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FPGA Control of SPV Array Fed BLDC Motor Driven Water Pumping System Employing ILZ Converter

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Abstract This project proposes an efficient drive system for solar power fed irrigation pumps. An interleaved zeta converter is employed for regulating the voltage from solar panels. The proposed system eliminates the phase current sensor and thus is cost effective BLDC motor is fed from VSI. The proposed system is simulated on MATLAB platform with closed loop control obtaining satisfactory results. The hardware implementation is done for open loop control using FPGA controller of Xilinx Spartan 3AN and the results are demonstrated.

Keywords ILZ converter, SPV array, BLDC motor, Water pump, INC-MPPT, VSI

1. Introduction

Non-conventional source of energy are clean and ecofriendly and available in abundance. One of the promising non-conventional sources of energy is solar energy. This solar energy can be used in many applications like irrigation, water pumping, and solar water heater and so on. India is an agricultural country, 70% of Indians are farmers they are back bones of the nation. These farmers are still following old method of water pumping like use of diesel pumping system, use of fossil fuels etc. this leads to energy crises. In this context, SPV array generated electricity gains wide attention and appears as future prospective in agricultural fields. The MPPT technique is used to combine with ILZ converter in association with the BLDC motor.

The advantages of BLDC Motor and ILZ Converter can used to develop an S-PV array fed water pumping systems. The merits of BLDC motor as follows:-

- High reliability
- High efficiency
- High torque / inertia ratio
- Improved cooling
- Low radio frequency interference and noise and
- Requires practically no maintenance.

The ILZ converter has following merits verses conventional buck, buck – boost, and Cuk converter when used in spv based applications

- ILZ converter may be operated either to higher or lower the output voltage. This gives a boundless region for maximum power point tracking (MPPT) of S-PV array.
- Boost converters which highness the voltage level at its output, not ensures smooth operation, while in ILZ converter, it has facility for soft starting of BLDC motor.
- ILZ converter not having discontinuous output current. An output of inductor makes the current continuous and ripples free.

These advantages of the ILZ converter are good for suggested S-PV array- water pumping system. An INC-MPPT technique is makes to operate the ILZ converters and these leads to obtain MPP from SPV array. The VSI reduces the switching loss by adopting fundamental switching frequency these leads to power saving and increase efficiency. In this project the gate pulses for VSI are given by use of FPGA (Field programing gate array).

2. Block Diagram of the Simulated System in MATLAB

The general diagram of the suggested system is shown in fig 1. Solar panels are connected to the interleaved zeta converter to step-up the voltage, also used to extract more power. By this BLDC motor has smooth operation and controlling of speed on the joined water pump. Due to a controllable switches converter has very good efficiency and reduces pressure of the power devices and components because of continuous conduction mode (CCM) operation. The MPPT is used to track the high power drawn from the pv array. The controlled step up output is given to the three phase voltage source inverter is deduct the switching loss by adopting fundamental switching frequency hence increased efficiency and power saving. Then VSI connected to the BLDC motor, it achieves smooth operation by valid initialization of MPPT algorithm of PV array. FPGA

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controller produces a pulses and driver circuit used to enhance the pulses and isolate the from the MOSFET switches.

2.1. Design of Proposed System

Fig.2 shows a various operating stages are properly designed in order to get an effective water pumping system, the detailed design are described as follows.

