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Study on the Reliability of Capacitor Charging Factor Method in Design Solar Test Simulator Panel Surya

Howard Sifo[1], Amani Darma Tarigan[2]
[1,2]Department of Electrical Engineering, Universitas Pembangunan Panca Budi, Indonesia

ABSTRACT

This study aims to examine the reliability of the capacitor charging factor method in the design of Solar Test Simulator for Solar Panels. The equipment used is the I-V Tracer, which functions to read the current and voltage characteristic values of the Solar Panels. The value readings on the Solar Panel are greatly influenced by the surrounding environmental conditions and aim to evaluate whether the performance of the panel is in accordance with the available datasheet. The method used to obtain maximum performance data is to perform a short circuit on the output of the solar panel. The data is recorded through a capacitor charging system, where variations in capacitor values are used to determine the optimal component size to display the characteristic curve of the Solar Panel. The final results of the study show that capacitive loads can display the shape of current and voltage curves well through capacitor charging factor monitoring. Tracing the voltage variation in the solar cell and the calculation of the charging current on the capacitor shows that the current generated is relatively small. The 3300 μF capacitor was chosen because it was able to display a curve shape that matched the simulation in the PSIM program. The use of MOSFETs results in real-time charging of capacitors with fast readings in milliseconds.

Keywords: Solar Cells; Current and Voltage Characteristic Curves; Capacitor Charge Factors

Corresponding Author:
Howard Sifo,
Department of Electrical Engineering
Universitas Pembangunan Panca Budi
Jl. Gatot subroto km 4.5 medan, 20122, Indonesia.
Email : Ilham.amiluddin@gmail.com

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1. INTRODUCTION

The application of solar panel testing equipment with several methods using various light sources that exist today such as incandescent lamps, leds and halogens is carried out using equipment called a solar test simulator (Reichmuth et al., 2020). Testing is carried out to obtain solar panel performance in accordance with installation requirements according to power capacity requirements (Frolova et al., 2019). The characteristics of sunlight in Indonesia that are in the equatorial position are very possible to carry out a simulation process using halogen lamp light (Tanesab et al., 2019). The recording of test data is often carried out through lighting variations through the conditioning of the voltage supply voltage on the lamp. The design of solar panel testing equipment based on specified conditions is expected to be able to show the process of varying the output of solar panels on the market. Changes in the output value of solar panels to the energy source usage capacity can be shown through the characteristic curve displayed on the monitor screen. The display of the characteristic curve of a solar panel is able to provide information about the capacity of a solar panel as a whole. The data obtained through solar panel testing will be obtained in detail in the process of changing the conditioned light so that the percentage change in energy use of a solar panel on the market can be obtained.

The change process is expected to be able to provide recommendations regarding the feasibility of a solar panel being used at a solar panel installation point. Testing a solar panel needs to be carried out in order to be able to adjust the type of design for the use of solar energy so that maximum energy utilization is carried out by referring to the character of light that is in a specified position.

Good and maximum use of solar energy is carried out using appropriate equipment so that it is possible to develop in the future a location for the use of solar energy.

The application of solar panels in meeting electrical energy needs must be thoroughly analyzed. Knowing the characteristics of a solar panel will make it easier to determine the design and number of solar panels and the type that suits your needs. Various brands found on the market are obtained from abroad. Knowledge of solar panel testing equipment that can provide comprehensive information is carried out in order to obtain applied products in the form of solar test simulators through a simple series with measurements of capacitor charging factors. Calculation of current and voltage in the capacitor as soon as the switching process occurs has provided excellent information by showing comprehensive results. The problem of the high cost of testing equipment must be answered through the design of the tool to be made (López-Fraguas et al., 2019).

The design of applied technology by implementing a series of switching systems with measurements on the capacitor charging system will contribute to the technology of implementing the data recording system through the calculation of the capacitor charging factor used. The output of this research is in the form of a simple registered patent and additional outputs in journals and conferences in the field of electrical engineering.

The application of a series of calculation systems using capacitor charging factors in solar test simulator equipment will improve the method of simplifying the circuit and the application of program design by making modifications in data collection in detail so that it is possible to analyze changes in conditions that occur momentarily to lighting changes.

