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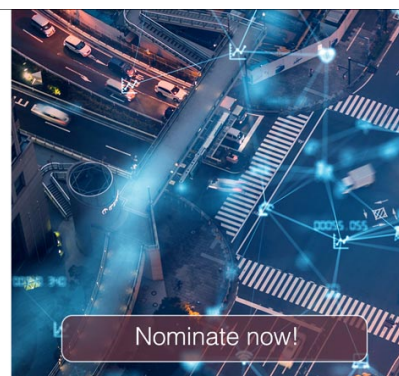


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Analysis of PWM- and MPPT-solar charge controller efficiency by simulation

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Abstract. Indonesia is a tropical country having high potential of solar energy. In contrary, solar irradiation is varied due to obstruction of the sun by clouds, the difference of intensity of the sun all day, the occurrence of clouds during the rainy season, and the presence of fog in certain areas making it irradiation rate of solar light thus causing the solar cell output power to be varied and not optimum. Therefore, control device is needed to stabilize output power from solar cell, called solar charge controller. This study aims were to measure its efficiency values and compare two type of SCC, *i.e.* PWM and MPPT. Solar cell voltage and current were obtained by measuring those parameters manually from solar panel on the field and analysed by MATLAB. The data showed that power value, voltage, and influx produced by MPPT were 6.23 W, 12.39 V, 4.9 A and PWM were 6.04 W, 12.16 V, 4.8 A. Average efficiency value of PWM was 172% and MPPT was 177%. Data analysis revealed that MPPT have superiority accorded to its power value, voltage, and influx compared to PWM. By this, MPPT was preference application onto solar harvesting system.

1. Introduction

Global energy consumption is predicted to continuously increase with the human populacy growth and technology advances. In fact, energy demand from 2000 to 2030 was estimated to increase by 70% [1]. Oil fuel was recorded as contributing the largest energy consumption, which was up to 80% of total world energy consumption [2]. Since the increasing energy demands, limited energy sources, and the earth protection of global warming, we need a solution to create new and eco-friendly technology for clean-renewable energy sources. RES was one of the most efficient and effective actions to solve the increasing human energy needs [3]. However only 0.3 percent of the electrical energy came from solar power [4].

The energy released by sunlight outside the earth's atmosphere is 1366 W/m^2 . Meanwhile, the sun's energy when it reaches the earth's surface is only 160 W/m^2 [5]. The supply of solar energy from sunlight that is received by the earth's surface is enormous, reaching $3 \times 10^{17} \text{ J/year}$, this energy is equivalent to $2 \times 10^{17} \text{ W}$. So, by covering just 0.1% of the earth's surface with solar cells that have an efficiency of 10%, it is able to cover energy needs around the world today [6].

Indonesia is a tropical country having huge potential solar energy. This is because Indonesia's territory stretches across the equator with a large irradiation of $4.80 \text{ kWh /m}^2/\text{day}$ [4]. However, the level of solar energy irradiation varies in time. This causes the power generated by solar cells to vary and un-optimal. In order for the maximum power generated by solar cells, a solution is needed. So that



the utilization of solar energy in Indonesia can be optimal. One of the efforts that can be made to maximize solar cells is by using a controller.

A controller that can be used to stabilize the energy produced by solar cells is called the solar charge controller (SCC) [7]. The common SCC used to stabilize energy are the Pulse Width Modulation (PWM) [8] and the Maximum Power Point Tracker (MPPT) [9]. The PWM type controller takes advantage of the pulse width to get a desired output voltage value [10]. Whereas for the MPPT type, it uses a special point which is usually called the Maximum Power Point (MPP). Where at this point, the solar cell produces the highest voltage and electric current.

Kinerja PWM controller telah ditelaah saat diaplikasikan pada sistem turbin [11], sedangkan telaah sistem MPPT controller telah dilakukan melalui simulasi dan modeling [12-14], dan telah ada review pengaplikasiannya pada sistem photovoltaic [15]. Penelitian ini merupakan telaah dari kedua tipe controller, yaitu masing-masing kinerja PWM dan MPPT controller menggunakan simulasi dan membandingkannya untuk mendapatkan telaah ilmiah tentang kinerja yang lebih baik dari keduanya menggunakan data riil keluaran dari sel surya yang mengkonversi energi matahari langsung di siang hari.

2. Methods

Research related to the comparative analysis of SCC types of PWM and MPPT was carried out in the yard Faculty of Mathematics and Natural Sciences, Gedung D12 Universitas Negeri Semarang. The tools and materials used for research and analysis were MATLAB software, digital multimeters solar cell that produces voltage and current whose data was taken for processing using MATLAB to be simulated.

