Vector Controlled Induction Motor Drive Using High Power Factor Converter

Anjana V C[1], Dr. Bos Mathew Jos[2], Acy M Kottalil[3]

[1]Post Graduate student, Department of EEE, MA College of Engineering, Kothamangalam, Kerala, India,

[2]Professor, Department of EEE, MA College of Engineering, Kothamangalam, Kerala, India,

[3]Professor, Department of EEE, MA College of Engineering, Kothamangalam, Kerala, India.

Abstract — *Adjustable-speed drives (ASDs) are widely used in both industrial and commercial applications as the most versatile and efficient means of achieving motion control. With the emergence of applications demanding accurate control of AC drives using induction machines, the betterment of such a drive system has become a major concern. This is being achieved with the advent of solid state semiconductor devices and cheap microprocessors which provide better control. The elements in the drive system and the control algorithm used are the factors which can be modified inorder to get the best outcome from the drive for a particular application. This work addresses the issue of poor power factor. One of the reason for poor power factor in conventional induction machine drives are the three phase diode bridge rectifier at the front end for AC-DCconversion. The use of a high power factor converter with ZVS transition leads to better power factor and lower conduction losses. Vector control provides better dynamic performance and lower energy consumption. The simulation of vector controlled induction motor drive has been performed using MATLAB/Simulink. The control circuit was implemented using TMS320f28335 DSP controller and results are verified.*

Keywords *—Vector control, Power factor, Induction motor.*

I. INTRODUCTION

Developments in the world of electrical machines have led to the large-scale deploymentof the motor drives for industrial applications in recent years. A major share of the motors in the industrial control and automation is occupied by induction motors as theyare robust, reliable, cheap and are available in a variety of power ratings. The inventionof high-speed power semiconductor devices has resulted in extensive developments inthe variable speed AC motor drives systems. In these drive systems, a conventionalsix switch three phase voltage source inverter fed by the DC supply obtained froma single phase AC supply using diode bridge rectifier is used. Hence, distorted currents are drawn from the line, which results in low PF and high THD. Consequently,Power Factor Correction (PFC) along with closed loop speed control of the machine isinevitable to improve the power quality and the overall efficiency of the drive system[1].

The non-linear characteristics of load in variable speed motor drives in various applications have made harmonic distortion a common occurrence in electrical distribution systems. However when operating together, the combined effect of these loads havethe capability of causing serious harmonic distortions. This results in a poor powerquality, voltage distortion, poor power factor at input ac mains, slowly varying rippleddc output at load end and low efficiency. Reduction in input current harmonics and theimprovement of power factor operation of motor drives and switching power supplies isnecessary from energy saving point of view. The variable frequency drive with a highpower factor converter at the front end will improve the power factor of the system.It will generate less harmonic distortion than a diode bridge rectifier. Owing to the advantages of simple circuit topology and easy control, boost or buck-boost convertershave been widely served as power-factor correctors.The replacement of conventionaldiode bridge rectifier at the front end by a high power factor converter[2] leads tolower conduction losses, higher efficiency and leads to improvement in power factor.Using this new converter, we require only single phase supply at the input side andalso the input supply current consists of lesser harmonics. Instead of six diodes in theconventional three phase diode bridge rectifier, this converter consists of four diodesand two switches and additional two inductors. Eventhough, the addition of these two inductors make the circuit bulky, the advantages provided by this circuit overweighsthis limitation.

Among the various control mechanisms available for induction motor drive, field oriented control consists of controlling the stator currents represented by a vector. Thiscontrol is based on projections that transform a three phase time and speed dependentsystem into a two coordinate (d and q frame) time invariant system. These transformations and projections lead to a structure similar to that of a DC machine control. FOCmachines need two constants as input references: the torque component (aligned withthe q coordinate) and the flux component (aligned with d coordinate). The three-phasevoltages, currents and flux of AC-motors can be analyzed in terms of complex spacevectors. Thistype of control provides independent control of flux and torque in themachine[3].

