PI Controller based LUO Converter for Power Factor Correction and Speed Control in Induction Motor

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Abstract— Solid state converters have reached a great level for improving power quality in terms of Power Factor Correction (PFC), reduced total harmonic distortion at input ac mains and precisely regulated dc output in buck, boost, buck–boost and multilevel modes with unidirectional and bidirectional power flow. In this paper an improved power quality converter using luo converter with PI controller is used to feed Induction motor drive. Induction motor consists of voltage source inverter(VSI) which is supplied from single phase supply through Diode Bridge Rectifiers(DBR). In this proposed System a PI control based LUO converter is used after the DBR it performs Power Factor Correction at the Input Side.

Key words: PI Controller, LUO Converter, Speed Control in Induction Motor

I. INTRODUCTION

The need of an efficient and low cost motor drive is required which is used for low and medium power equipments like refrigerators, air conditioners, fans and many appliances used in medical and industrial applications. In order to improve the efficiency the losses due to the components such as VSI, DBR and Front end converter has to reduced. The development of such Motor with high efficiency and minimum cost is the main Objective of this paper. In Existing system uses a two-stage cascaded converter which consists of a boost converter for PFC at the front-end followed by DC-DC converter in second stage for voltage regulation. At second stage normally a flyback converter has been used for low power application and a full-bridge converter for higher power applications. The demerits of two stage PFC converters are high cost and complexity in implementing two separate switch mode converters which use of a single stage PFC converter. Therefore, an improved single stage PQ converter drive is almost essential for the Induction Motor. A Luo DC-DC converter is employed as a single-stages PFC converter for power quality improvement in the IM drive due to its simplicity and low cost among other single switch converters. Additionally it provides minimum switching losses with reduced voltage drop in the secondary winding of the high frequency transformer resulting in improved efficiency of the PFC converter. The proposed single-stage PFC luo converter based drive needs a careful design to operate over a wide range of operating conditions for a Induction Motor drive i.e. variable input AC voltage and speed of the motors. A PI-based (Luo) converter-fed induction motor drive uses a single-phase supply followed by a filter and a Luo converter to feed VSI driving a induction motor.

The Luo converter is designed to operate in DICM to act as an inherent power factor preregulator. The speed of the induction motor is controlled by adjusting the dc-link voltage of VSI.

II. PROPOSED TECHNOLOGY

The proposed method uses a luo converter controls the DC link voltage as well as performs PFC action by its duty ratio (D) ata constant switching frequency.

This allows VSI to operate at fundamental frequency switching and hence has low switching losses in it, which are considerably high in a PWM-based VSI feeding a Induction motor.

The proposed scheme is designed, and its performance is simulated for achieving an improved power quality at ac mains for a wide range of speed control and supply voltage variations. Finally, the simulated performance of the proposed drive is validated with test results on a developed prototype of the drive.

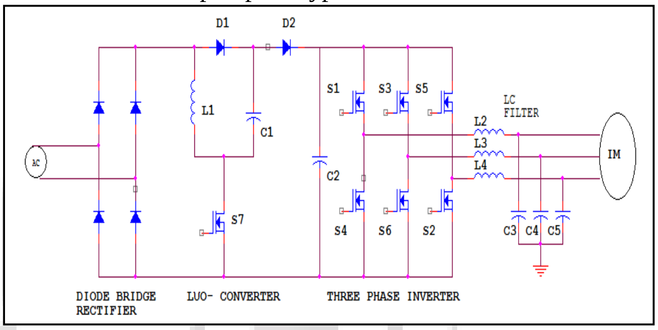

Fig. 1: Circuit Diagram of proposed System.

III. MODELING OF PROPOSED SYSTEM

The modeling of proposed isolated Luo converter fed IM drive involves modeling of the PFC converter and IM drive in the form of mathematical equations. The combination of these individual models represents a complete model of proposed PFC drive.

A. PFC Converter

The modeling of PFC converter involves the modeling of DC link voltage controller, reference current generator and PWM controller.

B. DC Link Voltage Controller

A PI controller is used as DC link voltage controller which provides a control output signal (Ic) to minimize the input voltage error. If, V*dc(k) is reference DC link voltage, $V_{dc}(k)$ is sensed DC link voltage at k^{th} instant of time then, the voltage error $V_e(k)$ is calculated as, $V_e(k) = V^*dc(k) - Vdc(k)$

At k^{th} instant the controller output is given as,

$$IC(k) = IC(k-1)+K_{pv}\{Ve(k) - Ve(k-1)\}+ K_{iv}Vc(k)$$

Where IC(k) is controller output, K_{pv} and K_{iv} are the gains of the voltage PI controller.

