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A Voltage Controlled Adjustable Speed Induction Motor Drive Using Pfc Half-Bridge Converter

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ABSTRACT

The techniques to improve the efficiency of motor drive by power factor correction play an important role in the energy saving during energy conversion. The ac-dc conversion of electric power is usually required for the Induction motor drive; nevertheless, it causes many current harmonics and results in the poor power factor at the input ac mains. The use of an Induction Motor is increasing because of its features of high efficiency, wide speed range, and low maintenance. This paper deals with the power factor correction of Induction motor with Double Cuk dc–dc converter. A three-phase voltage-source inverter is used as an electronic commutator to operate the IMD. The Prototype is designed with a double cage induction motor used for an air conditioning unit compressor which offers very good starting torque. Tested using Matlab/Simulation at various speeds.

Keywords: Induction Motor, Cuk Converter Power factor correction, Diode Bridge Rectifier, voltage-source inverter (VSI).

I. INTRODUCTION

An induction motor being rugged, reliable, and relatively inexpensive makes it more preferable in most of the industrial drives. They are mainly used for constant speed applications because of unavailability of the variable-frequency supply voltage [1]. But many applications are in need of variable speed operations. In early times, mechanical gear systems were used to obtain variable speed. Recently, power electronics and control systems have matured to allow these components to be used for motor control in place of mechanical gears. These electronics not only control the motor's speed, but can improve the motor's dynamic and steady state characteristics. Adjustable speed ac machine system is equipped with an adjustable frequency drive that is a power electronic device for speed control of an electric machine. It controls the speed of the electric machine by converting the fixed voltage and frequency to adjustable values on the machine side. High power induction motor drives using classical three – phase converters have the disadvantages of poor voltage and current qualities. To improve these values, the switching frequency has to be raised which causes additional switching losses. Another possibility is to put a motor input filter between the converters It is powered through a three-phase voltage source inverter (VSI) which is fed from single-phase AC supply using a diode bridge rectifier (DBR) followed by smoothening DC link capacitor. The compressor exerts constant torque (i.e. rated torque) on the IDM and is operated in speed control mode to improve the efficiency of the Air-Con system. The IMD drive, fed from a single-phase AC mains through a diode bridge rectifier (DBR) followed by a DC link capacitor, suffers from power quality (PQ) disturbances such as poor power factor (PF),increased total harmonic distortion (THD) of current at input AC mains and its high crest factor (CF). It is mainly due to uncontrolled charging of the DC link capacitor which results in a pulsed current waveform having a peak value higher than the amplitude of the fundamental input current at AC mains. Moreover, the PQ standards for low power equipments such as IEC 61000-3-2 [5], emphasize on low harmonic contents and near unity power factor current to be drawn from AC mains by these motors. Therefore, use of a power factor correction (PFC) topology amongst various available topologies [6-14] is almost inevitable for a IM drive. Most of the existing systems use a boost converter for PFC as the front-end converter and an isolated DC-DC converter to produce desired output voltage constituting a two-stage PFC drive [7-8].

The DC-DC converter used in the second stage is usually a Cuk converter for low power applications and a full-bridge converter for higher power applications. However, these two stage PFC converters have high cost and complexity in implementing two separate switch-mode converters, therefore a single stage converter combining the PFC and voltage regulation at DC link is more in demand. The single-stage PFC converters operate with only one controller to regulate the DC link voltage along with the power factor correction. The absence of a second controller has a greater impact on the performance of single-stage PFC converters and requires a design to operate over a much wider range of operating conditions. The main aim of the paper is to correct the power factor and to improve the Power quality to the Induction Motor. And the system is analysed in the Matlab/simulation.

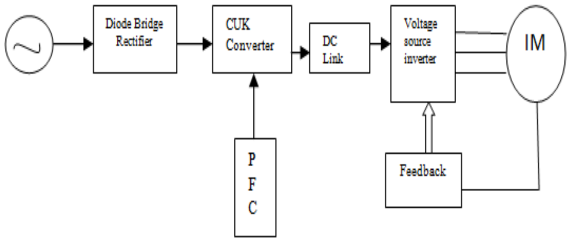

Fig 1: Block Diagram of Cuk Converter Fed IM Motor Drive

II. INDUCTION MOTOR MODEL

Driving the model equations can be generated from the dq0 equivalent circuit of the induction machine shown in figure 2. The flux linkages equations associated with this circuit can be found as follows:

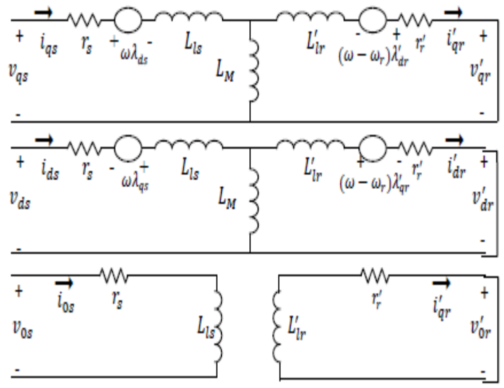

Fig 2: The dq0 equivalent circuit of an induction motor

$$\frac{d\Psi qs}{dt} = Wb\left[Vqs - \frac{we}{wb} * \Psi ds + \frac{Rs}{Xls}\right)(\Psi mq - \Psi qs)(1)$$

$$\frac{d\Psi ds}{dt} = Wb\left[Vds + \frac{we}{wb} * \Psi qs + \frac{Rs}{Xls(\Psi md - \Psi ds)}\right](2)$$

$$\frac{d\Psi qr}{dt} = Wb\left[Vqr - \frac{We - Wr}{Wb} * \Psi dr + \frac{Rr}{Xlr(\Psi mq - \Psi qr)}\right](3)$$

$$\frac{d\Psi dr}{dt} = Wb\left[Vdr + \left(we - \frac{wr}{wb}\right) * \Psi dr + \frac{Rr}{Xlr(\Psi md - \Psi dr)}\right](4)$$

$$\Psi mq = Xml[\frac{\Psi qs}{Xls} + \frac{\Psi qr}{Xlr}] \qquad (5)$$

$$\Psi md = Xml[\frac{\Psi ds}{Xls} + \frac{\Psi dr}{Xlr}] \qquad (6)$$

$$Xml = 1/(\frac{1}{Xm} + \frac{1}{Xls} + \frac{1}{Xlr}) \qquad (7)$$

$$iqs = 1/Xls(\Psi qs - \Psi mq) \qquad (8)$$

$$ids = \frac{1}{Xls} * (\Psi ds - \Psi md) \qquad (9)$$

$$iqr = \frac{1}{Xlr} * (\Psi qr - \Psi mq) \qquad (10)$$

$$idr = \frac{1}{Xlr} * (\Psi dr - \Psi md) \qquad (11)$$

$$Te = \frac{3}{2} * \left(\frac{P}{2}\right) 1/Wb(\Psi dsIqs - \Psi qsids) \qquad (12)$$

$$Wr = \int p/2l(Te - Tl) \qquad (13)$$

$$Va = \sqrt{2}VrmsSin(wt) \qquad (14)$$

$$Vb = \sqrt{2VrmsS}in(wt - 2pi/3) \qquad (15)$$

$$Vc = \sqrt{2}Vrms * Sim(wt + 2pi/3) \qquad (16)$$

$$\begin{matrix} va \\ vb \end{matrix} = 2/3[\begin{matrix} 1 & \frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{matrix}]\begin{matrix} Va \\ Vb \\ Vc \end{matrix} \qquad (17)$$

$$\begin{matrix} Vd \\ Vq \end{matrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix}\begin{bmatrix} Va \\ Vb \end{bmatrix} \qquad (18)$$

III. MODELLING OF PROPOSED DC-DC CONVERTER

The proposed synchronous cuk converter is the extension of classical converter but, for making the synchronous operation, the auxiliary circuit is added. The structure of proposed synchronous cuk converter is illustrated in figure 3. In the proposed cuk converter, the input side and output side inductors are denoted L1 and L2 as respectively. The output capacitor and inductor acts as filter circuit providing only the DC component and filtering the AC component. Here, three MOSFETs are used as main switch as well as auxiliary switches which are denoted as S, S1 and S2. The auxiliary switches S1 and S2 are parallel with the main switch. The resonant capacitor and resonant inductor are denoted as Cr and Lr. The resonant capacitor is charged at normal operation and it discharges the voltage during abnormal operation and the diode is conducted. The resonant capacitor is providing the time delay and to minimize the switching losses of converter. So this synchronous converter can be used for high as well as low switching frequencies. The output voltage, current, resistance and capacitor are denoted Vo, Io, Co. Ro as respectively.

