permanent magnet motor acts like separately excited DC motor, by the main factor of stator currents into flux and torque. The main goal of FOC is to give rapid response and less torque ripples. The only drawback of the Field orientated control is controlling the performance of motor is easily impacted by the disturbance of motor parameters.

The recent development of PMSM is designed such a way that the rotor is completely replaced by high resistive permanent magnet, preferably made up of Neodymium magnets which are also called as hard magnets.

By using Hysteresis current controller high performance vector-controlled drives is required. In order to ensure the bandwidth in the preferred width, the current tracking is required so to shorten the exceeding transient's period and also to force the voltage source to work as a current modifier with in the same loop. To maintain the voltage constant throughout the operation PI controller is adapted to obtain the constant volage irrespective of the load changes.

In this paper Simulation model are developed using MATLAB/Simulink tool for the Speed control of vector-based Hysteresis current controller the performance of the motor is observed for various operating conditions by using reference frame transformations (Park and Clarke).

II. Modelling of PMSM

The PMSM behaviour is usually described by their voltage and current equations. The Co-efficient of the differential equations that describe their behaviour are time varying. The mathematical model of such systems tends to be complex since the current, flux and voltage current changes continuously as the electric circuit is in relative motion.

The implementation of the dynamic model depends on the dynamic model of PMSM. The dynamic model of the drive has transformations of stator currents of 3phase (ia, ib, ic) and two orthogonal components of quadrature and direct axis (id & iq). The equations are carried out using the stator to rotating reference frame transformations.

The necessary decoupled control of torque, speed and flux are achieved through the individual contribution of the component id & iq respectively. The standard transformation's equations of PMSM of 3 phase rotating frame is given below:

$$I_{dq0} = TI_{abc} = \frac{2}{3}\begin{bmatrix} \mathrm{Cos}\,\theta & \mathrm{Cos}\left(\theta - \frac{2\pi}{3}\right) & \mathrm{Cos}\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

The inverse transformation's is given by;

$$I_{abc} = TI_{dq0} = \frac{2}{3}\begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix}\begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix}$$

Hence, the under steady state the id=0 because of the flux supplied by the permanent magnets.

III. Vector Control of PMSM

vector control of PMSM drive is derived from the above dynamic modelling and its 3 phase currents are obtained by;

$$i_a = i_s \sin(w_r t + \delta) \qquad (3)$$

$$i_b = i_s(w_r + \delta - \tfrac{2\pi}{3}) \qquad (4)$$

$$i_c = i_s \sin(w_r + \delta + \tfrac{2\pi}{3}) \qquad (5)$$

Where δ is a torque angle between the rotor field and stator current phasor

The q axis and d axis stator currents in rotor reference frame are given by,

$$\begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos w_r t & \cos\left(w_r t - \frac{2\pi}{3}\right) & \cos\left(w_r t + \frac{2\pi}{3}\right) \\ \sin w_r t & \sin\left(w_r t - \frac{2\pi}{3}\right) & \sin\left(w_r t + \frac{2\pi}{3}\right) \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (6)$$

Substituting equations (3), (4), (5) into equation (6) gives the stator currents in rotor reference frames;

$$\begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix} = i_s \begin{bmatrix} sin\delta \\ cos\delta \end{bmatrix} \quad (7)$$

Since δ is constant for a given load torque, both q and d axis currents in rotor reference frame and they are very similar to the armature and field currents in separately excited DC machine
Substituting equation (7) into the equation;

$$Te = \frac{3}{2}\frac{p}{2}\left[\frac{1}{2}(Ld - Lq)i_s^2 \, sin2\delta + \lambda af \; i_s \, sin\delta\right] \quad (8)$$

For $\delta = \frac{\pi}{2}$

Therefore, $Te = \frac{3}{2}\frac{p}{2}\,\lambda af\, i_s = K_1\, \lambda_{af}\, i_s \;\; N.m$ (9)

