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# Analysis of Torque and Flux Ripple Factor for DTC and SVM-DTC of Induction Motor Drive

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*Abstract*—**Recently induction motor control techniques have gained their importance in many industrial applications. To obtain fast dynamic torque & flux response Direct Torque Control (DTC) of Induction Motor is implemented using steady state & transient input conditions in MATLAB/Simulink. In order to control both torque and stator flux directly, they need to be predicted to limit them within hysteresis band closed to desired values. This can be realized by selecting suitable sector in space vector modulation. It can perceive that the torque is dependent on the stator flux, rotor flux and the angle between their vectors. In this paper, we have simulated and analysed torque and flux ripple factor for different conditions.**

*Keywords*—*Direct torque control, flux controller, induction motor, torque controller, voltage source inverter.*

## I. INTRODUCTION

Due to their robustness, low cost, high speed operation and least maintenance required, the induction motors (IM) are usual type of electromechanical drive in different industrial, commercial and domestic applications. Many new control techniques have been developed in the last few decades to outreach the best efficiency of induction motor drive (IMD).

In general, AC motor drives can be controlled by both open and closed loop control techniques. These two control techniques are called as scalar and vector control (VC). Vector Control is intended to control the rotor flux and torque of the motor by predicting shaft speed and voltage. This prediction can be directly done through measurements or indirectly through calculations [1].

The two most remarkable and trendy control techniques in AC drives are field oriented control (FOC) and direct torque control (DTC) [1]–[4]. Excellent steady state and dynamic performance can be offered using FOC technique by decoupling the stator current into torque component and flux component in synchronous frame [4]. Hence, FOC has gained popularity in industry for low and medium power drives. However, it requires complex tuning methods and high accuracy of machine parameters.

On the other hand, to obtain quick dynamic response DTC has become well known high performance control strategy in various industrial and commercial applications [5]. Compared to FOC, DTC purges the internal current loops and PWM block, hence reducing the delay caused by current regulator. It directly selects the relevant voltage vector from a predefined switching table to reduce both toque and flux fluctuations. Thus, DTC attributes simple arrangement and quick dynamic response. However, two noteworthy limitations of conventional DTC are high torque ripple and variable switching frequency. To overcome these drawbacks, a various techniques have been anticipated in the literature. Few techniques are to advance the steady state performance of DTC by initiating the perception of duty cycle [6]–[7]. For further progress, the control period can be segregated into two non-zero vectors and one zero vector [8]-[9]. The effect is, reduced sampling frequency and constant switching frequency.

Some modifications can be done in order to achieve significant performance conventional DTC for induction motor drives. Space vector modulation (SVM) is the best way to improve the performance of conventional DTC. To control both torque and flux perfectly SVM can produce random reference voltage vector within the linear range. Moreover, fixed switching frequency can be obtained using SVM.

The main interest of this paper is to analyse the performance of conventional DTC and SVM-DTC technique for induction motor drives. This paper is organized in following sections. In section II direct torque and flux control, section III generation of SVM waveform, section IV SVM-DTC based on closed loop flux and torque control, section V simulation results and section VI conclusion.

## II. DIRECT TORQUE AND FLUX CONTROL

DTC method offers proper switching pattern for VSI through two control loops of stator flux and electromagnetic torque. To form two control loops it needs to predict these quantities. On the other hand, the discrepancy between predicted and reference values are consumed in a different way compared with FOC. In order to control torque and stator flux DTC does not require current regulators but uses two and three level hysteresis comparators. Fig. 1 shows the block diagram of DTC. The hysteresis comparators determine the torque and flux discrepancy with considering that the torque and flux error is beyond the defined limits or not. Switching table is another part of DTC configuration. Inputs of switching table are: flux and torque hysteresis regulators output and the exact sector in which flux vector is rotating. Subsequently, an suitable voltage vector based on the switching approach is fabricated [11]-[12].

Essentially, both torque and stator flux desires to be predicted so that they can be directly controlled in a way that maintains them within a hysteresis band near to the preferred values. This is accomplished by selecting the suitable sector in space vector modulation which will be explained in section III. According to [12], the torque produced by a P pole machine can be calculated by equation.

