

Improved Performance of Three Phase Motor with High Power Quality Based on Dual Boost Converter

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Abstract: With rapid advancement in power semiconductor device, make it possible many to develop many applications in industrial and daily life. One of the most interested application in a broad area is the induction motor control. The aim of this paper is to implement a new control system for driving three-phase induction motor .this control system aim to enhance the performance of induction motor as well as improving the power factor at both input sides and output sides with remarkable reduction in total harmonics distortion of the supply current .the system consists of dual boost converter connected in parallel with uncontrolled rectifier for producing a dc voltage .this approach depends on the power-sharing optimization strategy to enhance the current quality, which leads to keeping power factor at the input side near unity with minimization of the total harmonics distortion (THD) of supply current . The dc voltage produced from this structure is delivered to a three-phase inverter which is controlled by space vector pulse width modulation (SVPWM) for driving three phase induction motor. The proposed system has been implemented using MATLAB/Simulink software package. The simulation results show promising improvement of the induction motor performance.

Keywords: Induction motors, dual boost converter, total harmonic distortion, Space vector PWM.

I. INTRODUCTION

In AC electric power system, voltage conversion and inductive loads leads the system to have poor power factor causes an increase in its current compared with that of high power factor. The higher current leads to increase the energy losses in the power system. Despite reliable in many applications, the induction motor is the type of a poor power factor loads. The tremendous developments in power electronics made it possible to use them for the techniques that overcome the drawback of the induction motor. Many techniques that rely on power electronics to improve the performance of induction motors have been proposed in the literature [1-8].

In this paper, dual boost dc-dc converter 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 inverter which controlled by (SVPWM) technique for driving three phase induction motor.

The leftover of this paper is as follows: in section II, the system configuration is explained in details. A mathematical model of the induction motor and the necessary equations presented in section III, while section IV contains the control techniques for controlling dual boost converter and three phase inverters. Simulink implementation of the proposed system with simulation results included in section V, section VI contain the conclusions obtained from simulation results.

II. SYSTEM CONFIGURATION

The proposed system for controlling three phase induction motor with power factor correction consists of three main stage, these are:

- uncontrolled rectifier for converting single phase AC voltage delivered from the supply to a DC voltage.
- dual boost DC-DC converter for power factor correction at input side.
- Three-phase inverter for driving three phase induction motor.

The schematic of the proposed system is shown in fig (1)

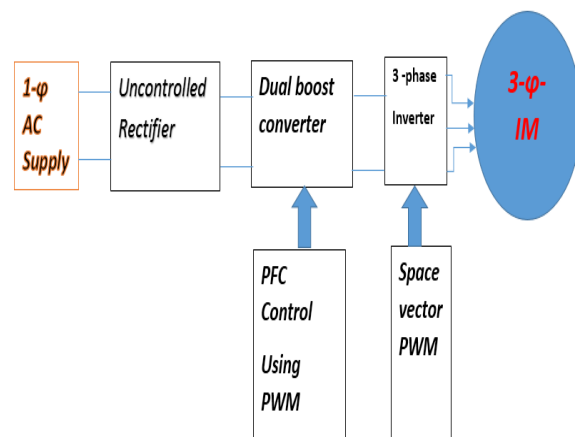


Fig.1. schematic of the proposed system

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 [9]. The PFC process is obtained by forcing the converter input current to be as close as possible in phase with the input voltage. The system consists single-phase AC supply, rectifier circuit, a dual boost converter as PFC and load as shown in fig (2)

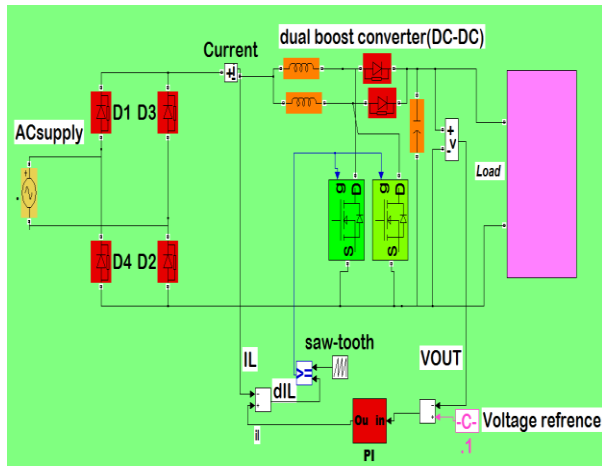


Fig .2. Schematic of dual Boost Converter

The enhanced DC voltage produced from the structure as shown in fig (2) will be delivered to the three-phase inverter which drives 3-φ induction motor. The overall proposed controlled power system with the control circuit is shown in fig (3) which the input 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 inverter.

