ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

Direct Torque Control of Induction Motor Using Three-Level Neutral Point Clamped Inverter

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ABSTRACT: The direct torque control strategy of squirrel-cage induction motor using three-level neutral point clamped inverter is presented. The strategy used for controlling the torque of induction motor includes the change in applied voltage to the squirrel-cage induction motor .The variable voltage is provided with the help of look up table to the inverter. It is observed that the torque ripples are much in three-level inverter as compared to three level ineverter. This is because of the high dv/dt ratio of the output voltage of inverter. The current ripple produces torque ripples in steady state. The performance of motor in transient state and steady state are shown. The parameters of machine are given and the controlling strategy is performed using MATLAB/Simulink software. The control strategy is simulated on a 5 hp SQIM drive with three-level insulated-gate bipolar transistor (IGBT) inverter in MATLAB/Simulink software.

KEYWORDS: Direct torque control, Space vector technique, Switching table.

I.INTRODUCTION

Squirrel cage induction motors are widely used in industrial applications. Various methods are applied in order to control the torque. The torque can be controlled directly by providing the variable voltage to the motor. The variable voltage is provided with the help of multi-level inverter. The multi level inverter control strategies are of three type's scalar and vector control. Out of this, vector control strategies are mostly used. Direct torque control comprises proportional-integral controllers, current regulators and coordinates transformations and it ensures good torque control in steady and transient states [1].

DTC is easy to implement but the use of PI regulators makes it complex. PI regulators requires precise math model and also high torque and flux ripples calculations [1].DTC using artificial neural network provides the good steady state response[2]. Multi-level inverter in DTC ensures fast dynamic response [1,2,3]. Flux control strategy and conventional direct torque with multi-level inverters also been reported [3].DTC most of the time uses space vector modulation method of control (SVM)[3].In this, the method is suggested for three-level inverters. The reports, based on DTC-SVM method with multilevel inverters [5-8], shows change in line voltages from 0,-V_{dc} and +V_{dc}.

The voltage transition causes high dv/dt at the motor terminals and cause high current ripple in steady state. This paper presents the direct torque and flux control of SQIM using three-level neutral point clamped inverter. The switching strategy of the three-level inverter has shown using Space Vector Modulation technique. The three level inverter is having 3^3 =27 switching vector .This switching vectors are used in look up table to control the switching of inverter. Out of these switching vectors 18 are the active vectors which have distinct voltage levels. The essential requirement for motor is to have the fast torque response with lower torque ripples during transients and low switching current ripple in steady state. This paper shows the result of three-level inverter switching with transient and steady state response of induction motor. The performance of the motor is also shown.

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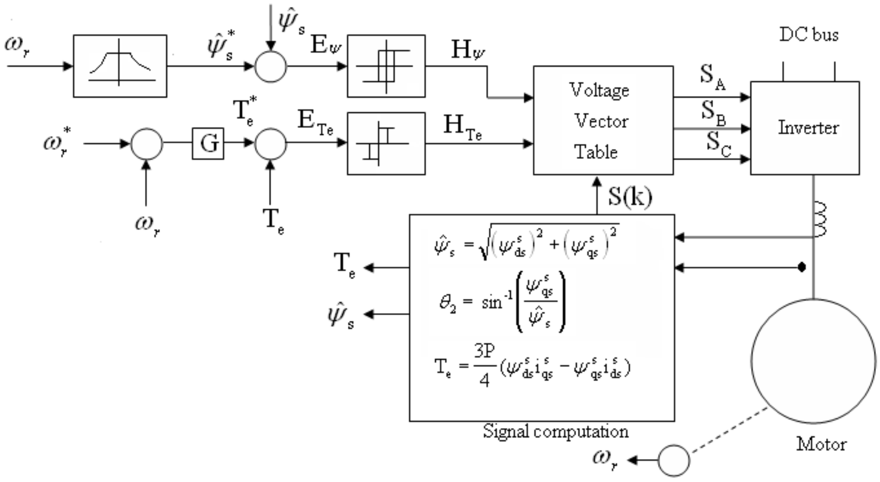

Fig.1: Block diagram of direct torque control of induction motor

II.STATOR VOLTAGE AND FLUX CALCULATION

The configuration for the three-level inverter for the SQIM drive is shown in Fig. 2. A three-level inverter is having lower dv/dt as compared to a two-level inverter thereby decreasing the shaft voltage and bearing current problems for the high power motors .The motor torque and flux are directly controlled based on DTC technology [1].