C. PWM Controller

The reference input current of the Luo converter (i*d) is compared with its sensed current (id) to generate the current

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error Δid = (i*d - id). This current error is amplified by gain kd and compared with fixed frequency (fs) saw-tooth carrier waveform md(t) to generate PWM signals for the MOSFET of the PFC converter as,

If kdΔid>md(t) then S =1

If kdΔid<= md(t) then S = 0

Where S is the switching function representing "ON" position of the MOSFET of the Luo converter with S=1 and its "OFF" position with S=0.

D. Induction Motor Drive

The IM drive has a speed controller, a reference winding current generator, a PWM current controller, a VSI and a Induction motor as major components.

E. Speed controller

A PI controller is used as speed controller which closely follows the reference speed. If at kth instant of time, ω*r(k) is the reference speed, ωr(k) is the actual rotor speed then the speed error ωe(k) can be calculated as,

We(K)=W*r(K)-Wr(K)

This error in speed is fed to a speed controller to get a control signal. The controller's output at kth instant T(k) is given as,

T(K)=T(K-1)+Kpw{(K)-We(k-1) +KiWe(K)

Where Kpω and Kiω are the proportional and integral gains of the speed PI controller.

F. Reference Winding Current Generator

The stator winding current amplitude can be calculated using vector model approach. The reference phase currents of the Induction Motor are denoted by i*a, i*b, ic* for phases a, b, respectively. For duration of 0-60º the reference currents aregiven as,

i*a = I , i*b = − I* and i*c = 0

Similarly, the reference winding currents during other 60º duration are generated in rectangular 120º block form in Phase with sinusoidal voltage of respective phases.

G. PWM Current Controller

The sensed currents (ia, ib, ic) are compared with reference winding currents in a PWM current controller to get the current errors

Δia=(i*a - ia), Δib=(i*b - ib), Δic=(i*c - ic)

For three phases of the motor. Before comparison with a fixed frequency carrier waveform m(t) to generate the switching sequence for the VSI, the current errors (Δia, Δib, Δic) are

Amplified by gain k1 and is shown for phase "a",

If k1Δia > m (t) then Sa = 1 (MOSFET "ON") (15)

If k1Δia ≤ m (t) then Sa = 0 (MOSFET "OFF") (16)

The switching sequences Sb and Sc are generated using similar logic for other two phases of the motor.

The proposed developed DC-DC converter is Luo converter overcomes the parasitic problems present in the classical dc-dc converter.

H. Voltage Source Inverter

The VSI bridge feeding Induction motor uses Metal Oxide Semiconductor Field Effect Transistor (MOSFETs) to reduce the switching stress, because of its efficiency increases at high switching frequency.

The output of VSI for phase "a" is given as,

V_{a0}= (v_{dc}/2) for Sa1 = 1, and Sa2 = 0

V_{a0} = (-v_{dc}/2) for Sa2 = 1, and Sa1 = 0

Va_0 = 0 for Sa1 = 0, and Sa2 = 0

The voltages (V_{bo}, V_{co}, V_{bn}, V_{cn}) for other phases of the VSI fed Induction motor are generated using similar logic

V_{an}=V_{a0}-V_{n0}

Where v_{ao}, v_{bo}, v_{co}, and v_{no} are voltages of 3-phases and neutralpoint (n) with respect to virtual mid-point of the DC link voltage. The voltages V_{an}, V_{bn}, V_{cn} are voltages of 3-phases with respect to neutral point (n). The values 1 and 0 for Sa1 or Sa2 represent "ON" and "OFF". Condition of respective MOSFETs of the VSI. The switching of other MOSFETs of the VSI i.e. S_b and S_c are obtained in a similar way.

IV. OPERATION OF LUO CONVERTER

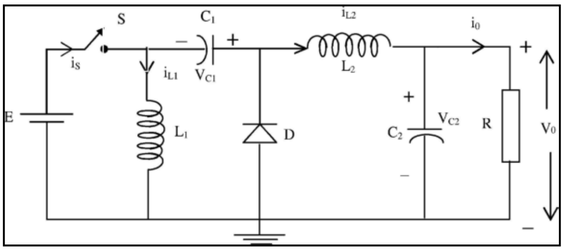

Fig. 2: Circuit diagram of Luo converter

In the circuit, S is the power switch and D is the freewheeling diode. The energy storage passive elements are inductors.L1, L2 and capacitors C1, C2, R is the load resistance. To analyse the operation of the Luo converter, the circuit can be divided into two modes. When the switch is ON, the inductor.

