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DESIGN OF MAXIMUM POWER POINT TRACKING BASED ON ADAPTIVE NEURO-FUZZY SYSTEM FOR SOLAR ARRAY SYSTEM

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ABSTRACT

This paper proposes a design of maximum power point tracking (MPPT) based on adaptive neuro-fuzzy system for solar array system. In a solar power plant, MPPT serves to maximize the solar array output power. The characteristics of solar array performance always follow the sun's line. Under normal circumstances, the maximum solar array output power is obtained when the maximum sunlight intensity. This power will decrease as the intensity of sunlight decreases. Therefore, MPPT technology is needed to maximize solar array output power at any time. Several methods have been applied to MPPT technology. In this study the proposed method is adaptive neuro-fuzzy based method. MPPT supported by this adaptive neuro-fuzzy method is mounted on a power converter connected to the solar array output. Along with this MPPT, it is expected that solar array output power is always maximal. Solar array with adaptive neuro-fuzzy-based MPPT method has been implemented in Simulink software. Based on the research results, they have been obtained that MPPT is able to maximize solar array output power well.

Keywords: *Fuzzy Adaptive; MPPT; Optimization; Solar Array, Renewable Energy.*

1. INTRODUCTION

Today the world has experienced serious problems in the energy field [1]-[4]. The world's fossil fuel reserves are increasingly depleted, requiring new sources of energy. This energy issue is also always associated with environmental issues [5]-[6]. So far, fossil energy is considered as a source of environmental pollution. Therefore, new sources of energy are needed, renewable and environmentally friendly. Almost every country on earth has sought to find new, renewable and environmentally friendly energy sources. Country of Indonesia is one of the countries in the world that give serious attention to new energy source, renewable and environmentally friendly. The Indonesian government has issued a law on electricity that by 2025 the contribution of power generated from renewable energy is 23% [7]-[8], and 2050 to 31% [9]-[11]. The issuance of this law is proof that the Indonesian government is committed to the environment that has become an important world issue associated with energy utilization [12]. The Government of Indonesia has encouraged academics, practitioners, and researchers to find new and potential renewable energy sources for use throughout the country.

In Indonesia, one of the most potential renewable energy power plants is solar power generation [14]. The Government of Indonesia has mapped areas of potential for large scale solar power plants. Almost all areas of Indonesia is very potential for solar power plants, because it is located in the tropics. However it needs to be mapped to determine priorities and planning. Along with the government's efforts to build solar power plants, academics and researchers have paid great attention in terms of renewable energy generation, especially solar energy [15]-[18]. Solar power plants get considerable attention because of the low efficiency of the plant. Research to improve the efficiency of solar power plants can be categorized into two, namely research on the meterial for solar cell and research on increasing the output power of solar array electrically.

Increased solar array output power can be performed by maximizing output power based on solar array performance characteristics, called Maximum Power Point (MPPT) [19]-[21]. Several methods have been applied to obtain maximum power in this MPPT technology, among which are conventional method, harmony search algorithm, artificial neural network methods, fuzzy logic controllers, particle swarm optimization, genetic algorithms, ant colony optimization, chuckoo search optimization, and any others [22]-[23]. Basically, these methods work based on the basic principle of optimization, which is to find and find the maximum power point [24]. In addition to the maximum search power, these methods also compete in terms of computing time. The shorter the search time the maximum power point, the better the method.

In this research, the application of adaptive neuro-fuzzy method to manage MPPT technology. The adaptive neuro-fuzzy method is a combination of neural network method and fuzzy logic system. The application of neuro-fuzzy methods in electric power systems has proven successful [25]-[26]. This artificial intelligence based method is able to optimize the output power of solar power plants well. This solar power system can also be developed by installing monitoring systems based on information and communication technology, such as monitoring solar array power output and solar light intensity. This research is expected to contribute to the development of solar power plants, thus helping the government in the effort to build infrastructure in the electricity sector.

