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Performance Analysis of Dircet Torque Controller Based Variable Structure Control of Induction Motor Drive

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Abstract

Induction motor drives are widely used in industries for its simple and easy control. Variable structure controller (VSC) for an induction motor drive is an effective method of control in case of non linearities and uncertainities to enhance robustness. Dynamic performance of an Induction motor drives is an essential characteristic for many industrial applications. Quality of the product is an industry and the profit of the industry are mainly depends on the performance of the induction motor drive. Transient state performance of the VSC based an induction motor drive to be improved. To enhance the performance of the system this paper proposes Direct torque control based VSC for induction motor control. The entire system is simulated using Matlab / Simulink to analyse the performance of a drive. Performance of a drive using DTC based VSC is analysed and compared with conventional VSC. To analyse the dynamic performance of the system machine is subjected to constant and variable load in this paper.

Keywords: Induction Motor, variable structure controller, Direct torque control, DTC based VSC,

Introduction

In many industries Induction motors plays vital role like backbone of an industry. It is used for its reliability and low cost. Performance of an induction motor drive decides the efficiency of an industry. So many reaserchers analysed to enhance the performance of a drive. Recently, many researchers presented the advanced control strategies for PWM inverter fed induction motor drive. Particularly, the vector control, which guarantees high dynamic and static performances like DC motor drives, has become very popular and has been developed and improved. Fast digital processor and power devices in the vector control drives provides the possibility of achieving high performance induction motor drive control. There are many works devoted to the vector control, but only few deals with the improving the performance of controller structure [1]. Classical control theory using Conventional PI controllers, provides good performance only in case of linear processes whose exact model is known. However, it is not possible to deal always with linear process. To achieve effective control using PI controller needs precise knowledge of motor and load parameters which is not possible in always.

Variable structure controller (VSC) is a sysetm to deal with nonlinearities[2]. The variable structure system is inherently aimed at dealing with system uncertainties, lead to good performances even in presence of strong and fast variations of the motor parameters. Many authors analysed the performance of variable structure systems with a sliding mode [3-5]. The VSC works on the principle of imposing the system motion to occur on a given manifold in the state space, which is defined according to the control tasks. VSC is more advantageous for its robustness, insensitivity to parameter variations, fast dynamic response. In the conventional VSC based induction motor drive PI controller is used [6]. In recent years, several investigations have been performed with the aim of improving steady state performance of the DTC method [16], e.g., Direct Self Control (DSC) for three phase induction motor control is analysed in [7] with various loads. DTC utilizing Space Vector Modulation (SVM) is analysed in [8] for induction motor control. Still to enhance the performance of drive with minimum components variable structure control is proposed in DTC in this paper.

Variable Structure Control Algorithm Description

The vector controlled induction motor drives are easily adoptable to VSC algorithm. In a sliding mode (SM) control, the reference model is stored in the form of a predefined phase plane trajectory, and the system response is forced to follow or slide along the trajectory by a switching control algorithm [9]. Sliding surface or sliding line is defined as the starting point of a sliding mode control design [10]. Ensuring the ablity of the system to reach or cross the chosen sliding line is the next stage of a control algorithm. After the system crossing the Sliding line, it will be able to cross it again for an infinite number of times.

