International Journal of Science, Engineering and Technology Research (IJSETR), Volume 3, Issue 5, May 2014

IMPLEMENTATION OF DIRECT TORQUE CONTROL OF PMSM DRIVE USING SVPWM AND THREE LEVEL INVERTER

P. Kavinshankar,
PG scholar, Dept of PGES,
P.A College of engineering and technology,
Pollachi, India.

V. Balamurugan, M.E., Ph.D.,
Dept of ECE,
P.A College of engineering and technology,
Pollachi, India.

Abstract— **Permanent magnet synchronous motors (PMSM) have been universally used as variable speed drives due to its characteristics such as small volume, light weight, high efficiency, small inertia and hence high torque / inertia ratio, maintenance free and ease of control, high steady state torque density create possibility of replacing induction machines with PMSMs in industrial drive applications. PMSM are now widely accepted as high performance drives such as industrial robots and machine tools. A novel direct torque control (DTC) scheme incorporating space vector pulse width modulated (SVPWM) inverter, for speed control of PMSM drive has been presented. Which has advantage of fast dynamic response with low ripples in torque and speed response, elimination of current controllers and least dependency on motor parameters. According to the differences in estimated value of torque and stator flux linkage with actual reference value; the stator voltage vectors are directly selected, in DTC to control the speed of motor. A simulation model is developed in MATLAB /SIMULINK to judge the various performance parameters.**

Index Terms— **Permanent magnet synchronous motors (PMSM), direct torque control (DTC), space vector pulse width modulated (SVPWM) inverter.**

I.INTRODUCTION

Industry automation is mainly developed around motion control systems in which controlled electric motors play a crucial role as heart of the system. Therefore, the high performance motor control systems contribute to a great extent to the desirable performance of automated manufacturing sector by enhancing the production rate and the quality of products. In fact the performance of modern automated systems is defined in terms of swiftness, accuracy, smoothness and efficiency, mainly depends on the motor control strategies. The recent developments of the power electronics industry resulted in a considerable increase of the power that can be manipulated by semiconductor devices. In spite of that, the maximum voltage supported by these devices remains the major obstacle in medium and high voltage applications. Newly developed permanent magnet synchronous (PMS) motors with high energy permanent magnet materials particularly provide fast dynamics, efficient operation and very good compatibility with the applications if they are controlled properly[1]-[3]. However, the AC motor control including control of PMS motors is a challenging task due to very fast motor dynamics and highly nonlinear models of the machines. Therefore, a major part of motor control development consists of deriving motor mathematical models in suitable forms. Synchronous motors with an electrically excited rotor winding have conventional three phase stator winding (called armature) and an electrically excited field winding on the rotor, which carries a DC current. The armature winding is similar to the stator of induction motor. The electrically excited field winding can be replaced by permanent magnet (PM). The use of permanent magnets has many advantages including the elimination of brushes, slip rings, and rotor copper losses in the field winding. It leads to higher efficiency. Additionally since the copper and iron losses are concentrated in the stator, cooling of machines through the stator is more effective. The lack of field winding and higher efficiency results in reduction of the machine frame size and higher power/weight ratio.

II. SPACE VECTOR PULSE WIDTH MODULATION

The space voltage vector diagram, for the three-level inverter, is divided into twelve sectors by using the diagonal between the adjacent medium and long vector.

