Design and Implementation MPPT-CPG for Constant Power Battery Charger

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***Abstract*— The power produced by photovoltaic is very dependent on irradiation and temperature so that the power can be low or high. The load cannot work if the power is low, but it harms the load if the power is too high. Two modes are used for this system, they are MPPT and CPG mode. When PV power is less than limit power (Plimit), then it works on MPPT mode. The MPPT finds maximum power, then if PV power reaches Plimit or more, it works on CPG mode. During CPG mode, SEPIC converter output power is maintained constant at Plimit so the battery can be charged using the Constant Power Method. The Algorithm used for each mode is the variable Step Size Climbing. The Variable Step Size Hill-Climbing on MPPT performs maximum power according to irradiation conditions. Variables Step Size Hill-Climbing on CPG stabilizes the output power value of SEPIC being constant to charge the battery using the power constant method by keeping the power as constant as its limit power, voltage and current electricity bring into line with charge conditions. The results of the hardware integrated test for MPPT-CPG using 100WP of PV, the Variable Step Size Hill Climbing algorithm can search for the maximum power point (MPP) generated by PV and can produce an output power of 27.97 W in average by the CPG.**

Keywords—Constant Power Generation, Hill Climbing, Maximum Power Point Tracking, SEPIC Converter, Solar Power Plant.

I. Introduction

The demand for electricity supply is increasing as the population grows every year while the availability of non-renewable energy such as coal and oil is running low and pollution is increasing. Therefore, renewable energy such as water, wind, or solar energy has begun to be utilized by many countries, including the State of Indonesia, because the energy supply cannot run out and is more environmentally friendly.

Indonesia is a tropical country that gets enough sunlight throughout the year. Based on data from the National Energy Council, the potential for solar energy in Indonesia reaches 4.8 kilowatt-hours per square meter per day (kWh/m^2/day), equivalent to 112GWp compared to land potential in Indonesia [1]. This makes Indonesia very potential to utilize solar energy as a power plant. Solar power is a renewable energy that has many advantages such as being pollution free, causing no greenhouse gas emissions, almost no maintenance because solar panels last more than 30 years, and reducing dependence on fossil fuels. So that the solar panel which is a device to convert solar energy into electrical energy will be very useful. In order for the power generated by the solar panels to be immediately balanced with the load power, a maximum power point from the solar panel is required which is commonly called the Maximum Power Point (MPP). To find this point, the Maximum Power Point Tracker (MPPT) method is used.

For the manufacture of MPPT, the Variable Step Size Hill Climbing algorithm is tried with a DC to DC converter, namely the SEPIC Converter. However, overvoltage can occur when the solar panels are working at maximum power. To limit the maximum power of MPPT, Constant Power Generation (CPG) control is used. When the power of the MPPT is limited, the output voltage of the SEPIC Converter becomes constant according to the load requirements. The algorithm that is used for making CPG is the Variable Step Size Hill Climbing algorithm as well. Therefore, two modes are used for this system, namely MPPT (Variable Step Size Hill Climbing) mode and CPG (Variable Step Size Hill Climbing) mode. Where when the PV power is less than the limiting power, then the MPPT mode works. If the PV power reaches the power limit or more, then the CPG mode works. When in CPG mode, the output power of the SEPIC Converter is kept constant according to the power limit of the CPG. The previous research mostly used only MPPT, to maximize the output power of PV. The CPG added in this research to keep the battery being charged using Constant Power method by limiting the output power of SEPIC Converter as the battery need.

II. Methods

The hardware system design will be shown in block diagram Fig. 1. Also, the system modeling will be explained in the following points.

A. System Design

The first step of the research is system design. In this step, the block diagram is created. The block diagram created is shown in Fig. 1.

