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PERFORMANCE EVALUATION OF CONVENTIONAL PI CONTROLLER BASED DIRECT TORQUE CONTROL STRATEGY FOR SPEED CONTROL OF INDUCTION MOTOR UNDER HIGHLY VARIABLE LOAD CONDITIONS.

Yagya Bharti Goswami*, S. M. Deshmukh

* Department of Electrical and Electronics, Disha Institute of Management and Technology, Raipur(CG) India.

Department of Electrical and Electronics, Disha Institute of Management and Technology, Raipur(CG) India.

ABSTRACT

Direct torque control (DTC) is one of the most excellent speed regulation strategies for induction motor via controlling of torque. The purpose is to control effectively the torque and flux. Direct torque control is the first technology to control the real motor control variables of torque and flux. This method made the motor more accurate and fast torque control, high dynamic speed response and simple to control. The reference value can be calculated using the flux and torque estimated and also motor parameter. In the conventional DTC strategy, speed control of motor is performed by employing PI controllers. Usually the performance of conventional PI controller, employed in DTC, is found satisfactory during the motor speed regulation. But the scenario of speed regulation with this controller, highly dependent on the system load characteristics. This paper presents a complete performance evaluation of conventional PI controller based DTC strategy for the speed regulation of induction motor under highly variable load conditions. For the implementation and performance evaluation a versatile simulation package, MATLAB/SIMULINK 2012(b) has been utilized.

KEYWORDS: Induction Motor, Speed Regulation, Direct Torque Control, MATLAB/SIMULINK.

INTRODUCTION

The interest for industrial applications of Induction Motor (IM) drives is continuously increasing, and a huge number of solutions have been proposed in order to fulfil two main objectives , namely :

i) precise and quick control of the motor flux and torque, and ii) reduction of the complexity of the control algorithms. The Direct Torque Control (DTC) technology has gained popularity for induction motor drives since its inception. It is considered particularly interesting due to its several advantages [1]. Proposed in the middle of the 1980s by I. Takahashi as Direct Torque Control (DTC) [2] and by M. Depenbrock as Direct Self Control (DSC) [3] DTC has attracted great interest since the beginning for its simplicity, good performance, independent machine rotor parameters and robustness [4]. Recently, DTC has become more and more useful in the industrial field; various applications are founded in literature, even in renewable energy applications [1], [5,6]. The DTC strategy involves a simple control scheme, using flux and torque as primary control variables and employs two hysteresis comparators and a heuristic switching table to obtain quick dynamic response which makes it possible rapid real-time implementation [2].

The major problem in this basic DTC is the presence of ripple in the electromagnetic torque and stator flux, leading to vibration of connected mechanical parts causing acoustic noises [7]. This makes the voltage source inverter operated in high and variable switching frequency, requiring a high sampling frequency. Since then, many DTC strategies carried out in attempt to improve the performance of the original DTC strategy. These could be classified within two major categories: In the first category, (SVM-DTC) space vector modulation is employed to produce continuous voltage vectors; hence, the torque and flux ripples were reduced while obtaining fixed switching frequency [8]. In the second category, the multilevel inverter is introduced to obtain more voltage vectors [9]. However, the drawbacks of the cited controls are: rotary coordinate transformation is often needed, a complicate schema and more computationally intensive compared to the conventional DTC. So, the cost and complexity of the control is increased proportionally. An alternative method to reduce the ripples is based on space vector modulation (SVM) technique [10], [11]. Direct torque control based on space vector modulation (DTC-SVM) preserve DTC transient merits, furthermore, produce better quality steady-state performance in a wide speed range. At each cycle period, SVM technique is used to obtain the reference voltage space vector to exactly compensate the flux and torque errors. The torque ripple of DTC-SVM in low speed can be significantly improved.

In the conventional DTC strategy, speed control of motor is performed by employing PI controllers. Usually the performance of conventional PI controller, employed in DTC, is found satisfactory during the motor speed regulation. But the scenario of speed regulation with this controller, highly dependent on the system load characteristics. This paper presents a complete performance evaluation of conventional PI controller based DTC strategy for the speed regulation of induction motor under highly variable load conditions.

