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Photovoltaic system performance improvement by applying enhanced incremental conductance algorithm

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ABSTRACT

This research aims to optimize the performance of a photovoltaic system using the Incremental Conductance algorithm (INC). The incremental conductance method is susceptible to oscillations in the steady state and tracking accuracy under solar radiation variations. This research investigates how Incremental conductance can be modified to improve its performance in reducing oscillations and accelerating cycle speed. Tests were carried out at irradiation variations of 200, 400 and 600 W/m². The INC method produces conventional tracking times of 500 ms, 555 ms, and 300 ms with maximum power of 1.89 W, 5,542 W, and 8,232 W at increased irradiation. Meanwhile the INC modification method shows a significant improvement with tracking times of 345 ms, 330 ms, and 205 ms, producing maximum power of 2.73 W, 7.36 W, and 9.9 W. When reducing irradiation, the modification method achieves tracking times of 195 ms and 455 ms. These results show that the INC modification method is superior in reducing oscillations, speeding up tracking time, and producing higher maximum power so as to increase the overall efficiency of the photovoltaic system.

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1. INTRODUCTION

The consumption of electrical energy from fossil fuels is increasing, causing a shortage of non-renewable resources and impacting environmental damage. So a solution is needed to overcome the problem of energy crises in the future. One solution to reduce dependence on fossil fuels is to utilize renewable resources such as solar energy [1]. Solar energy can be developed to be converted into electrical energy through a photovoltaic system [2].

The solar energy absorbed by photovoltaics depends on the intensity of radiation and temperature received by the solar panels. These factors are the problems in the use of solar panels, resulting in the amount of PV output power not reaching the maximum, especially when solar radiation is low [3]. This output power can be stabilized by utilizing the performance of Maximum Power Point Tracking (MPPT). The MPPT system helps improve photovoltaic performance so that the maximum power point remains at the maximum point [4]. There are 3 types of MPPT including conventional MPPT, MPPT Intelligence and MPPT Hybrid [5]-[10]. Each MPPT has weaknesses, but researchers chose the conventional type of MPPT to be developed because this MPPT is simpler, has low complexity, and low implementation costs [11]-[12].

Incremental Conductance is one type of conventional MPPT. One of the advantages of the Incremental Conductance method is its ability to respond to rapid changes in environmental conditions [13]. This algorithm is used to control the converter output voltage and adjust the duty cycle of the DC-DC Converter [14]. The type of DC-DC Converter used is the Boost Converter or step up converter. The MPPT system will be connected to the DC-DC Converter so that the PV remains at its maximum point. The duty cycle regulated by the MPPT will be the control value of the DC-DC Converter. The Boost Converter will channel power to the load and regulate the panel output voltage so that the panel maintains the position of the MPP point. This design will compare the performance results of the PV system for both types of algorithms, both conventional and modified algorithms.

2. METHOD

The MPPT system design block diagram consists of photovoltaic, MPPT control circuit, MOSFET driver, boost converter circuit, and load as shown in Figure 1.

