Proportional Resonant Controlled Interleaved CUK Converter Space Vector Modulated Inverterfed Induction Motor Drive System with Improved Torque Response

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*Abstract This work presents the simulation and application of a Proportional Resonant (PR) controlled Interleaved Cuk Converter Inverter fed Induction Motor Drive (ICCIIMD) system. This work recommends Photo Voltaic (PV) fed interleaved cuk converter to fabricate essential DC voltage in the input of the inverter. The output of the PV system is boosted utilizing an interleaved cuk converter. The output of the interleaved cuk converter is inverted and fed to a three phase induction motor. Closed loop PR controlled ICCIIMD system is simulated and the torque ripple along with time domain parameters are **compared** with a Proportional Integral (PI) controlled ICCIIMD system. The hardware is contrived and the investigational outcomes are related with the simulation outcomes. The PR controlled drive system has benefits like decreased torque ripple and enhanced time domain response.*

Keywords: Interleaved Cuk Converter, Photo Voltaic System, Proportional Resonant Control, Torque Ripple and Voltage Source Inverter.

I. INTRODUCTION

Solar Photo Voltaic (SPV) System is the most preferred power supply system in recent years due to the increasing price of non-renewable resources like hydrocarbon. Industries largely prefer SPV system to sustain their development by meeting the increase in energy demand.Farming sector prefers induction motors as they are rugged, reliable and relatively inexpensive when compared to synchronous motors and direct current motors.The speed of the motor can be controlled as per the mechanical load demand by using power electronic circuits and control systems. Apart from effectively controlling the speed of the motor, power electronic circuits can also improve the motor's dynamic and steady state characteristics.

A voltage controlled cuk converter based Permanent Magnet Brush Less DC (PMBLDC) drive for air conditioners is given by Singh.The paper [1] manages a cuk dc-dc converter as a solitary stage control power factorrectification converter for a PMBLDC motor sustained through a diode connect rectifier from a solitary stage air conditioning mains. A three stage voltage source inverter is used as an electronic commutator to work the motor driving aeration and cooling system compressor. The speed of the compressor is controlled to accomplish ideal ventilating utilizing an idea of the voltage control at dc connects corresponding to the coveted speed of the PMBLDCM [1].

A bridgeless cuk converter based induction motor drive for PFC applications is presented by Raichel. Another bridgeless topology for power factor adjustment is proposed here. Acceptance engine drives are usually used in mechanical areas on account of their high effectiveness, unwavering quality, yield and so on. They are considered as the significant Prime movers and devour around 70% to 80% of the aggregate power. Thus these drives confront numerous Problems identified with control quality and power factor. The principle reason is the input rectifier bridge. An induction motor drive designed using a new bridgeless topology is used for power factor correction [2].

Hardware of a dual half bridge chopper is implemented and compared with its simulation performance. The bidirectional chopper uses Field Programmable Gate Array (FPGA) based switching control scheme for Zero Voltage Switching (ZVS)[3].

An active snubber circuit is used with a converter to achieve soft switching. It also limits the voltage stress across power switches. The primary windings of two transformers are connected in series in the converter.Current stress on the secondary winding of the transformer is reduced by connecting two half wave rectifiers in parallel [4].

Different topologies of regulators are proposed and compared for power factor correction. Less number of power semiconductor switching devices in the current path and the absence of diode bridge can result in less conduction losses with improved thermal management [5]. Low voltage outputs of ac to dc converter can be managed using a bridgeless boost regulator. Both positive and negative halves of input ac voltage can be conditioned using a topology with boost and buck boost regulator [6].

High power factor can be obtained from a

modified version of a single ended primary inductance converter (SEPIC). High gain at low voltage can be obtained from a SEPIC by applying a voltage multiplier technique. A regenerative snubber can be used for soft commutation and the losses during reverse recovery can be reduced [7].

A cuk converter with SEPIC can be used for power factor correction.Power factor value close to unity can be obtained during discontinuous conduction mode using the combination of cuk regulator and SEPIC [8].

A cuk converter can be used to regulate the dc voltage from solar photo voltaic array and can be inverted to ac using a voltage source inverter (VSI). Maximum power point tracking (MPPT) technique like incremental conductance can be used to extract maximum power from the PV array. A dc link capacitor is designed based on new approach to power a motor used for water pumping application [9]. Torque ripple of a brush less dc motor is compensated by a cuk regulator using ARDUINO [10].

