An Adjustable-Speed PFC Bridgeless SEPIC Converter-Fed Induction Motor Drive

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***Abstract*— A power factor corrected bridgeless SEPIC converter-fed induction motor drive as a cost-effective solution for high-power applications. An approach of speed control of the induction motor by controlling the voltage of the voltage source inverter is used with a single voltage sensor. This facilitates the operation of voltage source inverter at fundamental frequency switching by using the electronic commutation of the induction motor which offers reduced switching losses. A bridgeless configuration of the SEPIC converter is proposed which offers the elimination of the diode bridge rectifier, thus reducing the conduction losses associated with it. A power factor corrected bridgeless SEPIC converter is designed to operate in discontinuous inductor current mode to provide an inherent power factor corrected at AC mains. The performance of the proposed drive is evaluated over a wide range of speed control and varying supply voltages with improved power quality at AC mains. The operation of the PFC BL SEPIC converter is classified into two parts which include the operation during the positive and negative half cycles of supply voltage.**

***Keywords*— Bridgeless (BL) SEPIC converter discontinuous inductor current mode (DICM), power factor corrected (PFC), power quality.**

I .INTRODUCTION

The demands for high power factor and low THD in the current drawn from the utility are increasing in the near future. With the stringent requirements of power quality, PFC has been an active research topic in power electronics, and significant efforts have been made on the developments of the PFC converters. Power supplies with active PFC techniques are becoming necessary for many types of electronic equipment to meet harmonic regulations and standards, such as the IEC 61000-3-2. The quality of the currents absorbed from the utility line by electronic equipment is increasing due to several reasons. In fact, a low power factor reduces the power available from the utility grid; while a high harmonic distortion of the line current causes different problems like electromagnetic Interference and cross interferences, through the line impedance, between different systems connected to the same grid. From this point of view, the standard rectifier employing a diode bridge followed by a filter capacitor gives unacceptable performances. Thus, many efforts are being done to develop interface systems which improve the power factor of standard electronic loads and the system. An ideal PFC should emulate a resistor on the supply side while maintaining a fairly regulated output voltage. In the case of sinusoidal line voltage, this means that the converter must draw a sinusoidal current from the utility; in order to do that, a suitable sinusoidal reference is generally needed and the control strategy is to force input current to follow, as close as possible, this current reference. This paved the way for a better technology that can compensate the above disadvantages. Power Factor is the ratio of the power needed to do the work within customer premises to the power delivered by the utility. A power factor of 1.0 is ideal. Equipment located in customer premises emits reactive power that lowers the power factor. There are devices that can be attached to the loads to raise the power factor and reduce the amount of energy lost as heat on the wires in buildings and on the electrical distribution system.

Input power factor (PF) is defined as:

$$\text{Power Factor} = \frac{\text{Real power}}{\text{Apparent power}}$$

In commercial/industrial life, most AC apparatus (e.g. lifts, lights, machinery, air Conditioning, motors and so on) take more from the Regional Electricity supply than they actually need. The higher the power factor, the more effectively electrical power is being used and vice versa. A distribution system's operating power is composed of two parts: active (working) power and reactive (non-working) magnetizing power. The active power performs the useful work while the reactive power does not, as its only function are to develop magnetic fields by inductive devices. Generally, power factor decreases with increased motor loads. Therefore, it can be seen that to reduce the total current to the actual current required would result in greater efficiency. Power Factor values are in the range of 0-1, hence an electrical system with a power factor of 1 (unity) is using 100% useful current with no inefficiency. However, an electrical system with a power factor of 0.5(50%) is using twice as much current as it needs. Where this is the case, improvement in power factor (i.e. moving closer to unity), can in most instances, be achieved by connecting a power factor correction capacitor to the electrical supply, resulting in energy efficiency.

Sawmills	0.5
Freezer shops	0.65
Engineering works	0.7
Quarries	0.7

Table1.1 Typical power factors of various electrical Systems

Low power factor means poor electrical efficiency. The lower the power factor, the higher the apparent power drawn from the distribution network. When low power factor is not corrected, the utility must provide the non-working reactive power, in addition to the working active power. This results in the use of larger generators, transformers, bus bars, cables and other distribution systems devices, which would otherwise be unnecessary. As the utility's capital expenditures and operating costs are going to be higher, they are going to pass these higher expenses down the line to industrial users in the form of power factor penalties. With a power factor of 1.0, given a constant power load, the 100% figure represents the required useful current. As the power drops from 1.0 to 0.9 power is used less effectively. Therefore, 11% more current is required than when the power factor was 1.0 to handle the same load. A power factor of 0.7 requires approximately 43% more current, while a power factor of 0.5 requires approximately 100% more (twice as much) as when the power factor was 1.0 to handle the same load.

