International Journal of
Science and Engineering Investigations vol. 5, issue 58, November 2016
ISSN: 2251-8843

High Quality Performance of Three Level Inverter Based AC Drives

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Abstract- Direct torque control (DTC) is one of the most important control techniques used in induction motor drives to obtain high-performance torque control and speed response. However, the classical DTC-SVM has disadvantage through transient, steady state and low speed. One of the most important defects is a high torque ripple and harmonics in stator current. In this paper, the proposed control system for solve these problems by utilizing space vector modulation upon the reference torque and flux. In this proposed control technique, PI flux and PI torque controller are designed to investigation estimated flux and torque with good tracking and fast response with reference torque and there is no steady state error. In addition, design PI flux and PI torque controller are utilized to improve voltage in d-q axis which applied to SVM. Also, the power factor is improved in input side to reduce distorts in input current and voltage waveform. Therefore, reduce power quality associated with it. A dual boost converter is implemented on the front side circuit of the proposed system for improving power factor. The DTC-SVM is applied to the three-phase three-level neutral point clamped diode inverter (NPC) which fed the induction motor drive. This paper confirms using the Space Vector Pulse Width Modulation (SVPWM) technique for derivation of switching states. The proposed control is implemented using MATLAB/Simulink software package. Resulting tests which obtain from the proposed control is corrector of the power factor into near unity and improved overall performance induction motor.

Keywords- *Direct torque control, Three-level inverter neutral point clamped (NPC), Space vector pulse width modulation (SVPWM), PI controller, Dual boost converter*

I. INTRODUCTION

In recent years, the induction motor is the motor drive most widely used in the industry. With a development of technological advances in the field of microcontroller microcomputers, and simplify operations and control theory performance of induction motors so it can replace the role of the DC motor as electric drives. The induction motors have Simple construction, low cost and easy maintenance, it makes most popular than other electrical motors. Three-phase induction motors has a complex operating principle, which is reflected in the complexity of the mathematical equations that describe it, and this leads to a difficulty in applying control methodologies [1-2]. In spite of the complexity mentioned above, there is no doubt that induction motors are currently preferred in industry for the different features and facilities they offer [3]. While a lack of induction motor which is of its nature that is not linear, the pace setting techniques relatively difficult and requiring a high starting current about six to eight times the nominal current of the motor. Induction motor speed settings can be done in various ways such as control voltage/frequency (v/f) or known scalar control. The principle is to force the motor has a relationship constant between voltage and frequency. As well as vector control the set directly the current stator motor. Method vector control is today continuing to be developed is the method of the Direct Torque Control (DTC). That is a technique control which leads to a torque value settings that changed as needed load. The fundamental difference between vector control technique with DTC is on control vector input system is the speed and flux of stator. While in the DTC system is the input flux and torque [4]. However, classical DTC drive has ripples in torque, flux and stator currents during the transient and steady state [5]. The continuously these problems in the steady state and transient effect on speed estimation and distort in input voltage and current waveform. It also leads to high acoustic noise and harmonic losses. The purpose of this paper is to solve these problems and to achieve the implementation of an advanced control technique, such as vector control for induction motors. Specifically, the methodology is direct Torque Control based on space vector modulation (DTC-SVM). The main characteristic of the DTC-SVM control is that it allows direct control of the stator current according to the desired requirements, improving its efficiency [6]. The DTC-SVM depended on two PI speed controllers to estimation reference torque and flux. In addition, designing PI flux, PI torque controller to controlling amplitude stator voltage. In this method, the torque, flux and stator currents are very low ripples and high response for variation of loads as compared with classical DTC. The DTC-SVM which drive switching of the three phase three-level neutral point clamped inverter which fed induction motor is investigated. While remain problem distorts in input current, voltage and output DC voltage from rectifier which fed the multi-level inverter. This means the system has a poor power factor. To solve these problems has been used dual boost dc-dc converter between the rectifier and multi-level inverter is considered to correct the poor power factor produced by rectification of AC power supply by the uncontrolled rectifier. The dc voltage from the dual boost converter is fed to 3-φ multi-level inverter which controlled by (SVPWM) technique for driving three phase induction motor. The proposed control system is described obviously.

II. PROPOSED METHOD

The proposed control system DTC-SVM dependent on amplitude stator voltage and stator flux angle. The calculation of reference torque and flux based on design two PI speed controllers. In this proposed method design PI torque, PI flux for controlling in amplitude stator voltage. While controlling the stator flux angle by slip angular frequency and rotor angular frequency. DTC SVM system of a simple block diagram is shown in Figure 1. Its system consists of five main sections. These sections; stator flux and torque estimator, two PI speed controllers, PI torque, PI flux controller, PI controller for slip angular frequency and transformation from Cartesian to polar to estimation the amplitude of stator voltage, while transformation from polar to Cartesian to estimation stator voltages in d-q axis at next sampling time. The stator voltages in dq axis are transformed from the d-q axis to α-β axis by parks transformation to fed space vector modulation (SVM). The SVM is applied to three levels NPC which feeding induction motor drive.