The characteristic of switched reluctance motor which is used in commercial application is improved by reducing the torque ripple content[11]. A single switch cuk regulator is designed and analyzed for lowpower battery charging application[12].A dc to dc converter based on SEPIC topology with increased input range is designed for fuel cell power inversion [13].

The total harmonic distortion (THD) of input current of a rectifier used in power factor correction can be reduced using a cuk converter topology[14].A BLDC motor used in water pumping application is powered using solar PV array and the power is modulated by employing a Zeta Converter [15].

SEPIC Converter is designed for improving power factor in an induction heating system [16]. Torque ripple of a BLDC motor drive fed from solar PV array is reduced using SEPIC converter. This improves the life time of the dc link capacitor used at the input side[17]. SEPIC with a modified topology is proposed for improving power conversion efficiency[18].

The control switch of a boost regulator is replaced by a VSI bridge network to obtain a hybrid converter that provides both dc and ac as output. The hybrid converters require lesser number of switches to provide either dc or ac output. The circuit has a higher reliability due to the inherent shoptthrough protection in the inversion stage [19]. Synchronous reference frame based control ofboost inverter is used in nano-grid applications [20]. Integration control is performed by instantaneous current monitoring in a class D seriesresonant converter [21].

II. RESEARCH GAP

The above literature does not discuss about interleaved cuk converter inverter fed induction

motor drive with PR controller. This investigation suggests a PV fed interleaved cuk converter with a PR controller forfeeding an induction motor through a VSI to reduce torque ripples. The speed of Interleaved Cuk Converter Inverter Fed Induction Motor Drive (ICCIIMD) is regulated using PR Controller.

IEC 61000-3-2 emphasizes low harmonic contents and near unity power factor current to be drawn from AC mains by low power motors. Therefore reduction of torque ripple is inevitable for an IMD.The objective of this work is to reduce the torque ripple and moderatethe power supplied to the drive to control its speed. The purpose of this work is also to upgrade the time reaction of ICCIIM drive framework utilizing PR controller. DC from the yield of PV is regulated using an interleaved cuk converter. The dc yield of the interleaved cuk converter is associated with the space vector modulated inverter through a dc interface. The VSI is used to control the speed of the drive by varying the ac voltage. The dc voltage of the interleaved cuk converter is controlled by using PR controller to reduce the torque ripple. The Block diagram of the existing system is shown in Figure 1.
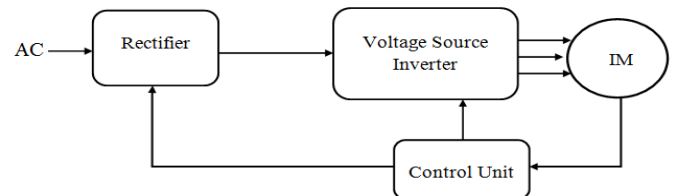

Fig.1 Block Diagram of theConventional System

In the conventional system the AC supply from the grid is rectified to DC using a rectifier the output of which is in turn converted into a controllable AC using a Voltage Source Inverter and then fed to an induction motor. The speed of the motor is controlled by the control unit using pulse width modulation. TheBlock Diagram of Interleaved Cuk Converter Fed IM Drive is shown in Figure.2.
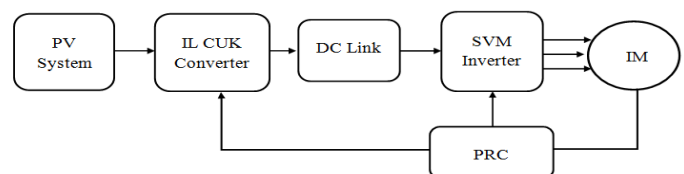

Fig2. Block Diagram of Interleaved Cuk Converter Inverter Fed Induction Motor Drive (ICCIIMD) System

DC from the yield of PV is assisted utilizing aninterleaved cuk converter. The DC yield of the interleaved cuk converter is connected to the VSI through a dc interface. The VSI is then used to control the speed of the drive by varying the ac voltage. The dc voltage of the interleaved cuk converter is controlled by utilizing proportional resonant control to lessen the torque ripple.