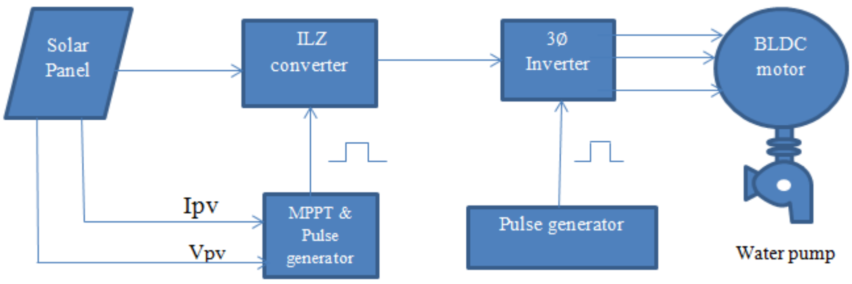

Figure 1. General Diagram of SPV arrangement for water pumping application

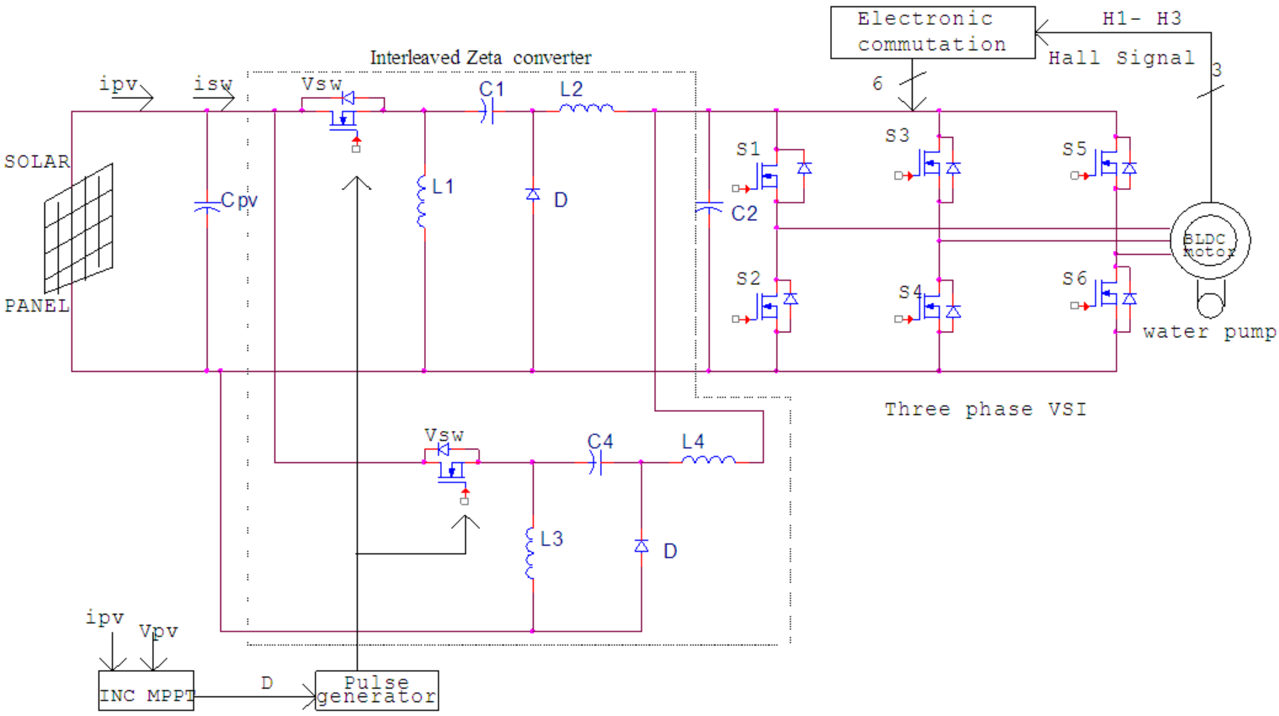

Figure 2. Proposed SPV –ILZ converter fed BLDC motor drive for water pump

2.1.1. Design of SPV Array

The size of the SPV array is selected slightly more than demanded peak power capacity of motor-pump.

Electrical specification, parameter and formulae of SPV array are shown in table 1.

Table 1. Specifications of Sanyo HIP-225HDE1 spvmodule

Peak power, *Pm* (Watt)	225
Open circuit voltage, *Vo* (V)	41.7984
Voltage at MPP, *Vm* (V)	33.9
Short circuit current, *Is* (A)	7.133
Current at MPP, *Im* (A)	6.6341
Number of cells connected in series, *Nss*	60

The current of SPV array at MPP, I_{mpp} is estimated as,

$$I_{mpp} = P_{mpp}/V_{mpp} \quad (1)$$

The numbers of module required to connect in series are as,

$$N_s = I_{mpp}/V_m \quad (2)$$

The number of modules required to connect in parallel are as,

$$N_p = I_{mpp}/I_m \quad (3)$$

2.1.2. Design of ILZ Converter

The next stage is interleaved zeta converter in this to design various components like inductor and capacitor are in CCM resulting in reduced stress on its components and devices.