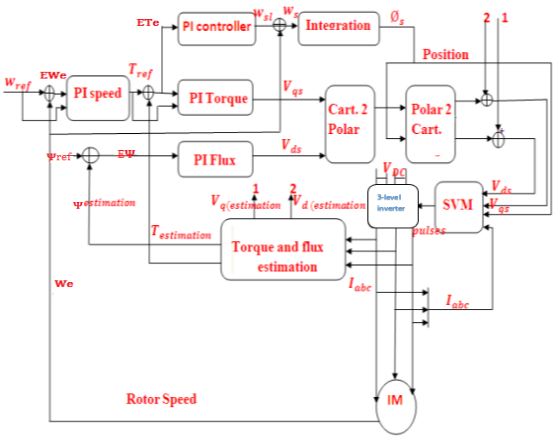


Figure 1. Scheme proposed of DTC-SVM

In the figure (1) The speed calculation is compare with absolute value of the reference speed and the error signal applied to the PI speed controller to obtain reference flux linkage as shown in fig (2).

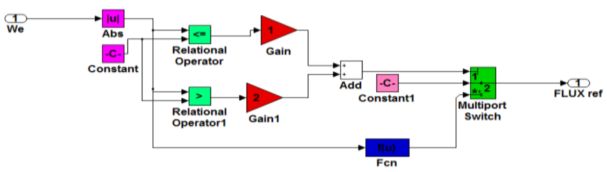


Figure 2. PI flux controller

The error between reference flux and actual stator flux linkage is applied to PI flux controller to produce stator voltage in dq axis as follow:

$$U_{sd} = Kp[E\Psi s + \frac{1}{Ti}\int E\Psi s \ dt\,] \quad (1)$$

The flux error is equal:

$$E\Psi s = \Psi s_{ref} - \Psi s_{cal}. \quad (2)$$

Where U_{sd}, EΨs is stator voltage and error flux, respectively.

The error between speed calculated and reference speed is applied to PI speed controller to obtain reference electromagnetic torque as follow:

$$T_{ref} = Kp[E\omega + \frac{1}{Ti}\int E\omega \ dt\,] \quad (3)$$

The speed error is equal:

$$E\omega = \omega e^{*} - \omega e_{cal} \quad (4)$$

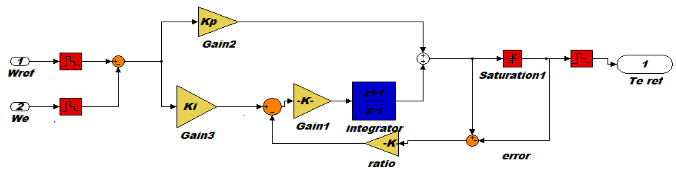


Figure 3. PI flux controller

Then the error between reference torque and actual torque of induction motor is applied to PI torque controller to produce stator voltage in dq axis as follow:

$$U_{sq} = Kp[ETe + \frac{1}{Ti}\int ETe \ dt\,] \quad (5)$$

The torque error is equal;

$$ETe = Te_{ref} - Te_{cal} \quad (6)$$

The stator voltage obtained by equation (1,5) are transformed into amplitude voltage based on transformation Cartesian to polar. Output can be expressed as:

$$|U| = \sqrt{U_q^{\,2} + U_d^{\,2}} \quad (7)$$

Also, the error from comparative reference torque with an actual torque applied to PI slip angular frequency to estimate the value of slip angular frequency (W_{sl}) required to regulate stator flux angle can be expressed as:

$$W_{sl} = Kp[ETe + \frac{1}{Ti}\int ETe \ dt\,] \quad (8)$$

Then the stator angular frequency equal

$$W_s = W_e + W_{sl} \quad (9)$$

Where, ws, we, wsl are rotor, stator and slip angular frequency, respectively. Then obtain the stator flux angle as bellow:

$$\theta_s = \int W_s \ dt \tag{10}$$

based on the position of the amplitude stator and stator flux angle it's switching selected to produce the appropriate voltage vectors to control on torque and flux. Then applying equations (7,10) on polar to Cartesian transformation on both stator flux angle and amplitude stator voltage to obtain the stator voltage in d-q axis which can expressed as:

$$U_{sd} = |U| \cos\theta_s \tag{11}$$

$$U_{sq} = |U| \sin\theta_s \tag{12}$$

Then the error of the votage can be expressed as:

$$EU_d = U_d - U_{d_{cal}} \tag{13}$$

$$EU_q = U_q - U_{q_{cal}} \tag{14}$$

The reference of stator voltages in d-q axis are computed to make the stator voltage error is zero at next sample period. The following stator voltages are expressed as:

$$U_{sd}(i+1) = EU_d + R_s.I_{sd}(i) \tag{15}$$

$$U_{sq}(i+1) = EU_q + R_s.I_{sq}(i) \tag{16}$$

The stator voltage obtain in dq axis by the above equation are converted to two phase system in alpha (α), beta (β) axis winch fed SVM using transformation can be written in matrix form:

$$\begin{bmatrix} \mathrm{U}_\alpha \\ \mathrm{U}_\beta \end{bmatrix} = \begin{bmatrix} \cos(wt) & -\sin(wt) \\ \sin(wt) & \cos(wt) \end{bmatrix} \begin{bmatrix} \mathrm{U}_{sd} \\ \mathrm{U}_{\mathrm{sq}} \end{bmatrix} \tag{17}$$

III. MODELLING OF DTC-SVM OF INDUCTION MOTOR

Reference frame theory is most widely used in mathematical modeling of DCT-SVM of induction motor to convert from three-phase quantities (abc) become two-phase quantities (dq) is required in order to facilitate the analysis in the setting of position or speed and also in order 3-phase induction motor has a behavior resembles the DC motor and thus more easily controlled [7]. Convert from three phase system to dq axis system by park's transformation can be written in matrix form:

$$\begin{bmatrix} \mathrm{V_d} \\ \mathrm{V_q} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \mathrm{V_{an}} \\ \mathrm{V_{bn}} \\ \mathrm{V_{cn}} \end{bmatrix} \tag{18}$$