DIRECT TORQUE CONTROL OF INDUCTION MOTOR

The basic concept of the Direct Torque Control (DTC) method was proposed by Takahashi and Noguchi in 1986. This method is more used in controlling the induction motor because it is considered a simple and robust method. The power inverter operational control is an important key in this method and modern power electronics has made this cost effective as well. The simple objective is to control two quantities which are the stator flux vector and the electromagnetic torque. Those quantities are directly controlled by selecting the proper inverter state with a combination of sense, command and control feedback loops and by power electronics drive control in the inverter stage. High dynamic performance can be achieved by the stator flux because the latter is close to being sinusoidal.

The stator EMF depends on the stator flux, so the magnitude of the EMF depends on the stator voltage. Hence, e $=\int(Vs\text{-}\ r_s i_s)dt$, and the torque, as the general definition, is the cross product of the stator flux and the rotor flux. As a result, the magnitude of the stator flux and the developed electromagnetic torque can be adjusted by selecting the state of the inverter of space vectors of the stator voltage [12].

Space Vector Modulation of Three Phase Voltage Source Inverter with DTC

If the voltage vector is shifted (lag or lead) with respect to the stator flux vector by an angle which is not more than 90°, this causes the flux to increase and vice versa. The developed torque is then directly controlled by selecting the inverter situation in order to boost the statorflux up or buck it down. The circuit diagram of the inverter is shown in Figure 1 and the state of square-wave operation as in Figure 2; the voltage vector is obtained by the equation 1.

$$V_K = V_i e^{j\theta v,k} \qquad \dots (1)$$

When $V_i$is the dc voltage rare, and $\theta_{v,k}$ is given as:

$$\theta_{v,k} = (K-1)\frac{\pi}{3} \qquad \dots (2)$$

The plane is divided by 6 sectors; hence each sector has a 60° interval as shown in Figure 2. K, in Equations (1) and (2), is the sector number which defines the state of the inverter. Because the stator flux vector, which can be defined as

$\lambda_s = |\lambda_s| e^{j\theta s}$ is depending on the complex stator voltage (V^K), When the voltage falls into the a specific sector K that means the operation is on that sector.

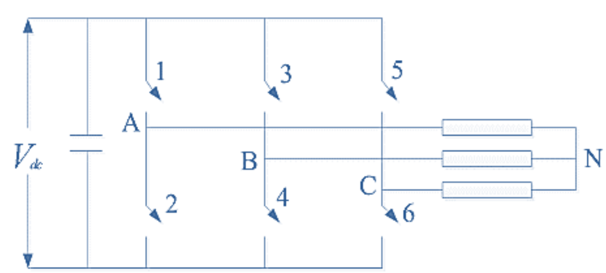

Figure 1 : Circuit Diagram of Three phase Voltage Source Inverter, where control of the switch sequencing allows determination of the frequency and the phase of the generated AC

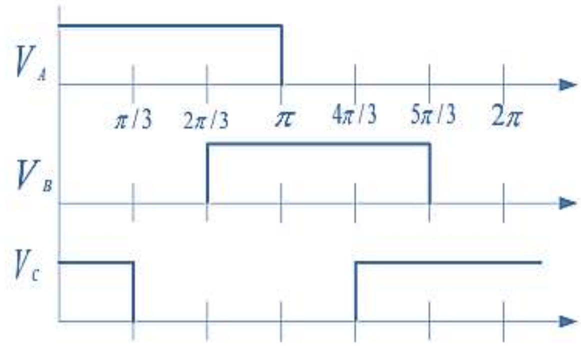

Figure 2: Three phase square-wave forms which is produced by the inverter

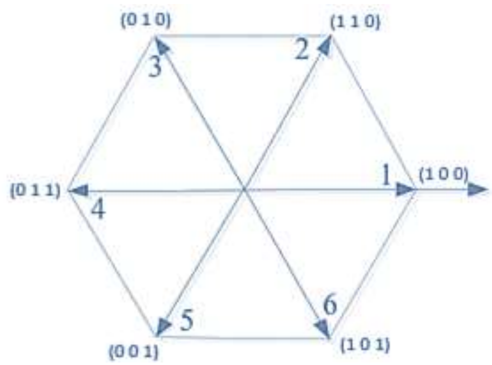

Figure *Error! No text of specified style in document.* ***: illustrative Phase Voltages in Space Vector***

Basic principles of Switching Table

The main concept for employing a switching table in DTC is that the measured values of stator flux and electromagnetic torque are compared to reference values, i.e. λs*and Tem*through what is called hysteresis controller. These two hysteresis controllers are different for Torque and flux. Because the flux and torque have to fall into a certain band for switching table DTC, we have two limits, which is considered as the tolerance number of allowing being "how far" from the desired value we can employ this method and still be accurate. In practice, the flux controller provides two cases (a two level controller). In contrast to achieve the desired output torque the hysteretic controller need provide three separate cases. The equations 3 and 4 represent the hysteresis band limits for the flux tables and equations 5 through 7 represent the three levels hysteresis bands of the torque tables [16].