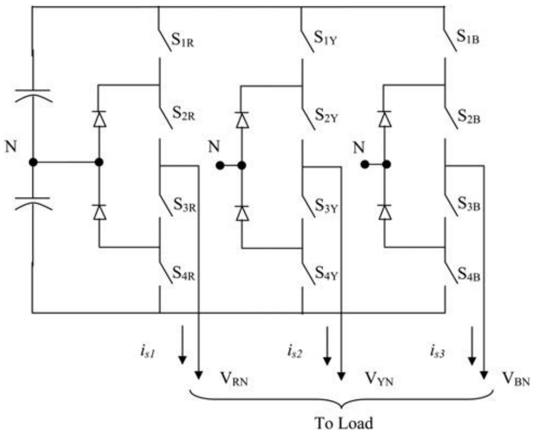

Fig.2: Three-Level Neutral Point Clamped Inverter

The actual flux, motor torque and speed of the rotor are estimated from the equations. The equations for the flux, motor voltage and current are shown. The stator voltage vector (V_s) and flux vector (Ψ_s) in the stationary reference frame, are related as below

$$V_s = R_s i_s + \frac{d\psi_s}{dt} \qquad (1)$$

The stator flux vector is calculated using (1) by integration method. The stator flux (Ψ_s) is

$$\psi_s = \int (V_s - i_s R_s) dt$$

$$\psi_s = \int V_s \bullet \Delta t \qquad (2)$$

The motor torque vector ($\overline{m_d}$), angle between the d-q flux (Θ) and rotor flux vector (Ψ_{rs}) is calculated in stationary reference frame using the equation (4), (5), (6) and (7). Depending upon the switching states and dc bus voltage, the stator voltages V_{sd} and V_{sq} in stationary frame are calculated. The switching logic for three level inverter for one leg is

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as shown in Table No. 1.The generalised voltage vector selection table of three-level inverter is as shown in Table No.2.The increased in flux error is indicated by 1 and the decrease in flux error by 0. Similarly, increase in torque is indicated by 1 and decrease in torque is indicated by -1.While the proper switching state for particular vector for three level inverter is given in Table No. 3.

$$\overline{m_d} = \frac{3}{2}\frac{P}{2}\left(\overline{\psi_s} * \overline{i_s}\right) \qquad (4)$$

$$m_d = \frac{3}{2}\frac{P}{2}\left(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}\right) \qquad (5)$$

$$m_d = \frac{3}{2}\frac{P}{2}\left|\psi_{rs}\right|\left|\psi_s\right| \sin\gamma \qquad (6)$$

$$\theta = \tan^{-1}\left(\psi_{qs} / \psi_{ds}\right) \qquad (7)$$

Table No.1 Switching logic for single leg of inverter

Possible switch status of R-phase inverter leg	State	Output Voltage
S_{1R}=ON	+	$V_{dc/2}$
S_{2R}=ON		
S_{3R}=OFF		
S_{4R}=OFF		
S_{1R}=OFF	0	0
S_{2R}=ON		
S_{3R}=ON		
S_{4R}=OFF		
S_{1R}=OFF	-	$-V_{dc/2}$
S_{2R}=OFF		
S_{3R}=ON		
S_{4R}=ON		

III.SECTOR SELECTION

In three-level inverter, there are 12 sectors 30 degrees each as shown in Fig. 3. Assume that the reference stator flux vector (Ψ_s) is in sector 1 and depending upon the stator flux increase or decrease and torque increase or decrease the respective voltage vectors should be chosen from Table No. 2 for respective sector. The presence of reference stator flux vector in particular sector is calculated by Θ (angle between Ψ_{sd} and Ψ_{sq}) which is given by equation (7).

