BLDC Motor Driven Solar PV Array Fed Water Pumping System Employing Zeta Converter

1.Unnikrishnan P
Department of Electrical and Electronics Engineering
Kerala Government Polytechnic College ,West Hill
unnisrishylam@gmail.com

2.Ajay Kumar EP
Department of Electrical and Electronics EngineeringSreerama Government Polytechnic College,Thriprayar
epajay2010@gmail.com

3. Muraleedharan MT
Department of Electrical and Electronics Engineering
Government Polytechnic College ,Kalamassery
muraleedharan5149@gmail.com

4. Basheer K
Department of Electrical and Electronics Engineering
SSM Polytechnic College Tirur
hodelectrical@ssmpoly.ac.in

5.Kamal VV
Department of Electrical and Electronics Engineering
Kerala Government Polytechnic College ,West Hill
vvkamalvv@gmail.com

6.Akhil Ahammed KE
Department of Electrical and Electronics Engineering
kerala Government Polytechnic College ,West Hill
akhilahmedsav@gmail.com

***Abstract*—This paper proposes a simple, cost effective and efficient brushless DC (BLDC) motor drive for solar photovoltaic (SPV) array fed water pumping system. A zeta converter is utilized in order to extract the maximum available power from the SPV array. The proposed control algorithm eliminates phase current sensors and adapts a fundamental frequency switching of the voltage source inverter (VSI), thus avoiding the power losses**

due to high frequency switching. No additional control or circuitry is used for speed control of the BLDC motor. The speed is controlled through a variable DC link voltage of VSI. An appropriate control of zeta converter through the incremental conductance maximum power point tracking (INC-MPPT) algorithm offers soft starting of the BLDC motor. The proposed water pumping system is designed and modeled such that the performance is not affected under dynamic conditions. The suitability of proposed system at practical operating conditions is demonstrated through simulation results using MATLAB/ Simulink followed by an experimental validation.

I. INTRODUCTION

The drastic reduction in the cost of power electronic devices and annihilation of fossil fuels in near future invite to use the solar photovoltaic (SPV) generated electrical energy for various applications as far as possible. The water pumping, a standalone application of the SPV array-generated electricity, is receiving wide attention nowadays for irrigation in the fields, household applications, and industrial use. The merits of both BLDC motor and zeta converter can contribute to develop an SPV array-fed water pumping system possessing a potential of operating satisfactorily under dynamically changing atmospheric conditions. The BLDC motor has high reliability, high efficiency, high torque/inertia ratio, improved cooling, low radio frequency interference, and noise and requires practically no maintenance. On the other hand, a zeta converter exhibits the following advantages over the conventional buck, boost, buck–boost converters, and Cuk converter when employed in SPV-based applications. Belonging to a family of buck–boost converters, the zeta converter may be operated either to increase or to decrease the output voltage. This property offers a boundless region for maximum power-point tracking (MPPT) of an SPV array . The MPPT can be performed with simple buck and boost converter if MPP occurs within prescribed limits. This property also facilitates the soft starting of BLDC motor unlike a boost converter which habitually steps up the voltage level at its output, not ensuring soft starting. Unlike a classical buck–boost converter, the zeta converter has a continuous output current. The output inductor makes the current continuous and ripple free. Although consisting of same number of components as a Cuk converter, the zeta converter operates as no inverting buck–boost converter unlike an inverting buck– boost and Cuk converter. This property obviates a

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requirement of associated circuits for negative voltage sensing, and hence reduces the complexity and probability of slow down the system response.

II.ZETA CONVERTER

2.1 INTRODUCTION OF ZETA CONVERTER

The main use of zeta converter is to vary the output dc voltage to meet the requirement of dc equipment. The output voltage is measured form open circuit output of the converter. Zeta converter is more beneficial than other types of converters like it have both the properties of buck and boost converter (means it can act as a step up/down converter). It is non-inverting polarity type means it gives non inverting output it can be design to achieve low ripple output current and as it has lower settling time, adaptability etc. The output voltage vary by varying the duty cycle by using microcontroller which decide the zeta converter to operate whether in buck or boost converter. We are using ac supply and solar PV panel as a multiple input to our converter. It shows that the converter is multiple inputs to single output which can be called as a zeta converter. While the design of ZETA Converter is done on MATLAB. Day by day the renewable energy sources are becoming more popular and more importance given to it as it free form pollution, low maintenance cost, etc. So we are including solar PV panel as an input as well as ac supply. The zeta converter is nothing but the DC to DC converter which are widely used as an application in traction motor, e-riksha, power factor correction battery charging, etc. The zeta converter is 90-93% efficient.

The ZETA converter provides a positive output voltage for input voltage that varies above and below the output voltage. The ZETA converter also needs two inductors and a series capacitor, sometimes called a flying capacitor. The zeta converter is used for to give the gate pulse for MOSFET which is used the driver circuit in our paper we can see that how the gate pulse is given to it, this converter which is configured with a standard boost converter, the ZETA converter is configured from a buck controller that drives a high-side P_{MOSFET}. The ZETA converter is another option regulating an unregulated input-power supply. All non-conventional system energy system requires particular power converters. Seen the power electronic converter is the heart of the entire system, show proper design necessary. ZETA Converter Is mentioned and it is use provide positive output from the input voltage it can be used to increase as well as decrease the voltage. This converter is used for power factor correction applications and short circuit protection.

