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Implementation of Solar Powered Street Lighting System

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Abstract

Solar powered street lighting is a green energy technology to reduce electricity cost to illuminate streets at night. Solar energy received during day time will be converted into electricity to charge the battery. Key aspect of street lighting is appropriate charge controller for battery management system. The proposed system helps to charge the battery between upper and lower voltage limits in addition to the continuous checking of the status of charge level of battery. It is achieved by making rise or fall in the charging current as per the requirement of the system. Efficient use of solar energy in street lighting system is achieved by ZETA converter based solar charge controller. This controller protects the battery from overcharging and deep- discharging. Since, ZETA converter is made to act itself act as charge controller in addition to the maximum power point tracking, converter is used to optimize street lighting system to reduce the power losses and cost. The designed circuit provides alternative path to the power when battery is fully charged. So, in the concept of centralize architecture of photovoltaic street lighting system this design provides a best alternative solution.

Keywords: *MATLAB, MPPT, Solar PV system, Street lighting, ZETA converter*

Introduction

The solar energy is a sustainable source of energy and recently it attracts more attention in green energy generation. Since, it is free, clean and long-lasting near future it becomes primary source of energy for off grid locations. It is the suitable choice for distributed power production because of its low maintenance and operational cost. Because of the developments in converter technologies, generated direct current power can be effectively stored and utilized in many house hold, commercial and industrial applications. The conversion of DC-AC involves huge power loss. So, the effective utilization of the DC power generated in solar PV street lighting system is achieved by DC-DC ZETA converter [1-3]. Because of the topology of the converter such as using inductor in series and capacitor in parallel at its output side, converter gives a smooth and ripple free output voltage [4]. Because of its performance during low solar radiation conditions, it yields efficiency more than other converters like Buck-Boost converter. Also, its output voltage polarity is positive that can be used in all common direct current applications. ZETA converter controls the charging and discharging phenomena of battery by acting as a cut-off circuit which charge and discharge battery between the system requirements to prevent it from deep discharging [5]. Hence, the life of battery is increased along with a fall in power loss, which indirectly makes the street lighting system more efficient. It also gives power to alternative load when the battery is fully charged [6]. In this proposed street lighting system maximum power point tracking is achieved by perturb and observe (P&O) method. The block diagram of the proposed system is shown in Figure1.

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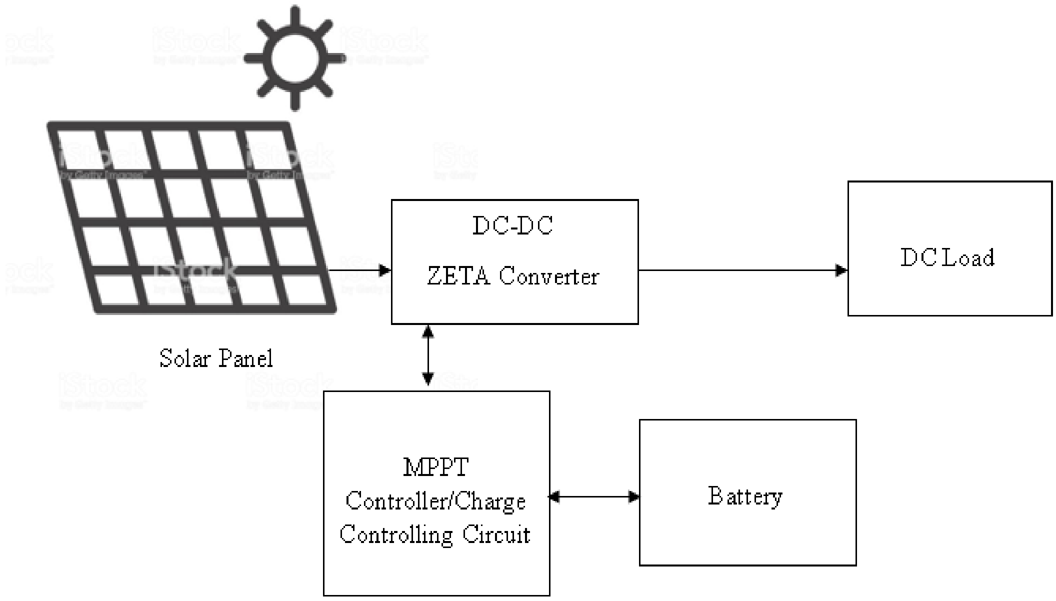

