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Minimum Voltage Vector Error Based Direct Torque Control for Induction Motors

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***Abstract:** Traditional DTC popular because of its simplicity, Robustness, and first torque response. However, it is associated by high THD, large torque ripples and variable switching frequency. Which leads the way to scope of research in traditional DTC drive. thus, to further raise the performance, a method based on minimum voltage vector error is proposed in this dissertation. To cut down the error value between voltage vector imposed on the machine terminal and reference voltage vector, the value of Duty ratio is effectively optimized by propose method. The Optimization process does not increase the complexity of method. The proposed method is simulated in MATLAB environment.*
***Keywords:** TDTC, MVE DTC, Torque ripples, voltage-vector, current THD*

I. INTRODUCTION

Induction machines are intensively used in industries for numerous speed control application because of its advantages such as maintenance requirement, robustness, compactness and ease to manufacture. Generally, DTC is used for high-performance control applications.

The Noguchi and Takashi were the first author who proposed the DTC method in 1985, this DTC method is widely accepted due to its merits: Low switching frequency, strong robustness, easy implementation and no rotational co-ordinate transformation. How where its use is limited due to its drawback: Variable switching frequency, large torque ripples, high current THD [1-3].

In DTC method, out of 6 active voltage vectors only one voltage vector is selected and 2 voltage vectors are generated by voltage source inverter. this selection is done in the way that stator flux and torque remain within its limits for both hysteresis bands. The systematic application of TDTC results into decouple control of induction motor without any Complex co-ordinate transformation, PWM pulse and current regulator [3]. However, ripples are produced due to the use of hysteresis band controller for stator flux and torque. And these problems get more serious at heavy load. Just to provide the better solution with low torque Ripple, fast dynamic response low current THD by without making Complex calculation minimum voltage vector error based direct torque control method is proposed. In this method PI type torque regulator is used while hysteresis comparator is eliminated. the complete performance of the method is clearly demonstrated under MATLAB environment.

II. MOTOR MODEL

In DTC, Stationary reference frame is generally used for expressing the dynamic equations of induction motor.

$$0 = R_r i_r + \frac{d\psi_r}{dt} - j\omega_r \psi_r \quad (1)$$

$$u_s = R_s i_s + \frac{d\psi_s}{dt} \quad (2)$$

$$\psi_r = L_m i_s + L_r i_r \quad (3)$$

$$\psi_s = L_s i_s + L_m i_r \quad (4)$$

$$T_e = \frac{3}{2} p(\psi_s \otimes i_s) \quad (5)$$

For estimating the torque and flux at next sampling instant in MVE-DTC, we need to build full order observer by taking ψ_s and i_s as a state variable.

$$\dot{\hat{x}} = A\hat{x} + Bu_s + G\Delta i_s \quad (6)$$

$$\hat{y} = C\hat{x} \quad (7)$$

Where,

$\hat{x} = \left[\hat{\imath}_s, \hat{\psi}_s\right]^T$, $\hat{y} = \hat{\imath}_s$, $\Delta i_s = i_s - \hat{\imath}_s$, $a = -\frac{1}{\sigma}\left(\frac{1}{\tau_s} + \frac{1}{\tau_r}\right) + j\omega_r$, $b = \frac{1}{\sigma L_s \tau_r} - j\frac{1}{\sigma L_s}$,

$A = \begin{bmatrix} a & b \\ -R_s & 0 \end{bmatrix}$, $B = \left[\frac{1}{\sigma L_s}, 1\right]^T$, $C = [1,0]$, $\sigma = 1 - \frac{L_m^2}{L_s L_r}$, $\tau_s = \frac{L_s}{R_s}$, $\tau_r = \frac{L_r}{R_r}$,

$G = [K_1 + jK_2, K_3 + jK_4]^T$

discretizing equation number 6 and 7 for estimating the present sampling instant we get,

$$\hat{x}^k = \hat{x}^{k-1} + [A^{k-1}\hat{x}^{k-1} + Bu_s^{k-1} + G^{k-1}\Delta i_s^{k-1}]T_s \quad (8)$$

At next sampling instant stator current and stator flux will be

$$\hat{i}_s^{k+1} = i_s^k + \left(a^k i_s^k + b\hat{\psi}_s^k + \frac{u_s^k}{\sigma L_s}\right)T_s$$
$$\hat{\psi}_s^{k+1} = \hat{\psi}_s^k + (-R_s i_s^k + u_s^k)T_s \quad (9)$$

Therefore, torque can be predicted at next sampling instant by

$$\hat{T}_e^{k+1} = \frac{3}{2}p\left(\hat{\psi}_s^{k+1} \otimes \hat{i}_s^{k+1}\right) \quad (10)$$

Equations 9 and 10 are used to remove one step delay.