IV.SWITCHING TABLE

Depending upon the switching states and dc bus voltage, the stator voltages V_{sd} and V_{sq} in stationary frame are calculated. The switching logic for three level inverter for one leg is as shown in Table No. 1. The voltage vector table of three-level inverter is as shown in Table No.2.The increased in flux error is indicated by 1 and the decrease in flux error by 0. Similarly, increase in torque is indicated by 1 and decrease in torque is indicated by -1. In Fig. 3, the stator flux vector Ψ_s is assumed to be in sector 1. Neglecting the stator resistance drop (R_s*i_s), the incremental change of stator flux vector ($\Psi_{s=}$ V_s T_s) is along the lines of the corresponding stator voltage vector. It is clear from Fig. 3 that the voltage vectors V_1 , V_2 and V_6 increase the stator flux magnitude for any position of Ψ_s in sector 1. On the other hand voltage vectors V_3, V_4 and V_5 decrease the stator flux magnitude for any position of Ψ_s in sector 1. Similarly, the voltage vectors V_2 and V_3 increase the torque angle between the stator flux vector (Ψ_s) and the rotor flux vector (Ψ_{rs}) in the positive direction. So, the motor torque increases. Similarly, the voltage vectors V_5 and V_6 decrease the torque as

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ISSN (Online): 2278 – 8875

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Vol. 4, Issue 5, May 2015

seen from Fig. 3 for any position of Ψ_s in sector 1. The voltage vector V_2 should be selected to reduce the positive torque error and the positive flux error when Ψ_s is in sector 1.

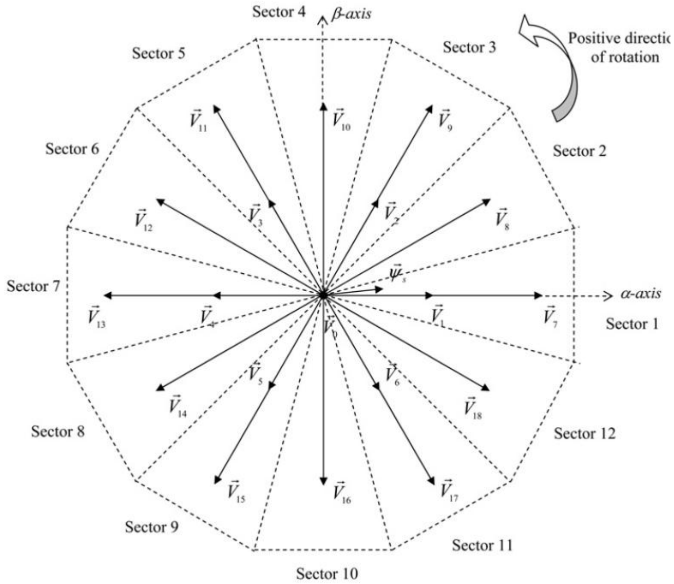

Fig.3: Sectors and Space voltage vectors.

During motoring, the rotor flux vector (Ψ_{rs}), which lags Ψ_s continues to come towards Ψ_s and reduce the torque as seen from Fig.(3). There are active vectors that cause the decrease or reduction of the motor torque. It can be seen that the required active vector V_6 introduces more current ripple while reducing the torque than the null vector V_0. So, at steady state, V_0 is used to decrease the torque value. However, during regeneration, Ψ_{rs} leads to Ψ_s. Hence Ψ_s moves away from Ψ_s when the null vector V_0 is applied to stop Ψ_s. This causes the motor torque to rise. Thus, a use of null vector is desired to control the motor torque with minimum current ripple.

