

Advanced Optimization of Solar Panel Efficiency Using Novel Incremental Conductance MPPT Techniques

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Abstract

Photovoltaic (PV) is an unlimited and popular resource because it does not require high maintenance costs and is emission free. Photovoltaic modules are affected by changes in sunlight intensity, so a method is needed to find the maximum power point of the photovoltaic module. Maximum Power Point Tracker (MPPT) is one of the methods used to find the maximum power point on a Photovoltaic module. Connect current and voltage sensors on the input side of the converter to be read by the microcontroller and connected to the buck converter circuit and applying the incremental conductance method to the microcontroller to regulate the output voltage of the buck converter by adjusting the duty cycle on the PWM generated by the microcontroller. By comparing power gradients, this method can efficiently track the MPP and optimize the power generated by the solar panels. After testing and analysis, the incremental conductance method provides an efficiency maximum of 99%, as evidenced by a comparison of the power values. Using MPPT, the output power of the solar panels can be optimized at 42.24 watts with an accumulator load of 12 volts.

Keywords: Buck Converter, Incremental Conductance Method, MPPT

1 Introduction

Recently, the growing demand for energy has increased dramatically and improving living standards are likely to put additional pressure on power outages, rising fossil fuel prices have encouraged many enterprises and consumers to develop and use types of new energy sources are high reliability. Renewable energy in this context is a form of energy produced using resources that are naturally replenished in the short term through natural processes such as sunlight, rain, wave power, flowing water and geothermal heat, hydrogen, ocean energy and fuel cells.

The most popular method of generating solar energy is photovoltaic (PV) power. The output power of a single PV cell, the fundamental building block of PV power generation, is quite low. Multiple PV modules must be connected in series and parallel to create a PV array in real applications because to the voltage and power requirements. The output current and voltage of a PV array are modified by environmental factors (such as temperature and irradiance), giving the impression that they are nonlinear. Its output power also fluctuates regularly. Therefore, it is crucial to understand how to modify the load characteristics in PV systems in order to achieve maximum power point tracking (MPPT), which would allow the system to produce the maximum power in real time.

MPPT methods mainly include conventional methods and intelligent control algorithms [1]. Conventional methods of MPPT include hill climbing, incremental conductance methods, perturbation and observation, while intelligent control algorithms include artificial neural networks, flower pollination algorithm, fuzzy logic, and particle swarm optimization. Although numerous experiments have demonstrated the efficacy of intelligent control algorithms, these algorithms nevertheless suffer from the drawbacks of being highly complex and having a sluggish convergence rate, making them less frequently used in actual projects. Currently, the most popular direct control technique is the incremental conductance method.

The MPPT's current development course is algorithm focuses primarily on ongoing optimization of mathematics and control model for PV systems [2]. Because the converter duty cycle is directly controlled, other parameters don't need to be changed. This condenses the MPPT control architecture is efficient and effective when the environment is external performance stable. Nevertheless, the algorithm must constantly utilize a disruption to the task cycle to as certain that when the external source is at its maximum power point (MPP), the functioning point may shift as the surroundings do diverge from the intended tracking trajectory, leading to in an error of judgment This would slow down the reaction time and tracking the effectiveness of the system, and lead to loss of power [3].

The nonlinear I-V and P-V characteristics of a PV array, which shift continuously with irradiance and temperature, can be modeled from datasheet parameters at the open-circuit, maximum-power, and short-circuit points [4]. Because the maximum power point (MPP) moves with these conditions, many MPPT techniques have been proposed and reviewed. Esum and Chapman surveyed nineteen techniques and compared them in terms of cost, complexity, sensors required, and convergence speed [5]. Subudhi and Pradhan noted that every technique has its own merits and demerits [6], and Karami et al. classified forty methods in a single review [7].

Among the conventional direct methods, the incremental conductance (INC) algorithm was proposed by Hussein et al. for rapidly changing atmospheric conditions [8]. It exploits the fact that dP/dV is zero at the MPP to decide the direction of the next perturbation. The perturb and observe (P&O) method is simpler, but its operating point oscillates around the MPP at steady state and can be misled when irradiance changes quickly [9]. A detailed analysis in [10] found P&O and INC to be mathematically equivalent, with efficiency deviations of only 0.13% (dynamic) and 0.02% (static) in tests following the EN 50530 standard. This shows that parameter selection and implementation quality strongly influence the tracking result. To balance tracking speed and steady-state accuracy, variable step-size INC [11] and variable step-size incremental-resistance methods [12] have been developed, and the practical performance of the INC algorithm has also been assessed experimentally [13].