III. TDTC

In the middle 1980's, TDTC was proposed. This method was list sensitive towards parametric vibrations of induction motor as compared to vector control method [4]. Due to absence of PWM (pulse width modulation) its control algorithm become quite simple. This method provides fast torque dynamics and accuracy and also ensure high efficiency operation. Principle of DTC is based on the implementation of control sequence on switches of voltage source inverter. Choice of control sequence is made by using to hysteresis regulators and switching table [5-7]. Figure 1 shows the MATLAB model of TDTC. For Controlling the electromagnetic torque, three level hysteresis comparators are used. The switching table is determined by using the flux vector information find output of hysteresis comparator.

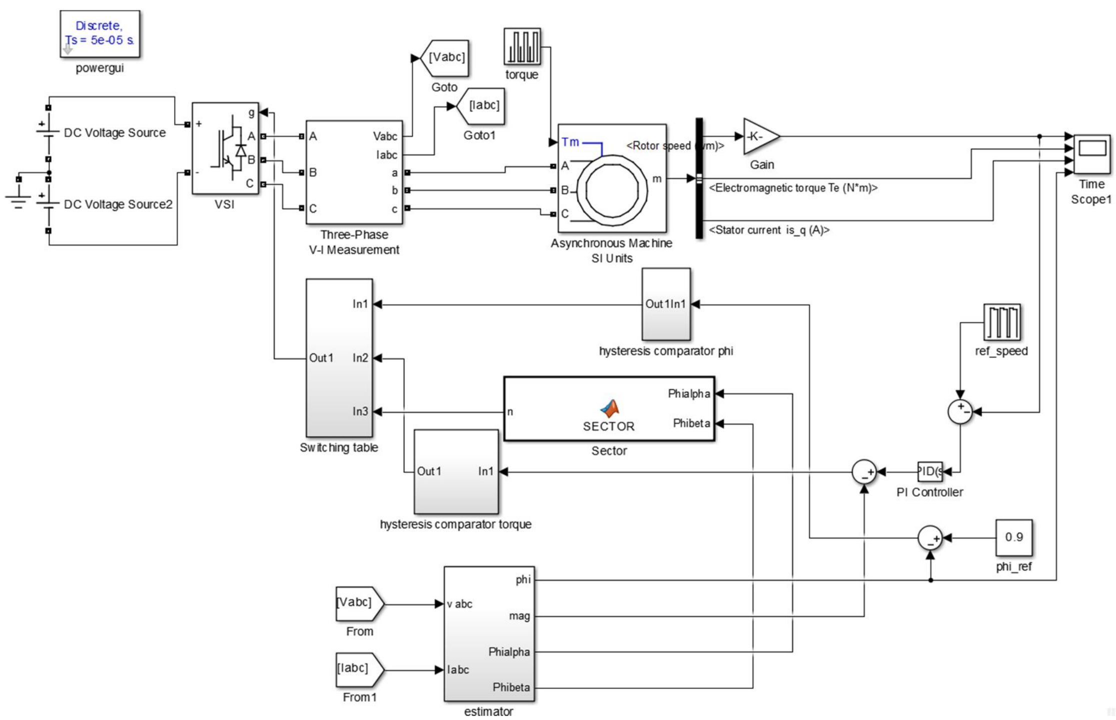


Fig. 1 Simulation Diagram For TDTC

In DTC to ensure status factory performance, electromagnetic torque accuracy and estimation of stator flux is very important. So, several parameters need to be determined, switching table and DC voltage is used to produce switching State on which stator voltage is depend and also stator current is measured[1,5].

Electromagnetic torque and stator flux are estimated by following equation

$$T_e = \frac{3}{2}\frac{P}{2}(\psi_{ds}i_{qs} - \psi_{qs}i_{ds}) \quad (11)$$

$$\psi_{qs} = \sqrt{\psi_{ds}^2 + \psi_{qs}^2} \quad (12)$$

With the stator flux components in the reference

$$\psi_{ds} = \int (V_{ds} - R_s i_{ds})dt$$
$$\psi_{qs} = \int (V_{qs} - R_s i_{qs})dt \qquad (13)$$

Then the estimated values of electromagnetic torque and estimated stator flux are compared respectively with reference value of electromagnetic and stator flux. These results of comparisons are taken as input to hysteresis comparator. By using the control table selection of voltage vector is done.