II. HIGH POWER FACTOR CONVERTER

This circuit topology is derived by integrating a boost converter and abuck converter. The boost converter performs the function of power-factor correction(PFC) to obtain high power factor and low current harmonics at the input line. Thebuck converter further regulates the dc-link voltage to provide a stable dc output voltage. Without using any active-clamp circuit or snubber circuit, the active switches ofthe proposed converter can achieve zero-voltage switching-on (ZVS) transition togetherwith high power factor.

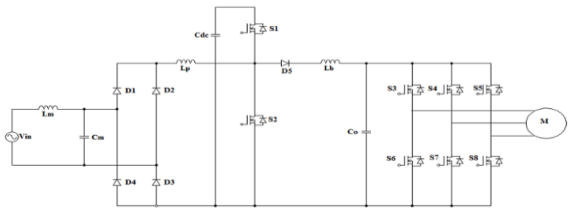


Fig 1: High power factor driven induction motor

A. Modes of Operation

The circuit operation is divided into 8 operating modes

a). Mode1: This mode starts when S_1 is turned off by the gate voltage V_{GS1}. The time interval of this mode is the turn off transition. At the beginning of this mode i_b is diverted from S_1 to flow through the output capacitors C_{DS1} and C_{DS2}. C_{DS1} and C_{DS2} are charged and discharged respectively.

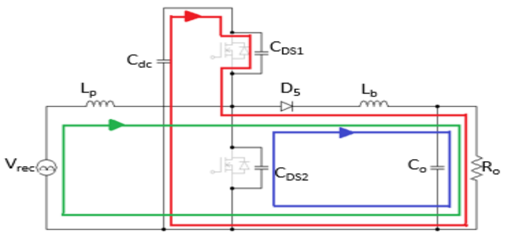


Fig 2: Mode 1

b). Mode2:After a short dead time, S_2 is turned ON by the gate voltage V_{GS2}. In mode2, i_b is higher than i_p. Current i_b has two loops. Part of i_b flow through S2 and the rest are equal to $i_p$and flow through the line voltage source, diode rectifier and L_p. This mode ends when i_p rises to become higher than ib.

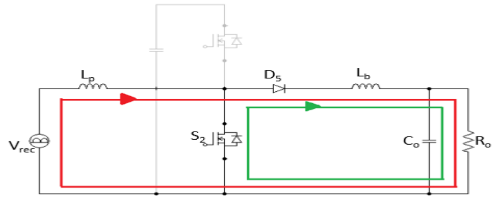


Fig 3: Mode 2

c). Mode3:In this mode i_p is higher than ib. current ip has two loops. Part of i_p are equal to i_b and flow into the buck converter, while rest flow through S_2. At the end of this mode i_b will decrease to zero.

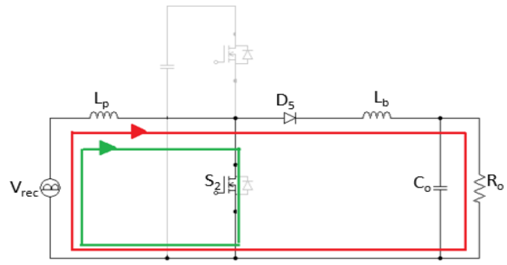


Fig 4: Mode3

d). Mode4: S_2 remains ON to carry i_p. Because i_b is zero, the buck converter is at OFF state and the output capacitor C_o supplies current to the load. S_2 is turned OFF at the end of this mode.

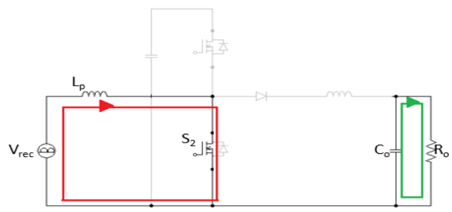


Fig 5: Mode4

e). Mode5: Current i_p reaches a peak value at the time instant of turning OFF S_2. C_{DS1} and C_{DS2} are discharged and charged respectively.

