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Design of 30 A PWM Type Solar Charge Controller Module for 100 Watt Lamp Load

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ABSTRACT

The electrical energy produced by solar panels has been used as a renewable energy solution to support human life. In reality, this alternative energy has not been widely used due to the constraints of expensive initial investment, so it is necessary to design solar power generation components, one of which is a reliable, optimal, efficient and economical solar charge controller. The controller is made using the switching method. The switching process can occur by setting the duty cycle through the embedded controller in the solar charge controller circuit. Based on the test results, a duty cycle value of 1% to 100% can occur the switching process. The duty cycle that has been set on the solar charge controller is 90%. The duty cycle is a duty cycle where the output voltage approaches the setpoint of the minimum charger voltage. The input voltage from the solar panel when connected to the battery of ±16 volts can be regulated to ±14 volts by the solar charge controller. Based on the battery charging specifications, the controller output can be used to charge a 12 volt battery.

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1. INTRODUCTION

Solar energy is energy in the form of heat and light emitted by the sun. Solar energy is one of the most important renewable energy sources to be developed and utilized in everyday life. The use of solar energy as an alternative energy source to overcome the energy crisis, especially oil, which has occurred since the 1970s has received considerable attention from many countries in the world. In addition to its unlimited amount, its use also does not cause pollution that can damage the environment. Light or sunlight can be converted into electricity using solar cell or photovoltaic technology [1].

Indonesia has abundant solar energy potential. However, the abundance of solar energy sources in Indonesia has not been optimally utilized. The potential of solar energy in Indonesia is very large, namely around 4.8 KWh/m2 or equivalent to 112,000 GWp, but only around 10 MWp has been utilized [2]. Currently, the government has issued a roadmap for the utilization of solar energy, targeting the installed capacity of PLTS until 2025 to be 0.87 GW or around 50 MWp/year. This number is a picture of the large market potential in the development of solar energy in the future [3].

Alternative electrical energy produced by solar panels has been used as a renewable energy solution to support human life. The construction of solar power plants requires very good planning so as not to cause excessive impacts on the environment. Building a solar power plant requires a fairly expensive initial investment. So it is necessary to design solar power plant components, one of which is a reliable, optimal, and economical solar charge controller, so that optimal PLTS construction planning is obtained [4].

One of the efforts that can be made to maximize solar cells is by using a controller. The controller that can be used to stabilize the energy produced by solar cells is called a solar charge controller (SCC). The solar charge controller is known as a DC regulator and controller [5]. Controlling the amount of power generated by the solar panels and storing it in battery backup systems is the goal of the solar charge controller system [6]. Typically, a solar panel generates 16 to 24 volts. However, a voltage between 12 and 14.6 volts is needed to charge the battery. The voltage is lowered via a charge controller [5].

A charge controller's primary function is to prevent overcharging of the battery [7]. The battery's lifespan is shortened by frequent overcharging. In this situation, the charge controller senses the battery's voltage and, if it rises, stops or lowers the charging current. The system is shielded from electrical overloading by change controllers, which also stop the batteries from over-discharging [5]. A solar charge controller system's operational block diagram is displayed in Figure 1. The charge controller maintains the battery's current from the solar photovoltaic array and delivers it as needed. The charge controller then transfers this current from the battery backup system to the DC load.

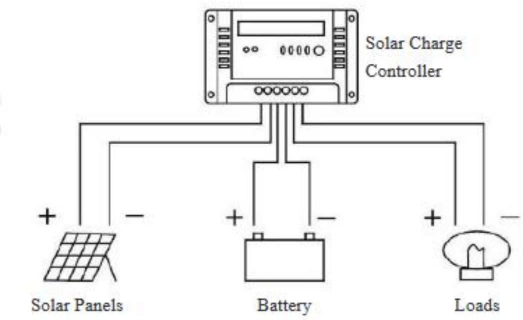

Figure 1. Solar Charge Controller Principle [5].

For regulator the input energy of solar panel, based on the principle of solar charge controller in figure 1, there are two types of switches are utilized namely: solid-state and relay-type switches [5].

In this research, it describes the implementation of switching mosfet with a capacity of 30 A to control the input obtained from the solar panel to match the battery specifications so that the charging process occurs. The advantages of the switching method used are reduction power loss, fast working and reliability so that this controller will work efficiently and optimally to be used on a 100 watt lamp load.

