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Performance Analysis of Double Boost Converter Powered FSTPI Fed Induction Motor

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Abstract

Pulse Width Modulated (PWM) inverter-fed induction motor drives are most common in industrial applications. This paper aims at development of double boost converter for PWM inverter-fed three-phase induction motor. The inverter topology is designed with four switches. The proposed drive system has been simulated using Matlab/Simulink and the performance of has been assessed in terms of output voltage, output current, power factor and THD. From the simulation results, it is evident that the three-phase voltage waveforms of the proposed system are less distorted, with their currents being more sinusoidal. A comparative analysis has been made with the conventional six-switch inverter fed drive. The proposed system offered a THD of 1.84%, whereas for the conventional system it was 13.96%. These results inferred that the proposed double boost converter with four-switch based drive scheme exhibits superior performance.

Keywords

FSTPI, Induction Motor, Harmonics, SSTPI, THD

1. Introduction

Three-phase induction motors become quite popular in industries owing to their robust construction and better speed-torque characteristics. Many researchers have focused on improving the speed control techniques of these motors. In particular, sensorless speed control techniques are becoming more popular, which are effected through Direct Torque Control (DTC). This control technique utilizes a three-phase inverted system, whose switching pulses are generated through Pulse Width Modulation (PWM) technique. Generally, the three-phase PWM inverters, used so far, consist of a Six Switches topology. The switching sequences for these switches are obtained from a lookup table based on the inverter states [1]-[3]. In Six Switch Three Phase Inverter (SSTPI), the harmonics is generated to a greater extent, which results in over heating of the drive system.

Capacitors are meant for power factor correction, which tends to increase the total harmonic distortion. The second concern is the switching of the power factor correction capacitors. During a capacitor switching, transient over voltages are produced which contain a high frequency component. These transient over voltages, if large enough, can damage sensitive power electronic devices. The impact of the power factor correction circuit on induction motor drive system, in which the power factor correction circuit has a single power device with a forward diode in the boost configuration, has been analyzed [4]. The above approach increases the losses in diode and bridge rectifier and consequently decreases the system efficiency. A zero voltage transition isolated PWM boost converter for single stage power factor correction has been proposed [5], which suffers from the problem of existence of low ripple frequency. A canonical switching cell converter has been designed and analyzed with CMOS gate [6] [7]. The designed topology produces heat problem due to power loss and hence system performance is affected by poor efficiency. A Boost PFC converter has been analyzed in terms of input voltage and current [8]. The above converters are not suitable to relatively small size power supply due to its lower efficiency.

In most electronic power supplies, the AC input is rectified and a bulk capacitor is connected directly after the diode rectifier bridge. This type of utility interface draws excessive peak input currents and hence it produces a high level of harmonics and low input power factor. Due to low power factor the load efficiency is reduced. To overcome this drawback, a Four Switch Three Phase Inverter (FSTPI) has been addressed in this paper. In order to meet the harmonics limits, new AC-DC converter designs must employ active power factor correction at the input. Therefore boost Power Factor Corrector (PFC) converter is designed and it is implemented with FSTPI fed induction motor. By digital simulation the characteristics of the induction motor system are investigated and simulation results are presented.

2. Six-Switch Three-Phase Inverter

Figure 1 depicts the circuit of Six Switch Three Phase Inverter. The circuit consists of three legs connected in parallel across the dc source. Two switches are connected in series to form one leg. The three-phase output is taken from the midpoint of each leg. As shown in the circuit diagram, Q_1 to Q_6 are the six power switches that shape the output, which are controlled by the switching variables a, a', b, b', c and c'. When an upper switch is switched ON *i.e.*, when a, b or c is 1, the corresponding lower switches is switched OFF, *i.e.*, the corresponding a', b' or c' is zero. Therefore, the ON and OFF states of the upper switches Q_1, Q_3 and Q_5 can be used to determine the output voltage. Hence, there are eight sets of switching combinations from 0, 0, 0 to 1, 1, 1. The working principle of the conventional 6 switch 3 phase inverter is based on space vector modulation technique.

Space Vector Modulation (SVM)

Space Vector Modulation (SVM) is quite different from the PWM methods. With PWMs, the inverter can be thought of as three separate push-pull driver stages, which create each phase waveform independently [9]. SVM, however, treats the inverter as a single unit, specifically, the inverter can be driven to eight unique states. The concept of space vector is derived from the rotating field of ac machine which is used for modulating the inverter output voltage. If three phase sinusoidal and balanced voltages are applied to a three-phase induction motor, it can be shown that the space vector $\bar{V}$ with magnitude V_m rotates in a circular orbit at angular velocity $\boldsymbol{\omega}$ where the direction of rotation depends on the phase sequence of the voltages.