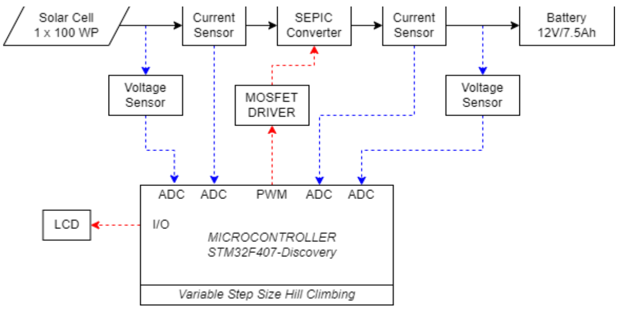

Fig. 1. Overall system

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From Fig. 1 it can be explained that this system is in the form of hardware that can improve the performance of solar panels by using the MPPT method and limiting its output power by using the CPG method. It can be seen that to get maximum power on solar panels using the MPPT method, the power increased. While the load power requirements have been determined. Therefore, the CPG method is used when reaching the power rating to be able to charge and avoid overloading the load.

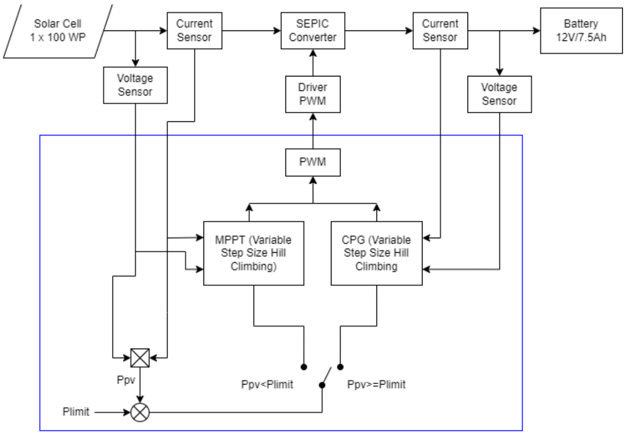

Fig. 2. Block diagram of MPPT-CPG

Fig. 2 can be explained, this system consists of 2 modes, namely MPPT mode and CPG mode. MPPT mode will work when the condition of the PV output power is lower than the limiting power (Plimit). While the CPG mode will work when the PV power has reached the power limit or more. The parameters used to determine the operation of the MPPT mode or CPG mode are the PV output power (Ppv), and the limiting power (Plimit). Plimit used in this system is 28W. The Plimit value then compared with Ppv to determine the working mode. If Ppv<Plimit, then MPPT mode will be active. Meanwhile, if Ppv≥Plimit then CPG mode will be active. So that the output power of this system can be kept constant. With the use of MPPT-CPG control, the system can find the maximum power point of the PV and keep it safe for the load as the power has been limited.

B. *Solar Panel*

A solar panel is a device that can convert solar energy into electrical energy made of semiconductor materials [2]. Solar panels can work because of the photovoltaic effect [3]. The working principle is that sunlight hits the semiconductor medium and can cause electrons in the medium to be separated from their atomic structure (negatively charged) and act as electron donors called N-type semiconductors "hole" (positively charged) and acts as an electron acceptor which is called a P-type semiconductor. At the junction of the positive and negative regions (PN Junction), it generates energy that pushes electrons and holes to move in opposite directions which will cause electric current. Electrons then moves away from the negative region while holes moves away from the positive region [4-5].

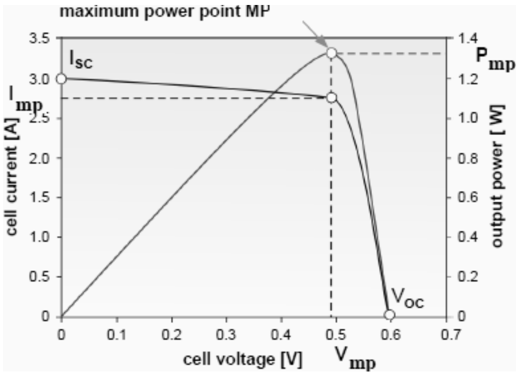

Fig. 3. I-V and P-V Characteristic Curves in solar panels

In general, the electrical characteristics of solar panels can be explained through the current-to-voltage curve (I-V Curve) and the power-to-voltage curve (P-V Curve) which can be seen in Fig. 3.