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_s L_r}\left|\psi_r\right|\left|\psi_s\right|\sin\theta_{rs} \tag{1}$$

One can notice that the torque is dependent on the stator flux ($\psi_s$), rotor flux ($\psi_r$) and the angle between their vectors. However, they will be independently controlled.

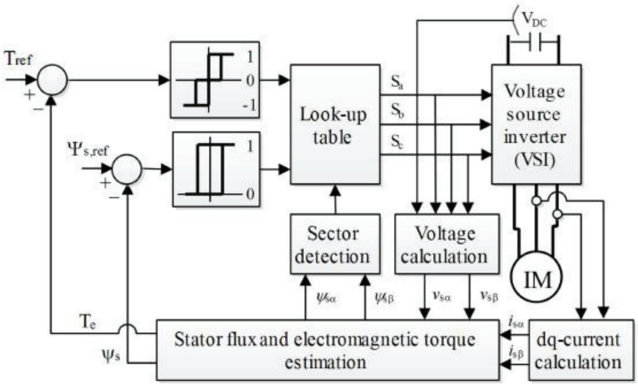

Fig. 1. Block Diagram of DTC

## III. GENERATION OF SVPWM WAVEFORM

The relation between $N$ and switch operation times is shown in Table I. Where $T_a=(T-T_1-T_m)/4$, $T_b=T_a+T_1/2$, and $T_c=T_b+T_m/2$, $T_{cm1}$, $T_{cm2}$ and $T_{cm3}$ are the operation times of the three phases respectively. Table I shows relation between $N$, $T_{cm}$, $T_a$, $T_b$, and $T_c$. Ton1 = 0.25*$T_0$; Ton2 = Ton1+T1/2; Ton3 = Ton2+T2/2.

TABLE I: Relation between $N$, $T_{cm}$, $T_{on1}$, $T_{on2}$, and $T_{on3}$

| N | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| **Tcm1** | Ton1 | Ton2 | Ton3 | Ton3 | Ton2 | Ton1 |
| **Tcm2** | Ton2 | Ton1 | Ton1 | Ton2 | Ton3 | Ton3 |
| **Tcm3** | Ton3 | Ton3 | Ton2 | Ton1 | Ton1 | Ton2 |

By comparing the computed $T_{cm1}$, $T_{cm2}$ and $T_{cm3}$ with the equilateral triangle diagram, a symmetrical space vector PWM waveform can be generated. The waveforms of PWM2, PWM4 and PWM6 are obtained by reversing those of PWM1, PWM3 and PWM5, respectively. The Induction motor is controlled by switching on or off the power electronic semiconductor devices.

## IV. SVM-DTC BASED ON TORQUE AND FLUX CONTROL

The predictive schemes described in [9], in other words, a type of differentiator has been used in their formation. Therefore, these techniques are too perceptive to instability and are more prone to unsteadiness in case of fault occurrence in closed loop. These difficulty lead to put forward SVM-DTC based on torque and flux control in stator flux coordinates. Fig. 2 shows block diagram of this proposed method. Two PI regulators and coordination transformation blocks are used in this method. This method limits the difficulty of previous methods and is advantegeous for industrial and commericial applications, but it is a little complex. Reference voltage vector is produced by means of PI regulators and the angle of stator flux vector [18]-[19].

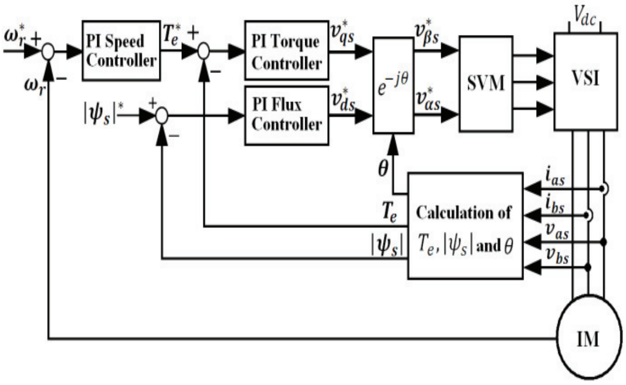

Fig. 2. Block Diagram of Direct Torque Control of Induction Motor Using Space Vector Modulation.

