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Sensorless Field Oriented Control Of Permanent Magnet Synchronous Motor Using Robust Hysterisis Current Controller With Rotor Position Tracking Pi Controller

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Abstract: *This paper describes a sensorless field oriented control of permanent magnet synchronous motor (PMSM) using rotor position tracking proportional-integral (PI) controller. With the advent of vector control methods, Permanent magnet synchronous motor (PMSM) can be operated like separately excited dc motor for high performance application. This technique can be applied to low and high speed operations. In this method a loop recovery technique is applied, to boost the bandwidth of PI controller.. The design, analysis, simulation of sensorless method is done using MATLAB R2011a.*
Keywords: *About Permanent magnet synchronous motor (PMSM) drive, proportional-integral (PI) controller, hysteresis PWM controller*

I. Introduction

The first generation back EMF method is proposed to eliminate the Hall Effect sensors. For the method of determining the zero-crossing point of back-EMF via terminal voltages, filter is required to remove the high switching frequency noise [1].The high frequency signal injection is needed for this controlling action which is very difficult in practical applications. Recently a new technology is developed which will eliminate the drawbacks of back EMF method. Normally the controlling of the torque of PMSM usually follows either the most popular Direct Torque Control (DTC) or Field Oriented Control (FOC). In this paper the field oriented control based sensorless method is used. This control is mainly done using rotor position tracking proportional – integral controller (PI) with low frequency signal injection. It can be applied to low and high speed operations. In the existing method the PWM inverter control method is used which is having lot of distortion in the output waveforms. The drawback of PWM inverter can be replaced by hysteresis current controller where the motor current iabc* and the vector transformed currents iabc can be taken as input. This hysteresis current controller gives better efficiency, accuracy and easy control compared to PWM controllers. The main advantage of this system is the simple control algorithm, wide speed range possible without shaft sensor, unity power factor control is possible, increased system efficiency, good speed regulation, reduced rating of switching device, wide range of speed control is possible, low noise [2]. A permanent magnet synchronous motor (PMSM) is a motor that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets [7]. These motors have significant advantages, attracting the interest of researchers and industry for use in many applications [4]-[8]. Permanent magnet synchronous motor has advantages like higher efficiency, high power density and high power factor.

This approach is based on d-axis synchronous current regulator output voltage, which includes the information of rotor position error. A loop recovery technique is applied to the control system. The proposed sensorless control algorithm can accurately determine the speed control and angular position control using mainly sensorless rotor position tracking PI controller. This paper is organized as follows Section II provides the existing control system,. Section III gives the proposed sensorless control algorithm. Section IV shows the analysis of sensorless control algorithm using PI controller. Section V gives the results and discussion of MATLAB SIMULINK simulation waveforms. Section VI gives the conclusion of proposed the system, Section VII gives the Appendix of the proposed system.

The existing system uses PWM inverter technique for the controlling action. The main drawback of this system is that it is not an accurate and efficient one and also the controlling action is very tedious [3].The basic principle of vector control is to get performance system through controlling flux and torque independently after getting the motor decoupling model through coordinate transformation. Here the vector transformations and their inverse transformations were applied in order to get the exact controlling action.

