



## Design, Construction and Performance Evaluation of Solar Charge Controller for Street Lighting Application

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### ABSTRACT

Solar powered equipment and applications are gradually making their ways into various sector of our day to day life. We need a storage or battery to store the solar energy harnessed during day. A Solar Charge Controller (SCC) which is a part of a solar power system has been designed using Proteus Software, to maintain batteries used in solar power harvesting and utilization in a charged state, without risk of over-charging or over-discharging, ensuring battery durability. The charge controller has battery management system in built, responsible for executing the desired charging algorithm based on the battery chemistry characteristics. After the circuit design and construction, tests like Power Supply test, Accuracy test, charging test and discharging test were conducted. From the results of the tests, the power supply met its requirement to out-put a constant voltage of 5V for the microcontroller and LCD circuit. The charging test result shows the charging characteristics of the charge controller. The discharging test result is a negative linear graph showing that the battery is discharging from 14.4 V to about 9.5 V where the microcontroller disconnected the battery from the load. The results showed that the charge controller was able to control and regulate the charging process well. Calculated Mean percentage error was 0.04.

**Keywords:** Design, Construction, Solar, Charge Controller, Evaluation, Performance.

### 1.0 INTRODUCTION

Electricity generation of the world has gone up with renewable energy technologies such as solar, heat energy, ocean waves and even wind energy (Makkiabadi, 2021). Solar energy has the ability to be used to provide power for our day-to-day activities in our lives. And according to sources, the rate of sunlight that reaches the surface of the earth in about two hours can take care of the entire world's energy demand for a complete year (Gangara and Danshehu, 2021). As the world's energy demand rise and resources become scarce, the search for alternative energy resource has become an important issue of our time. In the cause of PV production there is need for a battery to save the solar energy drawn during the sunshine hours (Sunardi *et al.*, 2020). When we charge a lead acid battery, its voltage will go up (Makkiabadi *et al.*, 2021). When the charge is first initiated, the internal resistance of the battery will try to stop the current, and the voltage will at once increase above the open circuit voltage. at the tail end, the voltage will increase sharply while the battery starts to "gas". And gassing can be defined as the separation of liquid water into hydrogen and oxygen gasses. It is also referred to as electrolysis (Amadi and

Gutiérrez, 2019). If we allow gassing to happen for a long time, the battery will become overcharged, causing battery plates to corrode quickly- and so becoming destroyed, and electrolyte will be lost. Therefore, overcharging should be prevented. A charge controller is therefore required to monitor the charge in and out of the battery based on a set of voltage thresholds (termed set point), regulates current flow in order to limit overcharge and discharge. Some batteries once drained beyond a level, cannot recover its charging capacity. For this reason, a level is maintained beyond which the battery should not be further drained. The duty of a controller in PV system is to implement an algorithm needed to give the battery charge without the risk of overcharging or over draining thereby safeguarding its life (Sofijan *et al.*, 2020)

The ways for the regulation of charge of battery for a stand-alone PV systems was examined by Samuel *et al.*, (2022) and he concluded that to design a PV system the battery data is very essential. Ndubuizu *et al.*, (2022) concentrated on the design of a super-fast battery charger anchored on neural fuzzy technology. And after comparison with conventional fast chargers, they found out that their

design caused reduction in the charging time. Varun *et al.*, (2021) said a fuzzy-controlled active state of-charge controller (FC-ASCC) can better the charging behavior of a lithium-ion (Li-ion) battery. The methodology to use is to design a fuzzy-controlled algorithm with the predicted charging characteristics and use it to program the charging trajectory faster and to remain the charge operation in a proposed safe-charge area (SCA). They make the charging speed to increase to about 23%.

Usman, (2020) constructed an intelligent charge controller, with the use of an SGS-Thompson microcontroller. And he explained the favorable use of such kind controllers of charging. The advantages he stated are they cause battery heating to reduce, they adjust temperature effects from the sun automatically and they also have the technology to control aging of battery.