At high frequency (>25 rad/s), the selection of voltage vector is taking place between the active vectors V_7 to V_{18} and V_1 to V_6. In this region of operation, the a–b plane of the voltage vector is divided into 12 sectors (sectors 1–12) as shown in Fig. 3. However, the choice of proper voltage vector at any time depends again on the torque error, the flux error and this sector number 'n', where the stator flux (Ψ_s) is as shown in Table 2. At some instant of time, the stator flux vector Ψ_s is assumed to be in sector 1 as shown in Fig. 3. It is clear from Fig. 3 that the voltage vectors V_1, V_2, V_6, V_7, V_8, V_9, V_{17} and V_{18} increase the stator flux magnitude for any position of Ψ_s in sector 1. On the other hand, the voltage vectors V_3, V_4, V_5, V_{11}, V_{12}, V_{13}, V_{14} and V_{15} decrease the stator flux magnitude for any position of Ψ_s in sector 1. The voltage vectors V_8, V_9, V_{10}, V_{11} and V_{12} increase the motor torque in the positive direction for any position of Ψ_s in sector 1. Similarly, the voltage vectors V_{14}, V_{15}, V_{16}, V_{17} and V_{18} decrease the motor torque in the positive direction for any position of Ψ_s in sector 1. V_5, V_6, and V_0 can also decrease the torque for any position of Ψ_s in sector 1. If speed < 2p ∗ 25 rad/s, then V_2, V_3 can reduce the torque with current ripple smaller than the current ripple caused by the other voltage vectors. These selection methods are explained below with phasor diagrams. It is shown that the voltage vectors V_9 and V_{10} increase the torque when Ψ_s is in sector 1. However, the incremental change in stator current is less when the voltage vector V_{10} is used as seen from the phasor. Similarly, the voltage vectors V_8, V_{11} and V_{12} will also cause more current ripple than the voltage vector V_{10} to increase the torque for any position of Ψ_s in sector 1. Hence, at high speed V_{10} is chosen to increase the torque when Ψ_s is in sector 1. In general, for any sector number 'n', the voltage vector V_{n+9} is used to increase the torque (Table 2).

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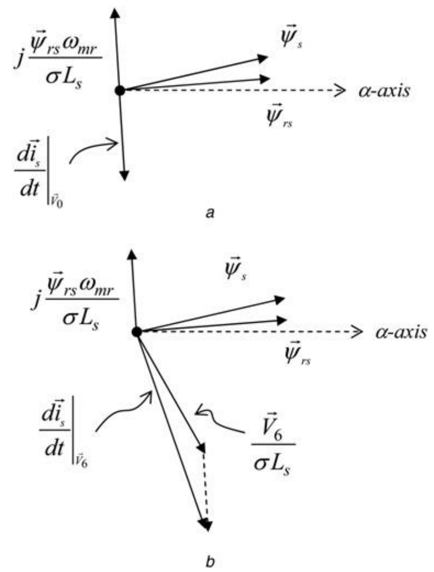

. Fig 4: Incremental change in stator current to decrease the torque at low speed (a). Null Vector (b). Active Vector

The torque can be reduced by the selection of a number of vectors as mentioned earlier. For example, at high speed when Ψ_s is in sector 1, torque can be reduced by selecting voltage vectors V_0, V_2, V_3, V_{14}, V_{15}, V_{16}, V_{17} and V_{18}. However, the incremental change in stator current is less when the voltage vector V_2 or V_3 is used as shown in Fig. 8. The choice between V_2 or V_3 depends on the flux error. When the flux error is positive, voltage vector V_2 is selected and when the flux error is negative, voltage vector V_3 is selected. In general, for odd sector number 'n' (1, 3, 5, 7, 9, 11) the voltage vector V_{n+1} or V_{n+2} is selected and for even sector number 'n' (2, 4, 6, 8, 10, 12) the voltage vector $V_{(n/2)+2}$ is selected (Table 2).