Where,

$$k = \frac{3}{2}\frac{p}{2} \quad (10)$$

If δ is maintained at 90 degree and flux is kept constant, stator current magnitude controls the torque. The above torque equation is similar to that of a separately excited DC motor.
For motoring action if δ is positive, the electromagnets torque will also be positive.
The mutual flux linkage is given as,

$$\lambda_m = \sqrt{(\lambda_{af} + L_d i_{d)}{}^2 + (L_q i_q)^2} \;\; (Wb - turns) \quad (10)$$

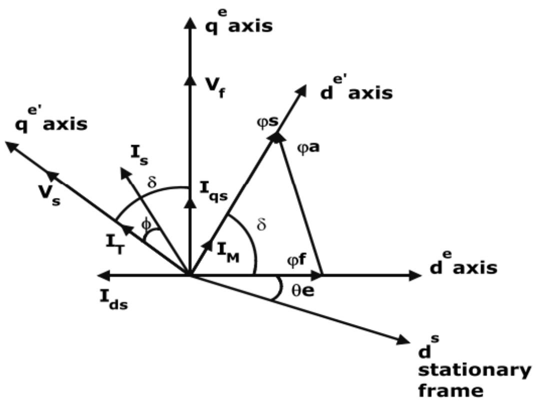

Fig1: Phasor diagram of PMSM

IV. System Configuration And Principle Of Operation

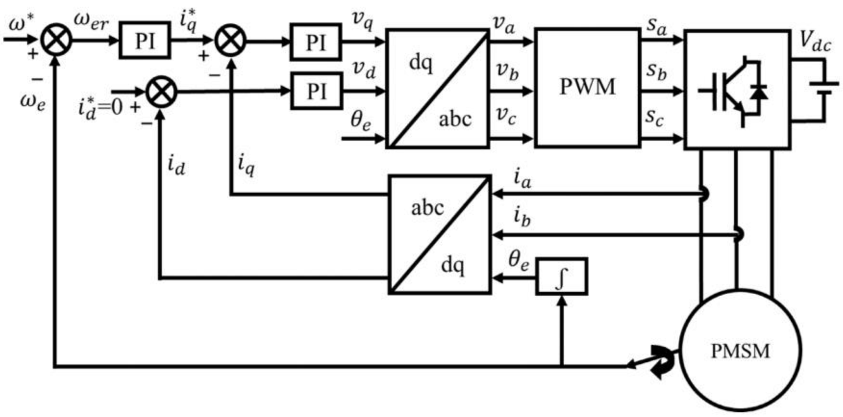

Fig2: Proposed block diagram of inverter fed PMSM speed control feedback loop

The above control feedback block diagram has 6 leg MOSFET inverter fed PMSM motor with speed feedback loop wit PI (proportional integral controller) is arranged to improve the dynamic response.

The hysteresis current controller is proposed in the inner loop of vector control of PMSM drive system in which the hysteresis band is programmed a function of speed of motor during various load conditions. The reference frame transformations using park and Clarke transformation to maintain the direct and quadrature axes from rotatory to stationary elements.

4.1 Hysteresis current controller

The hysteresis is a phenomenon which take reference and actual voltage or current and lags or leads the reference currents and it will force to match the reference point.

Hysteresis current controller is basically an instantaneous feedback current control method where the actual load current control method where the actual load current tracks the reference current within a specified hysteresis band.

The error current is produced by the resultant of actual PMSM current (i_{abc}) with reference current is (i^*_{abc}) of desired magnitude and frequency. The error current is fed to hysteresis controllers of tolerance band.