Despite of its robustness and simplicity TDTC has some major disadvantages. The hysteresis controller cause measure pulse in electromagnetic torque and flux. Which generate undesirable noise and thus the machine performance get better deteriorate[8].

IV. MVE DTC

Minimum voltage vector direct torque control (MVE DTC) is most recent advanced control method. This method was published by Xu Wu on 5th May 2021[9]. Main objective of this method is to reduce the torque Ripple without deteriorating the dynamic performance nor making the system complicated [9-12]. The basic principle of this method is to calculate the future behaviour of system and then use this behaviour to cut down the error value between voltage vector imposed on the machine terminal and reference voltage vector [13].

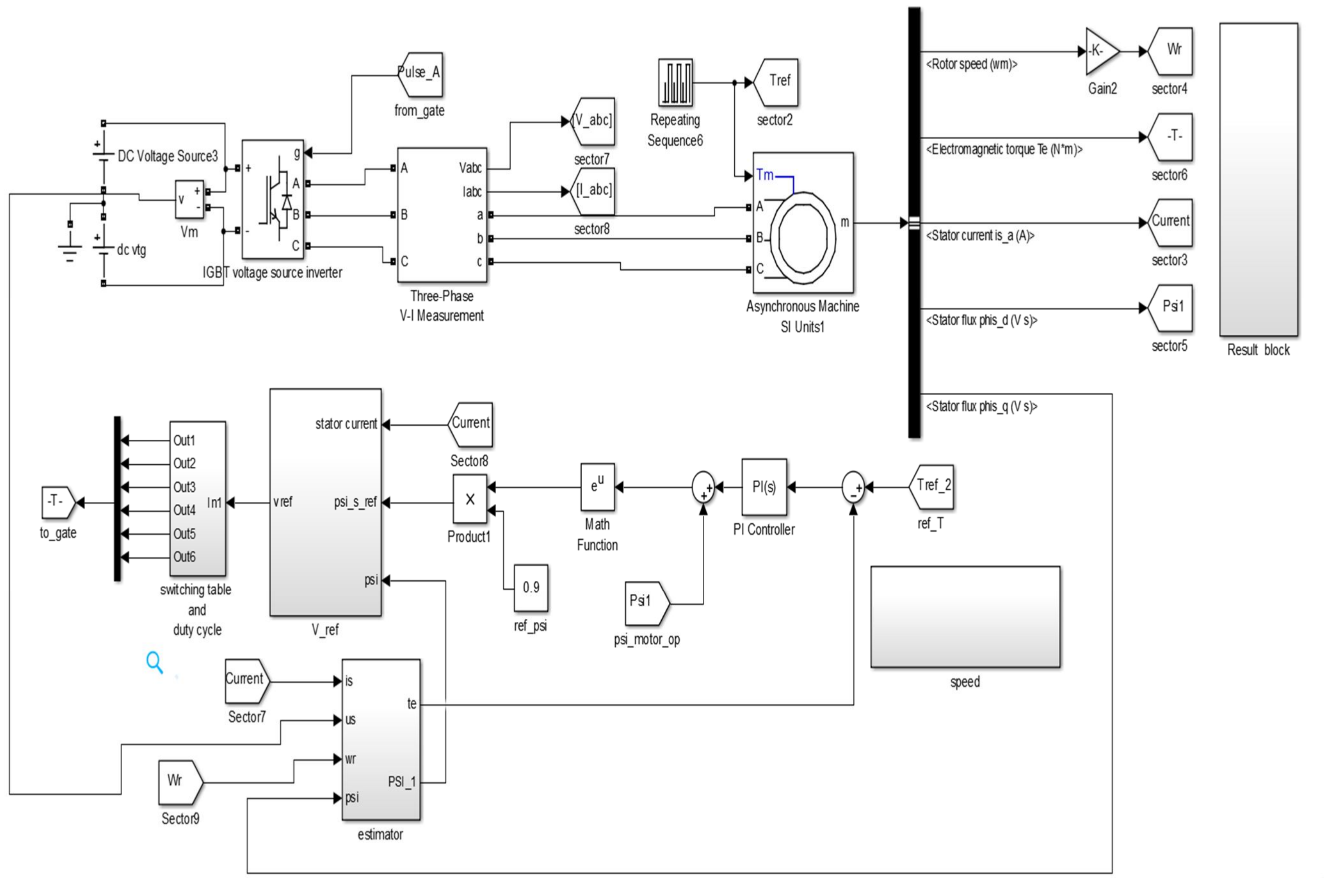


Fig. 2 Simulation Diagram For MVE-DTC

In MVE DTC, the rotor speed is considered as constant for one period because of mechanical inertia. Thus, by changing the rotational speed for stator flux, torque can be controlled.

$$\angle\Psi_s^{ref} = \angle\Psi_s + \left(k_p + \frac{k_i}{s}\right)\left(T_e^{ref} - T_e\right) \qquad (14)$$

Where,

$\angle\Psi_s$ = present stator flux

$\angle\Psi_s^{ref}$= phase of the stator flux reference

S = integration operator

k_p and k_i = proportional and integral coefficient

T_e^{ref} = torque reference

Then stator flux reference is

$$\psi_s^{ref} = |\psi_s|^{ref} e^{j\angle\psi_s^{ref}} \quad (15)$$

Where,

ψ_s^{ref} = amplitude of present stator flux reference

Now, u_s^{ref} can achieved by

