

FOCV-ased Control Scheme for a Hybrid Solar Panels Application

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Abstract This paper discusses the use of the Fractional Open-Circuit Voltage (FOCV) method to track the maximum power generated by solar panels. The implementation of the FOCV method has been conducted in the form of a hybrid solar panel to discover the actual results. The implementation was in several lamps containing relays, allowing them to obtain energy sources from PLN or solar panels. The number of lights switched to the solar panel source depended on the generated power, and this power was tracked using the FOCV method. The greater the power generated by the solar panel, the more lights were switched to use the solar panel source. The FOCV method was the simplest of other MPPT methods and was suitable for small-scale solar panels. The FOCV method was based on the characteristics of solar panel data. The characteristics of a solar panel must be identified first to build an algorithm from this method. In this study, various output characteristics of solar panels, such as under varying irradiation and varying temperatures, were simulated with MATLAB software. A simulation of a circuit of buck converters connected to solar panels and a control algorithm containing the complete FOCV was also conducted. A prototype implementation was made using an Arduino microprocessor in translating the FOCV method algorithm.

Keywords: FOCV, solar panels, a hybrid solar panel

1 Introduction

In recent years, the demand for electrical energy has grown continuously. Thus production continues to increase. Currently, power sourced from solar panels is proliferating [1]. Unpredictable weather factors make solar panels the primary source of electrical energy unreliable because they cannot produce energy constantly like a generator engine for electricity generation. When this energy source is combined with other energy sources to power the electrical load, it is necessary to determine when the maximum capacity is generated by finding the maximum power point (MPPT)[2]. When the total power generated by the solar panel is identified, the next task is a DC to DC converter, which will convert the energy so that electrical loads can use it. The maximum power operating point is obtained by adjusting the electrical load suitable for the solar panel. A control system is needed to regulate the solar panels to produce more electrical power [3].

The maximum power that a solar panel can produce is influenced by sunlight, temperature, and electrical load. The total power point of the solar panel is the relationship between variables I and V , where the variables depend on the sunlight and the temperature on the panel. The greater the sunlight obtained, the greater the value I will be. Meanwhile, if the temperature increases, the value of V will be decreased. The maximum power that a solar panel produces is called MPP. The point where this maximum power is located in a multiplication between the variables I and V . In its implementation, increasing the electrical load connected to the solar panel will cause more current to flow into the load resulting in a decrease in the output voltage of the solar panel. It will cause the solar panels will not to produce maximum power. On the other hand, the current will decrease if the electrical load is reduced, yet the voltage will increase. An MPPT (Maximum Power Point Tracker) algorithm is needed[4].

The Fractional Open-Circuit Voltage (FOCV) algorithm and the Fractional Short-Circuit Current (FSCC) algorithm are the simplest algorithms to find MPPT on solar panels. More complex algorithms such as the Hill Climbing (HC) algorithm, the Perturb & Observe (P&O) algorithm, the Incremental Conductance (INC) algorithm, the Bisection Numerical Algorithm (BNA), Artificial Neural Network (ANN) techniques, and Fuzzy Logic Control (FLC) require a high level of programming [5].

Figure 1 shows a schematic form of a solar panel system. This scheme consists of solar panels, converter, control unit, and load. The DC-DC converter served to make the voltage required by the load[6]. The input power is the same as the output power in this converter. The difference between the input and output is the amount of current and voltage. For solar panels to produce maximum power, this converter must regulate the voltage and current that must be issued to be given to the electrical load. MPPT methods have been widely discussed in several books and journals with the basic concept of simply setting the appropriate voltage and current points. Thus maximum power was obtained. Generally, this MPPT method is divided into online and offline. The offline method includes the Fractional Open-Circuit Voltage (FOCV) method[7].

In the online MPPT method, such as the Perturb & Observe (P&O) algorithm, complex systems require a microprocessor with high specs in coding this algorithm, resulting in greater power consumption for algorithm processing. In the offline method, the system is straightforward in finding MPPT by conducting an open circuit process for the Fractional Open-Circuit Voltage (FOCV) and a short circuit process for the Short-Circuit Current (FSCC). The process is continued by taking measurements, and the data obtained is used to calculate the maximum power from the available functional equations. The offline method consumes less energy for algorithm processing purposes. The online method is more advance when judged from the level of accuracy in determining MPPT [7].