Siphon and Tilahun, (2020) designed and constructed a solar charge controller with PIC16F877 microcontroller to control the activities of the charger. The problem with the charger is that it used a Peripheral Interface Controller (PIC) not Advance Virtual Risc (AVR) type which is more efficient in terms of memory as it has Flash memory thereby eliminating the requirement of any other external memory. design and constructed intelligent charge controller for PV panel using conventional relay system which does not minimize operational current losses.

An unprecedented switch-mode charger controller IC was staged by Varun, (2021). The IC can improve the charging performance of valve regulated lead-acid (VRLA) battery hence saving the life span. They also can be used to get fast immediate response of both constant current and constant voltage charge modes which is needed for this study.

Elementary regulators have a transistor that disconnects or reconnects the solar module to the charging circuit once a preset voltage is reached. However, advanced controllers use pulse width modulation to make the battery reach full charge.

Charge controllers available in the market are generally designed and constructed off the shores

of this country, hence expensive. The essence of the study is to design and construct a 3 staged PWM charge regulator of good quality applying locally available materials.

## 2.0 METHODOLOGY

The charge controller is designed to provide charging current to a connected battery. A buck-converter is used in the design to reduce the panel voltage to that matching the battery's expected terminal voltage of 14.4 V. The current to the battery is monitored using a series resistance inserted in the battery's ground return. The condition of charge of the battery is directly determined by the system software which drives a three state closed loop feedback around the battery and buck regulator employed in the charging process. Modulation of the on-resistance of the MOSFET by the control loop enables variable charging current to be delivered to battery. Determination of end of charge was effected by monitoring the continuously-reducing charging current. When this current falls below 1% of the A-H capacity of the battery, the battery is deemed charged, and the system transitions from the constant-current charge stage to the constant-voltage charge stage where it is floated at a voltage level just below 14.4V.

### 2.1 Charge Regulator Circuit Design

The charge regulator in this design is to limit the rate at which electric current is added to or drawn from batteries. This is to prevent overcharging which can damage the battery or reduce its performance. And by so doing, may become risky and dangerous. The circuit stops the draining completely ("deep discharging") of a battery, or performs controlled discharges, counting on the battery design, to save battery life span.

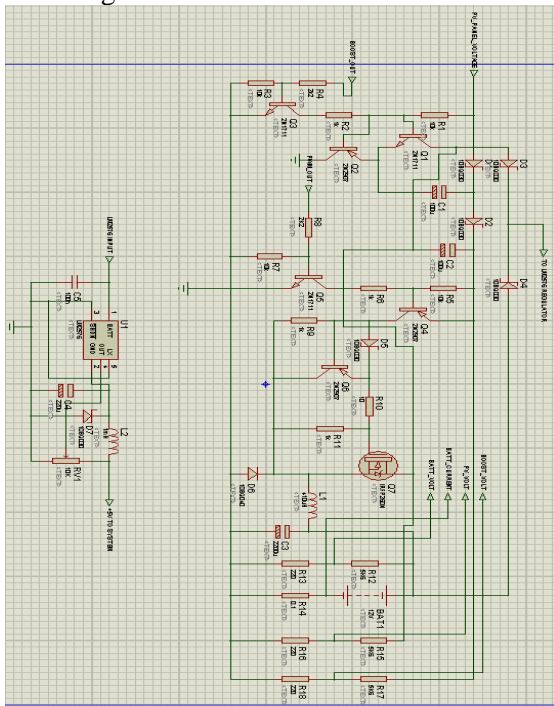
Solar Charge controller verifies the battery to see whether it needs charging and if so, it verifies if solar power is present and begins to charge the battery. As the controller is aware that the battery has reached the optimum level of charging voltage, it will stop the charging from solar panel. however, when it realizes that no solar energy is available then it takes on the night mode and switches on the load circuit. the load will be on until the battery voltage drops to its minimum level of voltage to protect the battery from deep-discharge. At the

same time, the LCD of the charge controller tells the condition of the battery. Present conditions like the discharge level of the battery, charging state-whether on or off etc.