$$u_s^{ref} = R_s i_s + \frac{\psi_s^{ref} - \psi_s}{T_s} \quad (16)$$

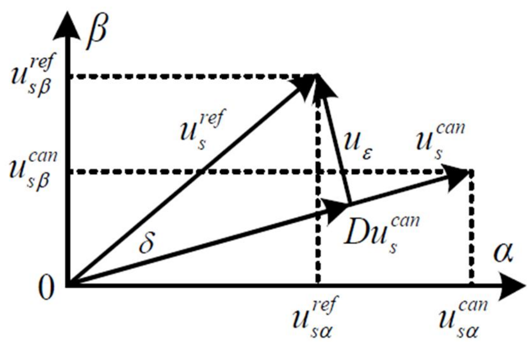


Fig. 3 Duty ratio optimization

After determining u_s^{ref}, for improving the current THD and torque ripples, we need to improve the duty ratio based MVE DTC. Fig 3 plots u_s^{can} and u_s^{ref}. When, changes 0 to 1, endpoint of Du_s^{can} moves from origin to endpoint of u_s^{can}. Now, u_ε is define as vector error between u_s^{ref} and Du_s^{can}. Here, D is duty ratio of u_s^{can} and can expressed as

$$D = \frac{|u_s^{ref}|\cos\delta}{2U_{dc}/3} \quad (17)$$

But to avoid the trigonometric and amplitude calculations for real time, another equation is formed for D.

$$D = \frac{u_s^{ref} u_s^{can}}{4U_{dc}^2/9} \quad (18)$$

By using above equations, control diagram is proposed and simulated in MATLAB environment.

Minimum voltage Victor error direct torque control has advantages over traditional direct or control. Here are some of the advantages:

1) There is difference in the way of selection of voltage vector in minimum voltage vector error direct torque control. In TDTC, the selection of voltage vector is completely dependent on the lookup table and hysteresis controller. While in the case of MVE DTC, selection of voltage vector is depends on PI type torque regulator.
2) In TDTC, the use of hysteresis controller causes the flux and torque Ripple one of the major drawbacks of TDTC. This drawback of torque ripple is effectively suppressed in case of MVE DTC avoiding the use of hysteresis controller.
3) The value of current THD is quite high in the case of TDTC which can be reduced by using MVE DTC.

