Dual Boost Converter fed Vector Controlled Induction Motor Drive

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Abstract- 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. And 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. One of the important element in the drive system is the converter that modulates the power supply available at the input side into that form which is demanded by the load. Conventional induction motor drives uses a three phase diode bridge rectifier at the front end which serves the purpose of AC-DC conversion. In this case, the displacement power factor is unity but due to harmonics, the distortion power factor is low. The use of a novel bridgeless power factor correction dual boost converter leads to lower harmonic input current, lower conduction losses and higher efficiency. The indirect field oriented control mechanism implemented here decouples the two components of stator current space vector, one providing the control of flux and the other providing the control of torque. The simulation of vector controlled induction motor drive has been performed using MATLAB/Simulink. The induction motor drive was implemented using dsPIC30F2010 microcontroller and the results were verified.

Keywords – Induction motor drive, FOC, PFC, Dual Boost Converter, SMPS

I. INTRODUCTION

Electric motors has become an inevitable part of our modern life. The systems that controlled electric motors in the past suffered from very poor performance and were very inefficient and expensive. Recently, the demand for greater performance of electric motors in various applications, combined with the development of better solid-state devices and advanced microprocessors has led to the development of modern adjustable speed drives(ASDs). The three phase diode bridge rectifiers operate by rectifying the input voltage and its output consists of a large capacitor filter. Capacitors always maintain a constant voltage approximately as its peak. Currents drawn by these capacitors are peaky in nature which results in major harmonic issues. It will also leads to severe power quality problems. Harmonics not only destroys its line but also disrupts other devices connected to it since pulsated currents are drawn.

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 have the capability of causing serious harmonic distortions. This results in a poor power quality, voltage distortion, poor power factor at input ac mains, slowly varying rippled dc output at load end and low efficiency. Reduction in input current harmonics and the improvement of power factor operation of motor drives and switching power supplies is necessary from energy saving point of view. A variable frequency drive with an active transistor rectifier at the front end will boost DC bus amps on a PWM drive. It will generate less harmonic distortion than a diode bridge rectifier. Various power factor correction boost topologies with varied performance are discussed and compared in [8]. In each circuit, the boost converter is implemented by replacing a pair of bridge rectifiers with switches and employing an ac-side boost inductor. With a bridgeless topology, one rectifier is eliminated from the line-current path, which minimizes the conduction loss. The most commonly used PFC converter is CCM type as it is simple and has high power capability. Constant efforts are been made to improve the efficiency of rectifiers. Many power supply manufacturers have started considering bridgeless power factor correction circuit topologies. Compared to conventional bridgeless boost rectifier, a bridgeless dual boost rectifier offers high efficiency owing to lower conduction losses and also avoids the problem of common mode noise.

Power Factor Correction (PFC) shapes the input current of the power supply to be in synchronization with the mains voltage, in order to maximize the real power drawn from the mains. In a perfect PFC circuit, the input current follows the input voltage as a pure resistor, without any input current harmonics. Conventional power factor correction (PFC) circuits for SMPS contain an input rectifier bridge. As a result, at any given moment the AC line current flows through three semiconductor components: two diodes of the bridge and then either a switch (such as a FET) or boost diode. This determines conduction power losses. The bridgeless dual boost rectifier is the modified form of conventional bridgeless boost rectifier by the addition of two slow diodes and an additional inductor to supply a low

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frequency path between the output ground and ac source. This topology consists of two DC/DC boost circuits with two inductors

Among the various control mechanisms for induction motor drive, the field oriented control consists of controlling the stator currents represented by a vector. This control is based on projections that transform a three phase time and speed dependent system 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. FOC machines need two constants as input references: the torque component (aligned with the q coordinate) and the flux component (aligned with d coordinate).The three-phase voltages, currents and fluxes of AC-motors can be analyzed in terms of complex space vectors. This type of control provides independent control of flux and torque in the machine.