The output voltage of the solar panel is affected by changes in irradiance and temperature. Irradiance or solar radiation on earth varies, depending on the state of the spectrum from the sun to the earth. Solar radiation has more effect on current (I) than on voltage (V) [6].

The characteristic curve of the influence of solar radiation between current and voltage can be seen in Fig. 4 and power toward voltage can be seen in Fig. 5 [2].

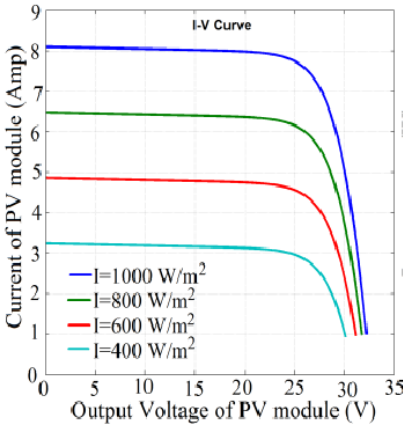

Fig. 4. I-V characteristic curve of solar radiation

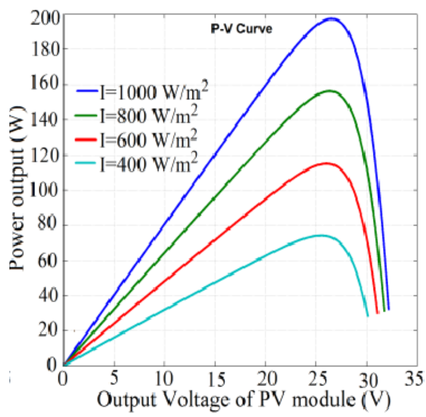

Fig. 4. P-V characteristic curve to solar radiation

This system uses a solar panel with a capacity of 100 WP as the main energy source. The type of solar panel used is the polycrystalline type. The specifications of the solar panels used for this hardware can be seen in Table I. The

TABLE I. SOLAR PANEL SPECIFICATIONS

Parameters	Value
Maximum Power (Pmax)	100 W
Vmp	17.6 V
Imp	5.68 A
Voc	21.9 V
Isc	6.4 A
Vmax system	1000 V
Dimension	1125×670×30 mm

C. *Modelling SEPIC Converter*

SEPIC (Single Ended Primary Inductor Converter) is a DC-DC converter that can increase or decrease the input voltage by adjusting the duty cycle of the switching components. In contrast to the Cuk converter, the SEPIC has the same output voltage polarity as its input (non-inverting) [7] and has a low input current ripple [8]. SEPIC Converter circuit is shown in Fig. 5.

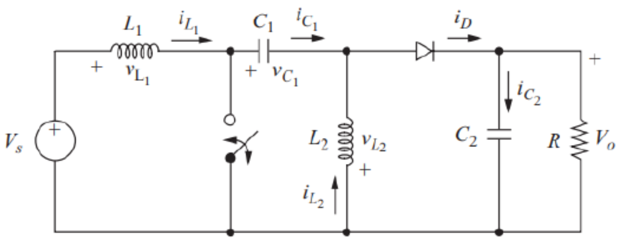

Fig. 5. SEPIC Converter circuit

There are inductors and capacitors on the output side to minimize output ripple. In the calculation, the inductor current is operated in continuous conduction mode (CCM). Kirchhoff's law of voltages on the linesV_s, L_1, C_1, and L_2 are

$$-V_s + v_{L_1} + v_{C_1} - v_{L_2} = 0 \quad (1)$$

Assuming the average inductor voltage is 0, then

$$-V_s + 0 + v_{C_1} - 0 = 0 \quad (2)$$

So, the average voltage across capacitor C_1 is

$$v_{C_1} = V_s \quad (3)$$

When the switch is closed, the diode is in reverse state. SEPIC circuit when the switch is closed can be seen in Fig. 6. The voltage flowing through L_1 in the time period DT is