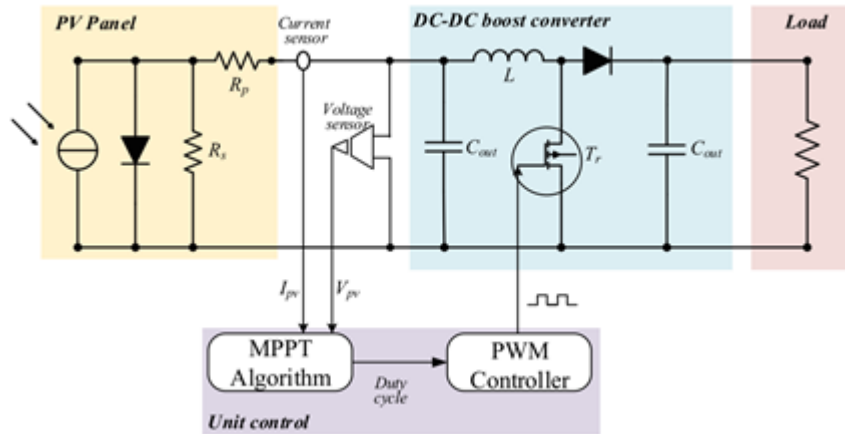


Fig. 1. Circuit schematic of a solar panel system containing an MPPT unit [6].

For the implementation of small and medium-scale solar panels, the Fractional open-circuit voltage (FOCV) method was the most suitable because this method is easy to apply to the algorithm. Besides, the microprocessor used for processing the algorithm consumes less energy. In simple terms, this method works by breaking the circuit that connects the solar panel to the electrical load. Then measurements are made with sensors to determine the open-circuit voltage. This voltage was used to find the peak voltage at maximum power with the formula $V_{mpp} = v \cdot V_{oc}$. The value of v is a constant obtained from the experimental process to determine the characteristics of a solar panel. In this FOCV method, the sampling process was carried out periodically by breaking the circuit to get the V_{oc} value. There is a linear relationship between V_{oc} and V_{mpp} [2].

In this paper, the characteristics of solar panels on irradiation intensity were simulated and analyzed using MATLAB software. This characteristic analysis becomes the basis for making algorithms from the FOCV method. This algorithm was integrated with the buck converter to produce maximum power generated from the solar panels. Furthermore, this algorithm was implemented into a prototype of a hybrid solar panel system and PLN to find out the real benefits of this method. The FOCV method was tested to determine the number of lights that must be switched to the Solar Panel source from PLN. The decision to determine this switch is the ability of the FOCV method to track the amount of power generated by the solar panels. The greater the power produced by the solar panel, the more lights connected to the solar panel and vice versa.

2 Effects of temperature variations and changes in radiation on solar panels

Analysis of solar panels and their modeling was provided in previous studies. A representative circuit of a solar panel is shown in **Figure 2**. There is an I_{ph} current source in this circuit where the amount of current generated was dependent on the sunlight obtained. A diode functioned as a forward bias when no load was connected or open circuit. Series and shunt resistance are properties of a material that always has resistance. The value of this resistance was changed because of the influence of temperature. When the temperature on the panel increases, the value of this resistance will increase so that the V_{OC} voltage will also increase, yet the current that comes out will decrease[8].

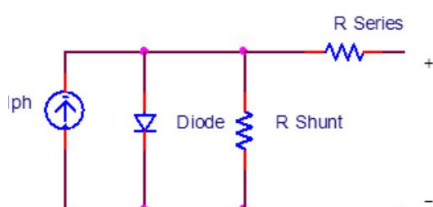


Fig. 2. A representative circuit of a solar panel.

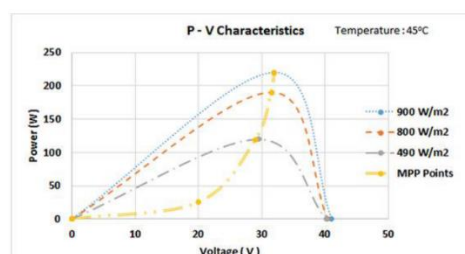


Fig. 3. The effect of differences in sunlight on the power and voltage generated by solar panels.

From **Figure 3**, the I_{ph} current source increases as the sunlight hitting the panel increases and vice versa. The voltage measured on the solar pad is influenced by two variables, namely current and resistance. Current is affected by the amount of sunlight. Moreover, the resistance is affected by the temperature in the solar panel. Tests on the effect of power and voltage have been carried out by [9] using a solar panel specification of 250 Watt, the voltage at the time of the open circuit is 44V, the voltage and current to produce a maximum power of 36V and 7A, respectively, the current generated in the short circuit is 8.2 A.