Figure 1. Block diagram of the proposed system

Modelling of Solar Panel and Maximum Power Point Tracking Technique

Modelling of solar panel is essential to predict the maximum power point of a solar PV system. An equivalent circuit of a solar cell is shown in Figure 2.

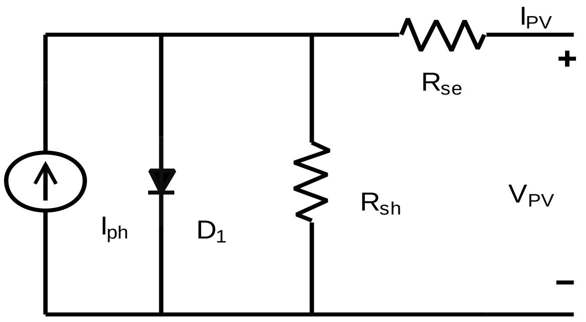

Figure 2. Equivalent circuit diagram of a solar cell

The basic equation which is derived from the theory of semiconductors and it mathematically explains the I–V characteristic of the ideal solar PV cell is given as follows [7],

$$I = I_{ph} - I_o \left[\exp\left(q * \left(\frac{V + IR_{se}}{akTN_s} \right) \right) - 1 \right] - \frac{V + IR_{se}}{R_{sh}} \quad (1)$$

In this paper, ELDORA 40W solar module is used for solar power generation. Table 1 illustrates the datasheet of 40W module,

Table 1. Electrical specifications of solar panel

PV Module	Voc(V)	Isc(A)	Vmpp(V)	Impp(A)	N_s	K_v(V/oK)	K_i(A/oK)
ELDORA40W	21.9	2.45	17.4	2.3	36	-0.123	0.0032

Novelty of the PV array model is the physical modelling technique which is done in MATLAB/Simscape environment. In order to model a panel in simscape the values of series resistance (R_{se}), parallel resistance (R_{sh}) and ideality factor(a) are required. Unfortunately, manufacturer data sheet doesn't have the values. Through Newton Raphson iterative technique the above said parameters are found. MATLAB/m-file coding is done for the N - R method and executed successfully []. The estimated values of R_{se}, R_{sh} and a are 0.010 Ω,188.02 Ω and 1.743 respectively. Then a MATLAB/Simscape simulation model is developed by connecting 36 solar cells blocks in series to form 40W panel. The MATLAB/Simscape model is simulated for 2 sec and its V-I & P-V characteristics are obtained for various climatic conditions. The dependency to insolation is shown in Figure 4 and temperature is in Figure 5.