2. LETERATURE REVIEW

A. Solar Cell Performance Model

Solar cells are devices that convert light into electrical energy. Solar cells are also called photovoltaic cells, photovoltaic (light-electric) means Solar cells depend on photovoltaic effects to absorb solar energy and cause current to flow between two oppositely charged layers.

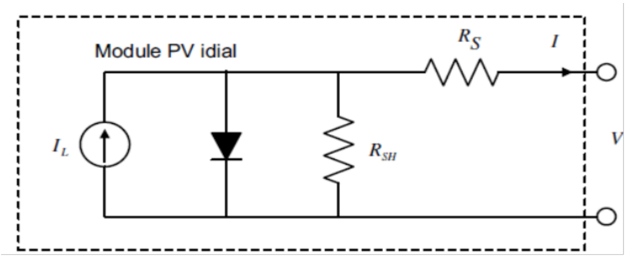


Figure 1. Solar cell equation series

The mathematical equation from the above series can be written as follows:

$$I = I_L - I_o\left[exp.\left(\frac{(V+IR_S)}{nKT/q}\right) - 1\right] - \frac{(V+IR_S)}{R_{SH}} \quad (1)$$

Where:

Io = reverse *saturation current* (Ampere) *n* = diode ideal factor *q* = electron charge factor (1.602·10-19 C) *k* = Boltzman constant (1.3806.10-23 J.K-1)
T = solar cell temperature (^{oK})

Solar Cell Current and Voltage Characteristic Curve

The electrical properties of solar cells in producing electrical energy can be observed from the electrical characteristics of the cell based on current and voltage at different light intensity and temperature conditions. The voltage usage of the solar cell depends on the semiconductor material used. The voltage generated from solar cells depends on the sun's radiation.

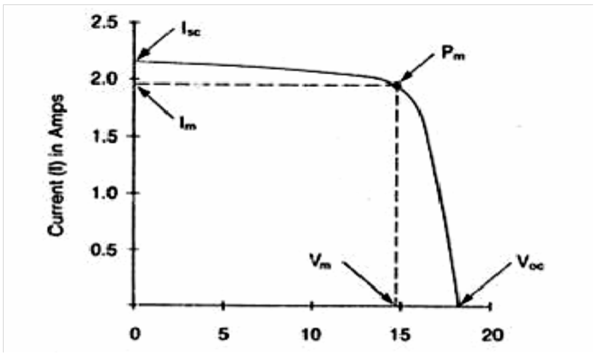


Figure 2. Characteristic curve I – V in solar cells

The parameters of the I-V characteristic curve can be classified into other categories:

1) The maximum power point (MPP) value is the point on the I-V curve where the solar cell is operating at maximum power. For this point power (Pmpp), current (Impp), and voltage (Vmpp) can be determined. This MPP power is a unit of *peak wattage* (WP).
2) Short circuit current (Isc) is the maximum value of the current output from a solar cell that can be discharged (*output*) under the condition of no resistance or *short circuit*.
3) The open-circuit voltage (Voc) is the maximum voltage value that can be achieved in the absence of current.

The Fill Factor (FF) is a parameter that determines the maximum power of *photovoltaic* in relation to Isc and Voc [12]. *The fill factor* is defined as the ratio of the *photovoltaic* maximum power to the product of Voc and Isc. *The fill factor* is also a measure of the deviation of the I-V characteristics against the ideal curve of the diode. *The fill factor* is an indicator of the quality of contact metallization that depends on the total resistance of a *photovoltaic*. The total resistance includes series resistance (Rs) and shunt resistance (Rsh).

B. Environmental Factors Towards Solar Cell Output

1). Temperature

Temperature also affects cell performance and photovoltaic efficiency. If the solar cells are in cold conditions, they will produce more power. In general, when the irradiation on the cell is 1 kW/m², the temperature of the cell is approximately 30°C higher than the air by about[1]. The characteristics of temperature changes in solar cells are shown in the figure below.