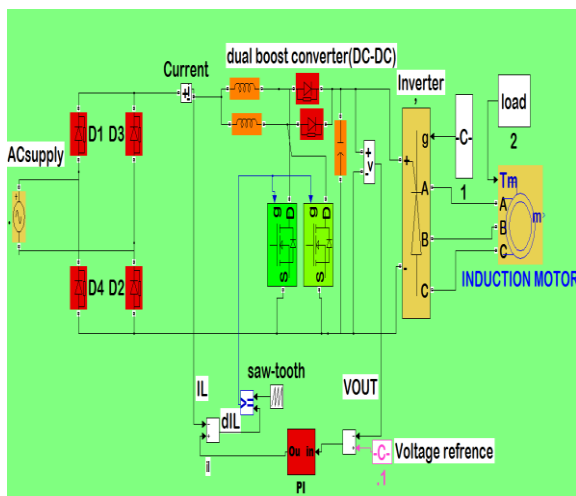


Fig 3 Circuit Configuration

III.MATHEMATICAL MODEL OF IM

The reference frame very widely used in the design of the induction motor due to simplification of the overall

system equations and to separate rotor field about stator field. This leads sinusoidal variables as the dc quantities by moving the angular speed equal the angular speed equal angular frequency of the sinusoidal supply [10-11]. This theory makes the different between the speed equal to zero. The result obtained from the reference frame is behaving as DC quantities. These quantities become is easy to control. In the design of the induction motor, the first step converts from three-phase system to two phase alphas, beta system. These quantities are converted to dq axis by transformations as shown in fig (4).

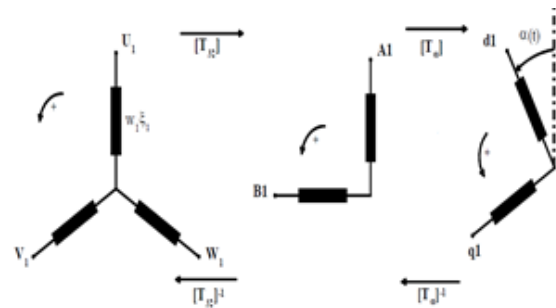


Fig.4. Transformation of dq-axis coordinate system. [12]

The transformation from of the three- phase system to two-phase system can be written in matrix form:

$$[T_{32}] = \begin{bmatrix} \sqrt{\frac{3}{2}} & 0 \\ \frac{1}{\sqrt{2}} & \sqrt{2} \end{bmatrix} \tag{1}$$

Transformation from two phase to dq axis system can be written in matrix form:

$$[T_{\alpha}] = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) \\ -\sin(\alpha) & \cos(\alpha) \end{bmatrix} \tag{2}$$

Where

α Angle displacement

After converting the three-phase quantities to two-phase dq axis reference frame rotating field can be to calculate the dynamic voltage and torque equations of the induction machine as below:

$$\begin{bmatrix} U_{d1} \\ U_{q1} \end{bmatrix} = R_1 \cdot \begin{bmatrix} I_{d1} \\ I_{q1} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \Psi_{d1} \\ \Psi_{q1} \end{bmatrix} + \omega_k \cdot \begin{bmatrix} -\Psi_{q1} \\ \Psi_{d1} \end{bmatrix} \tag{3}$$

Where

U_{d1} Stator voltages in d-q reference frame

U_{q1}

I_{d1} Stator currents in d-q reference frame

I_{q1}

Ψ_{d1} Stator flux linkage in d-q reference frame

Ψ_{q1}

R_1 Stator resistance

ω Angular frequency

$$\begin{bmatrix} U'_{d2} \\ U'_{q2} \end{bmatrix} = R'_2 \cdot \begin{bmatrix} I'_{d2} \\ I'_{q2} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \Psi'_{d2} \\ \Psi'_{q2} \end{bmatrix} + (\omega - \omega_k) \cdot \begin{bmatrix} \Psi'_{q'2} \\ \Psi'_{d'2} \end{bmatrix} \tag{4}$$

Where

- U'_{d2} Rotor voltage in d-q reference frame
- U'_{q2} Rotor voltage in d-q reference frame
- I'_{d2} Rotor current in d-q reference frame
- I'_{q2} Rotor current in d-q reference frame
- Ψ_{q2} Rotor flux linkage in d-q reference frame
- Ψ_{d2} Rotor flux linkage in d-q reference frame
- R_2 Rotor resistance

Flux linkages:

$$\begin{bmatrix} \Psi_{d1} \\ \Psi_{q1} \end{bmatrix} = L_{11} \begin{bmatrix} I_{d1} \\ I_{q1} \end{bmatrix} + L_h \begin{bmatrix} I'_{d2} \\ I'_{q2} \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} \Psi'_{d2} \\ \Psi'_{q2} \end{bmatrix} = L'_{22} \begin{bmatrix} I'_{d2} \\ I'_{q2} \end{bmatrix} + L_h \begin{bmatrix} I_{d1} \\ I_{q1} \end{bmatrix} \quad (6)$$