2. THE COMPREHENSIVE THEORETICAL BASICS

2.1. Basic Theory of Electricity

Electrical power is defined as the rate of change of electrical energy in an electrical circuit [8]. The SI unit of electrical power is the watt, which is the amount of electrical energy that flows per unit time (joule/second). An energy source such as electrical voltage will produce electrical power while the load connected to it will absorb the electrical power. The power generated by an electrical device is proportional to the amount of current flowing through it. Power is also proportional to the voltage that drives the current. The greater the power generated. So, if written in equation form, it can be seen in equation 1.

$$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = v \cdot i \tag{1}$$

2.2. Switching Mechanism of Charge controller

The switching mechanism of the solar charge controller based on [5], there are three mechanisms, namely on-off, PWM and MPPT.

2.2.1. On-Off Swtiching Mechanism

On-off switching mechanism in [9], there are two types, namely shunt controller (shunt interrupting) and series controller (series interrupting).

The shunt interrupting method can be seen conceptually in Figure 2. diverts array energy to a parallel (or shunt) path when the battery reaches the full charge VR setpoint. Charging is then resumed once battery voltage falls below the VRR setpoint. This approach is not recommended for larger systems, since power losses in the switching element are high and require a means of heat dissipation. When system voltages exceed 24 VDC, shunt controllers must be used with caution, since extended periods in short circuit may cause "hot spot" damage to PV cells when many are linked in series.

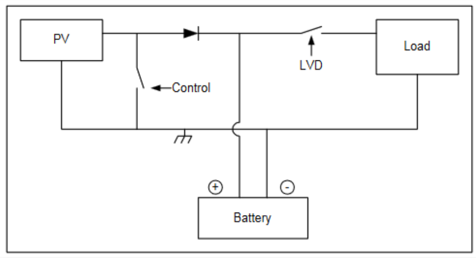

Figure 2. Shunt Control [9].

The series interrupting method can be seen conceptually in Figure 3. erminates charging at the VR setpoint with an in-series element which open-circuits the PV array. As with the shunt interrupting on/off controllers, charging is then resumed once battery voltage falls below the VRR setpoint. These controllers may, or may not, require a blocking diode depending on the switching element design.

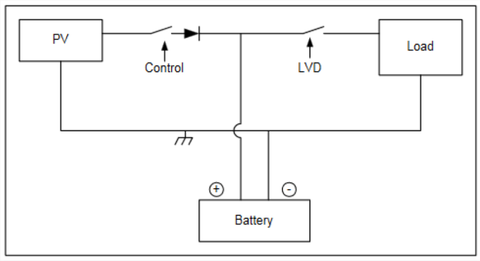

Figure 3. Series Control [9].

2.2.2. Pulse Width Modulation (PWM)

This method uses solid state switches to apply pulses of current at a reasonably high frequency (e.g., 300Hz), but with a varying duty cycle, such that the battery receives a constant voltage charge from the array. This type of controller, shown in a series configuration in Figure 4, can also be configured in the shunt topology. Although similar to the series linear and shunt linear controller in function, power dissipation is reduced with PWM topology compared to series linear control.

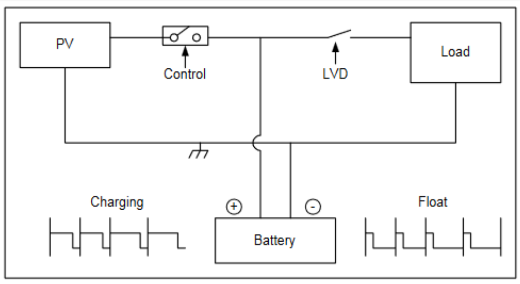

Figure 4. Pulse width modulation (PWM) [9].

2.2.3. Mosfet

MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is a type of transistor that has a very high input impedance (gate) (almost infinite) so that by using MOSFET as an electronic switch, it is possible to connect it to all types of logic gates. By making MOSFET as a switch, it can be used to control loads with high currents and at a lower cost than using bipolar transistors. In general, this component is divided into two, namely N-channel and P-channel [10], see figure 5.