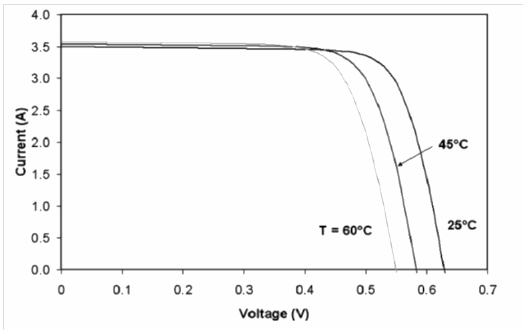


Figure 3. Characteristics of I-V at different solar cell surface temperatures.

2). Light Intensity

The effect of light intensity on solar cells (photovoltaic) is very significant. If the intensity of sunlight received by solar cells decreases or weakens, then the voltage and electric current generated will also decrease. However, voltage drops are usually smaller compared to current drops. The figure below shows the current and voltage changes of the solar cells based on the variation in the intensity of sunlight received.

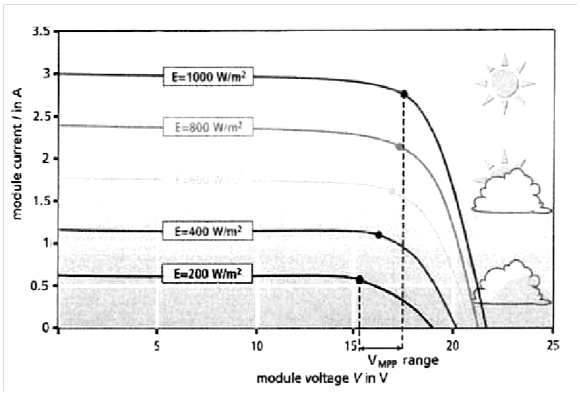


Figure 4. I-V Curve Relative to *Irradiance* and Fixed Temperature

C. Supporting equipment

1). Switching System

Switching converters are now increasingly popular because they offer higher conversion power efficiency and flexibility in design. With a switching converter, the output voltage can be generated in various multiples with different polarities of a single input voltage. In a switching converter, the transistor functions as an electronic switch that can be opened (OFF) and closed (ON), resulting in two states: saturation and cut-off. Therefore, this circuit is also often called DC Chopper.

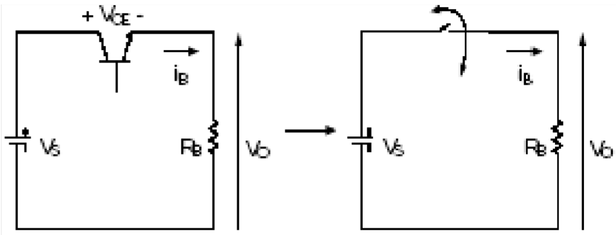


Figure 5. Basic switching *converter* series [14]

The average or DC component quantity of the output voltage can be derived from the following equation:

$$v_O = \frac{1}{T}\int_O^T V_O(t) = \frac{1}{T}\int_O^{DT} V_S\, d_t = V_S.D \quad (3)$$

From equation (3), it can be seen that the DC output voltage can be adjusted by adjusting parameter D. Parameter D is known as *the duty cycle* , which is the ratio between the length of time the switch is closed (tons) and the T period of the output voltage pulse.

2). Capacitive Load

In a direct current circuit, the presence of a capacitor for a long time can usually be considered a broken wire (open circuit). The process occurs after the charging of the capacitor occurs.

It can be explained in the figure that at the beginning, the capacitor has not been charged so it can be considered a closed circuit (connected wire) without a capacitor as follows.

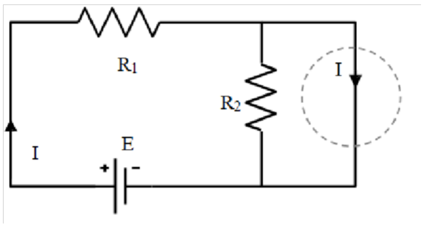


Figure 6. At the beginning of the current prefers through the capacitor and the presence of the capacitor can be considered as a closed wire

$$E - IR_1 = 0 \quad (8)$$

But after a long time and the capacitor has been charged, the capacitor becomes polarized in the opposite direction of the battery and against the current. So the capacitor can be considered as an open wire as below, and the current I prefers to go through R2 rather than through the capacitor