Become equations induction motor after the conversion of the three-phase system to two-phase system as follows:

A. *Voltage equation in dq axis*

$$U_{d1} = R_1.I_{d1} - \omega_1.\Psi_{q1} \tag{19}$$

$$U_{q1} = R_1.I_{q1} + \omega_1.\Psi_{d1} \tag{20}$$

$$U'_{d2} = R'_2.\mathrm{I}'_{d2} + (\omega - \omega 1)\Psi'_{q2} \tag{21}$$

$$U'_{q2} = R'_2.\mathrm{I}'_{q2} - (\omega - \omega 1)\Psi'_{d2} \tag{22}$$

Where the flux linkages:

$$\begin{bmatrix} \Psi_{d1} \\ \Psi_{q1} \end{bmatrix} = L_1.\begin{bmatrix} I_{d1} \\ I_{q1} \end{bmatrix} + L_h \begin{bmatrix} \mathrm{I}'_{d2} \\ \mathrm{I}'_{q2} \end{bmatrix} \tag{23}$$

$$\begin{bmatrix} \Psi'_{d2} \\ \Psi'_{q2} \end{bmatrix} = L'_2.\begin{bmatrix} \mathrm{I}'_{d2} \\ \mathrm{I}'_{q2} \end{bmatrix} + L_h \begin{bmatrix} I_{d1} \\ I_{q1} \end{bmatrix} \tag{24}$$

Where, Ud_1, Uq1, $U'd_2$, U'_{q2} is stator and rotor voltages in dq axis respectively. Then, $Id1.Iq_1$, $I'd_2$, $I'q_2$ is stator and rotor currents in dq axis respectively. The resistance and inductance with mutual inductance of the stator and rotor are denoted as R_1, R'_2, L_1, L'_2, Lh respectively. The stator flux linkages and rotor flux linkage are denoted as Ψ_{d1}, Ψ_{q1}, Ψ'_{d2}, Ψ'_{q2} respectively. While ω is angular frequency.

B. *Stator flux linkages and electromagnetic torque calculation*

Can rewrite equations of stator flux from the above voltage equations as follow:

$$\frac{\Psi_{d1}}{dt} = U_{q1} - R_1.I_{q1} \tag{25}$$

$$\frac{\Psi_{q1}}{dt} = U_{d1} - R_1.I_{d1} \tag{26}$$

The phase angle and magnitude of the stator flux (I_s) in dq axis can be expressed as

$$\Psi_s = \Psi_{d1} + \mathrm{j}\Psi_{q1} \tag{27}$$

$$|V_{ref}| = \sqrt{{\Psi_{d1}}^2 + {\Psi_{q1}}^2} \tag{28}$$

$$\theta = \tan^{-1}\frac{\Psi_{q1}}{\Psi_{d1}} \tag{29}$$

The electromagnetic torque of the induction motor is obtained from flux linkages in stator and stator currents in dq axis. The flux linkages in the stator are obtaining from inductance and stator current in dq axis.

$$\mathrm{T}_e = {}^3\!/_4\, P(\Psi_{d1}.I_{q1} - \Psi_{q1}.I_{d1}) \tag{30}$$

The electromagnetic torque of the induction motor in terms of rotor speed can be expressed as follow:

$$\mathrm{T} = \mathrm{T}_e - T_w = \frac{J}{P}.\frac{d\omega}{dt} + B\ \omega_r \tag{31}$$

Where,

TL is the load torque,

Te is the electromagnetic torque

P is the number of poles,

J is the moment of inertia of rotor,

ωr is the rotor speed,

B is the damping coefficient.

IV. DTC-SVM WITH THREE-LEVEL INVERTER

In this scheme, the proposed control system DTC-SVM is shown in Figure (1) used three phase three-level NPC inverter instead of two level inverters. The three-level inverter used in high-power medium voltage applications due to the three-level inverter has more advantage over standard two-level inverter, for example, more level voltage in output side, reduce voltage on the power switches, less dv/dt, less basic mode voltage and less total harmonics distortion in output current and voltage [8-10]. For generate gate pulses applied on switching of the three-level inverter using space vector modulation due to has several advantages, for example, identifies each switching sector in (α, β) space and directly uses the control variable come by the control system. The SVPWM is suitable for digital signal processing implementation and optimizes switching sequences. Considering the three-level inverter shown in Fig.4, shows that each switch has three possible positions. The map of synthesizable vectors significantly expands, as shown in Fig. 5. At the end of each vector are indicated the positions of the switches synthesize column. Shown in the same figure, some vectors are obtained with more than one combination of states of the switches. Precisely all vectors make the internal hexagon have two possible combinations, while the null vector has three. This redundancy feature can be summarized 19 different vectors 3^3= 27 possible combinations.