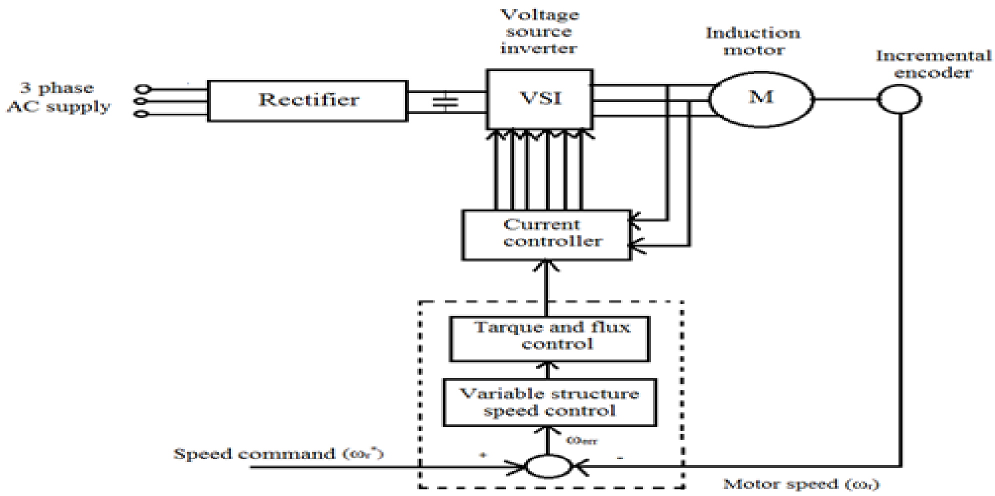

Figure 1: Configuration of the control system

In this paper, the motor speed is controlled in order to obtain a constant motor speed. So, the vector control task is to impose the convergence of the motor speed magnitude to a reference one. This goal can be fulfilled applying the VSC synthesis procedure to the error speed system equation. The block diagram of the vector control with speed controller is shown in Fig. 1.

The error between the motor speed and its reference can be obtained as follows;

$$\omega_{err}(t) = \omega_r^*(t) - \omega_r(t) \tag{1}$$

and its derivative can be obtained as [2];

$$\omega_{err}^0(t) = \left(-\frac{B}{J} + \frac{3P}{2}\frac{L_m}{L_r}k\right)\omega_{err}(t) \tag{2}$$

Where, k is a linear feedback-gain, B is the viscous friction, J is the moment of inertia, p is the number of pair poles, Lm is the mutual inductance, and Lr is the self inductance of the rotor per phase of the induction motor. So, the equivalent dynamic behavior of control system can be rewritten as [1];

$$\omega_{err}^0(t) = (a + bk)\,\omega_{err}(t) \tag{3}$$

Where, £ = −B/J , ¥ = 3p/2. Lm/Lr , k is a feedback gain, and (£ + ¥k) is designed to be strictly negative. The switching surface with an integral component for the sliding mode speed controller is designed as follows [1];

$$S(t) = \omega_{err}(t) - \int_0^t (a + bk)\,\omega_{err}(\Gamma)\,d\Gamma \tag{4}$$

It is obvious from the equation (3) that the speed error will converge to zero exponentially if the pole of the system is strategically located on the left-hand plane. Thus, the overshoot phenomenon will not occur, and the system dynamic will behave as a state feedback control system. Based on the developed switching surface, a switching control law, which satisfies the hitting condition and guarantees the existence of the sliding mode, is then designed. So, the variable structure speed controller is designed as the following,

$$I_q^s(t) = k\ \omega_{\text{err}}(t) - \beta \text{sgn}(S(t)) \tag{5}$$

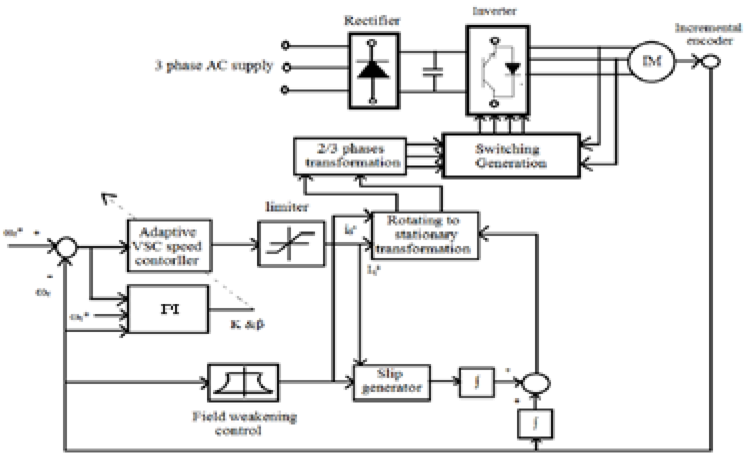

Figure 2: VSC For Vector Controlled Induction Motor Drive

Where, β is denoted as switching gain, with the following assumption, $\beta \geq 0$, Iq is the reference torque component current, and sgn(·) is a signum function defined as,

$$\text{Sgn}(S) = \begin{cases} 1 \text{ for } S > 0, \\ 0 \text{ for } S = 0, \\ -1 \text{ for } S < 0, \end{cases} \tag{6}$$

Hence, the dynamic behavior on the sliding surface can be described by Equation (3), and the tracking error err (t) converges to zero exponentially. The torque current command can be obtained according to Equation (5). The values of k and β plays an important role in control structure. In this paper PI and Fuzzy controller based determination of these paraemetrs and performance of drive are analysed.