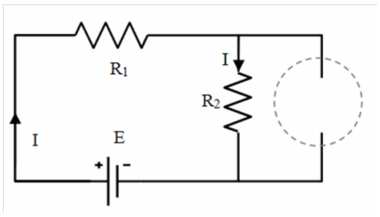


Figure 7. After some time the capacitor can be considered as an open wire

D. Control System

1). *Hardware Equipment* (Arduino Mega)

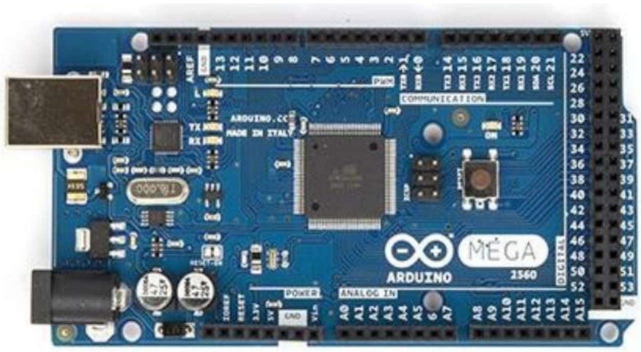


Figure 7. Arduino Mega 2560 Module

Arduino mega 2560 is an Atmega 2560 microcontroller board based on (*datasheet*) has 54 digital *input* pins or *outputs* (of which 15 pins can be used as *PWM or* Pulse Width Modulation *outputs*), 16 *analog* inputs, 4 UARTs (*Universal Asynchronous Receiver/Transmitter*), *16 MHz crystal oscillator, USB connection,* jack electricity, *ICSP* (*In-Circuit Serial Programming*) headers, and reset buttons.[15]

3. RESEARCH METHOD

In this research method, several stages are carried out to realize the application of an automatic watering system on plants. These stages include:

1. Start Research
    - Determine the goals and targets of the research.
2. I-V Tracer Equipment Design

- Collect and analyze design methods based on research achievement targets.
- Designing the I-V Tracer tool takes into account various factors such as component types and network configurations.

3. Data Recording System Testing
   - Testing the data recording system by varying the value of the capacitor on the switching system.
   - Collect current and voltage data on various conditions.
4. Data Analysis and Characteristic Curve Creation
   - Analyze the data obtained to form the I-V characteristic curve of the solar panel.
   - Compare the results with the datasheet for validation.
5. Conclusion and Recommendations
   - Conclude the results of the research.
   - Provides recommendations for the use of solar panels based on customized environmental conditions.
6. End of Research
   - Documentation of research results and publications.

4. Results and discussion

A. Network Simulation

Solar cell testing is applied by short *circuiting* the circuit. In solar cell systems, based on the current and voltage characteristics graph of I-V at the time of the *short circuit* current, the voltage shows at the zero position and vice versa when *the voltage is open at* the maximum position. The design of the component equipment was initially simulated on the Psim program to get the desired results and see the shape of the curve according to the circuit on the solar cell. The simulation of the series is in the following figure.

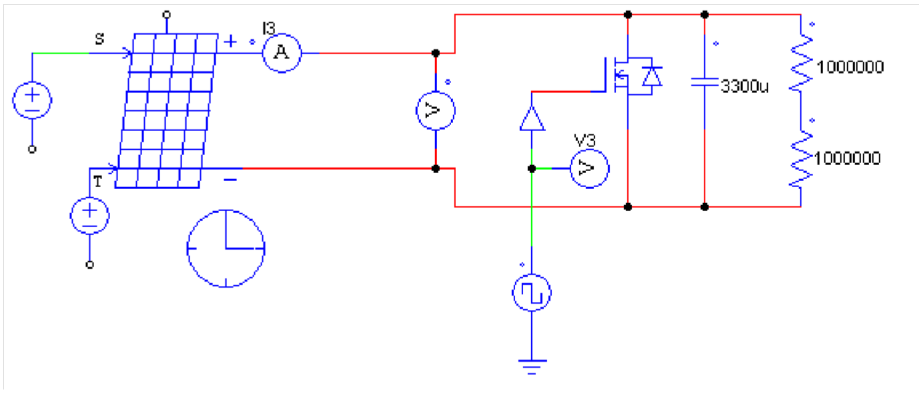


Figure 11. prototype of *the Tracer IV* design and Components of the entire sensor

In the simulation circuit based on the specifications of solar cells that are tested by designing a solar *short circuit* circuit using capacitive loads. The solar cells used have a voltage specification of 5 Vdc and a current of 189 mA. With the small specifications of the solar cells used, detailed readings of the characteristics of solar cells must be carried out.