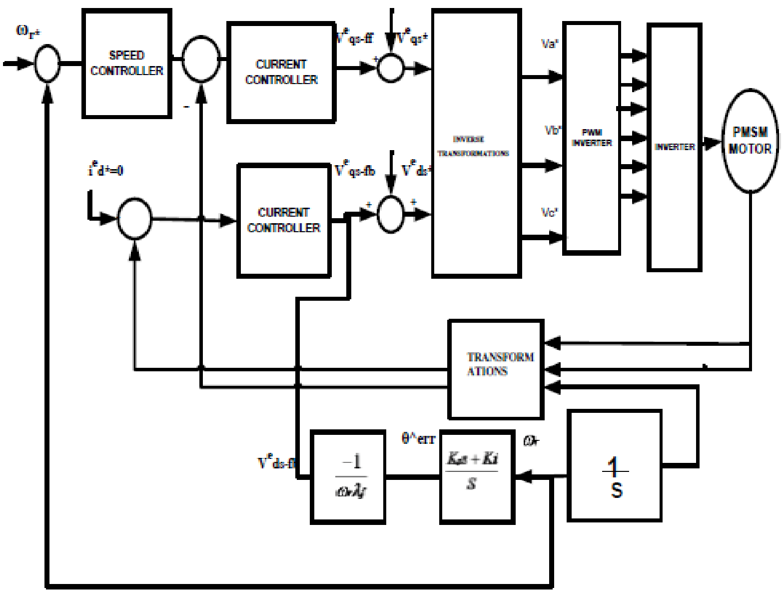

Fig.1 Overall block diagram of existing sensorless control system

A.VECTOR TRANSFORMATIONS

The transformations mainly include Park and Clarke transformations and also their inverse transformations.

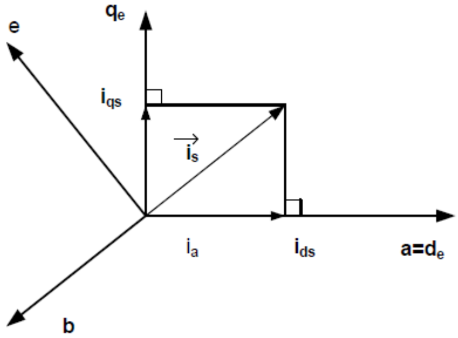

Fig.2 Clarke vector transformations.

$$i_{ds} = i_a \qquad (1)$$

$$i_{qs} = \frac{1}{\sqrt{3}} i_a + \frac{2}{\sqrt{3}} i_b \qquad (2)$$

Inverse Clarke transformation transforms from a 2-phase (α, β) to a 3-phase (isa, isb, isc) system.

$$i_{sa} = i_{s\alpha} \qquad (3)$$

$$i_{sb} = -\frac{1}{2} i_{s\alpha} + \frac{\sqrt{3}}{2} i_{s\beta} \qquad (4)$$

$$i_{sc} = -\frac{1}{2} i_{s\alpha} - \frac{\sqrt{3}}{2} i_{s\beta} \qquad (5)$$

Id-Direct axis current component
Iq-Quadrature axis current component
ia-a phase component of current
ib-b phase component of current
ic-c phase component of current

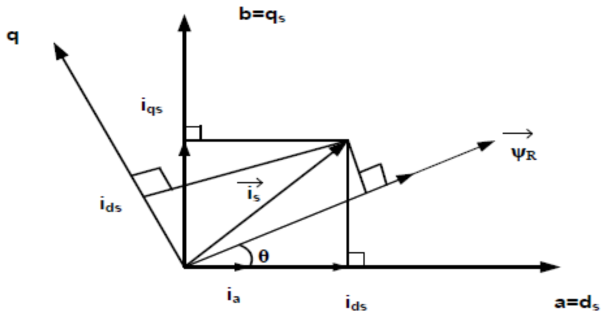

Fig.3 Park transformations

$$i^*_{ds} = i_{ds}\cos\theta + i_{qs}\sin\theta \quad (6)$$

$$i^*_{qs} = -i_{ds}\sin\theta + i_{qs}\cos\theta \quad (7)$$

II. Proposed Sensorless Control

ALGORITHM

Here the reference speed and the estimated speed obtained from the sensorless estimator is compared and given to a speed controller. The output of the controller is the reference quadrature axis current which is compared with actual component obtained from the transformations and is given to a current controller. The output is given to inverse transformations.