To maintain a fast response speed and high steady state accuracy of the PV system under changing environmental conditions, in this experiment, proposes an improved incremental conductance method. To realize the effectiveness of solar panel work, it is necessary to implement and test MPPT statistics using Incremental Conductance Method with a research title "IMPLEMENTATION OF INCREMENTAL CONDUCTANCE METHOD FOR MPPT SOLAR PHOTOVOLTAIC". Therefore, this work implements the INC algorithm on a low-cost Arduino Uno-based buck converter that charges a 12 V battery, and compares the power obtained with and without the algorithm.

2 Review

2.1 Photovoltaic

Photovoltaic is a renewable energy source with great potential for the future. Photovoltaic systems using solar energy offer an environmentally friendly energy source. However, technological developments in photovoltaic are still unable to achieve efficiency at a high level. The photovoltaic effect is used by photovoltaic cells to convert sun lights into an electric current.

There are several types of photovoltaic, namely thin film, and polycrystalline [14]. Some of the things that distinguish each type of photovoltaic are the materials used for absorption of solar radiation. The following are examples of types of photovoltaic.

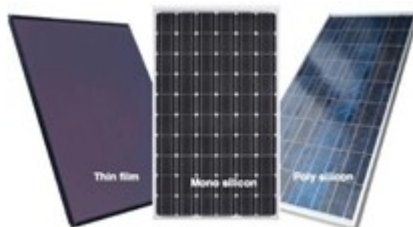


Figure 1: Types of Photovoltaic

Thin film is a type of solar cell made of a thin layer of a semiconductor material such as amorphous silicon, cadmium telluride (CdTe), or copper indium gallium selenide (CIGS). The main advantages of thin film solar cells are lower production costs, the ability to be flexible and lightweight, and good performance in low light conditions. They also have a better tolerance to temperature fluctuations and shading. However, the efficiency of thin film solar cells is generally lower than that of crystalline silicon solar cells, so they require more space to generate the same power. The efficiency thin-film solar panel is generally between 10-13% in the market.

Polycrystalline PV panels use many smaller silicon crystals, making the manufacturing process simpler and more economical. The main advantage of polycrystalline solar cells is lower production costs compared to monocrystalline solar cells. In addition, they also have good efficiency and stable performance in low light conditions. However, the efficiency of polycrystalline solar cells is generally slightly lower than that of monocrystalline solar cells, and they also require more space to generate the same power. Polycrystalline solar panels typically have a lower efficiency compared to monocrystalline panels, ranging from 15% to 18%.

Monocrystalline PV panels are made of a single silicon crystal, so they have high efficiency in converting sunlight into electricity. The main advantage of monocrystalline solar cells is their high efficiency, which means they can generate more electricity in a smaller space compared to other types of solar cells. In addition, monocrystalline solar cells also have a long life and good resistance to high temperatures. However, the main drawback is the higher cost of production compared to other types of solar cells. Typically, a monocrystalline solar panel can reach 15-25% efficiency.

2.2 Photovoltaic Characteristics

The characteristics of solar panels are a non-linear function of voltage and current with temperature and the intensity of light it receives [15]. The relationship between the output and temperature and solar irradiation as illustrated in Figures 1 and 2 respectively sequentially. The graph shows the output power of the solar panel according to the irradiation received. In addition to irradiation, the temperature value also has a role in the output power solar panel. To tackle these issues and guarantee that the PV system is functioning at the maximum power point (MPP), a maximum power- point tracker (MPPT) is needed [16].

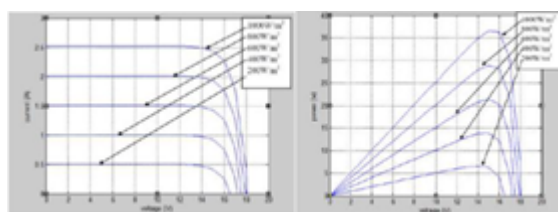


Figure 2: (a) I-V characteristic of solar PV module with varying solar radiation intensity and constant module temperature, (b) P-V characteristics of solar PV module with varying solar radiation intensity and constant temperature

Temperature also has an impact on the properties of solar panels in addition to solar radiation. Figure 2 displays the I-V and P-V characteristics for temperature variations with a constant irradiation value. The resultant current has a nearly constant value for under these circumstances, different temperature readings. Voltage and power values of solar panels fell as panel temperature values increased. These findings support the photovoltaic module's non-linear nature.