$\lambda_{err} = 1, for\ \lambda_s < \lambda_s^* - \varepsilon_\lambda$ ... (3) $\lambda_{err} = -1, for\ \lambda_s < \lambda_s^* + \varepsilon_\lambda$... (4)
$T_{err} = 1, for\ T_{em} < T_{em}^* - \varepsilon_T$.. (5)$T_{err} = 1, for\ T_{em} < T_{em}^* - \varepsilon_T$.. (6)$T_{err} = 0, for\ T_{em} = T_{em}^*$ ..
(7) $T_{err} = -1, for\ T_{em} < T_{em}^* + \varepsilon_T$..(8)

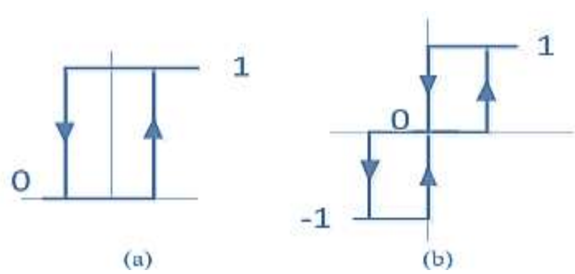

Figure 4: Hysteresis bands (a) The stator flux,

(b) Electromagnetic torque

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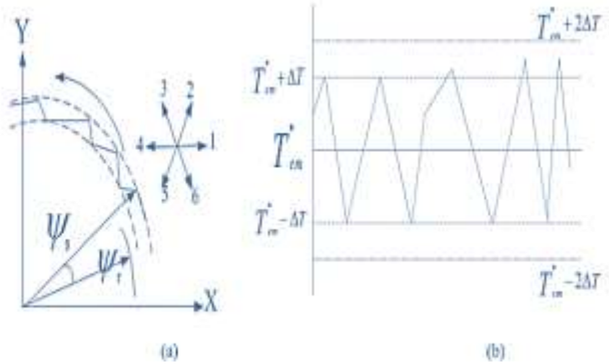

Figure 5 (a): The hysteresis band controls the stator flux voltage,

(b): The torque is controlled by the three level hysteresis bands

Table 1 . The effect of the voltage vector on the stator flux vector in Sector I

$\vec{v}_s$	Tem	$\hat{\lambda}_s$
$\vec{v}3$	Increase	Increase
$\vec{v}2$	Increase	Decrease
$\vec{v}4$	Decrease	Decrease
$\vec{v}5$	Decrease	Increase

Where $2\varepsilon_\lambda$ is the flux tolerance band and $2\varepsilon_T$is the torque tolerance band. Table 1 represents the switching table logic based on the equations 3 to 7. This results in the six sectors of the hysteretic table below for inverter outputs.

Table 2. Switching table of inverter vector voltages

$\lvert\lambda_{err}\rvert$	T_{err}	Sectors					
		I	II	III	IV	V	VI
FU	TU	V_2	V_3	V_4	V_5	V	V_1
FU	TD	V_6	V_1	V_2	V_3	V	V_5
FD	TN	V_7	V_0	V_7	V_0	V	V_0
FD	TU	V_3	V_4	V_5	V_6	V	V_2
FD	TD	V_5	V_6	V_1	V_2	V	V_4
FD	TN	V_0	V_7	V_0	V_7	V	V_7

It should be noted that FU: Flux Up, TU: Torque Up. FD: Flux Down, TD: Torque Down and TN: Torque Neutral. The voltages from V1 to V6 are the active six voltage vectors and V0 and V7 are the zero voltages.

