Space Vector Based Direct Torque Control of Open End Winding Permanent Magnet Synchronous Motor Fed with 5-level Inverter

Bhanoday. K[1]

Under the guidance of **Mr. D. Kiran Kumar**[2]

[1]*IDP (B-tech+M-tech) (Power Electronics)Department of Electrical and Electronics Engineering JNTUH College of Engineering Hyderabad& College*

[2]*Assistant Professor Department of Electrical and Electronics Engineering JNTUH College of Engineering Hyderabad*

---***---

Abstract -The paper suggests the novel DTC of PMSM using Dual Space Vector modulation based 3-level inverter. The Dual Space Vector Modulation of 3-level inverter is adopted to obtain the desired performance of the open end winding (OEW) PMSM. However, the Dual Space Vector of 3-level inverter considered as a 5-level Inverter for getting the PWM signals. PMSM is configured as its stator windings open that is neither star connected nor delta connected. The overall system is implemented through the Simulink or the MATLAB environment. In fact the proposed control strategy fed drive is investigated under constant speed and variable load conditions. Therefore the obtained simulation results are demonstrated the efficiency of the motor with low percentage of ripples in electromagnetic torque, flux and stator currents. Additionally, the proposed drive is significantly achieved the fast transient state control during dynamic operation.

***Key Words*:**Direct Torque Control (DTC), Permanent Magnet Synchronous Machine (PMSM), Space Vector Modulation (SVM), PI Controller (PI)

1.INTRODUCTION.

Speed control is very crucial for controlling the machines as it is most desired in many applications say rolling mills, cranes, hoists, pumps, draught fans and many more. Today with the environment competitive in producing many goods and facilities and with a heavy demand for electric machinery and control techniques in automotive industry the demand for optimum and efficient machine drives is already very high. Speed control of machines, primarily AC machines are basically classified as scalar and vector controls, out of which vector control offers better precision and reliability. Vector control in turn is classified into DTC and FOC (Field oriented Control) control methods. DTC is preferred due to its simplicity and less control signals fed back in system. The disadvantages in the conventional DTC that include, high torque ripple and peak overshoot in speed in transient state can be eliminated by using SVM. Furthermore, a 5-level inverter is used which results in various voltage vectors for precision control. This 5-level inverter is comprised of four 2-level inverters that together produce a 5-level voltage

As it is said the DTC technique used implements SVM where in the Torque and flux controllers as in the conventional controllers i.e., the hysteresis controllers do not work. Hence rather than hysteresis controllers we use PI controllers.

The PMSM are preferred for low power and medium power applications where the speed stability is a major concern irrespective of the load variations. Some applications include reciprocating pumps, draught fans, blowers, printing works, etc. Although the price of these machines is high they are robust, small in size and are much more efficient than induction machines.

Here a simulation implementing DTC using SVM technique using 5-level inverter on an open-end winding PMSM. It also deals with the speed response of the machine at different load conditions.

2. MATHEMATICAL MODELLING EQUATIONS OF PMSM.

The simulation is done on a mathematical model of PMSM which consists of certain equations as below. Where, i_d and i_q are the stator currents and v_d and v_q are the stator voltages in dq reference frame. J is the moment of inertia of the permanent magnet rotor. B is the frictional constant. L_d and L_q are the inductances in dq reference frame. P is the no. of poles. r_s is the stator resistance and T_{em} and T_l are the electromagnetic and load torque with ω being the speed of the rotor. ψ_f is the magnetic flux of the permanent magnet rotor.

The reference frame used in this project rotates at synchronous speed of the machine in steady state. The inverter used here produces a voltage whose frequency is 50 Hz, and hence by considering the parameters of the motor the speed remains constant at different load variations provided the load in within the pull out region, else the machine loses its synchronism.

3. PROPOSED FIVE-LEVEL SPACE VECTOR DTC

As the DTC implements the SVM technique the controllers used are PI controllers. The torque controller produces the quadrature component of the voltage V_q whereas the direct component of the voltage V_d is produced by the flux controller. Since hysteresis controllers only produce errors they cannot be used here and hence we use the PI controllers as they offer better reliability and fast response at desired rate.

The DTC technique used can be explained by the schematic diagram in fig.1. The work incorporates a space vector modulator that produces the gating signals for the inverter by using the αβ components of the voltage signals from the dq to αβ transformation block which gets its input estimated rotor position angle (θ_{est}) from the estimation block.