Thus we can use solar photovoltaic cell for the input to the Zeta converter to full fill the requirement of DC input to the converter, as the solar means renewable energy is more popular now a days as the output solar cannot be doubled but due to zeta converter the output of dc voltage can double the output of input voltage and it can be triple by varying Duty cycle. Thus we are using switching techniques for varying the duty cycle. Thus we are using Driver circuit to give the Gate pulse to the ZETA Circuit for the MOSFET to operate in on state.

The Zeta Converter provides Non-inverted output, its ripple less, low voltage diode and Continuous conduction mode. While the load can be use at the output of converter, as the output can be vary we can use large power DC loads. There are many types of converters which can also be use in place of ZETA converter .But however they have certain intrinsic limitation.

BOOST: This is not naturally isolated and operates only as a Step-Up voltage. It is not capable of protecting itself against a load and it not able to handle the short circuit or over current.

BUCK: This Converter is capable of handling inrush current and protecting against the overload. Thus when used in power factor correction application the dc output voltage is reflected to the primary side of the transformer thus blocking the rectifier diode. Thus it indicates that it has no future scope in power factor correction.

BUCK-BOOST: We can say that this converter is capable of satisfying all the mentioned specification simultaneously.

CUK and SEPIC: This Converter are naturally isolated and it can be operating as step-up and step-down voltage. While it does not protect itself against overload and an additional circuit is needed to limit the inrush current.

Zeta: It is similar to the Fly back Converter and in some application it is more advantageous over other DC-DC converter.

2.2 ZETACONVERTER SCHEMATIC

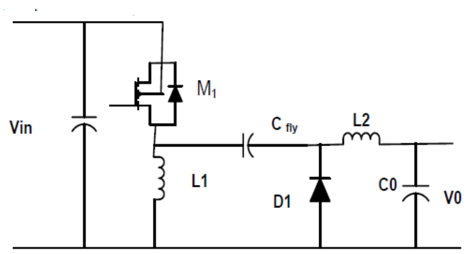

Fig 2.1 Zeta converter schematic

A zeta converter is a fourth order Nonlinear system being that, with regard to energy input, it can seen as buck-boost-buck converter and with regard to the output, it can be seen as boost-buck-

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boost converter. The ideal switch based realization of zeta converter is depicted. A non-isolated zeta converter. Circuit is shown in the fig3.1 above. Although several operating modes are possible for this converter depending on inductance value, load resistance and operating frequency, here only continuous inductor current ”iL1”analysed using the well-known state-space averaging method .The analysis uses the following assumptions.

1. Semiconductors switching devices are considered to be ideal.
2. Converter operating in continuous inductor current mode. Line frequency ripple in the dc voltage is neglected

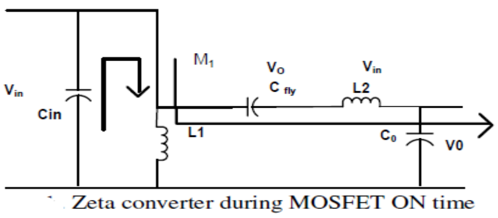

Fig 2.2 Zeta converter on time

3. The switch M_1 is in ON state, so voltages VL_1 andVL2 are equal to VIN . In this time interval diode D1 is OFF with a reverse voltage equal to -(VIN + V_O). Inductor L_1 and L_2 get energy from the voltage source, and their respective currents IL_1 and IL_2 are increased linearly by ratio V_{in}/L_1 and V_{in}/L_2respectively. Consequently, the switch current IM1=IL_1+IL_2 is increased linearly by a ratio V_{in}/L, where $L=L_1.L_2/ (L_1+L_2)$. At this moment, discharging of capacitor C $_{fly}$ and charging of capacitor C_0 take place.Stage-2 [M_1 OFF] is no DC voltage across either inductor. Therefore, C_{FLY} across C_{FLY} is equal to VOUT ground potential at its left side and V_{OUT} at its right side, resulting the DC voltage

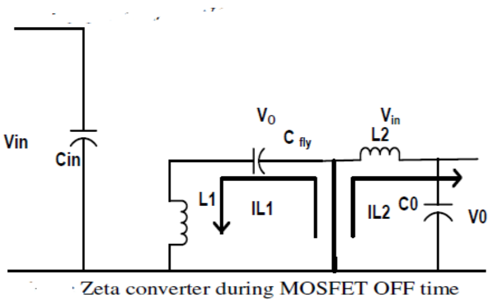

Fig 2.3 Zeta converter off time

In this stage, the switch M_1 turns OFF and the diode D_1 is forward biased starting to conduct. The voltage across L_1 and L_2 become equal to $–V_O$ and inductors L_1 and L_2 transfer energy to capacitor C $_{fly}$ and load respectively. The current of L1 and L2 decreases linearly now by a ratio $–V_0/L1$ and $–V_0/L2$, respectively. The current in the diode $ID_1=IL_1+IL_2$also decreases linearly by ratio –V0/L. At this moment, the voltage across switch M_1 is $V_M= V_{IN} + V_0$. Figure shows the main waveforms of the ZETA converter, for one cycle of operation in the steady state continues mode.