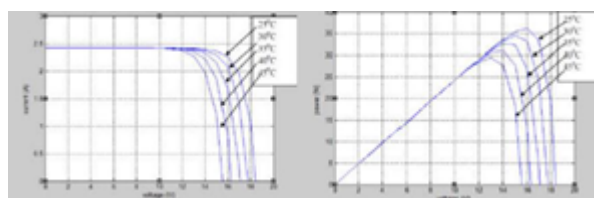


Figure 3: (a) I-V characteristic of solar PV module with varying temperature and constant solar radiation intensity, (b) P-V characteristic of solar PV module with varying temperature and constant solar radiation intensity

2.3 Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking Algorithm (MPPT) is required to maximize the efficiency of big photo-voltaic modules. Many MPPT algorithms have been created and refined in this field [17]. The complexity, precision, speed, oscillation around the MPP, and hardware implementation and sensor requirements of these approaches vary [18].

The MPPT algorithm is divided into two types, namely the Direct Search Method (DSM) and the Module Integrated Algorithm (MIA). The Integrated Algorithm module is more complex than the Direct Search Method [19].

The perturbation and observation (P&O) algorithm [20], the incremental conductance (IC) approach [21], and hill climbing (HC) [22] are the most widely used MPPT strategies. MPPT controllers utilizing particle swarm optimization (PSO) and genetic algorithms have been developed for faster speed and more accuracy [23]. Fuzzy and neural network techniques are also widely used for addressing nonlinearity in numerous applications [24]. Although these approaches work well when dealing with the onlinear properties of the I-V curves, they need substantial computation, which limits their adaptability.

2.4 Incremental Conductance Method

The Incremental Conductance (ICM) method works based on the P-V gradient curve or the P-I curve characteristic of solar cells. The maximum working point of a solar cell is located at a different voltage value for each different environmental condition, it is called VMPP. MPPT provides Vref so that the working point of the solar cell is at the VMPP value. The characteristic of a P-V solar cell is a function of power over voltage, reaching a maximum point when the gradient is zero. This method requires a voltage and current sensor that shows the output of the solar panel. The maximum voltage generated when the maximum power is Vmpp and value always changes according to the value of the intensity of the sun. The curve gradient value is zero at the maximum point of the P-V curve [25]. So, from the graph on figure we can obtain:

$$\frac{dP}{dV} = 0 \quad S_0, \text{ on the MPP}, \quad \frac{dI_{pv}}{dV} = -\frac{I_{pv}}{V_{pv}} \quad (1)$$

$$\frac{d(VI)}{dV} = \frac{V dI + dV I}{dV} \quad S_0, \text{ on the MPP}, \quad \frac{dI_{pv}}{dV} = -\frac{I_{pv}}{V_{pv}} \quad (2)$$

$$\frac{V}{I} \frac{dI}{dV} + 1 = 0 \quad S_0, \text{ on the MPP}, \quad \frac{dI_{pv}}{dV} = -\frac{I_{pv}}{V_{pv}} \quad (3)$$

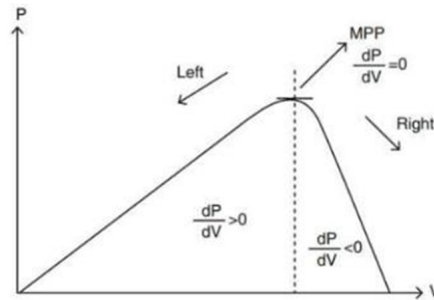


Figure 4: Tracker Schematic Diagram using the Incremental Conductance Method

The pulse width modulation (PWM) value is the value regulated by MPPT for then used to adjust the signal on the DC-DC converter so that the condition is $dI/dV + I/V = 0$ can be fulfilled.

