DIAGNOSTYKA, 2023, Vol. 24, No. 3

e-ISSN 2449-5220
DOI: 10.29354/diag/166428

FAULT DETECTION AND DIAGNOSIS OF PHOTOVOLTAIC SYSTEM BASED ON NEURAL NETWORKS APPROACH

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Abstract

Solar energy has become one of the most important renewable energies in the world. With the increasing installation of power plants in the world, the supervision and diagnosis of photovoltaic systems have become an important challenge with the increased occurrence of various internal and external faults. Indeed, this work proposes a new solar power plant diagnosis based on the artificial neural network approach. The developed model was to improve the performance and reliability of the power plant located in Tamanrasset, Algeria, which is subjected to varying weather conditions in terms of radiation and ambient temperature. By using the real data collected from the studied system, this approach allow to increase electricity production and address any issues that may arise quickly, ensuring uninterrupted power supply for the region. Neural networks have shown interesting results with high accuracy. This fault diagnosis approach allows to determine the time of occurrence of a fault affecting the examined PV system. Also, allow an early detection of failures and degradation of the system, which contributes to improving the productivity of this photovoltaic installation. With a significant reduction in the time needed to repair the damage caused by these faults and improve the reliability and continuity of the electrical energy production service.

Keywords: photovoltaic system, fault detection, neural networks, diagnostic system, residue evaluation.

1. INTRODUCTION

In the past decades, the world has been using non-renewable raw materials such as coal, fossil fuels, oil, and radioactive sources. Due to the danger of non-renewable energy and the huge increase in the world's population, it has become very important and necessary to harness alternative renewable energy sources that do not involve fossil fuels such as solar, biomass, wind, geothermal, and hydropower. In fact, solar is one of the most sustainable energy sources today. It uses semiconductor materials such as Silicium and Germanium that convert sunlight directly into electricity.

Recently, artificial intelligence methods such as expert systems, neural networks, fuzzy logic have been successfully applied to solve the problem of diagnosis of industrial systems. However, neural networks are among the most popular techniques in the field of artificial intelligence, thanks to their precise reference behavior given by their strong self-learning and their data processing capacity. Also, the monitoring and fault detection of photovoltaic power plants have moved away from traditional techniques to move towards so-called artificial intelligence techniques. Motivated by the advantages of the approach based on neural networks, this technique makes it possible to deliver a reliable monitoring protocol for the photovoltaic system under examination, which makes it possible to detect the various faults affecting the system in real time.

Indeed, many research works have been published in the field of photovoltaic systems diagnosis, such as Ahmad Azharuddin et al. in [3], Amit Dhoke et al. in [7], Baojie Li et al. in [11], Fethallah Tati et al. in [15], Jenitha in [18], Salomé Ndjakomo et al. in [30], Van Gompel Jonas et al. in [32] and Zhou Li et al. in [34]. Clearly, many faults lead to abnormalities in the operation of the PV system, and can then cause untimely shutdowns of the system. Also, these faults reduce photovoltaic production and its performance. Thus, the technical

Received 2023-02-10; Accepted 2023-05-23; Available online 2023-06-07

assessment of the last years has influenced the improvement of the monitoring approaches of these photovoltaic systems, for sustainable development of electric energy production. These modern approaches have been studied and applied in several works, such as; Abdellatif Mahammedi et al. in [1], Ahmed Hafaifa et al. in [4], Aref Eskandari et al. in [8], Balamurugan et al. in [10], Barun Basnet et al. in [12], Fengxin Cui et al. in [14], Imed Kaid et al. in [17], Jianbo Yu et al. in [19], Kurukuru et al. in [22], Ruby Beniwal et al. in [28].
Other research works have been conducted in the direction of improving the quality of electrical power generation, and detecting faults over time with high sensitivity of the monitoring system, such as the works of Abdelmoumen Saci et al. in [2], Ahmed Zohair Djeddi et al. in [5], Ali Kidar et al. in [6], Azghandi Ali et al. in [9], Fan Jia et al. in [13], Ghadir Badran et al. in [16], José Miguel et al. in [20], Joshuva Arockia et al. in [21], Mohamed Ben Rahmoune et al. in [24], Mohammed Amine Deriche et al. in [25-26], Sally Abdulaziz et al. in [29] and Vincenzo Carletti et al. in [33]. However, the need to detect and locate a failure according to the needs of the industry and the complexity of the systems calls for several diagnostic techniques, which have different criteria characteristics for the detection and diagnosis of these failures, which solve the problems of fault diagnosis conveniently.