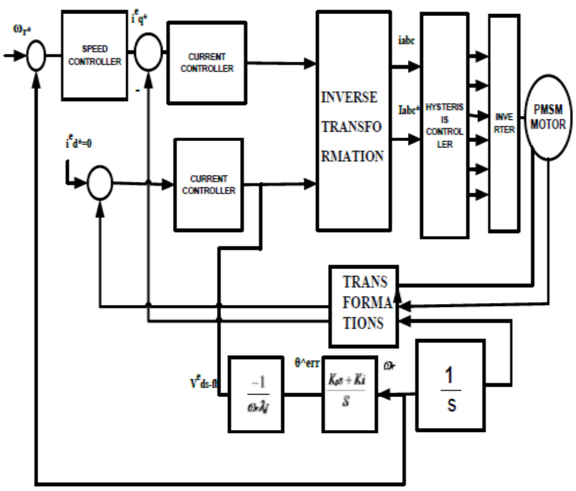

Fig.4 Proposed sensorless system block diagram

III. Analysis Of Sensorless Control

ALGORITHM USING PI CONTROLLER

The information of rotor position error can be extracted from the angular position as

$$\theta_{err} = \frac{V_{ds-fb}}{\omega\lambda_f} \quad (8)$$

θerr – Rotor angular Position error

ω - Estimated electrical rotor velocity

f- Flux linkage of the permanent magnet

Vds- Direct axis component of voltage.

Position error can be controlled to zero by the rotor position tracking PI controller. Thus, an initial starting may fail at standstill, and this control scheme is only available in the high-speed region To overcome these unwanted starting fails at zero and low speed.[8] It is desirable that the position error can be limited using constant as

$$\theta_{err} = \frac{V_{ds-fb}}{k\lambda_f} \qquad (9)$$

K-constant

λ-Flux constant

$Kp=\omega g\sqrt{(\tan\emptyset m)2/1+\tan\emptyset m2)}$ (10)

$Ki=\omega g2\sqrt{1/1+(\tan\emptyset m2)}$ (11)

Kp-propotional constant.

Ki-integral constant.

B. PRINCIPLE OF HYSTERISIS CURRENT CONTROLLER

In hysteresis current control, three independent controllers, one for each phase are employed three reference instantaneous current values for the A, B and C phases are generated based on the commanded torque and the actual rotor position. The actual phase currents of the motor are compared with the reference currents ia*,ib*,ic* using three independent comparators. The logic states of the 6 inverter switches are defined depending on the result of the comparison. When the phase current is smaller than (i*-h/2), where h is the hysteresis bandwidth, the output of the comparator becomes 1 and the related phase is connected to higher than (i*+h/2), the output of the comparator becomes 0 and the related phase is connected to the negative rail of the dc bus. Thus the actual motor phase currents are made to track the desired reference within a close band.

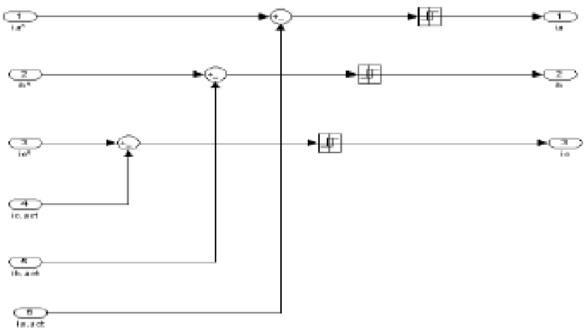

Fig.5 Hysteresis current control method

Fig.5 shows the block diagram for hysteresis controller in order to produce the output signal. The actual phase currents(ia,ib,ic) are compared with reference phase current (ia * ,ib * ,ic *).Using three independent comparator in hysteresis controller. The logic condition for six inverter switches is chosen by the output of the comparator. When the phase “a” current is smaller than(i*-i), the output of the comparator is“1” the “a” phase will be connected with the positive track of DC link. In contrast, if the phase “a” current is bigger than (i*-i),,the output of the comparator will become “0”, and the “a” phase will connected to the Negative track of DC bus. A similar procedure exists in other legs. The main advantage of hysteresis PWM controller include simplicity, excellent dynamic performance, speed regulation in no load and various load conditions.