An estimation of duty cycle D,

$$D = V_{dc}/(V_{dc}+V_{mpp}) \quad (4)$$

An average current flowing through the DC link of VSI, I_{dc} is estimated as,

$$I_{dc} = P_{mpp}/V_{dc} \quad (5)$$

Then L_1, L_2 and C_1 are estimated as,

$$L_1 = \frac{DVmpp}{fsw\,\Delta IL1} \quad (6)$$

$$L_2 = \frac{(1-D)Vdc}{fsw\,\Delta IL2} \quad (7)$$

$$C_1 = \frac{DIdc}{fsw\,\Delta VC1} \quad (8)$$

2.1.3. Estimation of DC Link Capacitor of VSI

The value of DC link capacitor of VSI are calculated by two frequencies rated speed and minimum speed,

$$C_{2rated} = \frac{Idc}{6*\omega rated*\Delta V\mathrm{dc}} \quad (9)$$

$$C_{2min} = \frac{Idc}{6*\omega mim*\Delta Vdc} \quad (10)$$

Where ω_{rated} and ω_{min} are

$$\omega_{rated} = 2\pi\, f_{rated} \quad (11)$$

$$\omega_{min} = 2\pi f_{min} \quad (12)$$

3. Control of Proposed System

In three various stages the proposed system are controlled. The two control techniques are MPPT and electronic commutation are discussed as follows.

3.1. INC-MPPT Algorithm

For solar PV applications INC-MMPT technique are commonly used in order to obtain high power from PV array and to help smooth operation of BLDC motor. Fig 3 shows the slope of P_{pv}-v_{pv} curve of INC-MPPT i.e.

$$\left.\begin{aligned} \frac{dP_{pv}}{dv_{pv}} &= 0; \quad at\ MPP \\ \frac{dP_{pv}}{dv_{pv}} &> 0; \quad left\ of\ MPP \\ \frac{dP_{pv}}{dv_{pv}} &> 0; right\ of\ MPP \end{aligned}\right\} \quad (13)$$

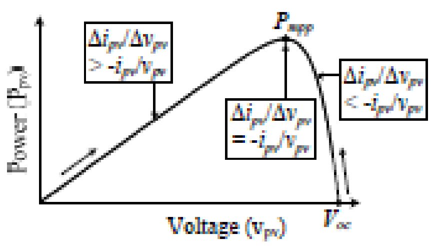

Figure 3. INC-MPPT with SPV array P_{pv}-V_{pv} characteristic

Since

$$\frac{dP_{pv}}{dv_{pv}} = \frac{d(v_{pv}*i_{pv})}{dv_{pv}} = i_{pv} + v_{pv} * \frac{di_{pv}}{dv_{pv}} \cong i_{pv} + v_{pv} * \frac{\Delta i_{pv}}{\Delta v_{pv}} \quad (14)$$

Therefore eqn (13) is rewritten as

$$\left.\begin{aligned} \frac{\Delta i_{pv}}{\Delta v_{pv}} &= -\frac{i_{pv}}{v_{pv}}; \quad at\ MPP \\ \frac{\Delta i_{pv}}{\Delta v_{pv}} &> -\frac{i_{pv}}{v_{pv}}; \ left\ of\ MPP \\ \frac{\Delta i_{pv}}{\Delta v_{pv}} &< -\frac{i_{pv}}{v_{pv}}; right\ of\ MPP \end{aligned}\right\} \quad (15)$$

By this equations increases /decreases the duty cycle.

3.1.1. Electronic Commutation of BLDC Motor

The BLDC motor is driven by 3ϕ inverter through an electronic commutation of motor. The motor is operated at 120° conduction mode. 6 switching pulses are generated as per various possible combinations of three hall signals. These hall signals are produced by inbuilt encoder according to the rotor position.

3.1.2. FPGA Controller

For the generation of PWM signal microcontroller can also be used but it has lots of hierarchical rules and commands over its input and output. Microprocessor can perform loops, timings, conditioned branching, and calculations like a small PC under program control they are used where the operation is relatively complex but processing speed relatively less than FPGA. FPGA is only an array of gate that can be connected as the user wishes. FPGA are used for relatively simpler operations but higher processing speed in comparison to microcontrollers.

4. Simulated Performance of Proposed System

The proposed Solar PV array fed BLDC motor driven water pumping system employing ILZ converter is modeled using MATLAB/SIMULINK.