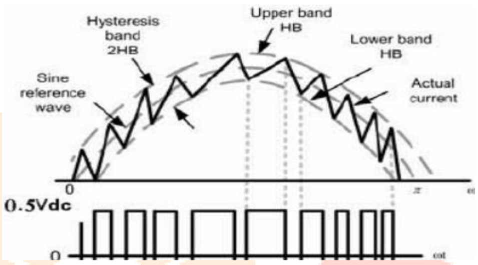

Fig3: Hysteresis band

4.2 PI Controller

PI controller is a conventional type of control technique that finds its application in various industrial application on control process. It consists of proportional controller is a type of controller in which signal shows proportionality with error signal.

$$m(t) \propto e(t) \quad m(t)\text{=kp e(t)}$$

Integral controller isa a controller where the output is proportional t the integral of the error signal. Proportional gain that is responsible for acceleration of control action and reduction of steady state error. The output and input relationship of PI speed controller is described as;

$$e_o = kp(e) + ki \int edt$$

4.3 Speed Feedback Loop

The output signal from speed feedback loop is compared with the actual speed of the rotor which is sensed by the speed sensor.it generates the error signal that is conditioned with a PI controller for significant correction to reduce the error in the input. PI controller technique is chosen to combine with hysteresis current control to overcome drawback of classical hysteresis current controller.

4.4 Motor Control Loop

To sum up the Block diagram show in Fig 2 the speed feedback loop is the most important feedback loop which generates a speed signal for the VSI to control the commutation of PMSM drive. The hysteresis current controller is used to limit the current is bounded to specified band and generates PWM pulses. Thus, it is fed to the 3 phases inverter which PMSM is maintained in to rotating frame. The PI helps to improve dynamic response of the motor by maintaining the constant voltage and current for high performance of the drive.

V. SIMULATION AND RESULT

Speed control of PMS motor with hysteresis current control is simulated using MATLAB/Simulink and the performance of the PMSM is observed and compared with the performance of the Induction motor [1]. For simulation study a 3 phase 10KW, 1500 rpm surface mounted PMSM with the ratings mentioned in the table.1. has been used

I. Table. PMSM PARAMETERS

Rated power	P	10Kw
Rated Voltage	V	415V
Rated Torque	T	3.182N-m
Rated Current	I	14A
Rated Speed	N	1500rpm
No. of Poles	P	2
Stator Resistance	Rs	0.944Ω
Stator Inductance	Sl	1.67mH
Armature Inductance	Ia	10*10^-3
Motor inertia	J	5.5e-3 Kg.m
PM Flux Linkage	$\lambda_a f$	0.185Wb
q-axis inductance	Lq	0.085 H
d-axis inductance	Ld	0.085 H