In addition, faults in a photovoltaic plant must be detected and dealt with as quickly as possible. Otherwise, they can lead to a partial or complete shutdown of the system. Thus, they can lead to negative effects in economic terms on the quality of electrical energy production, and other risks in terms of failures of the plant components, which affect the environment. Given the diversity of methods to conduct a diagnostic approach and prevent the earliest degradation of this type of photovoltaic system, such as the work of Noamane Ncir and Nabil El Akchioui in [27], where they proposed an intelligent improvement to determine the maximum power point of a photovoltaic panel using the concept of artificial neural networks. As well as the work of Suryanarayana Gangolu and Saumendra Sarangi in [31], where they developed a fault detection and classification strategy in a photovoltaic system based on fuzzy logic. In addition, Lipsa Priyadarshini et al. in [23] developed an intelligent classifier based on Deep Learning LSTM-Based Minimum Variance RVFLN of faults in a grid-connected system.

In this work, a fault diagnosis approach based on the use of artificial intelligence techniques, precisely by artificial neural networks, is used for the fault detection of a photovoltaic plant installed in the region of Tamanrasset in southern Algeria. The originality of the use of artificial neural networks for the diagnosis of faults affecting the examined photovoltaic power plant is their ability to operate satisfactorily in monitoring, even in the case of a fault of low amplitude and in the presence of noise.

Thus, the contribution of this work in the diagnosis of faults in the examined photovoltaic power plant is the search for signatures (fault indicators), allowing to characterize the operation of the system by identifying the origin of these faults. This guarantees a good detection of anomalies occurring in the different components of the system, with a classification of these faults using neural networks to better prevent the degradation of the monitored PV system.

The proposed neural network approach can perform fault detection of different PV plant components based on measurements and training without the need for complex mathematical models. Thus, this approach is easily implemented on-site by exploiting the different input/output measurements of the PV system.

However, an intelligent approach based on artificial neural networks is developed in this paper, with the aim of diagnosing and evaluating the various faults affecting the photovoltaic systems under study, which may be difficult to detect for traditional diagnostic approaches. The concept of artificial neural networks represents an efficient tool to manage the nonlinear dynamic behavior of the systems. Besides possessing the capabilities of generalization and prediction of future performance, and become one of the most commonly used diagnostic approaches in the nonlinear system. Based on their strong self-learning skills, generalization potential, and high fault tolerance.

Photovoltaic power plants and their locations are challenging, especially under variable weather conditions such as abrupt changes, full shading, temperature mismatch, and dust. These malfunctions can affect the efficiency of power plants by decreasing the reliability of PV modules, and reducing the power generated, which requires robust monitoring strategies.

Nowadays, monitoring and supervision of PV systems are becoming a challenge, especially to avoid non-linear behavior. In addition, to maintain photovoltaic systems in good condition and to improve the reliability and availability of photovoltaic systems. In this work, an intelligent approach based on artificial neural networks has been developed to diagnose and evaluate the various faults affecting photovoltaic systems. Artificial neural networks are nowadays an efficient tool to avoid the nonlinear dynamic behavior of photovoltaic systems and their generalization and prediction capabilities of future performances.

2. TAMANRASSET PHOTOVOLTAIC POWER STATION

The geographical position, Algeria has one of the highest solar deposits in the world (05 billion GWH/year), with a duration of sunshine in the Sahara and on the highlands that can reach 3000 hours/year, where the solar photovoltaic power plant of Tamanrasset has a sunshine of 3000 hours/year, as shown in Figure 1. This photovoltaic plant is part of the national program of renewable energy and energy efficiency.