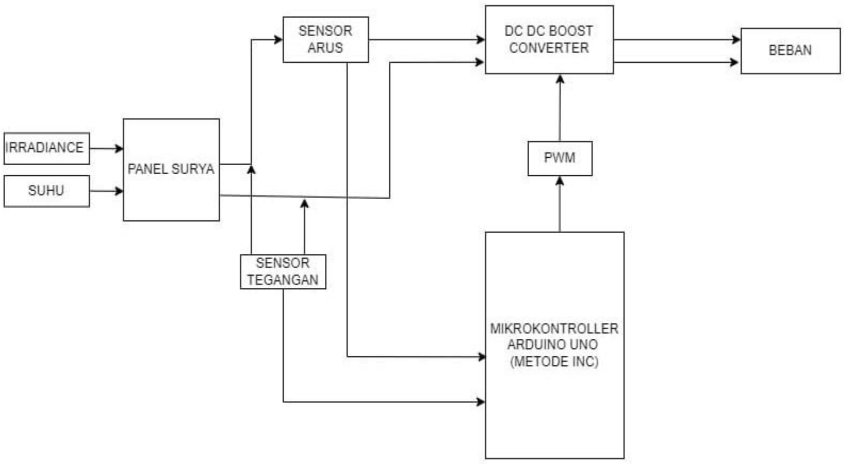

Figure 1. Block Diagram of MPPT System

Based on the block diagram above, Photovoltaic converts solar energy into electrical energy in the form of current and voltage. The current and voltage will enter the dc-dc Boost Converter. Because the current and voltage values of the photovoltaic are unstable due to changing solar intensity, the Incremental Conductance (INC) method is used to obtain maximum power. The Incremental Conductance algorithm will always adjust the duty cycle value to obtain the maximum MPP point [1]. The electrical energy produced is then distributed to the load. The photovoltaic used by Greentek MSP-100W is a monocrystalline type with characteristics as shown in table 1.

Table 1. Greentek MSP-100W Solar Panel

No	Parameters	Variable	Value
1	Maximum Power	P_{max}	100 W
2	Volateg at P_{max}	V_{mp}	18.1 V
3	Arus at P_{max}	I_{mp}	5.54 A
4	Open circuit voltage	V_{oc}	22.2 V
5	Short circuit	I_{sc}	6.00 A
6	Temperature Coefficient V_{oc}	K_v	-(0.40±0.05)%/°C
7	Temperature Coefficient I_{sc}	K_i	-(0.065±0.01)%/°C
8	Number of cells and connections	n_s	72(4 x 18)

Solar cells are devices that can convert solar energy into electrical energy [15]. Solar panels simply consist of p-type and n-type semiconductors, if the connection is connected it will form a p-n junction. When exposed to sunlight, photons that hit the cell will be absorbed by the semiconductor material, causing electron transfer and producing electrical energy [16]. Figure 1 illustrates the equivalent circuit of a PV cell consisting of a current source, diode, and resistor arranged in series and parallel. The mathematical model of the equivalent circuit of a solar cell can be seen in equation (1) [17]:

$$I_{pv} = I_{ph}N_p - I_0 N_p \left[\exp\left(\frac{q\left(v_{pv} + R_s \left(\frac{N_s}{N_p}\right) I_{pv} \right)}{N_s K T_a} \right) - 1 \right] - \frac{v_{pv} + R_s \left(\frac{N_s}{N_p}\right) I_{pv}}{R_{sh}\left(\frac{N_s}{N_p}\right)} \tag{1}$$

where Ipv is Solar panel output current, Iph is Current generated by the photoelectric effect per cell, Np is Number of solar cells connected in parallel, I0 is Reverse saturation current of the diode, q is Electron charge (1.6 x 10^-19 Coulomb), Vpv is Solar panel output voltage, Rs is Series resistance per cell, Ns is Number of solar cells connected in series, k is Boltzmann constant (1.38 x 10^-23 J/K), T is Solar cell temperature in Kelvin, a is Diode ideality factor and Rsh is Shunt resistance per cell. The relationship between current and voltage can be seen in the form of I-V characteristic curves as shown in Figures 2 (a) and 2 (b).