The estimator block estimates the torque (T_{est}), flux ($Flux_{est}$) and the rotor position (θ_{est}) by the inputs αβ components of the stator voltages ($V_{\alpha\beta}$) and stator currents ($I_{\alpha\beta}$). V_q component is produced from the torque PI controller by the error between the reference torque (T_{ref})and the estimated torque (T_{est}). Similarly the V_d component is produced from the flux controller by the error between the reference flux ($Flux_{ref}$) and the estimated flux ($Flux_{est}$). The reference values T_{ref} and $Flux_{ref}$ are produced from the speed controller from the error between the machine rotor speed (N_m) and the set reference speed (N_{ref}).

The complications in this work are at the gating signals that are to be divided to the inverter block A and B such that they operate in synchronously.

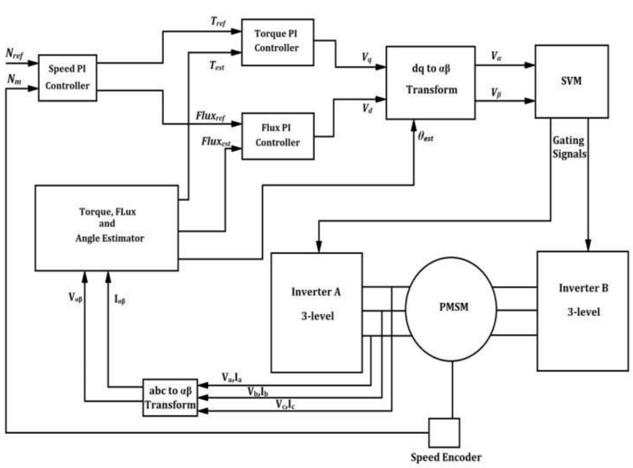

Fig.1 Schematic diagram of 5-level inverter fed OEW PMSM.

$$v_{ds} = r_s i_{ds} + L_{ds}\frac{d}{dt}i_{ds} - \omega L_{qs} i_{qs} \quad (1)$$

$$v_{qs} = r_s i_{qs} + L_{qs}\frac{d}{dt}i_{qs} + \omega L_{ds} i_{ds} + \omega\psi_f \quad (2)$$

$$T_{em} = \frac{3}{2}\frac{P}{2}\left[\left(L_{ds} - L_{qs}\right)i_{ds}i_{qs} + \psi_f i_{qs}\right] \quad (3)$$

$$J\frac{d\omega}{dt} + B\omega + T_l = T_{em} \quad (4)$$

A. 5-level Inverter circuit.

The inverter circuit implemented on OEW PMSM is shown in the fig.2.In the simulation the inverter output terminals are connected to the machine through a low pass filter as it is mathematical model representing the original machine that provides the necessary filtering due to the stator inductances. A 5-level is realized by connecting each phase leg of the 3-level inverter, realized from two 2-level inverters, to each terminal of the stator winding of the machine if the simulation is to be implemented on hardware.

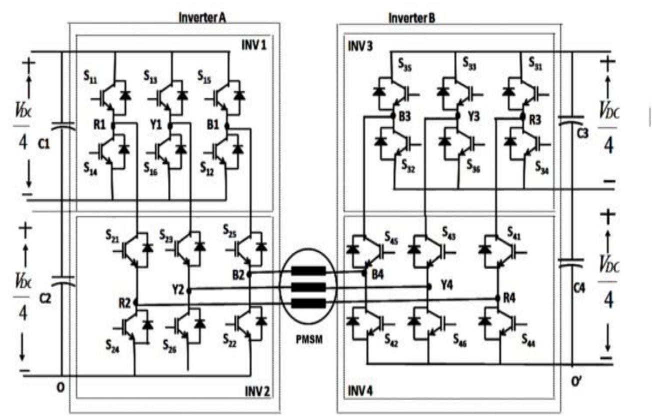

Fig.2 Inverter circuit.

Each 3-level inverter produces one half cycle of the output per phase voltage and are switched accordingly as per the tabular forms 1, 2. Here overall a 5-level voltage is realized from the whole inverter.

Each phase of the motor will generate 5 different voltage levels such as $-V_{DC}/2$, $-V_{DC}/4$, 0, $V_{DC}/4$ and $V_{DC}/2$ for different pole voltage levels of the inverter. For every 2-level inverter the upper and the lower switches are complimentary to each other.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 03 Issue: 09 | Sept -2019 ISSN: 2590-1892

Table 1 Realization of voltages levels in R-phase.