The studied photovoltaic plant is located in an area of 26 ha with a production capacity of 13 MW. It is composed of thirteen (13) fields, with one (1 MWc) for each field. The photovoltaic plant contains 4092 modules in the photovoltaic field, 186 strings in the PV field, and 22 modules in each string. In addition, the module can produce 245 W, with a module performance efficiency of 15%.

In this work, a three-day smart model was built with the real measurement data collected with solar radiation and ambient temperature as input and generated power as output. In addition, the input-output system was collected under a range of hours from 6:00 AM to 8:00 PM. The developed model characterizes the performance of the photovoltaic power plant and avoids non-linear dynamic behavior.

Fig 1. Tamanrasset power station in the south Algeria

3. MATHEMATICAL MODELLING

The most commonly used models of PV module essentially incorporate the one diode, its can represent as a mathematical model in order to obtains the relation between the current and voltage module [3, 17] :

$$I = I_{ph} - I_o(e^{\frac{q(V+R_S I)}{akTN_S}} - 1) - \frac{V+R_S I}{R_{sh}} \quad (1)$$

Where I_{ph} is the photocurrent, I_0 the reverse saturation current of the diode, R_s and R_{sh} are the series resistance and shunt resistant of the cell respectively, V the voltage at the terminals of the module, I the module current a the ideality factor.

The photocurrent has a relationship with the temperature, radiation and temperature at the standard conditions and the short circuit temperature coefficient as follow [1, 3]

$$I_{ph} = (I_{STC} + K_i(T - T_{STC}))\frac{G}{G_{STC}} \quad (2)$$

With T the ambient temperature,G the solar radiance, I_{STC}, $T_{STC}$and G_{STC} the photocurrent, temperature and radiation at standard conditions, q electron charge equal to $1.602 * 10^{-19}$, k is the Boltzmann constant $1.38 * 10^{-23} J/K$, K_i is the short circuit temperature coefficient.

Standard conditions : $(T_{STC} = 25°\text{C} = 298.15K)$ and ($G_{STC} = \frac{1000W}{m^2}$).

The reverse saturation current of the diode represent can be presented as follows [1,17] :

$$I_o = \frac{I_{STC}+K_i(T-T_{STC})}{e^{(\frac{q(V_{oc}+K_p(T-T_{STC}))}{akTN_S})-1}} \quad (3)$$

In practice, to produce the maximum power it's necessary to exploit both associations series and parallel mixed association by employing N_s and N_P parameters, therefore, the series association of the cells will increase the voltage of the output of the module as well as the parallel association of the cells will increase the current of module.

The maximum power of the photovoltaic module equal to the current at maximum power product to the voltage at maximum power can be presented follows

$$P_m = I_{mpp} * V_{mpp} \quad (4)$$

According to the equation above, the efficiency of the photovoltaic module equal to the ratio between the maximum power and the product of surface S (m²) by the cell by the sunlight G [1,4], given by :

$$\eta_{PV} = \frac{I_{mpp}*V_{mpp}}{SG} \quad (5)$$

Furthermore, the form factor can be defined as the ratio between the maximum power and the product of the short circuit current by the open circuit voltage which is presented follows [17] :

$$FF = \frac{I_{mpp}*V_{mpp}}{I_O*V_{oc}} \quad (6)$$

Therefore, the performance of the photovoltaic module is related by the electrical parameters, as well as by the environmental parameters, namely the temperature and the radiation.

In this work, an intelligent model was built to diagnosis and simulates the performance of the photovoltaic power station located in Tamanrasset in south Algeria which is founded by the Algerian company Sharikat Kahraba w Takat Moutajadida (SKTM) company, the real time measurements data was collected from the photovoltaic power station to build the intelligent model able to simulate the behavior of the studied photovoltaic power station, the intelligent model was collected the real measurements data during a three work days with a variations of the ambient temperature and radiation with associated produced power, from 6:00 morning until 20:00 evening time.