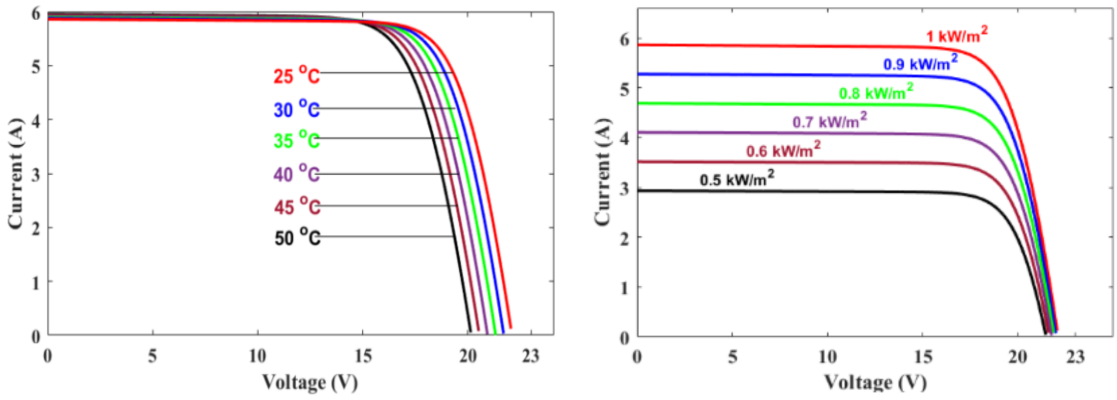

Figure 2. I-V Characteristic Curves (a) based on Temperature (b) based on irradiation.

Based on Figures 2(a) and 2(b), the effect of temperature changes with constant radiation values can be seen. Variations in temperature values will affect the output voltage value of the solar panel [18]. While Figure 2(b) illustrates the effect of radiation changes with constant temperature. So that variations in temperature values will affect the output voltage value of the solar panel [17]. Maximum power can be obtained by setting the solar panel voltage at the maximum point. This can be done by using a DC-DC converter. The type of DC-DC Converter used to stabilize the voltage by increasing the output voltage (Vout) higher than the input voltage (Vin) is the Boost Converter type [19]. Efforts to produce a higher output voltage require switching components that function to regulate the size of the duty cycle [20]. The boost converter topology consists of a DC input source (unidirectional), inductor, diode, capacitor, Mosfet and resistor [21]. which can be seen in Figure 3.

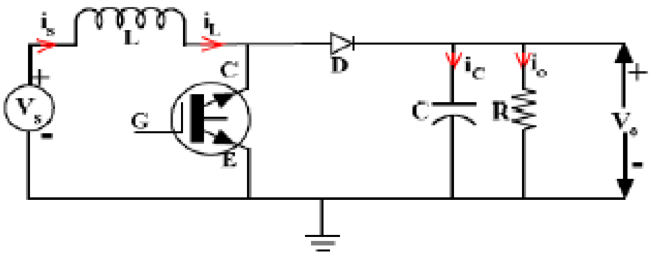

Figure 3. Boost Converter Topology

The working principle of the Boost Converter when the switch is On is that the diode becomes reverse biased so that the inductor will store energy. The voltage on the coil will be the same as the input voltage. When the switch is Off, the current in the coil will flow to the diode so that the stored energy is reduced. The load will be supplied by the source voltage plus the coil voltage that releases energy so that this causes the output voltage to be greater than the input voltage [19].

Boost converter design is needed to calculate the size of the components used, as well as the value of the duty cycle on the boost converter. This calculation requires 4 important parameters, namely input voltage (*Vin*), output voltage (*Vout*), switching frequency (*f*), voltage ripple, and current ripple. This calculation is carried out to obtain the value of the inductor (*L*), capacitor (*C*), and duty cycle value of the boost converter. The equations needed to obtain the parameter values of these components can be seen in equations (2), (3), and (4) [19]. The equations to obtain the value of the duty cycle are:

$$D = \frac{V_{in}}{V_{out}} \tag{2}$$

$$L = \frac{V_{in} D}{\Delta I_L f} \tag{3}$$

$$C = \frac{I_{out} D}{\Delta V_{out} f} \tag{4}$$

The boost converter will control the solar panel voltage at the maximum power point. Maximum Power Point Tracking (MPPT) is a technique used in monitoring and maintaining the maximum power point of solar panels by adjusting the output voltage of the solar panels [9]. The working principle of MPPT is to monitor the voltage from the solar panels whether it decreases or increases. If the maximum voltage *Vmpp* > *V*, then *V* will be increased until it reaches the maximum value, and vice versa. If it has reached the maximum point *Vmpp* then the output power will automatically be maximum [20]. MPPT works using a DC-DC Converter to regulate the output voltage of the solar panels [21].