Where

- L_{11} Stator inductance
- L'_{22} Rotor inductance
- L_h Mutual inductance

Torque equation:

$$T_e = \frac{3}{4} P \cdot L_h (I_{q1} \cdot I'_{d2} - I_{d1} \cdot I'_{q2}) \quad (7)$$

Where

- T_e Electromagnetic Torque
- P Number of pair poles

In steady-state operation the flux linkages and the speed are constant. Where,

$$\frac{d\Psi}{dt} = 0, \quad \frac{d\omega}{dt} = 0$$

Torque equation and voltage equation become as bellow:

$$\begin{aligned} U_{d1} &= R_1 \cdot I_{d1} - \omega_1 \cdot \Psi_{q1} \\ U_{q1} &= R_1 \cdot I_{q1} + \omega_1 \cdot \Psi_{d1} \\ U'_{d2} &= R_2 \cdot I'_{d2} + (\omega - \omega_1) \Psi'_{q2} \\ U'_{q2} &= R_2 \cdot I'_{q2} - (\omega - \omega_1) \Psi'_{d2} \\ T_e &= \frac{3}{4} P (\Psi_{d1} \cdot I_{q1} - \Psi_{q1} \cdot I_{d1}) \end{aligned} \quad (8)$$

Implementation of all the above equations in MATLAB /Simulink environment as shown in Fig.5

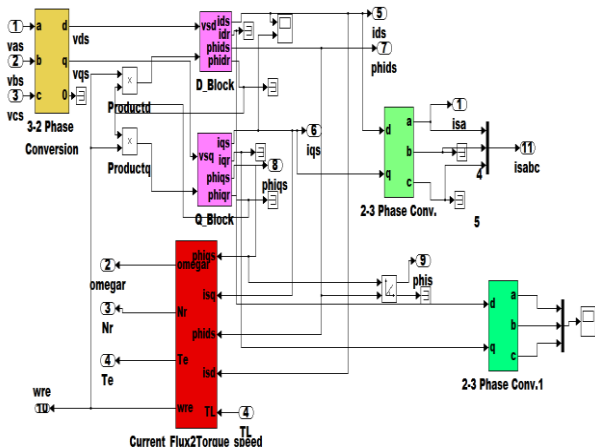


Fig.5. Simulink model for induction motor

IV. CONTROL TECHNIQUES

A. SVPWM Technique

The main understood SVPWM divided the two-dimension plane to six equal area called sector, each sector is calculated through four vectors. These vectors are called non-zero or active vector due to when these vectors are applied to switching power inverter output voltage will be nonzero. Other two vectors V_0 and V_7 are zero vector. The sectors are defined such as sector 1 means 0- 60 degree, sector 2 is 60- 120 degree, and so on, assume the reference vector is laying in sector 1 as shown in fig 6. T_1 is the time for which vector 100 is applied and T_2 is the time for which Vector 110 is applied. Alpha (α) is an angle by which reference vector is rotating in. Applying T_1 and T_2 for an appropriate time, we get the appropriate value of reference vector. T_1 , T_2 and T_z calculations are given below [13-14].

$$T_1 = T_z \cdot a \cdot \frac{\sin(\frac{\pi}{3-a})}{\sin(\frac{\pi}{3})} \quad (9)$$

$$T_2 = T_z \cdot a \cdot \frac{\sin(\alpha)}{\sin(\frac{\pi}{3})} \quad (10)$$

$$T_0 = T_z - (T_1 + T_2) \quad (11)$$

$$T_z = \frac{1}{f_s} \quad \text{and} \quad a = \frac{|V'_{ref}|}{\frac{2}{3} V_{dc}} \quad (12)$$

$$T_0 = T_z - T_1 - T_2 \quad (13)$$

Where

f_s fundamental frequency switching time duration.

T_1 Time applied to vector

T_2 Time applied to vector

T_0 Fundamental time.

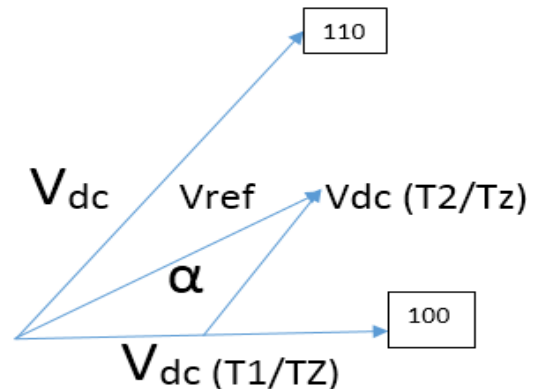


Fig. 6. Reference vector in sector 1

A three-phase inverter is shown below:

The upper switches are complementary to lower switches, so the only probable composition for the switching states are (000,001,010,011,100,101,110,111). There are Total eight switching states out of which two states are zero states and remaining six are non-zero.