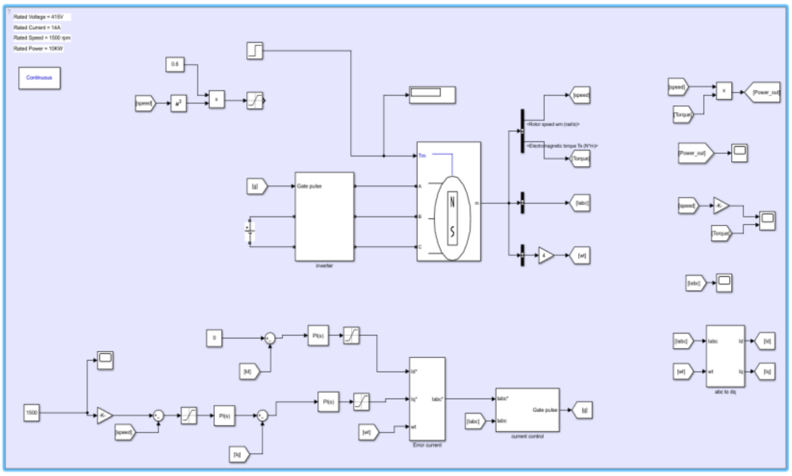

FIG4: SCHEMATIC SIMULATION DIAGRAM OF PROPOSED SPEED CONTROL OF PMSM

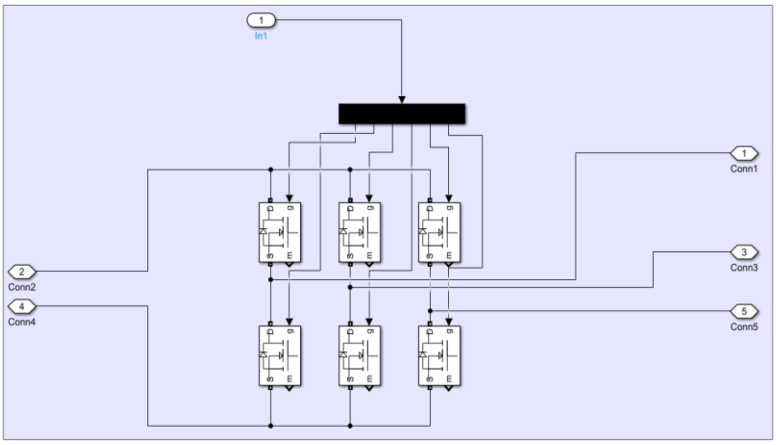

FIG 5: SIMULATION DIAGRAM OF 6 LEG MOSFET INVERTER

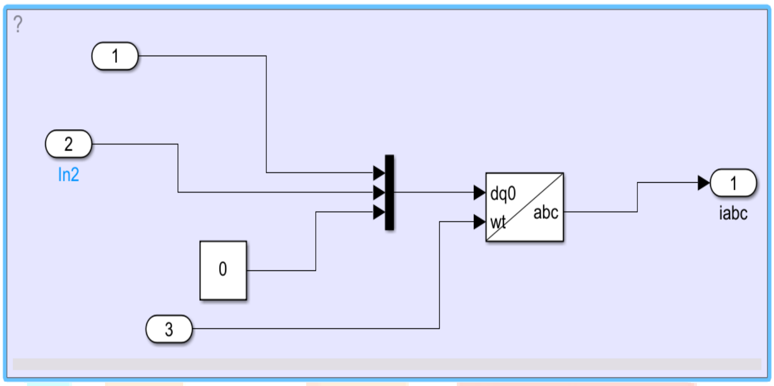

FIG 6: SIMULATION OF ERROR CURRENT

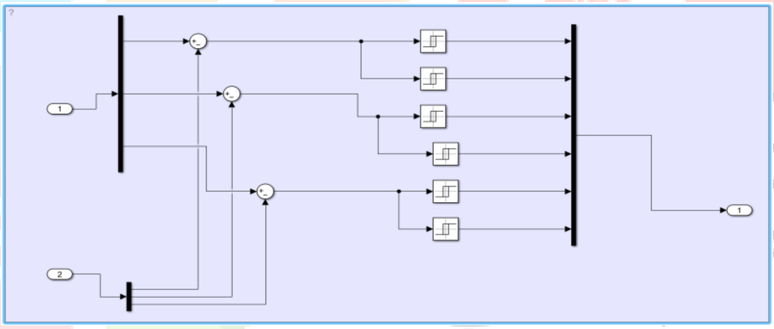

FIG 7: SIMULATION OF HYSTERESIS CURRENT CONTROL

VI. RESULTS

A. During No Load condition

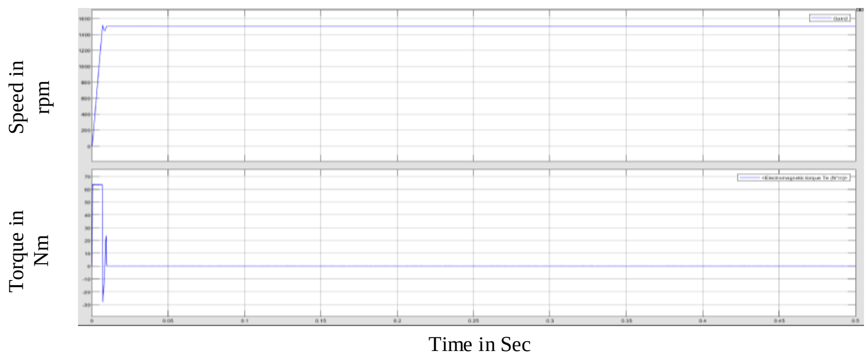

Fig 8: Speed and torque curves under no load of PMSM

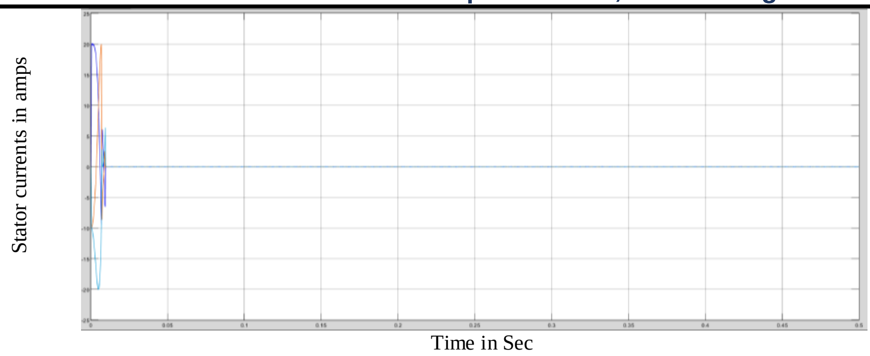

Fig 8.1: Stator currents under no load condition of PMSM

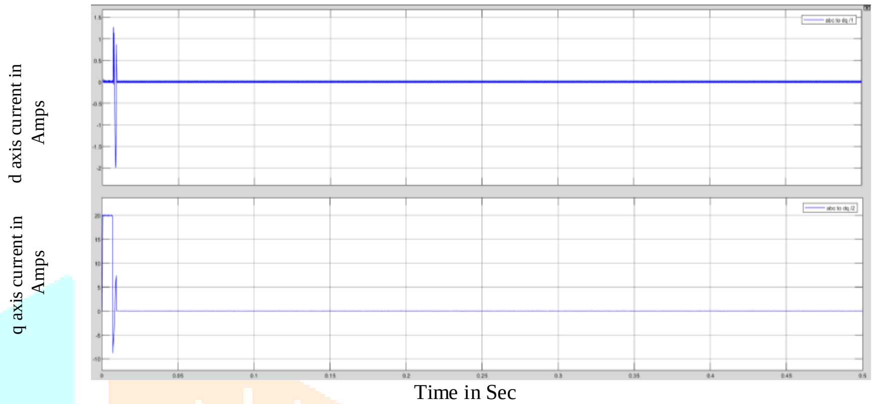

Fig 8.2: Current in I-d axis under no load condition of PMSM

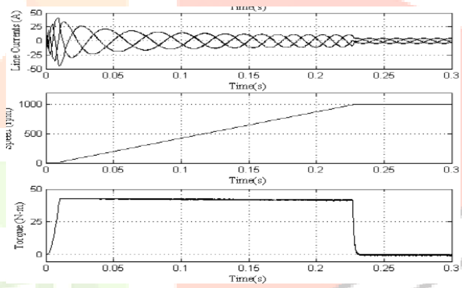

Fig 8(a): Stator current, speed and torque of IM under no load condition [1]

During no load conditions the motor is operating can be seen that at t=0.02 sec the speed is attained its maximum speed as shown in fig (8) and also torque also settles at t=0.02 sec from transient state. While in IM the time taken is more to reach the rated speed as in the fig:8(a), it can be clearly seen that the PMSM drive as fast acceleration and settling time that of IM behavior.

B. During Load conditions

During loaded conditions as show in fig 9, when motor attains its rated speed, it is observed that speed doesn't change due to change in load and due to effect of PI controller it is maintained constant and ripple less torque curve is also seen in fig:(9).
At t=0.3 a load of 50N-m is applied, due to sudden load changes the stator currents gradually increases as in the fig (9.1) with respect to change in quadrature axis currents is also proportional to the load torque. As shown in fig: (9.2).

