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Predictive Direct Torque Control Technique for Surface Mounted Permanent Magnet Synchronous Machine

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Abstract : This paper is to present the complete modeling and simulation of Predictive Direct Torque Control technique for Surface Mounted Permanent Magnetic Synchronous Motor to have good dynamic response. A sensor-less strategy is presented here to make system stable mechanically. The upcoming requirement in torque is predicted in advance. This is control scheme helps in digital implementation. A predictive DTC algorithm calculates the switching instants of two optimum active voltage space phasors (AVSPs) that build torque demand one step in advance. After that, the trajectory of the stator flux is predicted for the two preselected AVSPs and the AVSP that leads to the best trajectory of the stator flux at the end of the cycle will be applied to the machine at the next control cycle. With this control scheme is possible to obtain similar dynamic performance as with the conventional DTC scheme, with the advantages of inherently constant switching frequency and equidistant control sampling times for easy digital implementation. As an enhancement of this predictive DTC an encoderless strategy is proposed here. The rotor position is predicted through the future value of the stator flux which is estimated by using the measured stator currents and reconstructed stator voltages. Then, the estimated rotor position is processed by means of a Quadrature Phase-Locked Loop observer, so that, easy digital implementation and stable operation can be achieved. Simulated results confirm the theoretical work..

***IndexTerms* - Active voltage space phasor, Brushless Direct current, Digital quadrature phase-locked loop, Flux hysteresis width.**

I. INTRODUCTION

A controlling technique namely Predictive Direct Torque Control has been analyzed to get better results rather than conventional DTC when PM synchronous drive under consideration to get following objectives low torque ripple, constant switching frequency and digital implementation. The voltage and current from the motor measure the actual torque and feds to the Predictive Model where the switching instant of two favorable active voltage space phasor (AVSP) are selected with the help of torque criteria. The best AVSP is selected is selected using Flux control and applied to the machine through inverter. Thus torque and flux are controlled.

A permanent magnet synchronous motor (PMSM) is a motor that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets. These motors have significant advantages, attracting the interest of researchers and industry for use in many applications. The traction motors for railway vehicles must be robust ,compact, and lightweight .PMSMs which inherently feature high efficiency, compactness, and, are ideal for railway vehicles and essential for the times when energy saving ad environmental preservation are all important social problems.[1]

II. MODELING OF THE PMSM

Detailed modeling of PM motor drive system is required for proper simulation of the system. The d-q model has been developed on rotor reference frame as shown in fig 1. At any time t, the rotating rotor d-axis makes and angle θr with the fixed stator phase axis and rotating stator mmf makes an angle α with the rotor d-axis. Stator mmf rotates at the same speed as that of the rotor.

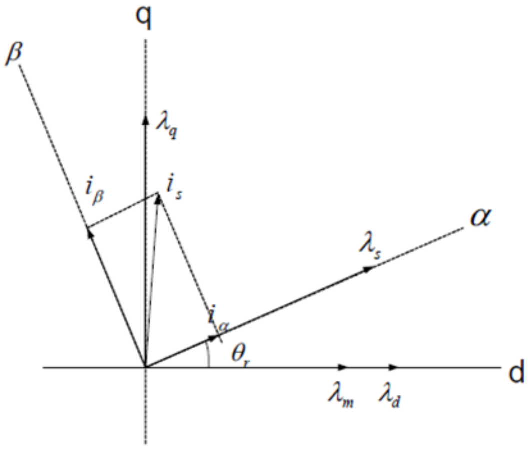

Fig 1: Vector Diagram of different reference frame

The model of PMSM without damper winding has been developed on rotor reference frame using the following assumptions: Saturation is neglected, the induced EMF is sinusoidal, eddy currents and hysteresis losses are negligible and there are no field current dynamics. [2 - 3]

Voltage equations are given by:

$$\mathrm{V}_q = R_s\, \mathrm{i}q + \mathrm{w}_r\, \lambda_{\boldsymbol{d}} + \rho\lambda\, q \qquad \textbf{(1)}$$

$$\mathrm{V}_{\boldsymbol{d}} = R_s\, \mathrm{i}_{\boldsymbol{d}} - \mathrm{w}_r\, \lambda_q + \rho\lambda_{\boldsymbol{d}} \qquad \text{(2)}$$