Where in this study was divided into 3 parts, namely assembling solar cells in series-parallel so as to get the expected voltage and current. Then simulate the data obtained from solar cells into two types of SCC so as to get a more stable power. Then, the processed data was displayed in the form of a plot image where the x-axis was the time (t) and the y-axis was the magnitude (power, voltage, and current) and compared.

3. Results and Discussion

The SSC was an electronic device used to control the current (current regulator) both the current entering the solar cell to the battery and the output load. In addition, SCC also worked to keep the battery from overcharging so that the battery lasts longer.

The test was carried out by a simulation method using the MATLAB *simulink* application with voltage and current data from solar cells. The solar cell used was a silicon polycrystalline type of 24 pieces assembled in series with dimensions 208 mm \times 156 mm. This test aimed to compare the performance between the two types of SSC that were often used in solar power plants systems, namely the PWM and the MPPT.

3.1. PWM Solar Charge Controller Type

PWM SCC was a solar cell power controller that uses pulse width modulation technology. This SCC test utilized the MATLAB *simulink* simulation as seen in Figure 1. The PWM signal generator used for the simulation was a pulse generator tool found in the Matlab *simulink* block. Then the input was controlled by the mosfet through the inductor and part of it passed the capacitor and to the output. The output produced a stable voltage with little ripple, likewise for other outputs in the form of power and current.

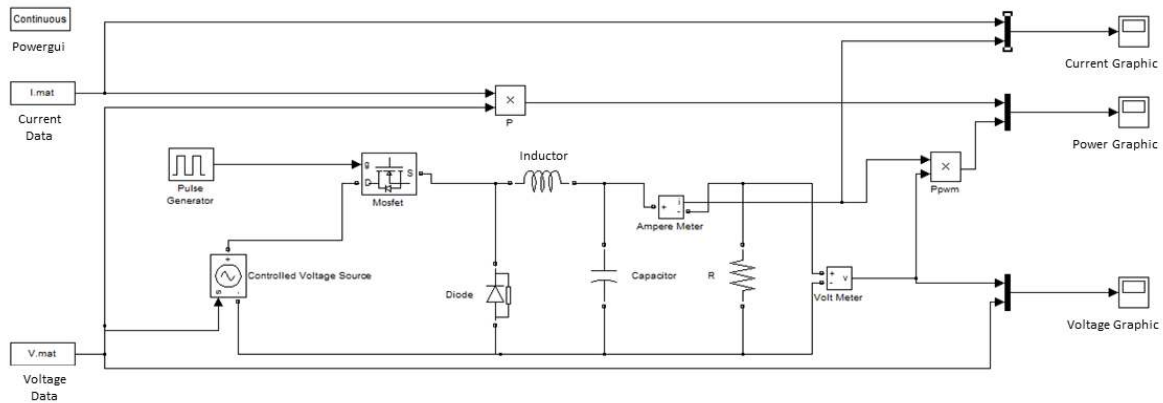


Figure 1. Simulink simulation of PWM SCC

3.2. MPPT-type Solar Charge Controller

The type of MPPT used in this research was the Perturb and Observation algorithm, Figure 2 was a simulink simulation of the algorithm that has been built.

