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Identify and Locating the Faults in the Photovoltaic Array Using Neural Network

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A B S T R A C T

In making the PV array system work optimally without a hitch, it is important to recognize and know where the fault occurs. The current and voltage represent the conditions of a PV array, so that, in this paper, the proposed method is based on the current and voltage values for each string, four identified conditions, namely free fault conditions, partial shading, short circuit and open circuit. Neural network is used as a tool for predicting the type and location of faults, fault samples are obtained from simulations through PSIM and the learning process is carried out through MATLAB/Simulink, the algorithms used in the learning process are also compared to see which are the best. As a result, neural network was able to identify the type and location of faults on the PV array. This proves that the condition of a PV array can be explained through its voltage and current values.

INTRODUCTION

The ever-increasing demand for low-cost energy and growing concern about environmental issues has generated enormous interest in the utilization of non-conventional energy source as PV generation. PV generation is playing an important role as a clean, long-lasting, and maintenance-free electrical source [7]. However, faults in the PV system, such as open-circuit, short-circuit, and shading faults, are often difficult to avoid and can result in system energy loss, PV module lifespan reduction, or even serious safety concerns. Hence, the development of a fault detection method for the PV array faults is particularly significant for improving the energy conversion efficiency of the PV system, increasing the service life of the PV modules, and reducing maintenance cost [10].

In recent years, artificial intelligence algorithms have attracted the attention of scholars. The artificial intelligence algorithms include mainly artificial neural network and machine learning methods to detect PV array faults [10]. Artificial neural networks (ANN) have been successfully employed in the field of PV, such as PV power forecasting, performances evaluation, modelling and simulation, as well as maximum power point tracking under shading conditions (MPPT) [6].

In this paper, in order to identify the fault types and its location of the PV array under various conditions of solar irradiation, a novel method based on voltage and current in each string is proposed.

Current and voltage are representations of a PV, through the values of these currents and voltages can explain what happen in the PV array. By using an artificial neural network, the current and voltage values of a PV array can indicate the type and location of the faults.

The paper is organized as follows: the next in this section presents the modelling, simulation of PV Array, and different types of faults. The proposed fault identification method is provided in METHOD section. The Results and Analysis of the PV array identification conditions are given in RESULT AND DISCUSSION section. And Conclusion of the proposed method in CONCLUSION section.

PV Cell Modelling

Solar cell gives the nonlinear I-V characteristics and it is obtained by a simple model which consists of a constant current source, diode, and resistors associated in both series and parallel model [6]. The equivalent circuit of a photovoltaic cell can be approximated and given in Figure 1.

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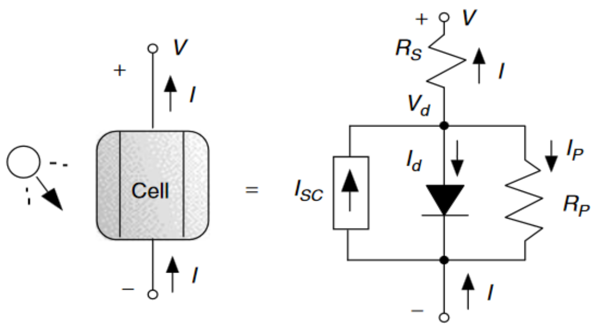

Figure 1. PV Cell Modelling [1]

$$I = Isc - Io\left(exp^{q\left(\frac{V+I.Rs}{KTs}\right)} - 1\right) - \left(\frac{V+I.Rs}{Rp}\right) \qquad (1)$$

Where, I is the maximum current from the solar cell, Isc is Input source current, Io is the reverse saturation current, q is an electron charge (1.6x10^{-19} C), V is the voltage across the load, Rs is the series resistance, K is the Boltzmann's constant (1.38x10^{-23} J/K), T is the temperature and Rp is the parallel resistance [6].

PV Array Configuration

The association of a number of photovoltaic cells form a module and the grouping of these in series and in parallel form called a photovoltaic array which are illustrated by the Figure 2 [2].

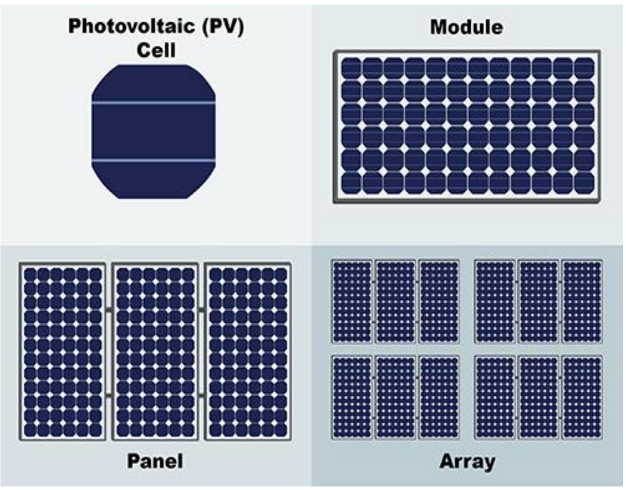

Figure 2. PV Array Configuration [2]

PV specifications used in this paper is a PV module Solarex MX-60, with specifications as shown in Table 1 below.