Analysis of Proportional Resonant controlled

Interleaved Cuk Converter Inverter fed Induction Motor Drive System

Expression for determining values of inductor and capacitor of cuk converter are as follows

$$L = \frac{V_i \, D}{f \, \Delta I} \; - - - - - - - -(1)$$

$$C = \frac{I_o \, D}{f \, \Delta V} \; - - - - - - - -(2)$$

Inverter output voltage is given by the following expression

$$V_o = 0.81 \, V_d \; - - - - - -(3)$$

In the above expressions V_i, I_o, D and V_d are input voltage of cuk converter, output current, duty cycle and dc link voltage respectively. The model of PR controller was developed from fractional differentiation. The response with PR is faster than that of the corresponding PI controlled system. The transfer function of an PR controller takes the form of

$$TF = K_1 + K_r \, w \, / \, (S^2 + w^2)$$

The closed loop control of ICCIIMD is done by regulating load voltage. The actual voltage is measured and compared with reference value. The obtained error signal 'e' and change of error 'ce' are taken as input to the PR controller. From the controller the PWM gating signals are generated by comparing actual and reference signals.

III. SPEED CONTROL SCHEME OF INDUCTION MOTOR

The interconnected structure of the source (Solar Panels), interleaved cuk converter, voltage source inverter and induction motor are shown in Figure 3. The output capacitor and inductor in the interleaved cuk converter act as filter circuit claiming only the dc component and straining the ac component. Here Metal Oxide Semiconductor Field Effect Transistor (MOSFET) is utilized as the switching device for greater switching frequency. The cuk converter can be used in both buck and boost operations. The output-voltage and current can both be simultaneously boosted. The output voltage has a reverse polarity when associated to the input voltage. Hence the terminals are reversed before connecting to the inverter.
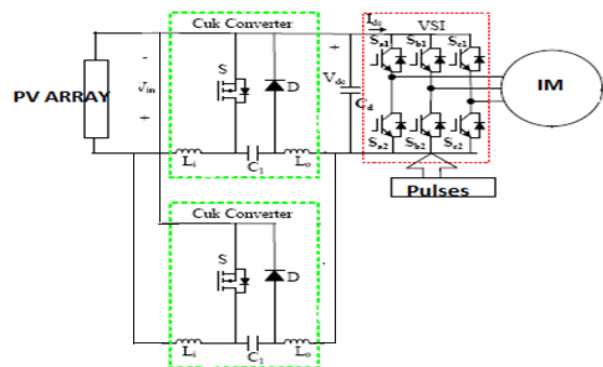

Fig.3 Circuit Diagram of Interleaved Cuk Converter Inverter fed IM Drive (ICCIIMD)

An interleaved cuk type dc to dc converter regulates the dc link voltage depending on the dutyratio (D) of the converter. For rapid and efficient regulation with decreased dimension of magnetic and filters, a greater switchingfrequency is utilized; equally, the switching frequency (f_s) is restricted by the switching device utilized, functioning powerlevel and switchinglosses of the device.

IV. SIMULATION RESULTS

TheICCIIMD system is modeled and simulated using Matlab in open loop and closed loop with PID and PR controllers.

V. Open-loop controlled ICCIIMD system

The open-loop controlled ICCIIMD system with change in insolation is experimented. Two cuk converters are connected in parallel to improve the current proficiency by maintaining the same voltage. The DC input voltage increases because of the variation in the insolation. The input voltage is increased from 150 volts to 175 volts as appeared in Figure5. The output-voltage of the interleaved cuk converter similarly increases from 500 to 520 volts as appeared in Figure6. The speed-response is appeared in Figure7 and the speed subsides at 1380 rpm. The torque-response is appeared in Figure8 and it becomes constant at 0.5Nm. The output voltage of cuk converter increases due to increase in input voltage. The driver pulses applied to the switches M1, M3 and M5 of voltage source inverter are shown in Figure 9.
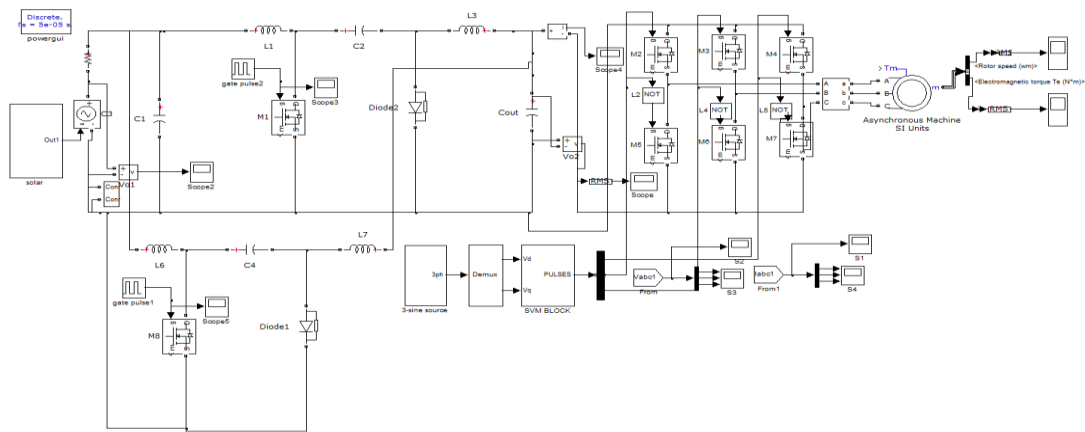
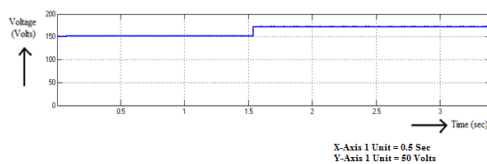Fig.4 Open loop ICCIIMD system with Measureing Devices