II. BRIDGELESS DUAL BOOST CONVERTER

This topology consists of two boost circuits. In the conventional boost circuit which acts as the switching regulator, the input will be usually constant DC and these are used as DC-DC converters. Here, the input is AC supply and we can see that there is a boost circuit in the positive half cycle and also another boost circuit in the negative half cycle. Figure 1 shows the circuit diagram of bridgeless dual boost converter. The combination of switch S_1 and inductor L_1 forms the charging path during the positive half cycle of input voltage whereas S_2 and L_2 forms the charging path during the negative half cycle. Thus the energy storage takes place whenever the switches are on and transferring of energy from source side to load side take place whenever the switches are off. The control scheme is less complex due to the fact that both switches are given same switching pulse, eventhough both of them doesn't turn on simultaneously. During the positive half-line cycle of the input voltage, the output ground is connected to the ac source through the slow diode D_2. During the negative half-line cycle of the input voltage, the output ground is connecting to the ac source through the slow diode D_1. The symmetric inductors also can be expected as a common-mode filter to reduce the common-mode problem. power supply to be in synchronization with the mains voltage, in order to maximize the real power drawn from the mains. In a perfect PFC circuit, the input current follows the input voltage as a pure resistor, without any input current harmonics.

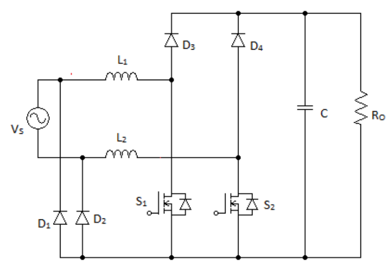
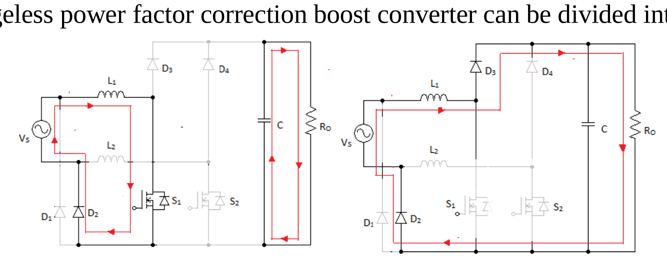


Figure 1. Bridgeless Dual Boost Converter

The bridgeless dual boost rectifier is the modified form of conventional bridgeless boost rectifier by the addition of two slow diodes and an additional inductor to supply a low frequency path between the output ground and ac source. This topology consists of two DC/DC boost converters. The symmetric inductors also can be expected as a common-mode filter to reduce the common-mode problem.

2.1 Modes of Operation

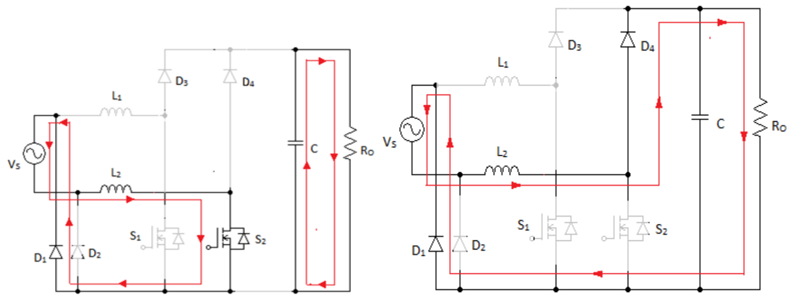
It consists of two boost PFC rectifiers, each operating during a half line cycle of the input voltage. Inductor L_1 operates during positive half cycle and inductor L_2 operates during negative half cycle. The power Switches S_1 and S_2 can be driven with the same PWM signal, which significantly simplifies the implementation of control circuit. The operating principle of bridgeless power factor correction boost converter can be divided into four modes.



(a) (b)

Figure 2. a) Mode 1 operation. (b) Mode 2 operation.

Mode 1 and mode 2 comes under positive half cycle of input voltage. During the positive half cycle of the input voltage, when S_1 is on, the first dc/dc boost circuit section, is active through diode D_2. Inductor L_1 stores energy. Capacitor discharges to the load. In mode 2, both switches are off. Energy stored in L_1 delivered to load. D_2 and D_3 are forward biased. Source and inductor together gives energy to load. Diode D_2 connects the ac source to the output ground.