## V. SIMULATION RESULTS

The DTC and SVM-DTC model is build using MATLAB/Simulink package. Simulation is carried out for 4 conditions i.e. under steady state and transient conditions as follows:

### A) Case1a- Analysis of DTC Based Induction Motor Control

The analysis is done for desired torque as varying i.e Step input & varying load torque. The corresponding flux and torque response are shown in Fig. 3 and Fig. 4 respectively.

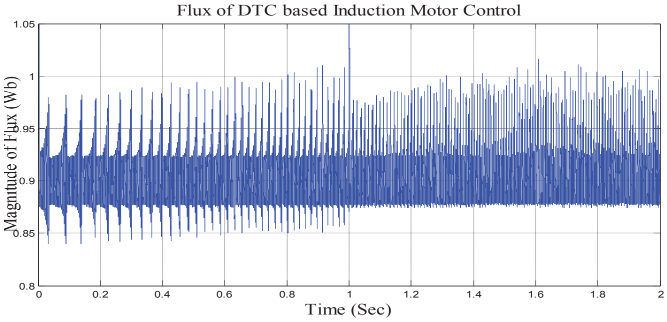

Fig. 3. Flux Vs Time for DTC Based Induction Motor Control

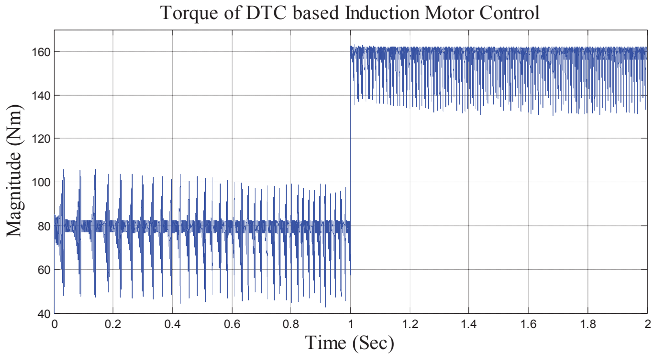

Fig. 4. Torque Vs Time for DTC Based Induction Motor Control

### *B) Case1b- Analysis of SVM-DTC Based Induction Motor Control*

The analysis is done for desired flux as varying i.e Step input & varying load torque. The corresponding flux and torque response are shown in Fig. 5 and Fig. 6 respectively.

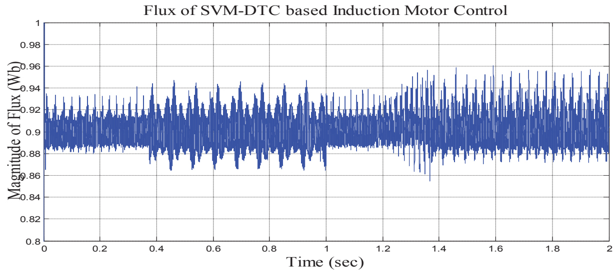

Fig. 5. Flux Vs time for SVM-DTC based Induction Motor Control

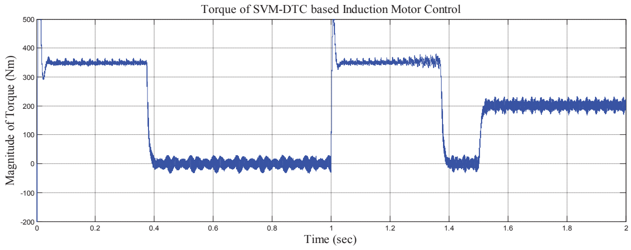

Fig. 6. Torque Vs time for SVM-DTC based Induction Motor Control

Torque and flux factor is defined as follows [22],

$$t_r = \frac{T_{max} - T_{min}}{T_{av}} \quad (2)$$

$$\psi_r = \frac{\psi_{max} - \psi_{min}}{\psi_{av}} \quad (3)$$

The comparison of flux and torque ripple factor for case 1a and case 1b is shown in Table II.