Table 1. PV Module Specification

Maximum Power (P_{MP})	60 Wp
Voltage at Maximum Power (V_{MP})	17.1 V
Current at Maximum Power (I_{MP})	3.5 A
Open Circuit Voltage (V_{OC})	21.1 V
Short Circuit Current (I_{SC})	3.8 A

In this paper the PV array used is a PV module with a 2x2 arrangement, which means two PV modules arranged in series and both then will be arranged in parallel. Hence, the voltage and current values generated at the PV array system in this paper is twice than the specification written in table 1. Which are the maximum voltage is 34.2 Volts and the maximum current is 7 A and the maximum power is 240 Watts.

With these PV array specifications, the P-V and I-V characteristics of the PV array are simulated. The simulation is run by PSIM, in 4 conditions, namely free fault conditions, partial shading, short circuit fault, and short circuit fault. For conditions free faults, short circuit faults, and open circuit faults, the simulation is carried out in the STC (Standard Test Condition) state, while for partial shading conditions it is carried out at a temperature of 25ºC and irradiation is successively 400W/m^2; 700 W/m^2; 1000 W/m^2; 1000 W/m^2.

The simulation results for free fault condition and fault conditions along with their location, namely partial shading, open circuit, and short circuit are shown in Figures 3, 4, 5, 6, 7, 8, 9, 10 and the maximum power that can be generated by these four conditions is presented in table 2.

Free Fault

In a free fault condition where this condition the PV array is able to provide full supply to the load without interruption. where in this condition the solar irradiation received by the entire PV array is the same so that the current and voltage values that will be read on both sides of the string will be the same

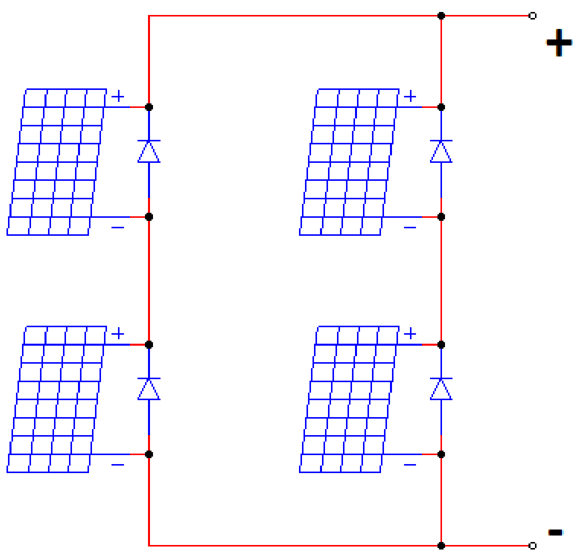

Figure 3. PV Array Configuration

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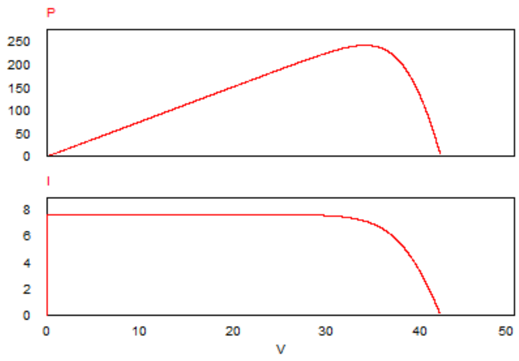

Figure 4. Free Fault P-V & I-V Characteristics

Partial Shading

In this partial shading condition, the PV array receives interference from the reception of solar irradiation for the whole uneven PV. this condition causes a difference in current flow from both sides of the string. In general, the cause of this condition is covered by clouds, dust and even bird droppings.