2. ADAPTIVE NEURO-FUZZY SYSTEM

The adaptive fuzzy method has been became a popular method in many application. A description in brief of the principles of adaptive fuzzy system, which is called as adaptive neuro-fuzzy inference system (ANFIS), is described in this section. Fundamental structure of the fuzzy inference system type could be seen as a model that maps input characteristics to input membership functions. Then it maps input membership function to rules and rules to a set of output characteristics. Finally it maps output characteristics to output membership functions, and the output membership function to a single valued output or a decision associated with the output.

Combination of neural network and fuzzy is commonly called as neuro-adaptive learning method. The method works similarly to that of neural networks. Neuro-adaptive learning techniques provide a method for the modeling of fuzzy procedure to learn information about a data set. The model computes the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data. The structure of network-type similar to that of an artificial neural network can be used to interpret the input and output map so it maps inputs through input membership functions and associated parameters, and then through output membership functions and associated parameters to outputs. All of parameters which are associated with the membership functions changes through the learning process. Then, computation of these parameters (or their adjustment) is facilitated by a gradient vector. Gradient vector will provide a measure of how well the FIS (fuzzy inference system) is modeling the input and output data for a given set of parameters. If the gradient vector is obtained then any of several optimization routines can be applied in order to adjust the parameters to reduce some error measure. Therefore, the error is usually defined by the sum of the squared difference between desired output actual outputs. The adaptive fuzzy system uses a combination of least squares estimation and back propagation for membership function parameter estimation.

The suggested adaptive fuzzy system has several properties:

1. The output of adaptive fuzzy system is zero-th order Sugeno-type system.
2. Adaptive fuzzy system has a single output, obtained using defuzzification of weighted average.
3. Adaptive fuzzy system has no rule for sharing. Different rules do not share for output membership function that has the same value.

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4. Adaptive fuzzy system has unity weight for each rule.

Figure 1 shows Sugeno's fuzzy logic model. Figure 2 shows the adaptive fuzzy system architecture, comprising by input layer, fuzzification layer, inference later, and defuzzification layer.