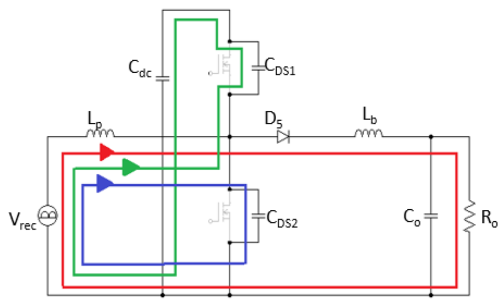


Fig 6: Mode 5

f). Mode6: After a short dead time S_1 is turned ON by V_{GS1}. i_p is higher than i_b.

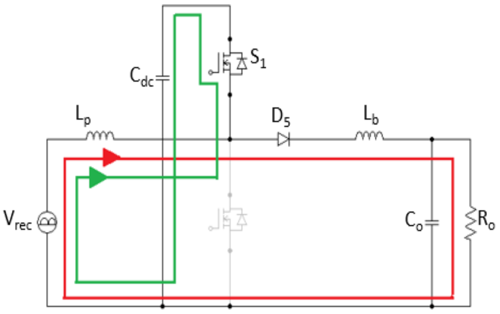


Fig 7: Mode 6

g). Mode7: In this mode i_b is higher than i_p. There are two loops for i_b. Part of i_b are equal to i_p and flow into the boost converter while the rest flow through S_1.

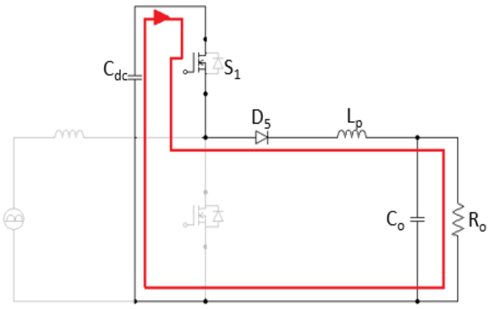


Fig 8: Mode 7

h). Mode8: S_1 remains on and i_b keeps increasing. This mode ends at the time when V_{GS1} becomes a low level to turn off S_1 and the circuit operation returns to mode1 of the next high frequency cycle.

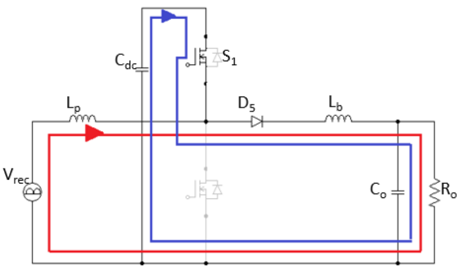


Fig 9: Mode 8

III. SIMULATION MODEL WITH RESULTS

Fig.10 shows the Simulink model of induction motor drive fed from high power factor converter. The simulation was performed on a 1hp, 415V ,50Hz three phase squirrel cage induction motor using MATLAB/Simulink. The various block inside the vector control block provides the suitable control mechanism for induction motor. We can see that the dc link voltage rises slowly and settles to its final value. The ripple in the voltage is almost negligible. The input current is nearly sinusoidal and thus provides a better waveform than the input current with diode bridge rectifier.

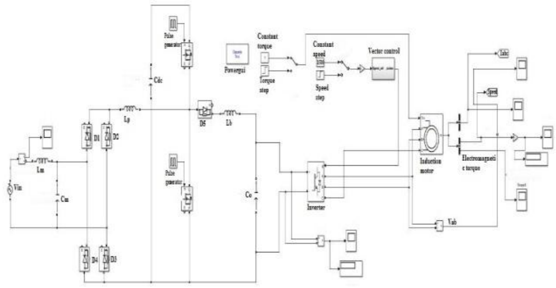


Fig 10: Simulink model of high power factor driven induction motor

Table I presents the simulation parameters of high power factor converter.