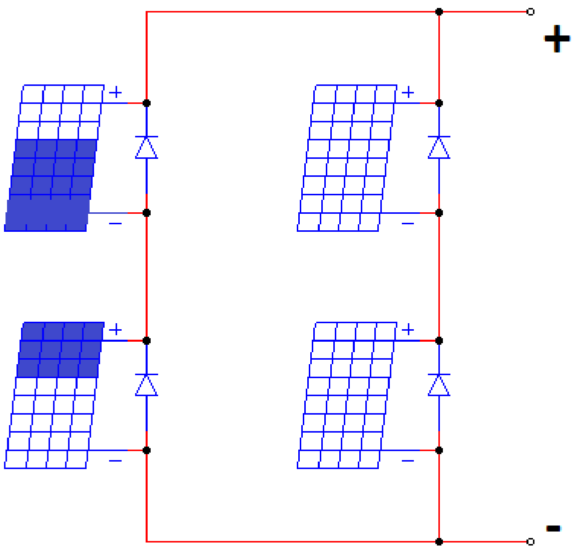

Figure 5. PV Array Partial Shading Configuration

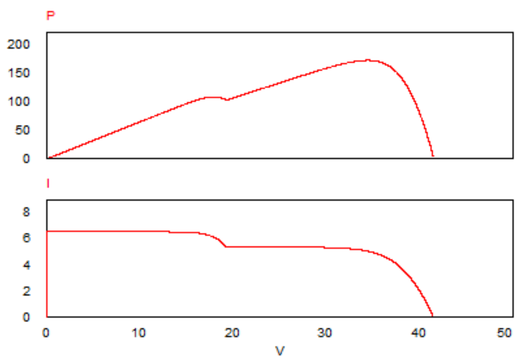

Figure 6. Partial Shading P-V & I-V Characteristics

Short Circuit Fault

Short circuit in a PV system is defined as an unintentional connection between two points in a V panel through a low resistance path [9]. The short circuit condition indicates that a PV in the PV array will lose the ability to supply power to the load because in this condition the PV module voltage value will be zero. So, in a PV array with four modules, if there is one short circuit, in the PV array, there are only three modules that can work in the PV array. Therefore, as shown in Figure 8, when the PV array is in short circuit, there will be a voltage reduction of almost half.

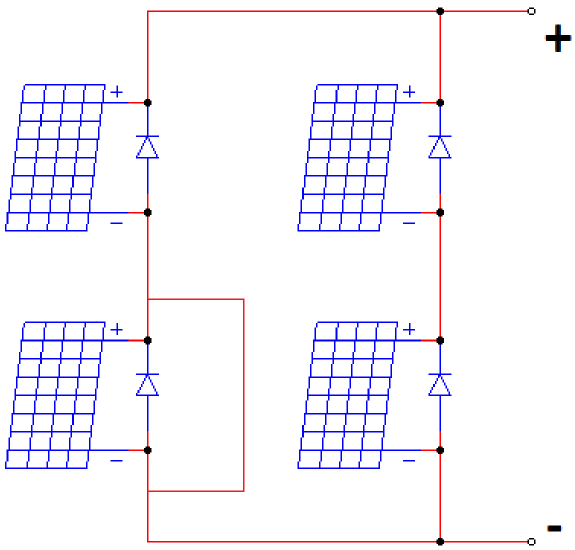

Figure 7. PV Array Short Circuit Configuration

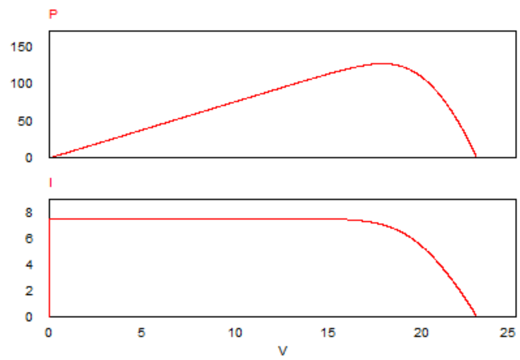

Figure 8. Short Circuit P-V & I-V Characteristics

Open Circuit Fault

Open circuit is an accidental disconnection at a normal current-carrying conductor [19]. In the open circuit conditions that occur on one of the strings, it will show that the PV array will lose its current supply by half as shown by the PV and IV characteristics in Figure 10. This is because the PV array loses supply from one of its strings due to the disconnection of one of the strings to provide supply to the load, so with the conditions of the PV array as shown in Figure 9, there are only two PV modules that work to supply the load.

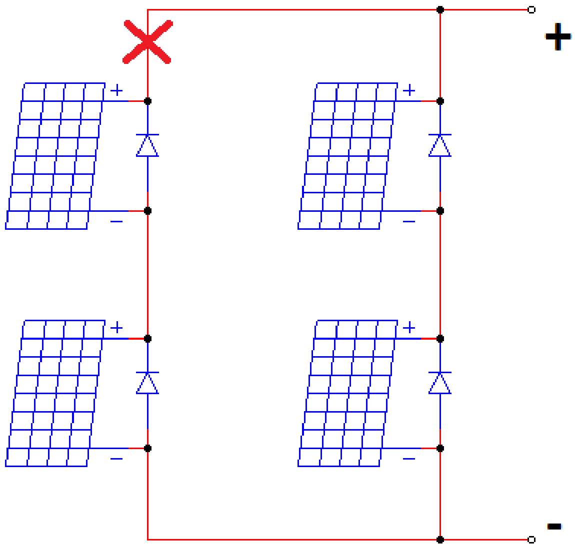

Figure 9. PV Array Open Circuit Cofiguration

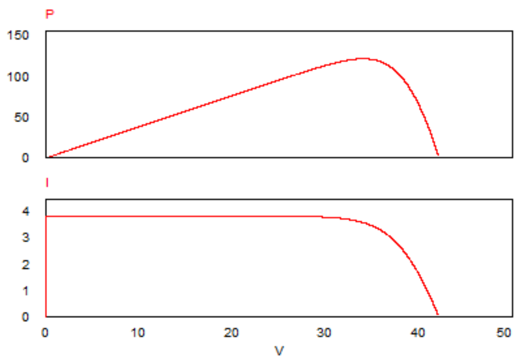

Figure 10. PV Open Circuit P-V & I-V Characteristics

Table 2. Maximum Power at Various Conditions

PV Array Condition	GMP (W)
Free Fault	242.13
Partial Shading	172.43
Short Circuit Fault	127.04
Open Circuit Fault	121.069