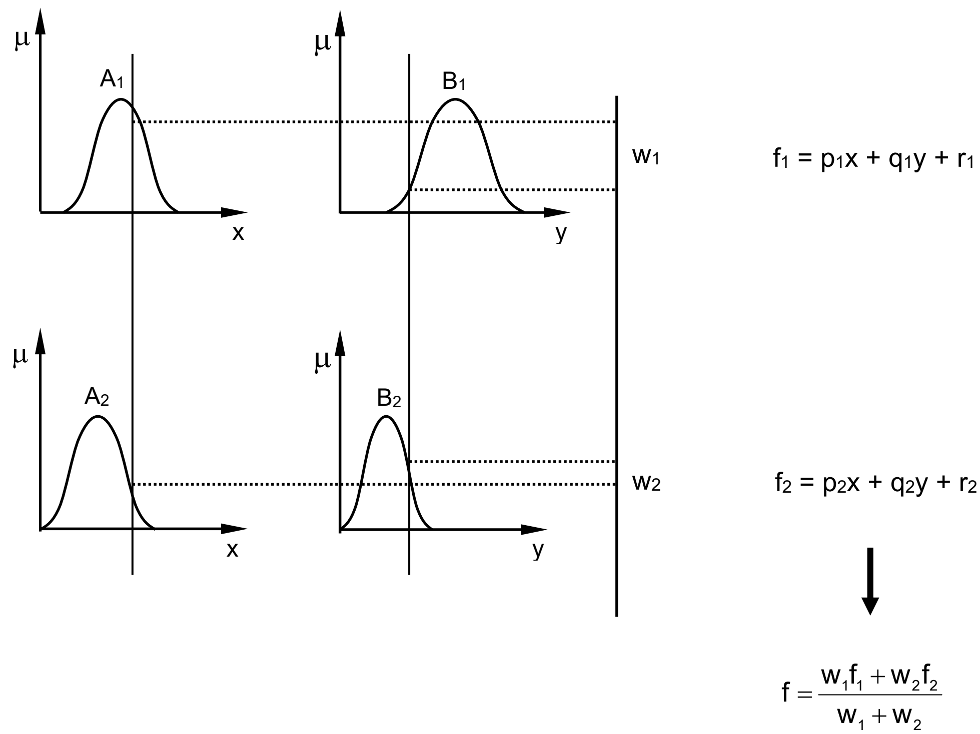

Figure 1. Sugeno's Fuzzy Logic Model

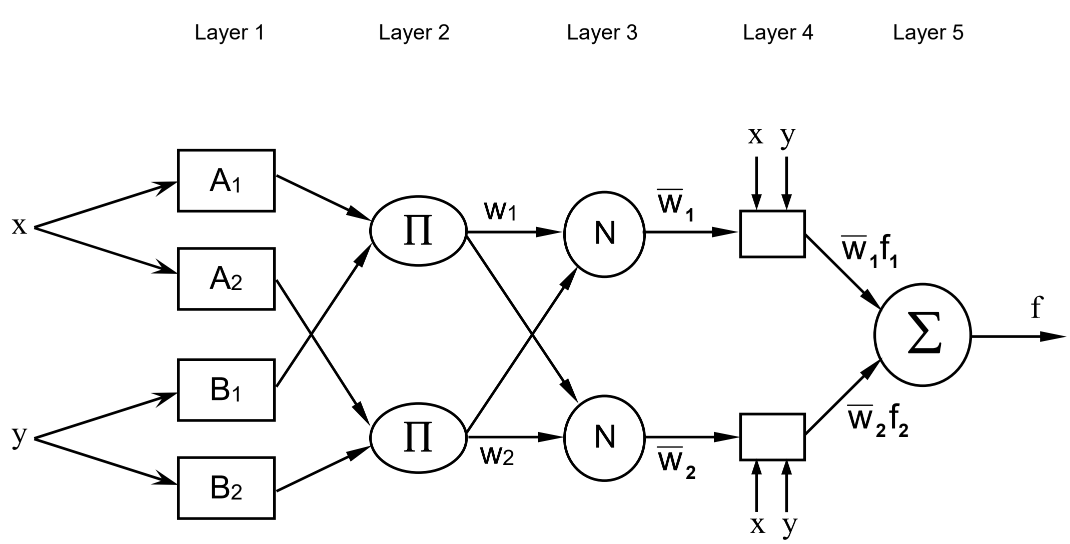

Figure 2. Adaptive Fuzzy System Architecture

The network can be visualized as consisting of inputs, with N neurons in the input layer and F input membership functions for each input, using F*N neurons in the layer of fuzzification. In this

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case, there are FN rules with FN neurons in the inference while there are defuzzification layers and one neuron in the output layer. It is assumed that the FIS under consideration has two inputs x and y and one output z, as can be seen in Figure 2. For a zero-order in Sugeno fuzzy model as used in this research, a common rule set with two fuzzy if-then rules is the following:

Rule 1: If x is A1 and y is B1, Then f1 = r1 (1)

Rule 2: If x is A2 and y is B2, Then f2 = r2 (2)

The output of the node i-th in layer n is denoted as $O_{n,i}$:

Layer 1. Every node i in this layer is a square node with a node function:

$$O_i^1 = \mu Ai(x), \text{ for } i = 1, 2, \quad (3)$$

or,

$$O_i^1 = \mu Bi\text{-}2(y), \text{ for } i = 3, 4 \quad (4)$$

where x is the input to node-i, and Ai is the linguistic label (small , large, etc.) associated with this node function. In other words, O_i^1 is the membership function of Ai and it specifies the degree to which the given x satisfies the quantifier Ai. Usually μAi(x) is chosen to be bell-shaped with maximum equal to 1 and minimum equal to 0, such as the generalized bell function:

$$\mu_A(x) = \frac{1}{1 + \left[\frac{x - c_i}{a_i}\right]^{2b_i}} \quad (5)$$

The parameters are referred to as premise parameters.