A.PI CONTROLLER TUNING

An electrical drive based on the Field Orientated Control needs two constants as control parameters: the torque component reference Iqref and the flux component reference Idref. The classic numerical PI (Proportional and Integral) controller is well suited to regulating the torque and flux feedback to the desired values as it is able to reach constant references, by correctly setting both the P term (Kpi) and the I term (Ki) which are respectively responsible for the error sensibility and for the steady state error. In Ziegler Nichols tuning method the desirable phase margin isgiven by 30 o ‹Øm‹60o.The numerical expression of the PI regulator is as follows:

$$U_k = K_{PI} e_k + K_I e_k + \sum_{n=0}^{k-1} e_n \qquad (12)$$

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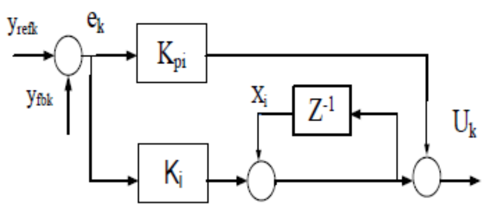

Fig.7 PI controller block diagram

IV. Results And Discussion

The simulation results of actual angular position and estimated angular position without sensor is compared.

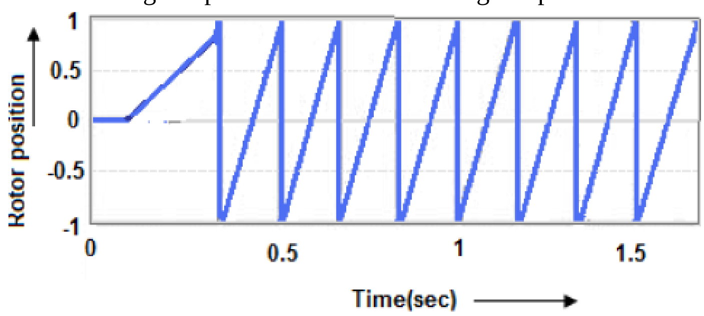

Fig.8 Actual rotor angular position for 300 rpm set speed using PWM VSI control

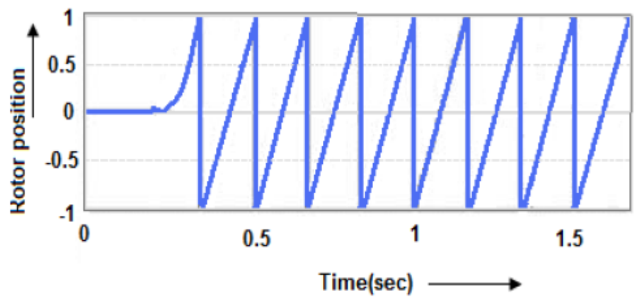

Fig.9 Estimated angular position for 300 rpm set speed using PWM VSI control

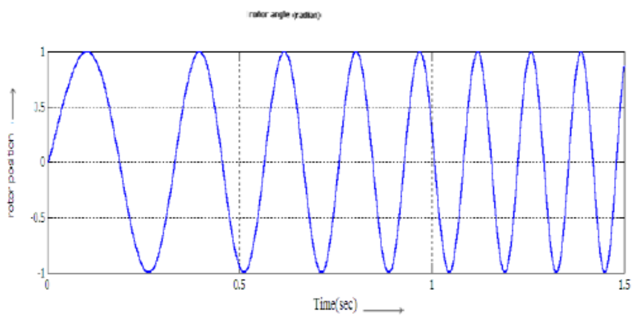

Fig.10. Actual rotor angular position for 300rpm set speed using hysterisis current controller.