It is shown in Table 2 that with similar conditions (STC), the power reduction between free fault conditions compared to short circuits and open circuits can be half. This kind of condition is trying to solve by giving the status of the PV array condition, so that the situation does not lead to a bigger problem or damage to the PV array. The same thing also happens in the partial shading condition, this condition is considered normal if it occurs briefly or temporarily, but different conditions can occur if the partial shading lasts for a long time. Partial shading that occurs in that conditions are long enough to cause hot spots on the PV module itself so that the worst possibility is the burning of the PV.

METHOD

The method proposed to prove that the output voltage and current of a PV is a representation of the PV itself. If there is a partial shading fault, the PV side where the fault occurs will have a current reduction, while when there is a short circuit fault, the PV part that occurs will not function because the voltage value is equal to zero, and also if there is an open circuit fault, the PV side that occurs fault also will not work because the current value will be zero, these can be seen through the current and voltage sensor readings.

Current and Voltage Reading

In the process like in the block diagram in Figure 11, the PV array that supplies the load will produce output in the form of currents and voltages, the current and voltage output from the PV array will be read by sensors connected to the neural network, this neural network will decide whether the PV array whether there is a fault or not.

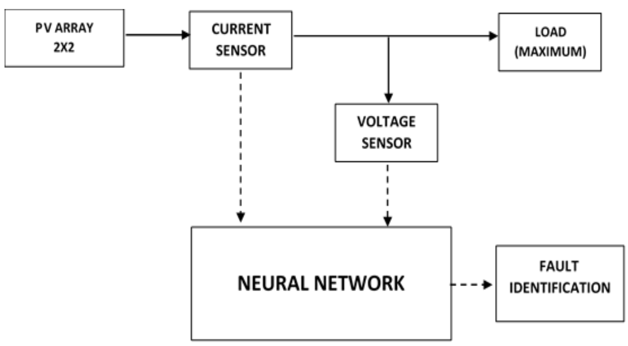

Figure 11. Block Diagram of Identification System

In this paper, fault identification will be carried out on each string, which is string 1 and string 2. Then on the PV array output there are two voltage sensors and two current sensors, as shown in Figure 12. It also shows how the process of sampling the current and voltage value data on string 1 and string 2 on various solar irradiation conditions through PSIM simulation, which will later be used as an input learning neural network.

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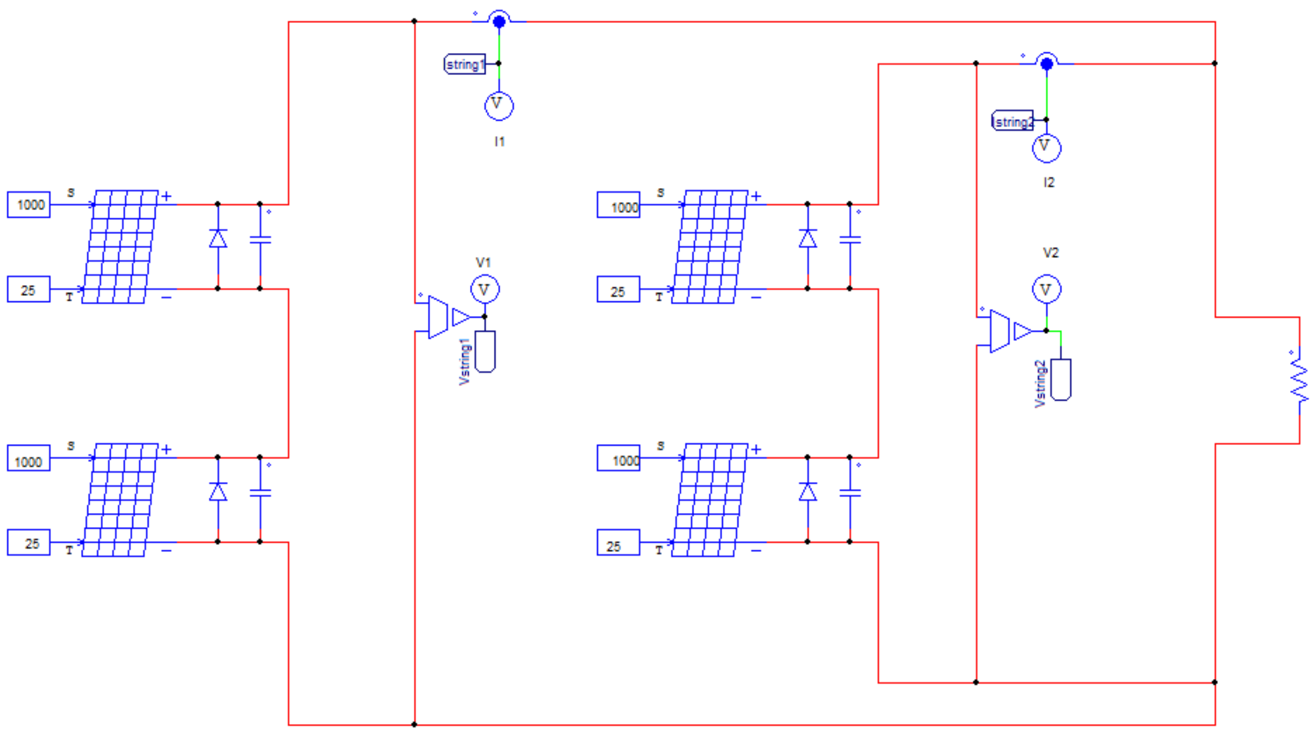

