

DTC-SVM Scheme for Induction Motors Fed with a Three-level Inverter

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Abstract—Direct Torque Control is a control technique in AC drive systems to obtain high performance torque control. The conventional DTC drive contains a pair of hysteresis comparators. DTC drives utilizing hysteresis comparators suffer from high torque ripple and variable switching frequency. The most common solution to those problems is to use the space vector depends on the reference torque and flux. In this Paper The space vector modulation technique (SVPWM) is applied to 2 level inverter control in the proposed DTC-based induction motor drive system, thereby dramatically reducing the torque ripple. Then the controller based on space vector modulation is designed to be applied in the control of Induction Motor (IM) with a three-level Inverter. This type of Inverter has several advantages over the standard two-level VSI, such as a greater number of levels in the output voltage waveforms, Lower dV/dt, less harmonic distortion in voltage and current waveforms and lower switching frequencies. This paper proposes a general SVPWM algorithm for three-level based on standard two-level SVPWM. The proposed scheme is described clearly and simulation results are reported to demonstrate its effectiveness. The entire control scheme is implemented with Matlab/Simulink.

Keywords—Direct torque control, space vector Pulsewidth modulation(SVPWM), neutral point clamped(NPC), two-level inverter.

I. INTRODUCTION

IN recent years, many studies have been carried out to develop different solution for the induction motor control having the features of precise and quick torque response and reduction of complexity of the field-oriented algorithms. The direct torque control (DTC) technique has been recognized as viable solution to achieve these requirements.

However, the main limit of conventional DTC scheme is high torque ripple, variable switching frequency, and the mean torque output, which does not match the torque demand [1].

A variety of techniques have been proposed to overcome some of the drawbacks present in DTC [2]. Some solution proposed are: DTC with Space Vector Modulation(SVPWM) [3]; the use of a duty-ratio controller to introduce a modulation between active vectors chosen from the look-up table and the zero vectors [4-5]; use of artificial intelligence techniques, such as Neuro-Fuzzy controller with SVPWM [6]. However the complexity of the control is considerably increased.

A different approach to improve DTC features is to employ different inverter topologies (Multilevel Inverter) from the standard two-level VSI.

Multilevel inverters are increasingly being used in high-

power medium voltage applications due to their superior performance compared to two-level inverters, such as lower common-mod voltage, lower dV/dt, lower harmonic in output voltage and current, greater number of levels in the output voltage waveforms, and reduced voltage on the power switches[7].

Among various modulation techniques for a multilevel inverter, space vector pulsewidth modulation (SVPWM) is an attractive candidate due to following merits. It directly uses the control variable given by the control system and identifies each switching vector as a point in complex (α, β) space. It is suitable for digital signal processor (DSP) implementation. It can optimize switching sequences.

In this paper three different DTC schemes will be compared with each other. These three schemes are Classical DTC with switching table, DTC-SVM with two-level inverter, and DTC-SVM with three-level inverter. The Proposed scheme is described clearly and simulation results are reported to demonstrate its effectiveness. The entire control scheme is implemented with Matlab/Simulink.

II. DIRECT TORQUE CONTROL SCHEMES

A. Classical DTC Scheme

The fundamental idea of DTC is to control both the torque and the magnitude of flux within the associated error bands in real time. In order to understand DTC principle some of the equations of the Induction motor need to be reviewed. The electromagnetic torque can be expressed as a function of the stator flux and the rotor flux space vectors as follows:

$$Te = -\frac{3}{2}P \frac{L_m}{L_s L_r - L_m^2} \vec{\psi}_s \times \vec{\psi}_r' \quad (1)$$

If the modulus of the previous expression is evaluated it is obtained:

$$Te = \frac{3}{2}P \frac{L_m}{L_s L_r - L_m^2} |\vec{\psi}_r'| |\vec{\psi}_s| \sin(\gamma_s - \gamma_r) \quad (2)$$

