A STUDY ON THE CHARACTERISTICS OF FSTPI FED INDUCTION MOTOR WITH INPUT ACTIVE BOOST CONVERTER FOR POWER FACTOR CORRECTION

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ABSTRACT: Growing consciousness and need for drawing sinusoidal current from the utility, both for optimal utilization of the utility power plant capacity and to minimize harmonics injection into it, require the study of the impact of the power factor correction circuit on inverter-fed induction motor drive systems. Such a system is very urgent for fractional hp drive systems due to their massive emerging applications in appliances, hvacs, hand tools, and industrial processes hitherto considered cost-ineffective. Of particular interest in the system study is the impact of the power factor correction circuit on the overall system efficiency and system input power factor. This paper is concerned with such a study of a three phase PWM inverter-fed induction motor drive with single phase utility input with power factor correction circuit. In the case of the study, detailed comparisons of induction motor efficiency, input power factor and THD are made.

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1. Introduction

This paper presents performance of a FSTPI fed induction motor with boost PFC converter. 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. In order to meet the harmonics limits, new AC-DC converter designs must employ active power factor correction at the input. Therefore boost 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.

Adly Girgis (1992) described the performance of capacitors 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. Krishnan (1995) analyzed 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. The above approach increase the losses in diode and bridge rectifier and consequently decreases the system efficiency. Jung Cho (1997) proposed zero voltage transition isolated PWM boost converter for single stage power factor correction. The above approach has one disadvantage like low frequency ripple which exists in the output. Yamamoto (2002) designed and analyzed canonical switching cell converter performance. Yuen-Haw Chang (2004) designed CMOS gate based switched capacitor boost DC-AC inverter. The designed topology produces heat problem due to power loss and hence system performance is affected by poor efficiency. Paul NosikeEkemezie (2007) designed boost PFC converter and performance analyzed in the case of input voltage and current. The above converters are not suitable to relatively small size power supply due to its lower efficiency.

2. Boost Converter: Principle of Operation

Figure 1 shows the basic circuit of 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 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.

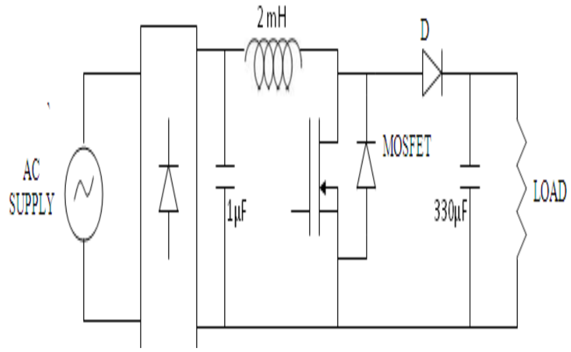

Figure 1 Basic Boost Converter Circuit

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.

3. Simulation Results

Design procedure of simulation parameters

Induction Motor

Consider the loop voltage equations of the induction motor

$$V_{as}= (R_s+j\omega_s L_{ls}).I_s + Z_o I_o \qquad (1)$$

$$0 = \left(\frac{R_r}{s} + j\omega_s L_{lr}\right).I_r + Z_o I_o \qquad (2)$$

where

$$I_s = I_r + I_o \qquad (3)$$

$$Z_o = j\frac{\omega_s L_m R_c}{R_c + j\,\omega_s L_m} \qquad (4)$$

I_s, I_r and I_o are the stator, rotor and magnetizing branch currents respectively. V_{as} is the stator phase voltage, $f_s$is the supply stator frequency, R_s and R_r are stator and stator referred rotor phase resistances, respectively. L_m, L_{ls} and L_{lr} are the magnetizing, stator leakage and stator referred rotor leakage inductances per phase, respectively. s is the slip which is given by

$$s = \frac{\omega_s - \omega_r}{\omega_s} = 1-\frac{\omega_r}{\omega_s} = 1-\frac{P}{2}.\frac{\omega_r}{\omega_s} = 1-\frac{nP}{120 f_s} \qquad (5)$$

where ω_m and ω_s are rotor mechanical and electrical angular speed, respectively. n is the rotor speed in rpm, and P is the number of poles. The mechanical power developed (P_m)in the rotor for a m-phase machine is given by

$$P_m = m I_r^2 R_r \frac{(1-s)}{s} \qquad (6)$$

where m is three in the present study.