$$v_{L_1} = V_s \quad (4)$$

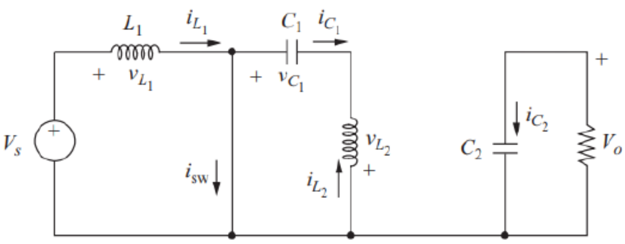

Fig. 6. SEPIC Converter when the switch is closed

When the switch is open, the diode is in a forward state. SEPIC circuit when the switch is open can be seen in Fig. 7 Kirchhoff's law of voltage on the outside is

$$-V_s + v_{L_1} + v_{C_1} + V_o = 0 \quad (5)$$

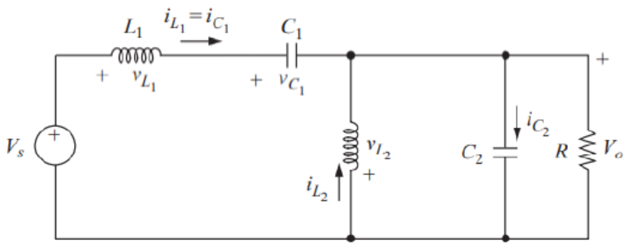

Fig. 7. SEPIC Converter when the switch is opened

Assuming the voltage flowing in C_1 is constant at the average voltage V_s

$$-V_s + v_{L_1} + V_s + V_o = 0 \quad (6)$$

$$v_{L_1} = -V_o \quad (7)$$

For the interval (1-D)T. Since the average voltage across the inductor is 0 for periodic operation, the equation

$$v_{L_1} = V_s \text{ and } v_{L_1} = -V_o \quad (8)$$

Merged into:

$$(v_{L_1,sw\ closed})(DT) + (v_{L_1,sw\ open})(1-D)T = 0 \quad (9)$$

$$V_S(DT) - V_O(1-D)T = 0 \quad (10)$$

Where, D is the duty cycle value of the switch component, then we get the equation

$$V_o = V_s\left(\frac{D}{1-D}\right) \quad (11)$$

Or

$$D = \frac{V_o}{V_o + V_s} \quad (12)$$

The calculation result of SEPIC Converter based on the design needed is shown in Table II.

TABLE II. RESULT OF SEPIC COMPONENTS DESIGN

Parameters	Value
Input Voltage (Vin)	17.6 V
Output Voltage (Vo)	14.4 V
Input Current (Iin)	5.68 A
Frequency Switching (fs)	40 kHz
Output Voltage Ripple (rVo)	1%
Input Voltage Current (riL)	20%
Duty Cycle (D)	0.45
Resistor (R)	7.96 Ω
Inductor (L1)	174.3 μH
Inductor (L2)	174.3 μH
Capacitor (C1)	1413.32 μF
Capacitor (C2)	1413.32 μF

Parameters	Value
Snubber Resistor (Rsnubber)	1290 pF
Snubber Capacitor (Csnubber)	2180.32 Ω

D. *Maximum Power Point Tracking (MPPT)*

Maximum Power Point Tracking (MPPT) is a method used to obtain optimal voltage and current values so that maximum output power is obtained from a solar panel. This maximum output power is generated in a high power ratio and reduce losses in solar panels [9]. MPPT requires two supporting components in its operation, namely input current (I) and input voltage (V). These two components are combined to get the power value (P) as in the equation P=$V\times I$ [10].

The working principle of MPPT is to increase the voltage and decrease the working voltage of the solar panel. If the voltage (V) falls in the area to the left of the maximum voltage (V_{mpp}) or (V) < (V_{mpp}), then (V) will be increased until it reaches (V_{mpp}), and vice versa if (V) is to the right of the maximum voltage (V_{mpp}) or (V) > (V_{mpp}), then (V) will be lowered until it reaches (V_{mpp}). After reaching (V_{mpp}), automatically the output power will also be maximum (P_{mpp}), whose job is to increase and decrease the voltage is the DC-DC converter [11]. The working graph of MPPT is shown in Fig. 8.