V. RESULT

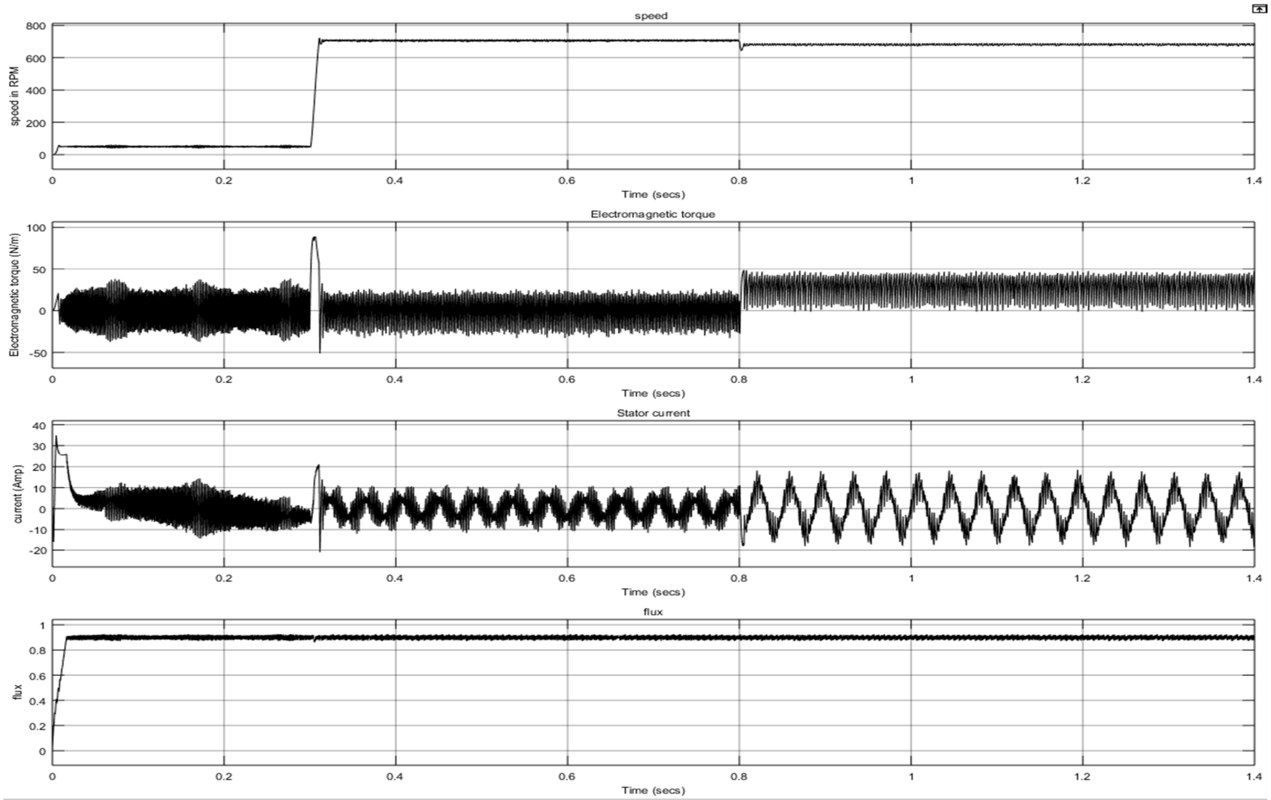
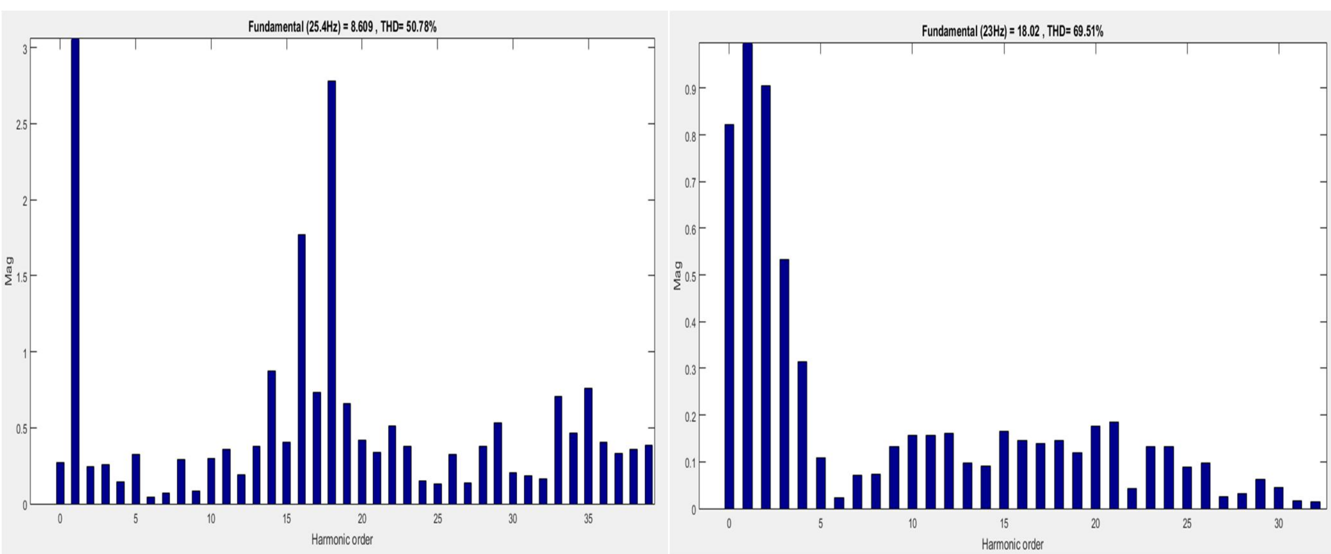