Flux Linkages are given by

$$\lambda_q = \mathrm{L}_q\ \mathrm{i}_q \qquad \textbf{(3)}$$

$$\lambda_{\boldsymbol{d}} = \mathrm{L}_{\boldsymbol{d}}\, \mathrm{i}_{\boldsymbol{d}} + \lambda_r \qquad \textbf{(4)}$$

Substituting equations

$$V_q = R_s \mathrm{i}_q + \mathrm{w}_r\, \mathrm{L}_d\, \mathrm{i}_d + \rho\, \mathrm{L}_q\ \mathrm{i}_q + \mathrm{w}_r\, \lambda_r \qquad \textbf{(5)}$$

$$\mathrm{V}_d = R_s\, \mathrm{i}_d - \mathrm{w}_r\, \mathrm{L}_q\ \mathrm{i}\, q + \rho\, \mathrm{L}_d\, \mathrm{i}_d \qquad \textbf{(6)}$$

The developed torque motor is being given by,

$$T_e = \frac{3}{2} P\, (\lambda_d\ {}_q - \lambda_q\ \mathrm{i}_d) \qquad \textbf{(7)}$$

The mechanical Torque equation is,

$$T_e = T_L + B * w_m + J * \frac{d}{dt} w_r \qquad \textbf{(8)}$$

Solving for the rotor mechanical speed form equation

$$\mathrm{w}_r = \int \left(\frac{T_e - T_L - B * w_r}{J}\right) \qquad \textbf{(9)}$$

Where P, no of pole pairs
w_r , rotor electrical speed.

III. Inverter

Voltage Source Inverters are devices that convert a DC voltage to AC voltage of variable frequency and magnitude. They are very commonly used in adjustable speed drives and are characterized by a well defined switched voltage wave form in the terminals. 3.5 shows a voltage source inverter. The AC voltage frequency can be variable or constant depending on the application.

Three phase inverters consist of six power switches connected to a DC voltage source. The inverter switches must be carefully selected based on the requirements of operation, ratings and the application. There are several devices available today and these are thyristors, bipolar junction transistors (BJTs), MOS field effect transistors (MOSFETs), insulated gate bipolar transistors (IGBTs) and gate turn off thyristors (GTOs). The devices list with their respective power switching capabilities . MOSFETs and IGBTs are preferred by industry because of the MOS gating permits high power gain and control advantages. While MOSFET is considered a universal power device for low power and low voltage applications, IGBT has wide acceptance for motor drives and other application in the low and medium power range. AC motors have been widely used in electric vehicle owing to their good performance However, the control performance of low speed of motor is still influenced by ripple torque because of harmonic wave. Space vector pulse width modulation (SVPWM) control can improve the quality of the stator currents and reduce the harmonic wave generation that is usual in the traditional current hysteresis comparator.[4]

IV. PREDICTIVE DIRECT TOQUE CONTROL

A predictive DTC algorithm calculates the switching instants of two optimum active voltage space phasors (AVSPs) that build torque demand one step in advance. After that, the trajectory of the stator flux is predicted for the two preselected AVSPs and the AVSP that leads to the best trajectory of the stator flux at the end of the cycle will be applied to the machine at the next control cycle. With this control scheme is possible to obtain similar dynamic performance as with the conventional DTC scheme, with the advantages of inherently constant switching frequency and equidistant control sampling times for easy digital implementation. As an enhancement of this predictive DTC an encoder less strategy is proposed here. The rotor position is predicted through the future value of the stator flux which is estimated by using the measured stator currents and reconstructed stator voltages. [3], [5]

V. Flow of Model

Power is supplied to the PMSM through an inverter fed with dc source 300 V. Current components are taken and Voltage components are calculated with gate switches and source voltage. Torque and flux are estimated using both current and voltage components. Sector is estimated with the help of voltage components. For a given torque reference (difference between timer and actual torque and processed through PI controller) in a particular sector, actual torque is compared with reference torque which is obtained from speed error. If error is positive we need to apply a voltage in aiding to the present voltage vector and results to increase in torque slope. The time for which AVSP is applied is calculated. And if torque error is negative zero voltage is applied in aiding to the present voltage vector which results to decrease in torque slope. The time for which ZVSP is applied is calculated. Each time two voltage sectors are selected for each torque comparison. [6-7]. Now, flux comes into picture. The future component of flux is estimated with the help of future components of voltage and current .hence the name prediction. The selection of AVSP for which flux deviation is minimum is selected and applied to the machine through inverter. Rotor position is estimated using future components of current and no position encoders are used. And the loop continuously happens to get best solution for toque and flux control.