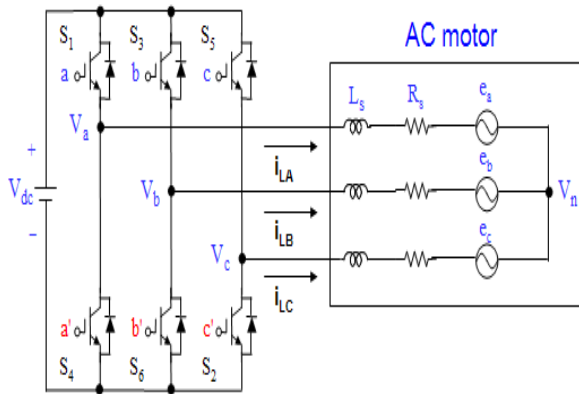


Fig. 7. Three-phase inverter

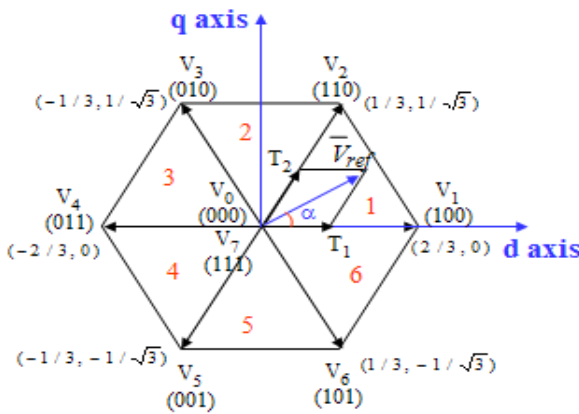


Fig. 8. Basic switching vectors [15]

Six non-zero vectors shape the axes of hexagonal and are used to supply power to the loads shown in fig 8. Two Zero vector V0 and V7 are at the origin and supply zero Voltage to the load. These eight vector are called as basic Space vectors and are denoted by (V0, V1, V2, V3, V4, V5, V6, and V7). The aim of the SVPWM technique is to assessment the reference vector using eight switching mode. In first steps implementation of SVPWM in MATLAB/Simulink is to convert three phase into two phase by park's transformation. This two-phase system used to determine of the reference voltage vector and angle by which the d-q axis which modulates the inverter output.

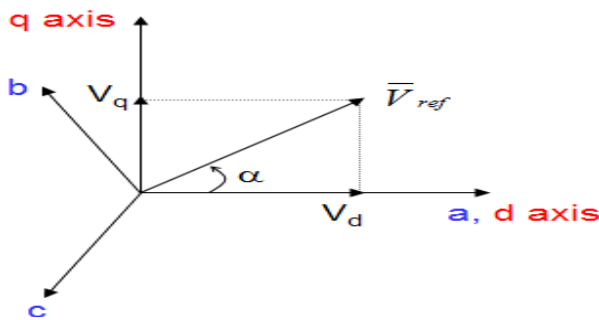


Fig. 9. Park's transformation

The equations of park transformations to convert three phase to two phase is given below:

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (14)$$

$$|V'_{ref}| = \sqrt{V_d^2 + V_q^2} \quad (15)$$

$$\alpha = \tan^{-1} \left(\frac{V_q}{V_d} \right) \quad (16)$$

Where

V'_{ref} Reference voltage vector

The two-phase quantities generated from the above equations were used to determine reference voltage vector and angle is shown in fig (10).

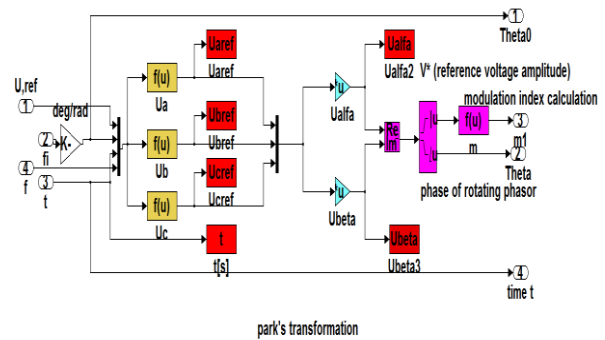


Fig.10. Simulink model for V-reference and angle

B. PWM Technique.

Recall Fig (2) 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. In this paper using current mode control. Here, this technique work 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 (11).