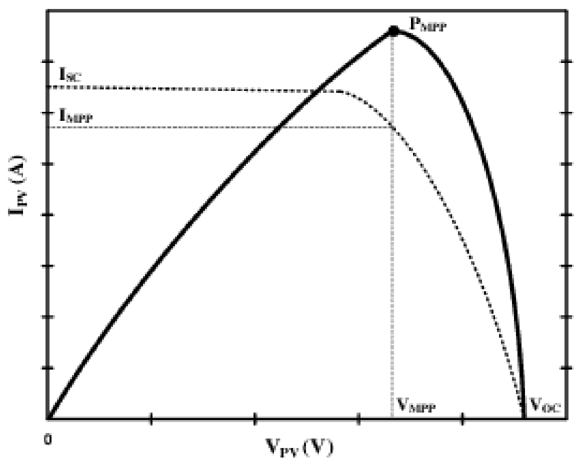

Fig. 8. MPPT Working Principle

E. *Constant Power Generation (CPG)*

The use of solar panels is usually operated with maximum power point tracking or MPPT to increase efficiency and get the maximum power value [12]. However, the use of solar panels in maximum conditions can cause several disturbances, including overcurrent and overvoltage on the load side [13]. To prevent this, a CPG control or constant power generation can be added.

CPG is a method used to limit the power generated by solar panels. With this method, the use of solar panels with MPPT control can avoid disturbances such as overvoltage [11]. One of the control strategies of the CPG method that can be implemented is to modify the MPPT control by adding a CPG mode (MPPT-CPG). This modification does not need to add additional tools and does not require additional costs in increasing the number of solar panels. The control algorithm on the solar panel using CPG control by modifying the MPPT control algorithm is shown in Fig. 9.

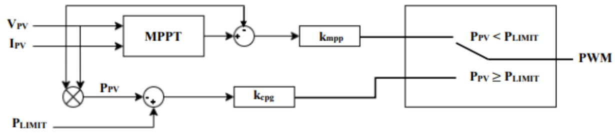

Fig. 9. Control diagram of MPPT-CPG

The CPG control keeps the output power constant during operation [14] as shown in Fig. 10.

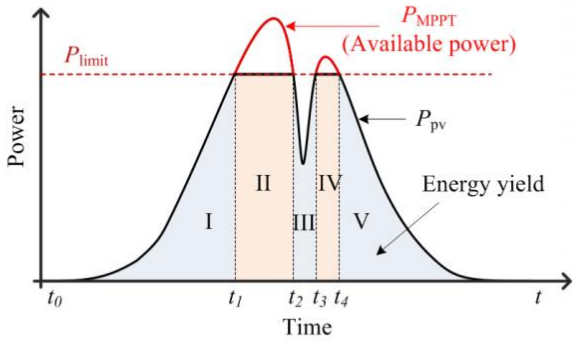

Fig. 10. MPPT-CPG concept

F. *Variable Step Size Hill Climbing Algorithm*

This method compares the current power output of the photovoltaic panel (n) with the power output of the previous photovoltaic panel sample (n-1), which is obtained by the sample voltage and current at regular intervals. According to the power change, the duty cycle (D) of the DC/DC converter is changed, the process repeats until MPP is reached, so that the maximum power point is reached if the power change with respect to the duty cycle is forced to zero by the MPPT Controller [15]. The process of changing the power output of PV step by step is shown in Fig. 11.

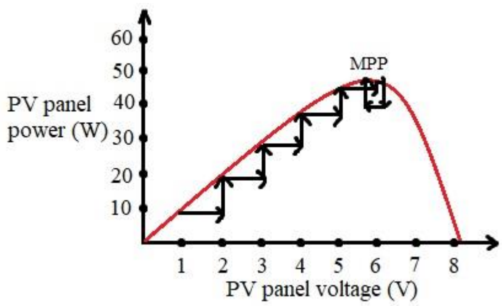

Fig. 11. Output power change of PV

III. Results and Discussion

The results of hardware testing are explained here. This test is carried out with the aim of knowing the performance of the system and knowing whether it is in accordance with the plans that have been made.