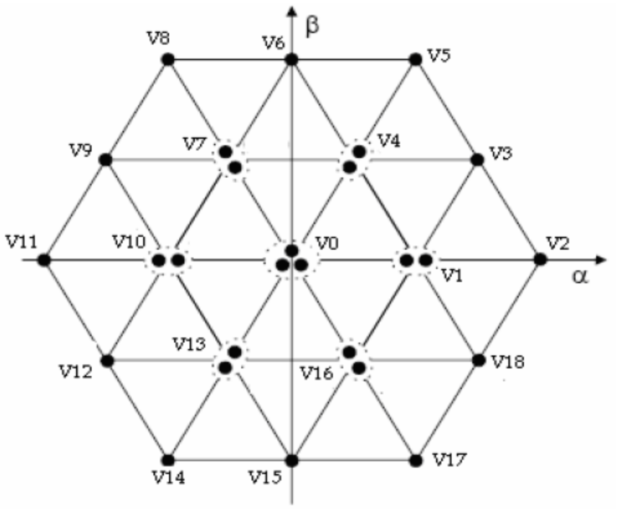

Figure 1: Space Vector Pulse Width Modulated

ISSN: 2278 – 7798

Table 1: Switching table

ϕ_s	Γ_{elm}	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
1	2	V_5	V_6	V_8	V_9	V_{11}	V_{12}	V_{14}	V_{15}	V_{17}	V_{18}	V_2	V_3
	1	V_3	V_5	V_6	V_8	V_9	V_{11}	V_{12}	V_{14}	V_{15}	V_{17}	V_{18}	V_2
	-1	V_{18}	V_2	V_3	V_5	V_6	V_8	V_9	V_{11}	V_{12}	V_{14}	V_{15}	V_{17}
	-2	V_{17}	V_{18}	V_2	V_3	V_5	V_6	V_8	V_9	V_{11}	V_{12}	V_{14}	V_{15}
0	2	V_7	V_7	V_{10}	V_{10}	V_{13}	V_{13}	V_{16}	V_{16}	V_1	V_1	V_4	V_4
	1	V_4	V_4	V_7	V_7	V_{10}	V_{10}	V_{13}	V_{13}	V_{16}	V_{16}	V_1	V_1
	-1	V_{16}	V_1	V_1	V_4	V_4	V_7	V_7	V_{10}	V_{10}	V_{13}	V_{13}	V_{16}
	-2	V_{13}	V_{16}	V_{16}	V_1	V_1	V_4	V_4	V_7	V_7	V_{10}	V_{10}	V_{13}
-1	2	V_8	V_9	V_{11}	V_{12}	V_{14}	V_{15}	V_{17}	V_{18}	V_2	V_3	V_5	V_6
	1	V_9	V_{11}	V_{12}	V_{14}	V_{15}	V_{17}	V_{18}	V_2	V_3	V_5	V_6	V_8
	-1	V_{12}	V_{14}	V_{15}	V_{17}	V_{18}	V_2	V_3	V_5	V_6	V_8	V_9	V_{11}
	-2	V_{14}	V_{15}	V_{17}	V_{18}	V_2	V_3	V_5	V_6	V_8	V_9	V_{11}	V_{12}

In analyzing the effect of each available voltage vector, it can be seen that the vector affects the torque and flux linkage with the variation of the module and direction of the selected vector[4]. For example, to increase the torque and flux V3, V4 and V5 can be selected, but the action on the increasing torque and flux respectively of V5 and of V3 is the biggest.

Table 1 represents one of the solutions adapted to choice the optimal selected voltage vector for each sector[4]. In this case, stator flux and torque are achieved by using respectively three levels and four levels hysteresis comparator. This technique doesn't use the null voltage vector for dynamics raisons.

III. THREE LEVEL INVERTER

Different circuit topologies have been implemented in multilevel inverters. One of the most used of these topologies is the Neutral point Clamped (NPC) topology. In Figure 2.1the scheme for the three level inverter is presented[14]-[15].

