



Modified Direct Torque Control of Induction Motor Using Three-Level Inverter

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ABSTRACT: This paper study the modified direct torque control strategy of squirrel-cage induction motor using three-level inverter is presented. By using this method we can control the torque of induction motor. Look up table give the variable voltage to the inverter. It is observed that the torque ripples are much in two-level inverter as compared to three level inverter. This is because of the high dv/dt ratio of the output voltage of inverter. These produces torque ripples in steady state. Transient and steady state are used to show the performance of machine. MATLAB/Simulink software is used. 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: DTC, Three level inverter, SQIM, look up table, vectors

I. INTRODUCTION

In industrial application we are mostly used the 3-phase induction motor. To control the torque of induction motor we are using different methods. Directly by providing the variable voltage to the motor we can control the torque of induction motor. Multi-level inverter is used to provide the variable voltage to the inverter. There are two methods are used by Multi level inverter which are scalar and vector. Out of this, mostly used vector control strategies is vector control. Direct torque control uses the proportional-integral controllers, current regulators and coordinates transformations and it ensures good torque control in steady and transient states [1].

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

The voltage transition causes high dv/dt at the motor terminals and give high current ripple in steady state. This paper presents the modified direct torque and flux control of SQIM using three-level neutral point clamped inverter. The Space Vector Modulation technique is used in switching strategy of three level inverter. The three level inverter has $3^3 = 27$ switching vector voltages. To control the switching of inverter we are using switching vector in look up table. 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 study 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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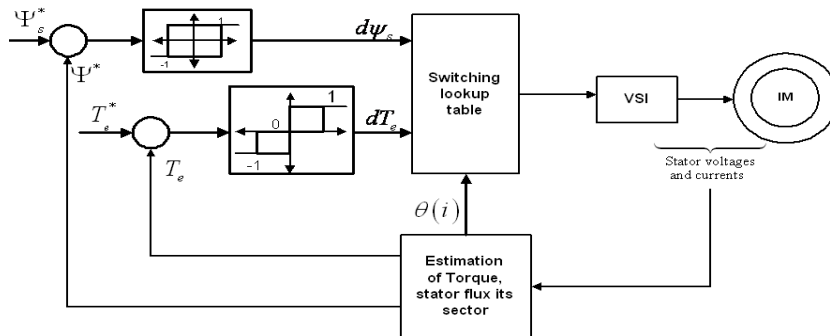


Fig.1: Block diagram of direct torque control of induction motor

II. STATOR VOLTAGE AND FLUX CALCULATION

The circuit diagram for the three-level inverter for the SQIM drive is shown in Fig. 2. A two level inverter has high dv/dt than three level inverter thereby decreasing the shaft voltage and bearing current problems for the high power motors. DTC technology is directly used to control the torque and flux of the motor [1].

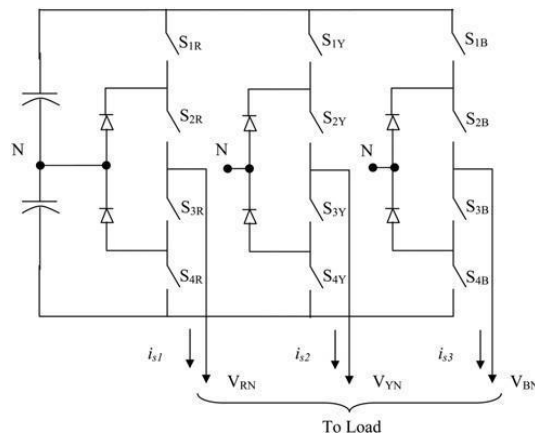


Fig.2: Three-Level Neutral Point Clamped Inverter

The actual speed, flux and motor torque 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

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

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

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

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

The motor torque vector (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

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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.

$$\bar{m} = \frac{3P}{2} \bar{\psi}_s * \bar{i}_s \quad (4)$$

$$m = \frac{3P}{2} (\psi_{ds} i_{qs} - \psi_{qs} i_{ds}) \quad (5)$$

$$m = \frac{3P}{2} |\psi_{rs}| |\psi_s| \sin \gamma \quad (6)$$

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

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 consists of 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. (angle between Ψ_{sd} and Ψ_{sq}) The presence of reference stator flux vector in particular sector is calculated by Θ which is given by equation (7).