A. *Test of SEPIC Converter*

SEPIC Converter hardware can be seen in Fig. 12. As shown in Fig. 13, the SEPIC Converter is tested using a DC power supply and resistor as the load. It is tested in 10 V, 15

V, 17.6 V, 20 V, and 25 V with various duty cycle, they are 0.3, 0.35, 0.4, 0.45, 0.47, and 0.5. The resistor value is 7.96 Ω. This test is done with the aim of knowing whether the SEPIC Converter which is a DC-DC Converter in the system is functioning properly or not. Table III shows the converter test results.

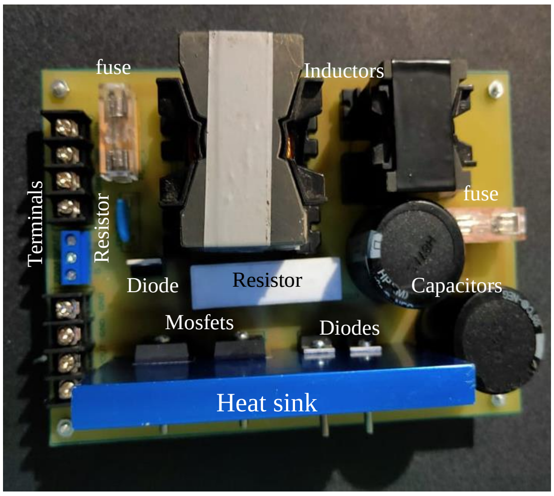

Fig. 12. The hardware of SEPIC Converter

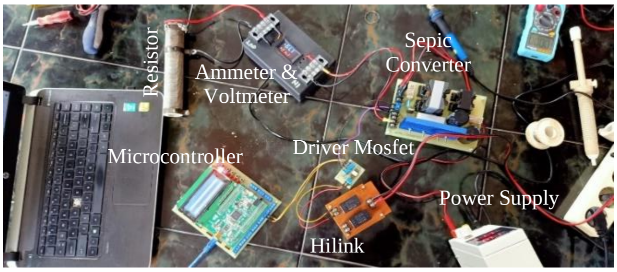

Fig. 13. Hardware test of a SEPIC Converter

As shown in Table III, when testing the hardware of SEPIC Converter, the average output voltage error is 7.9% and the average voltage efficiency is 82.12%. In this case, the SEPIC Converter is able to work well.