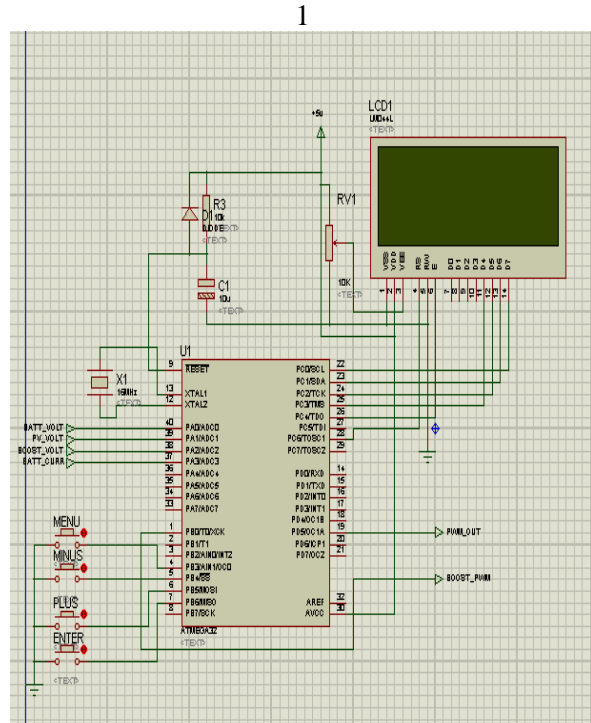
This project presents the designing of a PWM charge controller using a microcontroller which is a miniature computer containing a processor core, memory, and programmable input/output peripherals.

The work of this microcontroller in the design are:

- i. To measure solar panel voltage
- ii. To measure battery voltage
- iii. To measure battery current
- iv. To start battery charging when the need arises.
- v. To stop battery charging when the need arises.
- vi. To switch on the load when it is night time.
- vii. To switch off the load when it is day break.
- viii. To generate pulse train for DC-DC charge pump controller required for switching the high-side MOSFET.



**Figure 1: The Snap Short of the Circuit Diagram of the Charge Controller**



**Figure 2: The Snap Short Continuation of the Circuit Diagram of the Charge Controller**

## 2.2 System Power Supply Circuit Design

A stable dc voltage is required to power the microcontroller and the LCD circuits. The microcontroller requires 5V and current of 30mA (ATMEGA32A Data book, 2020) while the LCD voltage and current requirements are 5V and 10 mA (LCD databook, 2022). For this reason, a regulated 5 volts required was derived from the PV module. A 5V LM2576 voltage regulator was used for this design. With its current handling of 3A, it is envisaged that the voltage and current demand of the circuit is met.

LM2576 series are in monolithic integrated circuits form which can be used to work as step-down switching regulator, having the ability to drive 3A load without stress. These devices can be found in adjustable output format and in fixed output format having voltages of 3.3V, 5V, 12V and 15V. they have the advantage of needing few external components and are easy to use regulators. They are advancement over the three terminal regulators we have. In some versions heat sink is not needed and are small in size. Another advantage is that the inductors used with them are ready found amongst different manufacturer. These characteristics make LM2576 to be widely used.

Its other characteristics are a guaranteed  $\pm 4\%$  tolerance on output voltage and  $\pm 10\%$  on the oscillator frequency. It has  $50 \mu\text{A}$  standby current. It is incorporated with thermal shutdown facility for full protection under faulty conditions. Its specifications as shown in its data book are listed as follows:

The application circuit as shown in Figure 1 was adopted from the data book and used for the design. The internal schematic is in Figure 2.

