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Energy efficient solar LED lighting system with real time intensity control

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ABSTRACT

As years go by, the population increases, correspondingly increasing the energy demand. Given this scenario, it is essential to implement energy efficient technology to meet our energy requirements. Along this line of thought, came about the idea of solar powered LED street lighting system. It is evident from the title, the system is powered by a solar panel. LED lamps have very low energy consumption and high efficiency, thus are used as the lighting source. The output from the solar panel is fed to a charge controller which feeds a lead acid battery. The battery has a monitor circuit to show its current status of available charge. The voltage supplied by the battery needs to be reduced to a value suited to light up an LED array. For this purpose a buck converter is used. In order to complement the energy efficient nature of the system ,a dimmer circuit is introduced. This circuit is used to adjust the brightness of the LED array in accordance with the surrounding brightness in real time. This is achieved via PWM technique.PWM pulses are sent to the switch of the buck converter. Based on the width of the pulse received, the buck converter supplies a certain amount of output voltage to the LED array. Thus on varying the width of the pulse supplied , the voltage supplied to the LED array and in turn it's brightness can be controlled ,according to the existing brightness outside.

Key terms: LED street lighting, LED driver, Solar energy, Dimmer with intensity control

1. INTRODUCTION

With increasing energy demands, humanity is in search for a means to meet these demands in a manner that is sustainable, efficient, and environmental friendly. Lighting loads constitute about 25% of global energy demand. Of these, we would like to focus on the street lighting loads.

Conventional high pressure sodium vapourlamps (HPSV) are used for this purpose. LED lamps offer various advantages in comparison to these lamps as is clearly illustrated in the table below (Fig. 1).

Despite the greater cost of LED lamps, the advantage offered in other aspects easily compensates this.

Thus implementing LED lighting system will help reduce the energy demands by 230W for each HSPV lamp .Considering this over an area equivalent to that of Amrita Vishwa Vidyapeetham, Coimbatore, can produce energy savings of 69000 KWh daily (assuming 50 HPSV lamps working for 6 hours every day).

Table 1
Comparison of LED lamp with HPSV lamp

Parameters	LED lamp	250W HPSV lamp
Rating	19W	250W
CRI	93	76
Lifetime	20 years	5-6 years
Luminance	3000 mCd	3200 mCd

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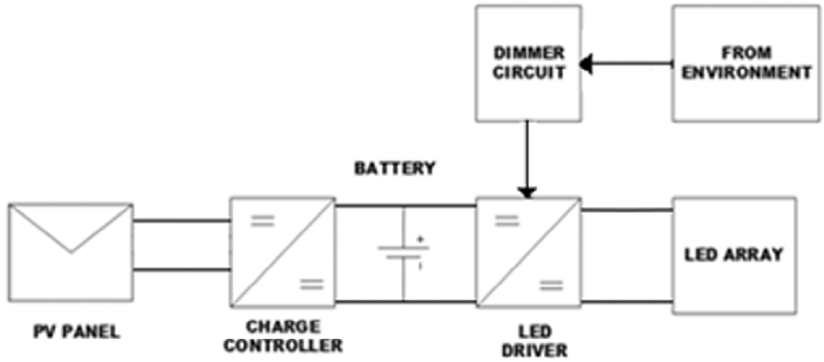

Figure 1: Block diagram of the system

LED lamps behave differently from HPSV lamps with respect to their non linear relationship between brightness and voltage. This means that for 50% reduction in input, the reduction in output (brightness) is less than 50%.Thus for reasonable brightness, only a small amount of voltage needs to be supplied. This variation in the input voltage to the LED array can be achieved through dimmer circuit, thus further optimizing the energy efficiency of the system.