The regulation of the output voltage of the solar panels is carried out using the MPPT algorithm. The MPPT algorithm used in this study is the Incremental Conductance Algorithm method. The main components needed in this algorithm are current and voltage sensors. This algorithm system compares instant conductance *I/V* with incremental conductance *dI/Dv* [22]. The basic principle of the INC algorithm uses the slope of the PV curve or the derivative of the power from the solar panels (*dP/dV*). If the slope of the PV array power and voltage curve where the change in power per change in voltage is zero, then the MPP point has been reached [23]-[27]. Figure 4 shows the P-V curve of the INC method.

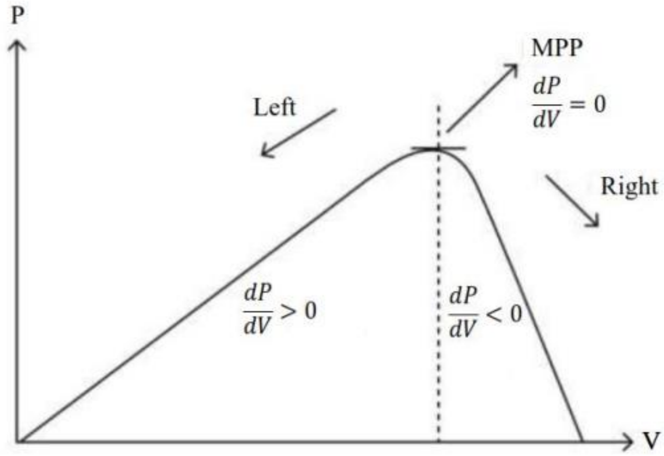

Figure 4. P-V curve of the INC method

Based on figure 4 above, the INC method obtains basic equations as follow [25] :

$$\frac{dP}{dV} = 0 \quad \text{on MPP} \tag{5}$$

$$\frac{dP}{dV} > 0 \quad \text{on the left of MPP} \tag{6}$$

$$\frac{dP}{dV} < 0 \quad \text{on the right of MPP} \tag{7}$$

The MPPT algorithm proposed in this study is Incremental Conductance which functions to track the maximum power point. The output value of the solar panel in the form of current and voltage will be observed by the MPPT algorithm to adjust the duty cycle value whether it should be increased or decreased [1]. The INC algorithm can be described by Figure 5.