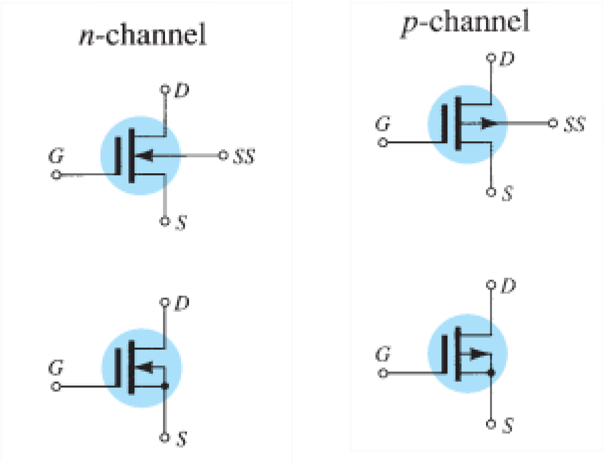

Figure 5. Graphic symbol for: (a) n-channel depletion-type MOSFETs and (b) p-channel depletion-type MOSFETs [10].

MOSFET has basic characteristics that make it perform better than bipolar transistors (BJT) and junction field effect transistors (JFET). An engineer must know and understand the characteristics of MOSFET before using it in building an electronic system. The characteristics of MOSFET can be seen in Figure 6.

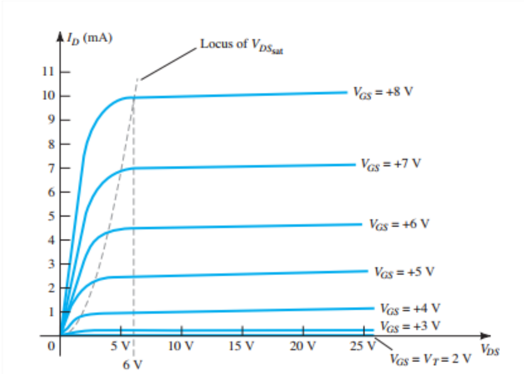

Figure 6. Drain characteristic of an n-channel enhancement-type MOSFET with $V_T = 2V$ and $k = 0.278 \times 10^{-3}\, A/_{V^2}$ [10].

An example of using the MOSFET as a switch, can see in figure 7. In this circuit arrangement an Enhancement-mode N-channel MOSFET is being used to switch a simple lamp "ON" and "OFF" (could also be an LED). The gate input voltage VGS is taken to an appropriate positive voltage level to turn the device and therefore the lamp either fully "ON", (VGS= +ve) or at a zero voltage level that turns the device fully "OFF", (VGS = 0).

If the resistive load of the lamp was to be replaced by an inductive load such as a coil, solenoid or relay a "flywheel diode" would be required in parallel with the load to protect the MOSFET from any self generated back-emf.

Above shows a very simple circuit for switching a resistive load such as a lamp or LED. But when using power MOSFETs to switch either inductive or capacitive loads some form of protection is required to prevent the MOSFET device from becoming damaged. Driving an inductive load has the opposite effect from driving a capacitive load. For example, a capacitor without an electrical charge is a short circuit, resulting in a high "inrush" of current and when we remove the voltage from an inductive load we have a large reverse voltage build up as the magnetic field collapses, resulting in an induced back-emf in the windings of the inductor.

For the power MOSFET to operate as an analogue switching device, it needs to be switched between its "Cut-off Region" where VGS = 0 and its "Saturation Region" were VGS(on) =+ve. The power dissipated in the MOSFET (PD) depends upon the current flowing through the channel ID at saturation and also the "ON-resistance" of the channel given as RDS(on).

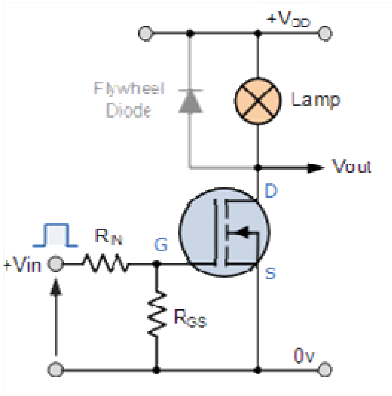

Figure 7. N Channel Mosfet Driver Circuit.

3. METHOD

3.1. Research Design

The research design in this thesis will be discussed related to the design of a solar charge controller for a 200 WP solar panel for a 100 watt lamp load. The design of the solar charge controller by describing the overall system design, hardware design.

3.1.1. Overall System Design

In figure 8, shows a functional block diagram design of the overall system, where there are two current sensors and a voltage sensor. current and voltage sensors on the input side, namely from the solar panel are used to read the current and voltage data flowing from the solar panel to the battery and load. while the current and voltage sensors on the output side of the mosfet driver (Buck converter) are used to carry out the charging process to the battery and load. electronic switches are used to control the electrical power from the solar panel and battery to the load.