However, the research conducted by [10], who investigated the output characteristics of solar panels through observation and analysis using different solar light intensities, revealed that the maximum power produced by solar panels was different. However, the open-circuit voltage has almost no change or remains constant. It would be a useless solution if measuring maximum power based on open-circuit voltage.

3 The method of fractional open circuit (FOCV)

The basic principle of the FOCV algorithm is to calculate the maximum power produced by a solar panel at a specific time by measuring the open-circuit voltage V_{OC} generated by the solar panel. This V_{OC} changes based on the temperature and sunlight intensity. From several studies and literature books, when the solar panel is produced, the maximum power of VMPP is in the

range of 0.6 to 0.8 times the voltage V_{oc} . By knowing the V_{MPP} voltage, the solar panel's amount of energy can be identified. Facts in the field that the installed solar panels get extreme conditions such as the intensity of light that suddenly changed drastically, shadows on the panels, and sometimes the temperature of the panels was very high so that the V_{OC} voltage did not become linear with V_{MPP} . In this condition, a smarter control system is needed so that the FOCV algorithm can work well.

One way to overcome this shortcoming is to perform a time-based circuit break. The time for the V_{oc} measurement was carried out by considering several conditions, such as temperature and sudden changes in lighting. The solar panel voltage was monitored, stored, and analyzed then the FOCV algorithm was applied to obtain the V_{oc} . This technique was enabled to overcome the shortcomings of the FOCV algorithm because the voltage data collection process was carried out at the right time.

The Perturb and observation algorithm compares the FOCV algorithm with other algorithms that are better at dealing with extreme lighting changes and high panel temperatures. However, unfortunately, this algorithm required two sensors to work, namely the current and voltage sensors, where the FOCV algorithm only requires one sensor, namely the voltage sensor. The weaknesses in the FOCV algorithm were overcome by the advantages on the other hand, such as a lighter computational load when searching for the maximum power being generated by solar panels. The linear relationship between V_{MPP} and V_{OC} was slightly disturbed under extreme changes in sunlight intensity and temperature, which can be overcome by time-based control [11].

$$V_{MPP} \approx k_v \times V_{OC} . \quad (1)$$

From equation (1), the k_v value was obtained by measuring the solar panels used. Different lighting and temperatures were applied to the panel, and then V_{OC} and V_{MPP} measurements were taken. According to several experiments, it can be calculated to get the value of k_v where this constant value was obtained and produces a linear equation.

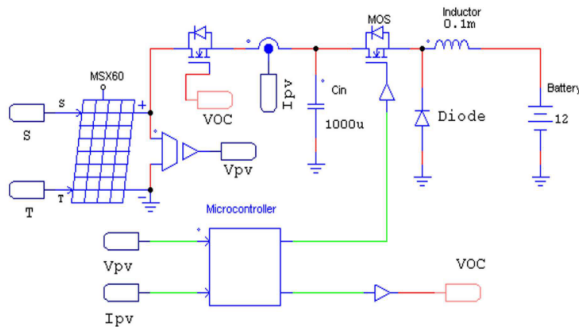


Fig. 4. Circuit schematic of a solar panel system containing the MPPT algorithm.

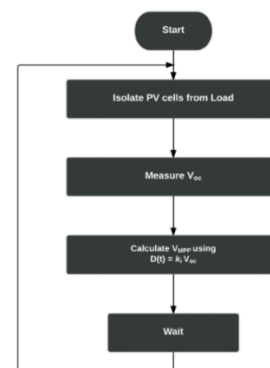


Fig. 5. Flowchart of the FOCV algorithm.

The flowchart in **Figure 5** can be explained as follows. The solar panels were disconnected from the electrical load. Then the V_{OC} voltage was measured. After that, the V_{MPP} was calculated using the k_v formula multiplied by V_{OC} . The k_v value was constantly determined from 0.7 to 0.8, provided that the solar panel temperature was between 0 to 60°C. After the V_{MPP} value was obtained, based on the datasheet from the solar panel, the power currently being generated by the solar panel was obtained. Then, the converter was turned on to supply this electrical power to the load. The disconnection of the solar panel to the load was determined based on the specified time. When the irradiation fluctuation was too large, the V_{OC} data collection period could be accelerated so that the actual condition of the solar panels could be identified. The result is that much of the solar panels' electrical power was wasted.