Stator Flux Linkage and Torque Control

When the proper inverter voltage sequence (V_1-V_6) is selected, the stator flux is going to be rotating at the desired synchronous speed within the specified band. As mentioned earlier, the stator flux monotonically follows the stator voltage, when the stator resistance is small enough to be neglected. Thus, changing the stator flux space vector can be accomplished by changing the stator voltage during a desired period of time.

$$V_s = \frac{d\psi_s}{dt} \rightarrow d\psi_s = V_s dt \quad \ldots (8)$$

$$\text{i.e. } \Delta\psi_s = V_s dt \quad \ldots (9)$$

We can obtain the electromagnetic flux using equation 8 and the electromagnetic torque depends on the sin of the angle between the stator flux and rotor flux, i.e.$\theta_{sr,}$as $\theta_{sr} = \theta_s - \theta_r$Since it is easier to adjust the stator flux through the stator voltage, the variation of the developed electromagnetic torque is done by varying the stator flux vector, the stator flux magnitude and the angle between stator flux and rotor flux as equation 9. It is summarized in Figure 6 that is Direct Torque Control Block Diagram of Induction motor operation.

$$T_{em} = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_s'}\psi_s\psi_r sin\theta_{sr} \qquad ..... (10)$$

$$\Delta T_{em} = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_s'}(\psi_s + \Delta\psi_s)\psi_r \, sin\Delta\theta_{sr} \quad ... (11)$$

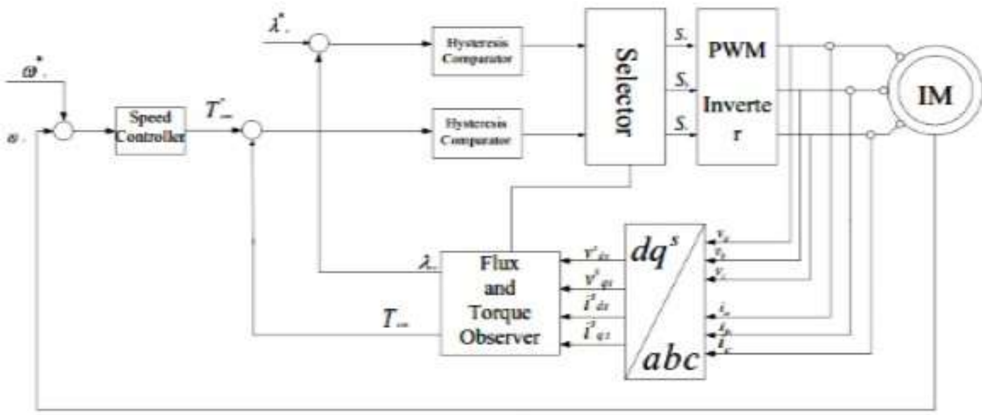

Figure 6 Block diagram of the Direct Torque Control of Induction motor

PERFORMANCE EVALUATION OF PI CONTROLLER BASED DTC SPEED CONTROL UNDER HIGHLY VARIABLE LOAD CONDITIONS

A MATLAB/SIMULINK model for the conventional PI controller based DTC is developed to present the speed control performance evaluation under highly variable load environment. For the simulation of highly variable load environment feedback torque is utilized and changed from 0 Nm to 180 Nm. the simulation is performed for 0.5 sec duration along with the load change at the 0.3 sec.

The 0 Nm torque indicates no load value, while 180 Nm torque represent very high load on the motor during the running of motor.

The actual simulation model developed for this work is shown in figure (7) and the parameters used for the simulation of the Motor are given below:

Power=15 kW, Rated voltage = 400V, Poles=2, Frequency =50Hz,Rs = 0.2147, Rr = 0.2205,
Ls = Lr = 0.000991 H,
Lm= 0.06419 H,J=0.102kg.m^2,F=0.009541 N.m.s