Layer 2. Every node in this layer is a circle node labelled Π which multiplies the incoming signals and sends the product out. For instance,

$$O_i^2 = wi = \mu Ai(x) \text{ x } \mu B(y), \ i = 1, 2. \quad (6)$$

Each node output represents the firing strength of a rule. (In fact, other T-norm operators that performs generalized AND can be used as the node function in this layer.)

Layer 3. Every node in this layer is a circle node labeled N. The i-th node calculates the ratio of the i-th rule's firing strength to the sum of all rules firing strengths:

$$O_i^3 = \overline{w} = \frac{w_i}{w_1 + w_2}, \quad i = 1, 2. \quad (7)$$

For convenience, outputs of this layer will be called normalized firing strengths.

Layer 4. Every node i in this layer is a square node with a node function:

$$O_i^4 = \overline{w}_i f_i = \overline{w}_i (p_i x + q_i y + r_i) \quad (8)$$

where $\overline{w}_i$ is the output of layer 3, and {pi, qi, ri} is the parameter set. Parameters in this layer will be referred to as consequent parameters.

Layer 5. The single node in this layer is a circle node labeled Σ that computes the overall output as the summation of all incoming signals, i.e.,

$$O_i^5 = \sum \overline{w}_i f_i \quad (9)$$

3. SOLAR PV WITH MPPT

In this part, the solar PV system with MPPT has been described. The component of PV (photovoltaic) is solar cell. The solar cell is commonly made of silicone material, although other materials can also be used. Basic principle of the cell can be explained below.

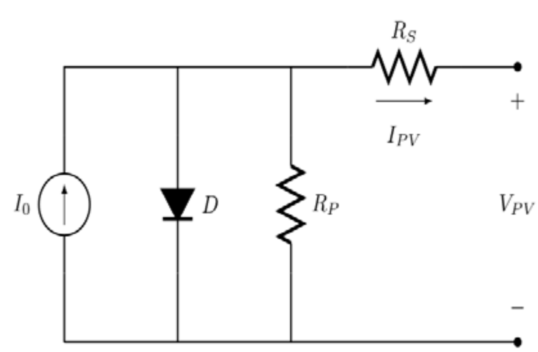

Figure 3. Equivalent Circuit Of Solar PV

Solar cell performance utilizes the effect of photoelectric. Photoelectric effect is semiconductors abilities to convert the electromagnetic radiation in the form of light directly into an electric current. Thus, in the cell, the electromagnetic radiation produces charged particles. The cell then separated easily to create an electric current with an appropriate the solar cell structure design. Figure 3 shows the equivalent circuit of solar PV.

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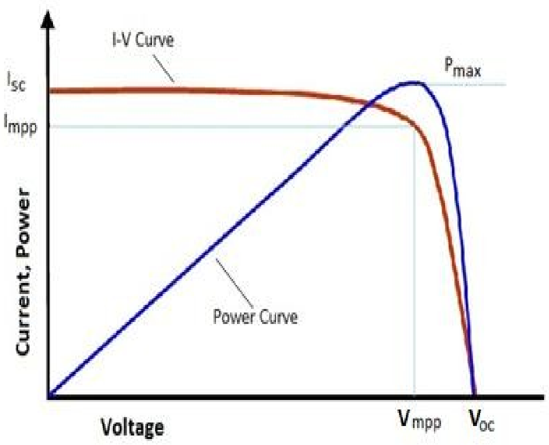

Figure 4. Curves Of Solar PV

In solar PV system, the condition of both open circuit voltage V_{OC} and short circuit current I_{SC} conditions, the power is equal to zero. Maximum power resulted will be achieved whenever the voltage and current is maximum. In the curve of power characteristic, the maximum power is reached at the voltage current characteristic point where the product of voltage and current are maximum. Figure 4 shows the P-V and I-V curves of Solar PV.

4. RESULTS AND DISCUSSION

In this section, the results of simulation of solar array system with maximum power point tracking (MPPT) control are described. The MPPT in tha solar array system has been controlled by using neuro-adaptive fuzzy system. Fuzzy system has been widely used in the control system area.