- A reduction in electricity charges, which depending on the individual premises.
- High power factor eliminates utility power factor penalties, which may be applied to consumers with poor power factors. Such penalties can result in electricity bills for consumers being increased up to 20%, depending on individual electricity companies.
- High power factor reduces the I^2R losses of transformers and distribution equipment.
- A reduction in the heat in cables, switchgear, transformers, and alternators will also prolong the life of such equipment.
- Reduced voltage drop in cables, allowing the same cable to supply a larger motor and improving the starting of motors at the end of long cable runs.

II .ADJUSTABLE SPEED PFC BRIDGELESS SEPIC CONVERTER-FED INDUCTION MOTOR DRIVE

Efficiency and cost are the major concerns in the development of low-power motor drives targeting household applications such as fans, water pumps, blowers, mixers, etc. The use of the BLDC motor in these applications is becoming very common due to features of high efficiency, high flux density per unit volume, low maintenance requirements, and low electromagnetic-interference problems. These induction motors are not limited to household applications, but these are suitable for other applications such as medical equipment, transportation, HVAC, motion control, and many industrial tools. An induction motor has three phase windings on the stator and permanent magnets on the rotor. The BLDC motor is also known as an electronically commutated motor because an electronic commutation based on rotor position is used rather than a mechanical commutation which has disadvantages like sparking and wear and tear of brushes and commutator assembly. Power quality problems have become important issues to be considered due to the recommended limits of harmonics in supply current by various international power quality standards such as the International Electro technical Commission (IEC) 61000-3-2. For class A equipment (< 600 W, 16 A per phase) which includes household equipment, IEC 61000-3-2 restricts the harmonic current of different order such that the THD of the supply current should be below 19% an induction motor when fed by a DBR with a high value of dc link capacitor draws peaky current which can lead to a THD of supply current of the order of 65% and power factor as low as 0.8. Hence, a DBR followed by a power factor corrected (PFC) converter is utilized for improving the power quality at ac mains. Many topologies of the single-stage PFC converter are reported in the literature which has gained importance because of high efficiency as compared to two-stage PFC converters due to low component count and a single switch for dc link voltage control and PFC operation. The choice of mode of operation of a PFC converter is a critical issue because it directly affects the cost and rating of the components used in the PFC converter. The CCM and DCM are the two modes of operation in which a PFC converter is designed to operate. In CCM, the current in the inductor or the voltage across the intermediate capacitor remains continuous, but it requires the sensing of two voltages (dc link voltage and supply voltage) and input side current for PFC operation, which is not cost-effective. On the other hand, DCM requires a single voltage sensor for dc link voltage control, and inherent PFC is achieved at the ac mains, but at the cost of higher stresses on the PFC converter switch; hence, DCM is preferred for low-power applications. The conventional PFC scheme of the induction motor drive utilizes a pulse width-modulated voltage source inverter (PWM-VSI) for speed control with a constant dc link voltage. This offers higher switching losses in VSI as the switching losses increase as a square function of switching frequency. As the speed of the induction motor is directly proportional to the applied dc link voltage, hence, the speed control is achieved by the variable dc link voltage of VSI. This allows the fundamental frequency switching of VSI (i.e., electronic commutation) and offers reduced switching losses.

A PFC BL SEPIC converter-fed induction motor drives as a cost-effective solution for low-power applications. An approach of speed control of the induction motor by controlling the voltage of the voltage source inverter (VSI) is used with a single voltage sensor. This facilitates the operation of VSI at fundamental frequency switching by using the electronic commutation of the induction motor which offers reduced switching losses. A BL configuration of the SEPIC converter is proposed which offers the elimination of the diode bridge rectifier, thus reducing the conduction losses associated with it. A PFC BL SEPIC converter is designed to operate in discontinuous inductor current mode (DICM) to provide an inherent PFC at ac mains. The performance of the proposed drive is evaluated over a wide range of speed control and varying supply voltages with