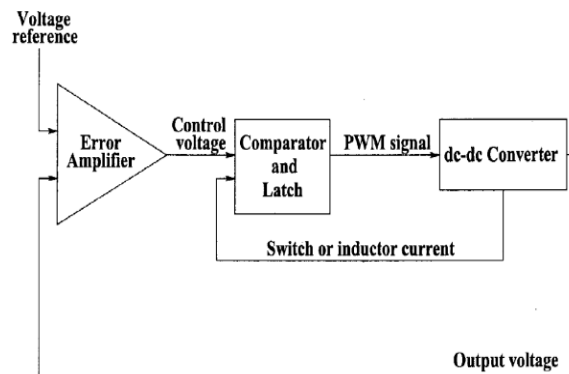


Fig.11. Current mode control

V. SIMULATIONS RESULTS

A) The results obtained with PFC

In order to verify the expected results obtained from the proposed system, the proposed system was implemented and simulated using MATLAB/Simulink software package. The Simulink model of the overall system is shown in fig (12), it consists of subsystems which represent, single phase Ac supply fed rectifier, dual dc-dc boost converter with a control circuit, three phase inverters with pulses and three phase induction motor is the load.

In order the results which obtained from the proposed system, the following parameters are considered:

Input voltage = 230V R.M.S.

Frequency = 50Hz

Inductance = 1200 μ H

Capacitance = 490 μ F

Voltage controller = Discrete PI

Current controller = PWM control

Switching frequency of boost converter = 50 kHz

Converter output voltage = 550V

Inverter switching frequency = 1.02 kHz

Three-phase Induction motor =1 HP, 550V, 50 Hz, 4-pole.

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 when compared to without, used it as shown in fig (13-14). The THD of the input phase current and line voltage reduced, therefore the input current and voltage in phase. While In fig (15) the Peak Input and Output stator currents of the induction Motor do not change and more steady state. At the same time change the high sharp currents to sinusoidal currents with using dual boost converter, when compared to without, used it. In fig (16) THD of the single-phase rotor current has decreased and therefore the power factor has increased with using dual boost converter when compared to without, used it. The steady state of rotor speed, torque and flux of the motor have increased and in the same time THD is decreased with using dual boost converter when compared to without, used it as shown in fig (17-19). From observing results obtained from proposed system the overall performance of the induction motor is improved.