Inverter

The inverter output phase voltage is programmed as a function of stator frequency command of the induction motor and given as

$$V_i = V_{as} = V_{of} + k_{vf}.f_s \qquad (7)$$

Where V_{of} is the offset voltage and it is given by

$$V_{of} = I_b R_s \qquad (8)$$

and the constant k_{vf} is given by

$$k_{vf} = \left(\frac{V_b - V_{of}}{f_b}\right) \qquad (9)$$

where I_b is the base (rated) stator phase current, V_b is the base (rated) stator phase voltage and f_b is the base (rated) stator frequency.

The inverter switching and conduction losses are given approximately by

$$P_{ins}= m[\tfrac{1}{2} V_{dc} I_s f_{sw}(t_{ri}+t_{fi}+t_{rri})] \qquad (10)$$

$$P_{inc}=m[I_s V_{CE}] \qquad (11)$$

where t_{ri} and t_{fi} are the rise and fall times of the power devices, t_{rri} is the reverse recovery time of the freewheeling diodes, f_{sw} is the inverter switching frequency, V_{CE} is the on state voltage drop across the power device, V_{dc} is the dc link voltage input to the inverter and P_{ins} and P_{inc} are the inverter switching and conduction losses, respectively.

Bridge Rectifier

The conduction losses are considered in this study and they are derived as

$$P_{br}=2V_d I_{in} = 2\times 0.7\times\frac{P_{in}}{V_{in}} = (1.4)\frac{P_{in}}{V_{in}}$$

whereV_d is the diode conduction voltage drop, P_{in} is the ac input power from the main supply, V_{in} is the ac input voltage and I_{in} is the ac input current and P_{br} is the conduction losses in a single phase rectifier bridge.

Boost PFC Circuit

AC input voltage (rms) 90V-270V

Input frequency 47-53 Hz

Target efficiency (η) is 72% (min) at 90V AC/1000W

The selection of boost converter components is based on the following standard procedure:

Maximum input power,

$$P_{in}\,(\max) = \frac{P_o\,(\max)}{\eta_{min}} = \frac{1000\,W}{0.72} = 1338\ W$$

Maximum rms input current,

$$I_{in}(rms)\ \max=\frac{P_{in}\,(\max)}{V_{in\,(rms)\,min}}=\frac{1338}{90} =15.4\ A$$

Maximum peak input current,

$$I_{in}(pk)\max=I_{in}(rms)\max=15.4\times\sqrt{2}=21.7\ A$$

Average input current,

$I_{in}(avg)max = \frac{2Iin(pk)max}{\pi} = \frac{2\times 21.7}{\pi} = 13.87$ A

Boost Capacitor

Boost capacitor,

$$C_{in} = K_{\Delta}I_L . \frac{I_{in}(rms)max}{2\pi . f_{sw} \times r \times V_{in(rms)min}}$$

$K_{\Delta}I_L$ = Inductor current ripple factor (20% in this design)

r= high frequency voltage ripple factor typically from 3% to 9% (5% used in this design).

Switching frequency, f_{sw}= 100000 Hz

Boost capacitance,

$$C_{in} = 0.2 \times \frac{15.4}{2\pi \times 100000 \times 0.05 \times 90}$$

C_{in} = 1 µF.

Boost Inductor

Minimum input peak voltage,

$V_{in}(pk)min = \sqrt{2}Vin(pk)min = 90\sqrt{2} = 127V$

Peak boost transistor duty cycle

$$D_{pk} = 1 - \frac{Vin(pk)}{V_o} = 1 - \frac{127}{400} = 0.6825$$

Inductor ripple current

$\Delta I_L = 0.2\ I_{in}(pk)\ max = 0.2 \times 21.7 = 4.34$ A

ΔI_L is based on the assumption of 20% ripple current

Peak inductor current

Maximum load current,

$$I_L(pk)\ max = I_{in}(pk)\ max + \frac{\Delta IL}{2} = 21.7 + \frac{4.34}{2} = 23.87A$$

$$\text{Inductance, } L = \frac{Vin(pk)min \times Dpk}{fsw \times \Delta IL} = \frac{127 \times 0.6825}{100000 \times 4.34} = \frac{86.6775}{434000}$$

$= 2\times 10^{-4}$ = 2mH is selected

Output Capacitor

The value of the output capacitor impacts hold up time and ripple voltage. In this design, the criterion for selection of this capacitor is the amount of tolerable ripple in the output voltage.

$$C_{out} = \frac{\frac{P_O}{v_O}}{2\pi f_r \times \Delta V}$$

where f_r is a frequency of the rectified sine wave and ΔV is desired peak to peak output voltage ripple

Output capacitor,

$$C_{out} = \frac{\frac{1000}{400}}{2\pi \times 100 \times 0.03 \times 400} = \frac{2.5}{7536} = 330\ \mu F$$

The parameters of the induction motor are given below.