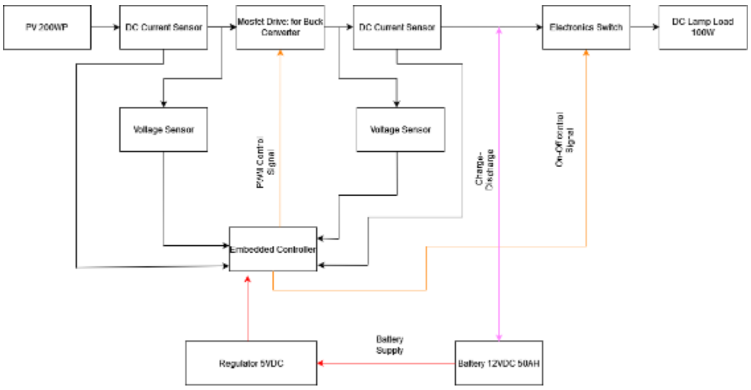

Figure 8. Functional block diagram of the system.

3.1.2. Battery Charging System Design Using Solar Panels

In the buck converter circuit scheme, because the topology used in this study is the PWM type, it uses a mosfet driver, where the voltage reduction process uses pwm which is connected to the gate leg on the IRF4905 mosfet. the algorithm used for the mosfet switching process is 3 stages of charge, where there are 3 stage, namely bulk, absorption and float, see figure 9.

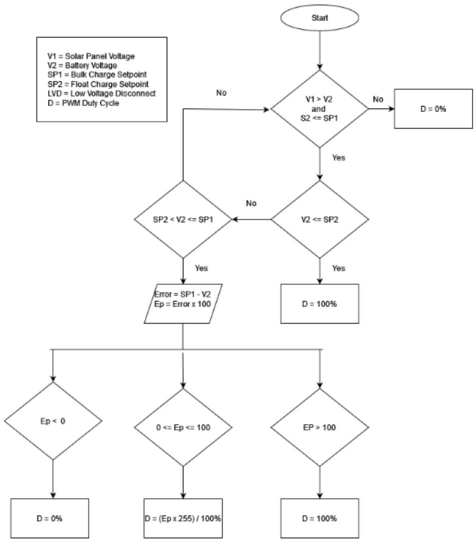

Figure 9. 3 Stage Charging Algorithm.

3.1.3. Schematic Design

An Arduino Nano board serves as the charge controller's central component. Two voltage divider circuits are used by the Arduino to sense the voltages of the solar panel and battery. It determines how to charge the battery and regulate the load based on these voltage levels.

In Figure 10, Two voltage divider circuits made up of resistors R1-R2 and R5-R6 are used to sense the voltages of the solar panel and battery. Filter capacitors C1 and C2 are used to remove undesired noise signals. Analog pins A0 and A1 on the Arduino are wired to the voltage dividers' output, respectively. Two ACS712 modules are used to sense the currents from the solar panel and the load. Arduino analog pins A3 and A2 are connected to the current sensors' outputs, respectively. Two p-MOSFETs, Q1 and Q2, essentially make up the control circuits. The battery receives the charging pulse from MOSFET Q1, and the load is driven by MOSFET Q2. Two transistors (T1 and T2) and pull-up resistors (R3 and R7) make up two MOSFET driver circuits. Resistors R4 and R8 regulate the transistors' base current.

The protecting circuit in figure 10, TVS diode D1 protects against input overvoltage from the solar panel side. A Schottky diode D2 protects the reverse current flowing from the battery to the solar panel. F1 is the fuse that protects against the overcurrent.

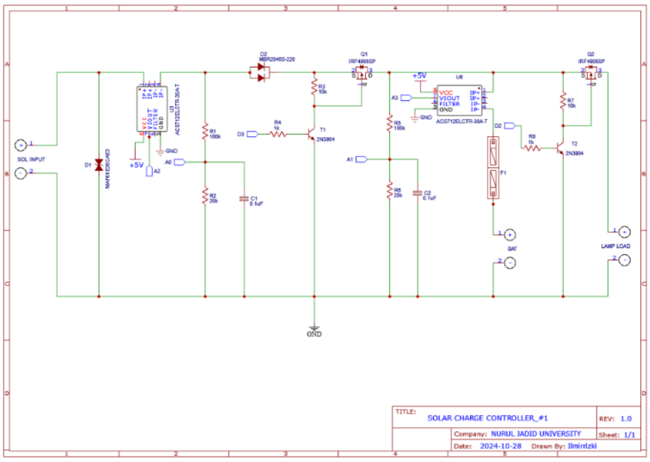

Figure 10. Schmatic Design of Solar Charge Controller for Lamp Load .