2.5 DC-DC Converter

The converter functions to change the electrical signal from one form to another as needed. The DC-DC converter is also called the DC Chopper, where this converter is one of four types of converters connecting solar panels to loads, namely Cycloconverter, Rectifier, Inverter, and the DC Chopper itself. The DC-DC converter is very influential on the operation of solar panels to produce maximum power using MPPT. The output of this converter can be varied depending on the needs.

2.6 MPPT Control with DC-DC Converter

One method for MPPT that has been extensively researched based on array voltage is by using a DC-DC converter. This method has the advantage of directly measuring the array voltage, so it requires lower costs compared to methods that use solar irradiation measurements and other environmental factors. In addition, MPPT using a DC-DC converter also does not require current measurements, so the system becomes simpler. The main purpose of controlling this MPPT is by adjusting the duty cycle of the MOSFET transistor in the DC-DC converter so that the array voltage remains at the MPP operating point. There are three types of MPPT, namely:

- a. MPPT with changing current and voltage
- b. MPPT with fixed voltage and varying current
- c. MPPT with an adjustable references voltage based on a fixed percentage of open circuit voltage

2.7 IRFZ44N MOSFET

MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) is a type of semiconductor transistor that uses an electric field to control the flow of current in it. The IRFZ44N MOSFET is an N- channel MOSFET type transistor designed to control high power currents with low resistance. The IRFZ44N MOSFET can work at voltages up to 55V and currents up to 49A, making it suitable for use in power systems that require high power. This MOSFET has semiconductor properties in a layer of semiconductor material between the source and drain which can be controlled by an electric field.

The IRFZ44N MOSFET has three terminals: gate, source, and drain. Its physical structure consists of a semiconductor layer insulated by an oxide layer and covered by a metallic layer. The metal coating on the gate is used to control the electric field which controls the flow of current. The IRFZ44N MOSFET has performance characteristics that are important to understand, including drain-to-source resistance ($R_{DS(on)}$), gate-to-source threshold voltage ($V_{GS(th)}$), maximum drain-to-source voltage ($V_{DS(max)}$), and maximum continuous drain current (I_D).



Figure 5: IRFZ44N MOSFET

2.8 Arduino Uno

This Arduino Uno is a circuit board based on the ATmega 328 microcontroller. It has 14 input pins for digital output, of which 6 can be used as PWM outputs and the remaining 6 inputs are for analog input, 16 MHz crystal oscillator, USB connection, jack power, ICSP header, and reset button. By simply connecting the Arduino circuit board to a computer using a USB cable or AC to DC adapter power supply cable or also with a battery, this is done so that the circuit board can be used.



Figure 6: Arduino Uno

2.8.1 Liquid Crystal Display (LCD)

LCD is a tool that is useful for displaying a character which can be in the form of numbers, letters and pictures. There are two types of LCD, namely text LCD and graphic LCD. In order to be connected to the minimum system in an LCD microcontroller requires a driver. The driver contains a safety circuit, brightness and data level controllers, as well as to facilitate installation on the microcontroller.

A text LCD is a type of LCD that can only display text or numbers, while a graphic LCD can display an image because each cell of a graphic LCD contains a liquid crystal "dot". The LCD function in the MPPT system is here to display the value of the input voltage, output voltage, input current and output current on the buck converter.

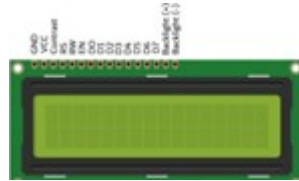


Figure 7: LCD

3 Research Methodology

3.1 Time and Research Place

Research carried out for the preparation of the thesis was carried out in:

- a. Time : December 2022 - May 2023
- b. Place : Renewable Energy Laboratory, State Polytechnic of Identification Headings

3.2 Method of Collecting Data

The research method that will be used in the preparation of the thesis is as follows:

1. Study of literature
This method is carried out by reading and studying various literature in the form of books, journals, internet articles as a support for the deepening of concepts and theories so that the writing of the final report is directed and completed on time.
2. Discussion/consultation
The author conducts discussions / consultations with the supervisor with the aim that the data to be retrieved is in accordance with the needs.
3. Observation
The author conducts research or direct data observation in the field using equipment and tools that have been installed where the test data results are used for analysis purposes.

3.3 Research Data Processing Methods

The research was carried out by directly measuring the current and output voltage of the solar panel as well as the output of the MPPT as shown in Figure 3.1 with a time duration of 09.00 to 12.00 WIB.