Figure 12. PV Array Configuration for Identification

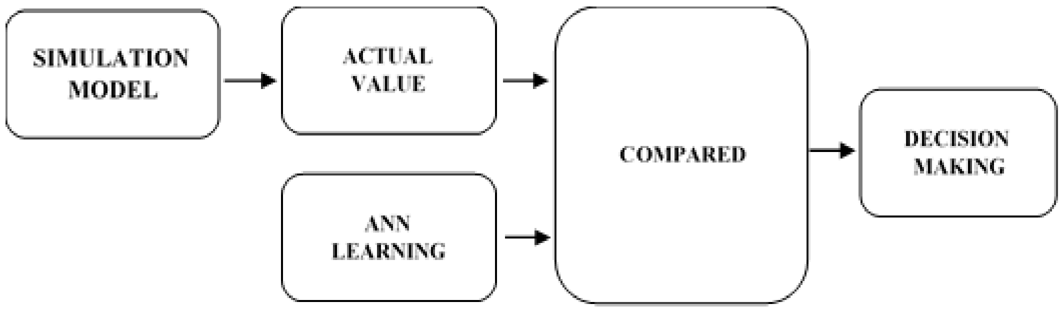

Figure 13. Flow Diagram for Identification

ANN Approach

As seen in Figure 13 above, fault identification is carried out by comparing the measured value at that time through a model simulation with the value of the learning neural network. Comparing in this case is whether there is a compatibility between the value of the current and the voltage in the PV array between the measured value and the value that has been learned through the neural network. So, it can be decided by the neural network whether the PV system is in fault condition or not.

The method used in this paper is a neural network, by modelling several fault conditions. First, collect data in various conditions, whether there is fault or not, the data to be modelled is collected and recorded, in this case are currents and voltages. After that, build a neural network topology by labelling the input and output parameters (target) obtained from the sensor readings. Then conduct training on the neural network that has been built through the appropriate algorithm, this is to see whether the desired results are appropriate and the smallest error rate (MSE). From the results of the appropriate neural network training, the neural network conversion will then be carried out to convert it to MATLAB/Simulink to confirm whether the identification has worked.

The identification process uses a neural network function fitting tool through the MATLAB application, where there are input and targets to be learned, the input value is obtained from the simulation results through the PSIM application with a sample range of 100W/m^2 to 1000W/m^2 solar irradiation with an increment of 50W/m2 for free fault, and sample range of 100 W/m^2 to 1000W/m^2 solar irradiation with an increment of 100W/m^2 for partial shading, short circuit and open circuit, so that there are 405 sample simulation data. The target is a numeric number to identify the conditions in the PV array as written in table 3 below.

Table 3. Numerical Number of Identification

PV Array Condition & Fault Location	Identification Number
Free Fault	1
Partial Shading String 1	2
Partial Shading String 2	3
Short Circuit Fault String 1	4
Short Circuit Fault String 2	5
Open Circuit Fault String 1	6
Open Circuit Fault String 2	7

For the neural network topology in the figure 14, four inputs (V1, I1, V2, I2) and one target (table 3) are used as well as a hidden layer where there are 4 neurons in it. The basis for selecting the number of hidden layers and neurons actually does not have a special formula, most of them use the trial-and-error method to get the lowest Mean Squared Error (MSE) value. However, a literature states that there are ways to get the number of hidden layers and neurons. For the hidden layer, using one hidden layer is enough to solve various problems with the neural network, but if the MSE value is still too high, increasing the number of hidden layers can be done. The number of neurons in the hidden layer can be determined based on the range of the number of input and target neurons, in this paper the number of input neurons is four and the target neurons is one, so the use of neurons in the hidden layer can be between one and four neurons, however, of course all of that depends how low is the MSE value of the learning results.

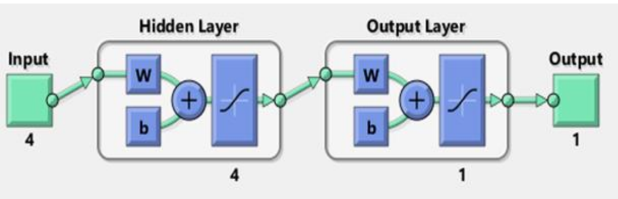

Figure 14. Neural Network Topology for Identification

RESULTS AND DISCUSSION

This section provides the results of the ANN and some sample identification conditions for the PV array. Figure 15 shows an image of the performance of learning results or MSE (Mean Square Error) values with the Bayesian Regularization algorithm, in this figure the lower or closer to the zero value, the better the learning results from ANN. In Figure 16 shows a regression image from the learning results, in this figure the closer to 1 (unity), then the learning results show the relevance between input and output is increasingly correlated. Table 4 also shows the results of ANN learning performance or MSE (Mean Square Error) values with different algorithms.