X-Axis 1 Unit = 0.5 Sec
Y-Axis 1 Unit = 50 Volts

Fig.5 Input Voltage to the interleaved cuk converter in open loop ICCIIMD system
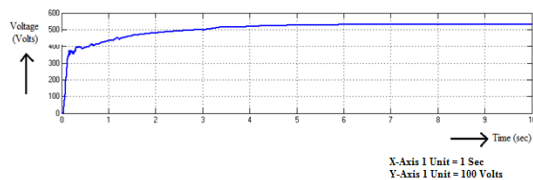
X-Axis 1 Unit = 1 Sec
Y-Axis 1 Unit = 100 Volts

Fig.6 Output voltage of the interleaved cuk converter in open loop ICCIIMD system

X-Axis 1 Unit = 0.5 Sec
Y-Axis 1 Unit = 500 RPM
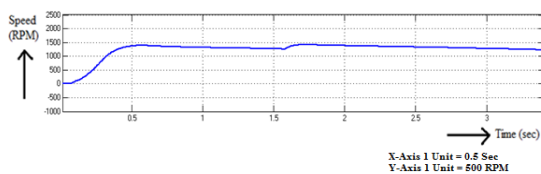
Fig.7 Speed response of the open loop ICCIIMD system

X-Axis 1 Unit = 0.5 Sec
Y-Axis 1 Unit = 0.2 Nm
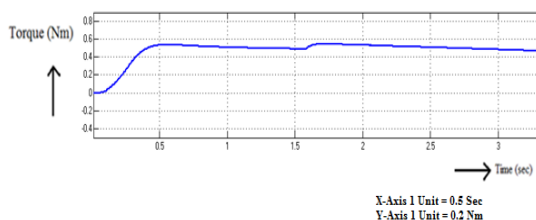
Fig.8 Torque Developed by the open loop ICCIIMD system

X-Axis 1 Unit = 0.5 milli Second
Y-Axis 1 Unit = 1 volt
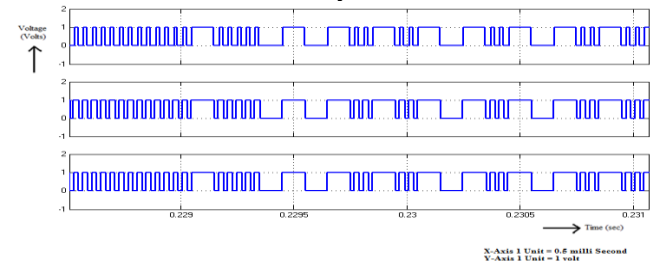
Fig.9 Pulses applied to theswitches M1, M3 & M5 of VSI in ICCIIMD system