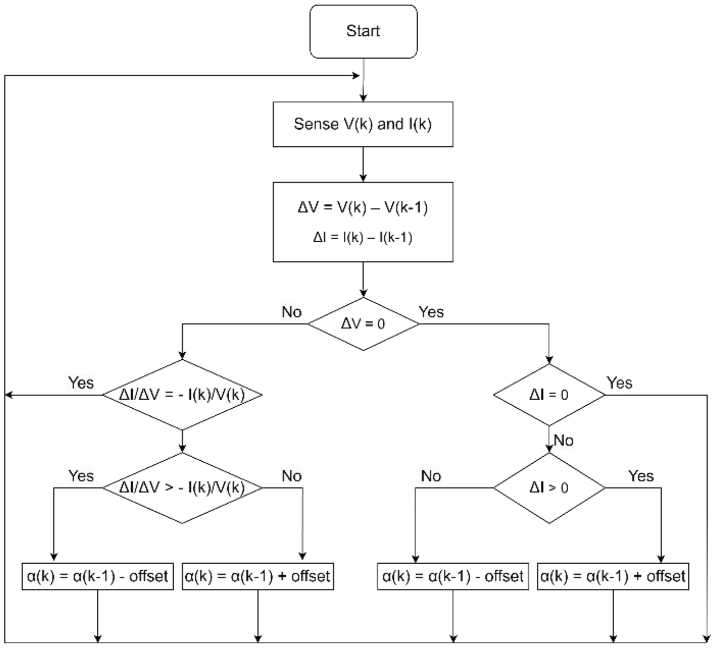

Figure 5. Conventional INC Algorithm

Based on the unstable solar panel output and one of the weaknesses of the INC algorithm which is susceptible to oscillations in a stable state [4]. This causes a decrease in the performance of the INC algorithm and disrupts the stability of the system voltage when the algorithm operates to achieve MPP. In addition, it also has an impact on tracking time [23]. Therefore, improvements or modifications are needed to improve the performance of the INC algorithm and overcome algorithm errors when solar radiation increases, as shown in Figure 6. Based on the diagram above, the flowchart above is a modification of the Incremental Conductance algorithm. This modification aims to increase stability around the MPP point, increase the convergence speed of MPP tracking, reduce oscillations and increase the overall efficiency of the MPPT system compared to the conventional INC algorithm method.

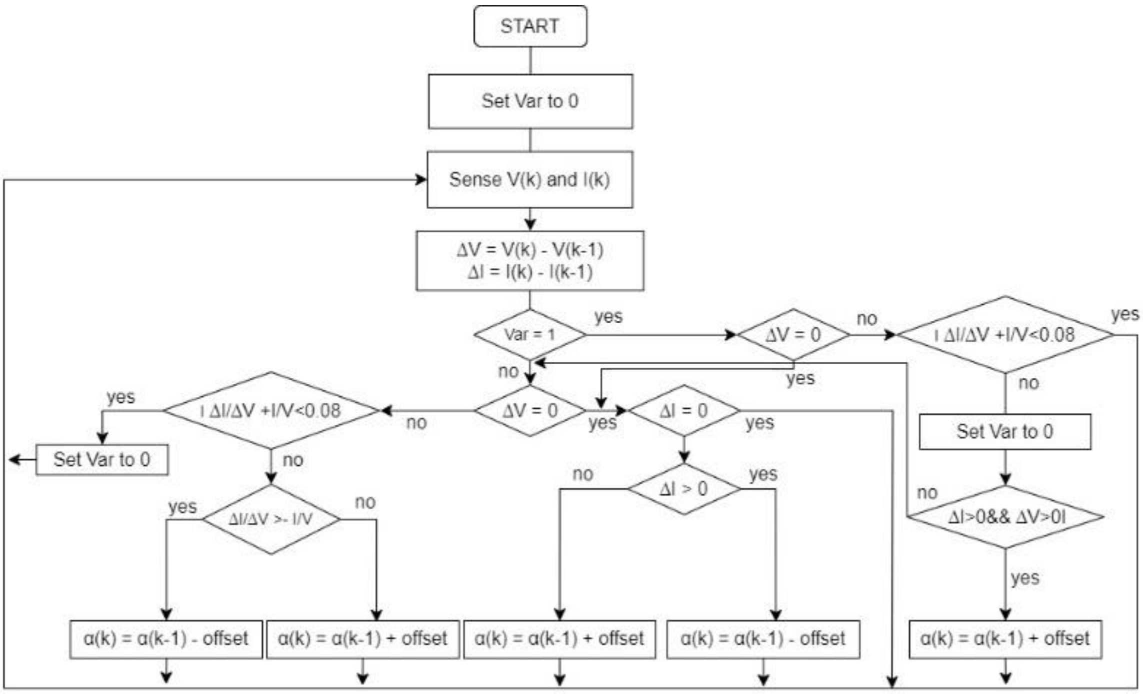

Figure 6. Proposed improved INC algorithm

3. RESULTS AND DISCUSSION

The first test is intended to determine the effect of PWM signal variations on the output voltage on the boost converter hardware circuit. The duty cycle used varies from 10% to 80% with a frequency of 62500 Hz. This test is set to an input voltage on the hardware circuit of 18 V and the output voltage results will be measured using a measuring instrument. Table 2 shows the results of the boost converter power circuit test..