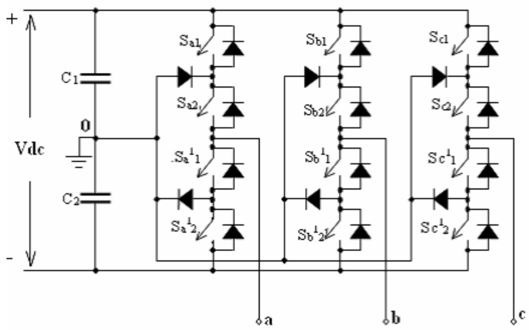


Figure 4. 3-level NPC inverter

In general, for N-level converter, there are N^3 different ways to combine column voltages, while the number of synthesizable vectors is given by the following expression: $L = 1 + 6\sum_{i-1}^{N-1} i$

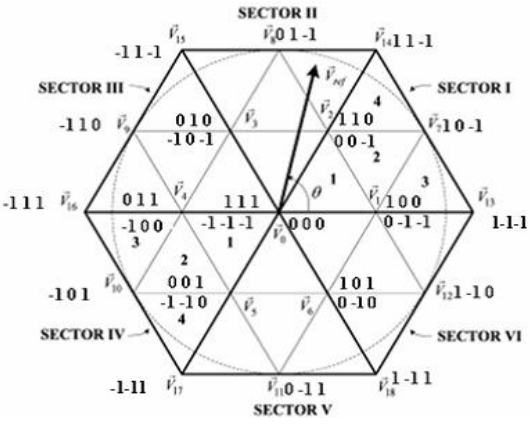


Figure 5. Vector map for three levels NPC.

V. DUAL BOOST CONVERTER FOR POWER FACTOR CORRECTION

A Dual boost converter is designed to improve the power factor and reducing distortion in input side which leads reducing the power quality problems is placed in the front end of the circuit. The overall circuit diagram of the dual boost converter is shown in Fig.6.

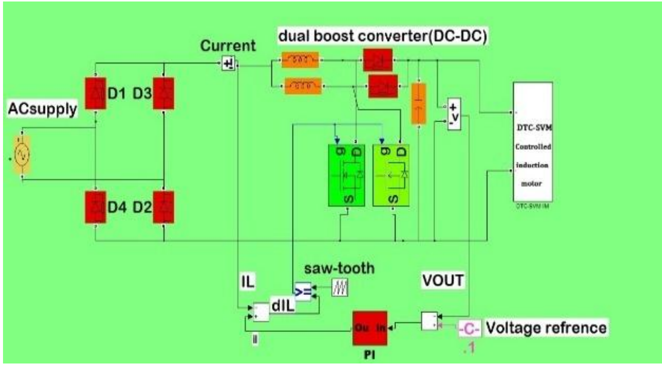


Figure 6. Schematic of the proposed system.

A dual boost (DC-DC) converter in continuous current conduction mode has been considered as PFC because the current is continuous which leads to lower level of the distortion [11]. The PFC process is obtained by forcing the converter input current to be as close as possible in phase with the input voltage. The enhanced DC voltage produced from the structure as above fig (6) will be delivered to the three-phase three level inverters which drives 3-φ induction motor. The overall proposed controlled power system with the control circuit which enter AC signal from supply to the rectifier and the output from the rectifier is dc. The dc voltage delivers to dual dc-dc boost converter which corrector the power factor. The dc out from dual dc-dc boost converter applied to the three-phase three level inverters. In a dual boost converter. It provides a regulated dc output voltage under varying load and input voltage conditions. The control of the output voltage should be performed in a closed-loop. The two usually common closed-loop control methods for PWM dc-dc converters, namely the voltage-mode control and the current mode control. Here, this technique (current mode control) works on comparisons between the Ref current and measured current in the comparator. The error signal compared with a saw tooth as a carrier constant high frequency for creating the pulses to the MOSFET.as shown in fig (7).

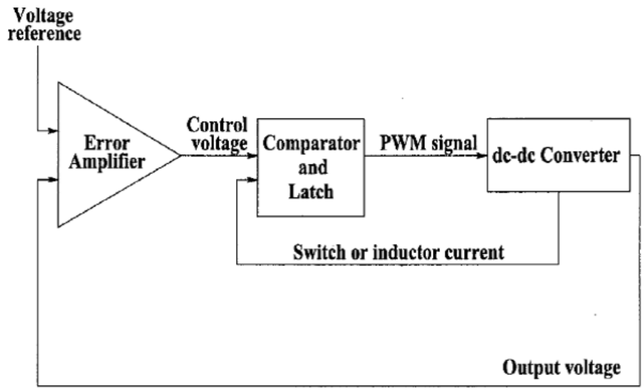


Figure 7. Current mode control

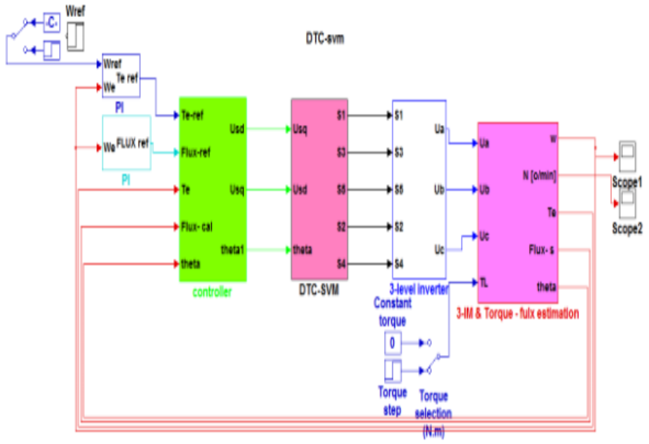


Figure 8. Overall Proposed DTC-SVM Of Motor.