As a result of this tremendous energy saving potential of LED lamps, our objective is to design and implement a lighting system using LEDs, which is powered by a PV panel. The proposed system consists of the following:

- Solar panel
- LED panel
- LED driver
- Dimmer circuit
- Battery
- Charge controller

2. LED ARRAY

For the lighting purpose a 4 × 3 LED array is used. Each LED requires 3.3V forward voltage, 250mA current with a power output of 3W, delivering 250 lumens output. So the net voltage required per string of

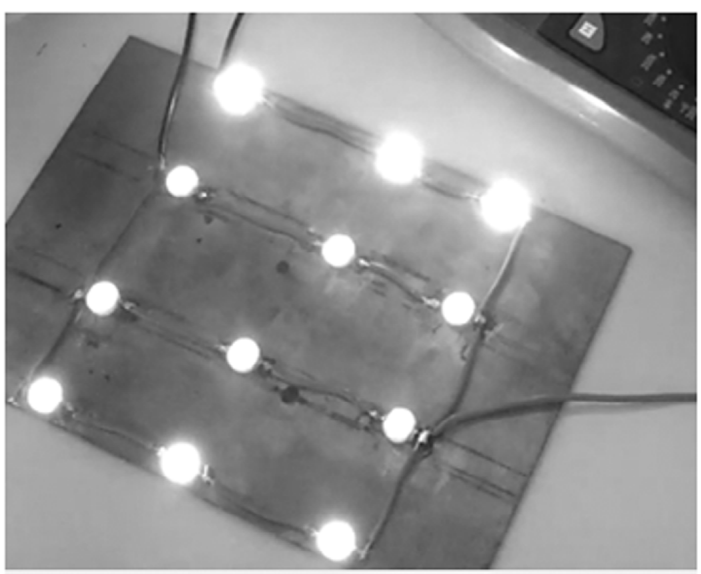

Figure 2: The fabricated LED array

Table 2
Variation of light intensity with distance from the Fabricated LED array

Voltage [V]	*Luminous Flux (At distance of 50cm) [lux]*	*Luminous Flux (At distance of 100cm) [lux]*
7.5	1	2
7.8	21	4
8.1	72	21
8.5	202	54
8.9	382	100
9.3	636	180
9.4	672	197
9.5	752	207
9.6	780	224
9.7	821	235
9.8	855	245

LED is 9.9V~10V, with a net current of 1A.The LED bulbs are stuck onto a printed copper board which acts as a heat sink to the entire array. The fabricated LED array is shown in Fig.2 below.

The supply for the LED array is taken from a 12V lead acid battery. However as the LED array requires only 10V to function, a buck converter circuit is used, to step down the voltage, from 12V to 10V. The brightness of the LED array is to be controlled by varying the voltage (correspondingly the current) through it .For this purpose a dimmer circuit is essential.

3. LED DRIVER

For our requirement we have implemented a buck

Converter to step down the input voltage from 12V to 10V which is required for the LED panel. In accordance to the above parameters, the capacitor and inductor values are found using the following formulae's:

- $$L = \frac{(Vin - Vop) * D * T}{\Delta i} \qquad (1)$$

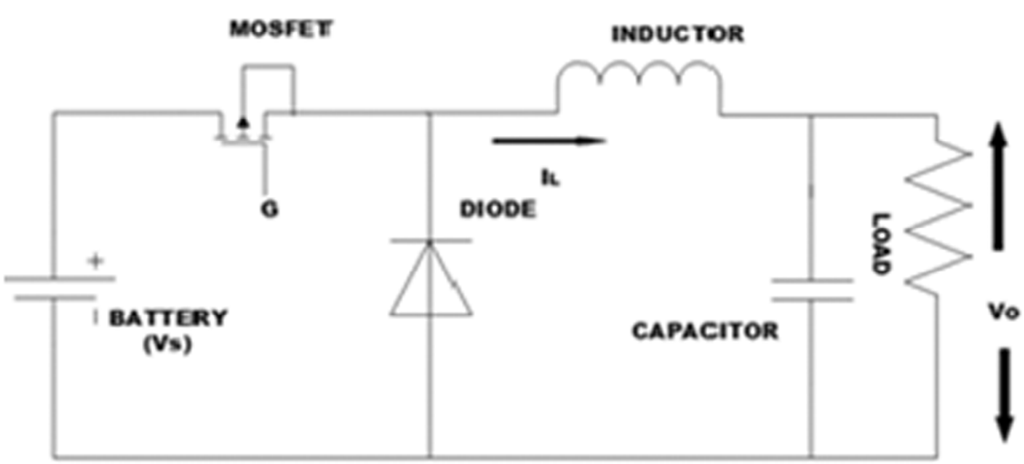

Figure 3: Buck converter circuit

- $$C = \frac{Vop(1-D)}{8 * L * C * f^2 * \Delta Vop} \quad (2)$$

Where,

L - Inductance value

C - Capacitance value

D - Duty ratio

T - Time period

ΔI - Allowable current ripple

ΔVop - Allowable output voltage ripple

Based on the above formulae the C and L are found to be L = 0.36mH

C = 0.47uf; which are the market available values closest to the designed values

MOSFET IRFZ34 is used as the switch in the implemented buck converter circuit. This MOSFET is capable of supporting the maximum VDS of 14V and IDof 1.1A. In the circuit the MOSFET switches between ON and OFF state at a frequency of 20KHz.Due to the high current flow through the circuit, a fast recovery diode 1N4741A had to be used. Further the inductor of the required value had to be fabricated. MATLAB/Simulink model of the implemented buck converter circuit.

4. DIMMER CIRCUIT

An LDR is used to implement the functionality of the proposed dimmer circuit. This is interfaced with an Arduino Uno, to provide pulses of varying duty ratio to the MOSFET switch of the buck converter. Thus as the duty cycle of the pulses change, the output voltage and current from the buck converter also changes. This correspondingly changes the brightness of the LED array. The system is designed to provide maximum