VI. CLOSED-LOOP CONTROLLED ICCIIMD SYSTEM WITH PI CONTROLLER

The schematic diagram of the closed loop PI-controlled technique is appeared in Figure 10.The parameters for K_p and K_i used for simulation are K_p = 0.18 and K_i = 4.5. The output-voltage of interleaved cuk converter is related with a reference voltage. The flaw is pragmatic to the comparator across a PI-controller. The output of comparator updates the pulse width applied to interleavedcuk converter. The variation in inputvoltage is appeared in Figure11. The speed response along with its detailed viewand the torque response are appeared in Figures 12, Figure 13 and Figure 14 respectively. The speed inhabits at 1245 rpm. The torque restores at 0.5 Nm . Staring torque is higher due to the increased starting current.
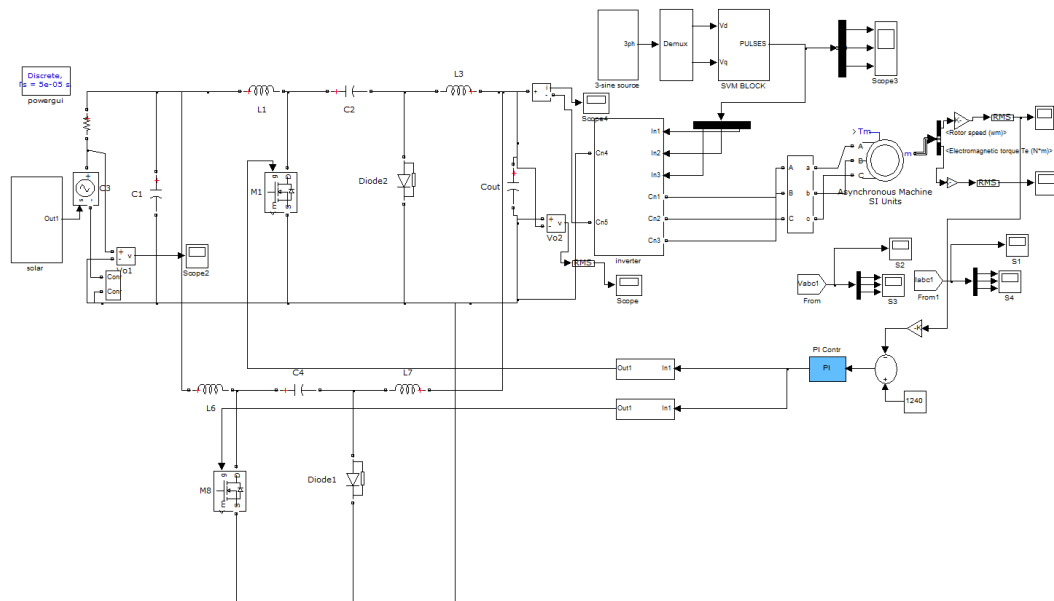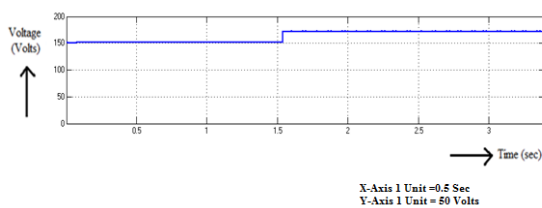
Fig.10 Closed loop PI controlled ICCIIMD system

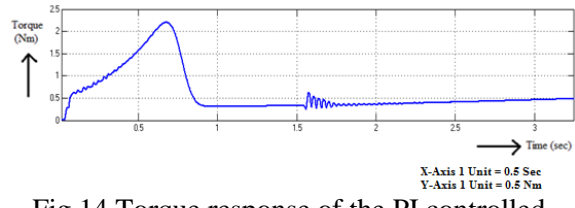Fig.11 Input Voltage to the PI controlled interleaved cuk regulator
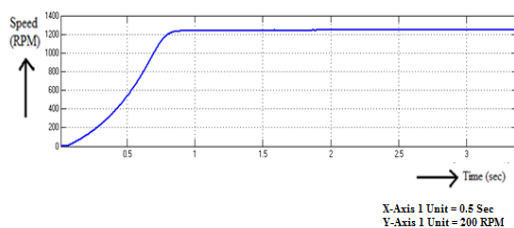

Fig.12 Speed of the PI controlled ICCIIMD system

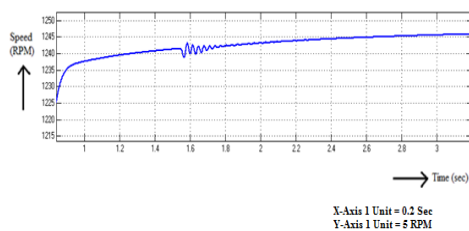Fig.13 Speed (expanded)response of the PI controlled ICCIIMD system

Fig.14 Torque response of the PI controlled ICCIIMD system

VII.   Closed-loop controlled CCIIMD system with PR Controller

The closed loop PR controlled ICCIIMD structure is appeared in Figure15. A PR controller substitutes the PIcontroller in the preceding system where as the VSI is kept unchanged to make comparative analysis. The variation in input voltage is appeared in Figure16. The speed response with its detailed view and the torque response are appeared in Figure 17, Figures 18 and 19 respectively. The speed inhabits at 1245 rpm and the speed settles without any oscillations. The torque restores itself at 0.5 Nm and the torque also settles without any oscillations.