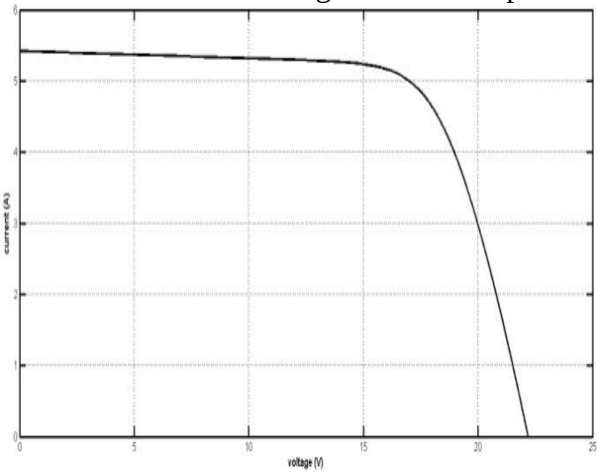

Figure 3. I-V Characteristics of a PV module for 1000W/m^2

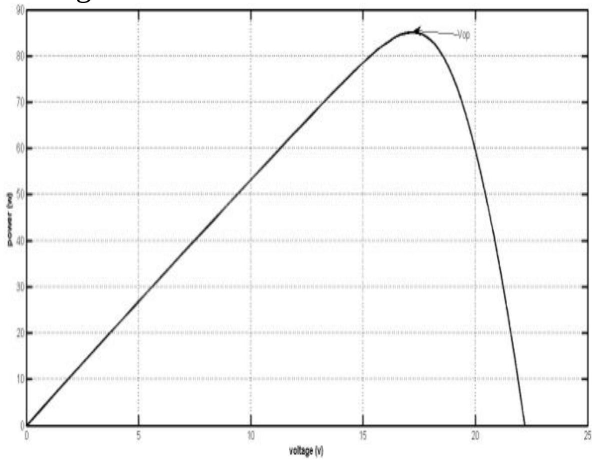

Figure 4.P-V Characteristics of a PV module for 1000W/m^2

Perturb and Observe (P&O) maximum power point tracking technique is used for available power extraction from solar panel. In this technique output voltage alone sensed for maximum power point calculation [8]. The power output of PV system is checked by chancing the voltage of the PV. When operating voltage is increased, power is also an increase further ΔD is increased otherwise ΔD is decreased. In same way, when voltage is decreased if power increases the ΔD is decreased. These steps are repeated until PV module approaches V_{op}. The flow chart is shown in Figure 5.

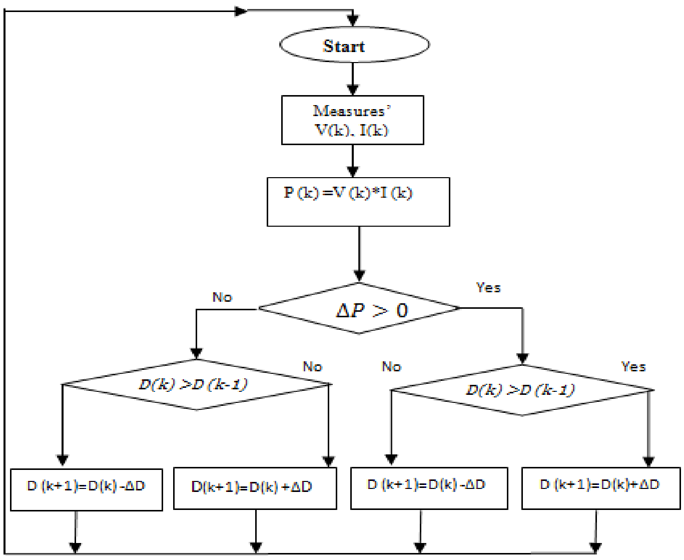

Figure. 5. Flow Chart of P and O method

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Modelling of DC-DC ZETA Converter

A zeta converter is a fourth order nonlinear system being that, with regard to energy input, it can be seen as buck-boost-buck converter and with regard to the output, it can be seen as boost-buck-boost converter [9]. ZETA converter because of using inductor in series and capacitor in parallel at its output side, this converter gives a smooth and ripple free output voltage. A simple block diagram of a ZETA converter arrangement is shown in Figure 6.