In the first stage, the solar array system in Matlab/Simulink software is modeled. The solar array model is assumed using mono-crystal type. Figure 5 shows the solar array model in Matlab/ Simulink application software. Specification of the solar array could be described below. The type of solar-cell is mono-crystal, with maximum power of 100 W, tolerance of ± 3%. The other specification are performance test variables. In open circuit arrange, the voltage is 22 volts, and the current is 6.06 amperes. The maximum power voltage of this cell, which is an important variable for the application of MPPT, is 18 volts and maximum electric current is 5.56 amperes. The solar array is commonly used in Indonesia. The efficiency of solar-cell module is 17.2% and efficiency of module is 14.9% when operating in the temperature of solar PV in the range from -40°C to 85°C. The maximum DC system voltage which can withstand in the solar cell is 1000 volts. Dimension of the cell is (1005 x 670 x 30) mm^3 while the weight of the cell is 8 kg.

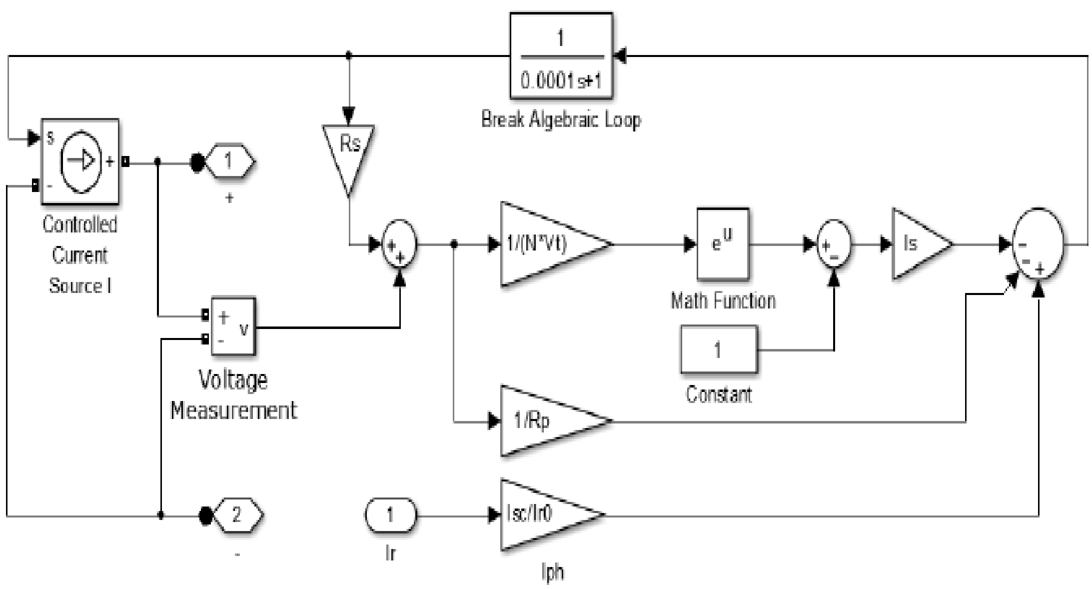

Figure 5. The Model Of Solar PV Model

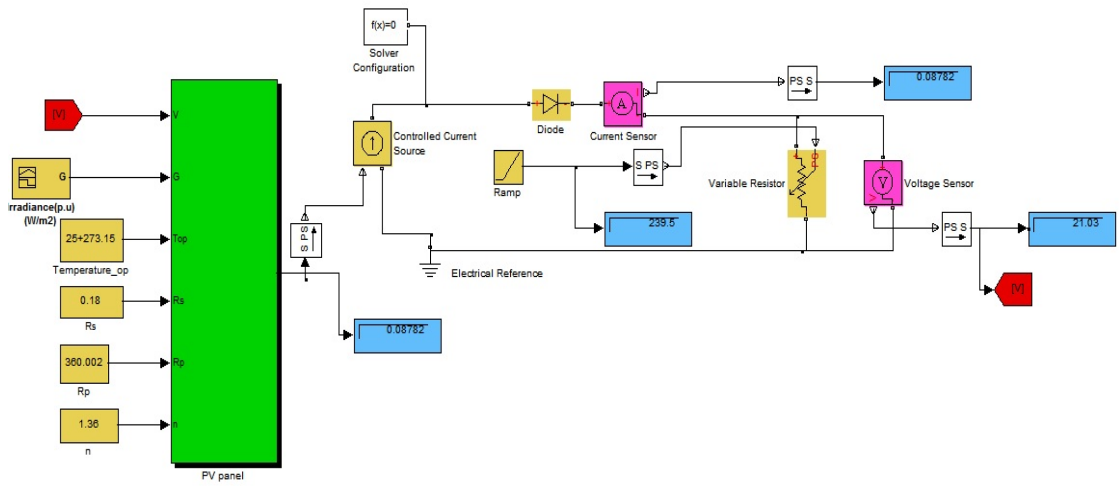

Figure 6. Validation Test Of Solar Array Model

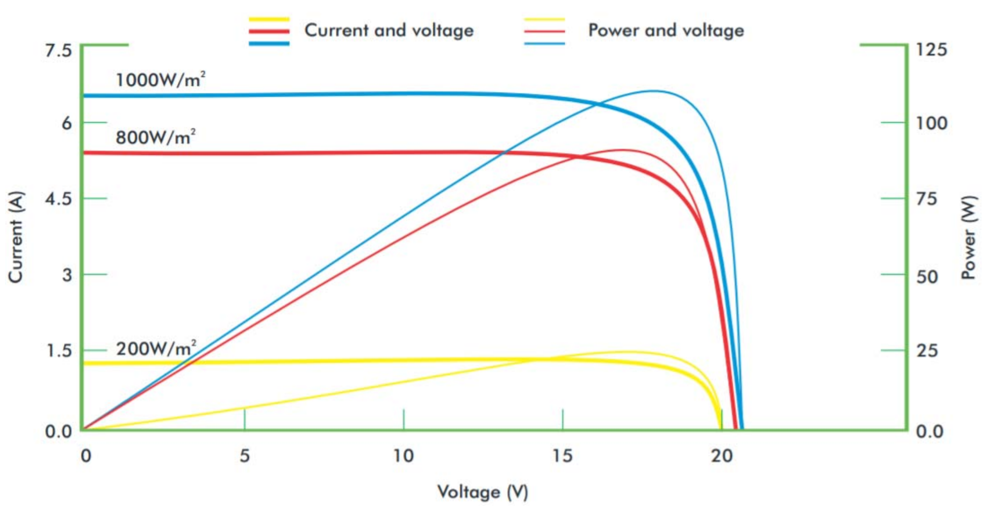

Figure 7. Solar Array Characteristics

The first step is to validate the solar array model in Matlab/Simulink software. This validation test can be seen in Figure 6. The purpose of the validation test is to ensure the truth and validity of the solar array model used in this study. Validation test results show that solar array model is in accordance with the standard, as shown in Figure 7. Figure 7 shows the solar array characteristics under various conditions. The figure shows the characteristics of solar array with a capacity of 100 watts used in this study. The important characteristic shown is the relation of current to voltage and the relation of power to voltage, as shown in Figure 7. The output power of 100 watt solar array which is its peak power is the power obtained when the output voltage is in at about 19 volts. By utilizing MPPT-based adaptive neuro-fuzzy method, it is hoped that solar array peak power can be achieved in many conditions although the solar light intensity regarding the solar array is not large. Another important variable is the graph of current and voltage relationships. This graph is also shown in Figure 7. As shown in Figure 7, the red curve is identical to the electric power density of 800 W/m^2, the blue curve is identical to the power density of 1000 W/m^2, and the yellow curve is the power density of 200 W/m^2.