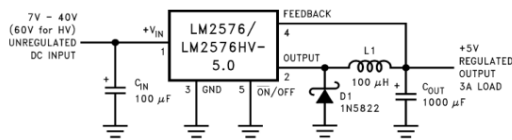


Figure 3: LM2576 Regulator

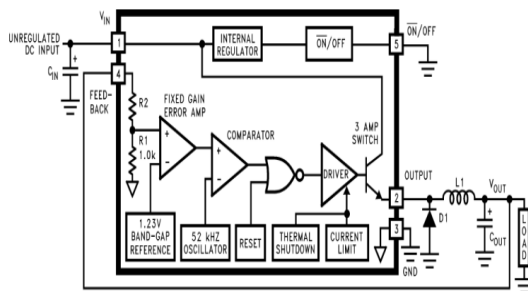


Figure 4: LM2576 Internal Schematic

The regulator was chosen based on its easy availability and efficiency

Its pin configuration is:

Given:

Given:  $V_{OUT} = 5\text{V}$        $V_{IN} (\text{Max}) = 40\text{V}$   
 $I_{LOAD} (\text{Max}) = 3\text{A}$

Starting from the left; the first pin is the input pin, the second pin is the output pin, the third pin is the ground, the fourth pin is the feedback pin and the fifth pin is the on/off pin.

### 2.3 System User Interface (LCD) Circuit Design

An alphanumeric liquid crystal display (LCD) was used as the human-machine interface (HMI) between the human user and the digital control system. The display size of 20 columns by 4 rows alphanumeric LCD module was selected, due to its compact size and ability to be connected in 4-bit mode to save microcontroller i/o ports availability. Data transferred between the microcontroller and

the LCD module using 4-bit interface mode only requires the upper four data lines (Ports); that is D4 to D7 are used and the data is transferred as two 4-bit nibbles.

A variable resistor is connected to the  $V_{EE}$  terminal of the LCD to control the voltage across its terminals, hence the contrast of the LCD backlight. This resistor allows a current range of  $0.09 - 0.15 \text{ mA}$  to be inputted to the  $V_{EE}$  terminal. Hence, the resistor value can be calculated using ohms law, which states that:

Operating on a supply voltage of 5 volts, and a minimum specified contrast current of  $0.09 \text{ mA}$  gave a resistance value of  $\left(\frac{5 \times 10^3}{0.09}\right) = 56 \text{ k}\Omega$

Hence a  $50 \text{ k}\Omega$  pot is to be used to provide the voltage dividing effect necessary for the LCD contrast port.

Below is the basic 4-bit interfacing connection for the LCD to the microcontroller.

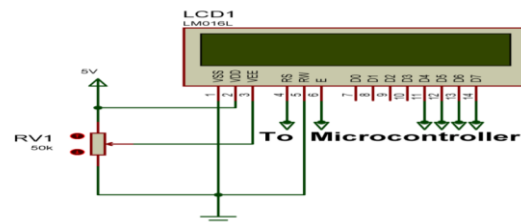


Figure 5: Liquid Crystal Display Circuit Diagram

### 2.4 Accuracy Test of the Charge Controller

The system has provision for measuring the charging current, battery voltage and the PV voltage. For these quantities an ammeter and two voltmeter displays was provided on the LCD. A simple test was design to test the accuracy of the three meters. This test is to ascertain the accuracy of the designed meters to ensure that data from the meters are accurate and reliable. To do the testing, two standard voltmeters were connected across the output of the solar panel and across the battery as shown in Figure 6.

An ammeter was also connected to take the readings of the charging current, the reading of the panel voltage, battery voltage and charging current as measured by the LCD system and standard meters was tabulated in Table 1.

### 2.5 Charging Test of the Charge Controller

The charging test of the charge controller was conducted to determine its charging characteristics. The set up for the experiment is as shown in Figure 7 with the charge controller input connected to the solar panel while its output is connected to a battery. The battery was initially almost fully discharged. As the battery charges the current and voltage through and across the battery was measured at every 30 minutes interval. This process continued until the voltage across the battery remained fairly constant an indication that the battery was fully charged. The setup is as shown in Figure 7.