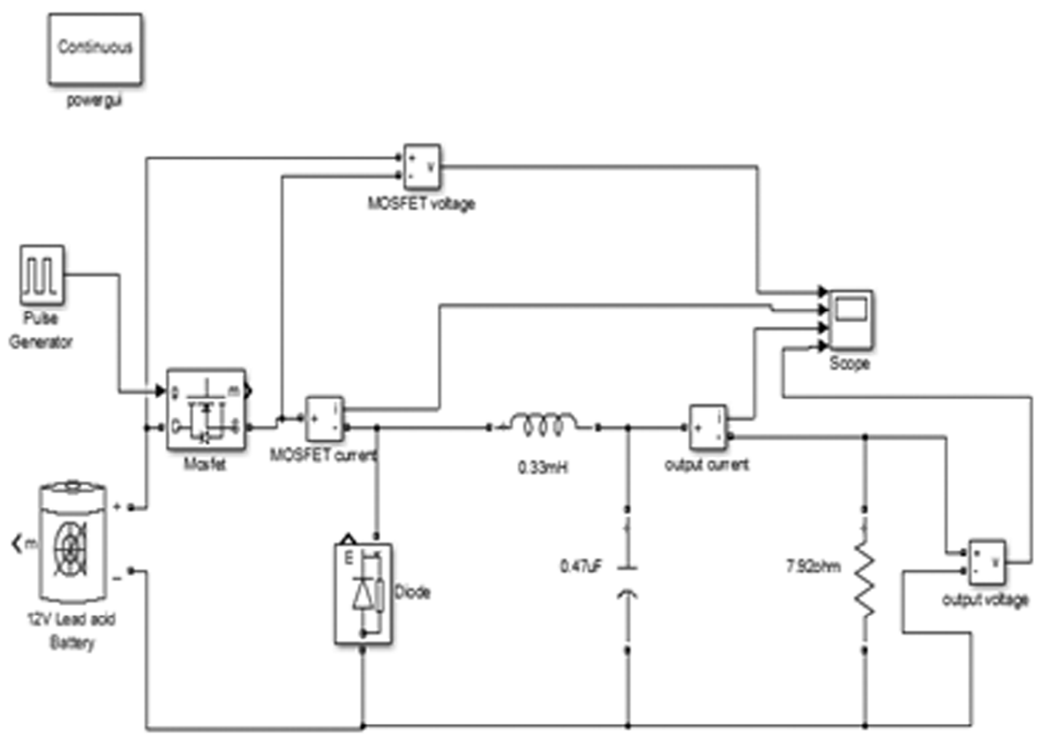

Figure 4: MATLAB/Simulink model of LED driver circuit

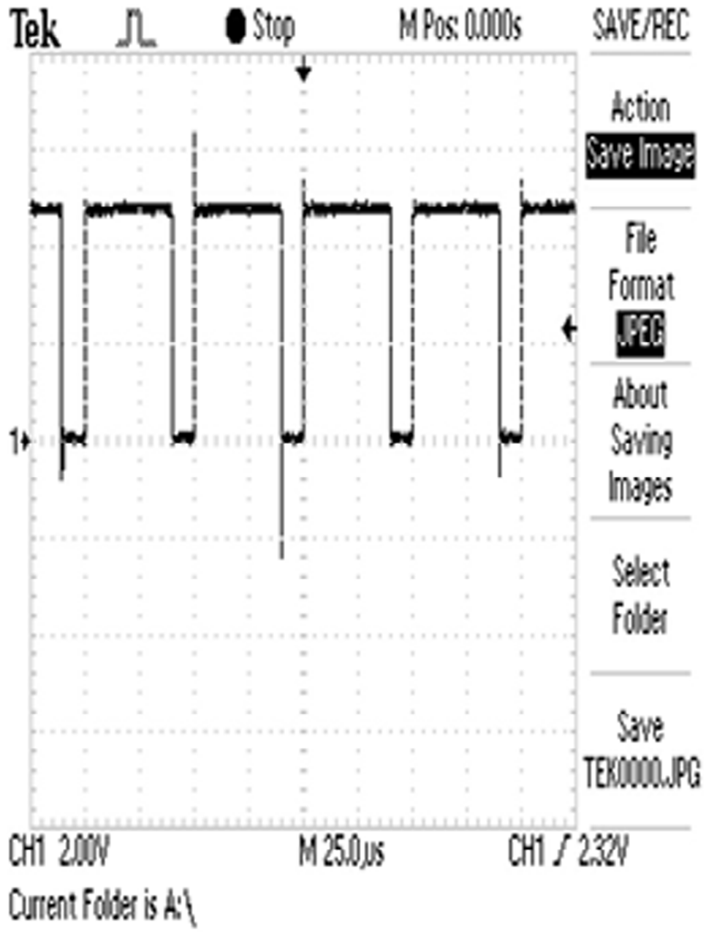

Figure 5: PWM pulses when LDR is covered

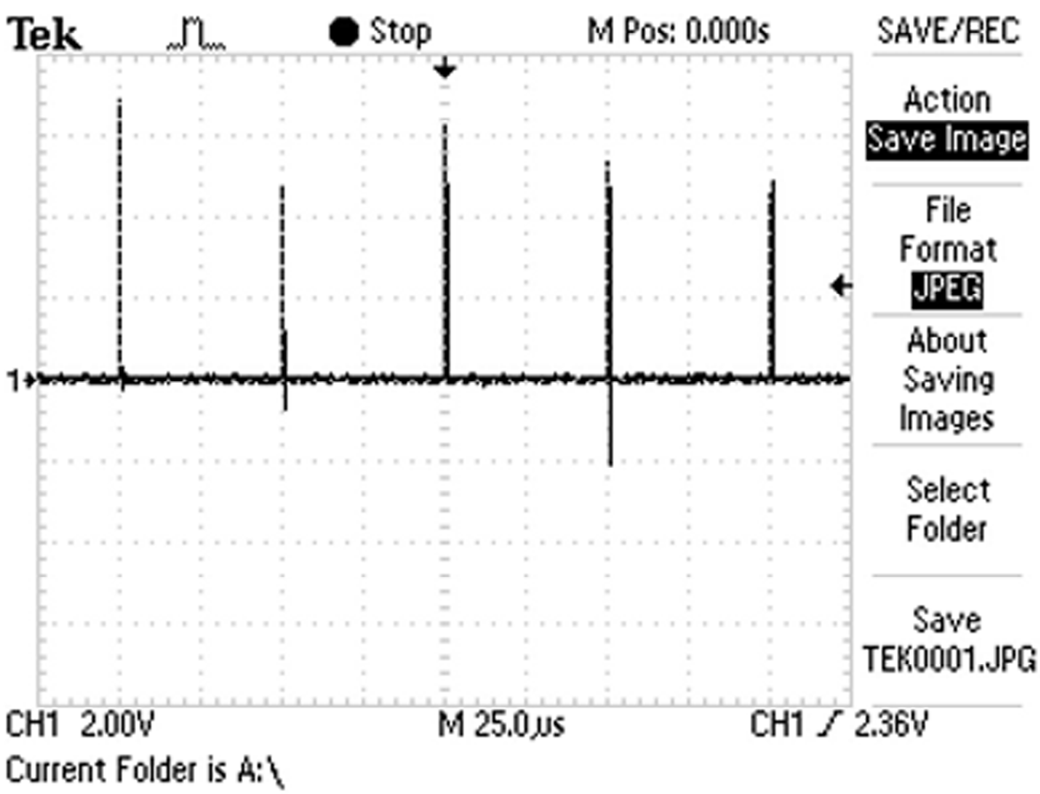

Figure 6: PWM pulses when LDR is exposed to light

duty cycle when LDR is exposed to a less intensity light situation (simulating lighting conditions during night time), and minimum duty cycle when LDR is exposed to a bright light situation (simulating lighting conditions during daytime).

Based on experimentation the following observations were made:

Table 3
Variation of PWM duty cycle for different lighting conditions over the LDR

Lighting condition Over LDR	*Room lighting*	*Fully closed*	*Fully lit*