Stator resistance, r_s= 1.11Ω, Rotor resistance, r_r= 1.08Ω

Stator inductance, l_s= 0.006H, Rotor inductance, l_r= 0.006H

Mutual inductance, M= 0.20H

Poles, P= 2

Moment of inertia, J= 0.02Kg m^2

Co-efficient of viscous friction, F= 0.00575 Nm/(rad/sec)

The parameters used in the simulation are

Nominal line voltage (V_{ac}):	200V
Output Voltage (V_o):	200V DC
Output power (P_o):	1KW
Boost inductor:	2mH
Boost capacitor:	1 µF
Output capacitor:	330 µF
Switching frequency:	100 KHz

The complete simulink block diagram of system is shown in Figure 2. This block diagram consists of two blocks. The block which consist switching pulses that generates PWM pulses for four switches of FSTPI at the terminals Out 1 to Out 4. The other block consist FSTPI, induction motor and diode bridge rectifier. Voltage block is used to display the three phase voltage waveforms. Figure 3 shows the circuit of FSTPI fed induction motor with boost PFC converter. This circuit contains three phase input AC power supply, diode bridge rectifier, boost power factor correction circuit with an inductor and capacitor, split capacitor, four MOSFET switches and three phase induction motor. Figure 4 shows the power factor measurement circuit of boost PFC converter. It can be seen that a better power factor of 0.998 is achieved in the designed converter than the existing power CMOS-gate based switched capacitor boost DC-AC inverter (CMOS-TG QSC boost DC-AC inverter). 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. The input voltage and current waveform of existing converter are shown in Figure 5. The waveform clearly indicates that the power factor of existing converter is 0.94.

Figure 6 presents the switching pulses applied to switches M1 and M2. Figure 7 illustrates the phase voltage applied to the three phase induction motor. Figure 8 shows the efficiency of three phase induction motor in which boost converter FSTPI is used. It can be seen that the efficiency has improved to 75% due to minimized conduction losses. The efficiency of designed converter is high when compared to existing CMOS-TG QSC boost DC-AC inverter which has only 70% of efficiency. The efficiency curve of CMOS-TG QSC boost DC-AC inverter is shown in Figure 9. The simulation results show that the designed converter provides better performance than existing CMOS-TG QSC boost DC-AC inverter. The performance comparison of designed boost converter and an existing converter is revealed in Table 1.

Table 1 Performance comparison between existing converter and proposed boost converter

Parameter	Performance of existing converter	Performance of proposed boost converter
Efficiency	70	75
Power Factor	0.94	0.998

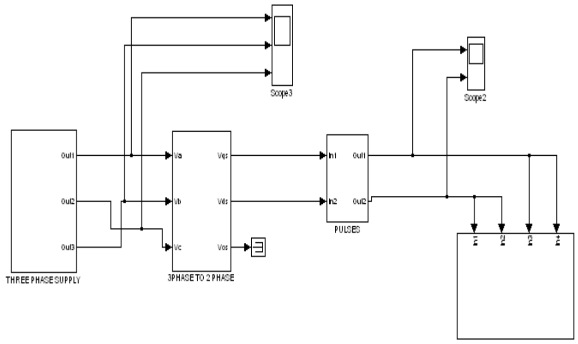

Figure 2Simulation Block Diagram of FSTPI Fed Induction Motor Drive System with Boost Converter

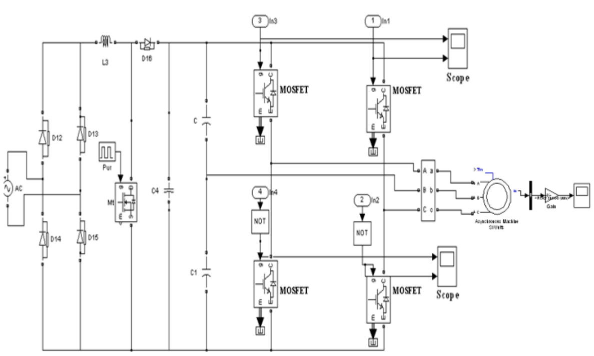

Figure 3 Four Switch Three Phase Inverter Fed Induction Motor System with Boost Converter