VI. SIMULATION

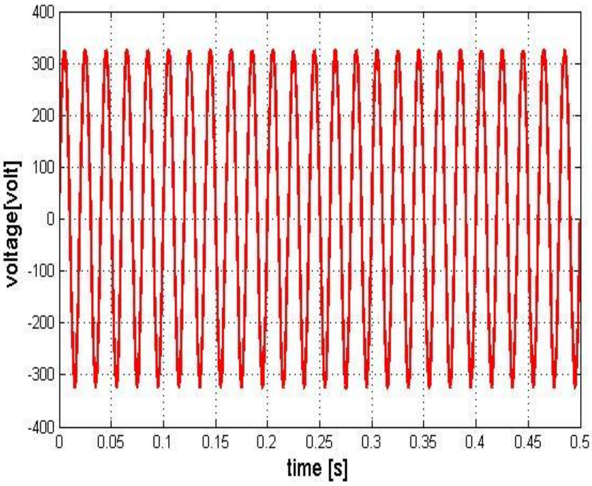
The proposed DTC technique based on SVM with two PI speed controllers to calculated reference torque, flux, and design PI torque controller, PI flux controller for controlling the amplitude stator voltage. This proposed method was implemented and simulated using MATLAB/Simulink software package. The parameter of the induction motor which using in simulation are shown in table I. The Simulink model of the overall proposed control method is shown in fig (8).

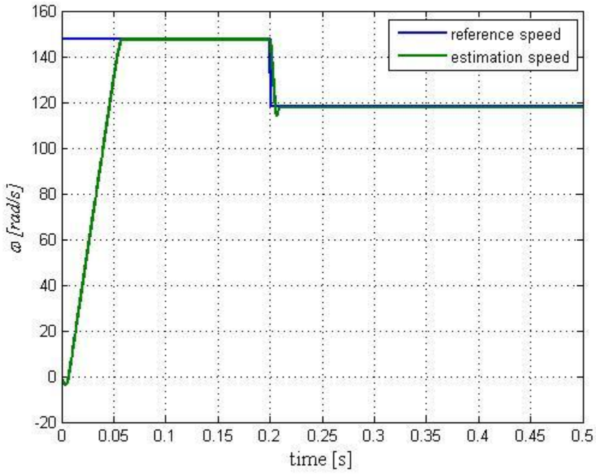
TABLE I. PARAMETERS OF INDUCTION MOTOR.

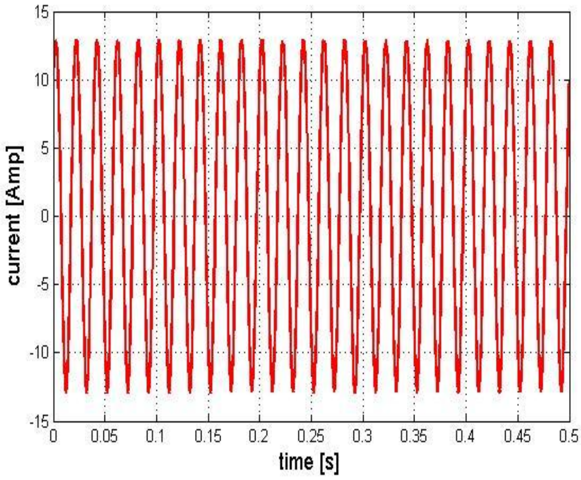
Stator Resistance =11.6	[Ohm]
Rotor Resistance=10.4	[Ohm]
Stator Inductivity=0.579	[H]
Rotor Inductivity =0.579	[H]
Mutual Inductivity =0.557	[H]
Inertia = 0.002	[kgm^2]
Nominal Frequency=50	[Hz]
Nominal Power=750	[W]
Nominal Speed=1410	[rpm]
Nominal Phase Voltage=220	[V]
NO. POLES=2	