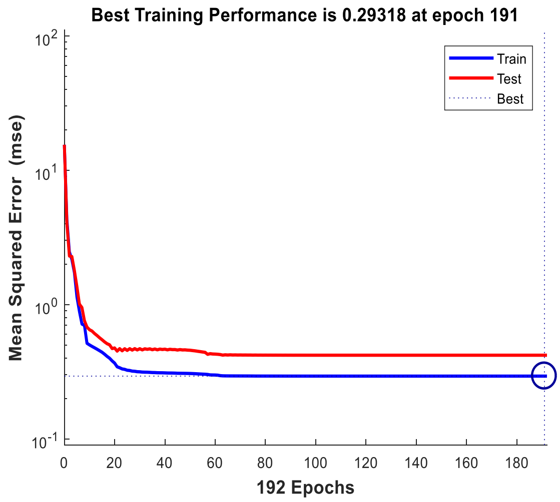

Figure 15. Performance under Bayesian Regularization Algorithm

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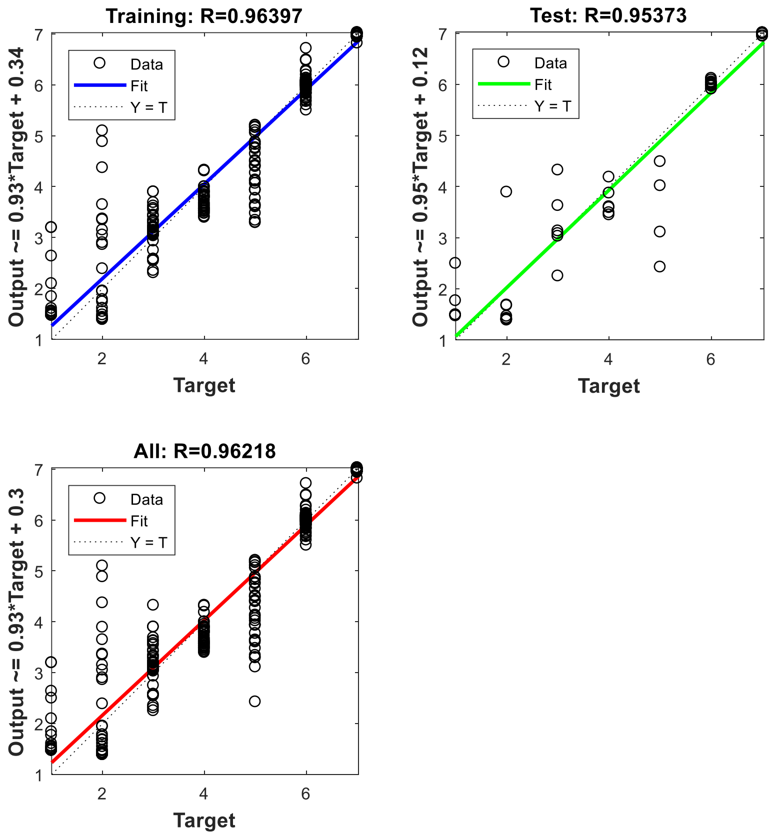

Figure 16. Regression under Bayesian Regularization Algorithm

Table 4. MSE Comparison of Various Algorithm

Algorithm	MSE (Mean Square Error)
Levenberg – Marquardt	0.3817
Bayesian Regularization	0.293
Scale Conjugate Algorithm	0.8694

In table 4 above, the algorithm with the lowest Mean Square Error (MSE) value is the Bayesian Regularization algorithm, so the Bayesian Regularization algorithm was used in the fault identification system in this PV array.

Figures 17, 18, 19, 20, 21, 22 and 23 respectively, show how the neural network identifies free fault condition and the type of fault along its location in partial shading, short circuit and open circuit, using MATLAB/Simulink. In the MATLAB/Simulink, input display from top to bottom are the parameters of the voltage string 1 (V1), current string 1 (I1), voltage string 2 (V2) and current string 2 (I2).