Table No. 2: Switching Table

Sector n	Ψ_{sError}	m_{dError}	
		1	-1
Odd	1	V_{n+9}	V_{n+1}
	0	V_{n+9}	V_{n+1}
Even	1	V_{n+9}	$V_{n/2+2}$
	0	V_{n+9}	$V_{n/2+2}$

For n= 1,2,....12, Voltage vector $=V_k$

$$K = \begin{cases} K-12 & For\ K > 18 \\ K & For\ K \leq 18 \end{cases}$$

V. RESULT AND DISCUSSION

The experimental verification is carried out on a 5-hp SQIM. The inverter used for this drive is a three-phase three-level inverter. A constant load of 20 N.m is applied to the induction motor at t=0.4 seconds. The transient response and steady state response of induction motor is as shown in fig.5. The speed of motor is steady after few seconds as shown in fig.6.The voltage supplied to induction motor is shown in fig. 7.The stator flux trajectory is as shown in fig. 8.

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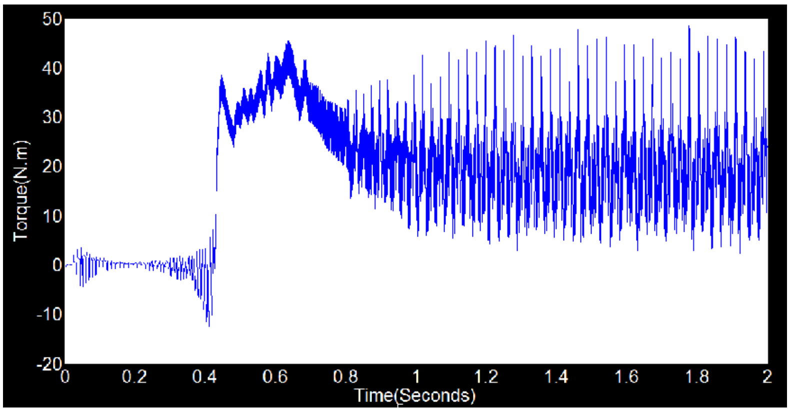