3.1.4. ACS712 30A Sensor Design

The design of the current sensor on the Solar Pump Controller, uses the ACS712 sensor with a maximum current of 30A, meaning that this sensor can be passed through a maximum of 30A. The calibration and calculation process of the ACS712 sensor, in order to be read more precisely, requires calculations based on the internal characteristic specifications in table 1.

Table 1. Internal Characteristics of ACS712 Sensor.

Characteristics	Description
ACS712 30A Sensitivity	: 66 mV/A
Ip = 0	: Output Voltage pin data 2.5 VDC (v_{cc}/2)
Internal Filter Resistance	: $R_{F(INT)}$ = 1.7 $k\Omega$
Supply Voltage (v_{cc})	: Between 4.5 - 5.5 VDC, use 5.0 VDC
Supply Current (I_{cc})	: at (v_{cc}) = 5.0 VDC, use10 – 13 mA
Output Capacitance Load	: C_{Load} which is connected to V_{Iout} = 10 nF
Output Resitive Load	: R_{Load} which is connected to V_{Iout} = 4.7 $K\Omega$

So that Arduino can read the actual input current that passes through the ACS712 sensor, we change equation (3) by finding the value of I, namely in equation (2).

$$I = \frac{((V_{Iout}) \times (resolution - 2.5\ V)}{Sensitivity}$$

$$I = \frac{((V_{Iout}) \times (resolution - 2.5\ V)}{0.066\ {}^{V}/_{A}} \quad (2)$$

3.1.5. Voltage Sensor Design

The design of the voltage sensor on the Solar charge Controller, uses a voltage divider with resistor values R1 = R5 = 100K and R2 = R6 = 20K. The resistor value will be used as a reference in the calibration process of the voltage sensor module, so that it can be read close to precision.

On the Arduino nano ADC, the pin resolution is 10 bits, so the data reading representation of the voltage changes read on the Arduino ADC pin has a data reading representation with a range of 0 - 1024 data. If we change the reading representation into volts, we need to calculate the voltage resolution first as in equation (3).

$$\text{resolution} = \text{Vcc}/1024$$

$$= 0.0048828\ \text{Volt} \quad (3)$$

By using the voltage divider principle, Vout can be calculated according to equation (4).

$$V_{out1} = \frac{R_2}{R_1 + R_2}\ atau\ V_{out1} = \frac{R_6}{R_5 + R_6} \quad (4)$$

To calculate Vout to be able to read the ADC data, we can calculate it using equation (5).

$$\text{Vout} = (\text{read\_adc}) \text{ x } (\text{resolution}) \quad (5)$$

By using the substitution of equation (4) into (5), the actual sensor reading Vin will be obtained based on equation (6).

$$V_{In1} = V_{out1}\frac{R_1 + R_2}{R_2}\ atau\ V_{In2} = V_{out2}\frac{R_5 + R_6}{R_6} \quad (6)$$

4. RESULTS AND DISCUSSION

In this study, the design of the solar charge controller on the mini PLTS plant was carried out, tool testing and data collection were carried out as follows.

4.1. PWM Signal Generator Circuit Testing

PWM is one of the methods used to drive the MOSFET used in the solar charge controller circuit. Testing is done by giving different duty cycle values. Then the results are viewed on an oscilloscope. Testing using an oscilloscope produces a pwm wave signal as in Figure 15 to Figure 18.

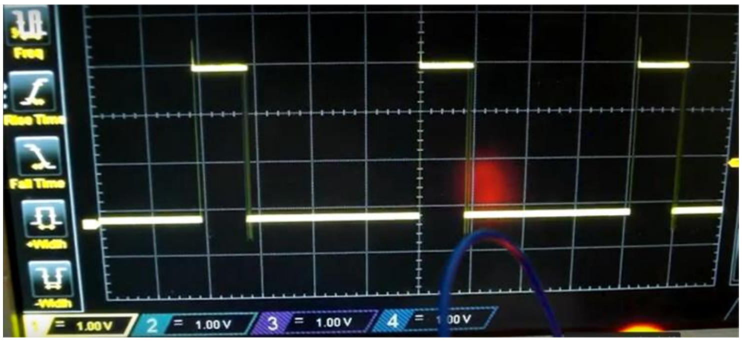

Figure 11. Results From Pwm Generator Signal With 25% Duty Cycle.