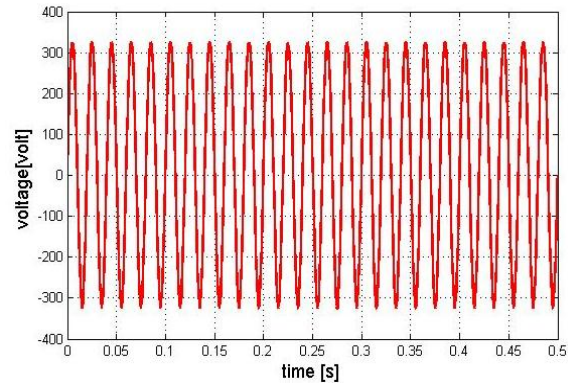


Fig.13. single phase input voltage

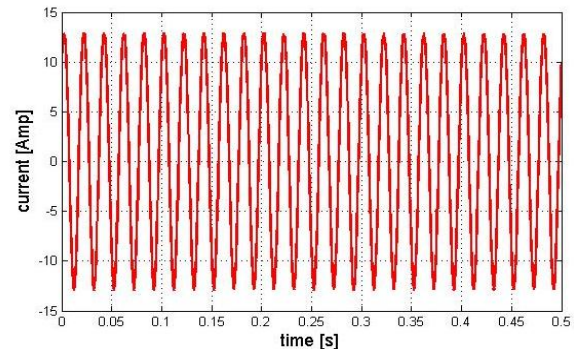


Fig.14. single phase input current

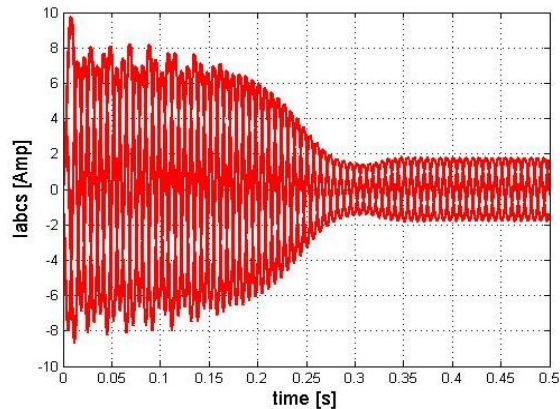


Fig.15. three phase stator currents

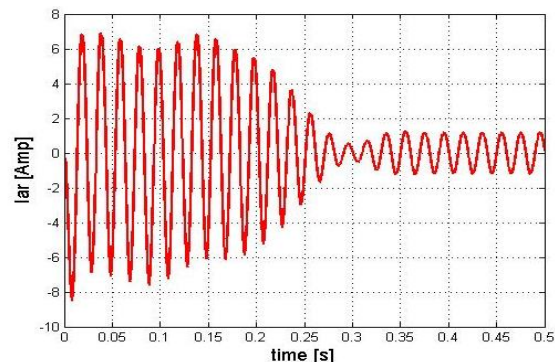


Fig.16. single phase rotor current

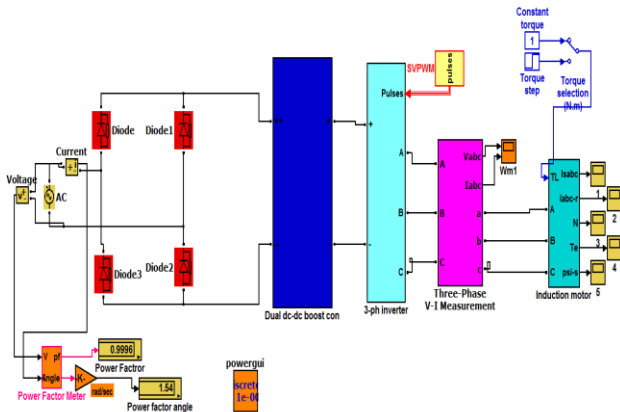


Fig.12. overall Simulink model

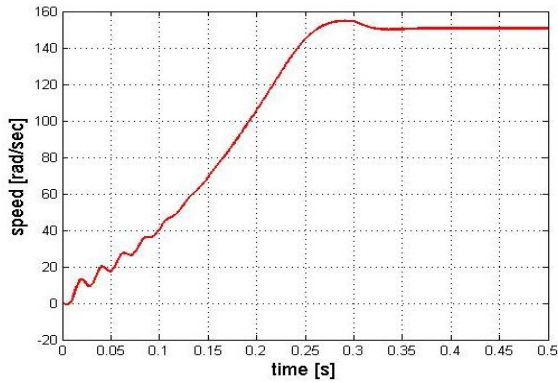


Fig.17. response of speed

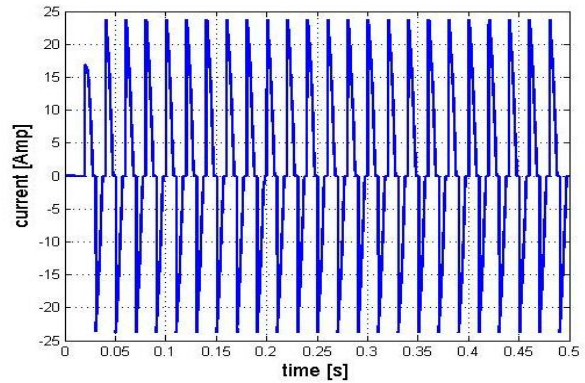


Fig.21. single phase input current

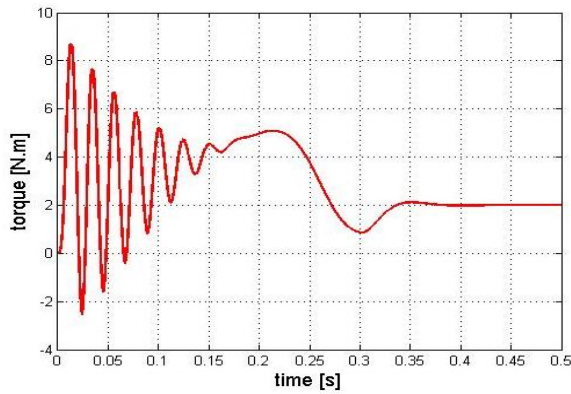


Fig.18. performance of torque

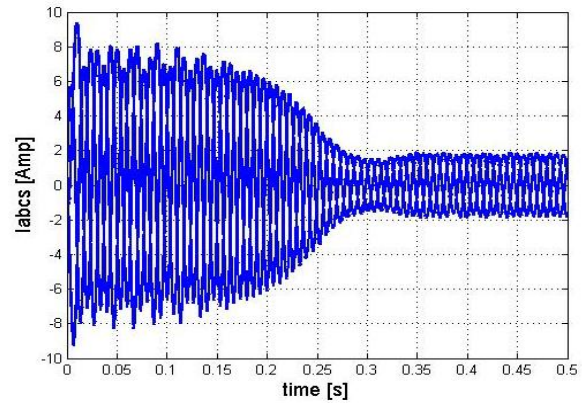


Fig.22. three phase stator currents

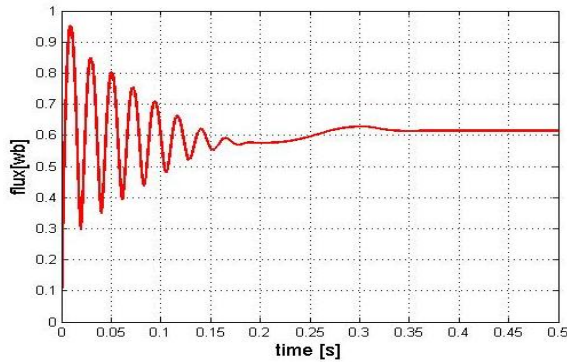


Fig.19. Stator flux.