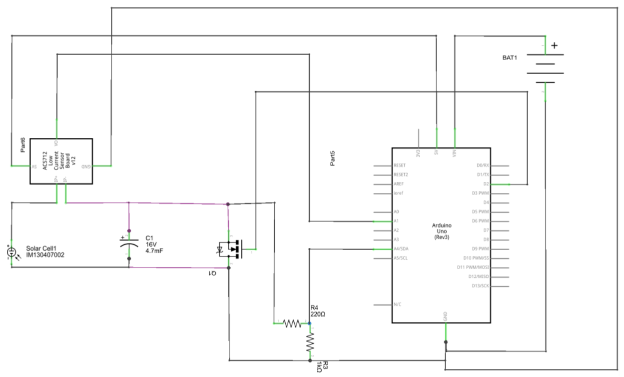


Figure 12. Solar cell and battery circuit systems and schematics

The selection of capacitive loading is intended to obtain the characteristics of the curve based on the variation in voltage on the properties of the capacitor charging factor. In the capacitive load circuit, a parallel R load of 2 MΩ is paired. The large resistance is intended to achieve *the open circuit* voltage when the charging current in the capacitor is full. The mosfet acts on the circuit as varying the voltage so as to change the condition *of the open circuit* to a *short circuit*. Based on the principle of *non-linear* loads , this produces a curve shape based on capacitive loads in *real time*. The selection of a large capacitor size is intended to obtain a long charging time on the capacitor so that it can display voltage variations to changes in conditions in the solar cell.

Figure 6. Position of light and temperature sensor placement at the time of testing

The performance of a circuit using a mosfet is to obtain the voltage variation against the solar panel based on the charging properties of the capacitor. When the switch is connected, the solar cell experiences *a short circuit* condition as well as the capacitor discharges the charge so that the charge condition on the capacitor is empty. When the switch is removed, the solar cell charges the capacitor until it is full, so it is considered an *open circuit circuit*. The installation of large resistors is intended so that on the circuit when the circuit is full capacitor is considered *open circuit*. The simulation carried out shows the shape of the current curve, voltage as well as the curve of current and voltage characteristics contained in the following figure:

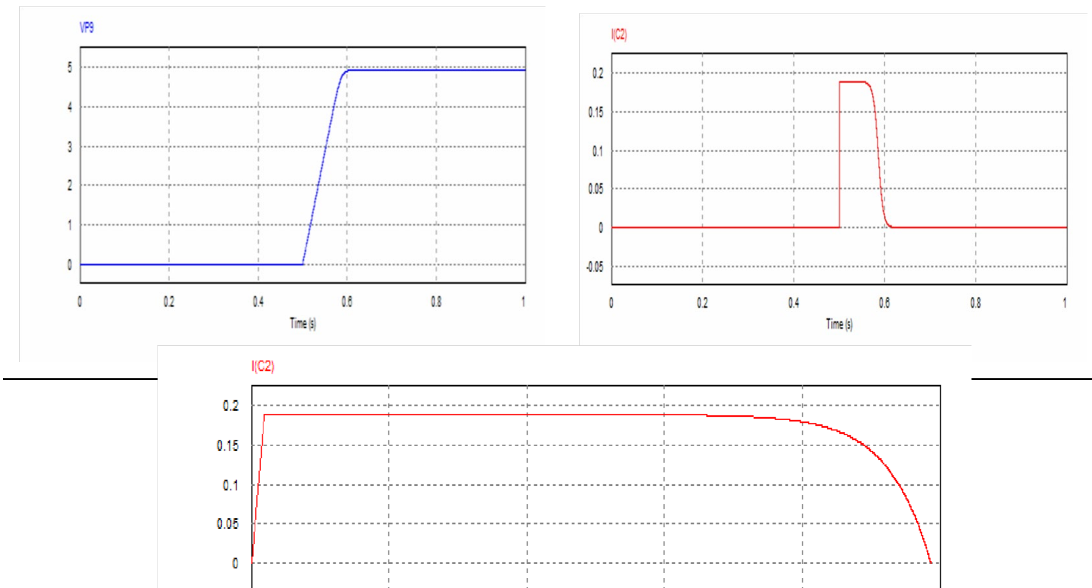


Figure 7. Current curve on the capacitor and voltage generated by the solar cell

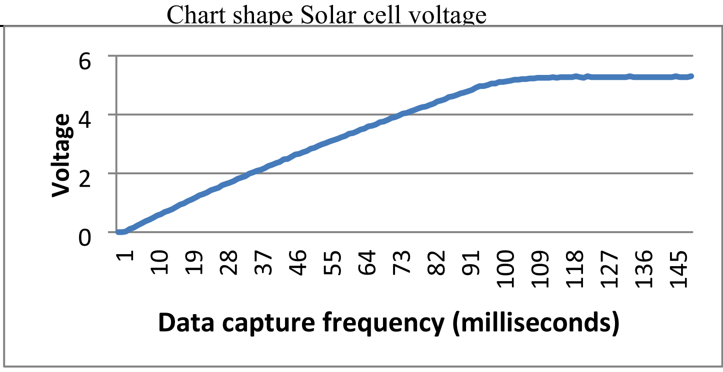
From the simulation results, it can be observed that the value of the current that occurs in the capacitor is the same as the current generated by the solar cell because the capacitors are paired in series on the solar cell as a load. The current and voltage characteristic curves with capacitor loads show voltage variations ranging from zero to the maximum voltage of the solar cell.

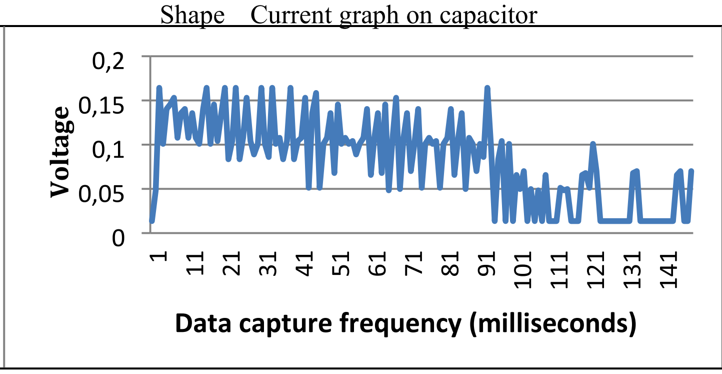
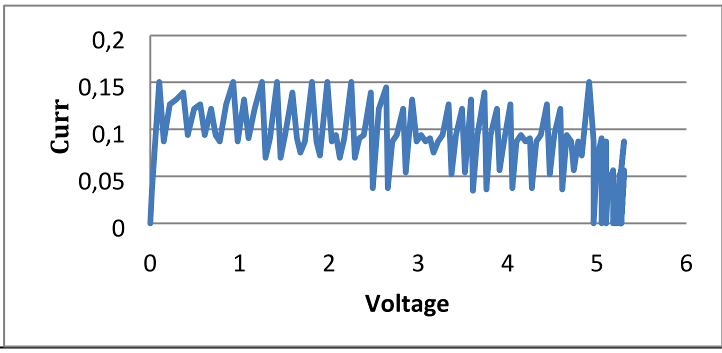
B. Tracer IV Series Test Analysis

The design of the inner circuit for capacitor selection is carried out to produce direct voltage variations in solar cells. The current and voltage value reading equipment using the ATmega 328 microcontroller attached to the arduino board is expected to be able to take detailed readings in the voltage variation on the charge factor on the capacitor.

