Designing ANFIS Controller for MPPT on Photovoltaic System

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Abstract—Photovoltaics’ current and voltage output characteristics depend on the intensity of solar radiation and temperature. Maximum Power Point works with maximum energy output and has the highest efficiency. The maximum energy point tracking method (MPPT) keeps the solar cell operating point at its maximum point. This study uses the Adaptive Neuro-Fuzzy Inference System (ANFIS) method designed and used to maintain that point. The Perturb and Observe (PnO) method is used to test the results, often used in determining this tracking. Based on the test, it was found that the average power efficiency obtained was 84.79%, and using PnO was 83.87%. The transient response using ANFIS is relatively smoother than that of using PnO, which will cause chattering when there is a change in radiation and temperature.

Keywords: Photovoltaic, MPPT, ANFIS, PnO

I. INTRODUCTION

Indonesia is a tropical country with a solar energy potential of 536 GW, of which only 152 MW is utilized or around 0.028% [1][2]. As a type of renewable energy, solar energy has advantages compared to others, namely the ease of implementation. The ease of implementation is used in the DKI Jakarta, Central Java, and Bali province to utilize photovoltaic as a rooftop [1]. The constraints when applying solar energy are the intensity of solar radiation and fluctuating weather that can affect the output of the electrical energy produced. Weather changes cause the electricity generated to change periodically. This results in the characteristics of the output power of the solar cell being unstable and varying according to the radiation and surface temperature of the solar cell [3]. The current technology to overcome fluctuations in the intensity of solar radiation and weather is the Maximum Power Point (MPP), where with this technology, the maximum power output is obtained [4][5][6]. Usually, there is a point on the V-I curve or V-P curve, which is called the maximum power point [7]. At this point, the solar cell works with maximum power output and has the highest efficiency.

The MPP is unknown but can be found by calculating the solar cell’s operating maximum point [8]. Based on the above background, this research is directed at designing an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller for a Maximum Power Point Tracker (MPPT), which is then tested on temperature and radiation change data contained in photovoltaic readings that have been obtained previously. The reason for using the controller (ANFIS) is because it can be used to perform estimations with high accuracy [9][10]. In a microgrid distribution system, to maximize the power output of (PV) and (WT), the ANFIS method has a maximum optimal efficiency [10].

II. LITERATURE REVIEW

A. Photovoltaic

Solar cells are devices in the form of semiconductors that can convert sunlight into electricity. Photovoltaic is a device consisting of solar cells that convert sunlight into electricity. Solar panels consist of many solar cells that can be formed in series or parallel [11]. Solar cells are semiconductor components that can convert solar energy into electrical energy based on the photovoltaic effect. The power that can be obtained is very cheap because it is free from solar energy.

The solar cell has a simple structure, namely the connection by two P-type and N-type semiconductors. In this P-N junction, three different regions are formed. The first region is the P-type which has mostly hole charges; the second region is the N-type, most of the charge is electrons; and the last region is the discharge region, where the internal electric field changes from N to P. This can form electrons and holes, then due to the influence of the internal electric field, the hole moves to P (the main charge carrier is the hole), and the electron moves to N (the main carrier is the electron). So, these two motions produce a photo diffusion current. In the discharging area after the movement earlier, there may also be pairs of holes and electrons. Due to the same internal electric field, these electrons move in the dominant direction, resulting in a current [3].

A photovoltaic can be modeled by constructing an equivalent circuit consisting of a current source, diode, and resistor arranged as shown in Figure 1. The equivalent circuit can be applied to define the characteristics of the module. Characteristics that can be calculated are the
characteristics of the voltage and current relationships of solar panels, as well as the relations of photovoltaic voltage and power. The relationship between the three variables can form a graph of photovoltaic characteristics. Temperature is an important parameter to know its characteristics, although it is difficult to know the actual temperature parameter, so the temperature of the solar cell must be measured directly on the surface.