The list of components and their ratings used in designing hardware of ICCIIMD system is shown in Table 1. The comparison of time domain parameters for a reference speed of 1240 rpm with PI &PR controllers is given in Table 2. The assessment signifies that the response is faster and steadystate error is reduced utilizing the PR controlled system.
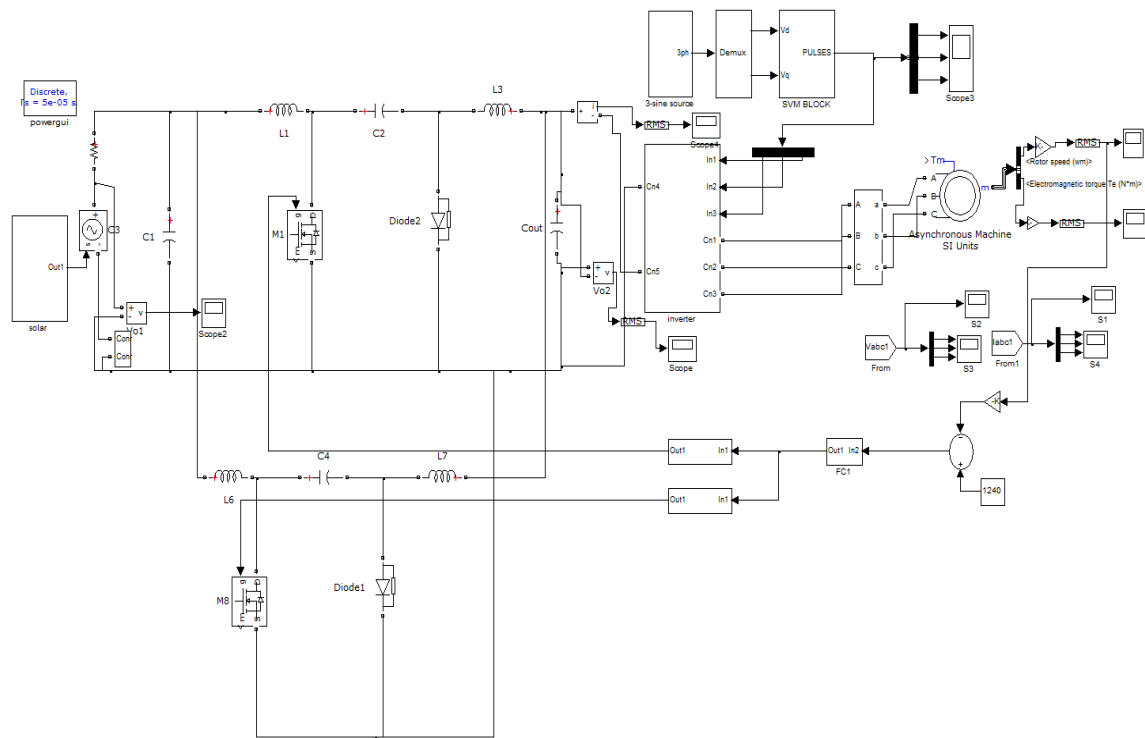
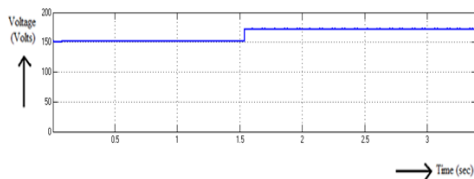Figure.15 Closed loop PR controlled ICCIIMD system

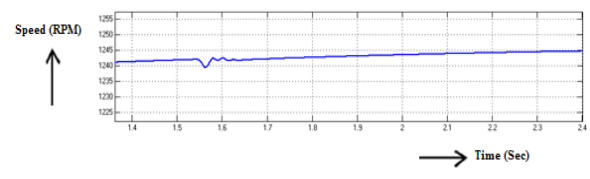Fig.16 Input Voltage to the PR controlled interleaved cuk converter

Fig.18 Motor Speed (expanded view) of the ICCIIMD system using PR controller
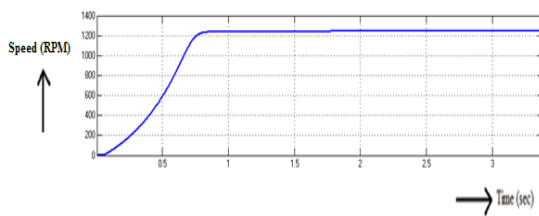