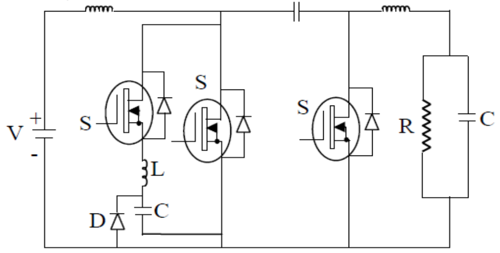

Fig 3: Proposed CUK Converter

From the above diagram, the main switch and auxiliary switch are not subjected to additional voltage stresses but the main switch has more current stress in comparison to the auxiliary one. The output inductor is chosen such that the output current is kept constant and the output capacitor is chosen in such a way that the output voltage remains constant and ripple free as well. The resonant capacitor and resonant inductor are calculated as following formula.

$$Cr = Iin(max)Td(a-1)^2/V0(1+pi(q-1/2)) \quad (19)$$

$$Lr = VoTD/Lin(max)(1+\frac{pi(a-1)}{2}) \quad (20)$$

IV. PROPOSED SPEED CONTROL SCHEME OF IM MOTOR

The proposed speed control scheme (as shown in Fig. 1) controls reference voltage at DC link as an equivalent reference speed, thereby replaces the conventional control of the motor speed and a stator current involving various sensors for voltage and current signals. Moreover, the rotor position signals are used to generate the switching sequence for the VSI as an electronic commutator of the IM. Therefore, rotor-position information is required only at the commutation points, e.g., every 60°electrical in the three phase [1-4]. The DC link voltage is controlled by a half-bridge buck DC-DC converter based on the duty ratio (D) of the converter. For a fast and effective control with reduced size of magnetic and filters, a high switching frequency is used; however, the switching frequency (fs) is limited by the switching device used, operating power level and switching losses of the device. Metal oxide field effect transistors (MOSFETs) are used as the switching device for high switching frequency in the proposed PFC converter. However, insulated gate bipolar transistors (IGBTs) are used in VSI bridge feeding IM, to reduce the switching stress, as it operates at lower frequency compared to PFC switches. The PFC control scheme uses a current control loop inside the speed control loop with current multiplier approach which operates in continuous conduction mode (CCM) with average current control. The control loop begins with the comparison of sensed DC link voltage with a voltage equivalent to the reference speed. The resultant voltage error is passed through proportional-integral (PI) controller to give the modulating current signal. This signal is multiplied with a unit template of input AC voltage and compared with DC current sensed after the DBR. The resultant current error is amplified and compared with saw-tooth carrier wave of fixed frequency (fs) in unipolar scheme to generate the PWM pulses for the half-bridge converter. For the current control of the IM during step change of the reference voltage due to the change in the reference speed, a voltage gradient less than 800 V/s is introduced for the change of DC link voltage, which ensures the stator current of the IM within the specified limits (i.e. double the rated current).

V. PERFORMANCE EVALUATION OF PROPOSED PFC DRIVE

The proposed IM drive is modelled in Matlab-Simulink environment and evaluated for an air conditioning compressor load. The compressor load is considered as a constant torque load equal to rated torque with the speed control required by air conditioning system. The performance of the proposed PFC drive is evaluated on the basis of various parameters such as total harmonic distortion (THD) and the crest factor (CF) of the current at input AC mains, displacement power factor (DPF), power factor (PF) and efficiency of the drive system (ηdrive) at different speeds of the motor. Moreover, these parameters are also evaluated for variable input AC voltage at DC link voltage of 416 V which is equivalent to the rated speed (1500 rpm) of the IM.

A. Performance during Starting

The performance of the proposed IM drive fed from 220 V AC mains during starting at rated torque and 1500 rpm speed is shown in Fig. 4. A rate limiter of 800 V/s is introduced in the reference voltage to limit the starting current of the motor as well as the charging current of the DC link capacitor. The PI controller closely tracks the reference speed so that the motor attains reference speed smoothly within 0.35sec while keeping the stator current within the desired limits i.e. double the rated value. The current (is) waveform at input AC mains is in phase with the supply voltage (vs) demonstrating nearly unity power factor during the starting.

B. Performance under Speed Control**:** Fig. 5 show the performance of the proposed IM drive under the speed control at constant rated torque and Change in speed and 220 V AC mains supply voltage. These results are categorized as performance during transient and steady state conditions.