Ton [us]	35.2	46.4	1
Total [us]	50	50	50
Duty cycle [%]	70.4	92.8	2

Fig. 7 shows the hardware implementation of the LED driver which is integrated with the dimmer circuit.

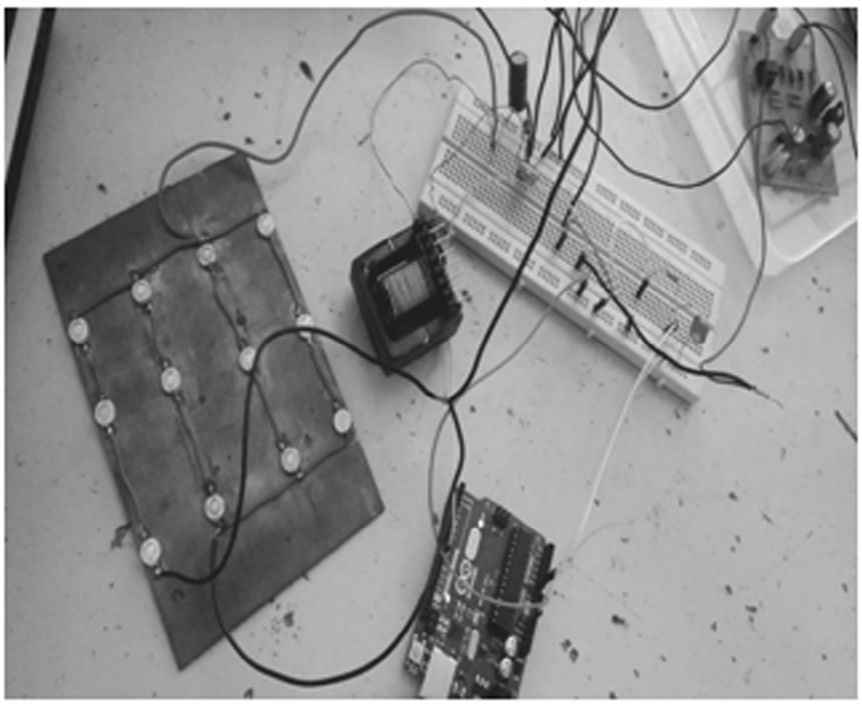

Figure 7: LED driver with dimmer circuit

5. BATTERY

For the proposed system, the battery power is stored in the morning and is used to light up the LED panel during evening or whenever the solar panel output is less. In the implemented system a sealed lead acid battery of 12V and 7.5Ah capacity is used as the storage device. This will supply power to the 10W LED panel, under the above mentioned conditions, with a peak voltage and current of 12.7 V and 0.7A.