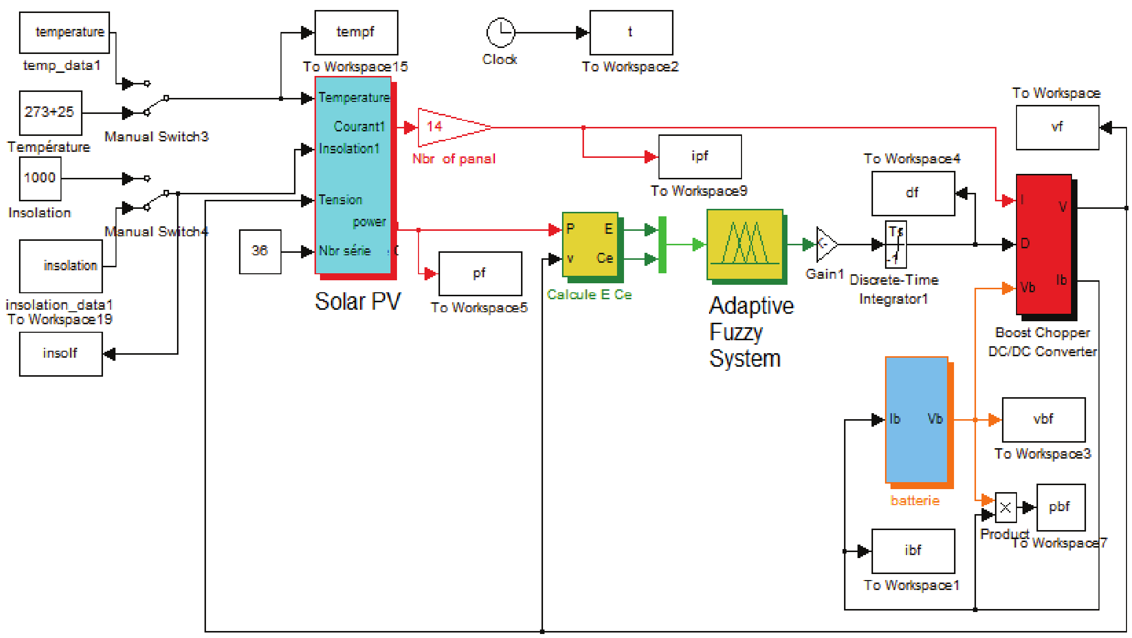

Figure 8. Solar Array System With MPPT Based On Adaptive Neuro-Fuzzy

In Figure 8, we have demonstrated a solar array system with adaptive neuro-fuzzy-based MPPT built in Matlab/Simulink software, where the solar array model has been built and validated as shown in Figure 6. Furthermore, to obtain optimal MPPT control results, fuzzy rules based on expert experience. The fuzzy rules used in this study are shown in Figure 9. This fuzzy rule uses two inputs and one output for MPPT control.

E \ CE	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	NS	ZE	NS	NS	NS
ZE	NM	ZE	ZE	ZE	PM
PS	PM	PS	PS	ZE	ZE
PB	PB	PB	ZE	ZE	ZE

Figure 9. Fuzzy Rule With Two Inputs And One Output For MPPT Control

As shown in Figure 9, there are five functional triangular fuzzy membership types. The five fuzzy membership functions used are Negative Big (NB), Negative Small (NS), Zero (ZE), Positive Small (PS), and Positive Big (PB). The selection of this triangular fuzzy type is to obtain adequate computing speed. Next the election of five membership functions is to obtain optimal results with appropriate computing speed.

Furthermore, the test results of solar array system with adaptive neuro-fuzzy based MPPT are shown in Figure 10, Figure 11 and Figure 12. Figure 10 shows the load current, Figure 11 shows the load voltage, and Figure 12 shows output power of the solar array system.