Classical Direct Torque Control (DTC)

The block diagram of classical DTC proposed by I. Takahashi and T. Nogouchi [11] is presented in Fig. 3.

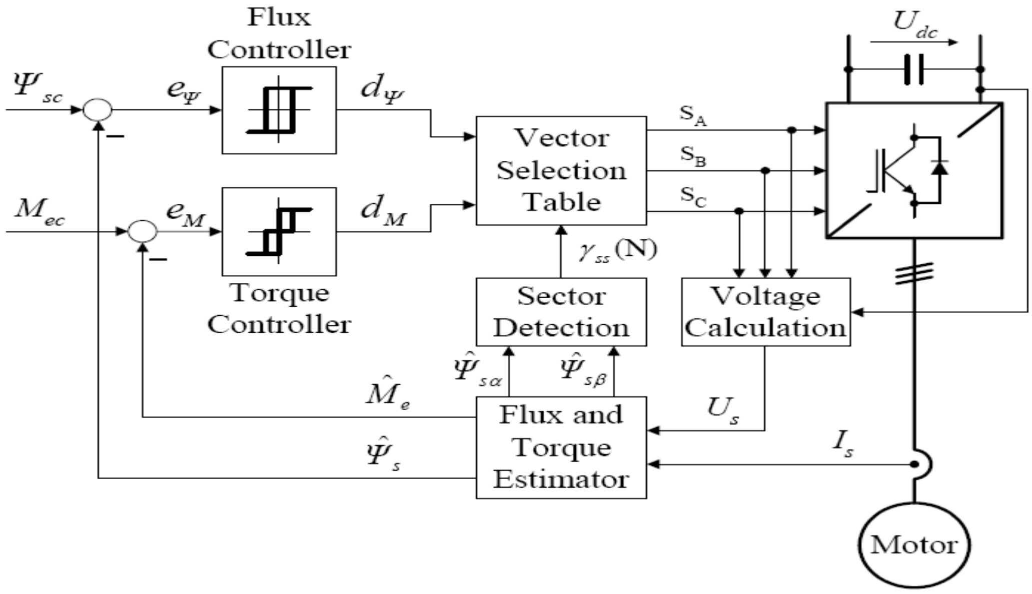

Figure 3: Block Scheme of The Direct Torque Control Method

The stator flux amplitude Ψ_s and the electromagnetic torque M_c are the reference signals which are compared with the estimated $\widehat{\Psi}_s$ and $\widehat{M}_e$ values respectively. The flux e_Ψ and torque e_M errors are delivered to the hysteresis controllers [13]. The digitized output variables d_Ψ, d_M and the stator flux position sector $\gamma_{ss}(N)$ selects the appropriate voltage vector from the switching table. Thus, the selection table generates pulses SA, SB, SC to control the power switches in the inverter [14]. For the flux is defined two-level hysteresis controller, for the torque three-level, as it is shown in Fig. 4.