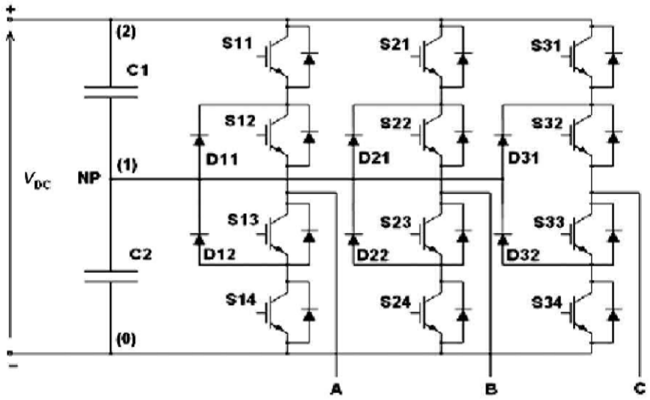

Figure 2: Three Level Inverter

IV. MATHEMATICAL MODEL OF PMSM

Development of the machine model through the understanding of physics of the machine is the key requirement for any type of electrical machine control[6]-[7]. Since in this project a Surface type Permanent Magnet Synchronous Motor (SPMSM) is used for the investigation, the development of those models is with the following assumptions.

- Three-phase motor is symmetrical.
- Only a fundamental harmonic of the magneto motive force (MMF) is taking in to account
- The spatially distributed stator and rotor winding are replaced by a concentrated coil.
- Anisotropy effects, magnetic saturation, iron loses and eddy currents are not taken into considerations.
- The coil resistance and reactance are taken constant.
- In many cases, especially when steady state is considered, the currents and voltages are assumed to be sinusoidal.

Permanent Magnet Synchronous Motor (PMSM) has a sinusoidal back emf which requires sinusoidal stator currents to produce constant torque. The PMSM is different from wound rotor synchronous machine as it has no damper and dc excitation winding. Different mathematical models viz. abc model, two axis dq model have been proposed for different applications, the two axis dq-model is simple and is widely used.

The dynamic model of PMSM is derived from two phase synchronous (stator) reference frame. For dynamic model of PMSM, the assumptions made are - spatial distribution of magnetic flux in air gap should be sinusoidal, and magnetic circuit should be linear (hysteresis and eddy current losses are negligible).

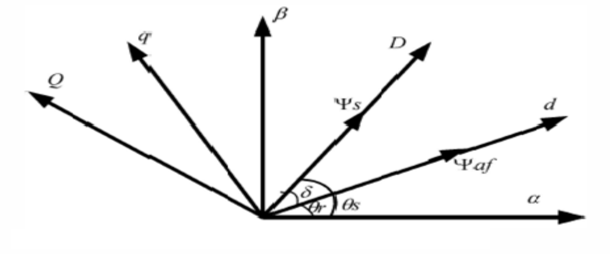

Figure 3: Stator and Rotor Flux Linkage in Coordinate System

The stator flux reference frame in D axis is in phase with stator flux linkage space vector 'Ps. Q axis (of SRF) leads 90° To D axis in CCW direction as depicted in Figure 3.

Where Ls is stator self inductance and Ψ_{af} is the rotor permanent magnet flux linkage[8]. The stator voltage equations in rotor reference frame (dq reference frame) are given in the equation 1 and equation 2.

$$V_d = R_s i_d + \frac{d\varphi_d}{dt} - \omega_r \psi_q \tag{1}$$

$$V_q = R_s i_q + \frac{d\varphi_q}{dt} - \omega_r \psi_d \tag{2}$$

Where $\psi_q = L_q i_q$ and $\psi_q = L_q i_q + \psi_{af}$, v_d and v_q are d-q axis stator voltages, id and iq are d-q axis stator currents, Ld and Lq are d-q axis inductances. Rs is stator winding resistance per phase, 'I'd, 'l'q are stator flux linkage in d-q axis & (Or is rotor speed in (rad/sec) electrical[9]-[10]. The developed electromagnetic torque is given by the equation 3.

$$T_e = \quad P[\psi_d i_q - \psi_q i_d] \tag{3}$$

Where P = No. of pole pair = p/2, and p = Total No. of poles Based on theory of dynamics the motion equation of PMSM is given by equation 4.

$$T_e = T_L + B\omega_r + J \tag{4}$$

Where T_L is load torque, J is moment of inertia; B is (viscous friction) damping coefficient. For simplifying modeling of PMSM; three phase system can be transformed to an orthogonal (dq) reference frame with direct axis (d) and quadrature axis (q), for rotor position[11]-[13]. The Simulink model of PMSM based on above equation is shown in Figure 4.