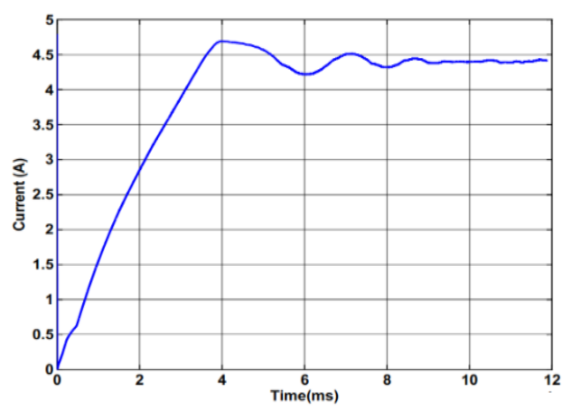

Figure 10. Characteristic Of Load Current Of Solar Array System

In Figure 10 it is stated that the maximum load current of the solar array, ie 4.7 amperes, occurs at a time indicating 3.8 ms. In this peak current, the MPPT system response applied to the solar array

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has worked very well. In this peak current condition the load voltage is 19 volts, as shown in Figure 11. Voltage 19 volts is also the peak voltage of the system. The next stage is a wave voltage and a small oscillating current wave and finally stabilized at 9 ms.

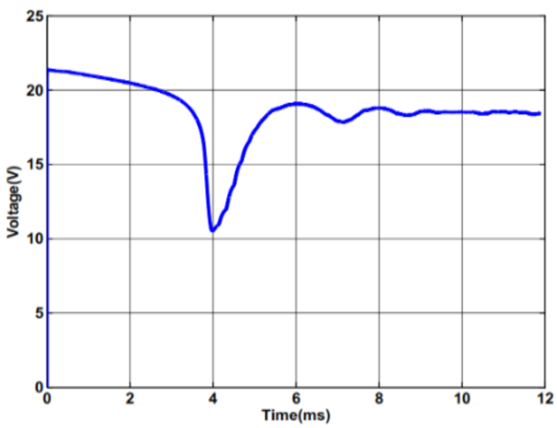

Figure 11. Characteristic Of Load Voltage Of Solar Array System

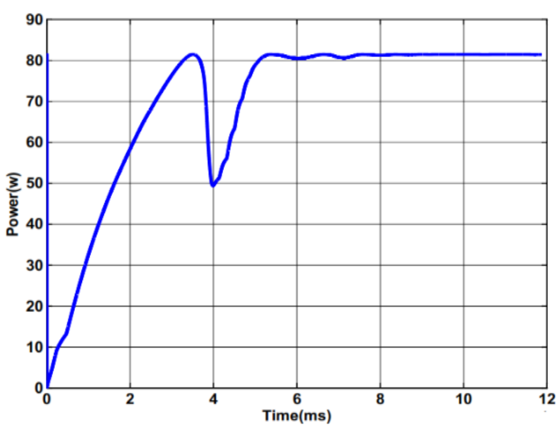

Figure 12. Characteristic Of Output Power Of Solar Array System

The solar array system power output is shown in Figure 12. The maximum power produced by the solar array is 83 watts which occurs for the first time at 3.8 ms. This maximum power is expected to last a long time. As shown in Fig. 12, that although there is a slight decrease in power at 4 ms, but then the solar array system's output power returns to a maximum of 5 ms. The maximum output power generated is 83 watts, this indicates that the efficiency of the solar array system maximum is 83%. Thus MPPT-based adaptive neuro-fuzzy system has worked very well.

5. CONCLUSION

A design of adaptive neuro-fuzzy system-based maximum power point tracking (MPPT) for solar array system has been presented in this study. Validation test has been done to solar array system model. This validation test to ensure that the model is made correctly. Validation results indicate that the model is feasible to be used in research. Furthermore, based on the results of solar array system test with MPPT based on adaptive neuro-fuzzy system show that the method used has worked very satisfactorily. The important variables observed in this research are load current, output voltage, and power output of the solar array system. Although slightly oscillatory, but overall the results showed excellent method performance. The maximum output power generated is 83 watts, this indicates that the efficiency of the solar array system maximum is 83%. Thus MPPT-based adaptive neuro-fuzzy system has worked very well.

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