4 MATLAB simulation

Figure 6 presents a simulation carried out in the Simulink MATLAB software. The sampling time used in this simulation was 1×10^{-8} s. This simulated circuit schematic contained a solar panel with a maximum power of 30 Watts. A DC-DC converter is also used to convert the voltage generated by the solar panel into the voltage level required by the load. A switch is also used to cut off power from the solar panel to the converter. This switch was controlled by a function block that contained the FOCV algorithm.

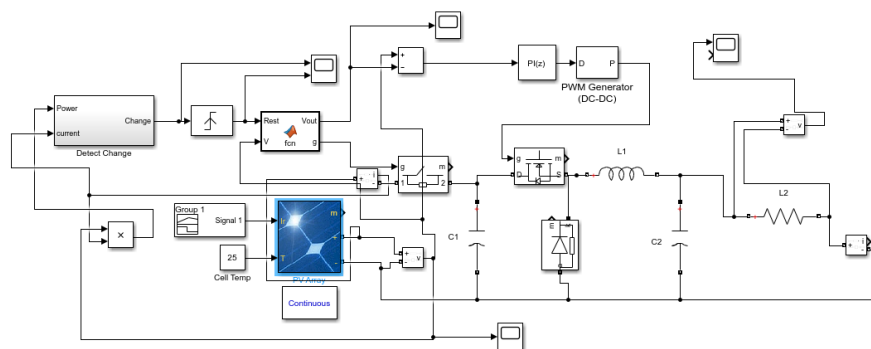


Fig. 6. Simulation of solar panel system in MATLAB.

The primary task of this circuit is to calculate the value of the V_{mpp} voltage. The unit function that contained the FOCV algorithm issued an output that functions to control Switch 2. This switch was opened if the unit function needed to get solar panel voltage data. When it was opened, it meant that the solar panel was not loaded, so that the measured voltage was the open-circuit voltage. This voltage value was an input for the unit function in calculating the power that the solar panel was producing. Based on this power, the unit's function controlled Switch 1 to generate a PWM signal on the converter. Through this converter, the properties of electrical power, namely the current and voltage generated by the solar panel, were converted according to the needs of the connected electrical load.

The V_{mpp} voltage value became a scale reference in knowing the maximum power produced by the solar panel. The value of the V_{mpp} voltage was obtained by the formula $V_{mpp} = V_{oc} \cdot K_v$. The V_{mpp} value was not available continuously but discretely within a specific time range, set by the unit function. If there was more than one solar panel installed, it was enough to take measurements on only one panel, then multiplied the number of available panels to get the maximum overall power, assuming that the panels were installed in parallel. The unit function will set the converter to produce the appropriate output power.

The simulation in **Figure 7** resulted in the solar panel constant illumination of 1000 W/m^2 . The measurements got an open-circuit voltage V_{oc} of 13.48 V . Therefore, based on the calculation of the voltage, when the solar panel produced maximum power, the V_{mpp} was $V_{mpp} = V_{oc} \cdot K_v = 12.24 \text{ V}$. From the results of this calculation, the unit function made a PWM signal for the DC-DC converter produced a voltage of 12.24 V .

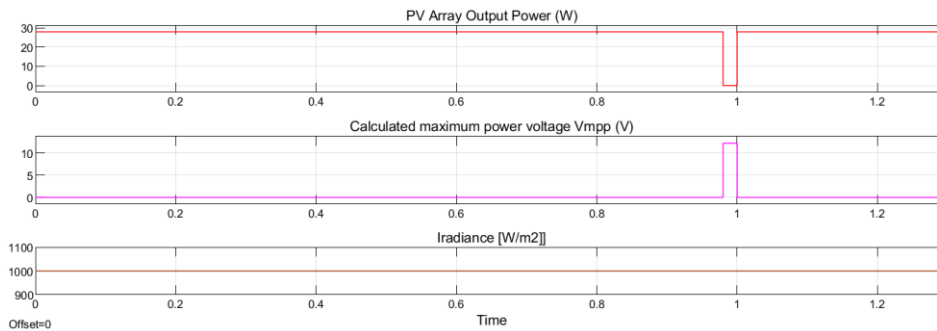


Fig. 7. Simulation results in MATLAB with constant sunlight parameters of 1000 W/m^2 .

The simulation in **Figure 8** was performed by suddenly lowering the sunlight. It was initially set at 900 W/m^2 , then suddenly set at 600 W/m^2 . During the measurement period, the open-circuit voltage was read at 13.39 V . So, the DC-DC converter issued a voltage equal to the V_{mpp} calculation, which is 10.92 V . When the sunlight suddenly changed to 600 W/m^2 , the data collection period has not occurred, so that the V_{oc} read was still 13.39 V . Thus, the voltage issued by the converter remained, even though the actual power generated by the solar panel had changed. It causes interference or confusion when the solar panels work with other energy sources to supply the electrical load. Based on the simulation, it can be concluded that the FOCV method was only suitable for constant irradiation.