Considering the modulus of rotor and stator fluxes constant, torque can be controlled by changing the relative angle between both flux vectors. Stator flux can be adjusted by stator voltage equation in stator fixed coordinates:

$$\vec{V}_s = \vec{R}_s \vec{i}_s + \frac{d\vec{\psi}_s}{dt} \quad (3)$$

If the voltage drop in the stator resistance is neglected the

variation of the stator flux is directly proportional to the stator voltage applied:

$$\vec{V}_s \propto \frac{d\vec{\psi}_s}{dt} \quad (4)$$

Because the rotor time constant is larger than the stator one, the rotor flux changes slowly compared to the stator flux. Thus torque can be controlled by quickly varying the stator flux position by means of the stator voltage applied to the motor. The desired decoupled control of the stator flux modulus and torque is achieved by acting on the radial (x) and tangential (y) component respectively of the stator flux vector. According to (5) these two components will depend on the components of the stator voltage vector applied in the same directions. The tangential component of the stator voltage will affect the relative angle between the rotor and the stator flux vectors and in turns will control the torque variation according to (2).

The radial component will affect the amplitude of the stator flux vector.

Fig. 1 shows the stator flux in the α - β plane, and the effect of the different states of a two level VSI according to torque and stator flux modulus variation.

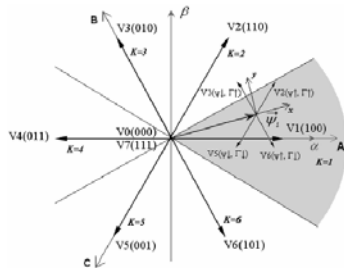


Fig. 1 Influence of the voltage vector selected on the variation of stator flux modulus and torque

According to the consideration illustrated in Fig. 1 the generic and or classical DTC scheme for a VSI-fed Induction Motor was developed a shown in Fig. 2.

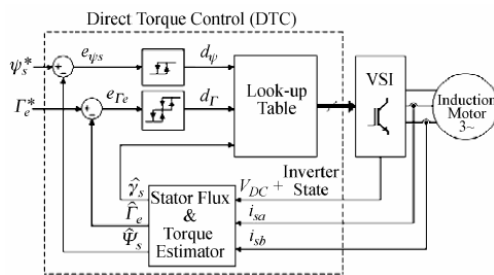


Fig. 2 Classical DTC scheme

As it can be seen, there are two different loops related to the magnitudes of the stator flux modulus and torque. The reference values for the stator flux modulus and the torque are compared with the estimated values, the resulting error values are fed into a level into a two-level and a three-level hysteresis block respectively. The outputs of the stator flux error and torque error hysteresis block, together with the position of the stator flux are used as inputs to the look-up Table I.

TABLE I
 CLASSICAL DTC LOOK-UP TABLE

| $K(\gamma_s)$ | | 1 | 2 | 3 | 4 | 5 | 6 |
|---------------|-----------|----|----|----|----|----|----|
| $d\psi = 1$ | $dT = 1$ | V2 | V3 | V4 | V5 | V6 | V1 |
| | $dT = 0$ | V7 | V0 | V7 | V0 | V7 | V0 |
| | $dT = -1$ | V6 | V1 | V2 | V3 | V4 | V5 |
| $d\psi = -1$ | $dT = 1$ | V3 | V4 | V5 | V6 | V1 | V2 |
| | $dT = 0$ | V0 | V7 | V0 | V7 | V0 | V7 |
| | $dT = -1$ | V5 | V6 | V1 | V2 | V3 | V4 |

The principle of DTC operation can also be explained by analysing the Induction Motor stator voltage equation in the stat-or flux reference frame.

$$\vec{V}_s = R_s \vec{i}_s + \frac{d\vec{\psi}_s}{dt} + j\omega_s \vec{\psi}_s \quad (5)$$

If this expression is separated into the direct (x) and the quadrature component (y) of the stator voltage, the following expression can be obtained:

$$V_{sx} = R_s i_{sx} + \frac{d\psi_{sx}}{dt} \quad (6)$$

$$V_{sy} = R_s i_{sy} + \omega_s \psi_{sx} \quad (7)$$

From use of expression (8) the following torque expression is obtained:

$$T_e = \frac{3}{2} P \frac{\psi_{sx} (V_{sy} - \omega_s \psi_{sx})}{R_s} \quad (8)$$

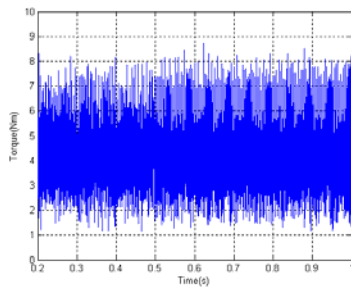
Electromagnetic torque can be controlled by means of the component of the stator voltage, under adequate decoupling of the stator flux.