Table 2. Power Circuit Test Results

Duty Cyle (%)	Voltge Input (V)	Voltge Output (V)
10	18	18.75
20	18	22.18
30	18	25.32
40	18	29.29
50	18	35
60	18	42.6
70	18	54.2
80	18	63.6

The maximum power value test without the MPPT algorithm is carried out by setting the duty cycle value on the boost converter with a range of 10% - 80% with a load of 50 ohms. This test is set the solar panel irradiation value from a range of 200 W / m2, 400 W / m2, and 600 W / m2 and the irradiation is reduced from 600 W / m2, 400 W / m2, 200 W / m2. This test includes measuring the voltage and current of the boost converter input. Figure 7 shows the input waveform without the MPPT algorithm using an oscilloscope

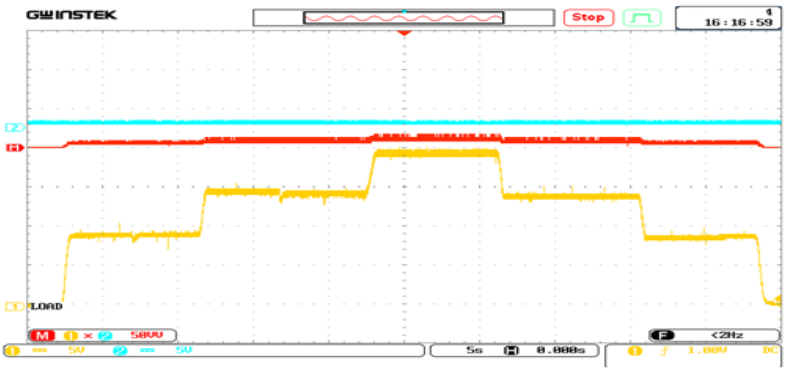

Figure 7. PV power value without MPPT algorithm

Figure 7 shows the input waveform with irradiation increasing 200 W/m2, 400 W/m2, and 600 W/m2 and irradiation decreasing from 600 W/m2, 400 W/m2, 200 W/m2. Figure 8 shows that the input waveform seen through the oscilloscope has many oscillations in the waveform and the tracking time to reach the maximum power point is not yet maximum. Maximum power testing using the Incremental Conductance type MPPT algorithm. This test is carried out in 2 ways, namely the conventional method and a modification of the Incremental Conductance algorithm. Conventional and modified method testing uses irradiation values from the range of 200 W/m2, 400 W/m2, and 600 W/m2 and irradiation is derived from 600 W/m2, 400 W/m2, 200 W/m2. The resistor value used is 50 ohms. The measurement results are in the form of tracking time to reach the MPP point, oscillations produced by both methods, and the maximum power produced.

Figures 8 show the results of conventional INC method testing with variations in irradiation changes. Figure 9 shows the measurement results of the conventional INC method with increasing and decreasing irradiation. The input wave produced has many oscillations around the MPP point and the tracking time in reaching the MPP point is not optimal. It can be seen in Figure 10 when the irradiation increases (0 -200 W / m2, 200 - 400 W / m2. 400 - 600 W / m2) the tracking time is observed at 500 ms, 555 ms, 300 ms, respectively. While the maximum power produced is 1.89 W, 5,542 W, and 8,232 W, respectively. When the irradiation reaches 600 W / m2 as shown in Figure 11, the input wave produces fewer oscillations compared to irradiation of 200 and 400 W / m2. When the irradiance decreases (600 -400 W/m2, 400 - 200 W/m2. 200 W/m2) the tracking time is observed to be 390 ms and 475 ms respectively. While the maximum power generated is 5,542 W and 1.89 W respectively. This means that any change in irradiance will cause initial oscillation before reaching steady state due to the adjustment of the duty cycle value in reaching the MPP point.