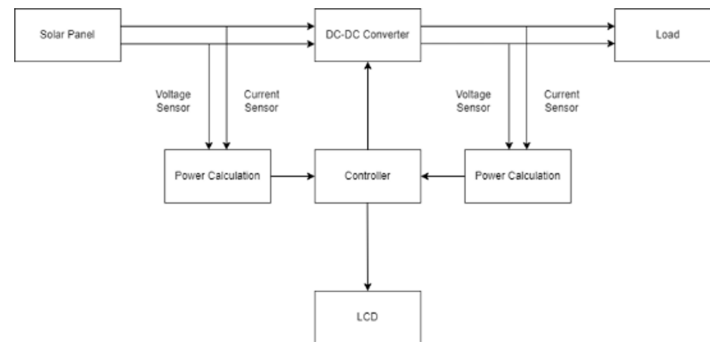


Figure 8: System Block Diagram

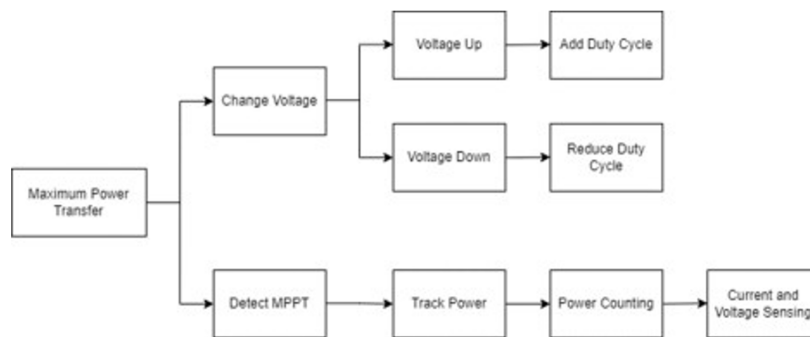


Figure 9: MPPT Implementation Block Diagram

4 Result and Discussion

4.1 System Functional Diagram

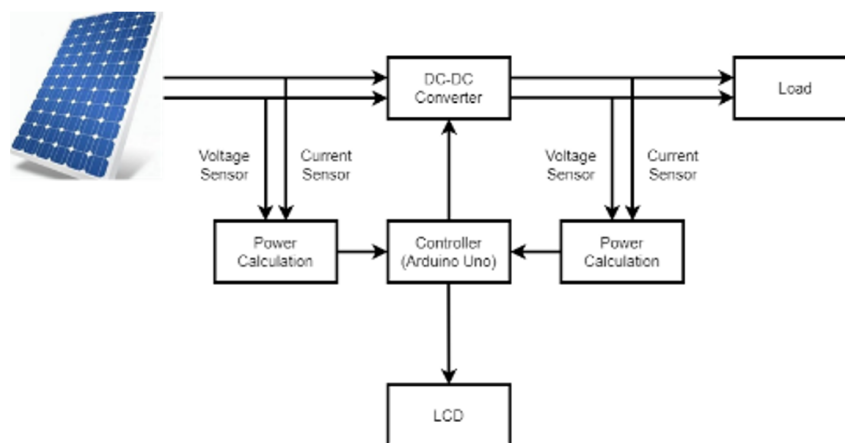


Figure 10: System Functional Diagram

In Figure 10, in the first part there is a photovoltaic which function to generate electrical energy from sunlight. The output of the photovoltaic will produce a voltage and current depending on the conditions of

the intensity of solar radiation.

From the functional diagram of the system above, there is a buck converter which has components in the form of 1 inductor and 1 capacitor and has an output voltage characteristic that is smaller than the input voltage. The buck converter here is also useful for lowering the output voltage as needed, and here it will be set at 12v so that it can charge the load in the form of an accumulator (battery) by adjusting the duty cycle on the buck converter.

The function of the microcontroller here is to receive analog input from existing sensors, modify it first to digital and then process it into the incremental conductance method algorithm. Then the result of the incremental conductance method algorithm is a PWM signal which will be used for switching MOSFETs in the buck converter circuit. The function of the load here is to store the power generated by the buck converter. The load used is a 12V 50 Ah accumulator.