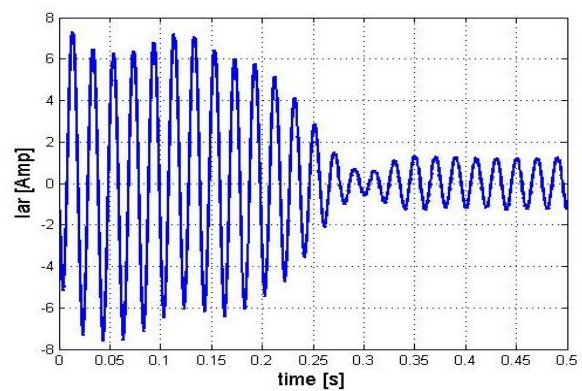


Fig.23. single phase rotor current

B) The results obtained without PFC

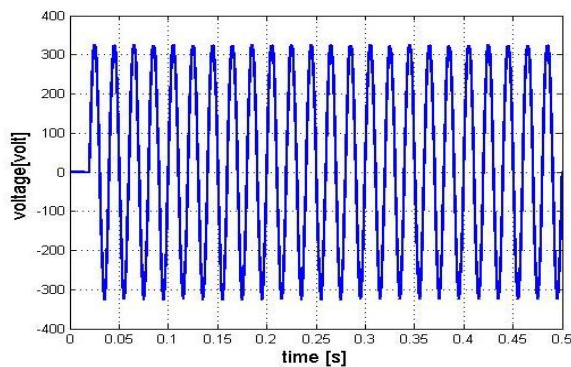


Fig.20. single phase input voltage

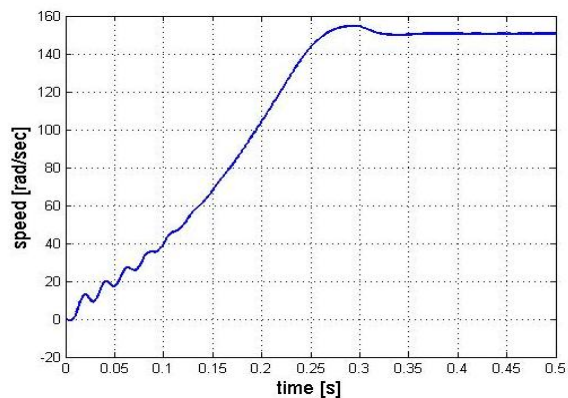


Fig.24. response of speed

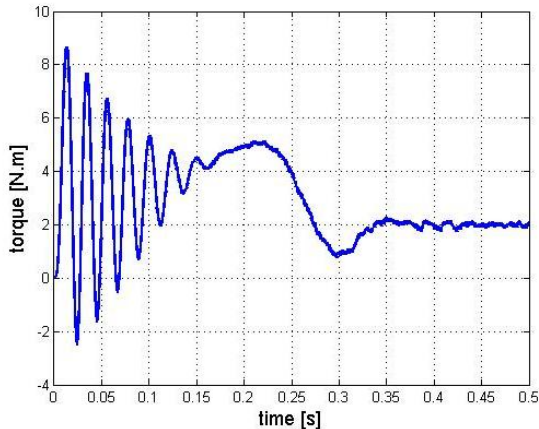


Fig .25. Performance of torque

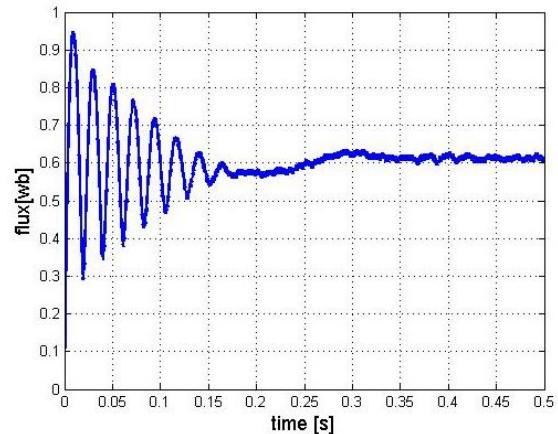


Fig .26. Stator flux.