IV. SWITCHING TABLE

The stator voltages V_{sd} and V_{sq} in stationary frame are calculated depending upon the switching states and dc bus voltage. 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, Assumed the stator flux vector Ψ_s to be in sector 1. Neglecting the stator resistance drop ($R_s * i_s$), Corresponding stator voltage vector is along the line of the incremental change of stator flux vector ($\Psi_{s=V_s T_s}$). It is clear from Fig. 3 the stator flux magnitude for any position of Ψ_s in sector 1 is increased by that the voltage vectors V_1, V_2 and V_6 . On the other hand the stator flux magnitude for any position of Ψ_s in sector 1 is decreased by. 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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seen from Fig. 3 for any position of Ψ_s in sector 1. To reduce the positive torque error and the positive flux error voltage vector V2 should be selected when Ψ_s is in sector 1.

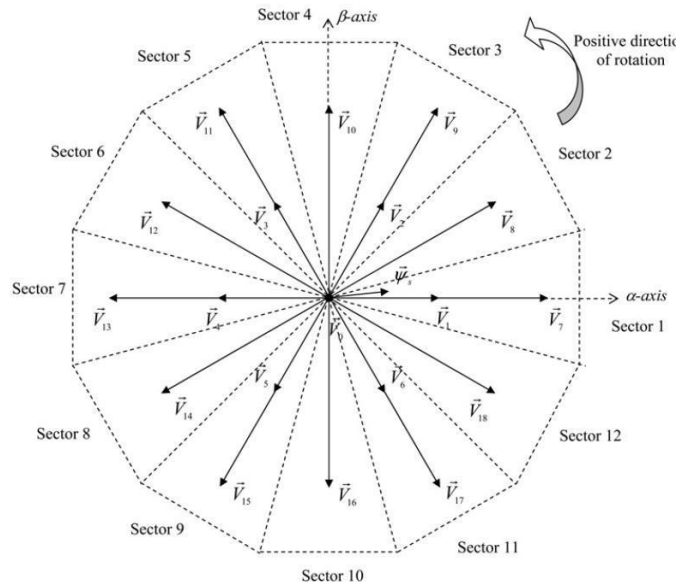


Fig.3: Sectors and Space voltage vectors.

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), V_7 to V_{18} and V_1 to V_6 voltage vector is selected. In this region of operation, the a–b plane is divided into 12 sectors (sectors 1–12) as shown in Fig. 3. However, the torque error, the flux error and this sector number „n“, will decide the choice of voltage vectors 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 the voltage vectors V_9 and V_{10} increase the torque when it 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 V_8, V_{11} and V_{12} will also cause more current ripple than the voltage V_{10} to improve the torque for any position of Ψ_s in sector 1. Hence, when Ψ_s is in sector 1 at high speed V_{10} is chosen to increase the torque . 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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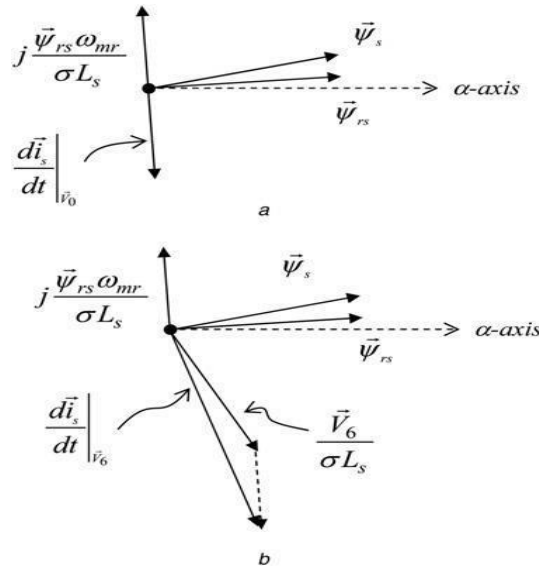


Fig 4: Incremental change in stator current to decrease the torque at low speed (a). Null Vector (b). Active Vector

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, when the voltage vector V_2 or V_3 is used the incremental change in stator current is less 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. For positive flux error even voltage are selected and for negative odd are 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).

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.