Fig.4 Simulation results of TDTC



(a) (b)

Fig.5 Simulation results of TDTC (a) On full load at 710rpm; (b) On no load at 710 rpm

The three-phase induction motor model is simulated by using the MATLAB/Simulink. Figure 1 depicts the complete Simulink model for TDTC and figure 2 for MVE DTC. In MVE DTC, method embrace PI type Torque regulator. While in TDTC hysteresis controllers are used. Induction motor is powered by using IGBT based Voltage Source Inverter (Universal Bridge). The performance of the motor is first checked out for 50 rpm speed on no load condition from 0 to 0.3 sec. At 0.3 sec Motor Speed Accelerates from 50 rpm to 710 rpm. At 0.8 sec, A rated load of 7.5 N is added and performance characteristics are drawn.

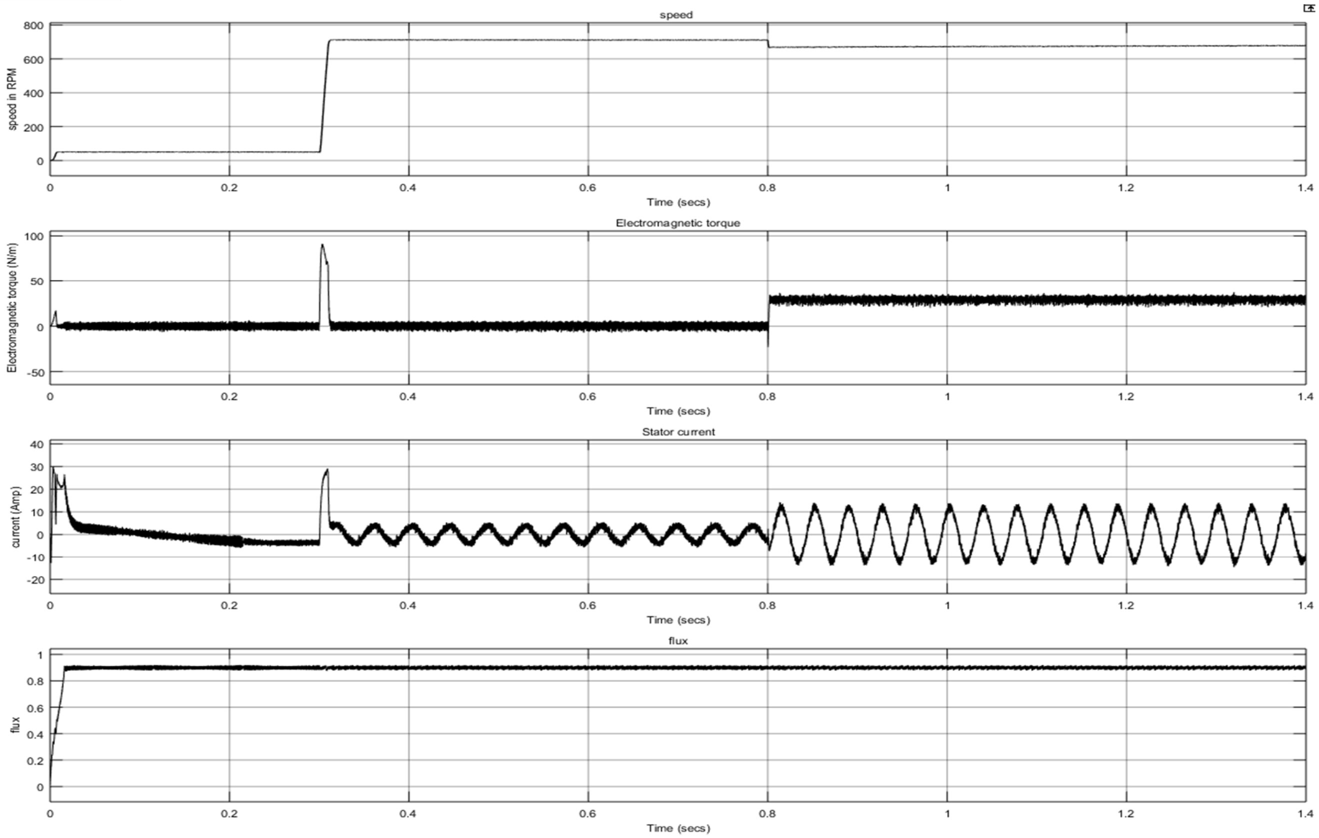
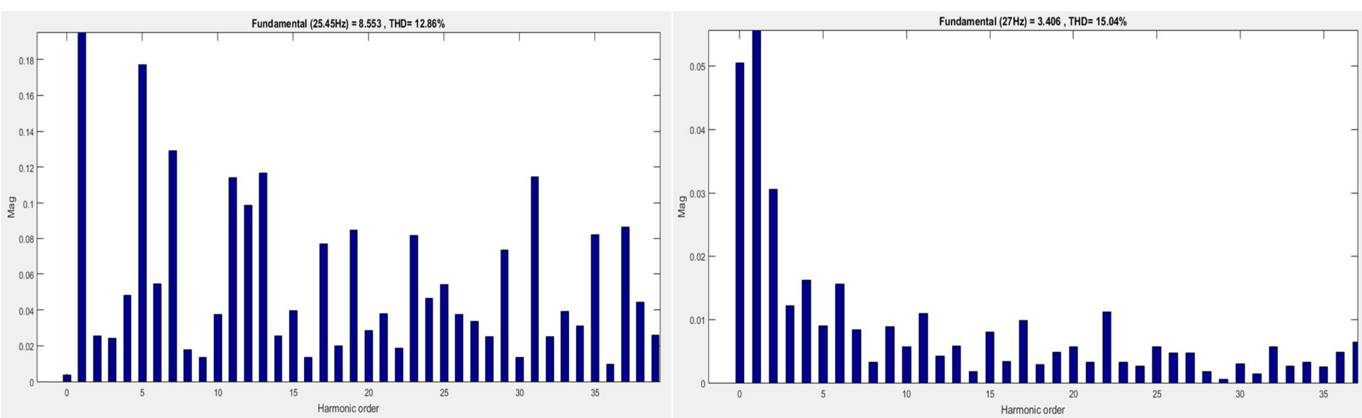