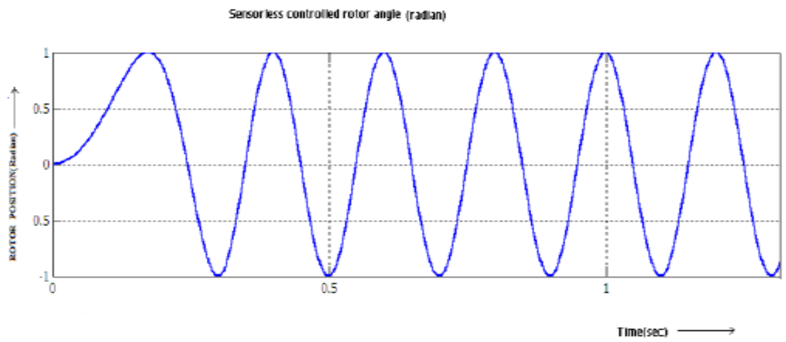

Fig.11 Estimated rotor angular position for 300 rpm set speed using hysteresis current controller.

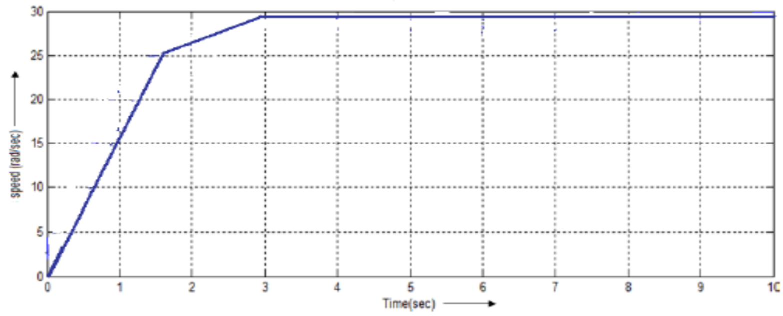

Fig.12 Actual rotor angular position for 300 rpm set speed using PWM VSI control

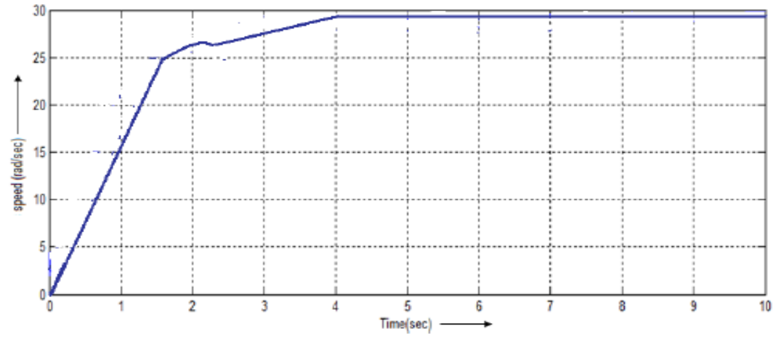

Fig.13 Estimated rotor angular position for 300 rpm set speed using PWM VSI control

From the fig.8, fig.9.fig.10, fig.11it is inferred that rotor angle estimated without sensor is tracking almost the actual rotor angle both in PWM VSI inverter and Hysteresis current controllers. By proper tuning of the sensorless controlled PI controller mainly Ziegler-Nichols tuning the speed waveforms are obtained as shown. The comparative result of rotor speed of PMSM motor with sensors and without sensors was performed using MATLAB versionR 2011b.