(a) (b)

Figure 3. a) Mode 3 operation. (b) Mode 4 operation

Mode 3 and mode 4 comes under negative half cycle of input voltage. When S_2 is turned on, L_2 charges through S_2 and D_1. D_1 is forward biased. Current through L_2 increases. Capacitor discharges to the load. In mode 4, bot switches are off. L_2 discharges to load. D_1 is forward biased. Source and inductor together gives energy to the load. Diode D_1 connects the ac source to the output ground.

III. VECTOR CONTROL OF INDUCTION MOTOR DRIVE

Scalar control such as the V/Hz strategy has its limitations in terms of performance. The scalar control method for induction motors generates oscillations on the produced torque. Hence to achieve better dynamic performance, a more superior control scheme is needed for Induction Motor. With the mathematical processing capabilities offered by the micro-controllers, digital signal processors and FPGA, advanced control strategies can be implemented to decouple the torque generation and the magnetization functions in an AC induction motor. This decoupled torque and magnetization flux is commonly called rotor Flux Oriented Control (FOC). The stator input currents to the induction machine is transformed to the synchronous reference frame so as to make possible the decoupled control.

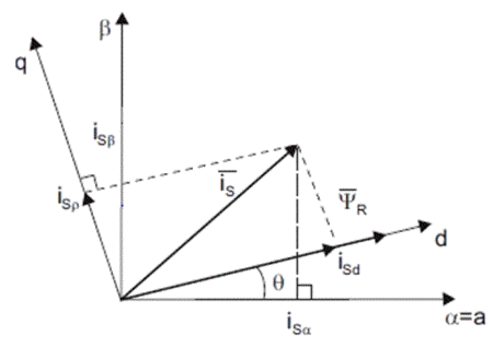


Figure 4. Alpha-beta and dq axis representation of stator current

If we take i_a, i_b, i_c as instantaneous currents in the stator, phases, then the stator current vector it defined as follows:

$$i_s = i_a + i_b e^{j2\pi/3} + i_c e^{j4\pi/3} \quad (1)$$

Where, (a, b, c) are the axes of three phase system. This current space vector represents the three phase sinusoidal system. It needs to be transformed into a two time invariant coordinate system. This transformation can be divided into two steps: (a, b, c) $\rightarrow$ (α,β) (the Clarke transformation), which outputs a two coordinate time variant system. (α, β) $\rightarrow$ (d,q) (the Park transformation), which outputs a two coordinate time invariant system. The decouplibetween torque and flux is achieved only if the rotor flux position is accurately known.

$$\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = 2/3 \begin{bmatrix} cos\theta & cos(\theta - 2\pi/3) & cos(\theta + 2\pi/3) \\ -sin\theta & -sin(\theta - 2\pi/3) & -sin(\theta + 2\pi/3) \end{bmatrix} \times \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

Where, θ is the angle between the rotating and fixed coordinate system. Based on how the rotor flux position is obtained, the vector control is classified into direct vector control and indirect vector control. The major disadvantage of direct vector method is the need of so many sensors. Fixing so many sensors in a machine is a tedious work as well as costlier. Several other problems like drift because of temperature, poor flux sensing at lower speeds also persists. In indirect vector control technique, the rotor position is calculated from the speed feedback signal of the motor. This technique eliminates most of the problems, which are associated with the flux sensors as they are absent. The overall dynamic performance of the indirect vector control technique is better than direct vector control.