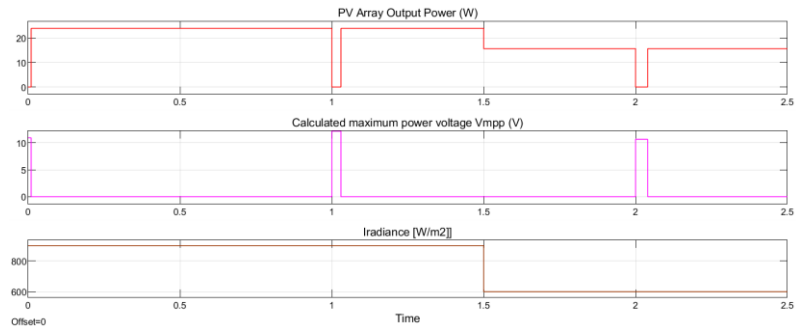


Fig. 8. The simulation results in MATLAB when the sunlight changes suddenly from 900 W/m² to 600 W/m².

5 Implementation of the VOC method on hybrid solar panels

The FOCV method that has been simulated with MATLAB was then implemented on a prototype solar panel hybrid system. This hybrid solar panel system consisted of several lamp loads that were connected in a hybrid way to PLN and the solar panel. A switch was used for each lamp load to determine whether a lamp load should be connected to PLN or a solar panel source. This switch was controlled by an Arduino microcontroller which contains the FOCV algorithm.

When the solar panel was not producing electricity, no lights would be switched to use the energy source from the solar panel. Meanwhile, when the solar panel produced less energy, some lights would be switched to the solar panel source. Moreover, if the solar panels produced much energy, many lights would be switched to the solar panel source. The number of lights switched to the solar panel energy source depended on the power being generated by the solar panel.

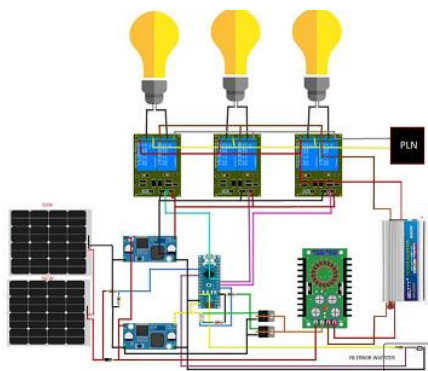


Fig. 9. Circuit schematic of a prototype hybrid solar panel system.



Fig. 10. The hybrid solar panel system prototype.

Experimental implementation of the FOCV method algorithm in this implementation used a solar panel with a maximum total power of 100 Watt. The total load used was 90 Watts consisting of three light bulbs of 30 watts each. These three lights were switched to the solar panel or PLN. The process of switching to this solar panel required the process of tracking the power being generated by the solar panel. This power tracking process used the FOCV method, simulated with MATLAB.

The experimental implementation of the FOCV method found that the power tracking process has been successfully carried out, evidenced by the number of lights connected to the solar panel depending on the power generated that was already working, as seen in **Table 1**.

Table 1. The power generated by the solar panel and the number of lamps connected to the solar panel.

The electrical power generated by solar panels	The number of lights connected to the Solar Panel
0 – 30 Watt	0 lamp
31 – 59 Watt	1 lamp
60 – 89 Watt	2 lamps
90 – 100 Watt	3 lamps

Testing the FOCV method in real terms in the form of observable implementation has been carried out in this study. The process of tracking the amount of power generated by solar panels can be seen from the number of lights connected to the solar panel energy source. From this research, it can be analyzed that the MPPT FOCV algorithm was very suitable for making hybrid solar panel applications. The simplicity of this algorithm and its capabilities made this method suitable for hybrid solar systems in households.

6 Conclusion

The FOCV method has been simulated and tested in real terms through the implementation of a prototype. Since the MPPT method was based on information from a solar panel, identifying the output characteristics of a solar panel based on the intensity of light is very important. This paper presents the voltage factor as a constant multiplier with the voltage of the solar panel without a load to get the voltage at the maximum power generated by the solar panel. This voltage factor was expressed in changes in irradiation and temperature. The presentation of actual evidence of the FOCV method has been made in a prototype implementation. From this prototype, it can be seen that the power was generated by the solar panels.

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