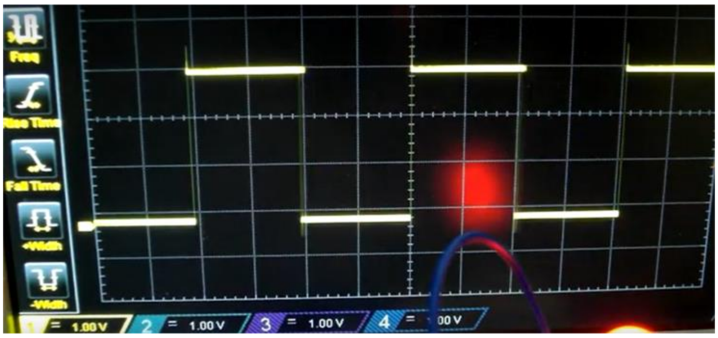

Figure 12. Results From Pwm Generator Signal With 50% Duty Cycle.

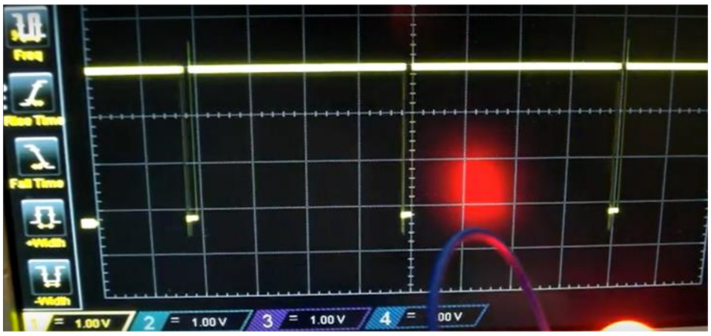

Figure 13. Results From Pwm Generator Signal With 99% Duty Cycle.

In Figure 11 to Figure 13 is the output of the pwm signal seen through an oscilloscope. The set values are varied from 25%, 50%, and 99%. From the results that match Figure 11 to Figure 13, it can be concluded that the duty cycle value is in accordance with the settings on the Arduino Nano.

4.2. Voltage Sensor Testing

Voltage testing was carried out at 10 measurement points with each voltage increasing by average approximately 0.2 V.

Table 2. Voltage sensor testing data with multimeter.

No.	Voltage Sensor (V)	

	Multimeter (V)	Min	Max	Average Voltage Sensor Readings (V)	Error (V)
1	7.2	6.7	6.9	6.8	0.4
2	8.1	7.6	7.8	7.7	0.4
3	8.5	7.8	8.2	8.0	0.5
4	9.1	8.6	8.8	8.7	0.4
5	10.2	9.7	9.8	9.75	0.45
6	11.3	10.7	10.9	10.8	0.5
7	12.2	11.8	11.9	11.85	0.35
8	13.1	12.6	12.7	12.8	0.3
9	14.3	13.7	13.9	13.8	0.5
10	15.2	14.8	14.9	14.85	0.35
Sum	109.2	104	105.8	105.05	4.15
Mean	10.92	10.4	10.58	10.05	0.41

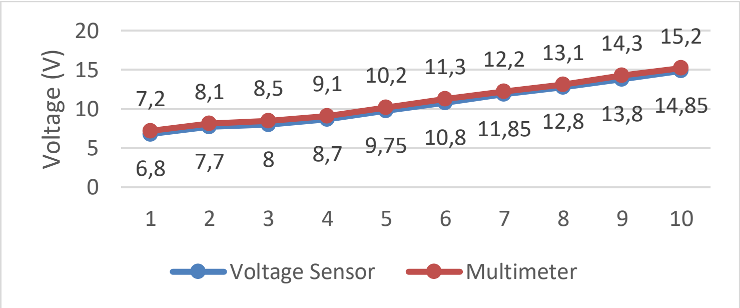

Figure 14. Voltage test graph from multimeter reading and voltage sensor reading.