The THD in FFT analysis for the waveforms are obtained from proposed system as shown in table I.

TABLE I: THD OF CURRENT AND VOLTAGE WAVEFORM.

description	No load		Half load		Full load	
	Without PFC	With PFC	Without PFC	With PFC	Without PFC	With PFC
Input PF	0.78%	0.99996.00%	0.78%	0.99996.00%	0.78%	99996.00%
THD in input current(1-ph)	105.55%	4.15%	105.55%	4.15%	105.55%	4.15%
THD in O/p voltage of converter	118.20%	1.11%	118.20%	1.11%	118.20%	1.11%
THD in I/P phase A current	60	15	32	5.4	32.5	1.98
THD in I/P phase B current	57	18	30.4	6.3	30.1	2
THD in I/P phase C current	54	18	37.06	2.9	35.3	2.4
THD in I/P Line A-B current	77	32	76	31.2	76.2	30.02
THD in I/p Line B-C current	77	31.02	80.1	36.04	80.12	35.06
THD in I/P Line C-A current	68	29.1	67.2	29.93	67.8	29.98

VI. CONCLUSION

A new power factor correction based on dual boost DC-DC converter is introduced. The design procedure for controlling three phase induction motor with the proposed PFC was presented. For the propose of comparison, single boost converter has been used as a PFC. simulation results show interesting improvements of power factor and total harmonics distortion when using dual boost converter compared with using single boost converter as well as when using conventional system (i.e. without PFC). Also, simulation results show promising improvement in induction motor performance from a reduction of ripples in current and torque.

REFERENCES

[1] 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.

[2] 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.
 [3] P.S Verma and G narayanan, "Space vector PWM as a modified form of sine-triangle PWM for simple analog or digital implementation", IEEE Journal of research, Dec 2006.
 [4] K. Zhou and D. Wang, "Relationship between Space-Vector Modulation and Three Phase Carrier-Based PWM: A Comprehensive Analysis," IEEE Transactions on Industrial Electronics, Vol. 49, No. 1, February 2002.
 [5] Jarupula Somlal, Venu Gopala Rao Mannam, "Analysis Of Discrete & Space Vector PWM Controlled Hybrid Active Filters For Power Quality Enhancement" International Journal of Advances in Engineering & Technology, Jan 2012, Vol. 2, Issue 1, pp. 331-341.
 [6] Bunyamin Tamyurek, "A high-performance SPWM controller for three-phase UPS system operating under highly nonlinear load" in IEEE transactions on power electronics, vol.28 no.8, August 2013.
 [7] Wa Ma, Mingyu Wang, Shuxi Liu, Shan Li, and Peng Yu, Stabilizing the Average-Current-Mode-Controlled Boost PFC

- Converter via Washout-Filter-Aided Method IEEE Transactions on Circuits and Systems-II, Express Briefs, vol. 58, no. 9, September 2011.
- [8] C. Attaianese, Senior Member, IEEE - V. Nardi, Member, IEEE - F. Parillo - G. Tomasso, Member, IEEE Department of Automation, Electromagnetism, Computer Science and Industrial Mathematics University of Cassino, via G. Di Biasio 43, I-03043 Cassino (FR) – ITALY, Predictive Control Of Parallel Boost Converters – 978-1-4244-1766-7/08 2008 IEEE.
- [9] P. C. Krause, O. Wasynczuk, S. D. Sudhoff “Analysis of Electric Machinery and Drive Systems”, IEEE Press, A John Wiley & Sons, Inc. Publication Second Edition, 2002.
- [10] P.C. Krause and C. H. Thomas, “Simulation of Symmetrical Induction Machinery”, IEEE Transaction on Power Apparatus and Systems, Vol. 84, November 1965, pp. 1038-1053.
- [11] E. Levi, “Multi-phase Machines for Variable speed applications” IEEE Trans. Ind. Elect., vol. 55, no. 5, pp. 1893- 1909, May 2008.
- [12] P.S Verma and G narayanan, “Space vector PWM as a modified form of sine triangle PWM for simple analog or digital implementation”, IEEE Journal of research, Dec 2006.
- [13] K. Zhou and D. Wang, “Relationship Between Space-Vector Modulation and Three Phase Carrier-Based PWM: A Comprehensive Analysis,” IEEE Transactions on Industrial Electronics, Vol. 49, No. 1, February 2002.
- [14] Jarupula Somlal, Venu Gopala Rao Mannam, “Analysis Of Discrete & Space Vector Pwm Controlled Hybrid Active Filters For Power Quality Enhancement” International Journal of Advances in Engineering & Technology, Jan 2012, Vol. 2, Issue 1, pp. 331-341.
- [15] 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.