TABLE III. TEST RESULTS OF SEPIC CONVERTER

Duty cycle	Vin (V)	Iin (A)	Vout (V)	Iout (A)	Vo theory (V)	Pin (W)	Pout (W)	Error Vo (%)	Eff (%)
0.3	10	0.24	4.519	0.408	4.29	2.4	1.84	5.44	4.519
	15	0.37	6.92	0.626	6.43	5.55	4.33	7.64	6.92
	17.6	0.44	8.22	0.744	7.54	7.744	6.12	8.98	8.22
	20	0.5	9.32	0.86	8.57	10	8.02	8.73	9.32
	25	0.63	11.9	1.097	10.71	15.75	13.05	11.07	11.9
0.35	10	0.36	5.497	0.508	5.38	3.6	2.79	2.09	5.497
	15	0.53	8.39	0.768	8.08	7.95	6.44	3.88	8.39
	17.6	0.62	9.86	0.907	9.48	10.912	8.94	4.04	9.86
	20	0.7	11.17	1.032	10.77	14	11.53	3.72	11.17
	25	0.86	13.94	1.293	13.46	21.5	18.02	3.55	13.94
0.4	10	0.4	5.875	0.545	6.67	4	3.20	11.88	5.875
	15	0.62	9.08	0.834	10.00	9.3	7.57	9.20	9.08
	17.6	0.73	10.74	0.992	11.73	12.848	10.65	8.47	10.74
	20	0.85	12.3	1.142	13.33	17	14.05	7.75	12.3
	25	1.07	15.56	1.451	16.67	26.75	22.58	6.64	15.56
0.45	10	0.6	7.21	0.68	8.18	6	4.90	11.88	7.21
	15	0.94	11.18	1.051	12.27	14.1	11.75	8.90	11.18
	17.6	1.12	13.27	1.247	14.40	19.712	16.55	7.85	13.27
	20	1.28	15.18	1.425	16.36	25.6	21.63	7.23	15.18
	25	1.61	19.15	1.795	20.45	40.25	34.37	6.38	19.15
0.47	10	0.71	7.83	0.737	8.87	7.1	5.77	11.70	7.83
	15	1.1	12.09	1.133	13.30	16.5	13.70	9.11	12.09
	17.6	1.3	14.38	1.346	15.61	22.88	19.36	7.87	14.38
	20	1.49	16.43	1.538	17.74	29.8	25.27	7.36	16.43
	25	1.88	20.7	1.94	22.17	47	40.16	6.63	20.7
0.5	10	0.88	8.74	0.799	10.00	8.8	6.98	12.60	8.74
	15	1.37	13.49	1.25	15.00	20.55	16.86	10.07	13.49
	17.6	1.63	15.95	1.483	17.60	28.688	23.65	9.38	15.95
	20	1.87	18.22	1.702	20.00	37.4	31.01	8.90	18.22
	25	2.37	22.97	2.163	25.00	59.25	49.68	8.12	22.97
Error Vo average (%)									7.90
Efficiency average (%)									82.12

B. Hardware Integration Testing

System integration testing from hardware is carried out with sources from solar panels, SEPIC Converters, and batteries as loads. The value of unstable PV output power is regulated by the SEPIC Converter using a digital PWM Generator by the microcontroller to get the duty cycle according to the conditions that occur.

This hardware used MPPT-CPG control with Variable Step Size Hill Climbing algorithm. The principle and workflow of this algorithm are generally described in Fig. 14.

Based on the flowchart in Fig. 14, there is a process of measuring the value of the input voltage, input current, output voltage, and output current. Then the input power is calculated to be compared with Plimit as the determination of MPPT or CPG mode. MPPT mode is run when Pin<Plimit, if the Pin<Plimit condition does not meet then the running mode is CPG mode. MPPT with Variable Step Size Hill Climbing applies the dP/dV position on the P-V characteristic curve of the solar panel. Maximum Power Point (MPP) is located at dp/dv=0, while dP/dV<0 is to the right of the MPP, and dP/dV>0 is to the left of the MPP. The difference in input power (dPin) is obtained by subtracting the current input power from the previous input power. At initial initialization, the input voltage was previously given a value of 21.9 V because it is in an open circuit state. After determining the dP/dV, the duty is increased or decreased according to the path that occurs. CPG with Variable Step Size Hill Climbing works by paying attention to the power limit, namely by reducing the power limit and the output power of the SEPIC Converter. When there is no difference between the limit power and the output power of the SEPIC Converter, the duty cycle is maintained. Meanwhile, if there is a difference, then the duty cycle is increased or decreased by the value of the step size, which depends on the magnitude of the difference in power.

The result of hardware integration testing can be seen in Table IV. The test was carried out at 11.00 – 16.30 WIB and data was taken every 30 minutes.

TABLE IV. RESULTS OF HARDWARE INTEGRATION TEST

Time (WIB)	Vin (V)	Iin (A)	Pin (W)	Vout (V)	Iout (A)	Pout (W)	Mode
11.00	18.46	1.8	33.98	14.33	1.91	28.1	CPG
11.30	18.37	1.90	33.14	14.33	1.98	27.5	CPG
12.00	18.44	1.8	34.03	14.32	1.87	27.8	CPG
12.30	12.45	2.82	35.86	14.56	1.89	28.4	CPG
13.00	12.51	2.77	35.25	14.58	1.87	27.9	CPG
13.30	10.30	3.59	37.21	14.60	1.96	28.2	CPG
14.00	9.33	3.58	33.4	14.61	1.91	27.9	CPG