4.2 Wiring Maximum Power Point Tracking

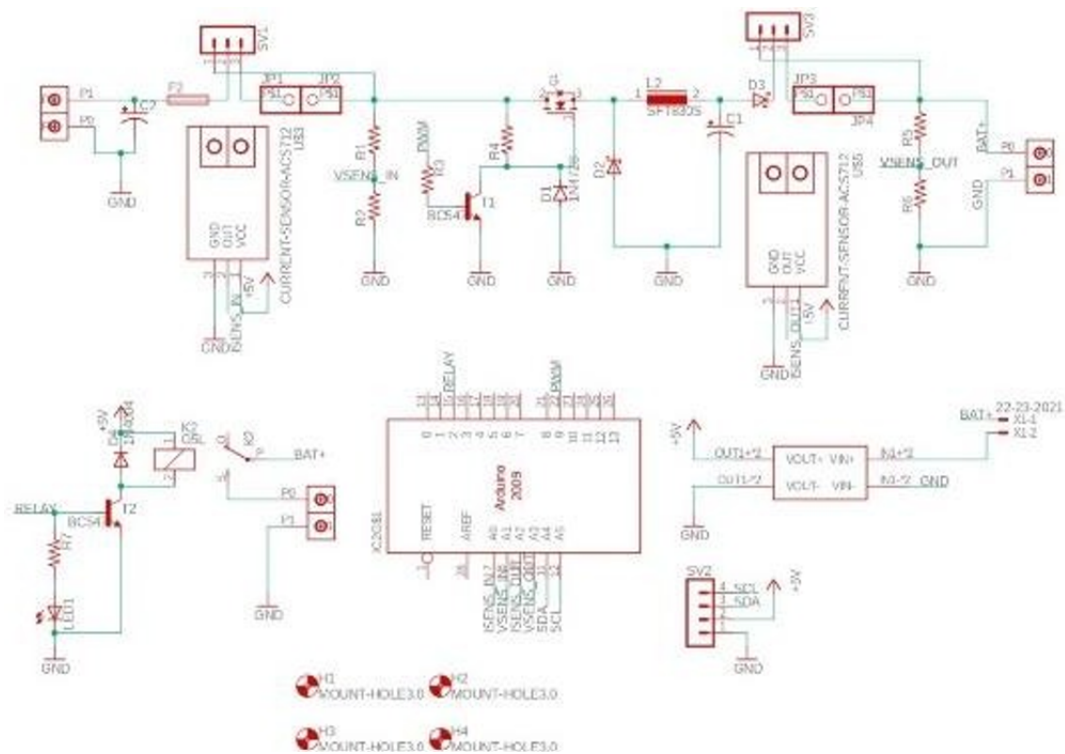


Figure 11: Wiring Maximum Power Point Tracking Incremental Conductance Method

In Figure 11 is the wiring of the entire MPPT incremental conductance method system made with the eagle application. The MPPT incremental conductance method system consists of several circuits, namely:

- Buck Converter
- Current Sensor
- Voltage Sensors
- MP1548 DC-DC Step Down
- LCD 16 x 2
- Arduino UNO

4.3 Duty Cycle Testing

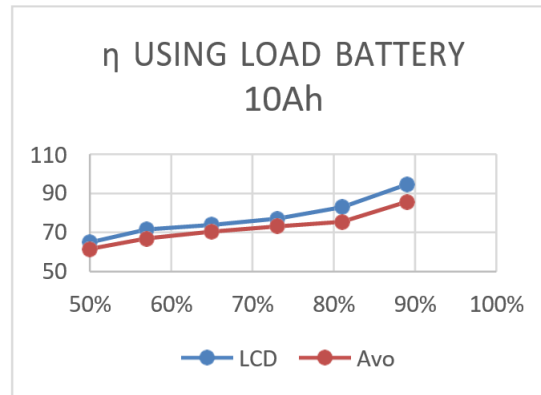


Figure 12: Buck Converter Measurement Chart with Duty Cycle (10ah Battery Load)

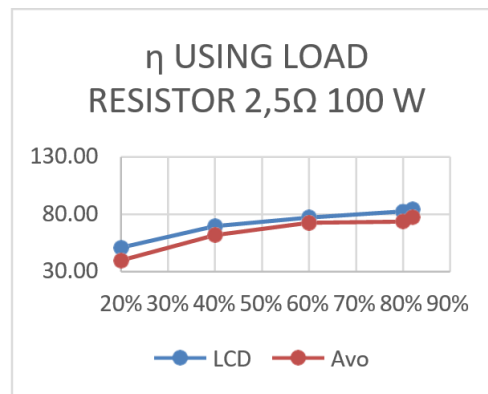


Figure 13: Buck Converter Measurement Chart with Duty Cycle (Resistor 2,5Ω 100 W Load)