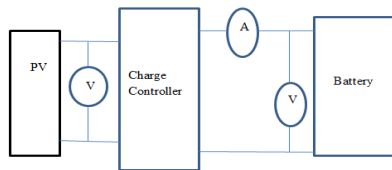


Figure 6: Set Up of Accuracy Test

Test

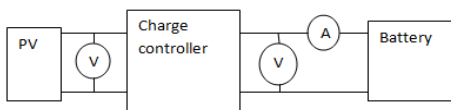


Figure 7: Set Up of the Battery Charging Test

### 2.6 The Discharging Test of the Charge Controller

For the discharging test, a standard meter was used to take the initial voltage reading of the battery. The battery was then connected to the load. A 30W LED lamp was used as load to discharge the battery. The discharging rate was monitored using standard meter to measure the voltage of the battery. The discharge voltage was recorded at 30 minutes interval. The setup is as shown in figure 8.

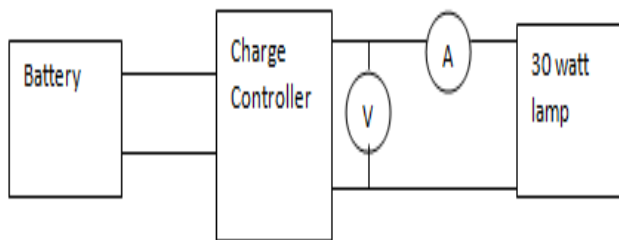


Figure 8: Set-up of Discharging Test

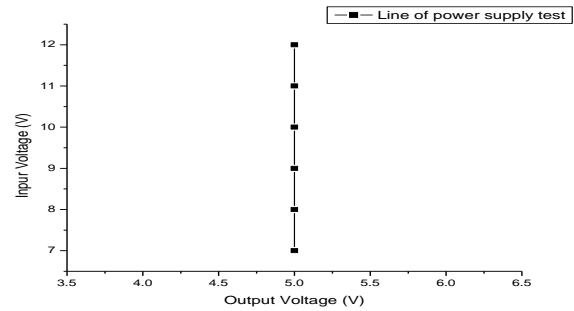


Figure 9: the Relations between input Voltage and Output Voltage of Power Supply

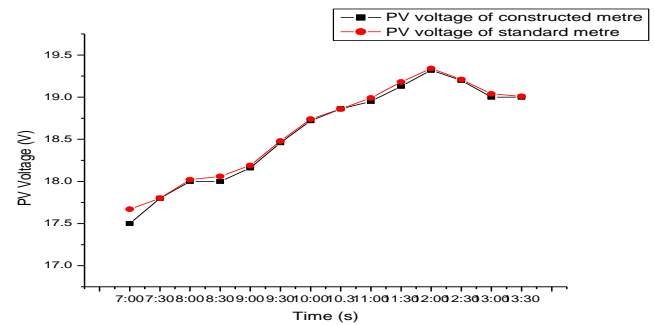


Figure 10: Accuracy Test

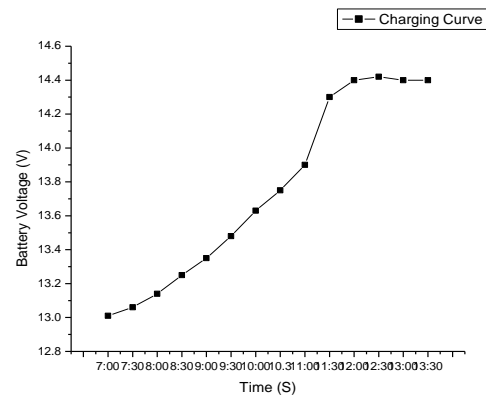
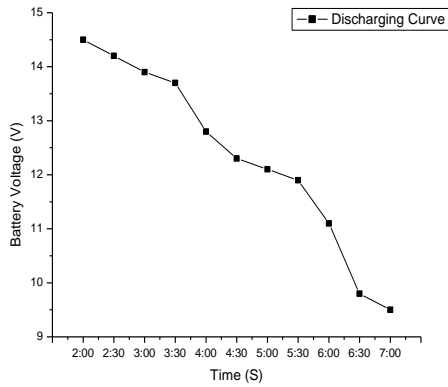


Figure 11: Charging Test



$$\text{Mean percentage error} = \frac{0.62}{14} = 0.04 = 4\%$$

Figure 12: Discharging Test

### 3.0 Result

Looking at the table below (Table 1) there is no much significant difference between the meters of the constructed solar charge controller and the standard meters that were at the laboratory.