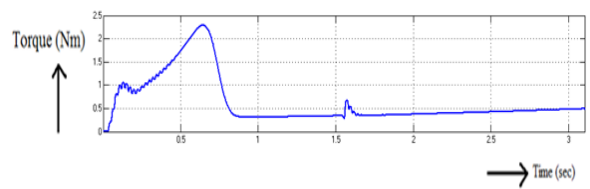Fig.17 Motor Speed of the ICCIIMD system using PR controller

Fig.19 Torque developed by the ICCIIMD system using PR controller

The settling time is as low as 1.65millisecond using PR controller. Settling time is reduced from 1.80 millisecond to 1.65 millisecond. The torque ripple is reduced from 0.15Nm to 0.08Nm using PR controller. Therefore the response of PR controlled

ICCIIMD system is superior to PI controlled ICCIIMD system.

Table 1: List of Components and their Ratings used in Hardware of ICCIIMD system

Sl.No.	Hardware Component	Rating of the Component	Type of Component
1	Capacitor	1000E-03	Electrolytic
2	Capacitor	4.70E-05	Electrolytic
3	Capacitor	3.30E-11	Disc
4	Capacitor	2.20E-03	Electrolytic
5	Diode	1000V ,3A	PN Junction
6	Inductance	10uH	ferrite coil
7	MOSFET (IR840)	600V,8A	N-channel
8	Resistor	1k	Quarter watts
9	Resistor	100E	
10	Resistor	22E	
11	Regulator	12V	L7812/TO3
12	Regulator	5V	L7805/TO220
13	IC	IR2110	Opto-coupler
14	Pic controller	PIC16F84A	RISC
15	PCB	V105	General

Table 2: Comparison of Time Domain Parameters using PI and PR basedICCIIMD Systems (for Nref=1240 rpm)

Type of Controller	Overshoot (Volts)	T_p(ms)	T_s(ms)	Steady state Error (E_{ss})	Torque Ripple (Nm)
PI Controller	1.54	1.60	1.80	2.1	0.15
PR Controller	1.53	1.56	1.65	1.8	0.08

VIII. HARDWARE RESULTS

The hardware arrangement for interleaved cuk converter inverter fed induction motordrive structure has been contrived and verified in the lab. The hardware arrangement for the suggested structure is shown in Figure 20. The hardware consists of a PV-panel, interleaved cuk converter board, inverter board, transformer board and control board. The output-voltage of solar-system is appeared in Figure21 and the output-voltage of interleaved cuk converter is shown in Figure 22. The switching-pulse for interleaved cuk converter is shown in

Figure 23. The output voltage of Voltage Source Inverter is shown in Figure 24. The hardware results match with the simulation-results of ICCIIMD system.The spikes in the output of inverter are due to change in switching sequence at every sixty degree interval.
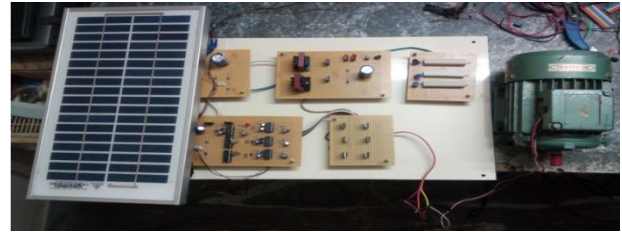

Figure.20 Hardware setup of Solar fed interleaved cuk converter based IM
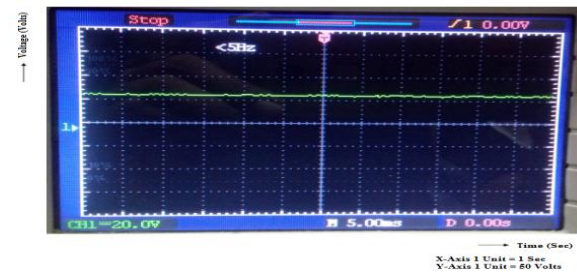