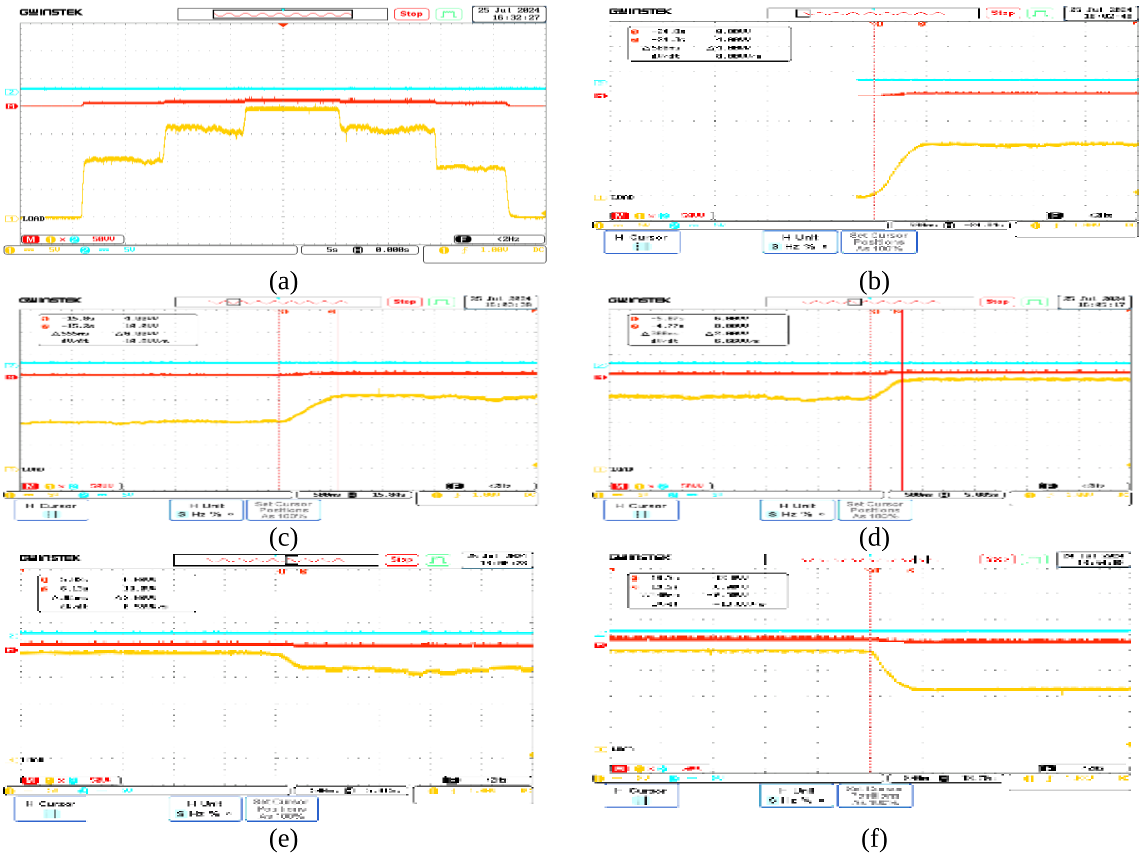

Figure 8. Conventional INC test results with variable irradiance, (a) input wave, (b) a) 0 – 200 W/m^2, (b) 200 - 400 W/ m^2, (d) 400 - 600 W/ m^2, (e) 600 – 400 W/ m^2, (f) 400 W/m^2 - 200 W m^2