III. PROPOSED SYSTEM

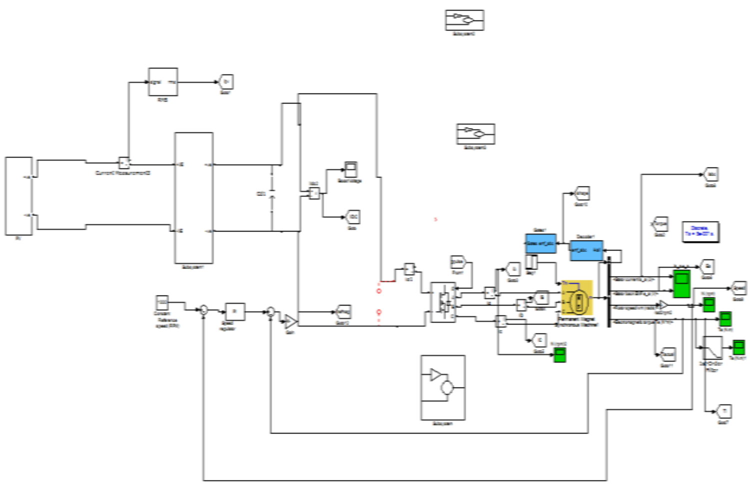

Fig 3.1 Simulation of PV array

Figure 5.1 shows the proposed PV Grid connected system. This is a two stage PV system. First stage is a DC to DC Boost chopper stage. The function of DC-DC converter is to execute the MPPT algorithm by controlling its input terminal voltage by sensing the PV voltage and PV current. The MPPT algorithm used in this proposed system is Incremental conductance. This MPPT algorithm is simple and it automatically control the duty cycle. This senses the PV voltage and PV current and generates the gate pulses for the Boost chopper. For transferring maximum power to the grid it is required to stabilize the voltage. The UN stabilized DC link voltage will cause large harmonic distortion in grid current and low power transfer from PV system to grid. The higher voltage at DC-link will cause stress in the power semiconductor switches used in Inverter stage. In the proposed system the DC link voltage is stabilized by a fuzzy PID controller in load current control loop. The second stage is inverter stage. This stage converts the DC voltage to AC voltage that is fed to the grid. The output current of the H Bridge inverter contains the ripple. To reduce the ripple and thus to minimize the THD within IEEE standard LCL filter is used in output circuit. In addition to this filter, since the PV system is a nonlinear, FPID, fuzzy Proportional Integral Derivative Controller is used in outer current control loop. This reduces the oscillation in DC-link voltage at transient and steady state conditions. It also helps to reduce the THD to considerable limit and reduces the settling time comparing to conventional PID and PR controller.

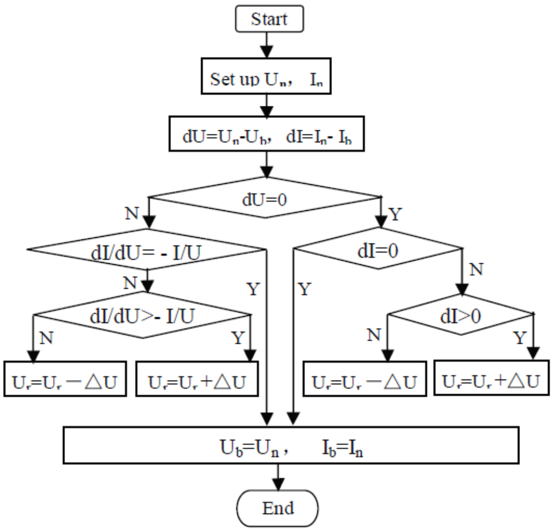

Fig 3.2 Flow chart of Incremental conductance MPPT

3.2 SPECIFICATIONS OF SIMULATION MODEL.

Output power - 2.5 KW

Maximum load current 11.5 A

Power Factor -0.9

Implement a PV array built of strings of PV modules connected in parallel .Each string consists of modules connected in series. Input 1 is sun irradiance and input 2 is temperature in degree centigrade.

PV Module used-Neo Solar power 7E00-6A260

No of Parallel Path-1

Series connected string -10

3.3 BOOST CHOPPER.

Boost chopper is basically DC –DC converter its output voltage

VO = Vs./ (1-D), here D is duty ratio.

The gain of boost chopper is

$$G_{boost} = \frac{Vout}{Vin} = \frac{Vdc}{Vpv}$$

$$= \frac{1}{(1-D)}$$

Maximum Switching Current $\Delta I = \frac{D \times Vpv}{Fsw \times Lboost}$

If L is not known then $\Delta I = (0.2 \text{ to } 0.4) \times I_{out(max)} \times \frac{Vout}{Vin}$