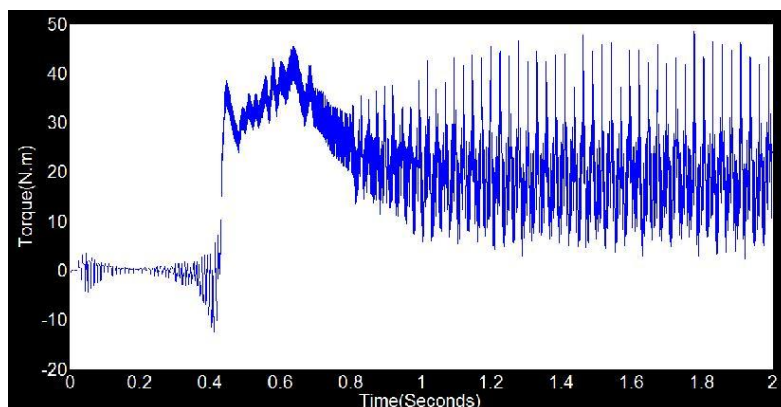


Fig.5 :Electromagnetic Torque of Motor

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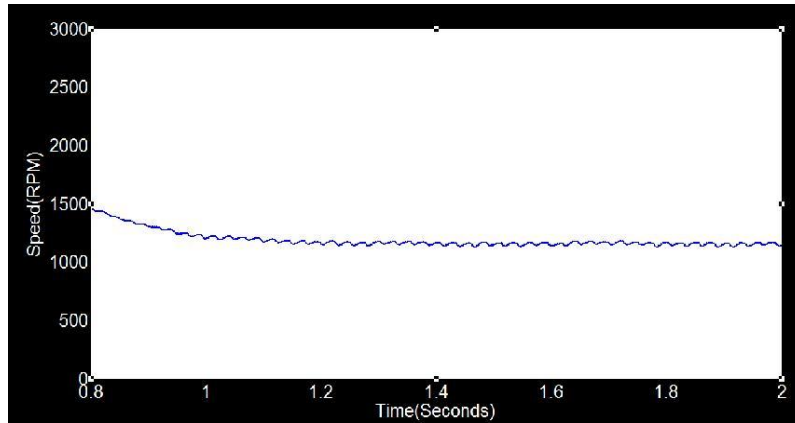


Fig.6: Rotor Speed of Induction Motor

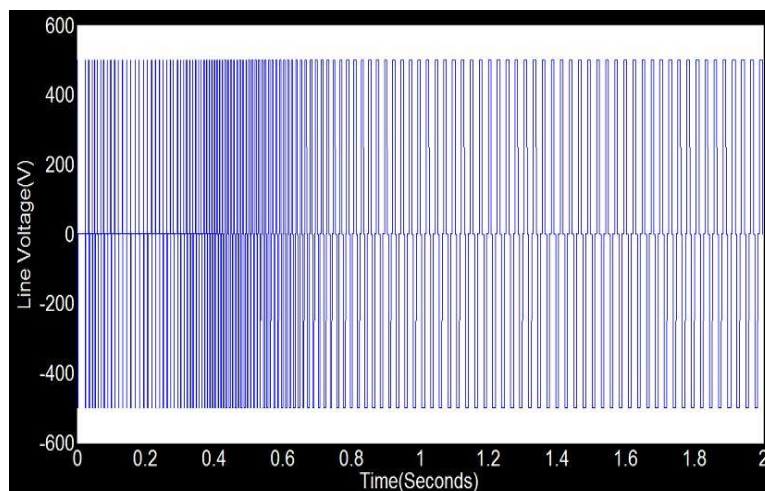


Fig.7: Output Voltage Waveform of Three Level Inverter

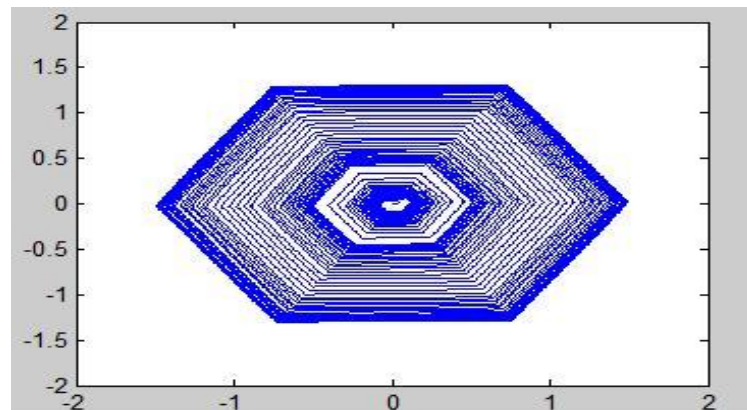


Fig.8: Stator Flux Trajectory



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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.

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