4.3. Current Sensor Testing

The Arduino analog pin, which features an analog to digital converter (ADC) with a resolution of 10 bits, receives the reading from the ACS712 current sensor as an analog signal with values between 0 and 1023. When the current sensor is not attached to the circuit, the ACS712 sensor has an initial offset or value of around 512.

The purpose of testing the ACS712 current sensor is to compare its reading with the ammeter's reading. Seven iterations of the ACS712 current sensor test were conducted using a variable power supply to change the resistance. Table 3 displays the test results.

Table 3. Data from current sensor test results.

No.	Resistance Ω	Multimeter (A)	Sensor (A)	Error (A)	%Error
1	1.0	4.22	3.03	1.19	28.19
2	1.5	3.68	2.58	1.10	29.89

3	2.0	3.16	2.43	0.75	23.10
4	2.5	2.82	2.16	0.66	31.22
5	3.0	2.46	1.76	0.70	28.45
6	3.5	2.02	1.44	0.58	28.71
7	4.0	1.77	1.36	0.41	23.16
			Mean	0.76	27.53

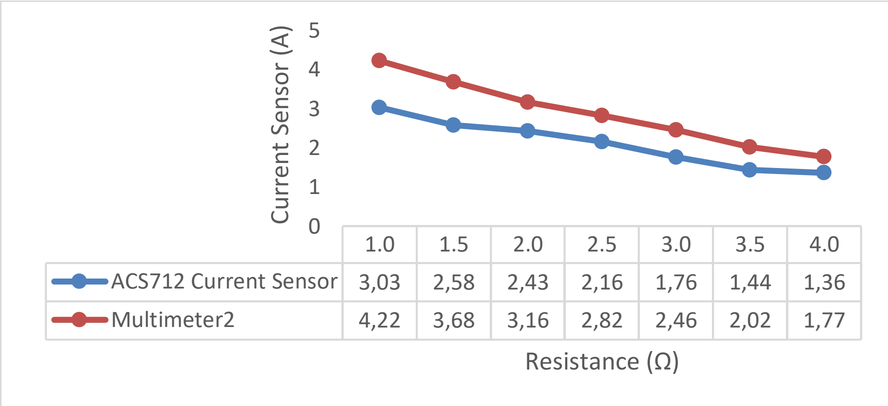

Figure 15. Current test graph from multimeter reading and current sensor (ACS712) reading with resitance.

Current testing was carried out at 7 measurement points with each current using resistance at 1.0 until 4.0 (see table 3). The mean of error current sensor reading is about 0.76 or 27.53%.

4.4. Solar Charger Controller Working Test

Several data on illumination values, battery voltage rise values, solar panel voltage values, and the output value of the buck converter circuit used to charge the battery were produced in order to test the solar charger controller.

Table 4. Data of Illumination, Temperature, and Voltage on Solar Panel.

No.	Time (At)	Temperature (ºC)	Illumination (Lux)	Solar Panel Voltage (V)
1	09.00	29.6	709	15.27
2	09.30	31.6	743	14.96
3	10.00	31.8	923	15.12
4	10.30	32.1	946	15.5
5	11.00	32.3	740	15.18
6	11.30	32.2	526	15.13
7	12.00	32.6	990	16.45
8	12.30	33.3	938	16.75

9	13.00	32.4	912	16.14
10	13.30	32.6	793	16.5
11	14.00	32.3	706	15.79
12	14.30	31.2	518	15.7
13	15.00	31.2	416	15.3
14	15.30	30.5	410	15.2
15	16.00	30.2	56	14.02
16	16.30	29.6	33	13.75
17	17.00	30.1	13	12.88

Table 4 shows the results of the Illuminance values for each time. The results show that the Illuminance values are uncertain, but the data shows that the greatest radiation that can be achieved is at 12:00-12:30. The graph of illumination value against time can be shown in Figure 16 as follows:

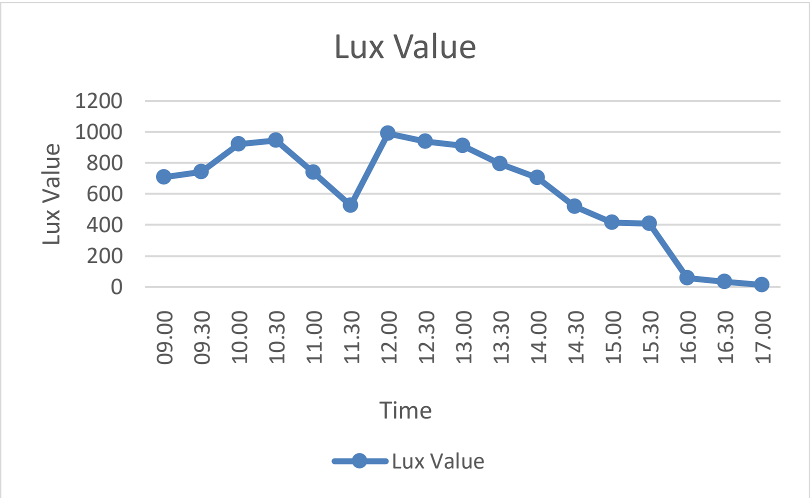

Figure 16. Illumination Value Graph Against Time.

Table 5. The output voltage value of the solar panel, buck converter, and battery voltage over time.

No.	Time (At)	Solar Panel Voltage (V)	Buck Converter Output Voltage	Battery Percentage (Open Circuit) (%)	Battery Voltage (Open Circuit) (V)
1	09.00	15.27	13.91	74.7	12.84
2	09.30	14.96	13.62	76.31	12.9
3	10.00	15.12	13.76	77.10	12.93
4	10.30	15.5	14.15	77.89	12.96

5	11.00	15.18	13.83	77.89	12.96
6	11.30	15.13	13.78	78.42	12.98
7	12.00	16.45	15.1	81.31	13.09
8	12.30	16.75	15.4	81.31	13.09
9	13.00	16.14	14.79	81.84	13.11
10	13.30	16.5	15.15	84.47	13.21
11	14.00	15.79	14.44	84.47	13.21
12	14.30	15.7	14.35	84.9	13.23
13	15.00	15.3	13.95	85.26	13.24
14	15.30	15.2	13.85	85.26	13.24
15	16.00	14.02	13.16	84.47	13.21
16	16.30	13.75	12.96	83.94	13.19
17	17.00	12.88	12.13	83.42	13.17

The output value of the solar panel and the output value of the buck converter based on the table above shows that the decrease occurs due to the pwm settings that have been made. The pwm from the Arduino Nano is what causes the buck voltage to decrease as the battery charging voltage. The voltage increase value based on time is obtained that the battery will be charged when the charge is carried out. The graphs of solar panel voltage and buck voltage, as well as the graph of battery increase compared to time can be seen in figures 17.

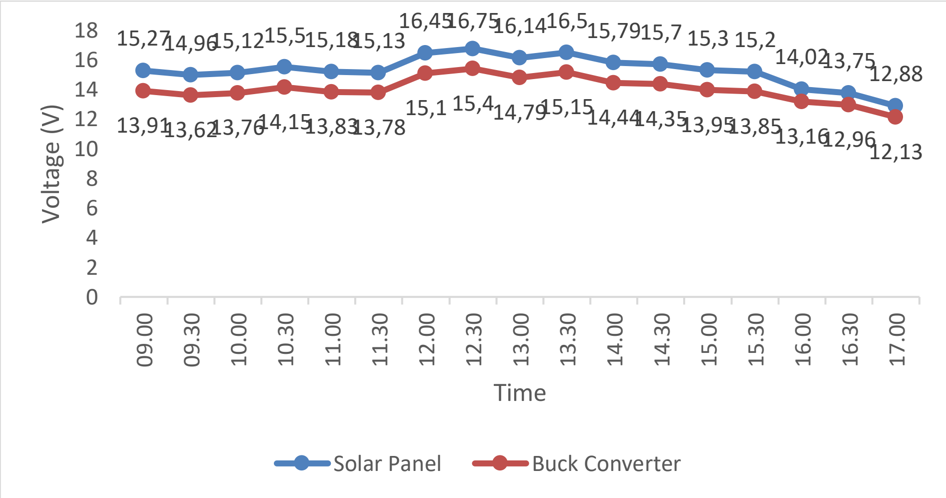

Figure 17. Comparison of Solar Panel Output Voltage and Buck Converter.

5. CONCLUSION

In order to reach the minimum voltage required to charge the battery using solar panels, the solar charge controller was designed with a charging voltage of ±14 volts. The solar charge controller uses the mosfet switching mechanism with a 95% duty cycle to manage the input variable from the solar panel. This allows the controller to regulate the input voltage from the solar panel to ±14 volts. It takes almost six hours for the solar charge controller circuit to raise the SoC battery level from 74.7% to 85.26% on average.

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