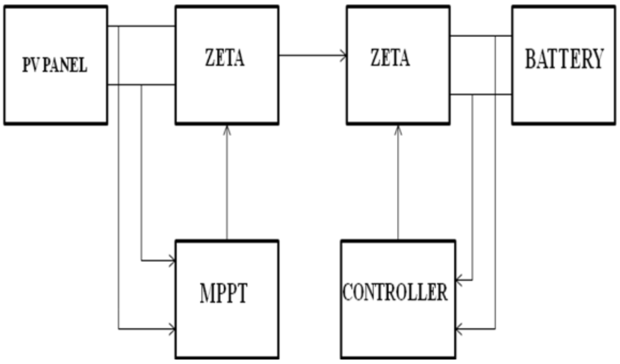

Figure. 6. Block diagram of converter arrangement

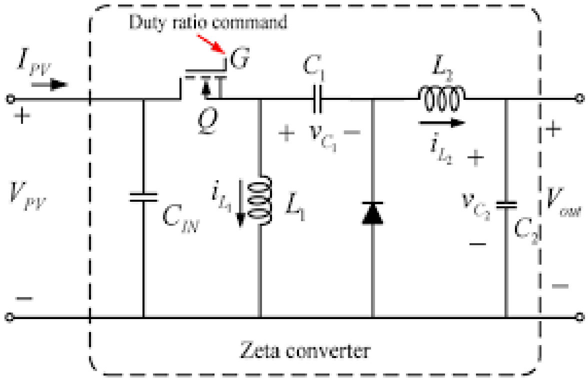

Figure .7. Circuit diagram of ZETA converter

Individual ZETA converter consists of two coupled inductors L_1 and L_2, output capacitor C_2, one AC coupling capacitor C_{in}, input capacitor C_1, also a MOSFET switch S_1 and a power diode D_1. The circuit diagram of converter is shown in Figure 7. When both switches (S_1 & D_1) are open and not switching, Capacitor C_1 will become in parallel with C_2, so C_1 is charged up to voltage magnitude that is equal to the output voltage, V_o [10]. It is the sum of input and output voltages. Because of this the voltage along L_1will be $-V_o$ with respect to the drain of MOSFET. When the switch S_1 is close, capacitor C_1, will charged equal to the magnitude of output voltage, coupling capacitor is now connected in series with L_2. Because of this voltage along L_1 is equal to V_{in}, so at this time the voltage across diode will be sum of input and output voltage [11]. Maximum and minimum duty cycle (D) for the operation of ZETA converter is calculated as per Equation (2) and Equation (3).

$$D_{min} = \frac{V_o}{V_o+V_{inmax}} \tag{2}$$

$$D_{max} = \frac{V_o}{V_o+V_{inmin}} \tag{3}$$

V_o is output voltage while V_{in} is input voltages of the converter. The inductor values are calculated as per the Equation (4),

$$L_1 = L_2 = 0.5\,\frac{V_{inmin}\,D_{max}}{\Delta I_{Lpp} f_{sw}} \tag{4}$$

ΔI_{Lpp} is inductors peak to peak ripple current. The output capacitor value is calculated as per the Equation (5),

$$C_2 \geq \frac{\Delta I_{Lpp}}{8\Delta V_{copp} f_{sw}} \tag{5}$$

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While $\Delta V_{copp}$is output peak to peak ripple voltage that is along output capacitor. is peak to peak ripple current of L_2. Input capacitor is calculated from following Equation. (6),

$$C_i = \frac{I_o D_{max}}{\Delta V_{c1pp} f_{sw}} \quad (6)$$

Where I_o is output current, $Vc_1n(pp)$ is input ripple voltage along input capacitor. The value of flying capacitor is determined by the following Equation (7).