TABLE II. Comparison of Ripple Factor DTC & SVM-DTC for Induction Motor Control

| Sr. No | Flux Ripple Factor | Torque Ripple Factor |
|---|---|---|
| DTC IM | 9.789 % | 17.928 % |
| SVM-DTC IM | 4.826 % | 4.315 % |

### *C) Case2a- Analysis of DTC Based Induction Motor Control*

The analysis is done for desired torque as varying i.e Step input & constant load torque. The corresponding flux and torque response are shown in Fig. 7 and Fig. 8 respectively.

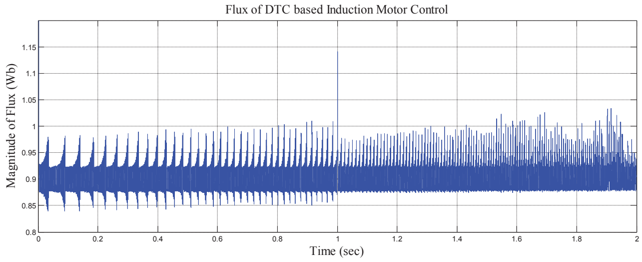

Fig. 7. Flux Vs Time for DTC Based Induction Motor Control

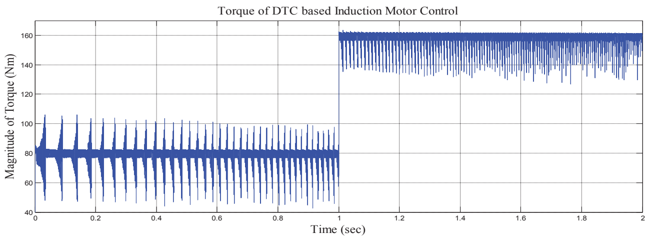

Fig. 8 Torque Vs Time for DTC Based Induction Motor Control

### *D) Case 2b - Analysis of SVM-DTC Based Induction Motor Control*

The analysis is done for desired flux as varying i.e Step input & constant load torque. The corresponding flux and torque response are shown in Fig. 9 and Fig. 10 respectively.

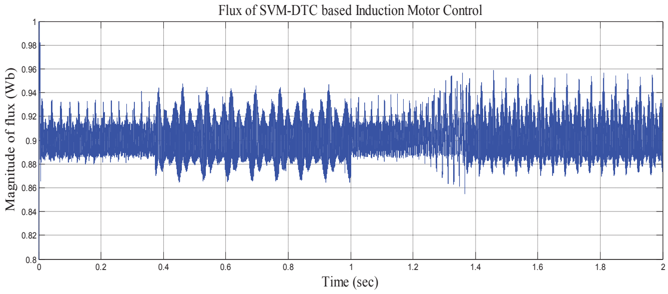

Fig. 9. Flux Vs time for SVM-DTC based Induction Motor Control

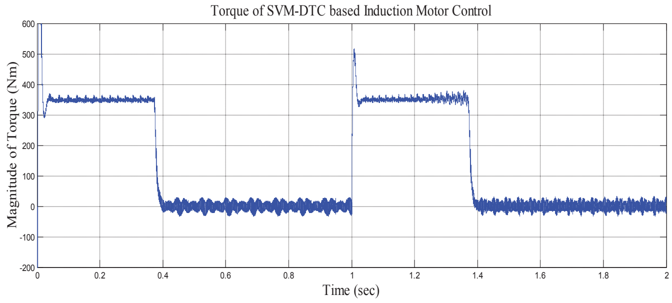

Fig. 10. Torque Vs time for SVM-DTC based Induction Motor Control

The comparison of flux and torque ripple factor for case 2a and case 2b is shown in Table III.

TABLE III. Comparison of Ripple Factor DTC & SVM-DTC for Induction Motor Control

| Sr. No | Flux Ripple Factor | Torque Ripple Factor |
|---|---|---|
| DTC IM | 8.33 % | 20.85 % |
| SVM-DTC IM | 5.348 % | 4.196 % |

### *E) Case 3a- Analysis of DTC Based Induction Motor Control*

The analysis is done for desired torque and load torque as constant. The corresponding flux and torque response is as shown in Fig. 11 and Fig. 12.