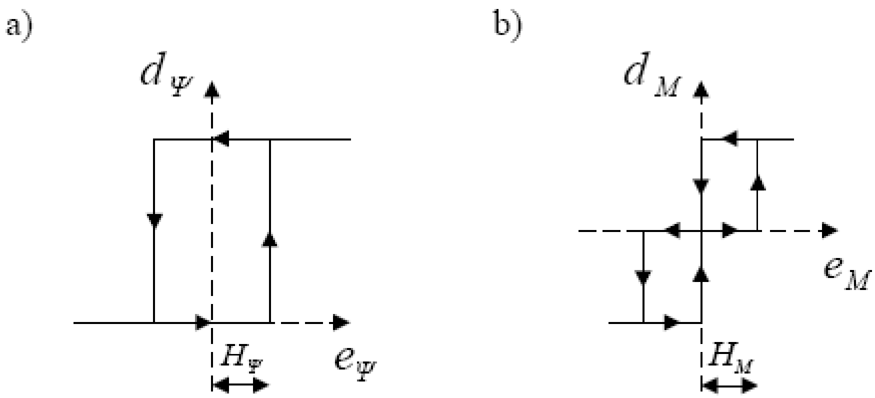

Figure 4: The hysteresis controllers a) two-level, b) three-level

The output signals d_Ψ, d_M are defined as:

$$d_\Psi = 1 \; for \; e_\Psi > H_\Psi \quad (7)$$

$$d_{\Psi} = 0 \; for \; e_{\Psi} < -H_{\Psi} \tag{8}$$

$$d_M = 1 \; for \; e_M > H_M \tag{9}$$

$$d_M = 0 \; for \; e_M = 0 \tag{10}$$

$$d_M = -1 \; for \; e_M < -H_M \tag{11}$$

In the classical DTC method the plane is divided for the six sectors (Fig. 5), which are defined as:

$$Sector\ 1{:}\ \gamma_{ss} \in \left(-\frac{\pi}{6}, +\frac{\pi}{6}\right) \tag{12}$$

$$Sector\ 2{:}\ \gamma_{ss} \in \left(+\frac{\pi}{6}, \frac{\pi}{2}\right) \tag{13}$$

$$Sector\ 3{:}\ \gamma_{ss} \in \left(+\frac{\pi}{2}, +\frac{5\pi}{6}\right) \tag{14}$$

$$Sector\ 4{:}\ \gamma_{ss} \in \left(+\frac{5\pi}{6}, -\frac{5\pi}{6}\right) \tag{15}$$

$$Sector\ 5{:}\ \gamma_{ss} \in \left(-\frac{5\pi}{6}, -\frac{\pi}{2}\right) \tag{16}$$

$$Sector\ 6{:}\ \gamma_{ss} \in \left(-\frac{\pi}{2}, -\frac{\pi}{6}\right) \tag{17}$$

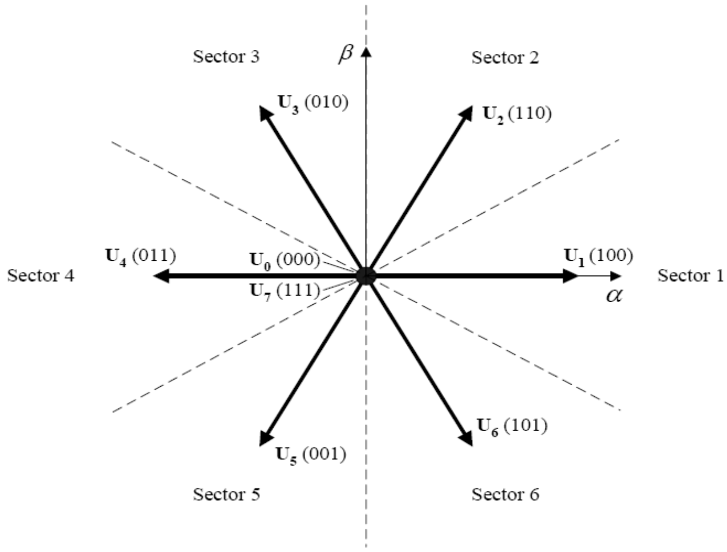

Figure 5: Sectors In The Classical DTC Method

For the stator flux vector laying in sector 1 (Fig. 5) in order to increase its magnitude the voltage vectors U1, U2, U6 can be selected. Conversely, a decrease can be obtained by selecting U3, U4, U5. The stator flux vector is not changed. For the torque control, angle between stator and rotor flux δ_{Ψ} is used [15] . Therefore, to increase motor torque the voltage vectors U2, U3, U4 can be selected and to decrease U1, U5, U6.