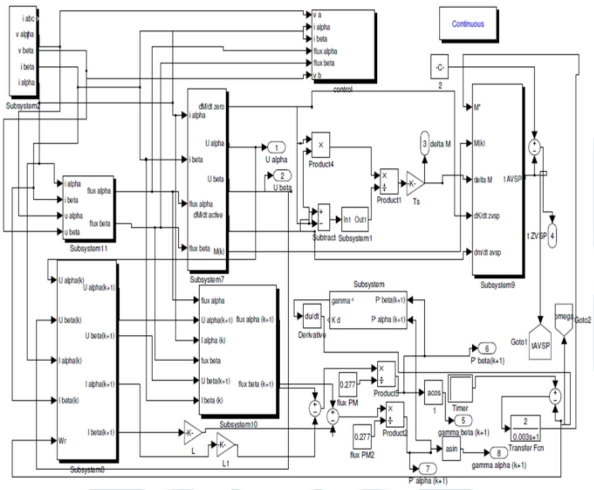

Fig 2: Matlab/Simulink Model of Predictive Direct Torque Control of PMSM

VI. RESULTS AND DISCUSSION

Simulations results for no load:

The results were obtained when no load is applied to the machine shaft. The stator currents are minimum and torque and speed are maintained according to the reference .thus speed control is achieved. rotor position gives the information about the speed of the shaft. Stator currents are low because there is no load. First speed of 1000 rpm is given as reference for 0.5 sec and later the reference has changed to 400 rpm (up to 1 sec).

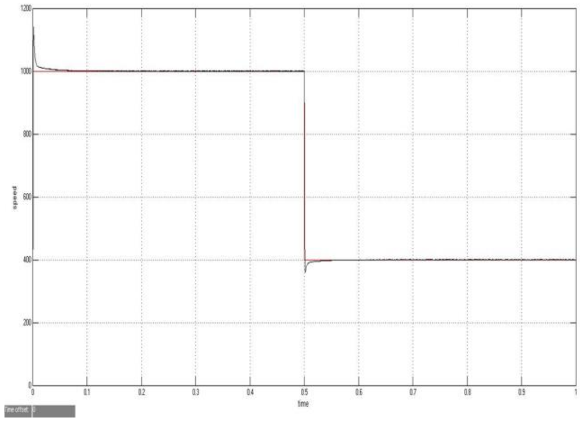

Fig. 3 Speed response for 1000 rpm and 400 rpm by PMSM.