SVM is a digital modulating technique, where the objective is to generate PWM load line voltages that are in average equal to a given load line voltage. This is done in each sampling period by properly selecting the switch states of the inverter and the calculation of the appropriate time period for each state. The SVM for a three leg voltage source inverter is obtained by sampling the reference vector at the fixed clock frequency $2f_s$. All the eight possible switching combinations of the switching network are mapped into an orthogonal plane. The results are six non-zero vectors and two zero vectors. The six non-zero switching vectors form a hexagon as shown below in Figure 2.

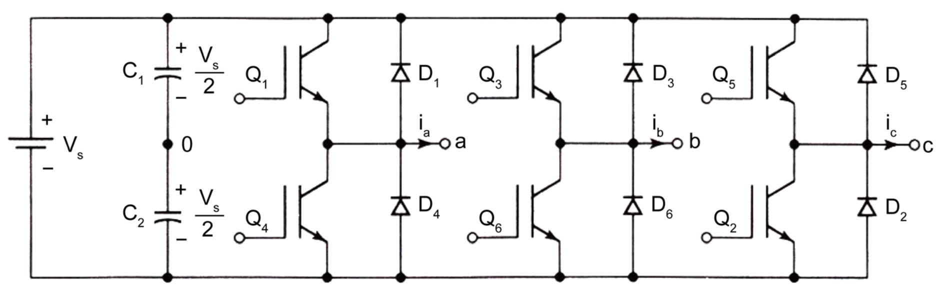


Figure 1. Six switch three phase inverter.

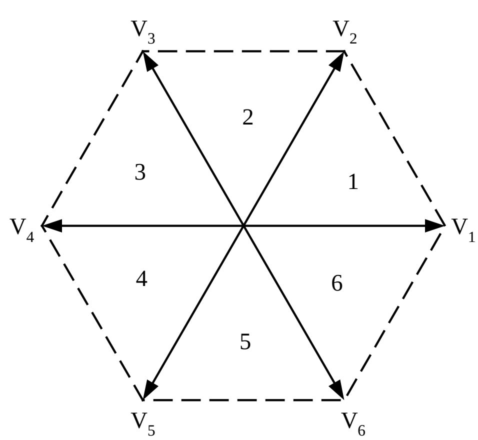


Figure 2. Vector representation.

To implement the space vector PWM, the voltage equations in the a-b-c reference frame can be transformed into the stationary d-q reference frame that consists of the horizontal (direct) and vertical (quadrature) axes. Then it involves vectorially decomposing a desired voltage space vector V into voltage vector components that can be generated using a typical three-phase inverter. There are eight possible combinations of ON and OFF patterns for the three upper power switches. The ON and OFF states of the lower power devices are opposite to the upper one and so are easily determined once the states of the upper power switches are determined.

3. Double Boost Converter: Principle of Operation

Figure 3 shows the basic circuit of Double boost converter for power factor correction. An uncontrolled diode rectifier with a boost converter is used to convert the single phase AC voltage into a constant DC link voltage, which is fed to the PWM inverter supplying an induction motor. The double boost converter is the widely used topology for achieving power factor correction. This converter draws unity power factor current from the AC mains and eliminates a harmonic current which regulates the DC link voltage even under fluctuating voltage conditions of AC mains. This circuit uses a snubber inductor which is connected in series with main switch and rectifier to control the di/dt rate of the rectifier.

The bulk energy storage capacitor sits on the output side of the converter rather than just after the diode rectifier bridge. The average inductor current which charges the bulk capacitor is proportional to the utility line voltage. For proper operation, the output voltage must be higher than the peak line voltage and current drawn from the line must be proportional to the line voltage. In circuit operation, it is assumed that the inductance of boost inductor is large so that it can be represented by constant current source and that the output ripple voltage is negligible so that the voltage across the output filter capacitor can be represented by constant voltage source. The designed values of the boost converter are tabulated in Table 1.