The above considerations allow construction of the selection table as presented in Table 1.

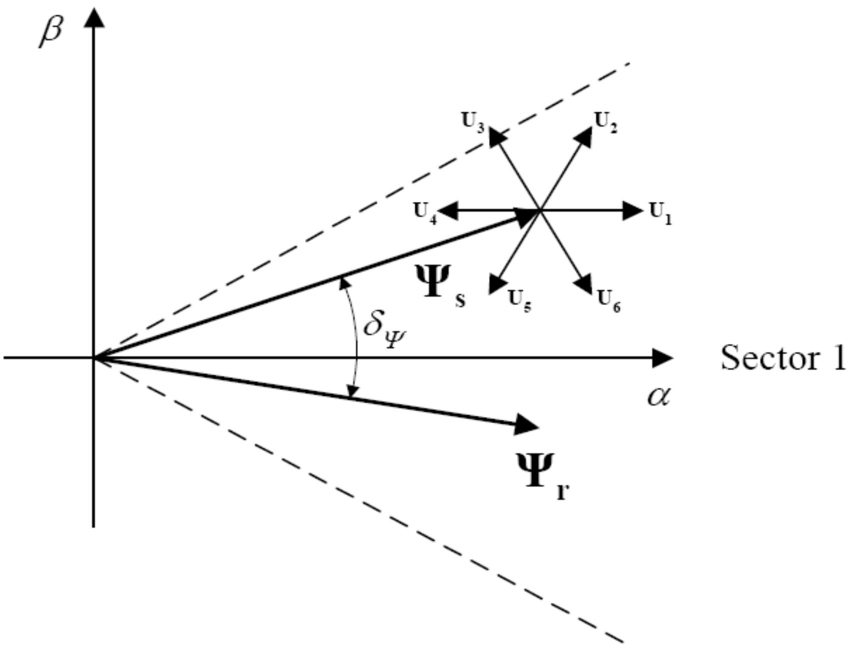

Figure 4.8: Selection of the optimum voltage vectors for the stator flux vector in sector 1

Table 1: Optimum switching table

d_Ψ	d_M	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
1	1	U_2	U_3	U_4	U_5	U_6	U_1
	0	U_7	U_0	U_7	U_0	U_7	U_0
	-1	U_6	U_1	U_2	U_3	U_4	U_5
0	1	U_3	U_4	U_5	U_6	U_1	U_2
	0	U_0	U_7	U_0	U_7	U_0	U_7
	-1	U_5	U_6	U_1	U_2	U_3	U_4

The DTC was proposed as an analog control method. The implementation of the hysteresis controller in the analog setup is easy and the control system works properly. When the hysteresis controller is implemented in a digital signal processor (DSP), its operation is quite different from that of the analog scheme [12]. The digital implementation of the hysteresis controller is also called *sampled hysteresis*.

Direct Torque Control Using Variable Structure Control Scheme:

In this thesis, the strategy is based on torque and square of stator flux variable structure controllers; the block diagram of the proposed strategy is shown in Fig. 4.10. The outer PI controller and the square of the stator flux generator produce the reference values of torque and square of stator flux, then the difference between torque and square of stator flux reference values and estimated values are sent to the variable structure direct torque controller, the results of the controller are the control voltage vectors in the stationary frame.