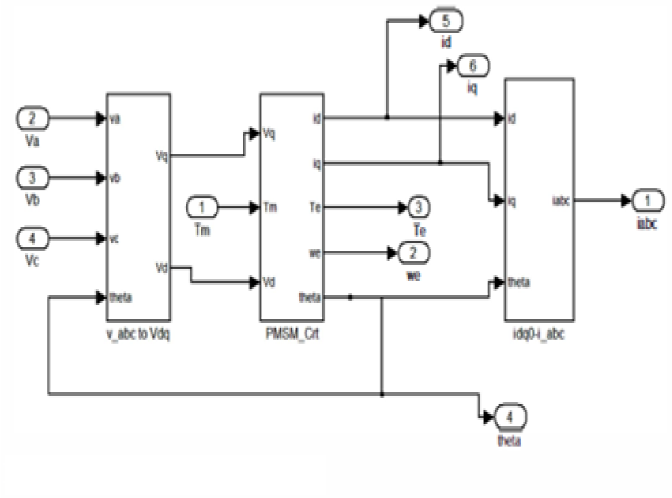

Figure 4: Simulink Model of PMSM

V. DIRECT TORQUE CONTROL

Direct Torque Control was introduced for induction motors (IM) by Takahashi and Noguchi in 1984 and the Direct Self Control method by Depenbrock in 1985. The methods were characterized by their simplicity, good performance and robustness. Unlike the FOC method, DTCworked without any external measurement of the rotors mechanical position. However, to ensure correct rotational direction of a PMSM, the rotor position shall be known at motor start up. The reason behind the simplicity is that DTC not require any current regulators, transformations to rotating reference frame or PWM generators.

The disadvantages are, difficulty to control torque at low speed, high current and torque ripple, variable switching frequency, high noise level at low speed and lack of direct current control[5]. It is also important to do a correct estimation of the dc-link voltage and stator resistance to get stability of the drive system.

VI. SIMULATION RESULTS AND DISCUSSIONS

[1]. Simulation model without DTC scheme

The Simulink model of proposed PMSM drive based on SVPWM and three level inverter without DTC scheme is shown in Figure 5.

In matlab Simulink model DC voltage split into two sources and given to the three level bridge. SVPWM switching technique is given for three level bridge. According to the switching pulse three level bridge switches turned on and off simultaneously. Step input is given as a mechanical input. For particular time ,torque will be constant and then it will increase suddenly. Due to sudden increase of torque the speed will get reduced.

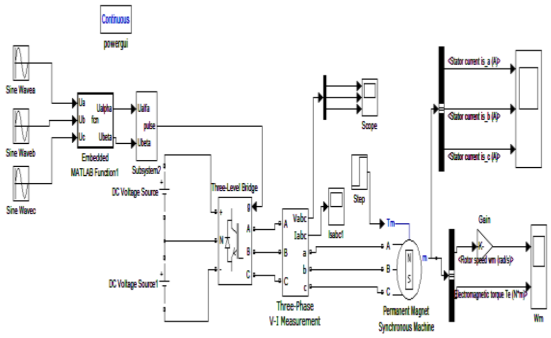

Figure 5: SVPWM of Permanent magnet synchronous motor

A. Voltage Waveforms From Three Phase Inverter

The Figure 6 shows the voltage waveforms of three level inverter. The each phase are shifted 120˚ apart.