4. Simulation Studies

The conventional and proposed systems have been simulated using Matlab/Simulink. The simulation results are depicted in Figure 4 & Figure 5. The input voltage, current waveforms and FFT analysis of existing converter SSTPI are shown in Figure 4 & Figure 5 illustrates the phase voltages, currents and FFT analysis applied to the proposed

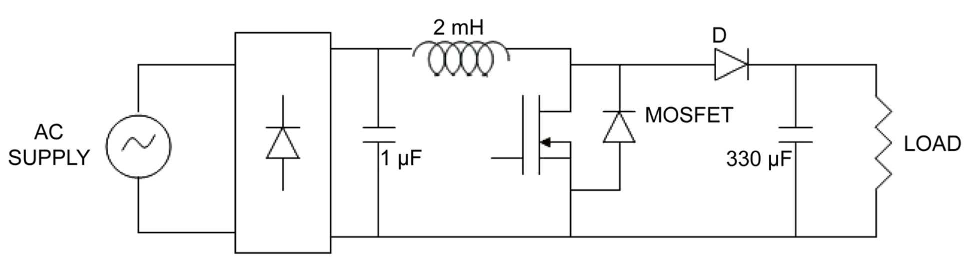
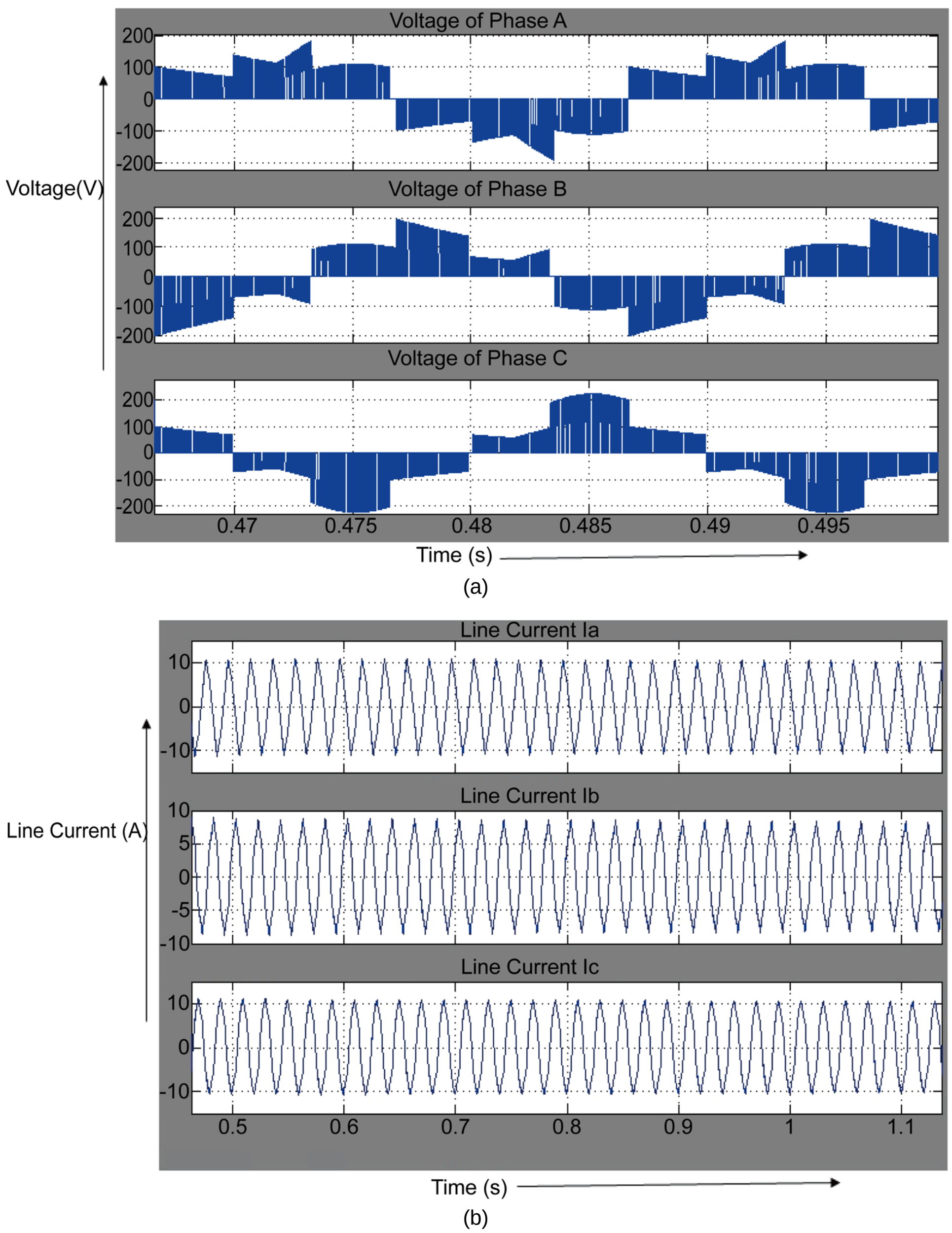
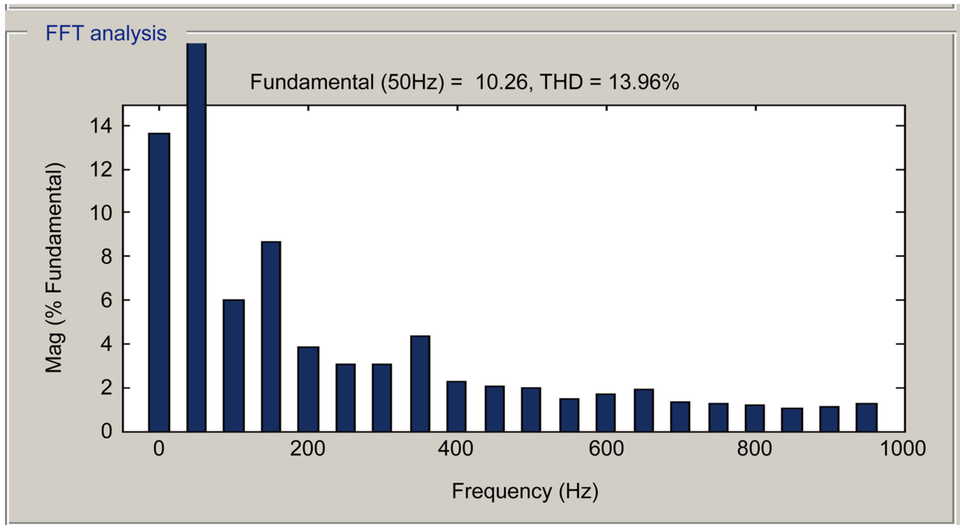