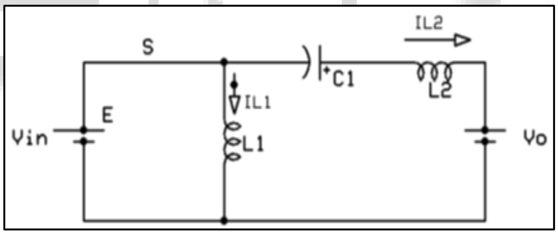

Fig. 3: MODE1 operation

During switch is in OFF state, and hence, the current is drawn from the source becomes zero. Current iL1 flows through the freewheeling diode to charge the capacitor C1. Current iL2 flows through C2 –R circuit and the freewheeling diode D to keep itself continuous. If adding additional filter components like inductor and capacitor to reduce the harmonic levels of the output voltage

A. Modes of Operation

- Mode 1: when the switch is ON, the inductor L1 is charged by the supply voltage E. At the same time, the inductor L2 absorbs the energy from source and the capacitor C1.The load is supplied by the capacitor C2. The equivalent circuit of Luo converter in mode 1 operation is shown in (a).
- Mode 2: switch is in OFF state, and hence, the current is drawn from the source becomes zero, as shown in (b). Current iL1 flows through the freewheeling diode to charge the capacitor C1. Current iL2 flows through C2 –R circuit and the freewheeling diode D to keep itself continuous.

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In discontinuous conduction mode, output should be in the form of discontinuous. In this mode diode is not present and inductor discharge through V0 and L2. The output stage of the Luobuck converter is comprised of an inductor and capacitor.

The output stages stores and delivers energy to the load, and smooths out the switch node voltage to produce a constant output voltage. Inductor selection directly influences the amount of current ripple seen on the inductor current, as well as the current capability of the buck converter itself. Inductors vary from manufacturer to manufacturer in both material and value, and typically have a tolerance of 20%.

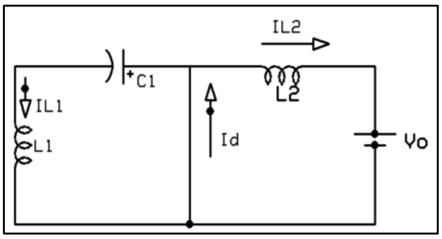

Fig. 4: MODE2 operation

B. *Selection of Inductance and Capacitance*

The performance of the output stage. Minimizing the DCR improves the overall performance of the converter. For that application it requires a high load current, it is recommended to select an inductor with a low DCR.

The DCR is smaller for lower inductor values, but there is a trade−off between inductance and ripple current; the lower the inductance, the higher the ripple current through the inductor.

A minimum inductance must be met in order to meet the ripple current requirements of the specific application circuit.

The output capacitance directly affects the output voltage of the converter and the response time of the output feedback loop, also the amount of output voltage overshoot that occurs during changes in load current. A ripple voltage exists on theDC output as the current through the inductor and capacitor increases and decreases.

Increasing the value of output capacitance value reduces the amount of voltage ripple present in the circuit. Increasing the capacitance reduces the output voltage ripple and output voltage overshoot, but increases the response time it takes output voltage feedback loop to respond to changes in load.

Therefore, a minimum capacitance must be considered, in order to reduce the ripple voltage and voltage overshoot requirements of the converter, while maintaining a feedback loop that can respond quickly enough to load changes.

V. PROPORTIONAL INTEGRAL CONTROLLER

Controllers improve the steady state performance by decreasing the steady errors. PI controllers reduce the system offset.

The output of PI control is equal to the summation of proportional of error and integral of the error signal. The Mathematical Expression is

$$A(t)=K_d\, d_e(t)/dt + k_p e(t).$$

A. *API Controller*

The acronym API denotes an Adaptive PI controller, whose parameters is not fixed but change, i.e. adapt, in reaction to different operating conditions. Adaptive controllers have a long history, but their use in practical applications has been limited by their usually high demanding computational equipment's

Indeed, computations like matrix inversions cannot be easily embedded in real-time applications, as they might cause runtime faults and consequently even lead to plant damages.

The resultant current error is amplified and compared with a saw-tooth carrier wave of fixed frequency (fs) for generating the PWM pulses for controlling the MOSFET of PFC converter. Use of a high switching frequency results in a instantaneous control of DC link voltage and effective PFC action along with additional advantage of reduced size transformer and filters.

The switching device, switching losses and operating power level are major factors that decide optimum switching frequency. A metal oxide field effect transistor (MOSFET) is used as the switching device for the proposed PFC converter.

This system comprises of Three Phase Induction Motor Voltage source Inverter (VSI), Luo converter, PI controller. The MOSFET switches of the inverter circuit are controlled by varying the firing Angle of the Luo converter switches.

The performance of the luo converter fed Induction Motor using PI control is determined and the results are verified through MATLAB simulation.