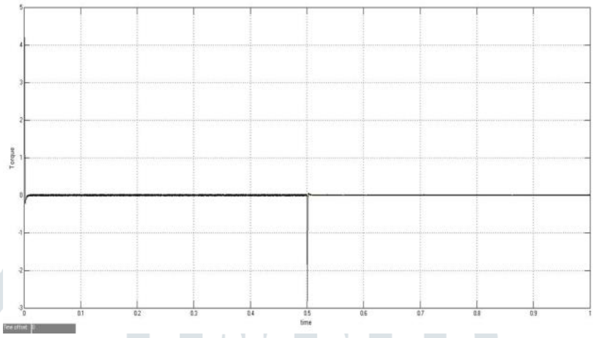

Fig 4 Torque response of PMSM for 1000 rpm and 400 rpm

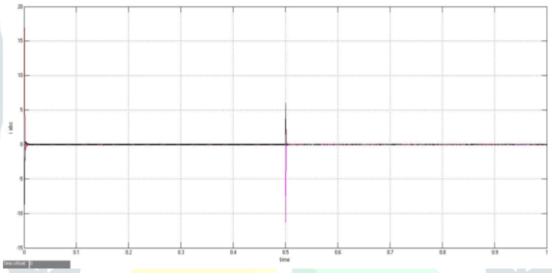

Fig. 5 Stator currents ia, ib, ic of PMSM for 1000 rpm and 400 rpm

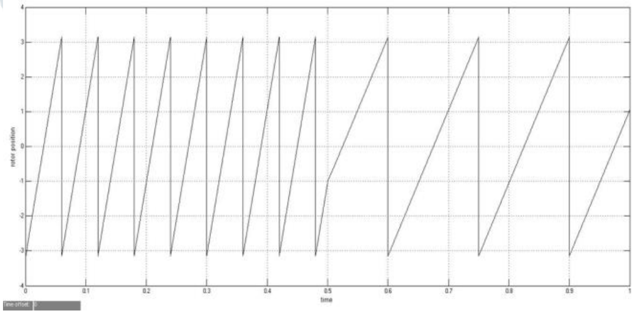

Fig. 6 Electrical Rotor position of PMSM for 1000 rpm and 400 rpm

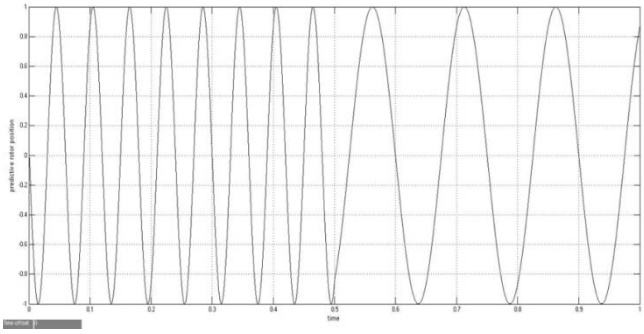

Fig. 7 Predictive Component of Electrical Rotor Position for 1000rpm and 400 rpm

Simulation results for constant load:

The results were obtained when constant load is applied to the machine and speed is varied. It is observed that the magnitude of stator current has never changed. the motor achieved the varying speed references. The frequency of motor currents have been changed. At first speed of 1000 rpm is given as reference for 0.5 sec and later the reference has changed to 400 rpm(upto 1 sec) keeping constant load of 8Nm.

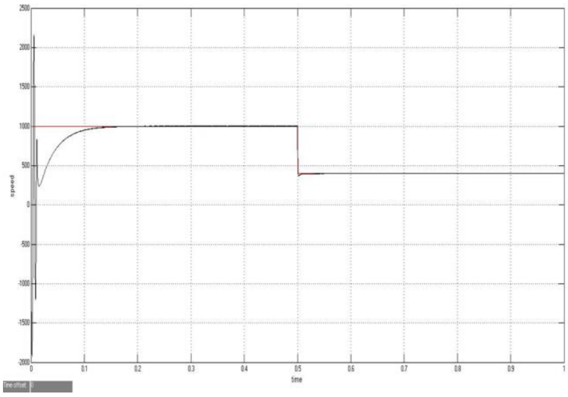

Fig. 8 Speed response for 1000 rpm and 400 rpm.

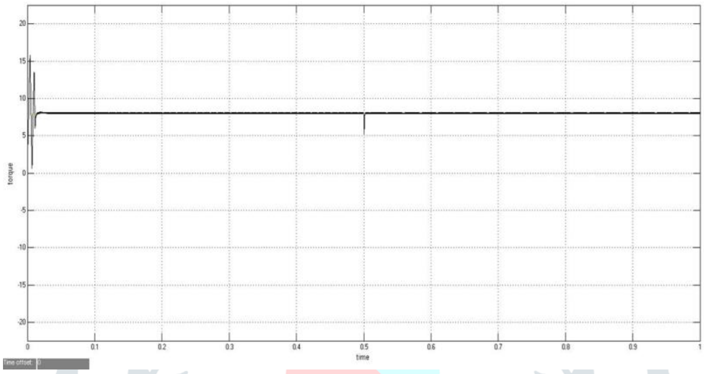

Fig. 9 Torque response for constant load torque of 8Nm.

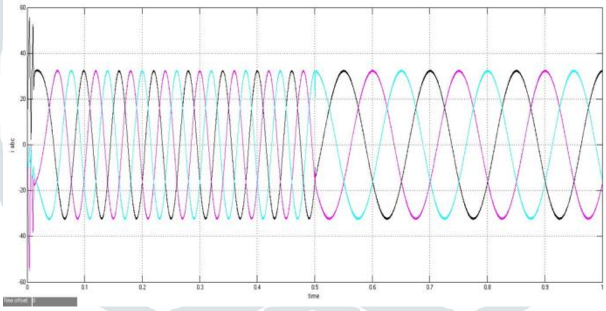

Fig. 10 Stator currents ia, ib ,ic for 1000 rpm and 400 rpm for constant load of 8Nm.