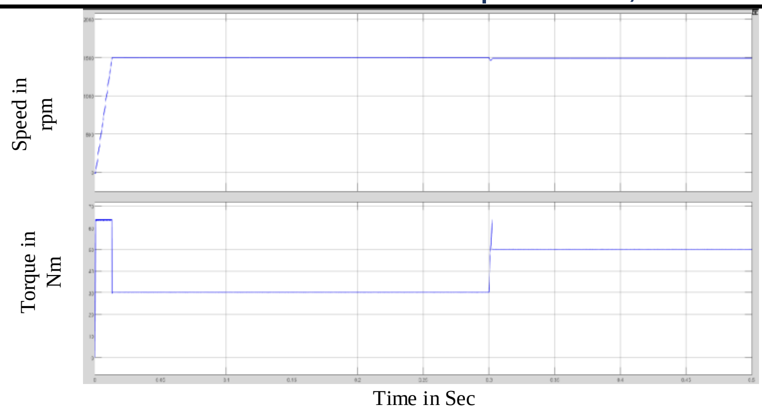

Fig9: Speed and torque curves under load condition of PMSM

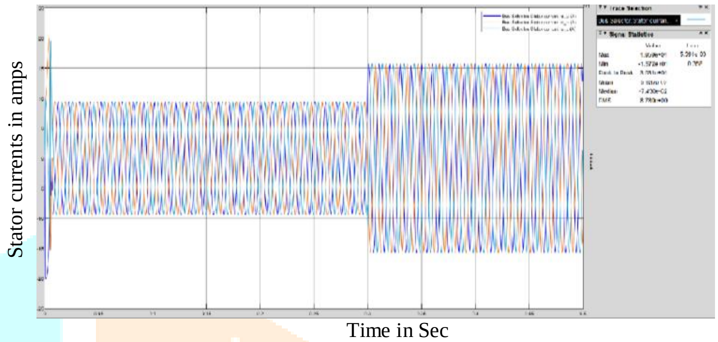

Fig 9.1: Stator currents under load condition of PMSM

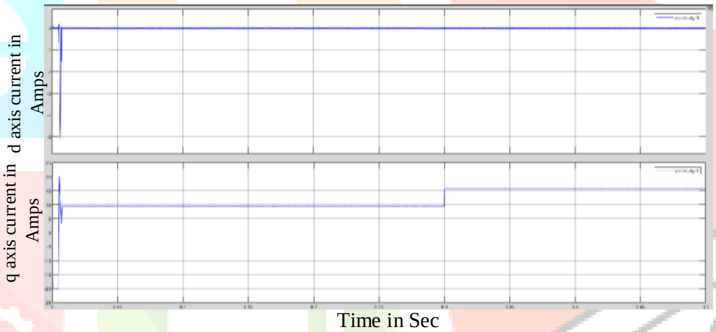

Fig 9.2: Current in I-d axis under load condition of PMSM

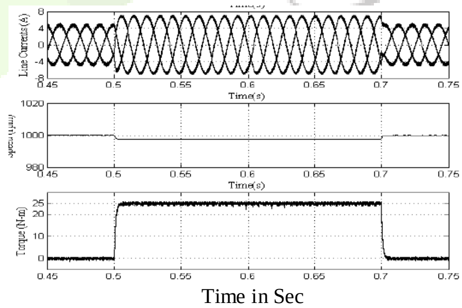

Fig9(a): Stator current, speed and torque of IM under loaded condition [1]

C. During Speed Reversal

During speed reversal motor closely follows the reference speed of -1500rpm as in fig (10) speed curve response with negative reference speed a load of 50N-m is applied during speed reversal under this the stator currents doesn't change with respect to the Id & Iq axis as in fig: (10.1) and (10.2).