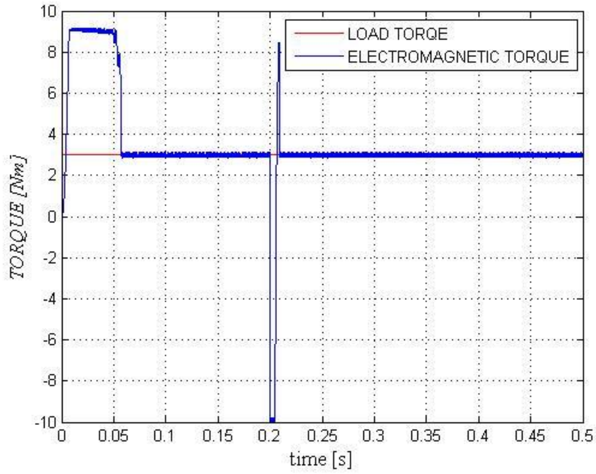
VII. RESULTS AND DISCUSSIONS

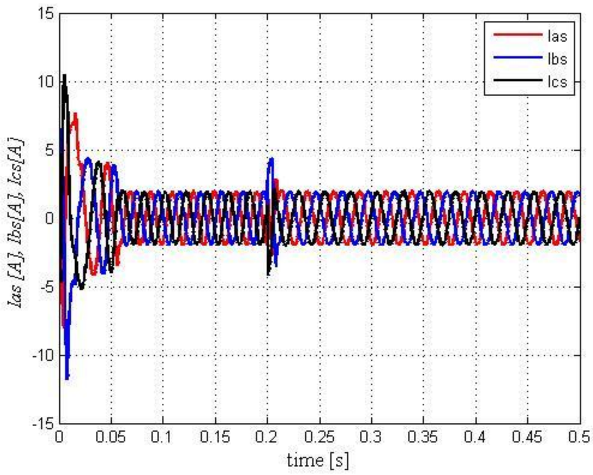
Implement the above Simulink model of the DTC-SVM in MATLAB/Simulink. The result obtained from the proposed method with and without PFC describes the performance of the induction motor at rating 750W/380V. When the speed reference varied from 147 rad/sec to 118rad/sec with load torque 3 N.m at duration 0.2. The performance of input voltage, input current, stator current, speed response, performance of torque, stator flux and comparison between speed estimator and reference speed also torque estimator and reference torque as shown in fig (9) with compared without PFC as shown in fig (10). Total harmonics distortion in the input current and voltage are decreased radically and in the same time the input power factor is increased to near unity by using dual boost converter as shown in fig .9. (a) & (b) with compared fig 10 (h) & (i). In fig.9 (c) shows the stator currents are higher stability in the steady state and very low ripple with compared in fig.10 (j). Fig.9. (d) shows fast response with good tracking by reference speed with estimation speed and there is no steady state error as compared with fig.10 (k). While fig.9 (e) shows high-performance and response with very low ripple by reference torque with estimation torque as compared with fig.10 (l). In fig.9 (f) the Lucas of stator flux is improved with very low ripple as compared with fig.10. (m).

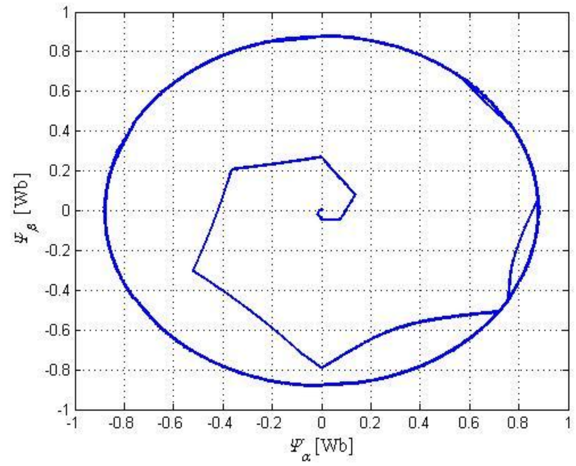

voltage[volt]
time [s]
(a)

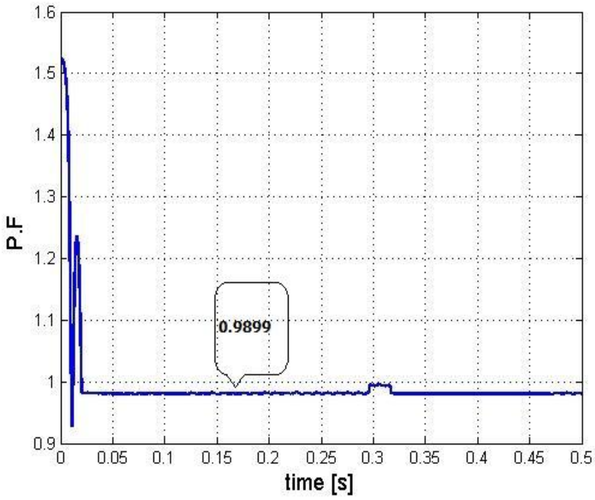

reference speed
estimation speed
ω [rad/s]
time [s]
(d)


current [Amp]
time [s]
(b)


LOAD TORQE
ELECTROMAGNETIC TORQUE
TORQUE [Nm]
time [s]
(e)

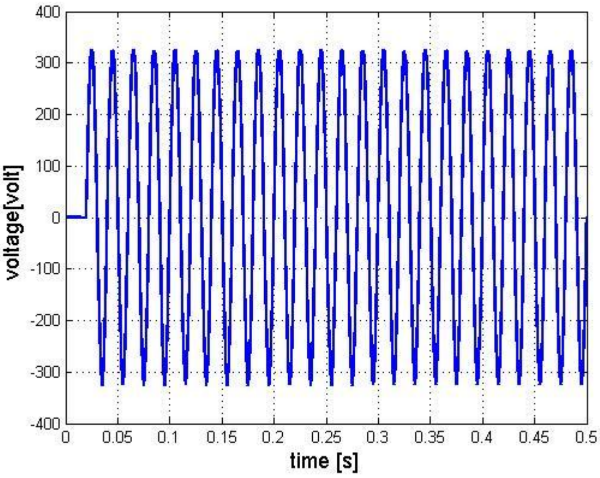

Ias
Ibs
Ics
Ias [A], Ibs[A], Ics[A]
time [s]
(c)


Ψβ [Wb]
Ψα [Wb]
(f)

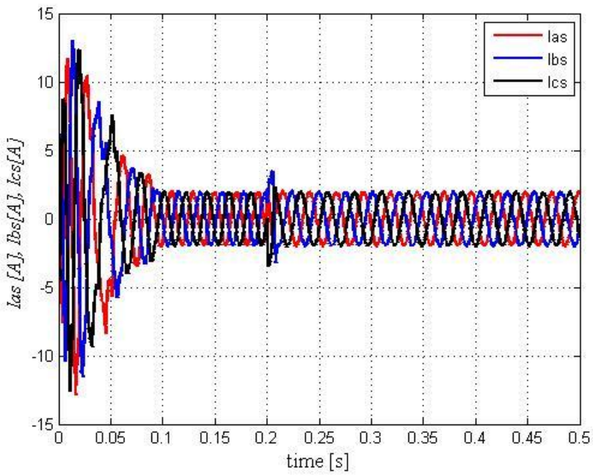


(g)