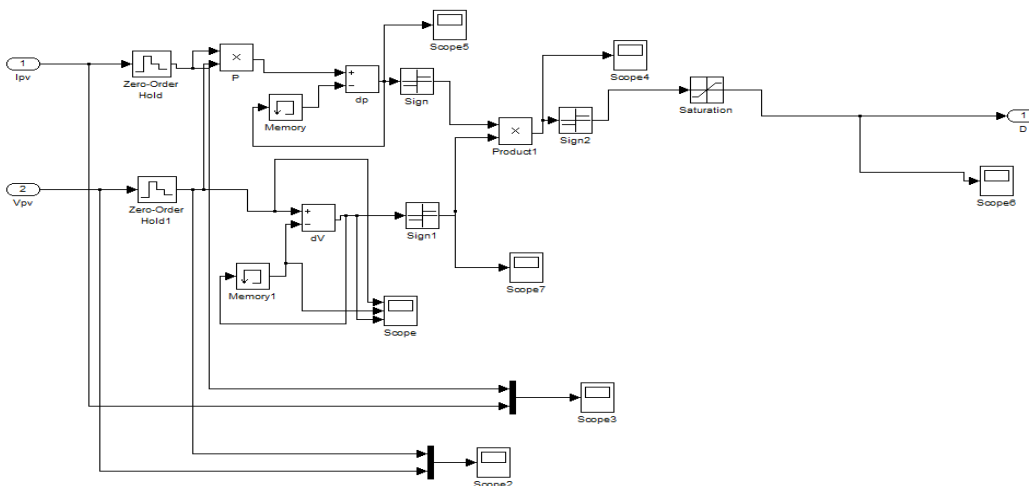


Figure 2. MPPT Perturb and Observe-type SCC algorithm

The controller adjusted the voltage parameters and then measured the amount of power at that voltage. As the power increased, the voltage parameter increased continuously until the power value was stagnant [16]. In starting condition of system operation, the input block provided an input signal in the form of voltage $V(n)$ and current $I(n)$ at that time. From these two values, the power value $P(n)$ was obtained. The value of the voltage and power on the solar cell was stored in a memory block, then the next value at the $P(n+1)$ value was measured again and the power was calculated from the measured value. The power and voltage at $V(n+1)$ were reduced by the value of $V(n)$. If we observed the power-voltage curve of the solar cell module, the slope of the power voltage was negative ($dP/dV < 0$) where as on the left side. The slope was positive on the right side curve where the voltage was almost constant, ($dP/dV > 0$). Depending on the signs $dP(P(n+1) - P(n))$ and $dV(V(n+1) - V(n))$ after the reduction the algorithm decided whether to increase the duty cycle or to reduce it. The sign block functions was to make the signal value become one if the input was greater than zero or the signal become zero and negative one when the input was less than zero.

3.3. Comparison of Power, Voltage and Current in Solar Cells, PWM, and MPPT

Based on the research that has been done, there was a difference between the average power, voltage, and current from the PWM and MPPT which can be seen in Table 1.

Table 1. The power, voltage, and current from solar cells, PWM, and MPPT.

Controller	P (W)	V (V)	I (A)	η (%)
Solar cells	3.5064	12.58822	0.27844	-
PWM	6.04207	12.16596	0.486348	172
MPPT	6.238015	12.39209	0.49551	177

Table 1 showed the data that has been taken from 24 solar cells arranged in series sized 208 x 156 mm², where the power, voltage, and current generated by the MPPT were always higher than the PWM system. It can also be seen that the efficiency produced by the MPPT type SCC was 5% greater than the PWM type SCC. Figure 3 showed the voltage generated by both the SCC and the voltage from the solar cell.

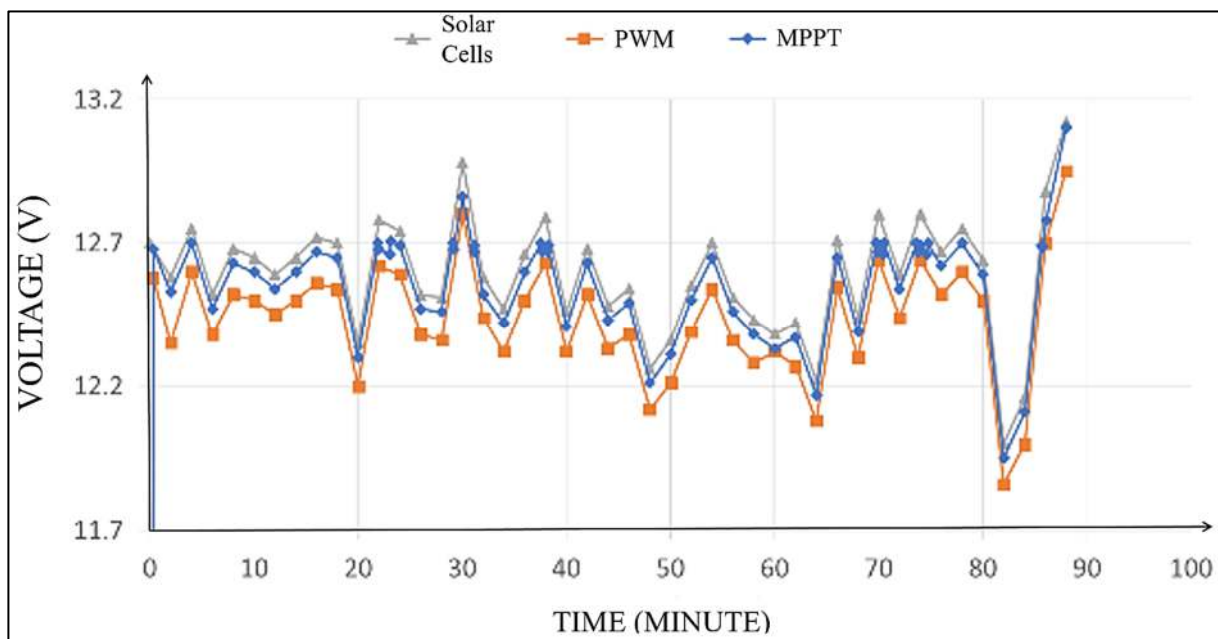


Figure 3. The Voltage Graph Comparison on Solar Cells, PWM-type SCC And MPPT-type SCC

Figure 3 showed the voltage conditions on the two controllers are lower than the two types of SCC, this was because this SCC works in a buck converter, where the output voltage condition would be lower than the input voltage to increase the current value. This was supported in research by Utami (2017) [17]. Figure 4 showed the current generated from the solar cell and that has passed the SCC.