The closed loop model is simulated with the following parameter values.

Input voltage (Vin) = 20.3 V

Inductor (L_1, L_2, L_3 & L_4) = 5×10^{-3}H

Capacitor C1 = C4 = 2.2×10^{-6}F C2 = 1500×10^{-6}F

Table 2. Simulation results

Solar-PV array output	20.35volt
Interleaved Zeta converter output	29volt DC
Three phase VSI inverter L-L Vab output	29 volt AC
Rotor Speed of BLDC motor	2840 rpm

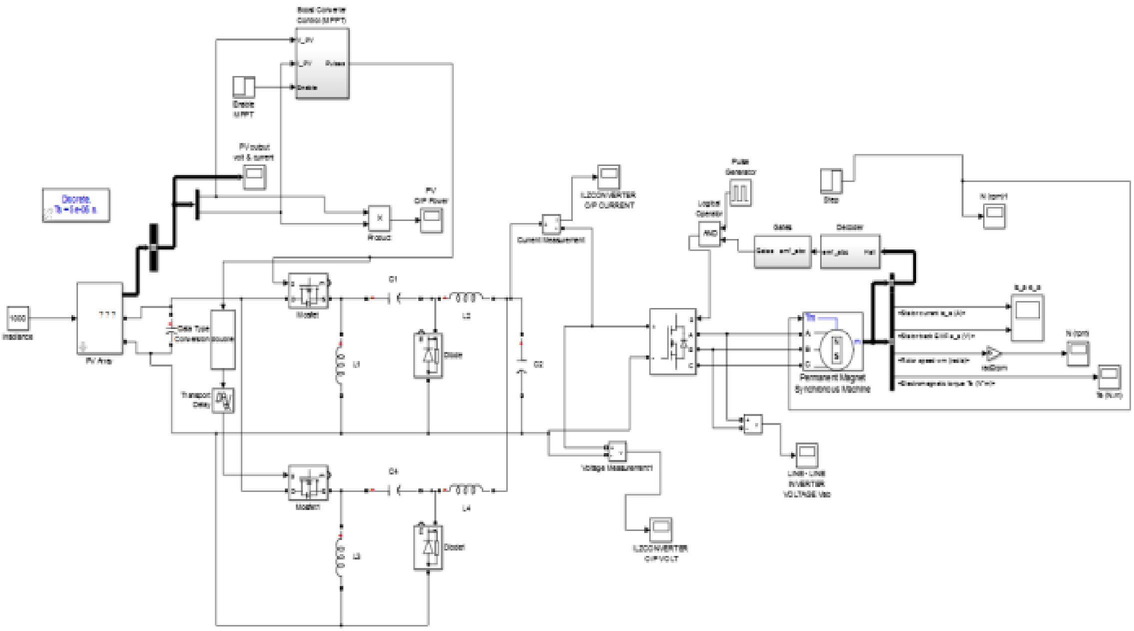

Figure 4. SIMUlation model of SPV array fed BLDC motor driven water pumping employing ILZ converter