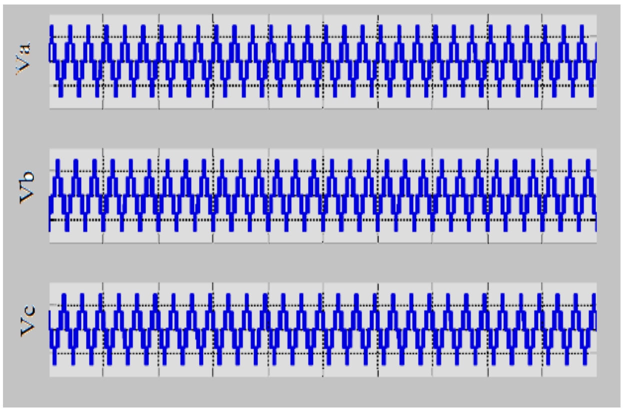

Figure 6: Voltage Waveforms vs Time

B. Current Waveforms From Three Phase Inverter

The three phase stator current is shown in Figure 7, will remains same for all values of speed only it changes with dynamic loading it may increase or decrease with values.

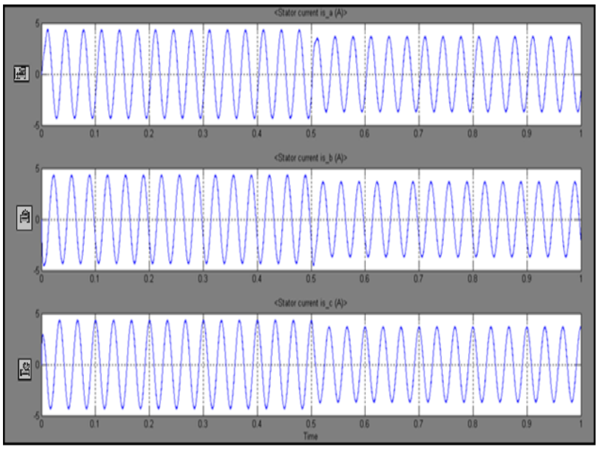

Figure 7: Current Waveforms vs Tim

ISSN: 2278 – 7798

C. Rotor Speed Characteristics

The Figure 8, shows rotor speed characteristics of PMSM. This shows that the speed has been controlled and maintained constant.

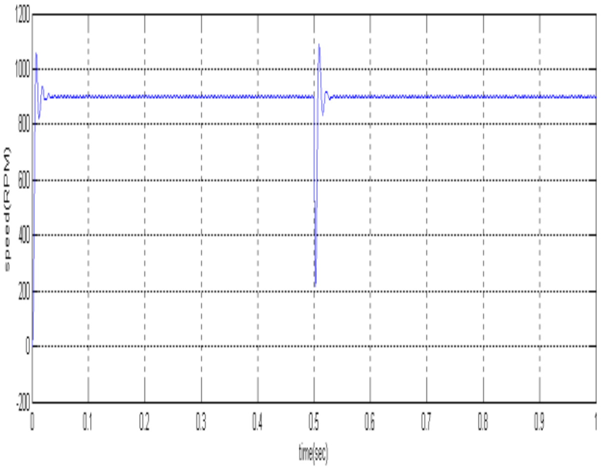

Figure 8: Speed vs Time

D. Torque Characteristics

The Figure 9 shows torque characteristics of PMSM. The torque ripple is very minimum in PMSM.