6. CHARGE CONTROLLER

The output power from the solar panel keeps varying depending upon the irradiation of the sun. This variation can be unhealthy to the life of the battery. Thus a charge controller is used to regulate the voltage with which the battery is charged .This is done by using PWM pulses of frequency 61Hz. The variation of PWM duty cycle of the charge controller with the battery voltage is shown in table 4 below.

Table 4
Variation of duty cycle to corresponding battery voltage

Battery Voltage Range	Duty Cycle (%)
Below 11.5V *Or* Above PV panel voltage	0
11.5V - 12.7 V	95
12.7V – 13.5V	10
Above 13.5V	0

Arduino Uno microcontroller is used to generate the PWM pulses. These are supplied to two MOSFETs:

- IRF9530 via a transistor 2N3904.

  This MOSFET opens and closes the connection between the solar panel and the battery. Thus regulating the switching frequency of this MOSFET controls the voltage supplied to the battery from the solar panel.

- IRF540 via a transistor 2N2222

  This MOSFET controls the connection between the battery and LED panel (via LED driver).

The transistors function as MOSFET drivers which regulate the voltage of the PWM pulses sent to the MOSFET gate pin.

Thus by sensing the voltage from the battery, solar panel and by comparing these against fixed values, and with each other, the microcontroller will ensure optimum charge and discharge conditions for the battery.

Fig. 8 shows the hardware implementation of the proposed charge controller circuit.

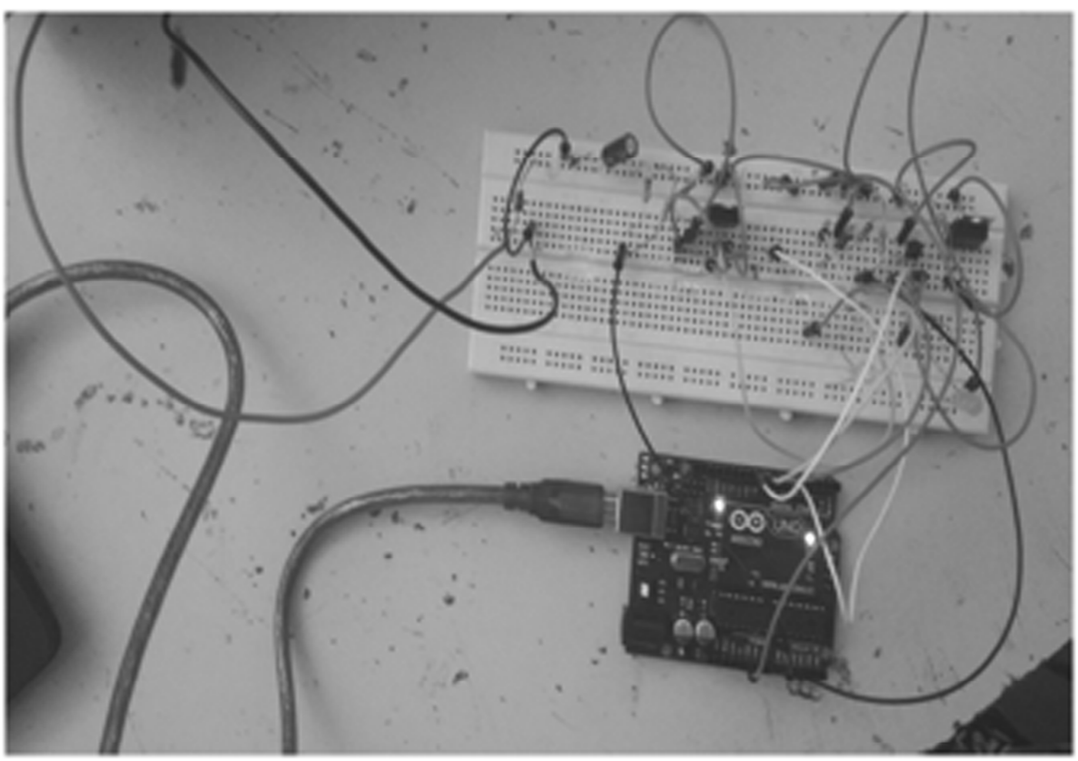

Figure 8: The charge controller circuit

The below figures shows the battery charging status when the solar panel voltage is less than or within limit.