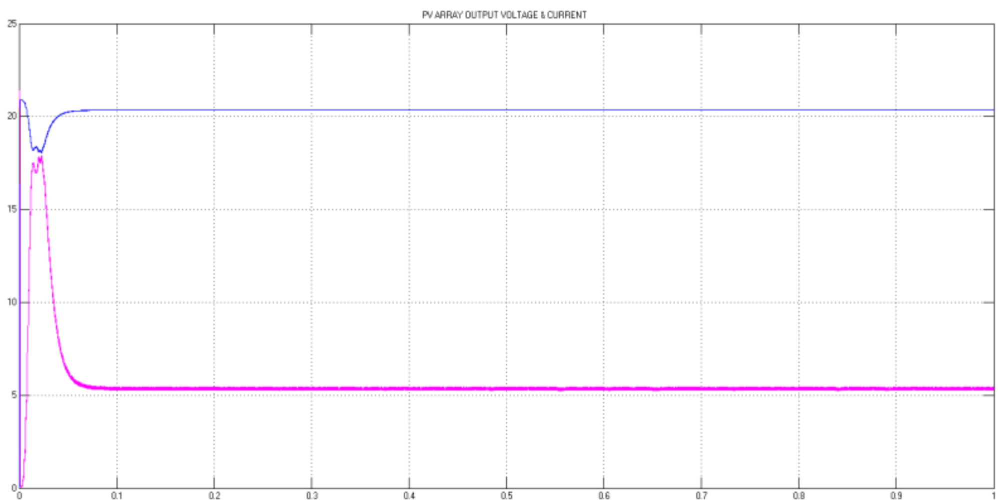

Figure 5. Solar – PV output voltage and current

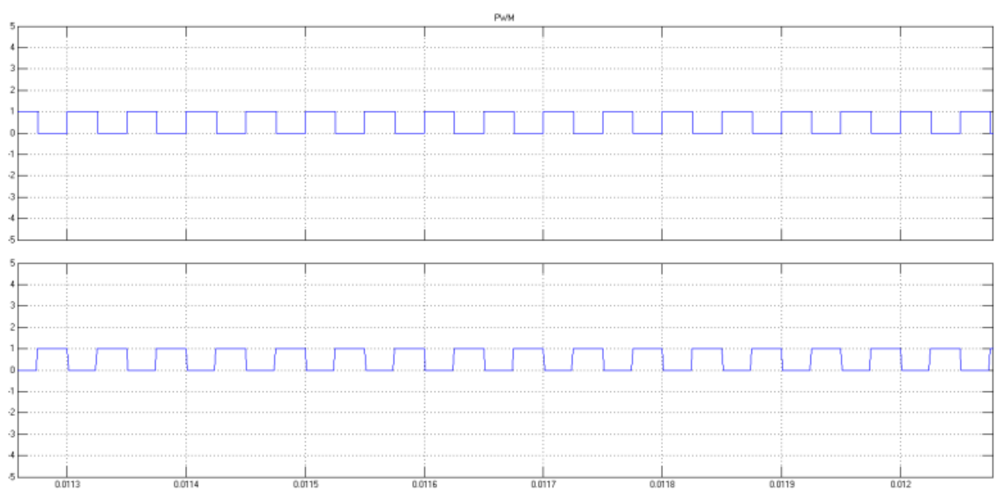

Figure 6. PWM output

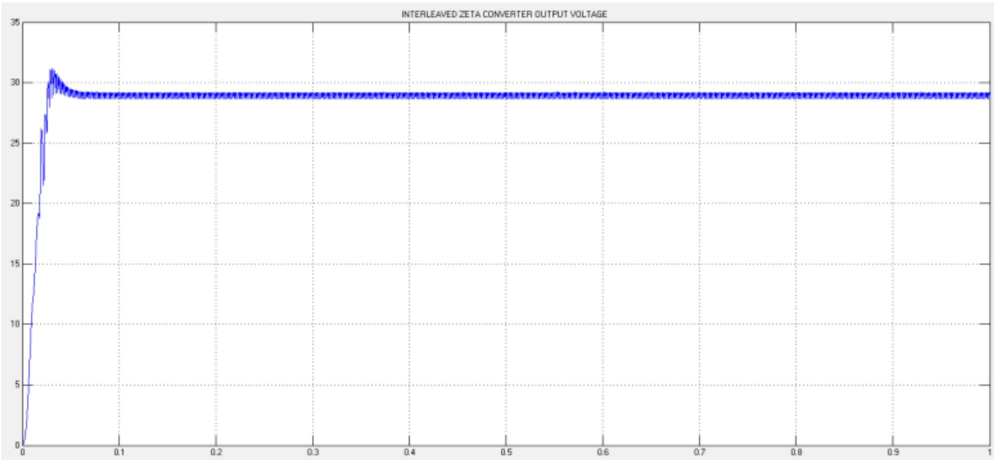

Figure 7. ILZ converter output voltage

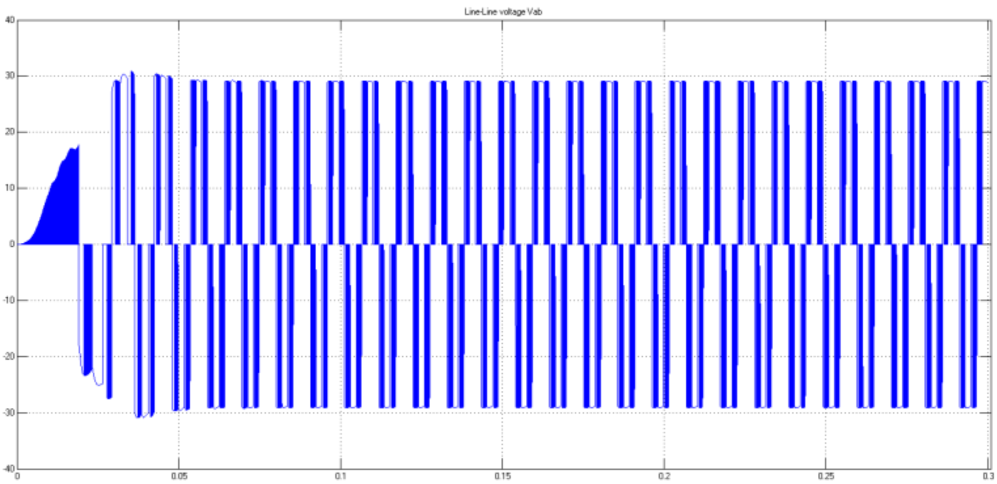

Figure 8. Line-line voltage of 3-ϕ inverter

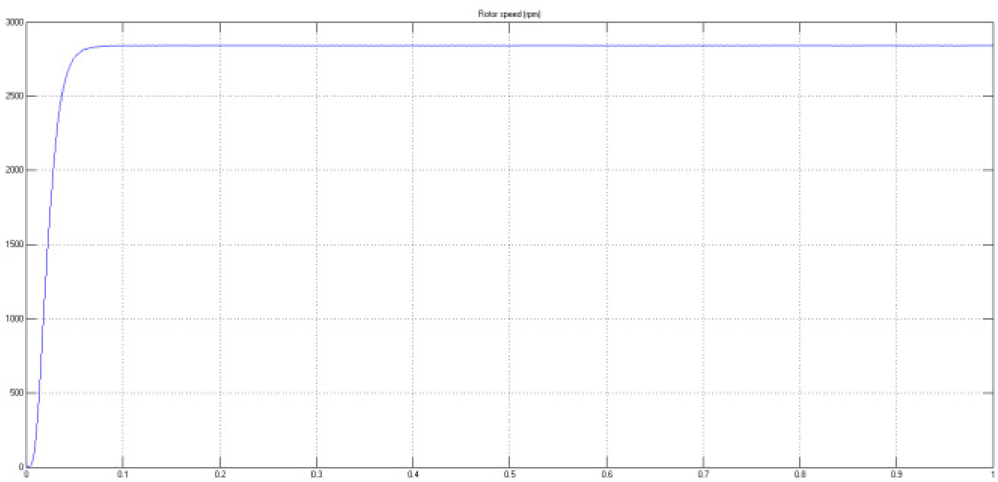

Figure 9. Rotor speed of BLDC motor

5. Hardware Implementation of the Proposed System

Fig 10 shows the hardware implementation of proposed FPGA control of Solar-Photovoltaic array fed BLDC motor drive water pumping system employing ILZ converter. In this hardware circuit the electrical supply is taking from solar panel and is connected to battery for charging, output of the battery is connected to diode full bridge rectifier with filter capacitor in order to produce dc voltage. This dc voltage having ripple in the signal to overcome ripple voltage regulator is used than constant dc voltage is attained. For indication purpose LED is used with current limiting resistor is protect the LED. In this hardware we used W01G diode full bridge rectifier and 7805 voltage rectifier, where 78 means positive, 05 means 5V. Next these signals move on the gate driver circuit to increase the switching voltages of MOSFET. Driver circuit has optocoupler and buffer circuit from this stable dc output get. This DC voltage is given to ILZ converter circuit which act as step-up converter. Here N-channel MOSFET is used. The boost voltage of 24volt is then given the **3-ϕ** voltage source inverter circuit kit, in this kit also having power circuit and driver circuit section is used. For 6 MOSFET switches of inverter circuit the switching gate pulse are given through the FPGA controller. Xilinx Spartan 3AN FPGA family kit is used to generate PWM signal this signal applied to the S1 to S6 switches. Voltage source inverter it converts the DC voltage signal to three phase AC signal. This ac signal given to the BLDC motor, then its starts rotating at rated speed.