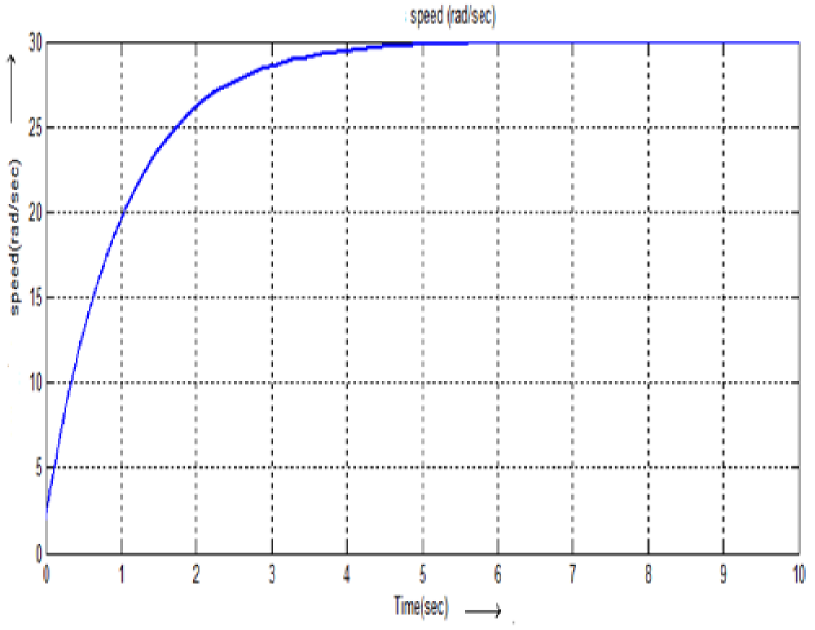

Fig.14 Actual rotor speed of PMSM for low speed operation(300rpm set speed)

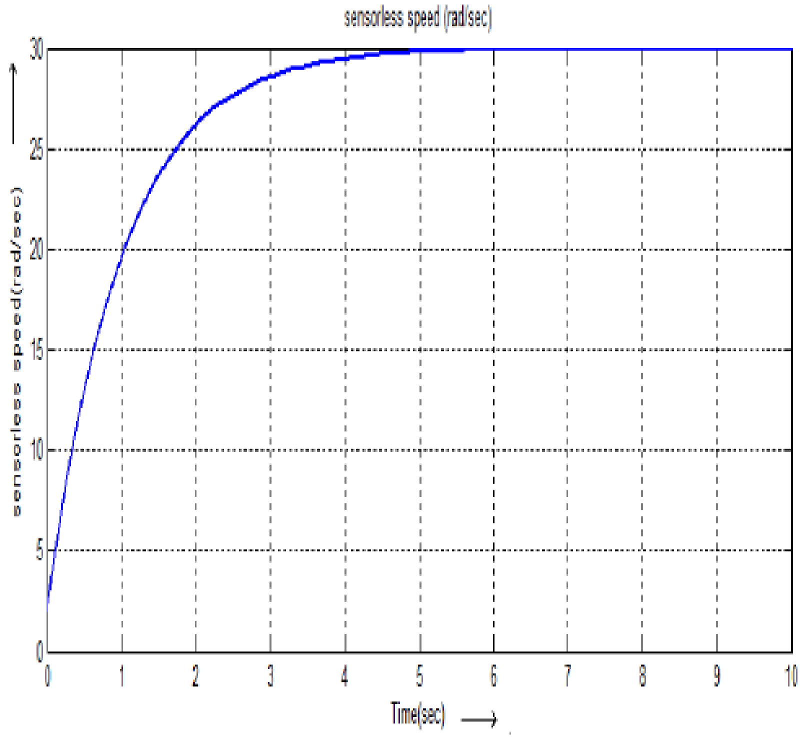

Fig.15 Estimated rotor speed of PMSM for low speed operation (300 rpm set speed).

It is clear that the speed and rotor position can be controlled using rotor position tracking PI controller. More over that this control is very accurate and having high dynamic performance.

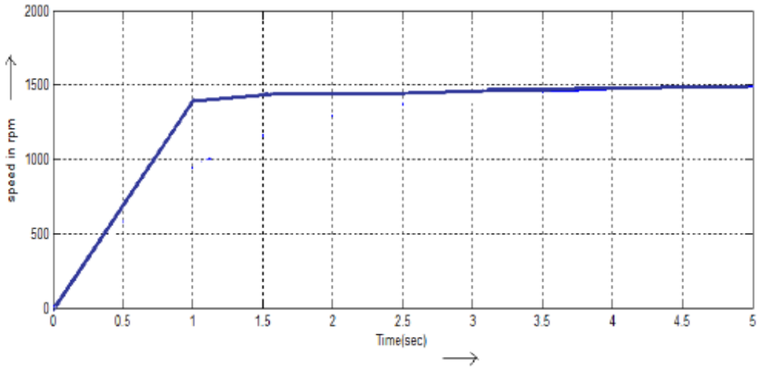

Fig.16 Actual rotor speed of PMSM for high speed operation (1500 rpm set speed) using PWM VSI control.