DTC requires the estimation of stator flux and torque, which can be performed by means of two different phase currents, the state of the VSI and the voltage level in the DC-link. This estimation is based in the stator voltage equation [8]:

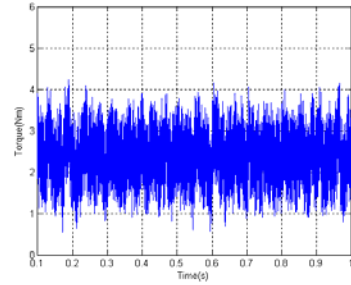
$$\vec{\psi}_s = \int (\vec{V}_s - R_s \vec{i}_s) dt \quad (9)$$

B. DTC-SVM with Two-Level Inverter

In this scheme there are two proportional integral (PI) type controllers instead of hysteresis band regulate the torque and the magnitude of flux. As shown in Fig. 3, two proportional integral (PI) type controllers regulate the flux amplitude and the torque, respectively. Therefore, both the torque and the magnitude of flux are under control, thereby generating the voltage command for inverter control. Noting that no decoupling mechanism is required as the flux magnitude and the torque can be regulated by the PI controllers. Due to the structure of the inverter, the DC bus voltage is fixed, therefore the speed of voltage space vectors are not controllable, but we can adjust the speed by means of inserting the zero voltage vectors to control the electromagnetic torque generated by the induction motor. The selection of vectors is also changed. It is not based on the region of the flux linkage, but on the error vector between the expected and the estimated flux linkage



(b) DTC-SVM (Two-level Inverter)

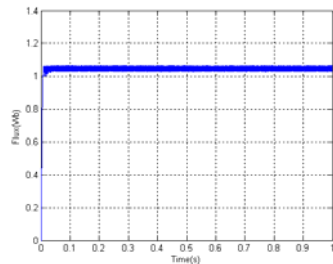


(c) DTC-SVM (Three-level Inverter)
 Fig. 9 Torque Response

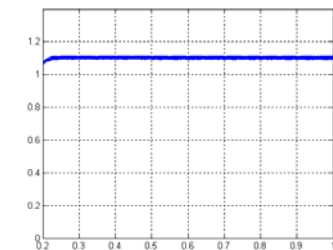
TABLE II
 COMPARATIVE ANALYSIS OF TORQUE RIPPLE

| Torque Ripple in Classical DTC | Torque Ripple in DTC-SVM with two-level inverter | Torque Ripple in DTC-SVM with three-level inverter |
|--------------------------------|--|--|
| 14 Nm | 7.4 Nm | 3.5 Nm |

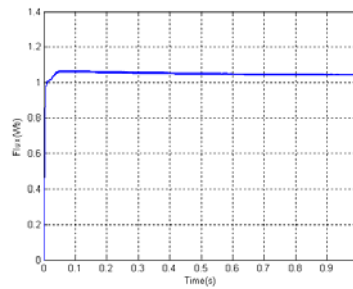
From the simulation results presented in Fig. 10 it is apparent that the flux ripple for the new system utilizing a three-level inverter with SVPWM switching is considerably reduced.



(a) Classic DTC



(b) DTC-SVM (Two-level Inverter)



(c) DTC-SVM (Three-level Inverter)
 Fig. 10 Stator Flux response

IV. CONCLUSION

In this paper the DTC principle is presented and it is shown that with a simple SVPWM algorithm for a three-level inverter based on a standard two-level inverter we can implement this method easily. The simulation results obtained for the DTC-SVM with three level inverter illustrate a considerable reduction in torque ripple and flux ripple compared to the existing classical DTC system and DTC-SVM utilizing two-level inverter.

APPENDIX

Motor parameter used in the simulation:

Induction Motor Detail

400V, 10HP(7.5KW), 4 Poles, 1440 rpm

Stator resistance 0.7384 ohm

Stator inductance 3.045 mH

Moment of inertia 0.0343 kg.m²

Friction coefficient 0.000503 N.m.s/rad

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