Inverter-A voltage (V_{R2O})	Inverter-B voltage ($V_{R4O'}$)	Net voltage levels in *R*-phase ($V_{R2R4} = V_{R2O} - V_{R4O'}$)	Switching Levels
0	$V_{DC}/2$	$-V_{DC}/2$	0
0	$V_{DC}/4$	$-V_{DC}/4$	1
0	0	0	2
$V_{DC}/4$	0	$V_{DC}/4$	3
$V_{DC}/2$	0	$V_{DC}/2$	4

Table 2 Inverter switching states for realizing 5 levels in R-phase.

Switching Levels	Voltage levels in *R*-phase	Switches to be made *ON* in R-phase leg			
		INV1	INV2	INV3	INV4
0	$-V_{DC}/2$	S_{14}	S_{24}	S_{31}	S_{41}
1	$-V_{DC}/4$	S_{14}	S_{24}	S_{34}	S_{41}
2	0	S_{14}	S_{24}	S_{34}	S_{44}
3	$V_{DC}/4$	S_{14}	S_{21}	S_{34}	S_{44}
4	$V_{DC}/2$	S_{11}	S_{21}	S_{34}	S_{44}

B. Fractal based SVM.

The five leveled output voltage is obtained by using fractal based approach as shown in the fig. 3

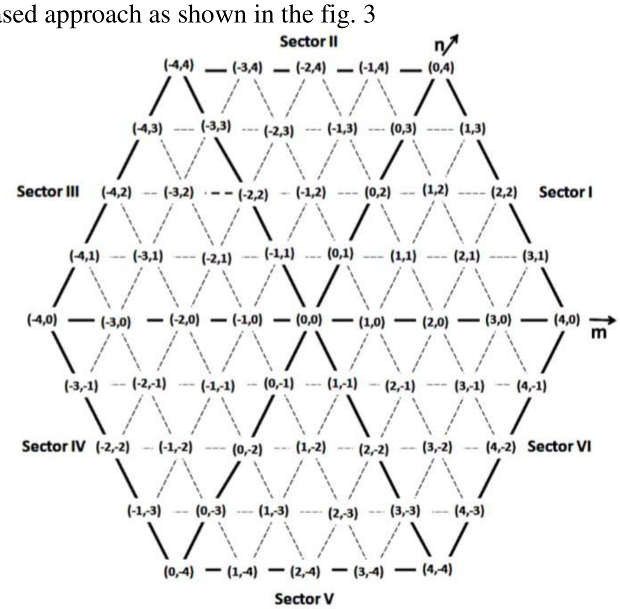

Fig.3 Fractal based approach for a 5-level inverter.

Here we obtain a total number of 92 vectors that are the combination of all 90 active vectors and 2 zero vectors. Of these vectors only 26 vectors come in use in steady state, which are the outermost vectors of the above fig. 3. For producing these vectors we go with the calculation of dwell times. It must also be observed that the voltage vector levels that are seen in the fig. 3 appears to be 9 level, but the project is for 5 level. It is to be noted by the reader that the voltage vectors that appear in the fig. 3 are line voltages and not phase voltages and hence the dwell times are calculated taking the line voltages into consideration.

C. Torque and Flux estimation.

The DTC scheme aims to determine correct voltage vectors using the above fractal based scheme. This can only be possible by the use of PI controllers. This required a reference value, to be compared with the existing values and accordingly necessary changes adopted in the system. The existing values are estimation of motor torque and the flux from the stator voltages and currents of the motor. This can be achieved by the following equations.

$$\lambda_{\alpha\beta} = \int (V_{\alpha\beta} - R_s I_{\alpha\beta}) dt \quad (5)$$

$$T_{est} = \frac{3P}{4}(\lambda_\alpha I_\beta - \lambda_\beta I_\alpha) \quad (6)$$

$$Flux_{est} = \sqrt{{\lambda_\alpha}^2 + {\lambda_\beta}^2} \quad (7)$$

$$\theta_{est} = \tan^{-1}\frac{\lambda_\beta}{\lambda_\alpha} \quad (8)$$

Firstly the flux is calculated by using eq. 5 and 7. Then the torque is calculated by the eq. 6. And finally the angle by the eq. 8. The estimated rotor position angle is used in determining the αβ components of voltages signals given to space vector modulator.