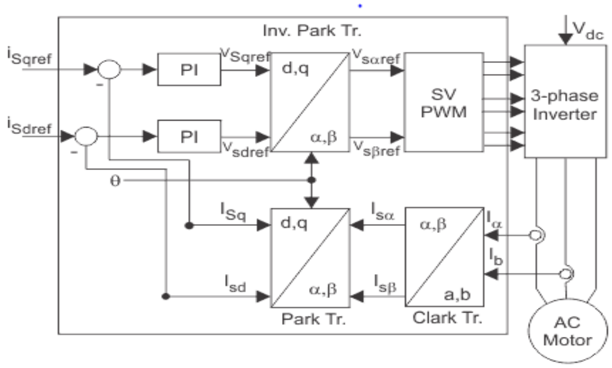


Figure 5. Block diagram of indirect vector control

Firstly, the stator phase currents are measured, and converted to complex space vector in (a,b,c) coordinate system. Current is converted to (α , β) coordinate system. After this, the currents are transformed to a coordinate system rotating in rotor reference frame, and for that, we require rotor position being derived by integrating the speed by means of speed measurement sensor. Rotor flux linkage vector is estimated by multiplying the stator current vector with magnetizing inductance Lm and low-pass filtering the result with the rotor no-load time constant Lr/Rr, namely, the rotor inductance to rotor resistance ratio.Thus the current vector is converted to (d,q) coordinate system.daxis component of the stator current vector is used to control the rotor flux linkage and the imaginary q-axis component is used to control the motor torque. PI controllers provide (d,q) coordinate voltage components. A decoupling term is sometimes added to the controller output to improve control performance to mitigate cross coupling or big and rapid changes in speed, current and flux linkage. PI-controller also sometimes need low-pass filtering at the input or output to prevent the current ripple due to transistor switching from being amplified excessively and destabilizing the control. However, such filtering also limits the dynamic control system performance. High switching frequency (typically more than 10 kHz) is typically required to minimize filtering requirements for high-performance drives such as servo drives.Voltage components are transformed from (d,q) coordinate system to (α , β) coordinate system and then to (a,b,c) coordinate system or fed in Pulse Width Modulation (PWM) modulator, or both, for signaling to the power inverter section.

IV. Simulation models and results

Figure 6 shows the simulink model of induction motor drive fed from a dual boost converter. The simulation was performed on a 1 hp, 415 V, 50 Hz three phase squirrel cage induction motor using MATLAB/Simulink. The various blocks 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 n the voltage is almost negligible. The input current through the inductor are nearly sinusoidal and thus provides a better waveform than that of input current with diode bridge rectifier.

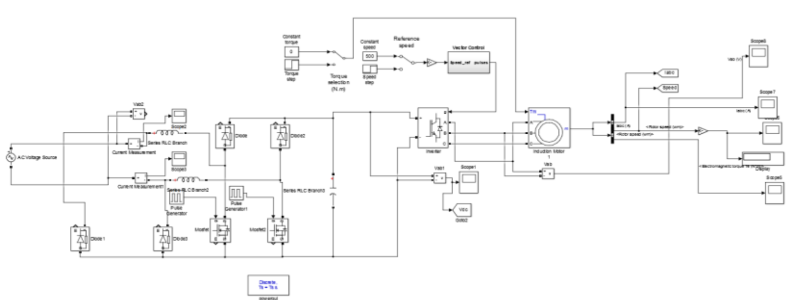


Figure 6. Matlab Model of Dual Boost Converter fed Induction Motor Drive

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 0.77 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.

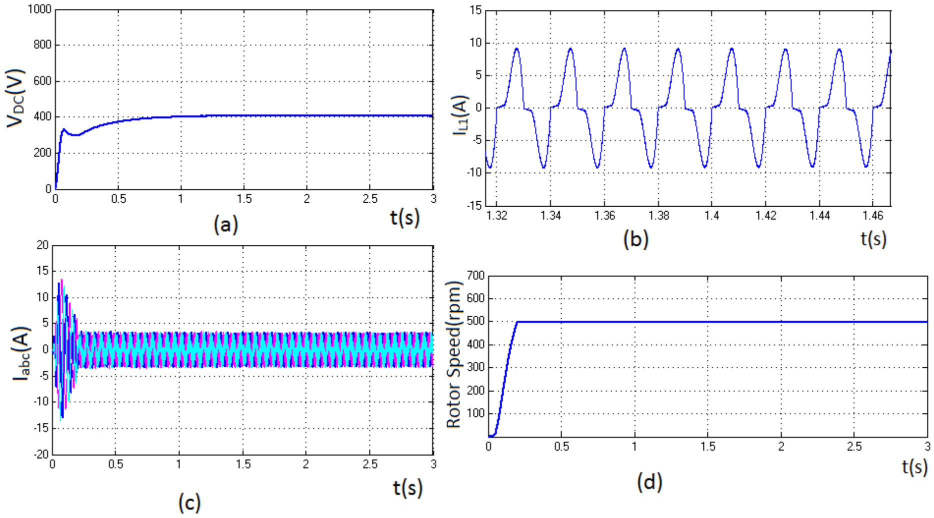


Figure 7. Simulation Results (a) DC link voltage (b) Current through input inductor(c) Stator current waveform (d) Rotor speed.