So $L = \frac{Vin \times (Vout - Vin)}{\Delta I \times Fs \times Vout}$

Duty cycle $D = 1 - \frac{Vin}{Vout}$

Output capacitor $C_{out} = \frac{Iout(max) \times D}{Fsw \times \Delta Vout}$

$$V_{out} = \frac{Iout(maxx)}{(1-D)} + \frac{\Delta Il}{2}$$

5.3.4 DESIGNING DC/DC CONVERTERS BASED ON ZETA TOPOLOGY

Similar to the SEPIC DC/DC converter topology, the ZETA converter topology provides a positive output voltage from an input voltage that varies above and below the output voltage. The ZETA converter also needs two inductors and a series capacitor, sometimes called a flying capacitor. Unlike the SEPIC converter, which is configured with a standard boost converter, the ZETA converter is configured from a buck controller that drives a high-side PMOS FET. The ZETA converter is another option for regulating an unregulated input-power supply, like a low-cost wall wart. To minimize board space, a coupled inductor can be used. This article explains how to design a ZETA converter running in continuous-conduction mode (CCM) with a coupled inductor. Basic operation Figure 1 shows a simple circuit diagram of a ZETA converter, consisting of an input capacitor, CIN; an output capacitor, COUT; coupled inductors L1a and L1b; an AC coupling capacitor, CC; a power PMOS FET, Q1; and a diode, D1. Figure 2 shows the ZETA converter operating in CCM when Q1 is on and when Q1 is off. To understand the voltages at the various circuit nodes, it is important to analyze the circuit at DC when both switches are off and not switching. Capacitor CC will be in parallel with COUT, so CC is charged to the output voltage, VOUT, during steady-state CCM. Figure 2 shows the voltages across L1a and L1b during CCM operation. When Q1 is off, the voltage across L1b must be VOUT since it is in parallel with COUT. Since COUT is charged to VOUT, the voltage across Q1 when Q1 is off is VIN + VOUT; therefore the voltage across L1a is –VOUT relative to the drain of Q1. When Q1 is on, capacitor CC, charged to VOUT, is connected in series with L1b; so the voltage across L1b is +VIN, and diode D1 sees VIN + VOUT. By Jeff Falin Senior Applications Engineer L1a L1b CC CIN D1 COUT Q1 VIN VOUT Figure 1. Simple circuit diagram of ZETA converter VOUT VIN CIN CC Q1 is On – V + OUT + V – IN VIN + – L1a COUT L1b IL1a GND IL1b Figure 2. ZETA converter during CCM operation (a) When Q1 is on (b) When Q1 is off VOUT VIN CIN CC Q1 is Off – V + OUT – V + OUT V

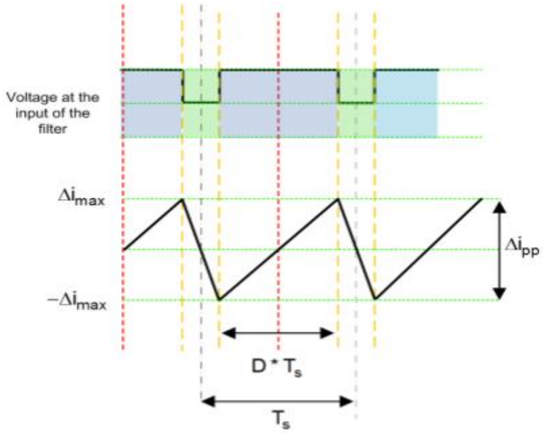

Fig.5.3 Voltage and current wave form at the inductor

The voltage across the inductor is given by:

$$V = L \times \frac{di}{dt}$$

For H Bridge inverter $V = V_{bus} - V_o$

$$\text{So} \quad V_{bus} - V_o = L \times \frac{di}{dt} = L_i \times \frac{\Delta Ipp}{D \times Ts}$$

$$\Delta Ipp = \frac{(Vbus - Vo) \times D \times Ts}{Li}$$

Assume modulation index be m_a the Duty cycle is given as

$$D = m_a \times \text{sine}(\omega t)$$

$$V_o = V_{DC} \times D$$

Therefore,

$$\Delta Ipp = \frac{Vbus \times Ts \times ma \times sine(\omega t) \times (1 - sine(\omega t))}{Li}$$

Differentiating the above equation and equating to zero we get,

$$\text{sine}(\omega t) = \frac{1}{2ma}$$

$$\Delta Ipp_{max} = \frac{Vbus \times Ts}{4 \times Li}$$

IV.STEADY STATE AND TRASIENT ANALYSI

4.1STEADY STATE RESULTS

MATLAB simulink 2017 is used for the simulation of proposed system. Neo Solar Power 7E00-6A 250-B PV Array is used. The VI characteristics and Power Vs Voltage characteristics of array is shown in figure.

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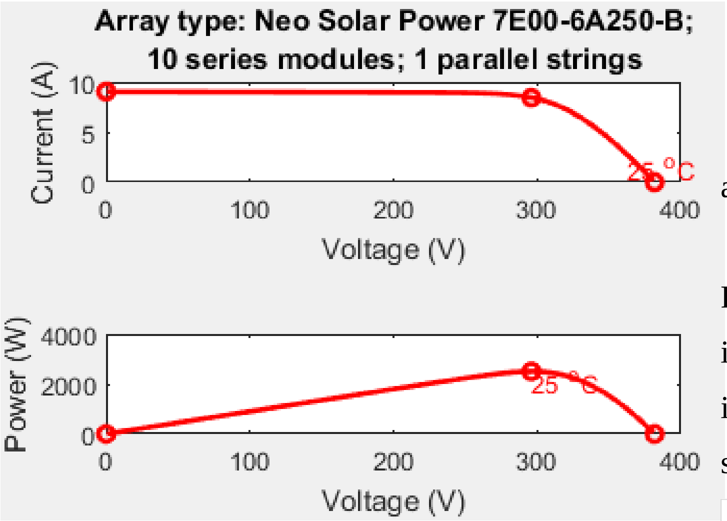


Fig 4.1 PV Array Characteristics.