4. SIMULATION OF THE PRESENTED MODEL.

The simulation is done in MATLAB R2018b software and the whole project is shown in the fig.4. As mentioned earlier the output of the inverter is given to the machine through a low pass filter since the mathematical model will not act as a filter as in practical case.

The parameters of the machine used in the project are given in the table 3. With these parameters of the machine was able to produce a max torque of 10 Nm effectively. As it is said the inverter produces voltage at a strict frequency of 50Hz and hence a speed of 1500 RPM is seen in the output. The voltages produced at the inverter output are seen to have sufficient THD values of 5.34%.

Table 3 Parameters of the PMSM used in the simulation.

Stator Resistance - R_s (Ω)	7.2
Direct-axis Inductance - L_d (H)	0.0060
Quadrature-axis Inductance - L_q (H)	0.01180
Permanent Magnet Rotor Flux - ψ_m (wb)	0.5330
Number of Poles - P	4
Inertia Constant - J (kg-m^2)	0.000482
Frictional Constant - B (Nm/rad/sec)	0.000392

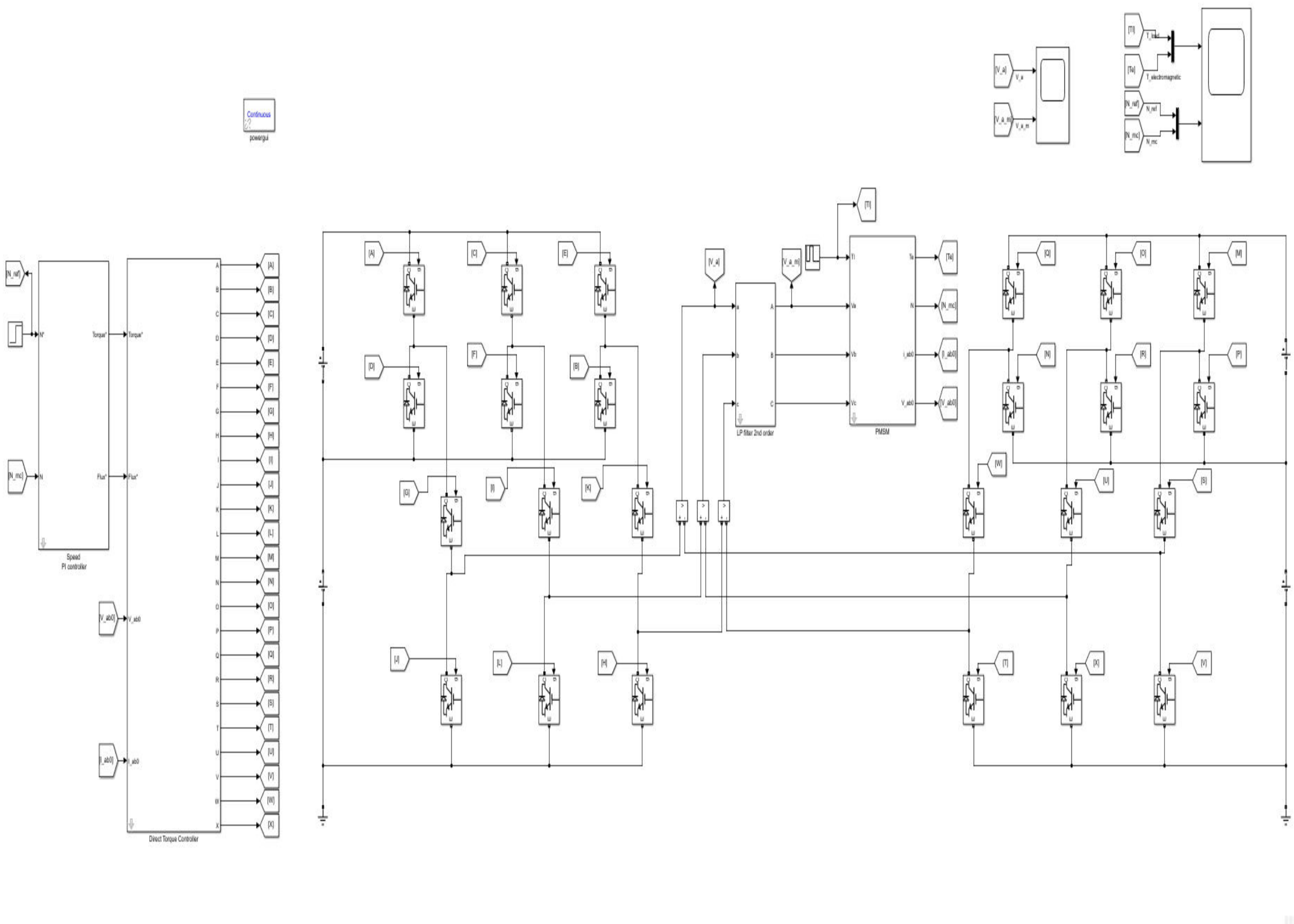

Fig. 4 The whole project simulation in MATLAB

5. SIMULATION RESULTS.

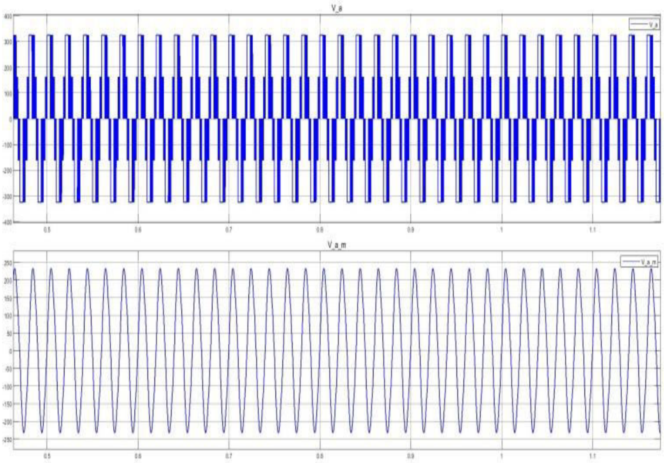

Fig. 5 Inverter output voltages and filtered voltages.

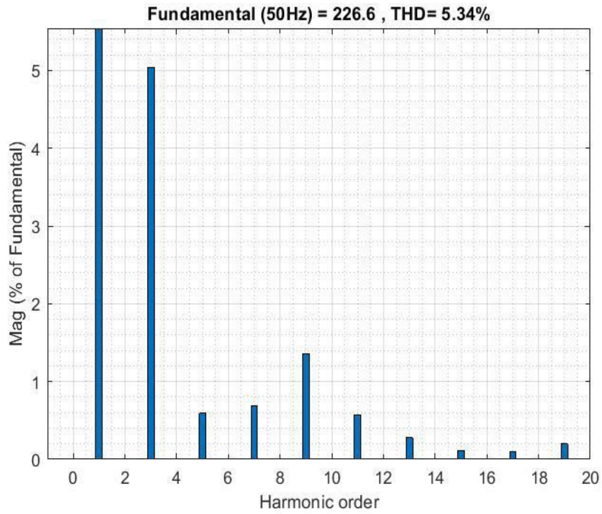

Fig. 6 THD values of the voltages.

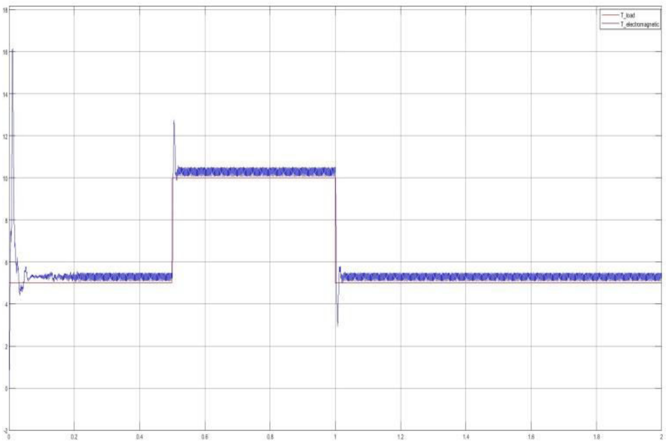

Fig. 7 Electromagnetic Torque output of the machine.

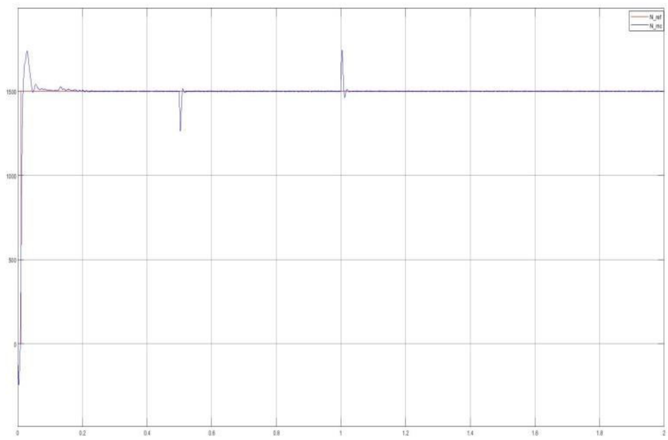

Fig. 8 The Speed output of the machine.