Figure 3. Double boost converter circuit.

Table 1. Parameters of double boost converter.

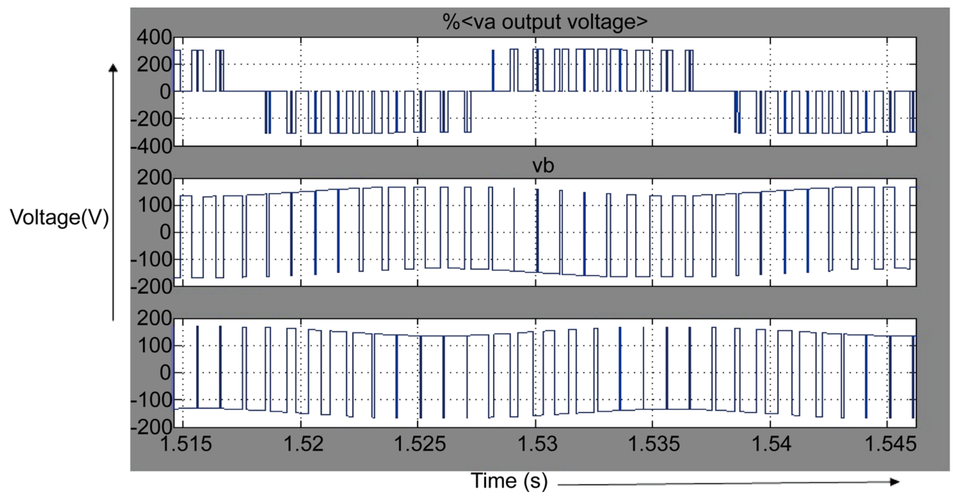
Parameter	Value
Line Voltage	200 V
Output Voltage	200 V DC
Output Power	1 kW
Boost Inductor	2 mH
Boost Capacitor	1 µF
Output Capacitor	330 µF
Switching Frequency	100 kHz