Steady state results of proposed system are shown in different figures. The figure 6.2 and Fig 6.3 are shows steady state result, DC output voltage of PV Array and PV output power. 10 PV modules are connected in string so open circuit voltage @ solar irradiation of 1000w/m^2 is 380 V at 25^0 C. Dc link voltage is varied from 300V onwards. But the results shows the maximum power is transferred at minimum THD, that is bellow IEEE standards, is at 350V. In the proposed system DC link voltage fluctuations are minimized. This helps to reduce the stress on the VSI components. Figure shows the variation of % THD in grid current at different DC-Link voltage.

Irradiance	1000 C^0	800 C^0
PV Power	1486 W	1086
Vdc	350	350
%THD	2.8	2.8
P inv	838	820
Loss	648	266

Table 6.1 Various parameters at temperature is 25C^0

From the above results shows the maximum power is transferred at irradiance is 800 C^0 . When the irradiation changes to a low value but the proposed system transfer maximum power.

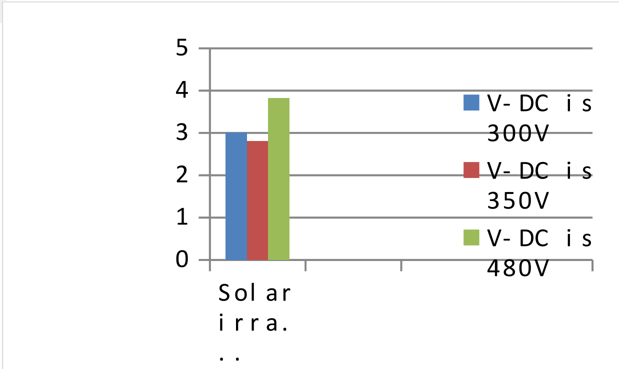
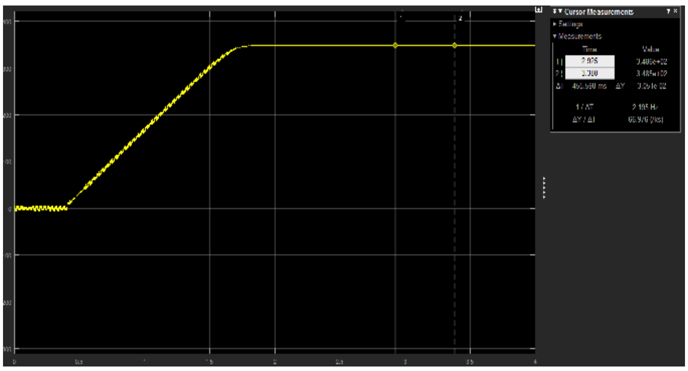


Fig 4.2 Bar graph of % THD of grid current at different DC-Link voltage.



350

Fig 4.3 PV output voltage.

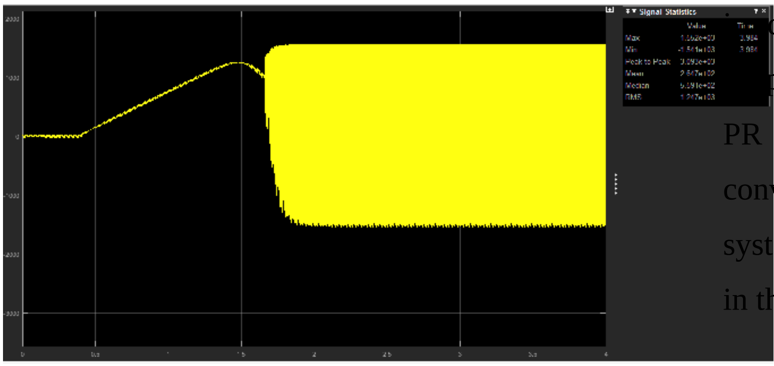


Fig 4.4 PV Power

Figure 5.7 shows the DC –Link voltage wave form at 1000W/m2 irradiance and 25^0 C. Figure shows the H Bridge Voltage Source Inverter output voltage. The results show that system takes about 5 seconds to reach the steady state value. This is due to the characteristics of the PV Array used in simulation that is sown in figure 5.8.

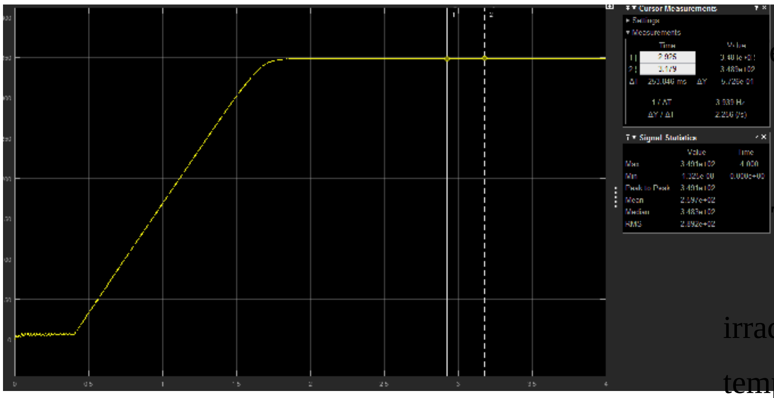


Fig 4.5 DC-Link voltage at steady state analysis

Steady state grid voltage and grid current wave forms are shown in figure5.9. The voltage THD is very small and current THD is 0.028 at 1000 W/m^2

diance. Figure5.9 shows the comparison of posed system with uncompensated conventional PR control based system and loss compensated conventional PR system. Comparing to these two systems the proposed system introduce small THD in the grid current.