TABLE I
SIMULATION PARAMETERS

System Specification	Parameters
Input Voltage	230 V
Output Voltage	400 V
Switching Frequency	50 kHz
Boost Inductor L_p	3.368 mH
Buck Inductor L_b	10.8 mH
Buck Capacitor C_o	100 μF
DC Link Capacitor C_{dc}	100 μF
Output Resistor R_o	267 Ω

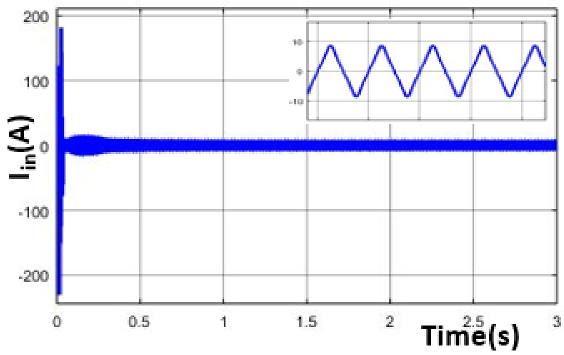


Fig 11: Input current

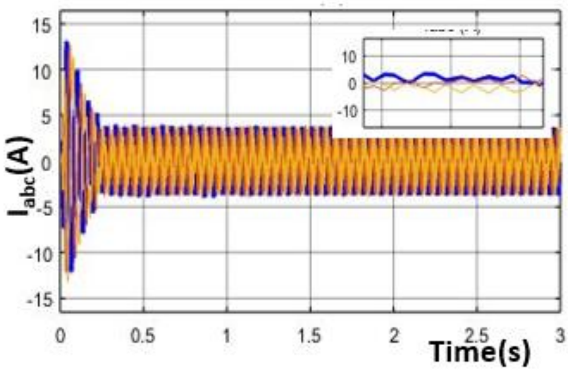


Fig 12: Stator current

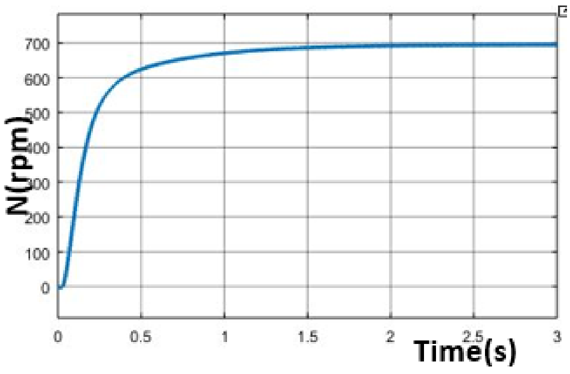


Fig 13: Speed

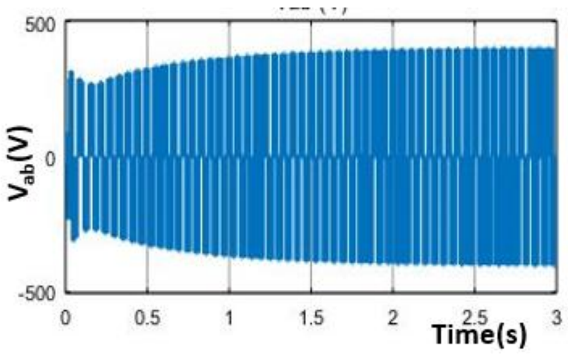


Fig 14: Inverter output voltage

This near sinusoidal waveform definitely leads to lower total harmonic distortion(THD) in the input current and thus better power factor. We can see that the speed response is smooth. A power factor of 0.93 is obtained in no load in simulation. The FFT analysis shows that there is a considerable reduction in THD of input current and also power factor improvement.

IV. EXPERIMENTAL RESULTS

The high power factor converter fed induction motor drive was setup at the laboratory.Fig 15 shows the experimental setup of induction motor drive. Since the output voltage was considerablylarge, the output voltage across the load was sensed by the Digital Storage Oscilloscope(DSO) via a reducer probe that reduces the voltage given across it by a factor of10.