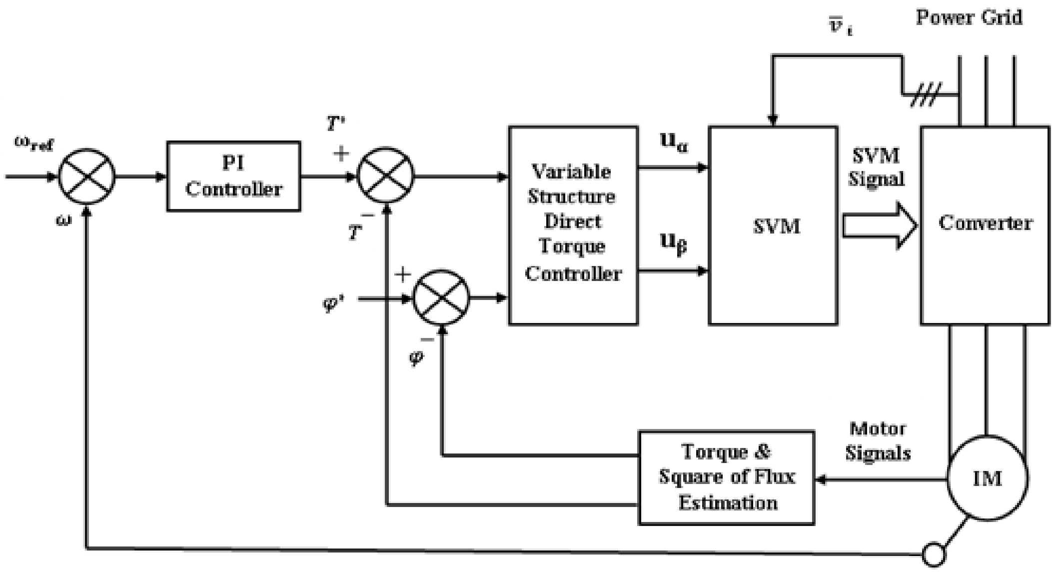

Figure 6: DTC of Induction Motor Based On Variable Structure Control

Simulation Results and Analysis

To analyze the performance of DTC based variable structure controlled induction motor 5 HP squirrel induction motor is taken. Parameters of induction motors are shown in table 2:

Table 2: Motor Parameters

Line Voltage	415
Frequency	50 Hz
Stator Resistance (R_s)	1.15Ω

Rotor Resistance (R_r)	1.083Ω
Stator inductance (L_s)	5.974 mH
Rotor inductance(L_r)	5.974 mH
Mutual inductance(L_m)	0.2037H
Moment of Inertia (J)	0.02 $Kg.m^2$
Number of poles (P)	4

The performance of the motor using VSC is shown in figure 12. The performance is analyzed under No load while the machine is running. The reference speed of the machine is set at 1500 rpm.

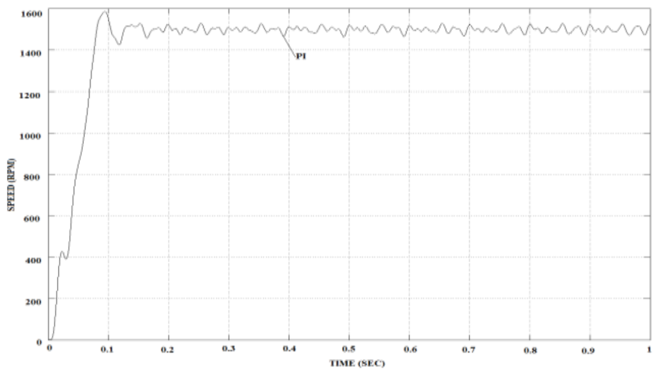

Figure 12: Speed performance of PI based VSC control

The performance of the motor using DTC based VSC are shown in figure.13 Conditions for analyses are same as a VSC controller test.