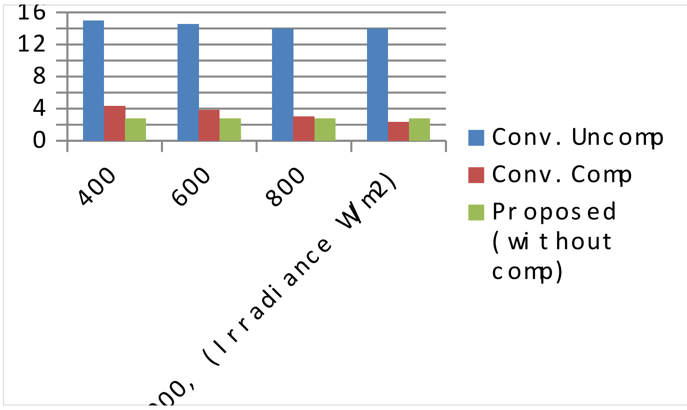


Fig 4.6 % THD at erent Solar Irradiance.

TRANSIENT RESULTS.

For transient analysis the solar irradiance is varied at 2.5 seconds keeping temperature as 25^0 C. Figure shows the effect of this variation on PV Voltage and power. Figure shows the transient result of DC-Link voltage. Here, in the proposed system the settling time is 0.1 seconds.

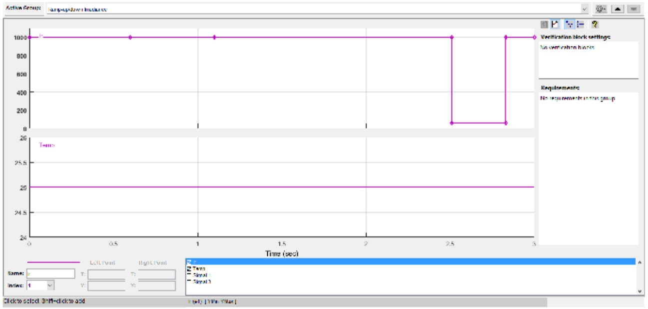


Fig 4.7 Solar Irradiance and Temperature.

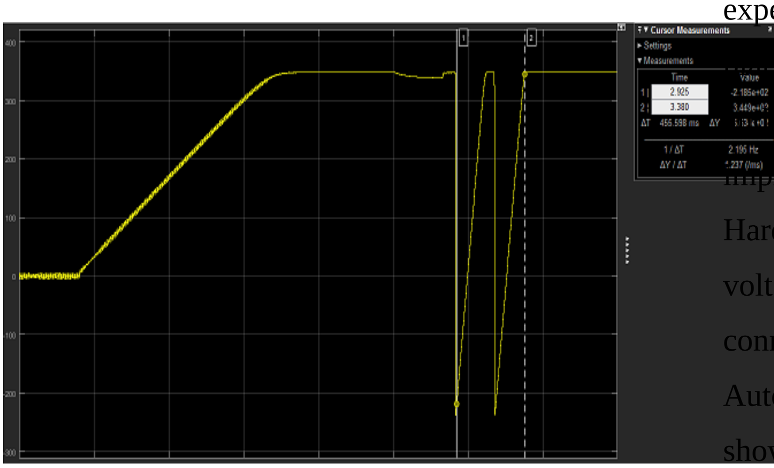


Fig 4.8 PV voltage variation due to change in solar Irradiance.

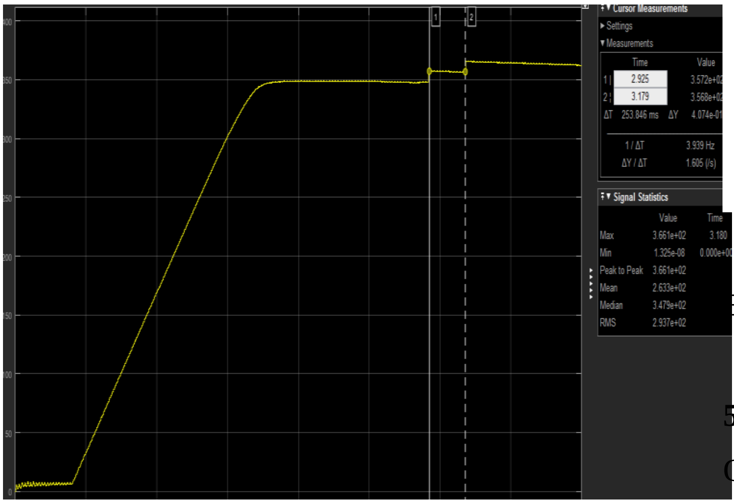


Fig 4.9 DC-Link voltage variation under transient condition.