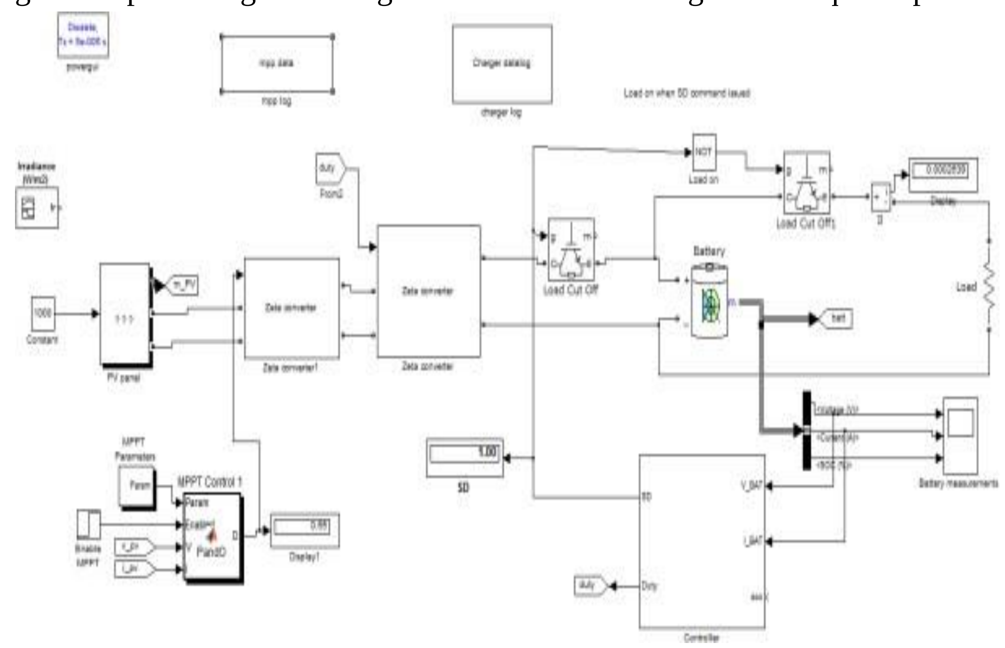
$$C_{in} = \frac{D_{max}\, I_o}{\Delta V_{cpp}\, f_{sw}} \quad (7)$$

Table 2 ZETA converter components specifications

PARAMETERS	VALUES
D_{max}	0.68
D_{min}	0.59
L_1=L2	0.0013H
V_o	26.5
C_C	10µF
C_1	100 µF

Simulation of the proposed system

In simulation of the circuit an extra switch used to isolate converter from load, battery or source which disturbs the power of line. Figure. 8a and 8b show the simulation diagram of ZETA converter-based PV system street lighting. Two ZETA converters are used. One is before the battery and second is after the battery. Left sided converter charge the battery by boosting or reducing the output voltage while right sided converter will give the required power to the load.



igure. 8a. Simulation diagram of ZETA converter based solar PV system

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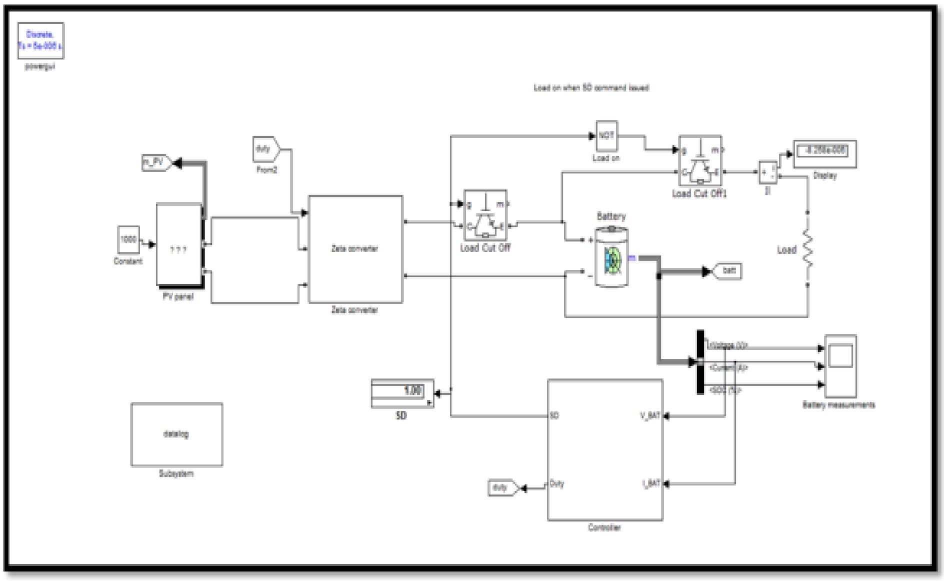

Figure. 8b. Simulation diagram of ZETA converter based solar PV system charge controller

. AND gates (U_1 and U_2) shows that when two control inputs (MOSFET switching pulse+ Source/load cut off signal) are high, switches S_1 or S_2 will pass power. The compliment of source or load on/off pulse will switch on/off the alternative load switch. In this proposed system ZETA converter based charge controller will be used so the circuit will be designed for Load voltage of 24 volts. The solar panel generally has output of 18 volts to charge the 12 volts battery.