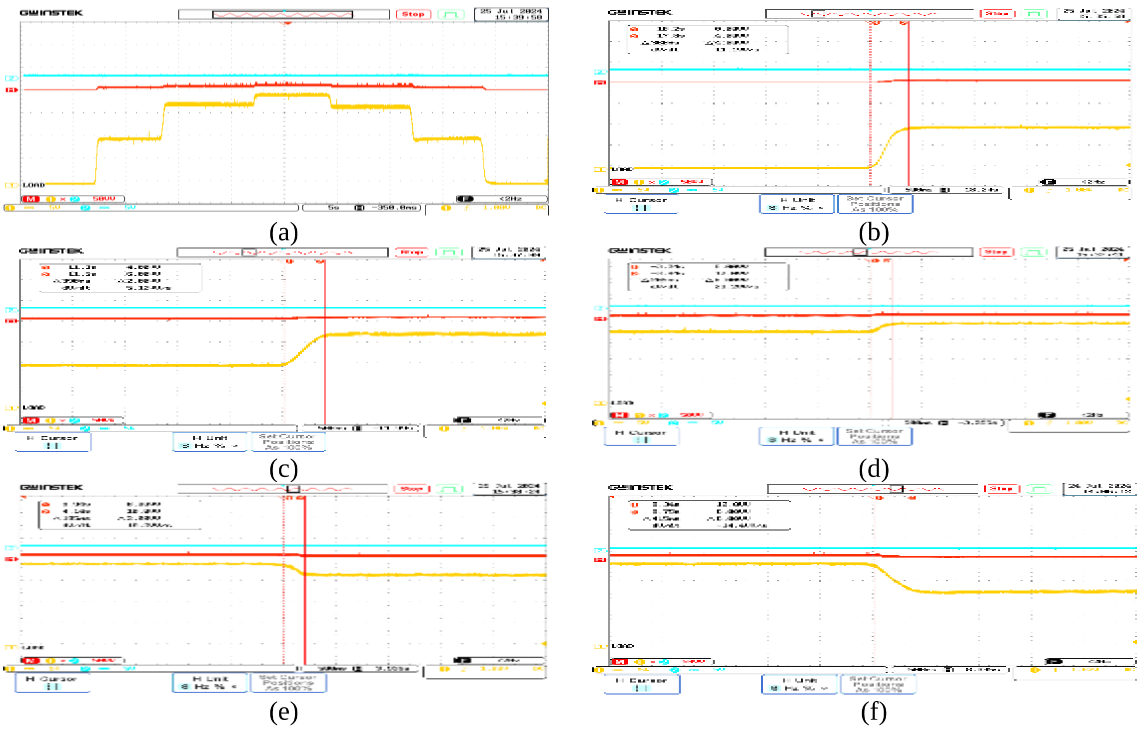

Figure 9. Modified INC test results with variable irradiance, (a) input wave, (b) a) 0 – 200 W/m^2, (b) 200 - 400 W/ m^2, (d) 400 - 600 W/ m^2, (e) 600 – 400 W/ m^2, (f) 400 W/m^2 - 200 W m^2

Figures 9 show the results of testing the modified INC method with variations in irradiance changes. Figure 9 shows the test results with the modified INC method through changes in irradiation. Based on the difference in waves between the modification and conventional, the resulting oscillation changes in reaching the MPP point are visible. Meanwhile, the tracking time through the modified method is faster than the conventional method. As seen in Figure 13 when increasing irradiation (0 -200 W/m2, 200 - 400 W/m2. 400 - 600 W/m2) the tracking time is 345 ms, 330 ms, 205 ms and the maximum power generated is 2.73 W, 7.36 W, 9.9 W. In Figure 14 when decreasing irradiation (600 - 400 W/m2, 400 - 200 W/m2) the tracking time reaches 195 ms, 455 ms and the maximum power generated is 7.36 W and 2.73 W.

4. CONCLUSION

Based on research that includes measurement and analysis of the MPPT (Maximum Power Point Tracking) system using the Incremental Conductance method has been realized. This research includes 2 stages of testing, namely conventional testing and modification of the INC algorithm. This test is carried out with various changes in irradiation with constant temperature. From the test results, the Incremental Conductance method outperforms in terms of oscillation around the MPP point, the speed of convergence to reach MPP, and the maximum power produced.Increased irradiation affects the tracking speed in reaching MPP. While the efficiency of the maximum power produced affects the performance of the photovoltaic system which becomes better. The difference in the resulting oscillations results in the system being able to reach the maximum power point (MPP) more quickly consistently. Based on the conclusions obtained, efforts can be made to maximize the development of the system and hardware further, then suggestions can be given that in this study it can be developed by adding a controller to reduce oscillations in the MPPT system so that the resulting oscillations are more stable and consistent in reaching the maximum power point (MPP).

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