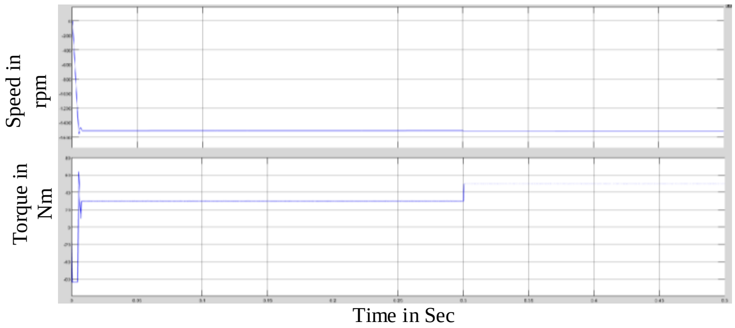

Fig10: Speed and torque curves under speed reversal of PMSM

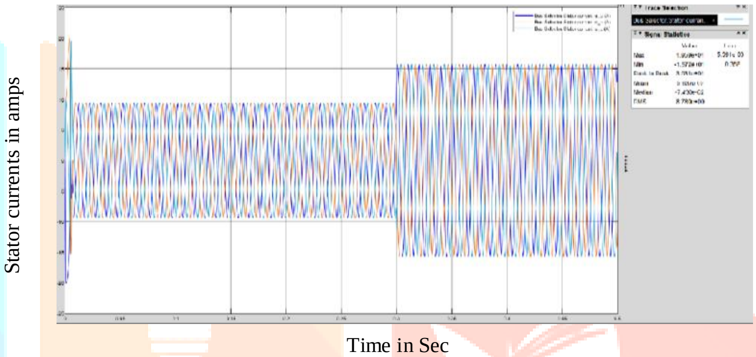

Fig 10.1: Stator currents under speed reversal condition of PMSM

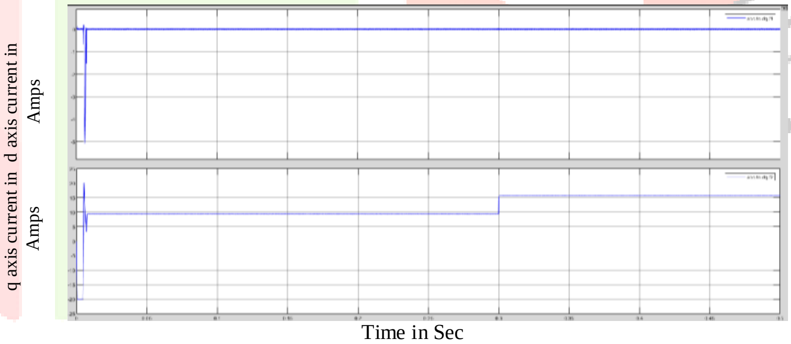

Fig 10.2: Current in I-d axis under speed reversal condition of PMSM

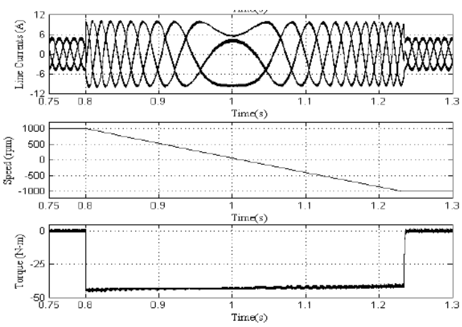

Fig 10(a): Stator current, speed and torque of IM under speed reversal [1]

VII. CONCLUSION

In comparison of IM performance with PMSM is made and studied. It is observed that PMSM with vector control gives fast response of speed and current. Simulation and analysis of a vector controlled PMSM motor has presented. The simulation is designed for field-oriented control of PMSM drive with hysteresis controller. The performance of the drive is analysed under different operating conditions such as no-load condition, step change in load, step change in speed and speed reversal condition is observed and compared with the results of IM performance. The result obtained from the model using hysteresis current controller justifies with the robust and dynamic performance of PMSM drive under various conditions is better.

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