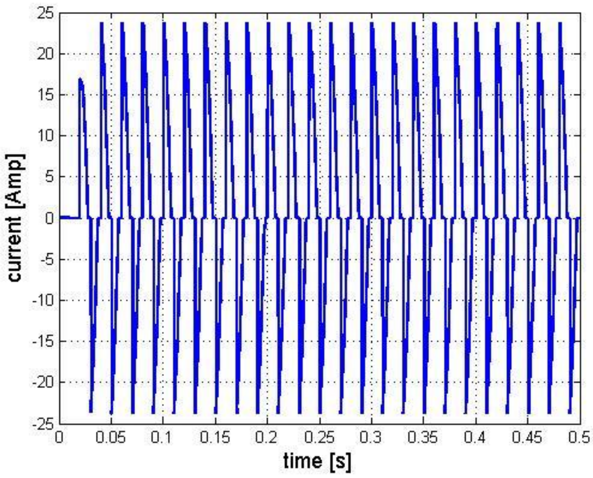
Figure 9. DTC-SVM with PFC. (a) input voltage, (b) input current, (c) dynamics stator currents, (d) speed response, (e) performance of torque, (f) locus of stator flux, (g) power factor with dual boost converter



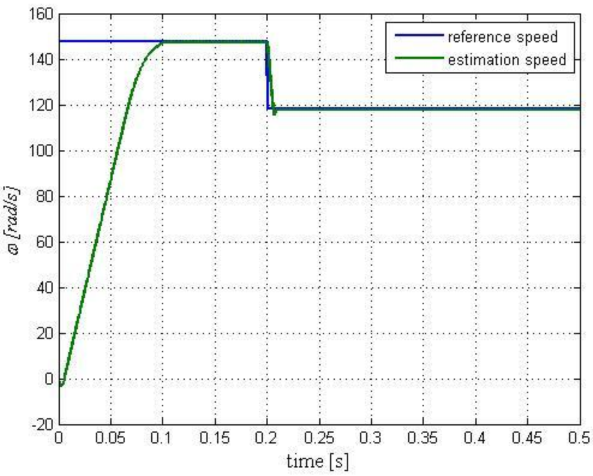
(h)



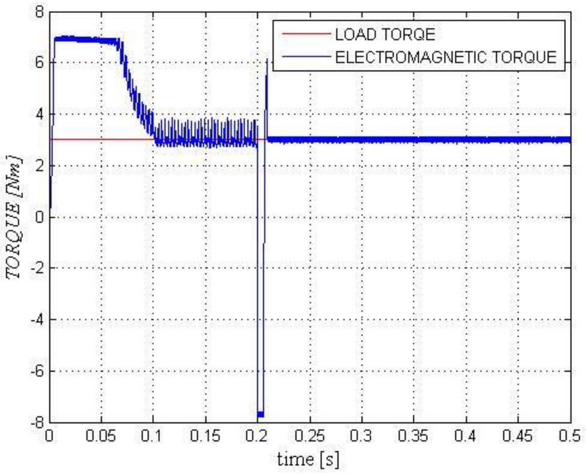
(j)



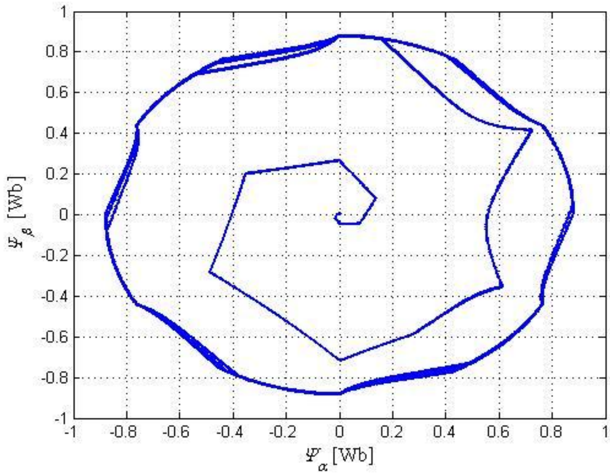
(i)



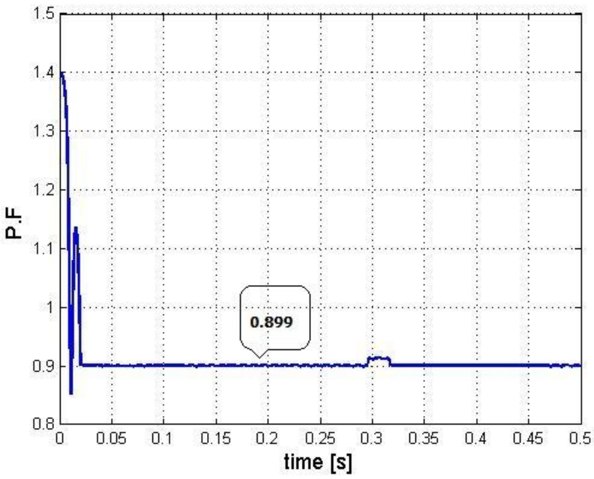
(k)



(l)



(m)



(n)

Figure 10. DTC-SVM without PFC (h) input voltage, (I) input current, (j) dynamics stator current, (k) speed response, (l) performance of torque, (m) locus of stator flux, (n) power factor without dual boost converter.