V.HARDWARE

5.1 HARDWARE DESCRIPTIONS

The proposed Grid connected converter using FPID is verified and evaluated by comprehensive test. Simulation ratings of PVGCFPID are not implemented in hardware because it is more expensive so it is in scaled down version. The test platform is shown in fig. The IC MPPT algorithm and FPID algorithm for inverter stage is implemented in AT Mega 328 microcontroller. Hardware is implemented for a maximum output voltage 30 to 90.Out put of the proposed system connected to the reduced grid voltage through Autotransformer. Block diagram of Hardware is shown in figure.

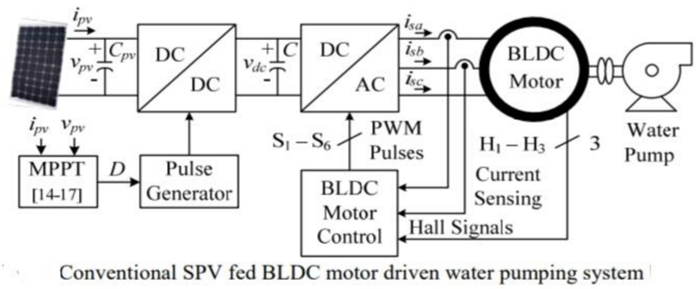


Fig 5.1 Block Diagram of Experimental Set up

5.2 SPECIFICATION

Output Power -10W

Out Put Voltage _ 90 V

Dc Link Voltage -30V

PV Voltage 8-12V

Grid Voltage 90 V

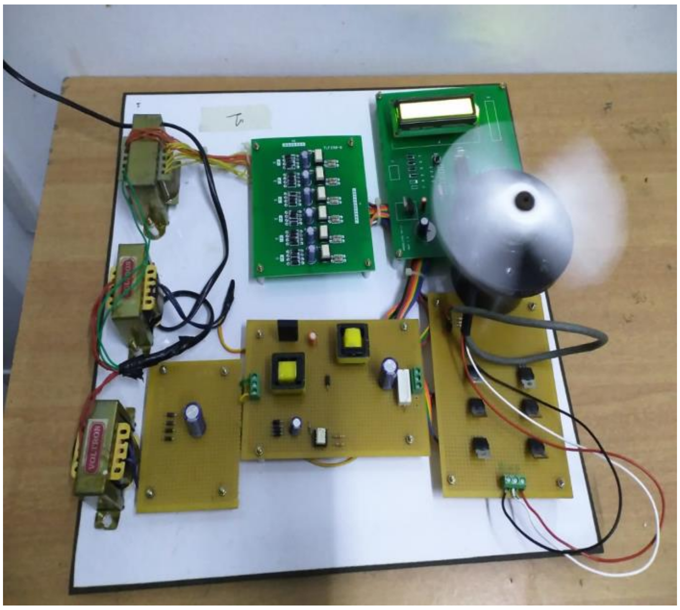


Fig 7.2 Experimental setup

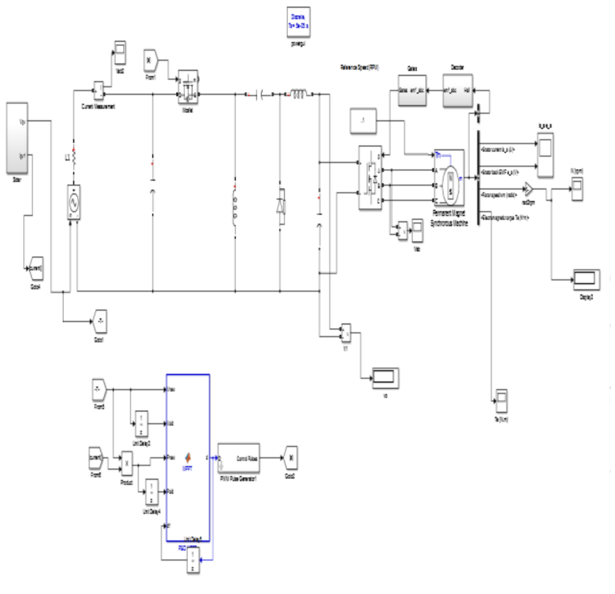


Fig 5.3Circuit diagram

5.3 DESIGN OF INDUCTANCE.

L_{max} = Vin (V_{out}-V_{in})/ ΔI_L x Fs x V_{out}

$I_{out(max)}$ = Pout/ V_{out} = 10/90 = 0.111A

ΔI_L = (.2 to .4)x $I_{out(max)}$ x V_{out} /V_{in}

= 0.4x o.111x 90/12

= 0.333

L = 12x (90-12)/ 0.333x10x10^6 x90

= 300 micro Henry

Since Area of product value A_p =68.88mm^2

Ferrite core P18/11 selected

Number of Turns N =Lim/Ac XB_m

Ac = .43 and B_m 0.2T

So N =775 Turns

Gauge = 35

5.4 Design of Capacitor

C= (Iout X D)/ (Fs X Vout)

Vout = (Iout/(1-D)]X I_L/2

D= 0.8

Vout = 0.0924

C = 1000Micro Farad

5.5HARDWARE DETAILS

MAIN CIRCUIT

MOSFET – IRF 840

DIODE - IN4007

CAPACITOR AS PER THE CIRCUIT

INDUCTOR AS PER THE CIRCUIT (CORE- FERRO MAGNETIC)

TRANSFORMER (230/ STEP DOWN) +RECTIFIER (10A)