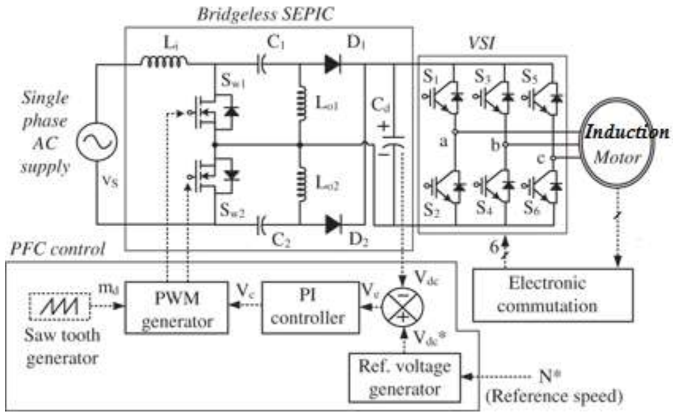

Fig 2.1Proposed PFC BL SEPIC Converter-Fed Induction Motor Drive

improved power quality at ac mains. The operation of the PFC BL SEPIC converter is classified into two parts which include the operation during the positive and negative half cycles of supply voltage. The proposed BL SEPIC converter-based VSI-fed induction motor drive is used. The parameters of the BL SEPIC converter are designed such that it operates in discontinuous inductor current mode (DICM) to achieve an inherent power factor correction at ac mains. The speed control of induction motor is achieved by the dc link voltage control of VSI using a BL SEPIC converter. This reduces the switching losses in VSI due to the low frequency operation of VSI for the electronic commutation of the induction motor. The performance of the proposed drive is evaluated for a wide range of speed control with improved power quality at ac mains. Moreover, the effect of supply voltage variation at universal ac mains is also studied to demonstrate the performance of the drive in practical supply conditions.

The proposed drive's performance can be evaluated for a wide range of speed control with improved power quality at ac mains. Moreover, the effect of supply voltage variation at universal ac mains is also studied to demonstrate the performance of the drive in practical supply conditions. Voltage and current stresses on the PFC converter switch are also evaluated for determining the switch rating and heat sink design. Finally, a hardware implementation of the proposed induction motor drive is carried out to demonstrate the feasibility of the proposed driver a wide range of speed control with improved power quality at ac mains.

The BL buck and boost converter configurations are not suitable for the required application due to the requirement of high voltage conversion ratio. The proposed configuration of the BL SEPIC converter has the minimum number of components and least number of conduction devices during each half cycle of supply voltage which governs the choice of the BL SEPIC converter for this application.

III .OPERATING PRINCIPLE OF PFC BL SEPIC CONVERTER

In Figure 3.1 the circuit of bridgeless SEPIC PFC is shown. During positive half cycle, the switch S1 is turned ON. The lower switch S2 remains OFF. During the positive half cycle the diode Do1 conducts. The components that conduct are L1, S1, DS2, Cb1, L2, DO1, Co and R. During negative cycle, the upper switch S1 is turned OFF and lower switch S2 is turned ON. The components that conduct are L1, Ds1, S2, Cb2, L3, Do2, Co and R. Thus during both the positive half cycle and the negative half cycle only eight components conducts which is comparatively less when compared to other power factor correction circuits. Here the converter is designed to operate in Discontinuous Conduction Mode (DCM). The converters operating in discontinuous mode offers several advantages, namely capability to operate as PFC is inherent, suitable for low power applications and lower component stress.

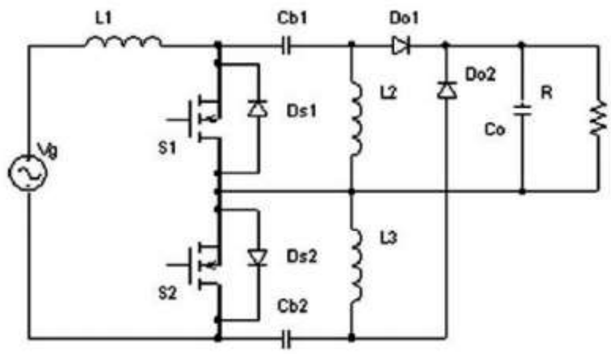

Fig 3.1Basic SEPIC Converter circuit diagram

The circuit operation of the converter during positive half cycle and negative half cycle are similar. Operation of converter during positive half cycle consists of three subintervals MODE 1 (d1TS), MODE 2 (d2TS) and MODE 3 (d3TS). Operation of the converter during MODE 1, is shown in Figure3.2. The upper MOSFET, S1, is turned on, the current flows from the source, Vg, to the input inductor, L1 and continue to S1 and Ds2 before completing the current path through Vg. The current through the inductor L1 increases linearly and reaches its peak value.