Based on figure 12 the experimental results of measurements using a duty cycle with a 10 ah battery load obtained the greatest power value of 11.88 watts when measuring using an 89% duty cycle and the lowest power value of 2.40 watts using a 50% duty cycle. obtained the greatest efficiency of 94.53% and the lowest 64.98%. The measurement results at the duty cycle setting below 50% the value is the same as 50% duty cycle.

Based on figure 13, the measurement experiment using a duty cycle with a load resistor of 2.5Ω 100 watts obtained the highest power value 46.41 watts at 82% cycle time and the lowest power value was obtained 1.24 Watt. The highest efficiency is 84% when the duty cycle setting is 82%.

4.4 Experimentation of the MPPT System

In testing the MPPT system, this is an overall test of every component in the MPPT system and has also been embedded with the incremental conductance method algorithm. This test was carried out on July 14 2023 at the Renewable Energy Laboratory of the State Polytechnic of Malang. This test takes 2 data, namely by using the incremental conductance method algorithm and without using the incremental conductance method algorithm. It aims to be able to compare the power generated with the algorithm and without using the algorithm. Testing was carried out from 09.00 WIB to 12.00 WIB.

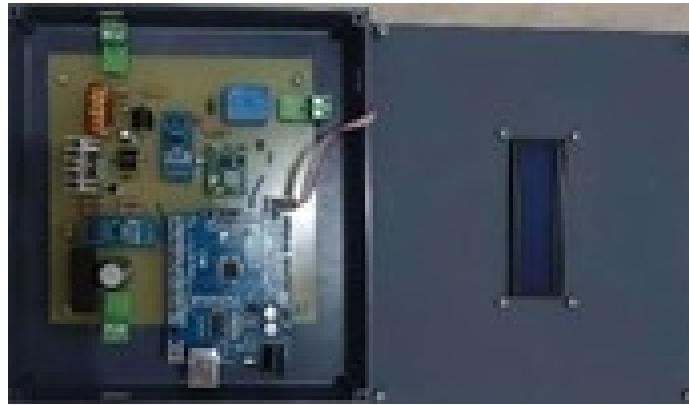


Figure 14: Maximum Power Point Tracking using Incremental Conductance Method

When testing MPPT with the incremental conductance method, an accumulator (battery) is used to load the MPPT system. The input source is a photovoltaic which will be connected to the buck converter and then the buck converter will be connected to a microcontroller which is used to set the duty cycle to find the maximum power point on the photovoltaic. In the MPPT system there are 4 sensors namely, 2 current sensors and 2 voltage sensors. The voltage and current read on the sensor will later be displayed on a 16 x 2 LCD.

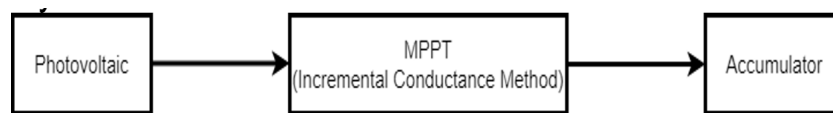


Figure 15: MPPT Test System Diagram

The efficiency value is obtained from the calculation between P_{out} and P_{in} and the energy value is obtained from the power value multiplied by the total time of the experiment that has been carried out. From the tests that have been carried out using the Maximum Power Point Tracker (MPPT) system using the incremental conductance method with the buck converter can be seen in figure 16 and 17, the data presented is voltage, current, power, and also efficiency data.