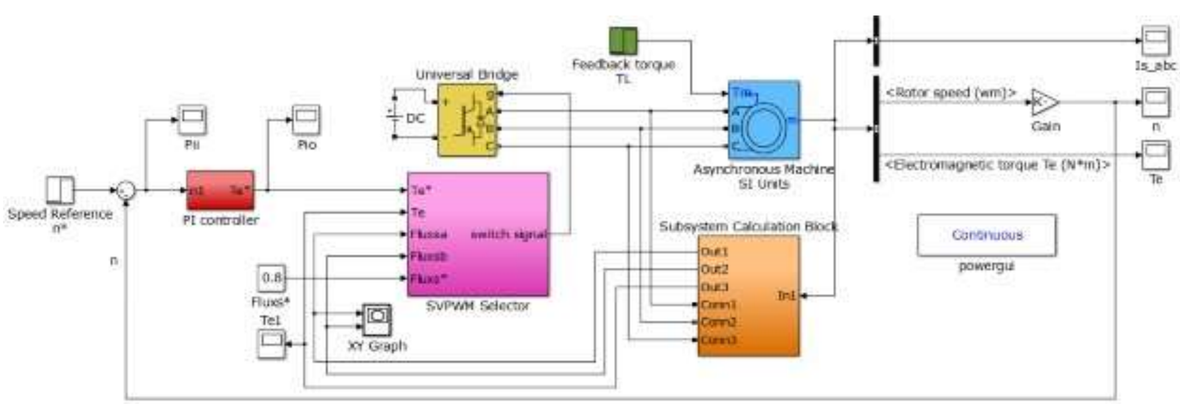

Figure 7 Actual Simulation Model Developed.

To present the simulation results under highly variable load environment, the reference speed of the motor is fixed at 1100 rpm and load torque is changed from 0 Nm to 180 Nm in steps of 30 Nm. Figure (8) to figures (14), shows the speed response waveforms of induction motor at 1100 rpm with different feedback torque values.

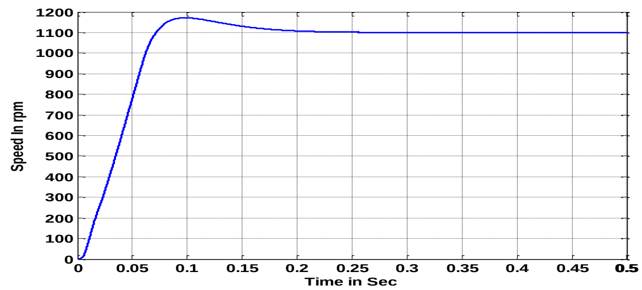

Figure 8Speed control of Induction motor using PI controller based DTC for reference speed = 1100 rpm and load Torque T_L= 0 Nm

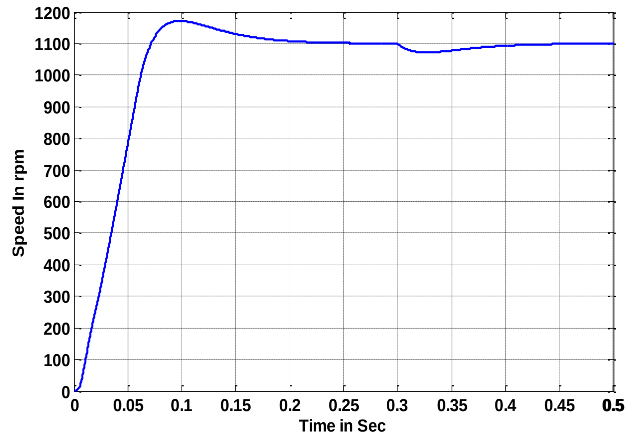

Figure 9 Speed control of Induction motor using PI controller based DTC for reference speed = 1100 rpm and load Torque T_L= 30 Nm.

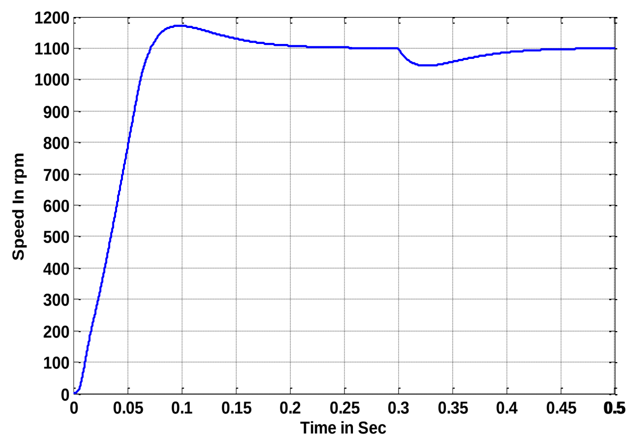

Figure 10 Speed control of Induction motor using PI controller based DTC for reference speed = 1100 rpm and load Torque T_L= 60 Nm.