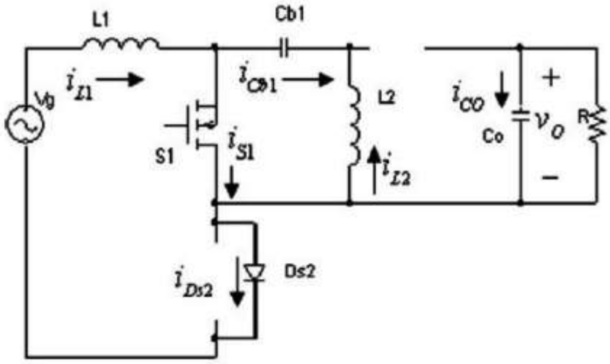

Fig 3.2Equivalent Circuit diagram for Mode 1

where d1 is the duty cycle. At the same time the second inductor, L2 discharges its energy linearly to capacitor Cb1. A closed path for current flow is provided by MOSFET S1, capacitor Cb1 and inductor L2. The net current flowing through switch S1 during MODE 1 is the addition of the current through L1 and L2. The output diode is reverse-biased and the output voltage during this interval is equal to the capacitor voltage Vo. In Figure 3.3 the circuit operation in MODE 2 is shown. Here S1 is turned off and the output diode Do1 is forward biased. During this interval, the current through inductor L1 falls linearly; as it discharges it's current to the load through iCb1 and iDo1 and creates the return path through diode Ds2. The inductor, L2 will discharge its current linearly to the load through iDo1. The current flowing through output diode Do1 is the summation of currents through inductors L1 & L2, iL1 and iL2 respectively. The peak current through diode Do1.Since Vcb1 ≈ Vg, Where La = L1//L2. The peak current flowing through switch S1 is exactly the same with Do1 due to the summation of current at inductors L1 and L2. The d2 width can be determined by examining the ripple current at inductor L1 such that,

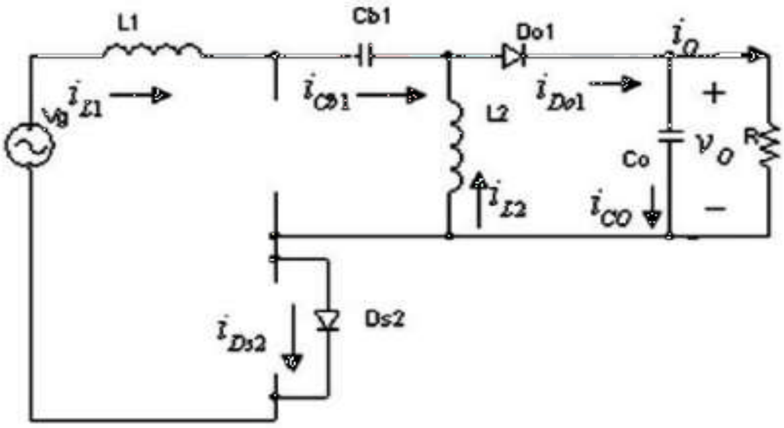

Fig 3.3Equivalent Circuit diagram for Mode 2

Finally, in MODE 3, both switch S1 and diode Do1 are turned off as shown in Figure. During this interval energy at inductors L1 and L2 are equal and input voltage, Vg is equal to VCb1. As a result, almost zero current flows. However, an almost DC current exist and the current through inductors L1 and L2 are equal but on the opposite direction.

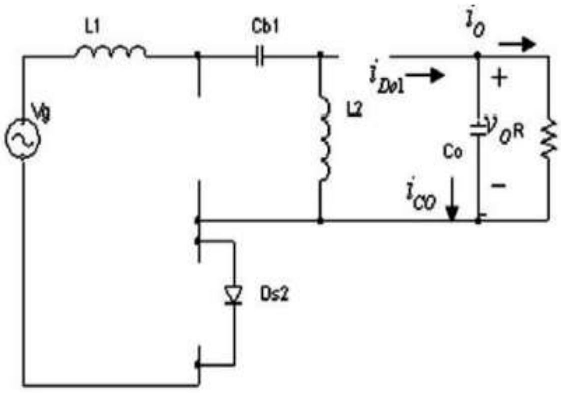

Fig 3.4Equivalent Circuit diagram for Mode 3

By equating the average current of Do1 with the output current, io =Vo/R, the relationship between input and output voltage is obtained.

IV .CONCLUSION

A PFC BL SEPIC converter based VSI-fed induction motor drive has been proposed targeting high-power applications. A new method of speed control has been utilized by controlling the voltage at DC bus and operating the VSI at fundamental frequency for the electronic commutation of the induction motor for reducing the switching losses in VSI. The front-end BL SEPIC converter has been operated in DICM for achieving an inherent power factor correction at AC mains. A satisfactory performance has been achieved for speed control and supply voltage variation with power quality indices within the acceptable limits of IEC 61000-3-2. Moreover, voltage and current stresses on the PFC switch have been evaluated for determining the practical application of the proposed scheme.

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