Table 1: Result of Accuracy Test

LCD System Measurement				Standard Meter Measurement		
Time	PV voltage	Battery (v)	Charging current (A)	PV voltage	Battery (v)	Charging current (A)
7:00	17.66	12.9	0.02	17.67	13.01	0.02
7:30	17.80	13	0.17	17.80	13.06	0.17
8:00	17.01	13.1	0.34	17.02	13.14	0.33
8:30	18.05	13.2	0.47	18.06	13.25	0.48
9:00	18.18	13.3	0.69	18.19	13.35	0.69
9:30	18.47	13.41	1.56	18.48	13.48	1.56
10:00	18.73	13.6	2.24	18.74	13.63	2.23
10:30	18.86	14	2.35	18.86	13.75	2.34
11:00	18.98	14.2	2.40	18.99	13.90	2.39
11:30	19.17	14.3	2.48	19.18	14.30	2.48
12:00	19.33	14.46	2.59	19.34	14.46	2.59
12:30	19.20	14.41	2.06	19.21	14.42	2.05
13:00	19.15	14.40	1.95	19.16	14.40	1.95
13:30	19.00	13.81	1.70	19.01	13.80	1.70



**Plate 1: The final construction of the charge controller**

#### 4.0 DISCUSSION

After the design and construction of the power supply part of the circuit, it was put to test and from the graph of power supply test (Figure 9), it can be seen that it met its requirement to output constant voltage of 5V for the microcontroller and LCD circuit.

From Figure 10, the relationship between the PV of the constructed meter and the PV of the standard meter, it can be seen that there is strong correlation between them and there is percentage error of 4%. This means that the constructed meter is very much the same as the standard meter. No much difference between the two meters.

Figure 11, which is the Charging Test Graph, is initially linear in nature, meaning that the battery started charging continuously from about 13.0 V until 14.4 V. Then at about 14.42 V, the graph became constant, which means the battery has reached full charge capacity.

Figure 12, is a negative linear graph, showing that the battery is discharging from 14.4 V to about 9.5 V. At this 9.5 V, the microcontroller will disconnect the battery from the load.

It can be noticed that the voltage of the panel was 17.67V as the battery voltage was 13.01V. This is what is needed for current to flow from the solar

panel to the battery. after this, the LCD displayed parameters like 'charging', battery voltage when the LED light was off. This is in agreement with the design which states that the charging will take place only during the sunshine hours when the light needs not be ON.

At 12:00pm, 'battery full' was shown on the LCD and it remained steady at 14.6 V. this indicates 'tapered' current from the panel to the battery. So, saving the battery from the problem with battery over charge. The voltage from the panel kept the light off making sure no waste during the day.

When the light was on, the voltage of the battery decreased gradually from 14.6 V to 9.5 V. The LCD showed 'load on' during the discharging process. The moment the battery voltage approach 9.4 V, the load went off. The charge controller has protected the battery from deep discharge to avoid the risk of losing it.

#### 4.0 CONCLUSION

In this research work a PWM solar charge controller with low switching capability has been designed and constructed. The features include ability to constant current charge, constant voltage charge and float charge a 12 volt 45Ah battery. The system provides for automatic detection of battery end of charge point, a key requirement of any good charging system. This prevents overcharging and consequently improvement in a battery operational performance leading to a longer battery lifespan. Human machine interface (HMI) was also

incorporated to enable a visual observation of system's and battery's states. When tested the system was able to charge a 12V (45Ah) battery in 7hours. During the charging it was noted that system transitioned from the trickle charging phase to the constant current phase then to constant voltage phase with charging finally terminating at 14.4V. The charging process finally settled to a float phase of 13.81V.

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