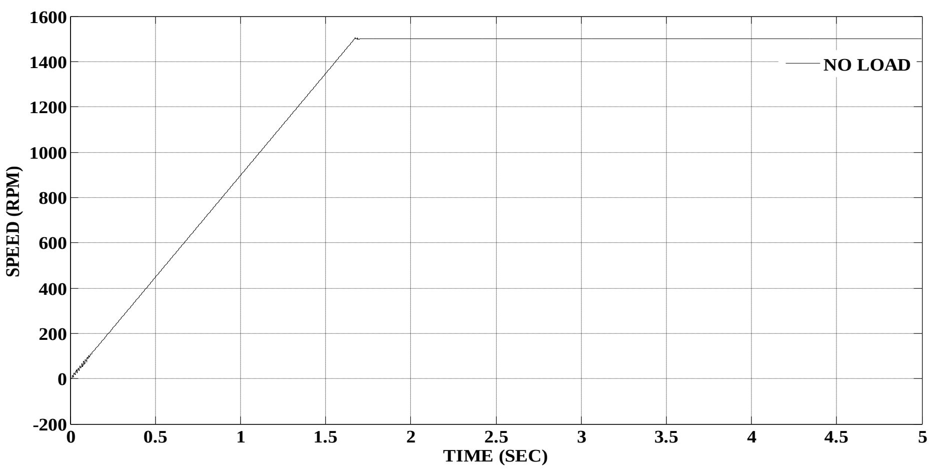

Figure 13: Speed performance of DTC based VSC control

The performance of the motor using VSC is shown in figure16. The performance is analyzed under a load while the machine is running. The reference speed of the machine is set at 1500 rpm.

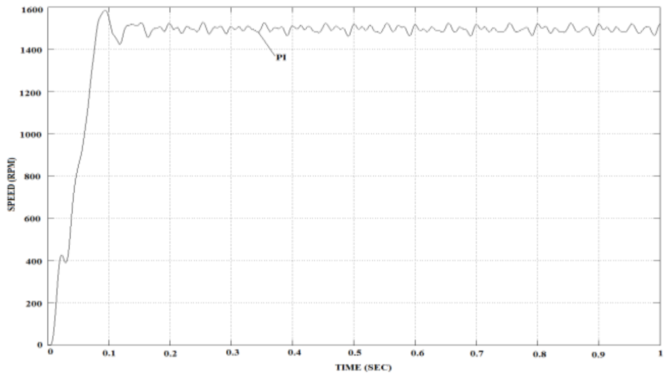

Figure 16: Speed performance of VSC control with change in load

The performance of the motor using DTC based VSC are shown in figure 17. Conditions for analyses are same as a VSC controller test.

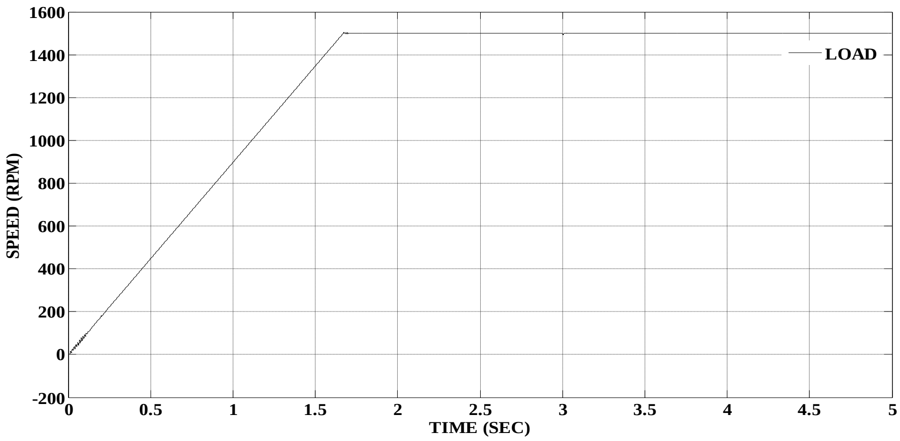

Figure 16: Speed performance of DTC based VSC control with change in load

Table 5: Performance comparison of VSC and DTC based VSC Controller

Controllers	Peak overshoot in %	Rise time in Sec	Settling time in Sec	Steady state error in %	Change in speed during load change in %
VSC	5.67	0.082	0.2	2.667	0.4
DTC based VSC	0.29	0.104	0.117	0.0030	0.4

Conclusions

Induction motors are widely used in many industries in daily applications. Performance enhancement of it is necessary to improve quality of product. The Direct Torque Control based Variable structure control is proposed in this for induction motor drive for its high robustness. It means that the system is completely insensitive to parametric uncertainty and external disturbances. Simulation is done using Matlab. Performance of VSC and DTC based VSC of IM are analyzed under various speeds and loads. From the simulation results it is obvious that VSC alone gives almost quick response but it produces large overshoot, steady state error and high fluctuation in speed while sudden change in load. The DTC based VSC performs well in all aspects such as overshoot, steady state error and change in speed while sudden change in load. Therefore it is optimum to use DTC based variable structure control for Induction motor control.

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