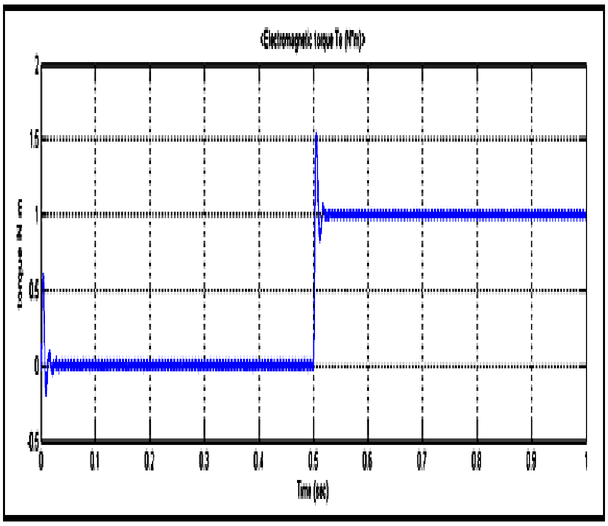

Figure 9: Torque vs Time

E. FFT analysis

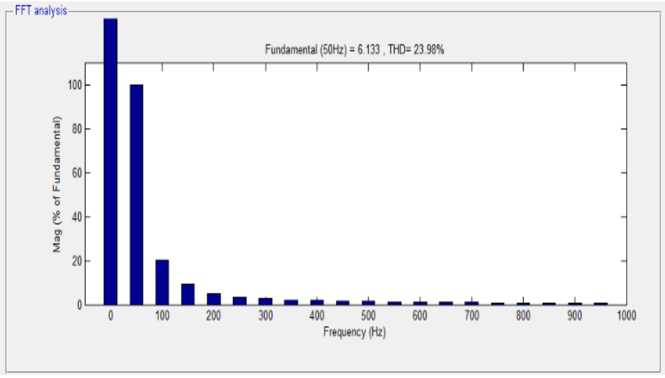

Figure 7:FFT analysis of current waveform

To find THD value of current waveform FFT analysis is used. For current waveform the THD obtained is 23.96% in the Figure 7.

[2]. Simulation model with DTC scheme

A. Circuit diagram of PMSM

The Simulink model of proposed PMSM drive based on SVPWM and three level inverter without DTC scheme is shown in Figure 10.

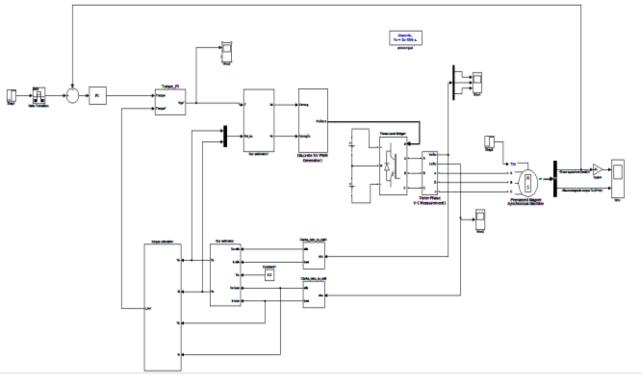

Figure 11: SVPWM and DTC based Permanent magnet synchronous motor

B. Speed and Torque characteristics

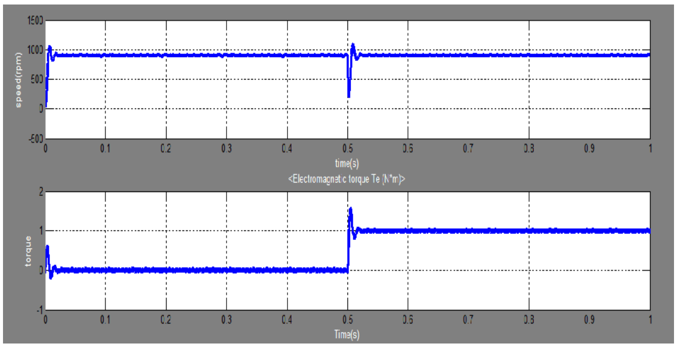

Figure 12 : output characteristics of speed and torque

The Figure 12, shows rotor speed characteristics of PMSM. This shows that the speed has been controlled and maintained constant.

ISSN: 2278 – 7798

C. Current characteristics

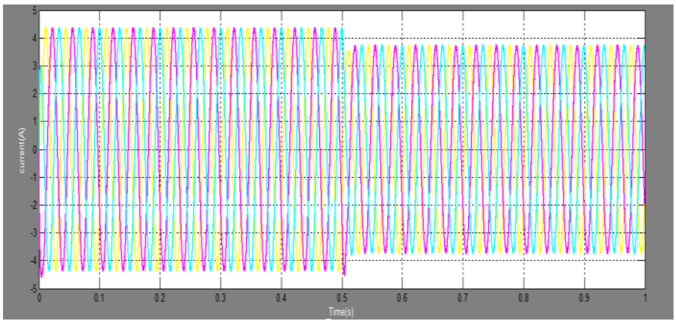

Figure 13 : Output characterictics of current

The three phase stator current is shown in Figure 12, will remains same for all values of speed only it changes with dynamic loading it may increase or decrease with values.