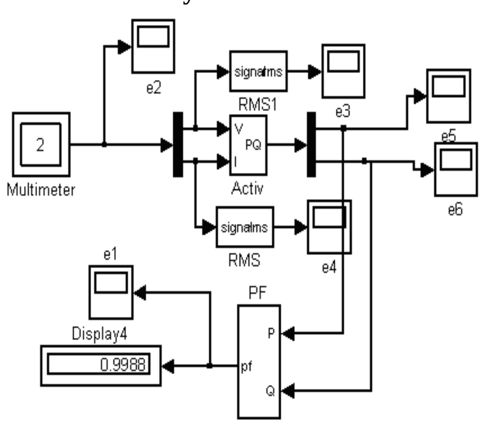

Figure 4 Power Factor Measurement of Boost PFC Converter

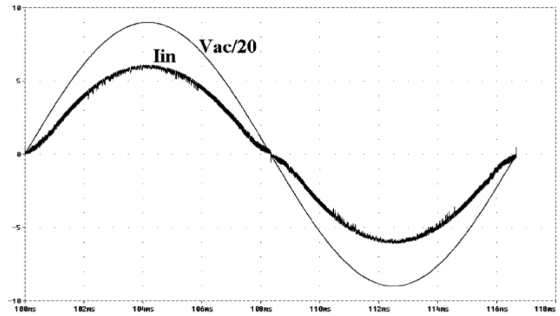

Figure 5 Power Factor Measurement of CMOS-TG QSC boost DC-AC inverter

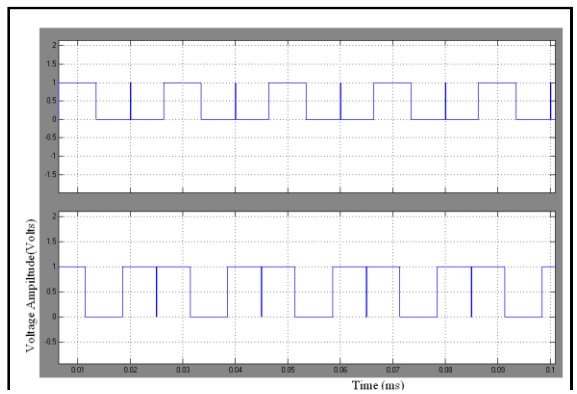

Figure 6 Driving Pulses for M1 and M2

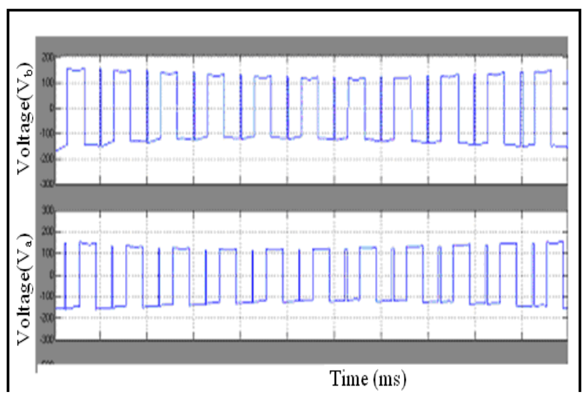

Figure 7 Phase Voltage

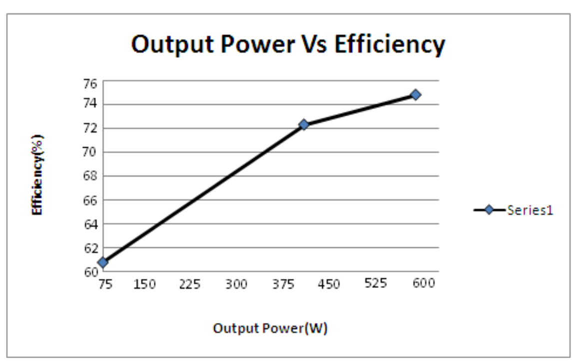

Figure 8 Output Power Vs Efficiency of FSTPI Fed Induction Motor with Boost Converter

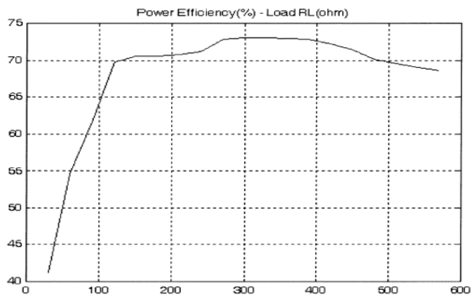

Figure 9 Output Power Vs Efficiency of CMOS-TG QSC boost DC-AC inverter

4. Conclusion

This chapter illustrates the simulation study of implementation of boost PFC converter with FSTPI fed induction motor. Implementation of boost PFC converter reduces the loss 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 a power factor of 0.998 compared to a value of 0.94 for the existing CMOS-TG QSC boost DC-AC inverter. The efficiency of FSTPI fed induction motor is 75% compared to 70% in case of the existing converter. The simulation result exhibits better performance of boost converter than existing converter.

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