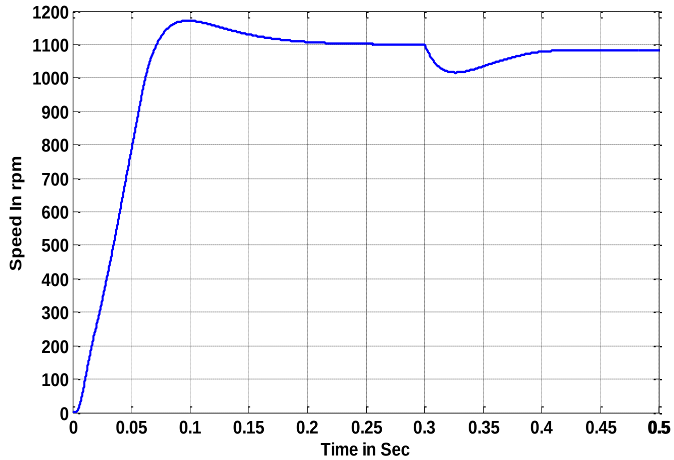

Figure 11 Speed control of Induction motor using PI controller based DTC for reference speed = 1100 rpm and load Torque T_L= 90 Nm.

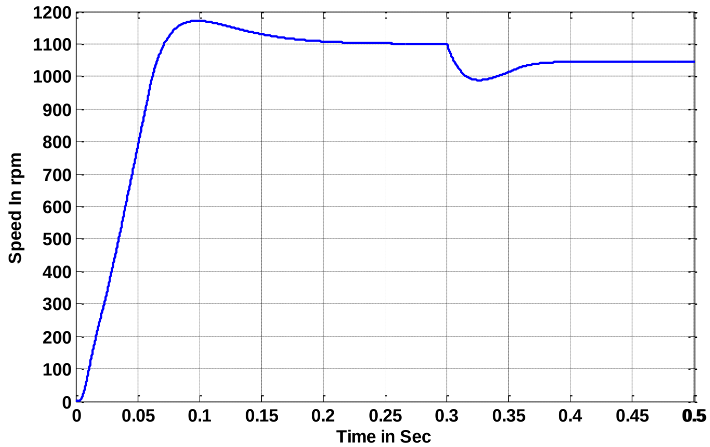

Figure 12 Speed control of Induction motor using PI controller based DTC for reference speed = 1100 rpm and load Torque T_L= 120 Nm.

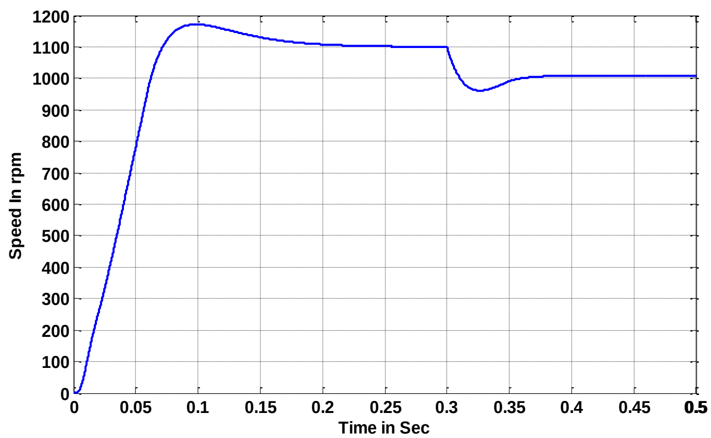

Figure 13 Speed control of Induction motor using PI controller based DTC for reference speed = 1100 rpm and load Torque T_L= 150 Nm.

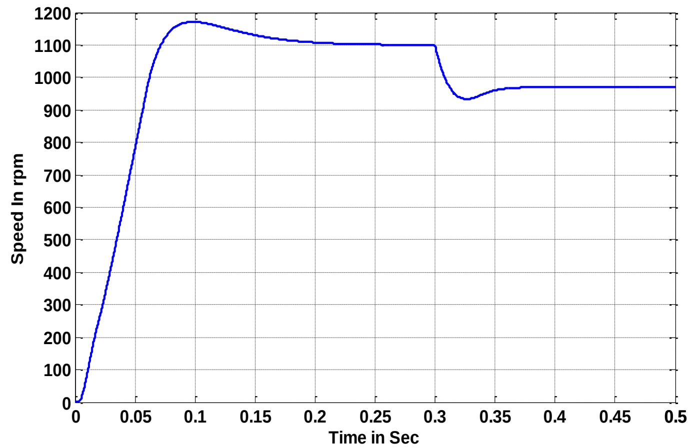

Figure 14 Speed control of Induction motor using PI controller based DTC for reference speed = 1100 rpm and load Torque T_L= 180 Nm.

From the resultant waveforms for speed control of induction motor shown from figure (8) to figure (14), it is clearly observable that, for no load case speed curve takes a big overshoot during the transient state and takes approximately 0.25 sec to reach the specified reference speed of 1100 rpm.