Fig.5 :Electromagnetic Torque of Motor

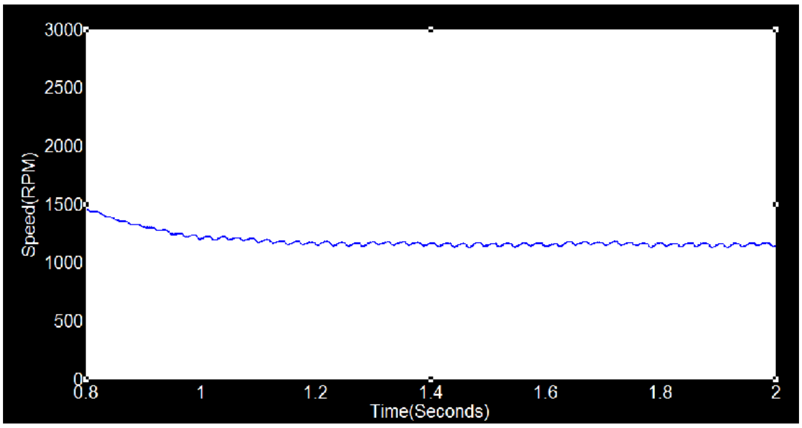

Fig.6: Rotor Speed of Induction Motor

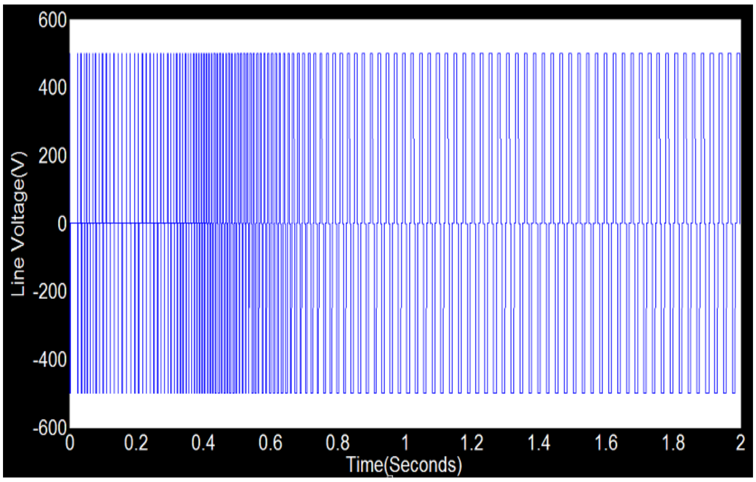

Fig.7: Output Voltage Waveform of Three Level Inverter

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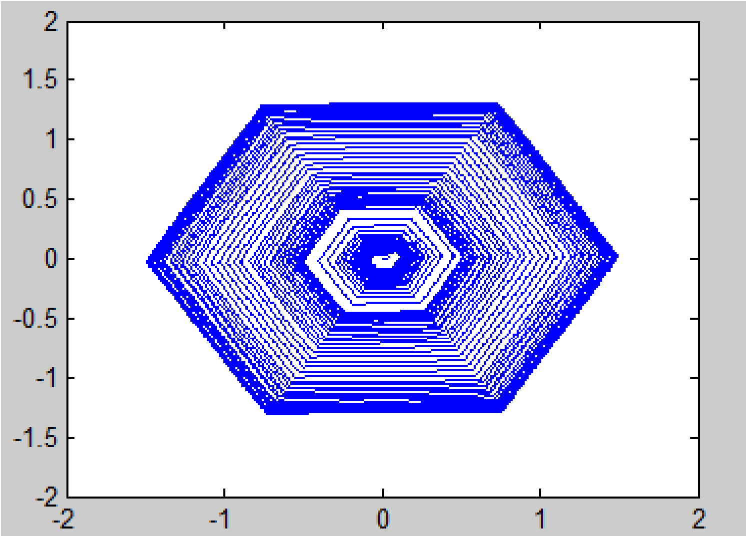

Fig.8: Stator Flux Trajectory

VI.CONCLUSION

This paper introduced the three-level inverter fed induction motor with direct torque controlled. It's observed that the torque ripples are of significance values. In order to decrease the torque ripples, switching strategy should be applied so that the minimum optimum current ripple produce. The machine is having steady state response for rated load. Direct torque control of induction motor is carried out with the three level inverter is validated by simulation results.

REFERENCES

[1] S. Mukherjee and G. Poddar , "Direct torque control of squirrel cage induction motor for optimum current ripple using three-level inverter", *IET Power Electron.*, Vol. 3, Iss. 6, 2010, pp. 904–914.

[2] Nabae A., Takahashi I., Akagi H., "A new neutral point clamped inverter", *IEEE Trans. Ind. Appl.*, 1981, IA-17, pp. 518–523

[3] McGrath B.P., Holmes D.G., LIPO T.A., "Optimized space vector switching sequences for multilevel inverters", *IEEE Trans. Power Electron.*, 2003, 18, (6), pp. 1293–1301.

[4] Buja G.S., Kazmierkowski M.P., "Direct torque control of PWM inverter-fed AC motors – a survey", *IEEE Trans. Power Electron*, 2004, 51, (4), pp. 744–757.

[5] Lee K.B., Song J.-H., Choy I., Yoo J.-Y., "Torque ripple reduction in DTC of induction motor driven by three-level inverter with low switching frequency", *IEEE Trans. Power Electron.*, 2002, 17, (2), pp. 255–264.

[6] S. Srinivasa Rao, T. Vinay Kumar, "Direct Torque Control of Induction Motor Drives for Optimum Stator Flux and Torque Ripple", *IEEE PEDS 2011*, Singapore, 5 - 8 December 2011.

[7] Satya Prasanth Yalla , P. Pugazhendiran , K. Sarmila Har Beagam "Synthesized Direct Torque Control for High-Power Induction Motor Drive" Proceedings of7'h International Conference on Intelligent Systems and Control (ISCO 2013)