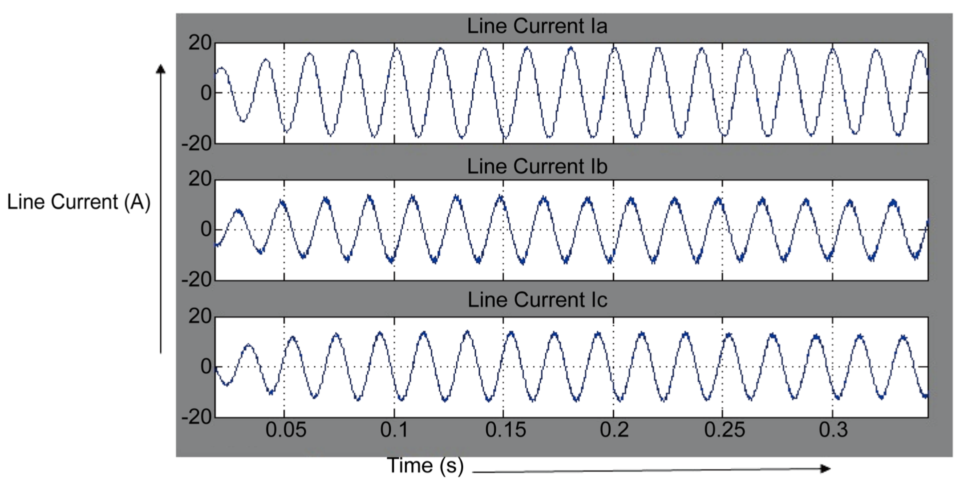


(c)

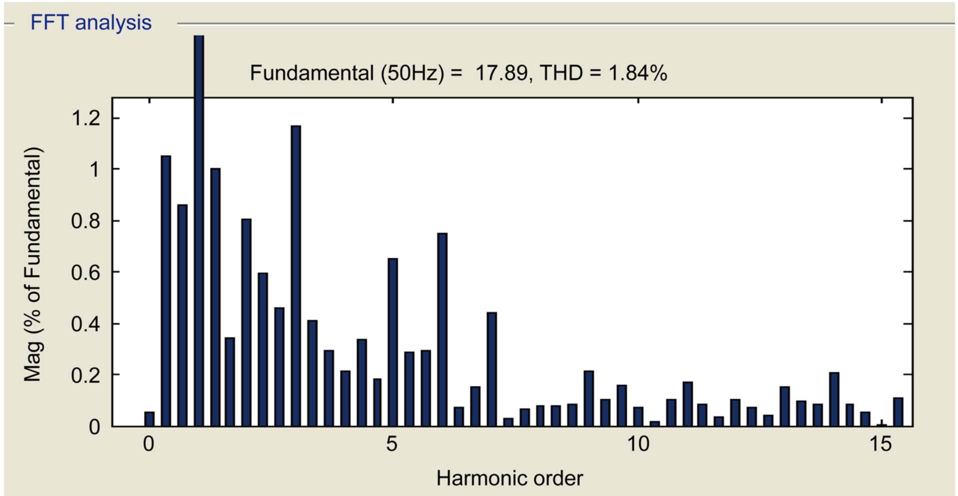
Figure 4. SSTPI simulation results. (a) Three phase voltage (Va, Vb & Vc); (b) Three current waveforms (Ia, Ib & Ic); (c) FFT analysis.



(a)



(b)



(c)

Figure 5. Simulated results of proposed system. (a) Three phase voltages (Va, Vb & Vc); (b) Three phase currents (Ia, Ib & Ic); (c) FFT analysis.

double boost converter based FSTPI fed three phase induction motor. The phase voltages observed with the conventional SSTPI is found to be more distorted and so the corresponding current waveforms. From Figure 5, it is obvious that the three phase voltages are resulted with less distortion and so their corresponding currents are found to be more sinusoidal.

The FFT analysis of the proposed and conventional systems illustrated the THD of the systems. The conventional system offered 13.96% of THD whereas the proposed system THD is observed as 1.84%. The inductor size and the amount of inductor current ripple will affect circuit efficiency and power factor. The designed converter increases the inductor size and hence reduces switching loss. Therefore proposed converter provides improved power factor and efficiency, which is evident from the resulted THD. The analysis indicates that the THD of the proposed system is very less compared to the conventional system.

5. Conclusion

The simulation study of implementation of boost PFC converter with FSTPI fed induction motor has been attempted. Implementation of boost PFC converter reduces the losses produced by system components and increases the system efficiency and input power factor. From the simulation study, it is established that the FSTPI fed induction motor with boost PFC converter provides reduced THD of 1.84%, whereas the THD of the conventional system is 13.96%. The simulation results also reveal that the proposed double boost FSTPI drive can be effectively used for the speed control of three-phase induction motors.

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