DRIVERCIRCUIT

TLP 250 DRIVER CIRCUIT

PIC 16F 877A MICRO CONTROLLER

IC 7805 --REGULATOR IC

CRYSTALL OSCILLATOR

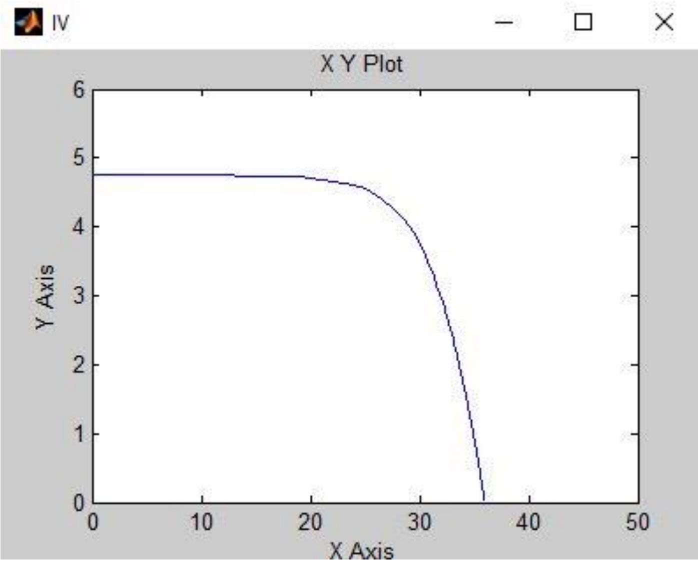


Fig 5.4waveform of PV cell

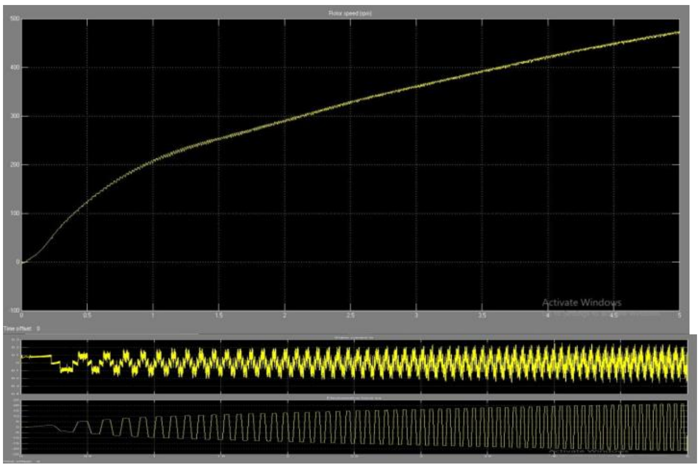


Fig.5.5 PV Voltage

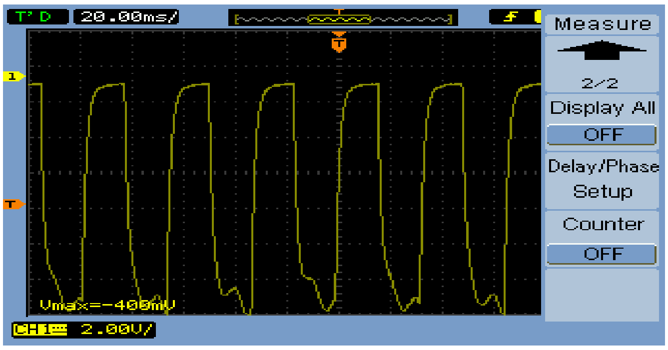


Fig 5.6 AC output voltage.

VI.RESULT AND DISCUSSION

Comparative results of proposed system and conventional control show that the proposed system will improve THD levels and power factor. In conventional system without loss compensation and with compensation THD level is 12% and 3.2% respectively. But in proposed system THD level is 2.1%. In the proposed system settling time is 0.1 seconds. The wave forms of simulation results and experimental set up are shown. Here experimental set up is in scaled down version so the results are not correctly match the simulation results. The proposed system offers an efficient control for stabilizing DC-link voltage. Since FPID system does not sensitive to plant variations the solar irradiance variation is not affect the grid current THD. The proposed system does not compensate the losses in inverter stage. By introducing soft switched inverter we can reduce the losses in inverter stage.Like the SEPIC converter, the ZETA converter is another converter topology to provide a regulated output voltage from an input voltage that varies above and below the output voltage. The benefits of the ZETA converter over the SEPIC converter include lower output-voltage ripple and easier compensation.The drawbacks are the requirements for a higher input-voltage ripple, a much larger flying capacitor, and a buck controller (like the TPS40200) capable of driving a high-side PMOS.

VII.CONCLUSION & FUTURE SCOPE OF STUDY

A solar photovoltaic array fed Zeta converter based BLDC motor has been proposed to drive water-pumping system. The proposed system has been designed, modelled and simulated using MATLAB along with its Simulink and simpower system toolboxes. Simulated results have demonstrated the suitability of proposed water pumping system. SPV array has been properly sized such that system performance is not influenced by the variation in atmospheric conditions and the associated losses and maximum switch utilization of Zeta converter is achieved. Zeta converter has been operated in CCM in order to reduce the stress on power devices. Operating the VSI in conduction mode with fundamental frequency switching eliminates the losses caused by high frequency switching operation. Stable operations of motor-pump system and safe starting of BLDC motor are other important features of the proposed system.

VIII. Reference:

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