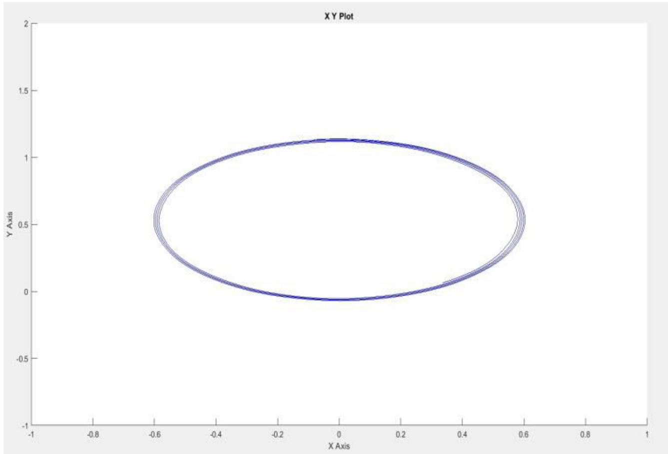

Fig. 9 Stator flux in (α, β) axis.

5. CONCLUSION.

In this paper, a 5-level inverter fed DTC drive for a Permanent Magnet Synchronous Motor using the OEW topology is presented. It was observed that the machine was able to respond in a stable manner upto the pull out torque with great efficiency. The results show that the DTC employed using SVM does reduce the torque pulsations and the peak overshoot of speed of the motor to a significant level which is what is seen in case of FOC technique. Hence it can be concluded that DTC with SVM can yield better results as that of FOC.

6. REFERENCES.

1.Space Vector Direct Torque control for five-level open-end winding Induction motor drive Vinod B. R, Shiny G., M. R. Baiju Power Electronics Research Laboratory Dept. of E & C, CET, Trivandrum, Kerala, India.

2. A Multilevel Inverter fed Direct Torque Control Strategy for an Induction Motor using PI Controllers .Vinod B. R, Shiny G.

3. A Fractal based Space Vector PWM Scheme for General n-Level Inverters. Shiny G., M. R. Baiju College of Engineering, Trivandrum, Kerala, India.

4. PM Synchronous Motor Speed Control by using Direct Torque Control Method.AmitA.Muley, Mangesh R Shelke and Nilesh Y Deshmukh.
5. Direct Torque Control of T-NPC Inverter-Fed Double-Stator-Winding PMSM Drives with SVM.
6. M. R. Zolghadri and D. Roye " A fully digital sensorless direct torque control system for synchronous machine,'' Electric Power Components and Systems, 1532-5016, vol 26, Issue 7, Pages 709 – 721, 1998.
7. D. Swierczynski, M.Kazmierkowski, and F. Blaabjerg, "DSP based Direct Torque Control of permanent magnet synchronous motor (PMSM) using space vector modulation (DTC-SVM)," International Symposium on Industrial Electronics (ISIE) vol.3, pp, 723 – 727, Nov 2002.
8. L. Tang, L. Zhong, M. F. Rahman, and Y. Hu "A novel direct torque control for interior permanentmagnet synchronous machine drive with low ripple in torque and flux a speed-sensorless approach", IEEE Transactions on industry applications, vol. 39, No. 6, Nov. 2003.
9. T. J. Fu and W. F. Xie "A novel sliding-mode control of induction motor using space vector modulation technique,", ISA Transaction vol 44, pp 481-490, 2005.
10. K. B. Lee, and F. Blaabjerg " A modified DTCSVM for sensorless matrix converter drives using a simple deadbeat scheme,'' HAIT Journal of Science and Engineering, vol 2, Issues 5-6, pp. 715-735, published June 2005.
11. T. J. Vyncke, R. K. Boel and J .A .A. Melkebeek, "Direct torque control of permanent magnet synchronous motors – an overview,'' 3rd IEEE Benelux young researchers symposium in electrical power engineering, Apr 2006.
12. S. V. Zadeh and E.Jalali "Combined vector control and direct torque control method for high performance induction motor drives,", Science Direct, Energy Conversion and Management, vol 48, pp 3095-3101, 2007.