In Figure 17, the solar irradiation of 850W/m^2 is given to the PV array equally, the result is that both the voltage and current values read on the two strings have the same value, this indicates that no fault or interference occurs on the PV array or one side of the string. Therefore, in this condition the PV array is said to be in a free fault condition, which in MATLAB / Simulink the identification number is displayed as 1.264 (1)

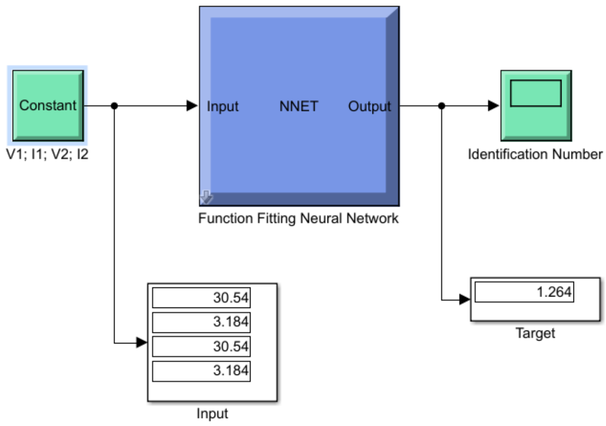

Figure 17. Free Fault Identification

In Figure 18 a PV array with solar irradiation conditions on a string 1 is 500 W/m^2 and a string 2 is 1000 W/m^2. In Figure 19 a PV array with solar irradiation conditions on a string 1 is 900 W/m^2 and a string 2 is 600 W/m^2. Thus, in the figure 18 the value of I2 is greater than I1, this indicates that the current supply in string 1 is stuck, which is assumed to be partially shaded on the PV string 1. The number 1.989 (2) on the display represents the occurrence of partial shading on string 1. The same thing also happens in Figure 18 which indicates the occurrence of partial shading in string 2, (3.081), where the current supply on string 2 is in stuck or I2 is lower than I1. In principle, the PV module works by converting non-electric units into electric units, namely from sunlight to voltage and current, so that if the conversion source of the PV module is partially shaded, of course the conversion results will also decrease. In Figures 18 and 19, it is explained that for each string that occurs a decrease in either voltage or current, it can be said that in the PV partial shading is occurring. However, in Figures 18 and 19, only the current shows a reduction, not the voltage. This is because there is a voltage divider from a high potential string to a low potential string, so that the voltage values on both sides of the string tend to be the same.

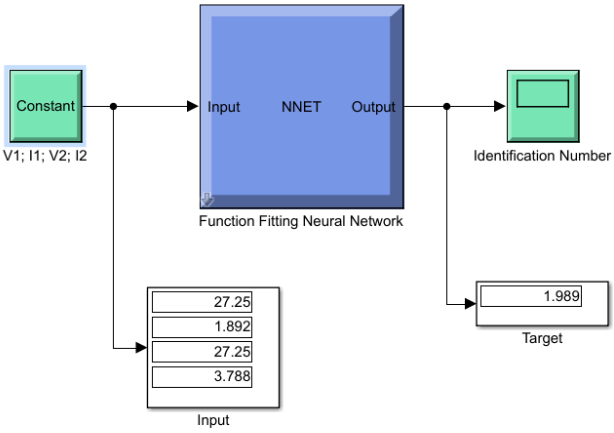

Figure 18. Partial Shading String 1 Identification

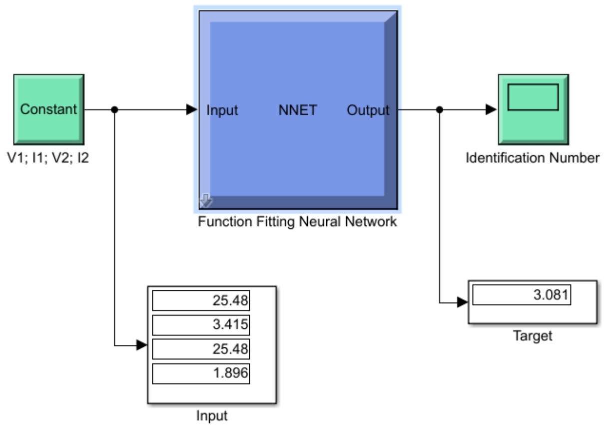

Figure 19. Partial Shading String 2 Identification

In Figure 20 with the conditions of one PV short circuit on string 1 and solar irradiation on string 1 is 900 W/m^2 and string 2 is 900W/m^2. And in Figure 21 with the conditions of one PV short circuit on string 2 and solar irradiation on both sides of string are 800 W/m^2. On the side that occurs a short circuit, either string 1 or string 2, there will be voltage reduction in the PV array because a PV on one of the strings is unable to provide supply to the load due to a short circuit, so there are three active PV. With the condition that the three PV module is active and one PV module does not function, it results in a voltage unbalance between the two sides of the string, where the voltage value of a circuit arranged in parallel should be the same, therefore, there is a voltage divider in the PV array system circuit. This condition causes reduction which also forces the current value to decrease on the side of the string that is affected by the fault. The number 3.548 (4) on the target display figure 20 represents the occurrence of short circuit on string 1. The number 4.753 (5) on the target display figure 21 represents the occurrence of short circuit on string 2.