D. Voltage characteristics

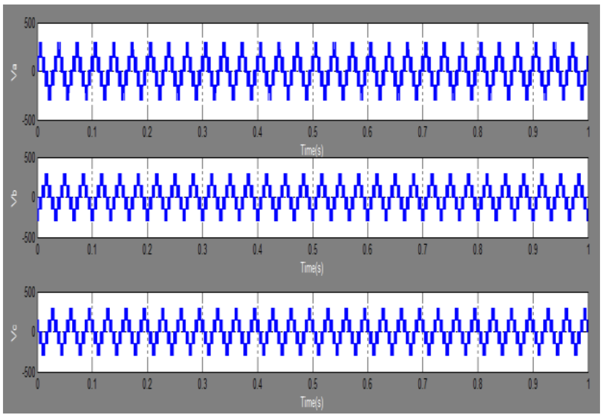

Figure 14 : Output characterictics of voltage

The Figure 14 shows the voltage waveforms of three level inverter. The each phase are shifted 120˚ apart.

E. FFT analysis

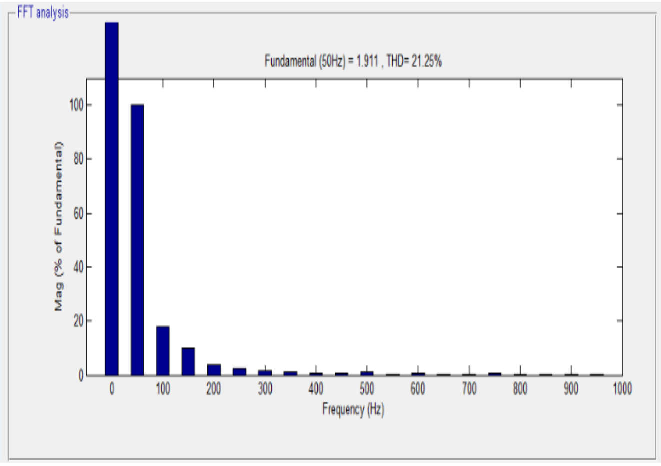

Figure 15:FFT analysis with DTC

Table 1: Comparision of FFT analysis

FFT analysis	Without DTC scheme	With DTC scheme
Current waveform	23.96%	21.25%

VII. CONCLUSION

The Simulink model of proposed space vector Control for PMSM drive has been developed and analyzed. With sensing of three phase stator voltages, this technique will be most reliable and promising with reduced cost. Space vector pulse width modulation technique has been used for twelve gate pulse generation of three phase bridge inverter. The simulation result shows the fast and smooth dynamic response of torque and stator flux linkage followed by excellent performance against sudden change in speed and torque. The excellent dynamic performance of DTC for PMSM will make it more feasible for industrial implementation. In future DTC scheme, the need of speed/Torque sensors may also be eliminated to making it more reliable and robust.

REFERENCES

[1]. A. Mahfouz, Wael Mohd. Mamdouh,(03 March 2012) "Intelligent DTC for PMSM Drive using ANFIS Technique", International Journal of Engineering Science and Technology, Vol. 4 No.

[2]. Yukinori Inoue, Morimoto, S., Sanada, M . "Comparative Study of PMSM Drive Systems Based on Current Control and Direct Torque Control in Flux-weakening Control Region", IEEE International Elec. Machines & Drives Conf. 2011, pp. 1094-109.