The value of the current flowing from the solar panel \( (I_{ph}) \) is affected by solar radiation and ambient temperature as in Equation (1), where \( I_{sc} \) is the short circuit current, \( K_i \) is the temperature constant, \( T \) is the ambient temperature, \( I_r \) and \( I_r \) is the sunlight intensity. The amount of output current generated can be affected by the current in the diode \( (I_D) \) and the current in the parallel circuit \( (I_{sh}) \). Therefore, the amount of output current can be calculated by Equation (2). Then to find the current flowing through the diode, you can use Equation (3), where \( q \) is the electron charge, \( V \) is the output voltage of the solar panel, \( R_s \) is the value of the series resistance on the solar panel, \( k \) is the Boltzman constant, \( I_o \) and \( I_o \) is the diode saturation current [7].

\[
I_{ph} = \frac{I_{sc} + K_i (T - 298) I_r}{1000}
\]

\[
I = I_{ph} - I_D - I_{sh}
\]

\[
I_D = I_o \left[ \exp \left( \frac{q(V + IR_s)}{nkT} \right) - 1 \right].
\]

Based on equations (1), (2), (3), an equation for the relationship between the current value and the voltage value that comes out of the solar panel can be obtained as in Equation (4) [7].

\[
I = I_{ph} - I_o \left[ \exp \left( \frac{q(V + IR_s)}{nkT} \right) - 1 \right] \cdot \frac{V + IR_s}{R_{sh}}.
\]

Based on this equation, the operation of solar panels can be described in the V-I characteristic curve. Under the solar panel’s fixed irradiation and operating spot temperature, it forms an intersection between the I-V characteristic graph and the load characteristic graph. The operating spot of the panel moves from zero resistance (causing \( I_{sc} \)) to unlimited resistance (causing \( V_{oc} \) to appear). Regarding these characteristics can be seen in Figure 2.

When the load and environmental conditions change, the maximum output power of the solar panel appears under different currents and voltages. The maximum output power is found at a certain point of voltage and current. The characteristic curve depends on two external factors, namely temperature and solar radiation. A method is used to keep power constant at this point, namely using MPPT. MPPT is a way of tracking the power operating point to release the highest power. The output of the quantity detected by the MPPT is then used to control the duty cycle of the boost converter so that the output voltage of the solar panel is adjusted according to the optimal point. The use of the MPPT regulator is expected to change the maximum power under various load conditions and environmental changes.

III. Method

This work analyzes the DC converter to a DC in an MPPT system. MPPT functions as a voltage shifter to the largest point by using an intelligent control approach. This shifting process produces optimal power from the solar panel, where the MPPT is located as shown in Figure 3.

A. Adaptive Neuro-Fuzzy Inference Systems (ANFIS)

ANFIS is a combination of the Fuzzy Inference System (FIS) mechanism described in the neural network
architecture. The fuzzy inference system used is the Takagi-Sugeno-Kang (TSK) fuzzy inference system model. ANFIS is an architecture that is functionally the same as Sugeno’s fuzzy rule base model. ANFIS is a method in which a learning algorithm is used to set the rules for a data set. ANFIS also allows the rules to adapt [14].

The ANFIS model block with 2 (two) inputs, one output, 2 (two) rules, as shown in Figure 4. Layer 1 is the process of converting numbers into fuzzy sets. For layer 2, each output from the fuzzy set is multiplied by one another to determine its value’s strength. Layer 3 is normalized to be re-weighted to have a maximum value of one. At layer 4, the process is continued by multiplying based on functions involving x and y inputs to produce the appropriate output. The final step on layer 5 is done by accumulating the results from the previous layer.

The MPPT ANFIS designed in this study consists of a DC-DC boost converter, an MPPT ANFIS controller, and a current-voltage sensor. The boost converter has the role of changing the \( R_{eq} \) value based on the received duty cycle value. In this case, The ANFIS MPPT controller can track by providing a certain duty cycle output so that \( R_{eq}=R_{opt} \) and MPP conditions are reached. The input for the ANFIS MPPT controller is in the form of photovoltaic panel radiation, and the input temperature of the photovoltaic panel comes from field data. The ANFIS output value \( V_{MPPT} \) is the value of PV. The \( V_{MPPT} \) voltage value is obtained using the PWM method. This method was chosen because it has fairly good efficiency, is simple, and is inexpensive because only a voltage sensor is needed to obtain \( V_{MPPT} \) value information. In the ANFIS MPPT research, temperature and solar radiation sensors are needed to estimate the \( V_{MPPT} \) value.

ANFIS requires prior training by using input-output data pairs. Training must be done so that ANFIS can learn about this data set. During the training process, premise and consequent parameters are adjusted so that ANFIS can form a model that fits the given set of training data. The block diagram of the MPPT system is shown in Figure 5.

B. Perturb and Observe (PnO)

The Perturb and Observe (PnO) method is a method that is often applied to MPPT photovoltaic systems to determine the MPP value in photovoltaics by increasing or decreasing the duty cycle value given to the boost converter [16]. Figure 6 shows a flow chart of the conventional P&O method applied to the MPPT system.