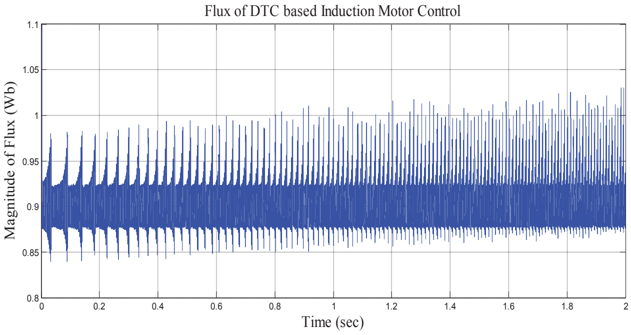

Fig. 11. Flux Vs Time for DTC Based Induction Motor Control

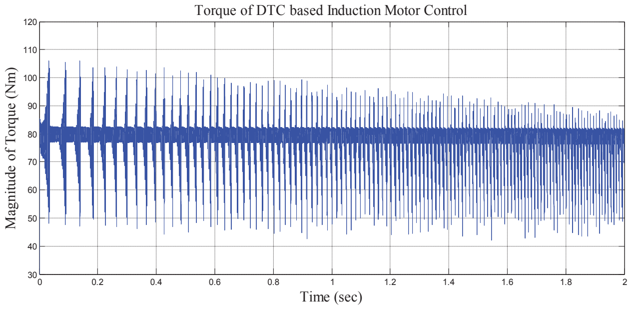

Fig. 12. Torque Vs Time for DTC Based Induction Motor Control

### *F) Case3b- Analysis of SVM-DTC Based Induction Motor Control*

The analysis is done for desired flux and load torque as constant. The corresponding flux and torque response is as shown in Fig. 13 and Fig. 14

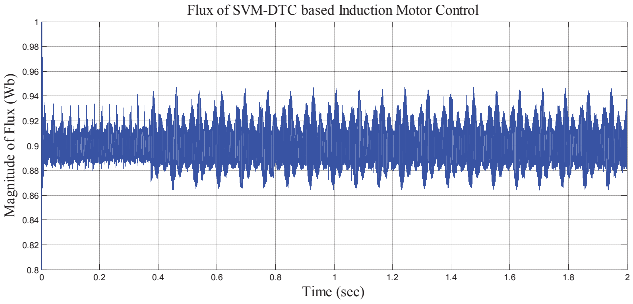

Fig. 13. Flux Vs time for SVM-DTC based Induction Motor Control

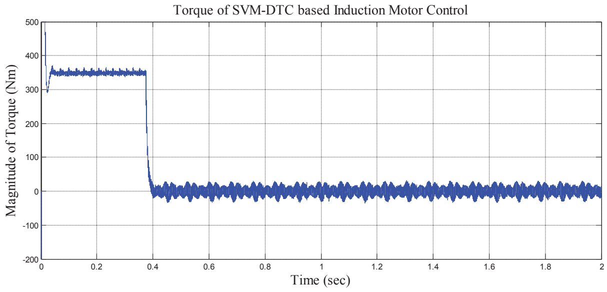

Fig. 14. Torque Vs time for SVM-DTC based Induction Motor Control

The comparison of flux and torque ripple factor for case 3a and case 3b is shown in Table IV.

TABLE IV. Comparison of Ripple Factor DTC & SVM-DTC for Induction Motor Control

| Sr. No | Flux Ripple Factor | Torque Ripple Factor |
|---|---|---|
| DTC IM | 11.17 % | 24.599 % |
| SVM-DTC IM | 3.985 % | 4.196 % |

### *G) Case 4a- Analysis of DTC Based Induction Motor Control*

The analysis is done for desired torque as costant & load torque is varying i.e. step input. The corresponding flux and torque response is as shown in Fig 15 and Fig. 16.