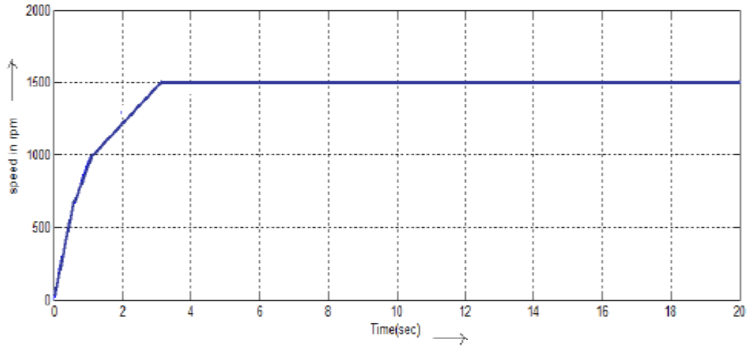

Fig.17 Estimated rotor speed of PMSM for high speed operation (1500 rpm set speed) using PWM VSI control.

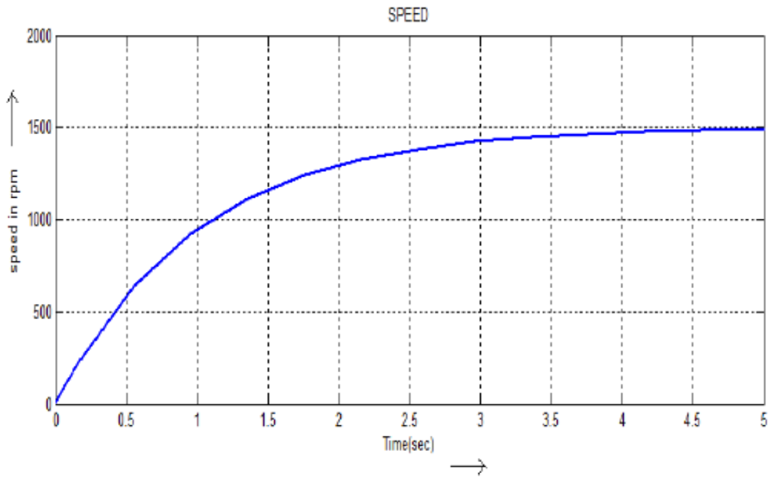

Fig.18 Actual rotor speed of PMSM for high speed operations (1500 rpm set speed) using hysteresis current control.

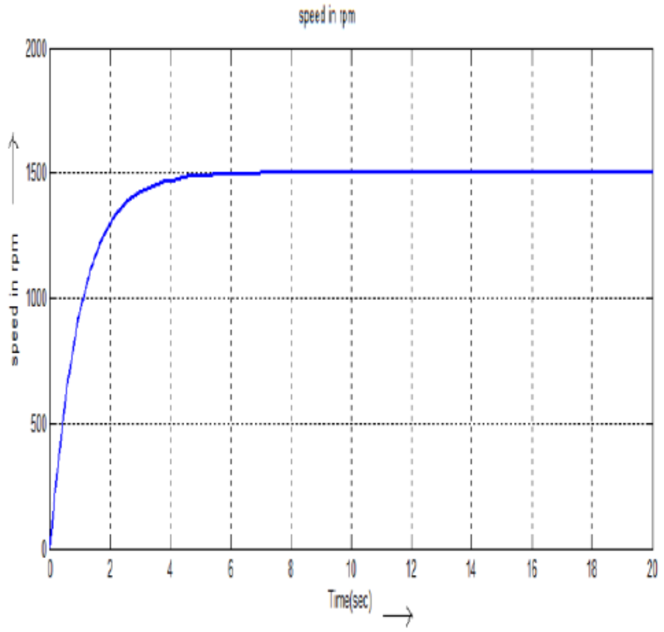

Fig.19 Estimated rotor speed of PMSM for high speed operations (1500 rpm set speed) using hysteresis current control.