The capacitors used are electrolytic capacitors with capacities of 240uF, 3300uF and 4700uF. Basically, the size of the capacitor affects the time to charge the capacitor to full so that there is *an open circuit* condition in the circuit. Data collection is carried out at solar cell temperature and lighting according to environmental conditions. The temperature sensor is attached to the solar cell module in order to display an overview of the temperature of the solar cell. The selection of capacitors with a capacity of 3300uF displays the full voltage variation over 1223 milliseconds in a form close to the simulation results on the Psim. The results of the experiments carried out are as follows:

Table 3. Drawing of the measurement results of the 4700uF Capacitor

Capacitor 4700uF	Temperature =34/ lux=2634
Chart shape Solar cell voltage	
	

Shape Current graph on capacitor

Current and voltage chart shape


The display of *the serial monitor* in data collection is in the following image

From the results obtained, it can be concluded that the use of 3300uF capacitors displays a curve shape that is close to the shape of the simulation image based on the Psim simulation. The design with a voltage sensor is then carried out to calculate the current on the capacitor to get the appropriate capacitor value because a very small current cannot be read on the existing current sensor. The results of the current calculation on the capacitor show the charge factor in detail with the charging time that can be seen in the calculation results displayed on the experimental data. Initial analysis of the circuit from the experimental results showed a visible transient voltage drop due to the large size of the capacitors. The drop in solar cell voltage is due to the large size of the capacitor with the small parameter condition of the solar cell. The test carried out with a capacitor size of 470uF produces a short curve shape, due to the very fast charging conditions so that the characteristic curve shape of voltage and current with a short time of 1048 milliseconds. The large 4700uF capacitor displays a very detailed reading of 3873 milliseconds to obtain variations in the capacitor charge factor to full. A very detailed reading that also shows the process of voltage rise and fall against the capacitor charge so that the shape of the graph displayed is not good.

The use of different sizes of capacitors in the Solar Test Simulator system to display the characteristic curves of the current and voltage of the solar panels. Based on the results obtained, the use of a capacitor with a size of 3300 µF produces a curve that is close to the simulation results using the Psim program. This shows that the selection of capacitor size is very important to match the measurement results with the simulation data.

Voltage sensors are used to perform current calculations on capacitors, which is important because very small currents from solar panels cannot be read with existing current sensors. The results of the current calculation on the capacitor show the charge factor in detail, and the detected charge time shows the performance of the system under different test conditions.

One of the important findings is the temporary voltage drop seen in the experimental results. This is due to the large size of the capacitor, which causes the voltage of the solar cells to drop when the capacitor starts to charge. This decline occurs because large capacitors take more time to reach full charge, especially when the conditions of the solar cell's parameters are not optimal.

Testing with a 470 μF capacitor results in a characteristic curve with a very short charging time, approximately 1048 milliseconds. This condition is due to the faster charging current, so the time to reach a full charge is shorter. In contrast, the use of a 4700 μF capacitor shows highly detailed readings with a charge time of about 3873 milliseconds. Although these readings are highly detailed, the resulting graph is not optimal because the process of voltage rise and fall during capacitor charging shows unwanted fluctuations.

Overall, selecting the right capacitor size is key to obtaining accurate and relevant data in the measurement of current and voltage characteristics on solar panels. Capacitor size that is too large or small can affect the resulting characteristic curve, both in terms of time resolution and data accuracy.

5. Conclusion

The results of the I-V Tracer equipment design show that the use of capacitive loads can accurately display current and voltage curves by monitoring the capacitor charge factor. The variation in the voltage in the solar cell and the calculation of the charging current in the capacitor show that the current generated by the solar cell is relatively small. The capacitor with a size of 3300 μF was chosen because it was able to display a curve shape consistent with the simulation results using the PSIM program. The use of MOSFETs in these systems allows the charging of capacitors to occur in real-time, with fast readings in milliseconds.

Suggestion

1) Sensor Calibration: It is recommended to calibrate each sensor found in the I-V Tracer tool to ensure the accuracy of the measurements and data generated.

2) Network Modeling: It is necessary to do more in-depth modeling of the circuit to achieve finer voltage variations related to capacitor charging, so that more precise values of solar cell parameters can be obtained.

3) Display and Data Storage: It is recommended to implement real-time display using a 1.8" TFT display for live data visualization. Additionally, it is important to store the measurement data on the memory card for further analysis and documentation.

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