VIII. CONCLUSION

This paper describes a new power factor correction based on dual boost DC-DC converter at the front-end circuit of proposed system. This providing near unity power factor and reduce total harmonics distortion. The controlling of induction motor by DTC based on space vector modulation (SVM) that generate pulses to the power switching of the three-level NPC inverter which fed induction motor drive. In this method, optimize reference torque and flux using two PI speed controllers. The stator voltage in dq axis feeding space vector modulation is higher stability and no fluctuation because it depended on output stator voltage from two PI torque and flux controller. Based on the position of the stator flux, it's switching selected to produce the appropriate voltage vectors to control both torque and flux. The proposed system of DTC-SVM shows a high dynamic performance of torque and flux with reduction ripples as compared with classical DTC-SVM and other methods such as vector control.

REFERENCES.

[1] Walid Emar, Hussein Sarhan, Rateb Al-Issa, Issam TTrad, Mahmoud Awad, "*V/F Control of Squirrel Cage Induction Motor Drives Without Flux or Torque Measurement Dependency*", International Journal of Robotics and Automation (IJRA), Vol.2, No. 2,2011.

[2] A. D. Cheok, S. Kawamoto, T. Matsumoto, and H. Obi, "High power AC/DC converter and DC/AC inverter for high-speed train applications," in Proc. TENCON, 2000, pp. 423-428.

[3] Yeong-Hwa Chang, Chun-I Wu, Hung-Wei Lin and Nien-Der Kuo,"Robust Performance Control Of Vector-Controlled Induction Motors With Gain-Scheduled Estimation And Input-Output Linearization," International Journal of Innovative Computing, Information and ControlVol.7, No.1, January 2011.

[4] Zhifeng, Z., T. Renyuan, B. Baodong and X. Dexin," Novel direct torque control based on space vector modulation with adaptive stator flux observer for induction motors". IEEE T. Magn., 46(8): 3133-3136, 2010.

[5] Allirani S., and Jagannathan, *"Direct Torque Control Technique for Voltage Source Inverter Fed Induction Motor Drive*", International Journal of Electrical Engineering, Vol.5, No.5, pp.629-640,2012.

[6] Tobias Geyer, "Computationally Efficient Model Predictive Direct Torque Control", IEEE Transactions on Power Electronics, Vol.26, No.10, pp.2804-2816, October 2011.

[7] Kyo-Beum, L. and F. Blaabjerg" An improved DTC-SVM method for sensorless matrix converter drives using an over modulation strategy and a simple nonlinearity compensation". IEEE T. Ind. Electron., 54(6): 3155-3166, 2007.

[8] Yuttana, K., P. Suttichai and A.T. Hamid, "Modified direct torque control method for induction motor drives based on amplitude and angle control of stator flux". J. Electr. Pow. Syst. Res., 78(10): 1712-1718,2008.

[9] Vasudevan, M., R. Arumugam and S. Paramasivam, "Development of torque and flux ripple minimization algorithm for direct torque control of induction motor drive". J. Electr. Eng., 89(1): 41-51. 2006.

[10] Monmasson, E. and J. Louis,"Presentation of a control law for IM drive based on the dynamic reconfiguration of a DTC algorithm and a SVM-DTC algorithm". Math. Comput. Simul., 63(3): 321-333, 2003.

[11] A. Gupta, A. M. Khambadkone "*A space vector pwm scheme for multilevel inverters based on two-level space vector pwm,*" IEEE Transaction on Industrial Electronics, Vol. 53, October 2006.

[12] V. Attaianes, V. Nardi, F. Parillo, G. Tomasso – "Dual boost High Performances Power Factor Correction(PFC)",Twenty-third IEEE Applied Power Electronics Conference (APEC 2008), Austin (USA),24-28.2.2008,PP.1027-1032.

[13] Attaianese, C., Nardi, V.,Tomasso,G.-"A novel approach to modeling and control of active front-end inverter feeding induction motors", Power Conversion Conference PCC, Osaka 2002,2-5.04.2002,pp.1322-1327 vol.3.

[14] Xavier Del Toro Garcia, Antoni Arias, Marcel G. Jayne, Phil A. Witting, Vicenc M. Sala, Jose Luis Romeral "*New DTC Control Scheme for Induction Motors fed with a Three Level Inverter"* AUTOMATIKA 46(2005) 1-2, 73-81, ISSN 0005-1144.

[15] T. G. Habetler, F. Profumo, M.Pastorelli, L. Tolbert "*Direct torque control of induction machines using space vector modulation,"* IEEE ransaction on Industry Applications, Vol. 28, no. 5, pp. 1045-1053, septembre/October 1992.

[16] I. Boldea, L. Janosi, F. Blaabjerg: *A Modified Direct Torque Control (DTC) of Reluctance Synchronous Motor Sensorless Drive»;* Electric Machines & Power Systems; Volume 28, Issue 2, 2000.

[17] Panneer Selvam, N., M. Arul Prasanna, I. Gerald, C. Raj and Dr. V. Rajasekaran"*A Novel direct torque controlled IM drives fed from CSI with minimum ripple torque"*. Int. J. Eng. Trends Technol., 3(4): 507-511, 2012.

[18] Lascu, C., I. Boldea and F. Blaabjerg, "*Direct torque control of sensorless induction motor drives: a sliding-mode approach*. IEEE T. Ind. Appl., 40(2): 582-590, 2004.

[19] Nalin Kant Mohanty and Ranganath Muthu,"Implementation of Proportional Integral (PI) Controlled DSP Based Cost Effective Inverter Fed Speed Control of Induction Motor Drive with VisSim/ Embedded Controls and Developer (ECD)", International Journal of the Physic.