It is inferred from the figures that the speed control using PWM VSI inverter From these results of angular position and speed we are getting the inference that the speed and angular position can be controlled using Sensorless methods and the best system among sensorless estimators of rotor position tracking PI controller in PMSM machines. By the proper tuning of PI controller the sensorless waveform follows the sensored one both in high and low speed. For high speed waveform the graph will settle at 1500 rpm at 4 sec where as in the sensorless control the graph took 5 sec to reach steady state value.

The dynamic load variations can also be plotted to get the accurate performance of the system. It will shows the variation of torque component for various external parameters so that the actual performance can be evaluated more precisely.Fig.20 shows the dynamic load variations with respect to time.

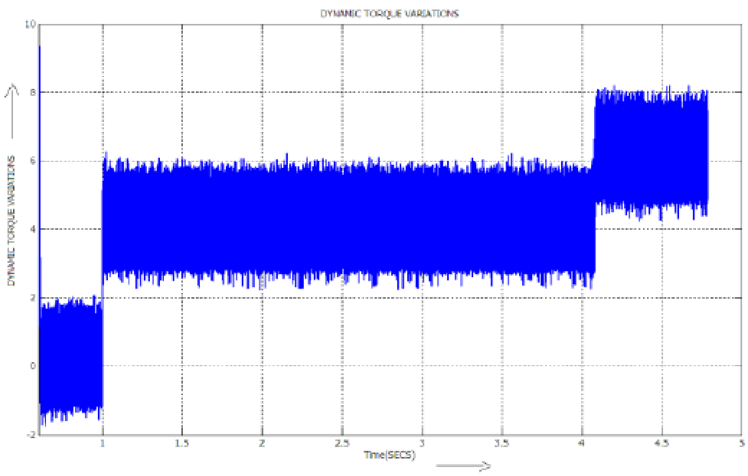

Fig.20 Dynamic load variations versus time

The variations of torque value for different time period is plotted. Here from 0 to 1 second the torque value settled at 2Nm and then from 1second to 4 second the torque value become 6Nm and also from 4 second to 5 second the rated torque was obtained .From this figure it can be inferred that for different load conditions the system works properly without considering whether it is no load or full load.

V. Conclusion

Sensorless control of PMSM motor drive using rotor position tracking PI controller have been simulated using MATLAB and the results have been presented. In this paper the speed and rotor position is simulated using PWM VSI control and hysteresis current control and compared. From the waveforms it is inferred that the hysteresis controller output waveforms give better performance. The simulated results have shown that the speed and rotor position of PMSM motor can be controlled without sensors and the values are remain the same as that with sensors . The results obtained from Sensorless speed control of PMSM demonstrate that the system is less cost compared to sensored control and also good dynamic performance is obtained. In this system it is easy to determine the possible operating range with a desired bandwidth and perform the vector control even at low speed. Obtained results confirm the effectiveness of the proposed scheme under heavy load conditions. In this proposed method only speed and angular positi n of PMSM motor controlled without sensors and using only rotor position tracking PI controller. In future implementation of other well tuning of PI can result in much better performance in this sensorless control area since they are cost effective and also having good dynamic performance.

VII.APPENDIX

MOTOR PARAMETERS

Type of motor PMSM
Rated power 2 HP
Number of phases 3
Number of poles 4
Rated current 10A
Rated voltage 300V
Rated speed 1500rpm
Stator resistance .9585 ohm
q-axis inductance(Lq) 0.00525 H
d-axis inductance (Ld) 0.00525 H
Stator flux linkages per phase due to rotor magnet (Af) 0. 1827V/ (rad/s)
Moment of inertia (J) 0.0006329Kg/m^2
Friction Factor (F) 0.0003035(N.m.s)

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