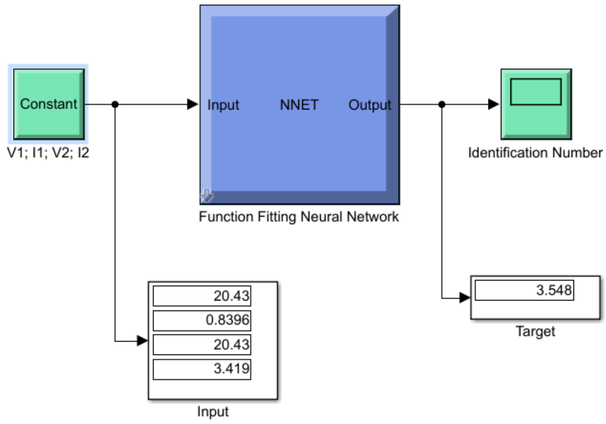

Figure 20. Short Circuit String 1 Identification

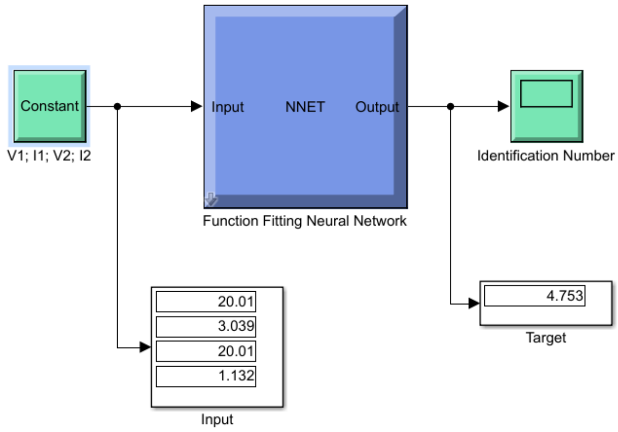

Figure 21. Short Circuit String 2 Identification

In Figure 22, with PV conditions there is an open circuit on string 1 and solar irradiation on both sides of string are 1000 W/m^2. Also in Figure 23, with PV conditions there is an open circuit on string 2 and solar irradiation on both sides of string are 800 W/m^2. If there is an open circuit on one of the strings or the connection between the string and the load is disconnected, the current value on the side of the string where the fault occurs will be zero. Because a string in this PV array system loses the ability to supply power to the load, there will only be one active string or only two PV modules still working out of the four PV modules, for example the location of this fault can be seen in Figure 9. So, this type of fault is a fault that causes the most reduction in power compared to other types of faults that are discussed in this paper. The number 6.003 (6) on the figure 22 display represents the occurrence of open circuit on string 1 and the number 6.879 (7) on the figure 23 display represents the occurrence of open circuit on string 2.

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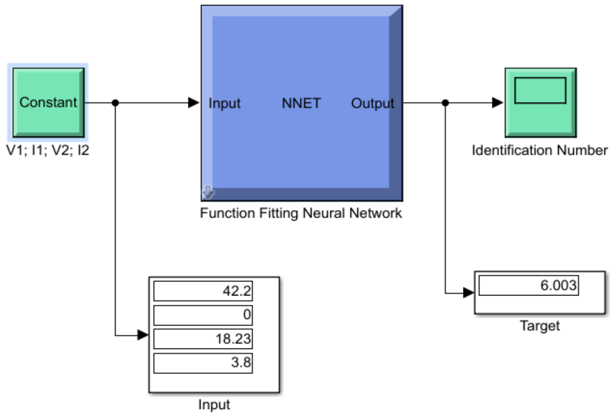

Figure 22. Open Circuit String 1 Identification

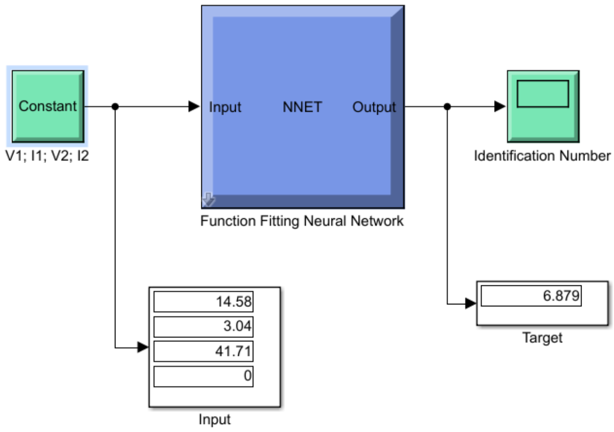

Figure 23. Open Circuit String 2 Identification

CONCLUSIONS

In this paper, current and voltage are proposed as units to identify the type and location of faults in PV array. Identification is carried out on each string so that a reading of two current values and two voltage value are required, identification in the form of partial shading faults, short circuits and open circuits. The proposed method is proven to be successful in identifying the type of fault and the location where it occurs, and also, current and voltage are really able to represent PV conditions for real, because current and voltage are the final product of the PV conversion from non-electric units in the form of solar irradiation, all of these things are validated based on MATLAB/Simulink. However better methods are needed for large scale PV array systems and more complex types of faults.

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NOMENCLATURE

V1	meaning of voltage value on PV string 1
I1	meaning of current value on PV string 1
V2	meaning of voltage value on PV string 2
I2	meaning of current value on PV string 2

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