Every time there is a change in the duty cycle, the power change is observed beforehand. The first thing to do is to measure the voltage \( V(k) \) current \( I(k) \) and find the power \( P(k) \), and then initialize it as the newest power \( k=(k+1) \). If the reduction in the latest power \( P(k) \) from the previous power \( P(k-1) \) results in a higher or lower than zero (0), then it is processed to increase or decrease the voltage value by reducing or increasing the duty cycle (\( \Delta D \)) value.

C. Power efficiency

To find out the effect of the output voltage on the PV and the output on the buck boost converter using MPPT, an efficiency calculation is carried out that fulfills Equation 5.

\[
\% \eta = \frac{P_{mppt}}{P_{in}} \times 100.
\] (5)
This study used a simulation approach, where the test was designed to obtain the expected results using several scenarios. The testing process uses MATLAB Simulink by using measurement data in the form of solar radiation intensity temperature, and the temperature is obtained based on direct measurements on the Adhi Tama Surabaya Institute of Technology campus. The measurements were carried out using a PV system equipped with radiation and ambient temperature sensors. The measurement results of these sensors are processed using a microcontroller and stored in a data logger. The parameters of the solar panel module used in this study are shown in Table 1.

Based on the parameters in Table 1, using Equations (1), (2), (3), and (4), the PV system can be modelled. Then several test scenarios were carried out in a simulated manner using MATLAB to determine the performance of the MPPT design using ANFIS. The first scenario provides input radiation values and constant temperature. The second scenario was to test with varying input radiation values and a fixed temperature. Third, testing using radiation and temperature data following the field measurements results.

The first test was carried out for the condition that all PV modules on the PV string were given radiation and a fixed temperature, namely \( G = 1000 \text{ W/m}^2 \) and \( T = 25^\circ \text{C} \). The test results show that the MPPT output voltage \( V_{\text{mppt}} \) is 19 V and the MPPT output current \( I_{\text{mppt}} \) is 1.9 A, which is the output voltage and current of the boost converter type DC-to-DC converter in the test using a 10 \( \Omega \) resistance load. Thus, the output power of PV string \( P_{\text{max}} \) is 36.6 W is obtained. The results of this test are shown in Figure 7.

The second test was carried out by giving varying radiation values, namely from 1000 W/m\(^2\), then 750 W/m\(^2\), then 500 W/m\(^2\), and 250 W/m\(^2\) with a fixed temperature condition of 25\(^\circ\)C. This test aims to determine the performance of the MPPT when there is a change in the input variable. The test results through a simulation approach are shown in Figure 8 and Table 2.

Based on the tests in Table 2, it shows that the average efficiency of MPPT reaches its highest value when the maximum radiation is 1000 W/m\(^2\). The overall efficiency of the test results has an average of 94.38%, where the efficiency decreases as the radiation level decreases.

The third test was carried out using a measurement data logger in the form of radiation and temperature in the field for 3 days. The results of the testing process are shown in Table 3, Table 4, and Table 5. The test results through a simulation approach are shown in Figure 9, Figure 10, and Figure 11.

The tests that have been carried out show that the
average power efficiency of MPPT using ANFIS is 85%.

Tests need to be carried out to test the performance of the MPPT controller design using ANFIS that has been carried out and then compared with the PnO (Perturb and Observe) method. This test has been carried out with the measurement data results in the field for 3 days. The results of comparing the two methods are shown in Figure 12, Figure 13, and Figure 14. The results of the efficiency comparison of these tests can be seen in Table 6.

Based on the experiments that have been carried out show that MPPT using ANFIS has better power efficiency values than PnO under conditions of changing radiation intensity and temperature, where the average power efficiency using ANFIS is 84.79% and using PnO is 83.87%. In addition, the transient response in ANFIS tends to be smoother than using PnO in maintaining the
In the PnO method, transient responses when environmental conditions change tend to cause chattering.

V. CONCLUSION

The tests that have been carried out show that the use of MPPT using ANFIS has good results, with an average power efficiency value of 84.79%. While using the PnO method, the average power efficiency is 83.87%. In addition, the transient response using ANFIS is relatively smoother than PnO, which can cause chattering when environmental changes occur.

<table>
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<tr>
<th>Day</th>
<th>ANFIS (%)</th>
<th>PnO (%)</th>
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<tbody>
<tr>
<td>1</td>
<td>85.33</td>
<td>84.2</td>
</tr>
<tr>
<td>2</td>
<td>83.65</td>
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<tr>
<td>3</td>
<td>85.4</td>
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<td>Average</td>
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REFERENCES