Figure.21 Output Voltage of the Solar Panel

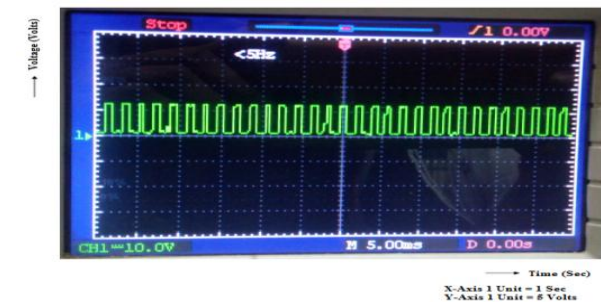Figure.22 Output voltage of interleaved cuk converter

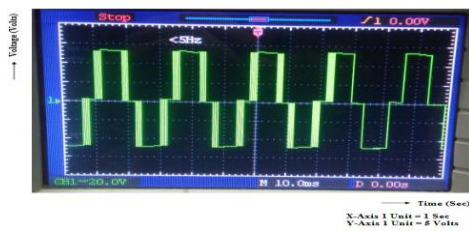Fig.23 Switching pulse for interleaved cuk converter

Figure.24 Output voltage of VSI

Complete hardware circuit of the proposed CCIIMD system is shown in Figure 25. PIC16F84 is used to generate pulses. Drivers IR2110 are used to amplify the pulses. The connections from control circuit to power circuit are also presented. The amplified pulses from IR2110 are applied to IRF840 MOSFETs.
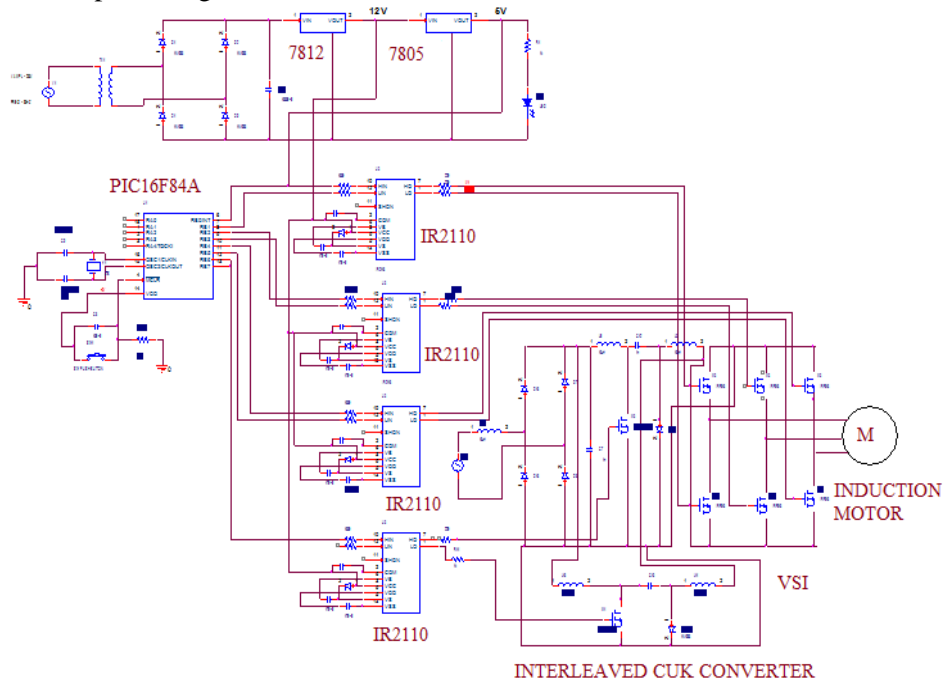

Fig.25 Complete Hardware Circuit Diagram of the proposed ICCIIMD system

IX. CONCLUSION

Simulation studies were done for open and closed-loop systems with PI and PR controllers. These studies were carried out using the Simulink based models for interleaved cukconverter inverter fed induction motor drive. The settling time with PR is reduced by 0.15ms with respect to PI controlled system. The outcomes signify that the PRcontrolled system gave an improved response as compared with PI controlled system. The hardware for 0.5HP induction-motor drive structure is contrived and verified. The investigational outcomes match with the hardware results. The torque ripple is reduced to 0.08Nm using PR controller. The benefits of the recommended ICCIIMD system are decreased torqueripple and enhanced response.

The scope of the current work is the comparison of PR and PIcontrolled open and closedloop systems. The comparison of Artificial NeuralNetwork (ANN) and Fuzzy based systems could be done in the future. The hardware may be implemented using FPGA to enhance the switching-frequency level of interleaved cuk converter.

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Declaration of Conflicting Interests

The Author(s) declare that there is no conflict of interest.

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