While considering the load change situations generated at the 0.3 sec, it is found that, the speed of motor starts deviation from the reference speed of 1100 rpm propostional to the amount of load used. For the highest load used here which is 180 Nm the deviation obtained is 150 rpm which is very high. In addition to this for high load situation the convention PI controller based DTC even not able to provide reduction in this difference after occurrence of the load.

CONCLUSIONS

In this paper a complete performance evaluation of conventional PI controller based DTC strategy for speed control of induction motor has been analyzed in detail. During the performance evaluation the main attention is given to obtain the capability of conventional PI controller based DTC to handle the variations in the load. The results obtained shows that, for no load case speed curve takes a big overshoot during the transient state and takes approximately 0.25 sec to reach the specified reference speed of 1100 rpm. While considering the load change situations generated at the 0.3 sec, it is found that, the speed of motor starts deviation from the reference speed of 1100 rpm propostional to the amount of load used. For the highest load used here which is 180 Nm the deviation obtained is 150 rpm which is very high. In addition to this for high load situation the convention PI controller based DTC even not able to provide reduction in this difference after occurrence of the load. Therefore the main contribution of this work is that, the conventional PI controller based DTC provides satisfactory speed regulation performance, but lacks with the handling of load variations.

REFERENCES

[1] D. Casadei, G. Serra, A. Tani, L. Zarri, "Direct torque control for induction machines: a technology status Review, IEEE Workshop on Electrical Machines Design Control and Diagnosis, WEMDCD 2013, pp. 117-129, Paris, France, 11-12 Mar. (2013).
[2] I. Takahashi, Y. Ohmori, "High-performance direct torque controlof an induction motor", J. sci. IEEE Trans. on IndustryApplications, vol. 25, pp. 257-264, Mar./Apr. (1989).
[3] M. Depenbrock, "Direct self-control (DSC) of inverter-fedinduction machine, J. sci. IEEE Trans. on Power Electronics, vol. 3,pp. 420-429, Oct. (1988).
[4] P. Vas, "Sensorless vector and direct torque control", ClarendonPress, (1998).
[5] J. Ben Alaya, A. Khedher, M.F. Mimouni, "Speed-sensorless DFIGwind drive based on DTC using sliding mode rotor flux observer",J. sci. International Journal of Renewable Energy Research, IJRER,vol. 2, no. 4, pp. 736-745, (2012).
[6] B. Mokhtari, A. Ameur, L. Mokrani, B. Azoui, M. F. Benkhoris,"DTC applied to optimize solar panel efficiency", in proc. of 5th IEEE Int. conf. on Industrial Electronics, pp. 1123-1127, IECON2009, Porto, Portugal, 3-5 Nov. (2009).

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[7] J. H. Leong, Z. Q. Zhu, "Acoustic Noise and Vibration of Direct-Torque-ControlledPermanent Magnet Brushless DC Drives , in proc. of 6th IET Int.conf. on Power Electronics, Machines and Drives, PEMD 2012, pp.1-6, Brighton, UK, 27-29 March (2012).
[8] Y. Zhang, J. Zhu, "Direct torque control of permanent magnetsynchronous motor with reduced torque ripple and commutationfrequency", J. sci. IEEE Trans. Power Electronics, vol. 26, no. 1, pp.235–248, Jan. (2011).
[9] B. EI Badsi, B. Bouzidi, A. Masmoudi, "Bus-Clamping-BasedDTC: An Attempt to Reduce Harmonic Distortion and SwitchingLosses", J. sci. IEEE Trans. Power Electronics, vol. 60, no. 3, pp.873–884, Mar. (2013).
[10] A. Arias, J. L. Romeral, and E. Aldabas, "Fuzzy logic direct torque control," in Proc. IEEE ISIE, 2000, vol. 1, pp. 253–258.
[11] D. Seyoum, M. F. Rahman, and C. Grantham, "Simplified flux estimation for control application in induction machines," in IEMDC'03, 2003, vol. 2, pp. 691–695.
[12] Yuedou Pan; Yihai Zhang; Zhe Wang, [1] "A novel variable domain adaptive fuzzy control of direct torque control for induction motor based on space vector control," Fuzzy Systems and Knowledge Discovery (FSKD), Seventh International Conference on, vol.2, pp.649,644, 10-12 Aug. 2010.