Table 3 Simulation output observation

Parameters	Values
Nominal Voltage	24V
Rated capacity	10Ah
Initial SOC	90
Maximum capacity	10Ah
Fully charged voltage	28V

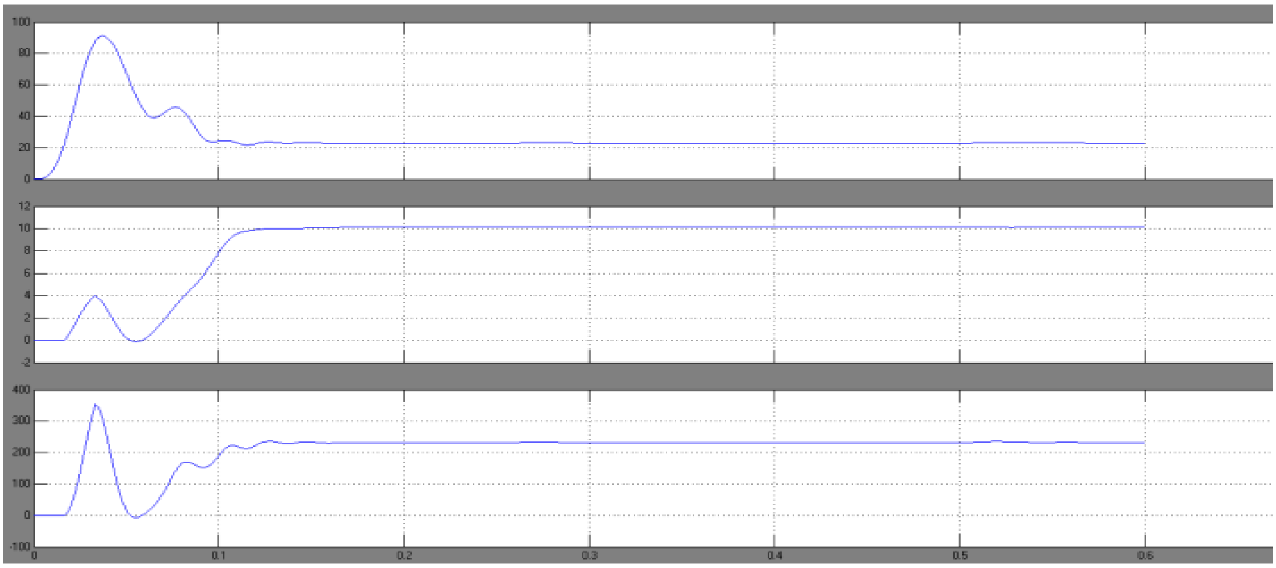

Figure 9(a). Simulation output of Vo ,Io and ,SOC

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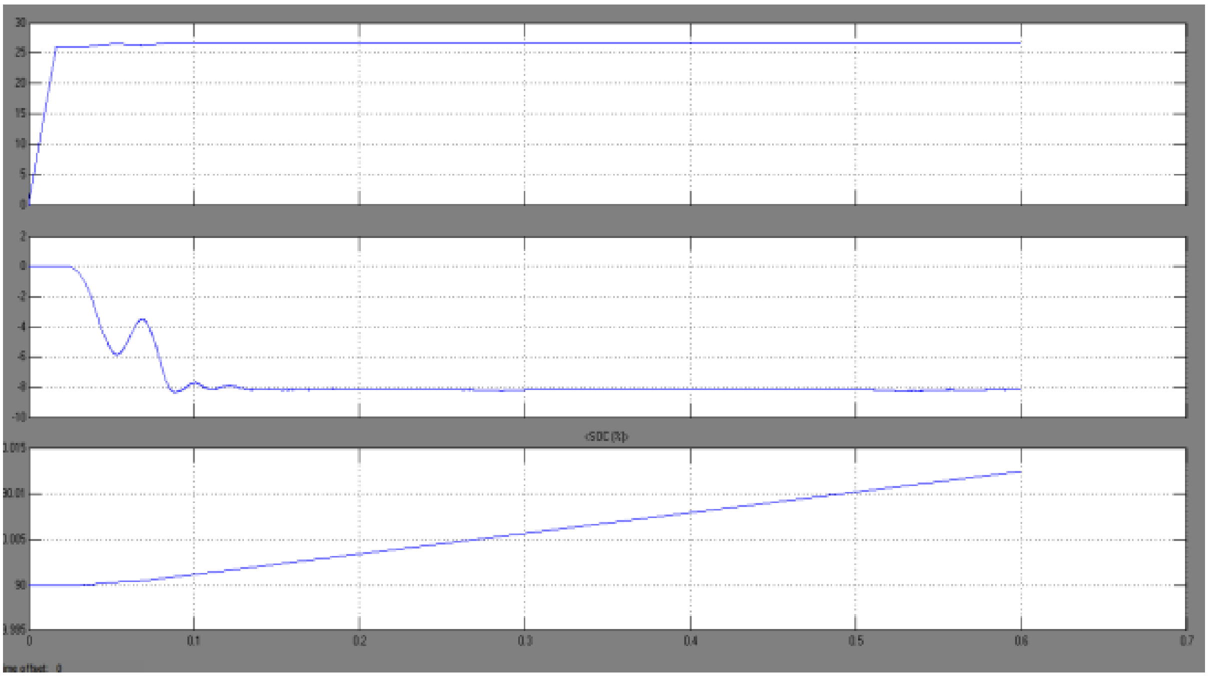

Figure 9(b). Simulation output of Vo, Io and, SoC

ZETA converter has less loss of power in boosting the voltage than reducing it at its output side So, according to our requirement we will use ZETA converter to boost 18 volts output of solar panel to 28 to 30 volts to charge 24 volt battery. This output voltage directly to power up street lights without transforming its amplitude with the help of converter [12-15]. So, power loss will be reduced. A Lithium-ion battery is used for energy storage [16-17]. Figure 9 shows the simulation results of the proposed system. Table 3 represents the simulation output observations. Figure 9a ,9b and 9cb show the simulation results of the proposed system.

Hardware Implementation and Result Discussions

The hardware setup of proposed system is shown in Figure 10. One ZETA converter is before the battery and second ZETA converter is after the battery.

Figure 10. Hardware Setup

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One ZETA converter charges the battery by boosting or reducing the output voltage while another ZETA converter will give the required power to the load. AND gates (U_1 and U_2) shows that when two control inputs (MOSFET switching pulse+ Source/load cut off signal) are high, switches S_1 or S_2 will pass power. Output of the Arduino is 5V this 5V is converted to the 12V by using opto coupler then it is given to the gate terminal of the MOSFET. PWM pulses of the first ZETA converter taken from the 10th pin of the Arduino and the pulses for the second ZETA converter taken from the 9th pin of the Arduino. The circuit is designed for Load voltage of 13.5 volts. ZETA converter has less loss of power in boosting the voltage than reducing it at its output side.