V. HARDWARE IMPLEMENTATION

The bridgeless dual boost converter fed induction motor drive was setup at the laboratory. The output voltage ripple was very low compared to the output voltage. Figure 8 shows the experimental setup of induction motor drive. Since the output voltage was considerably large, 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 of 10. Thus we can see the output voltage in DSO as 40 V corresponding to the output voltage of 400 V. The switching pulses for the dual boost converter and the inverter were provided from dsPIC30F2010 after passing through the driver circuit.

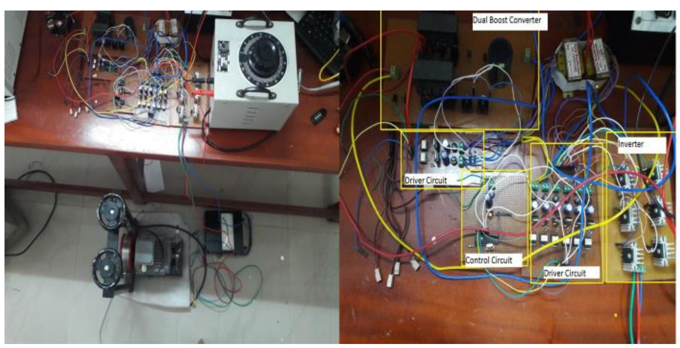


Figure 8. Experimental Setup

From the experimental setup we can assure that the hardware setup is working and produces the desired output. Due to the voltage drop across the four switches used in the bridge converter the diodes, maximum output voltage is less than the input. The output waveforms are shown in Fig.9.

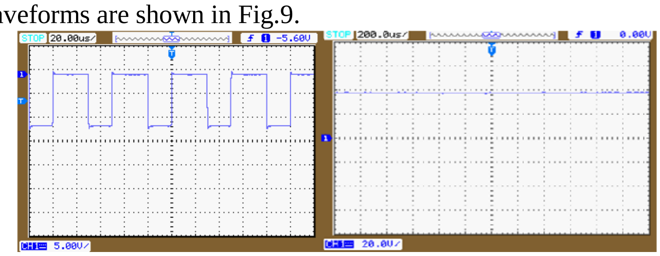


Figure 9. Pulse of switches of Converter and DC link voltage reduced by a factor of 10.

VI. CONCLUSIONS

The voltage source inverter(VSI) fed vector controlled induction motor drives with a front end diode-bridge rectifier provides poor performance since it provides lower power factor and efficiency. The replacement of diode bridge rectifier by a bridgeless dual boost rectifier leads to improved performance of the system in terms of power factor and efficiency. Moreover, such a converter requires only single phase supply at the input side. The replacement of diodes by switches leads to reduced conduction losses and these two switches can be properly controlled and the boost inductors properly designed to obtain the required output voltage at the dc link with minimum ripple content and also lower harmonics in the input current. Instead of peaky currents drawn by the diode bridge rectifier, the dual boost converter causes a near sinusoidal current, that is with reduced harmonic contents. The peaky currents in diode bridge rectifier cause the distortion factor to be very low eventhough the displacement factor is unity. Thus the power factor will be very low. We can see that the stator currents are almost sinusoidal. And also, by using the PI controller, smooth variation in speed response is obtained. The simulation results shows that the speed waveform is smooth. A power factor of 0.77 was obtained for the induction motor drive at no load in simulation. The induction motor drive fed with bridgeless dual boost rectifier was setup in the laboratory and output was observed in DSO and verified.

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