7. SOLAR PANEL

In the proposed system, energy from the sunlight is converted to electricity using a solar panel. This provides the power to run the entire circuit .For the proposed system a 68W, 22V amorphous solar panel is used. It provides a peak voltage and current of 16.5V and 4.13A.Further the Voc and Isc are at 23.1V and 5.1A respectively. The I-V characteristic of the panel is as follows:

```
solar input voltage :7.29
battery voltage :11.94
pwm duty cycle is :0%
solar input voltage :7.29
battery voltage :11.94
pwm duty cycle is :0%
solar input voltage :6.47
battery voltage :11.94
pwm duty cycle is :0%
solar input voltage :4.08
battery voltage :11.65
pwm duty cycle is :0%
solar input voltage :4.04
battery voltage :11.66
pwm duty cycle is :0%
solar input voltage :4.11
battery voltage :11.65
pwm duty cycle is :0%
```

Figure 9: Panel voltage less than the set limit, battery not charging

```
solar input voltage :11.78
battery voltage :11.96
pwm duty cycle is :0%
solar input voltage :12.67
battery voltage :11.96
pwm duty cycle is :95%
20% charged

************
solar input voltage :12.96
battery voltage :12.18
pwm duty cycle is :95%
30% charged

************
solar input voltage :12.95
battery voltage :12.18
pwm duty cycle is :95%
30% charged
```

Figure 10: Panel voltage within the set limit, battery charging

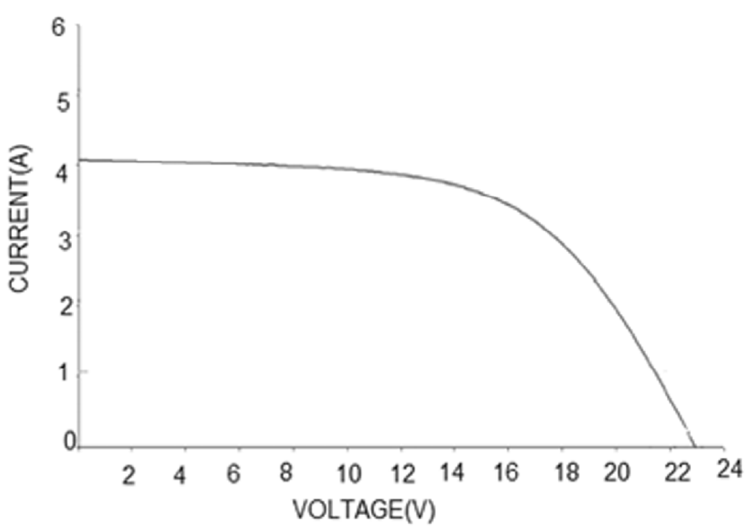

Figure 11: I-V characteristics of PV panel

8. CONCLUSION

This paper proposes an LED based lighting system. Through the use of LEDs, energy efficiency is achieved by the system. A 4X3, 10W LED panel is fabricated for this purpose. The input for the entire system is a 68W solar panel. Thus renewable energy utilized, not adding to environmental pollution. A lead acid battery is used to store the power from the solar panel for later use. A charge controller is used to ensure healthy charging and discharge condition for the battery, ensuring longer battery life. An LED driver is implemented to step down battery voltage to the range suitable for operation of the LED panel. A dimmer circuit is integrated with the LED driver to adjust LED panel brightness, in accordance to the brightness of its immediate surroundings. This further complements the energy efficiency of the system.

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