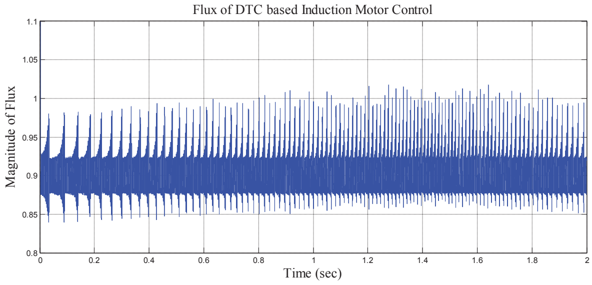

Fig. 15. Flux Vs time for DTC based Induction Motor Control

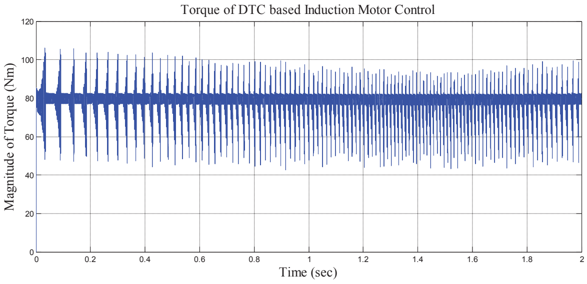

Fig. 16. Torque Vs time for DTC based Induction Motor Control

### *H) Case 4b- Analysis of SVM-DTC Based Induction Motor Control*

The analysis is done for desired flux as costant & load torque is varying i.e. step input. The corresponding flux and torque response is as shown in Fig 17 and Fig. 18.

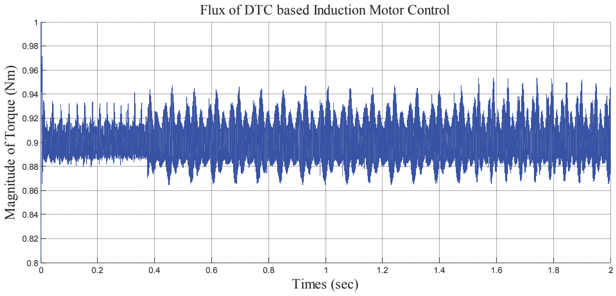

Fig. 17. Flux Vs time for SVM-DTC based Induction Motor Control

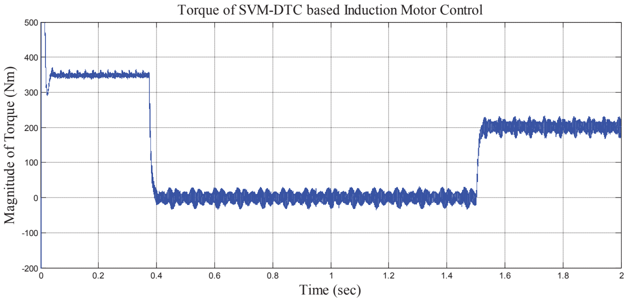

Fig. 18. Torque Vs time for SVM-DTC based Induction Motor Control

The comparison of flux and torque ripple factor for case 4a and case 4b is shown in Table V.

TABLE V. Comparison of Ripple Factor DTC & SVM-DTC for Induction Motor Control

| Sr. No | Flux Ripple Factor | Torque Ripple Factor |
|---|---|---|
| DTC IM | 10.015 % | 19.027 % |
| SVM-DTC IM | 4.889% | 8.539 % |

## VI. CONCLUSION

The performance of DTC is better but have few deficiency such as switching frequency proportional to load torque deviation. So, sampling frequency is essential to be increased. These results in increasing flux ripple and torque ripple in addition to increasing switching loss. In this paper, the design of SVM-DTC with closed-loop torque and flux control contribute to the dynamic responses and fixed switching frequency. The traditional DTC shows high torque and flux ripples where as proposed method limits torque and flux ripple appreciably. It can be observed that the use of DTC in conjunction with SVM improves torque performance to the great extent. It is believed that the work carried out in this paper is useful for analysis of torque and flux ripple factor for DTC and SVM-DTC of induction motor drive in industrial applications.

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