1) The MATLAB simulation is given below

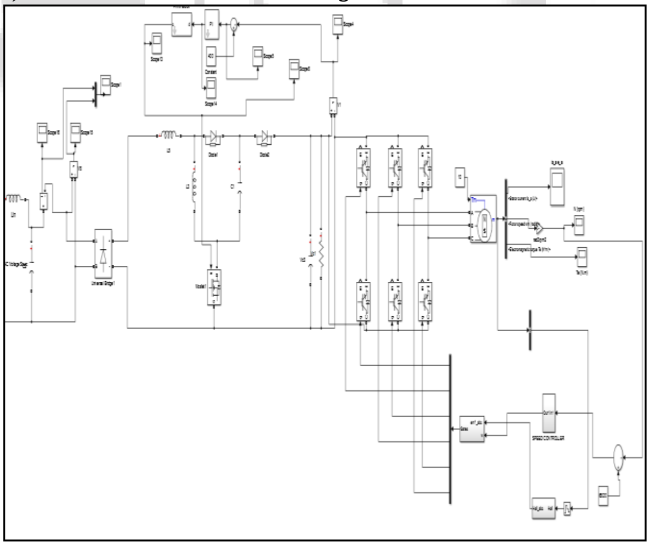

Fig. 5: MATLAB simulation

The model of the Luo converter fed induction Motor drive has simulated using MATLAB simulink library. The simulink consists of various blocks such as PWM block, discrete block, PI controller block, these various blocks for various functions.

The universal bridge block implements a bridge of selected power electronic devices. Series snubber circuits are connected in parallel with each switch device. The PI controller block control the steady state performance and used to improve the power factor thus increasing the motor efficiency.

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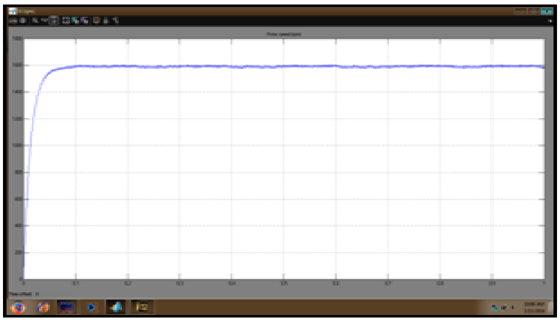

Fig. 6: Speed of luo converter fed IM drive

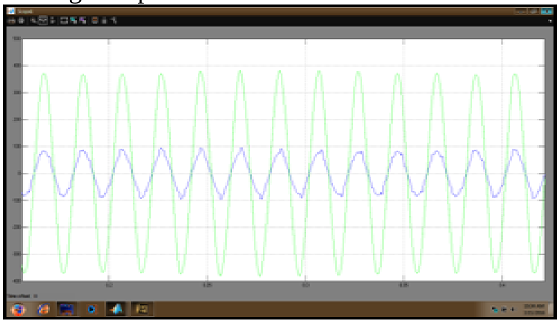

Fig. 7: Power factor at the input side

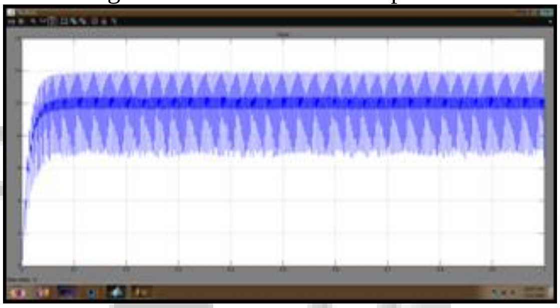

Fig. 8: Simulation of torque

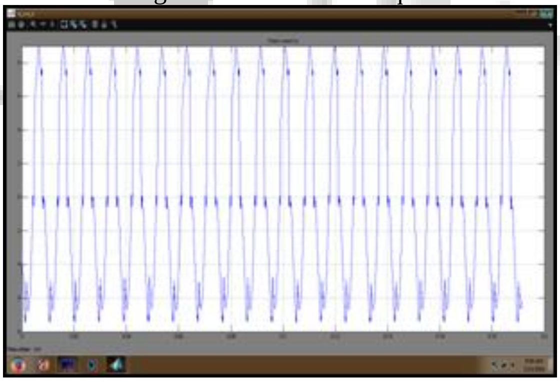

Fig. 9: Stator current luo converter fed IM drive

VI. CONCLUSION

The proposed PFC luo converter-fed Induction motor drives with PI controllers have been successfully simulated and those simulation results how that it has improved speed control, stator currents. The use of DC link capacitor allows the switching of VSI at fundamental frequency leading to less switching and conduction losses. The based luo PFC converter has ensured nearly unity PF in wide range of speed and the input AC voltage mains. High input power factor is the index which is related to maximum efficiency of the drive. When drive operates at maximum efficiency the loss are optimum with less power consumption and losses are less resulting in energy conservation.

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