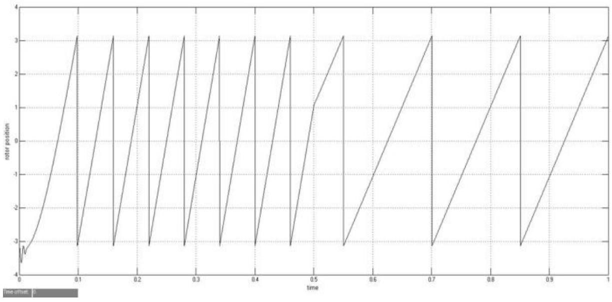

Fig 11 Electrical Rotor position of PMSM for 1000 rpm and 400 rpm for constant load of 8Nm.

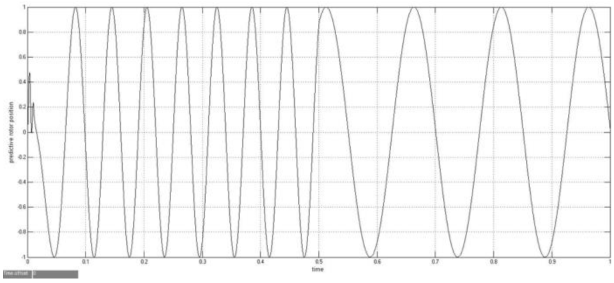

Fig. 12: Predictive component of electrical rotor position for 1000 rpm and 400 rpm for constant load of 8Nm.

Simulation results with varying load:

The results were obtained for conatant speed and for different load torques.the magnitud of current is varied but the frequency of current wave forms never changed.At first a load of 8Nm is applied to the machine upto 0.5 sec and later a reduced load of 4Nm is applied to PMSM.

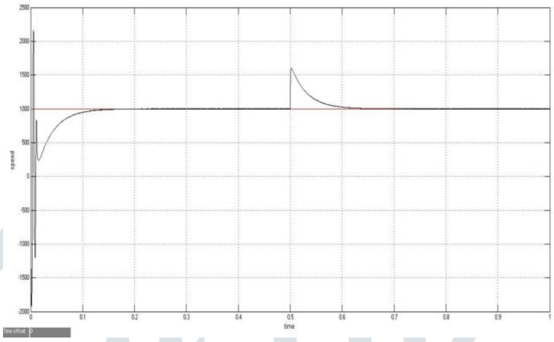

Fig. 13 Speed response for constant speed of 1000 rpm

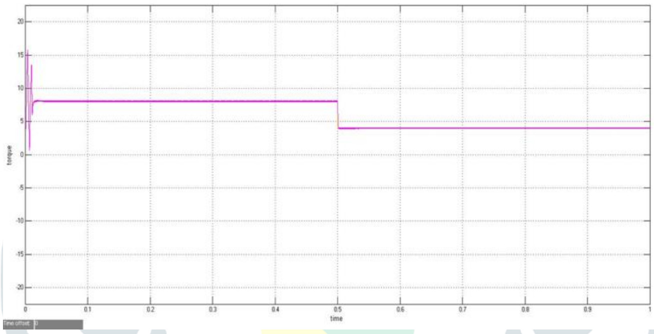

Fig. 14 Torque response for different load toques 8Nm and 4Nm.

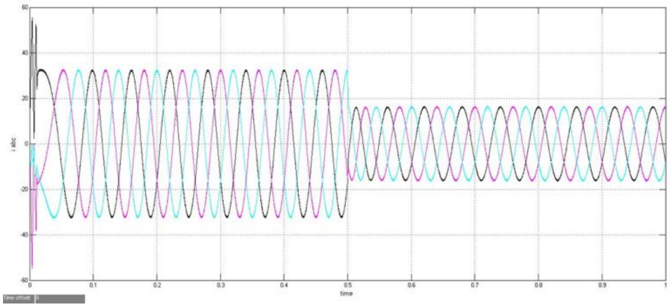

Fig.15 Stator currents ia ,ib, ic for load torques 8Nm and 4Nm.

VII. CONCLUSIONS

This paper has introduced a Sensorless PDTC scheme for Permanent Magnet Synchronous Machines. We can get a similar dynamic performance as with the conventional DTC, with this proposed control technique. This control algorithm is very suitable for digital implementation which works with constant sampling time. The method to estimate the electrical angular position of the rotor uses the terminal voltages and currents of the machine, and it does not need extra hardware or special current sensors in comparison with a standard drive with an encoder. However, the sensorless strategy deteriorates a few the performance of the predictive algorithm.

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