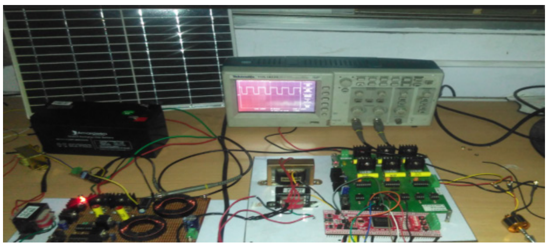

Figure 10. Hardware implementation of proposed FPGA control of S-PV array through ILZ converter via BLDC motor water pumping system

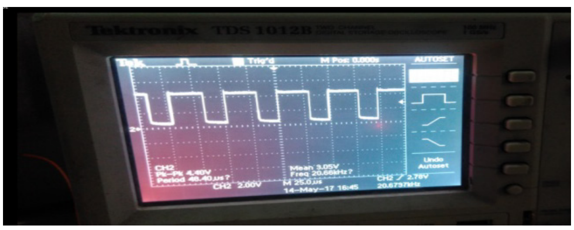

Figure 11. PWM output

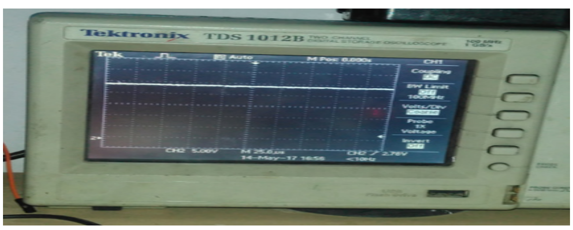

Figure 12. ILZ output voltage

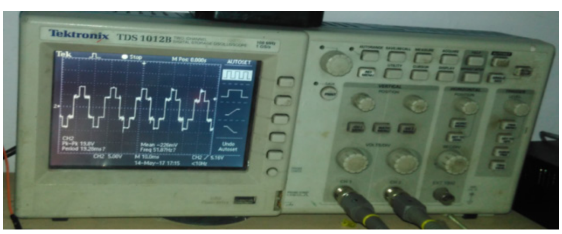

Figure 13. Three phase line-line inverter voltage

Table 3. Hardware result

Solar-PV array output	12V
Interleaved Zeta converter output	24V DC
Three phase inverter L-L Vab output	24V AC

6. Conclusions

For domestic and irrigational applications solar water pumping system has been proposed and demonstrated. Simulated result of the proposed model in MATLAB/SIMULINK is giving satisfactory results for closed loop control. The same is implemented in hardware using FPGA Xilinx Spartan 3AN controller for open loop control and satisfactory results were obtained.

FPGA is a very flexible controller, hence can be reprogrammed and reused based upon future modification and requirements.

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REFERENCES

[1] Samresh Satapathy., K. Mahesh. Dash., and B. Chitti Babu., “Variable Step Size MPPT Algorithm For Photovoltaic Array Using Zeta Converter- A Comparative Analysis”., Student Conference on engineering and System 12-14 April 2013.

[2] Zhou Xuesong., Song Daichun., Ma Youjie., and Cheng Deshu., “The simulation and design for MPPT of PV system Based on Incremental Conductance Method”. WASE international conference on information engineering., vol2 14-15 Aug 2010., pp., 314-317.

[3] R.F. Coelho., W. M.dos Santos., and D.C. Martins., “Influence of power converters on PV Maximum power point tracking algorithm”. 10th IEEE/IAS international conference on industrial applications. 5-7 Nov, 2012.

[4] Ke-Ming Chen., Tsorng-Juu Liang., “Design and Implementation of Interleaved Single-Phase Power Factor Correction of Zeta Converter”.

[5] D.N. Sonawane., M.S. Sutone., B.N. Choudhari., and abhijeet. Badurkar., “FPGA implementation of Simplified SVPWM Algorithm for three phase voltage source inverter”, international journal of computer and electrical engineering., vol2., no 6. Dec 2010.

[6] J. Padhye, V. Firoiu, D. Towsley, "A stochastic model of TCP Reno congestion avoidance and control", Univ. of Massachusetts, Tech. Rep. 99-02, 1999.

[7] B. Axelrod, and Y. Berkovich "New coupled inductor SEPIC converter with very high conversion ratio and reduced voltage stress on the switches".