Fig4: Represents the outputs at Constant reference speed of 1500RPM

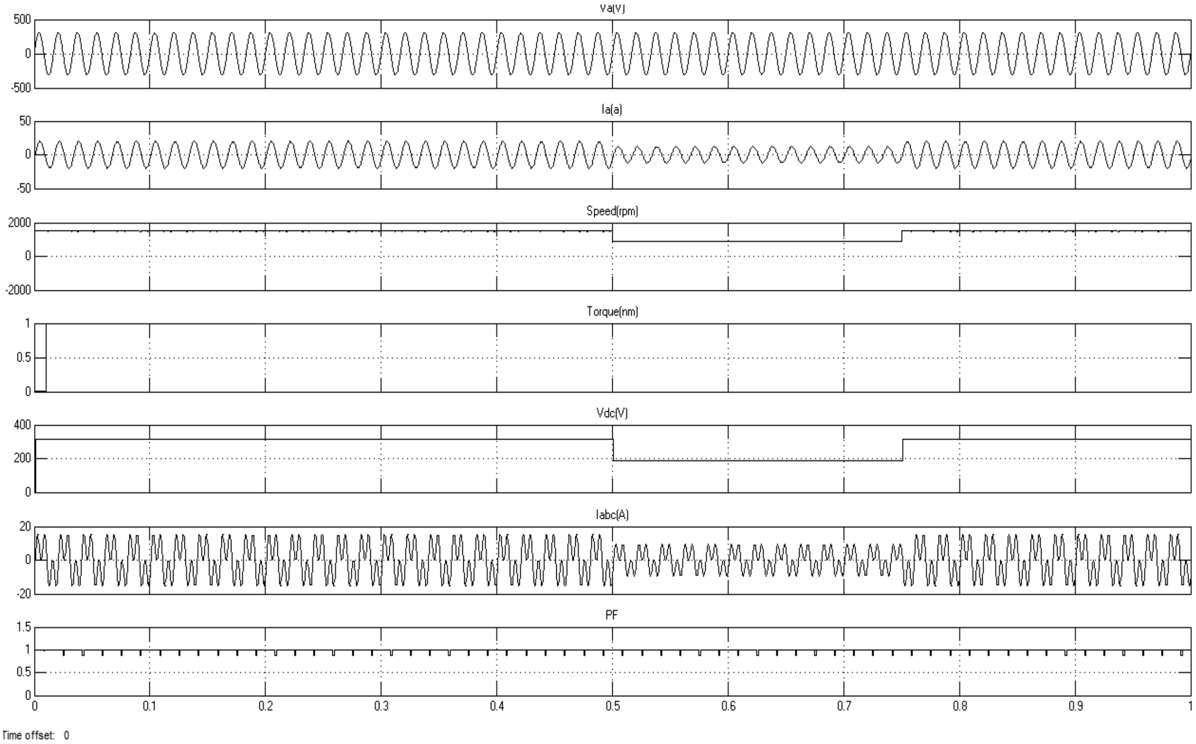

Fig 5: Represents the outputs at Stepped reference speed of 1500 to 900RPM

And we can absorb from the graph that the power factor is maintained unity and we can conclude that the machine is able to control properly at various speed conditions.

VI. CONCLUSION

The main objective of this project is to improve the input Power Factor with simultaneous reduction of input current harmonics. Simulations were initially done for elementary rectifier circuits without employing any PFC circuit. These simulations included circuits with and without source side inductors and capacitors. The changes in the input current waveform were observed and studied. A PFC circuit having a parallel boost converter i.e. two boost converters arranged in parallel was designed. The control strategy was based on average current mode control due to its relative advantages over voltage mode control and peak current mode control. The speed control is directly proportional to the voltage control at DC link. The rate limiter introduced in the reference voltage at DC link effectively limits the motor current within the desired value during the transient condition (starting and speed control). The additional PFC feature to the proposed drive ensures nearly unity PF in wide range of speed and input AC voltage. Moreover, power quality parameters of the proposed IM drive are in conformity to an International standard IEC 61000-3-2 The proposed drive has demonstrated good speed control with energy efficient operation .The drive system is used for ac compressor unit in the wide range of speed and input AC voltage. The additional advantage of the present proposed application eliminates the AC unit switching and further consequent disturbances in the distribution system.

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