Time (WIB)	Vin (V)	Iin (A)	Pin (W)	Vout (V)	Iout (A)	Pout (W)	Mode
14.30	6.12	4.359	26.67	14.00	1.28	18.00	MPPT
15.00	5.69	3.209	18.07	13.94	0.92	12.8	MPPT
15.30	4.72	1.026	4.82	13.36	0.27	3.737	MPPT
16.00	4.56	0.816	3.74	13.43	0.21	2.827	MPPT
16.30	4.06	0.736	2.90	13.41	0.15	2.107	MPPT

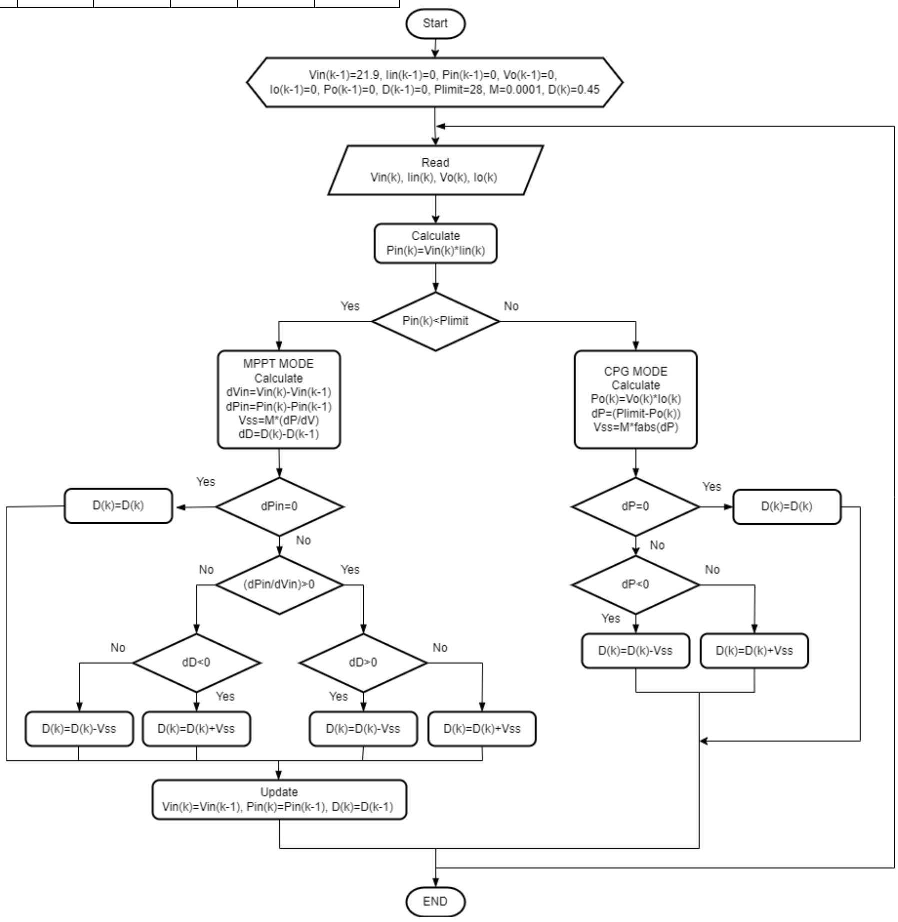

Fig. 14. Integration System Flowchart

From Table IV, it can be seen that in CPG mode, the constant power fluctuates by an average of 27.97 W. On the data at 14.30 – 16.30 WIB, MPPT has maximized the PV output power or the input power of the SEPIC Converter but cannot reach the power limit, so the battery does not charge.

IV. Conclusion

MPPT-CPG applied to SEPIC Converter using Variable Step Size Hill Climbing algorithm has been discussed here. The test results show that all parts can work properly, MPPT can find the maximum power that can be issued by the solar panel when the power is less than the limit. Also when the output power of the SEPIC Converter is more than the limit power, the CPG mode can limit the SEPIC output power with an average of 27.97 W, which is near to the limit power. So that, the battery can be charged.

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