Fig.6 Simulation results of MVE-DTC



(a) (b)

Fig.7 Simulation results of MVE DTC (a) On full load at 710rpm; (b) On no load at 710 rpm

TABLE I MOTOR AND INVERTER PARAMETERS

Quantity	Value
Stator Resistance	3.32 ohm
Rotor Resistance	2.11 ohm
Stator Inductance	4.39 mH
Rotor Inductance	4.39 mH
Mutual Inductance	0.2373 H
Power	2200 VA
DC bus Voltage	400 V
Poles pair	2

Figure 4-7 depicts the Obtain Results. Initially the motor runs at 50rpm with no load. At 0.3 sec motor speed accelerates from 50 rpm to 710 rpm. At 0.8 sec, A rated load of 7.5 N is added. This explains that developed Minimum voltage vector error-based DTC attains high dynamic performance in speed response to variations in demand torque. It can be clearly observed from current THD graphs for both TDTC and proposed method that value of current THD is reduced by using Proposed method. Thus, from the results obtain we can say that the by using minimum voltage vector error DTC we get stable output along with better current THD and High Dynamic performance.

VI. CONCLUSION

In this work we have studied the control of induction motor by using minimum voltage vector error-based DTC. The obtained results have shown that the use of minimum voltage vector error-based DTC control method is simple in construction, efficient, and output the desired values of speed and torque. As we have studied in TDTC hysteresis control loops are used which increase the ripples in output, thus in proposed method the PI type torque regulator is used, it does not affect the response or making it sluggish. Also as observed from simulation results, the Induction motor can run stably under different working conditions Which justify the effectiveness of proposed method.

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