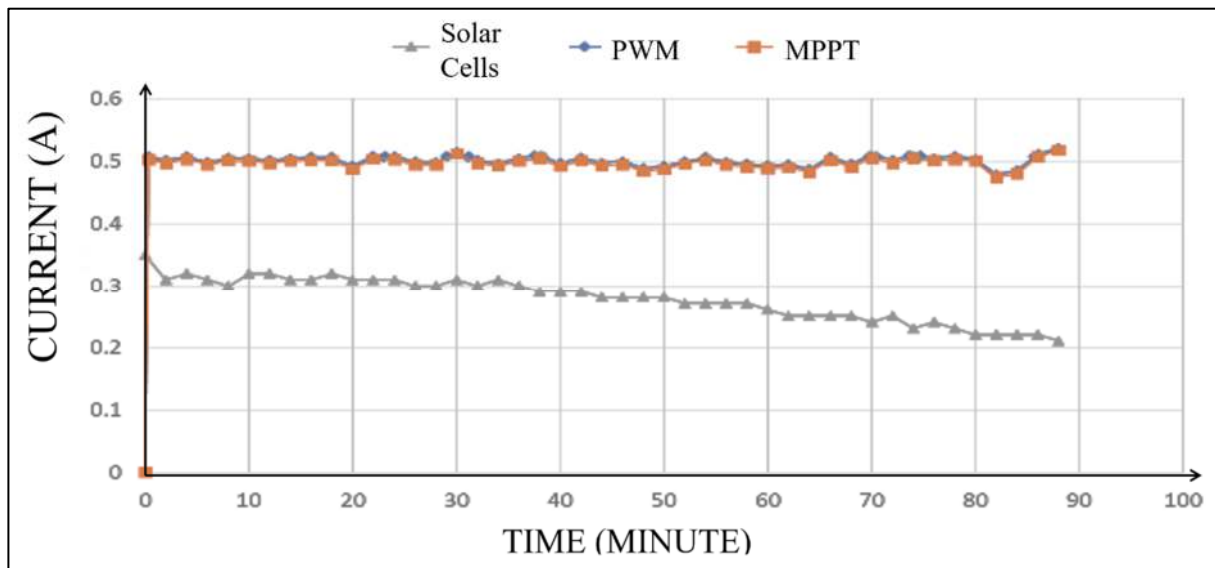


Figure 4. The Current Graph Comparison on Solar Cells, PWM, and MPPT

As can be seen in Figure 4, the current generated from the two types of SCC is about 0.5 A increasing 90-110% of the current generated by the solar cell. In a study conducted by Laguado-Serrano (2019) [18], in this state, the SCC works in a bulk state where the maximum current generated by the SCC was for charging the battery in an empty state to 80%, and then it entered the absorption condition when more than 80% of the battery was charged, however because in this study it did not use batteries in the simulation, SCC only worked in bulk conditions where the resulting current was always maximum.

Previous research stated that the PWM SCC had a tendency to decrease in efficiency if the battery voltage capacity was much lower than the solar panel, this was because the current delivered by the PWM SCC was a constant value while the voltage which was delivered adjusting the battery voltage [19]. Moreover, the MPPT SCC using the P&O algorithm worked in buck converter conditions so that the resulting voltage was lower than the solar cell and the higher current resulted in the output power to the battery which was always close to the power generated by the solar cell even under unconstantly conditions of lighting and temperature.

The MPPT SCC based on the P&O algorithm was able to increase the power efficiency of solar cells by 86% and for P & O-fuzzy by 89% with the test conditions carried out at 12.00 WIT when the sun was not obstructed by clouds [20]. The results of Victor (2019) research revealed the same tendency of this finding that the MPPT SCC being superior to the PWM SCC [19]. While the difference in the magnitude of the efficiency obtained from the research conducted by Machmud (2017) and this research probably occurred because of the use of different equations in analysis [20].

4. Conclusion

Comparison of power output (P), voltage (V), and current (I) on SCC of PWM and MPPT showed that MPPT SCC was more superior than PWM SCC. This was indicated by the difference in power, voltage, and current produced by the MPPT SCC of 0.07 watts, 0.09 volts, and 4.2 milli amperes higher than the power generated by the PWM SCC. The average efficiency value of the PWM SCC was 172% while the average efficiency value of the MPPT SCC was 177%. The MPPT SCC had higher power, voltage and current values compared to the PWM type controller, so that the MPPT SCC was better applied in solar power generation systems.

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