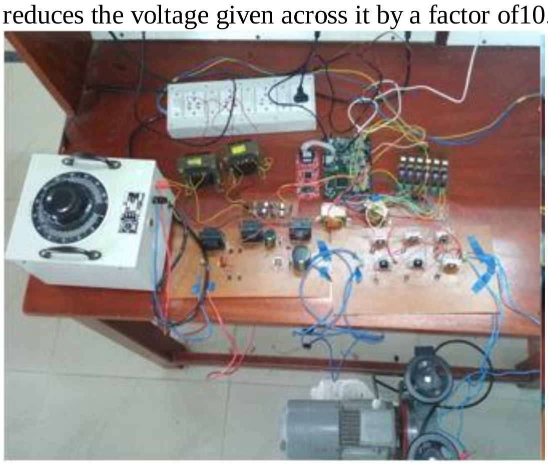


Fig 15: Experimental Setup

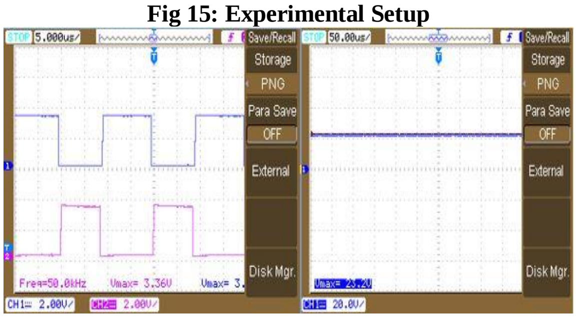
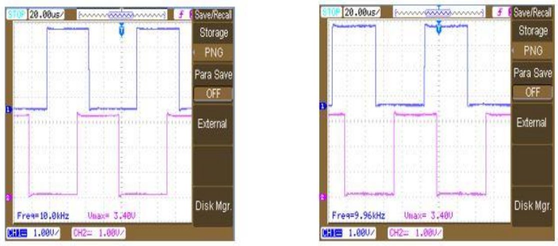


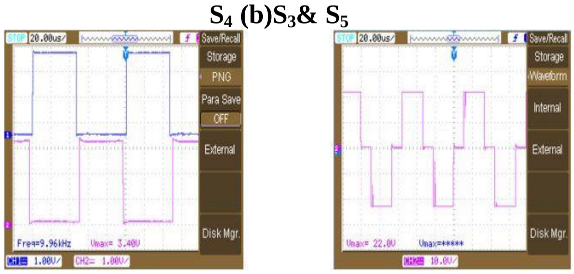
Fig 16: Switching pulses for the converter and output voltage

The switching pulses for the high power factor converter and the inverter were provided from TMS320f28335 DSP controller after passing through the driver circuit. The switches used for high power factor converter are MOSFETS whereas for the inverter the switches are IGBT's. However the driver circuits used for all switches are TLP250.



(a) (b)

Fig 17: Switching pulses of the inverter (a) S_3& S_4 (b)S_3& S_5



(a) (b)

Fig 18: (a) Inverted switching pulses (b)Output voltage of the inverter

V. CONCLUSIONS

The voltage source inverter(VSI) fed vector controlled induction motor drives with afront end diode bridge rectifier provides poor performance since it provides lower powerfactor and efficiency. The replacement of diode bridge rectifier by a high power factorconverter leads to improved performance of the system in terms of power factor andefficiency. Moreover, such a converter requires only single phase supply at the inputside. The replacement of diodes by switches leads to reduced conduction losses. TheFFT analysis also proves that there is a considerable reduction in THD of input currentthat shows that high power factor converter plays a considerable role in the power factorimprovement of the drive. THD of input current is reduced from 268.43% to 13.88% . Also power factor is improved from 0.37 to 0.941.

ACKNOWLEDGMENT

I would like to express my heartfelt gratitude to Prof. Dr. Jos Mathew Jos, EEE Department, MA College of Engineering, for providing me guidance and motivation to accomplish my work. He has been very patient andhas given me immense freedom during the course of work. I would also like to thank Prof. Acy M Kottalil, EEE Department, MA College of Engineering for the support and motivation throughout the completion of this work.

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