[3]. N. Bianchi, S. Boloqnani, M. D. Pre, G.Grezzani,.(2006) "Design considerations of fractional-slot winding configuration of synchronous machines," IEEE Transactions on Industry App, pp. 997-1006 .

[4]. Sanda Victorinne Paturca,(2006)" Direct Torque Control of Permanent Magnet Synchronous Motor (PMSM) - an approach by using Space Vector Modulation (SVM)", Proc. of the 6th WSEAS/IASME In!. Conf. on Electric Power Systems, High Voltages, Electric Machines.

[5]. T.Rekioua, D.Rekioua,(2003) " Direct Torque Control Strategy of Permanent Magnet Synchronous Machines", IEEE Power Tech. Conf.

[6]. Zhen Chen, XiangDong Liu, DaPeng Yang ,(2010) " Dynamic Sliding Model Control for Direct Torque Control of PMSM based on Expected Space Vector Modulation", 2nd International Conference on Industrial and Information Systems, IEEE .

[7]. Pragasan Pillay, Krishnan, R.,(Nov. 1988) " Modelling of Permanent Magnet Motor Drives", IEEE trans. Industrial electronics. Vol. 35, NO. 4.

[8]. Sanjeet Dwivedi, Bhim Singh,(2010) " Vector Control Vs Direct Torque Control Comparative Evaluation for PMSM Drive", IEEE proc. PEDES, pp. 1-8.

[9]. P. Vas, (1998)"Sensorless Vector and Direct Torque Control", Oxford University Press.

[10]. G. Mino-Aguilar. Etal,(2010) "A Direct Torque Control for a PMSM", proc.IEEE, pp.260-264.

[11]. Xiaoting Ye, Tao Zhang,(2010) "Direct Torque Control of Permanent Magnet Synchronous Motor Using Space Vector Modulation", Proc. IEEE Chinese Control and Decision Conference pp. 1450-1453.

[12]. Thomas J. Vyncke, Rene K Boel, Jan A.A. Melkebeek, (2006) "Direct torque control of Permanent magnet synchronous motors - an overview", 3rd IEEE Benelux young researchers symposium in Electrical Power Engineering.

[13]. LT Yaohua, Yu Qiang, Zhang Depeng, Guan Jiawu, Cai Hongmin ,(2011) " Study on the use of zero voltage vectors in the PMSM DTC Systems", Proc. 0f 30th Chinese control conf., pp. 3559-3564.

[14]. Antoni Arias, Luis Romeral, Emiliano, Marcel Jayne, (2005)" Stator flux optimized Direct Torque Control system for Induction motors", Electric Power Systems Research, pp.257-265

[15]. Kurihara, K., Rahman, M.A.,(March. 2004) "High-efficiency line-start interior permanent-magnet synchronous motors," IEEE Trans. Industry Applications, vol. 40, pp.789-796.

BIOGRAPHY OF AUTHORS

P Kavinshankar He received his B.E (Electrical and Electronics Engineering) degree from Sri Shakthi Institute of Engineering and Technology, Coimbatore, in 2012, and pursuing M.E., (Power Electronics and Drives) degree in P.A College of Engineering and Technology, Pollachi. He is now working on his project regarding Drives and Control.

Dr.V.Balamurugan received B.E degree in Electrical and Electronics Engineering from Government College Technology, Coimbatore and M.E degree in Applied Electronics with distinction from Karunya Institute of Technology, Coimbatore. He has received PhD degree in Information and Communication Engineering from Madras Institute of Technology campus, Anna University-Chennai. India. His current research interest includes in the area of content-based image retrieval, image processing and analysis, digital signal processing, wavelet theory and application, wireless networks and VLSI circuits. He is a life member of Indian Society for Technical Education. He is a Fellow of The Institution of Electronics and Telecommunication Engineers. He has published more than 50 papers in national and international journals and conferences. Currently working as professor in the department of Electronics and Communication Engineering, P.A College of Engineering and Technology, Pollachi. Coimbatore. India.