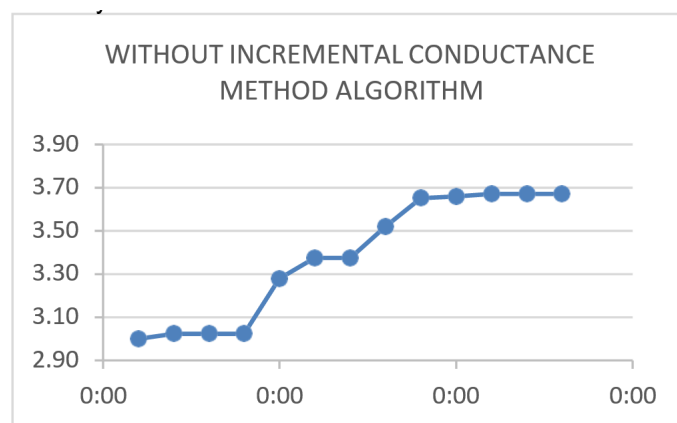


Figure 16: Experiment Without Incremental Conductance Method Algorithm

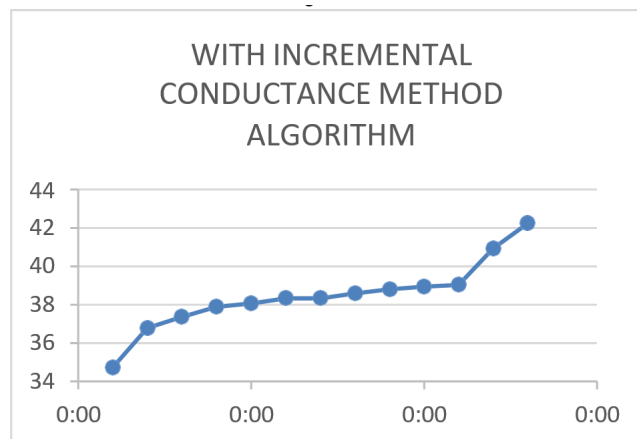


Figure 17: Experiment With Incremental Conductance Method Algorithm

In figure 16 is the test data from the MPPT system without using the incremental conductance method algorithm and the highest efficiency was obtained at 51% which occurred at 12.00 WIB with an MPPT power value of 3.67 Watt, with irradiation of 1178.1 W/m² and at a temperature of 69.5°C.

In table 17 is the test data from the MPPT system using the incremental conductance method algorithm and the highest efficiency was obtained at 99% at 09.15 WIB with a power value of 36.79 Watt with solar irradiation of 1160.4 W/m² and at a temperature of 65,9°C.

From the test results that have been obtained with the incremental conductance method algorithm and also without the incremental conductance method algorithm, it can be used as a comparison that the efficiency obtained without using the incremental conductance method algorithm can be said to be very little with the smallest efficiency of 27% and the greatest efficiency of 51%. with the highest power value of 3.67 Watt.

The data obtained by using the incremental conductance method algorithm has better efficiency than the efficiency obtained without using the incremental conductance method algorithm. The smallest efficiency obtained was 82% and the largest efficiency was obtained at 99% with the highest power value of 42.24 Watt.

With the comparison data above, it can be concluded that using the incremental conductance method algorithm will get a better power increase than without using the incremental conductance method algorithm.

5 Conclusion

1. To design MPPT design using the incremental method is to first collect all the necessary parameters for a photovoltaic (PV) system, including solar panel characteristics, battery or load specifications, sensor voltage and current values.
2. To test the performance of the MPPT controller on a solar panel charging system using incremental conductance method is Continuously monitor and measure solar panel voltage (V) and current (I) values. Calculate the instantaneous power (P) by multiplying the measured value of the voltage and current ($P = V \times I$). If the difference between these two measurements = 0 then the value of voltage, current and power will be used as the latest value (update). But if the power difference value is $\neq 0$, then the voltage addition and reduction will be given according to the specified reference voltage. Based the experiment the test data from the MPPT system without using the incremental conductance method algorithm and the highest efficiency was obtained at 51% which occurred at 12.00 WIB with an MPPT power value of 3.67 Watt, with irradiation of 1178.1 W/m² and at a temperature of 69.5°C. And the test data from the MPPT system using the incremental conductance method algorithm and the highest efficiency was obtained at 99% at 09.15 WIB with a power value of 36.79 Watt with solar irradiation of 1160.4 W/m² and at a temperature of 65,9°C.
3. The efficiency system using MPPT base incremental conductance method is obtained in the range of 82%-99%. When the efficiency is 82% we got the value of power is 38,32W at the irradiation of 1005,3 W/m² and temperature of 63,2°C. And the highest efficiency is reach when the irradiation of the irradiation of 1005,3 W/m² and temperature of 65,9°C with the power 36,79 watt.

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