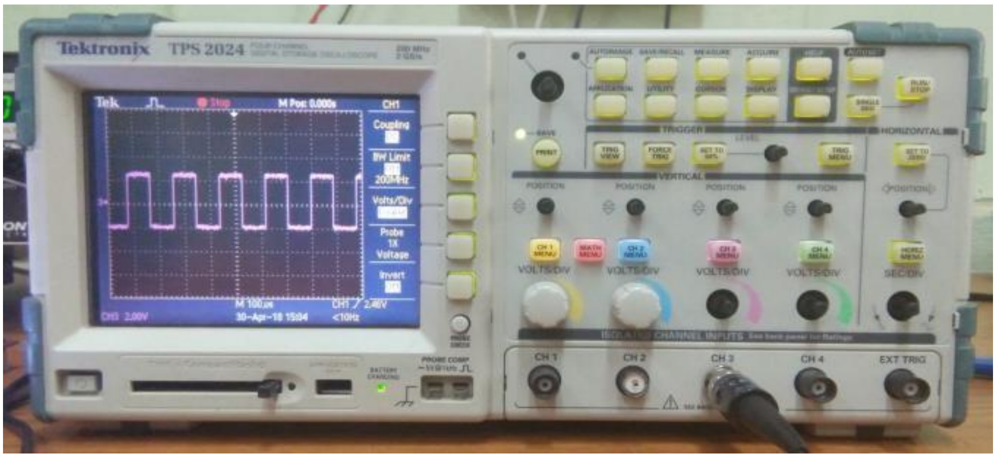

Figure 11. PWM signal of first ZETA converter

The input of the first ZETA converter is 7.43Volt here the first ZETA converter act as boost converter and the output is 16.5 volt. The output voltage is got through the following PWM signal.

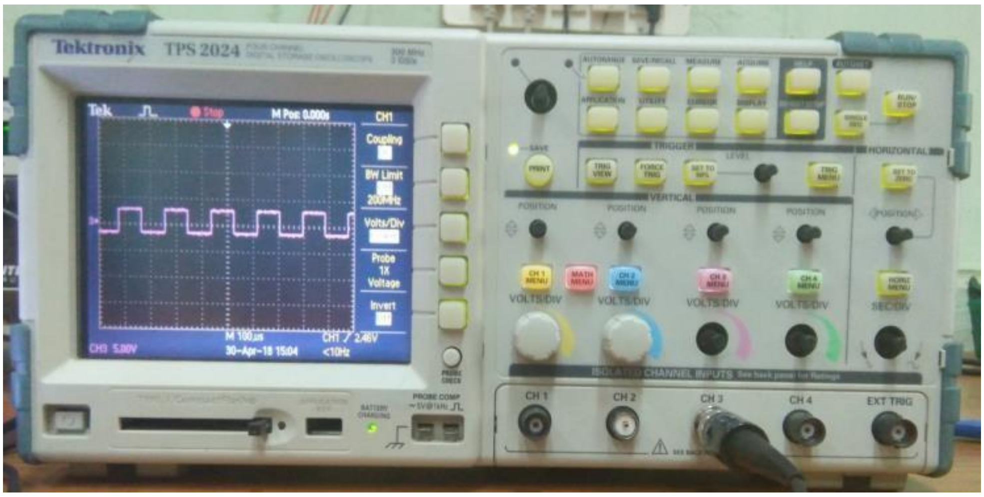

Figure 12. PWM signal of second ZETA converter

The input of the second ZETA converter is 16.5 volt here the second ZETA converter act as a buck converter and the output is 9.5 volt. This output voltage got through the following PWM signal shown in Figure 12. Table 4 represents the output voltage observations from hardware setup.

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Table 6. Hardware implementation observations

Converter	Input Voltage	Output Voltage	Boost/Buck
Zeta Converter-I	7.5	16.5	Boost
Zeta Converter- II	16.5	9.5	Buck

Conclusion

In solar powered street lighting application, an appropriate charge controller plays a vital role for battery management system. Through this proposed system a converter charge controller is designed and implemented in solar application to charge the battery between upper and lower voltage limits in addition to the continuous checking of the status of charge level of battery. Hence a rise or fall in the charging current is achieved as per the requirement of the system. A ZETA converter based solar charge controller is designed. This controller protects the battery from overcharging and deep- discharging. Since, ZETA converter is made to act itself act as charge controller in addition to the maximum power point tracking, converter is used to optimize street lighting system to reduce the power losses and cost.

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