The curve variation of ambient temperature during three days from 6:00 morning until 20:00 evening time shown figure 2, with an average of 24.05 as shows in figure 3.

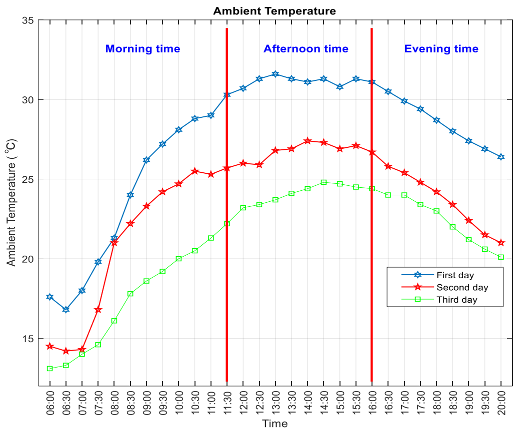

Fig. 2. The ambient temperature at Tamanrasset photovoltaic power station

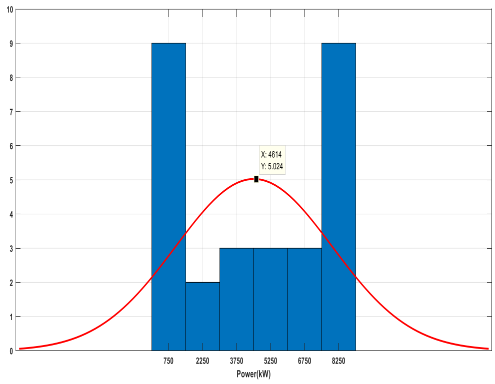

Fig. 3. Average of ambient temperature during three days at Tamanrasset photovoltaic power station

Furthermore, the curve variation of solar radiation during three days from 6:00 morning until 20:00 evening time can be presented in figure 4, it's clearly that the average solar radiation 529.4 W/m² as shows figure 5.

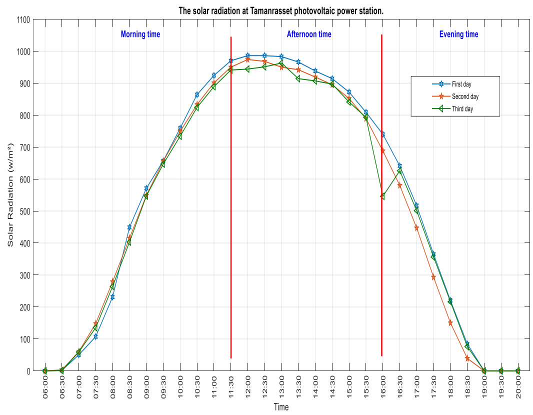

Fig. 4. Solar radiation at Tamanrasset power station

The photovoltaic system has a strong relationship with the environmental parameters as the ambient temperature and the solar radiation, the standard test conditions to achieve the maximum power is defined (STC, 25C or 298.15 DC, with 1000W/m²), Indeed, the real produced power at Tamanrasset photovoltaic power station presented in figure 6, with an average of 4614W as show in figure 7.

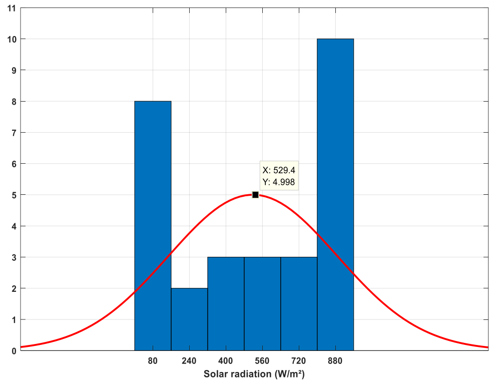

Fig 5. The average solar radiation during three days at Tamanrasset photovoltaic power station

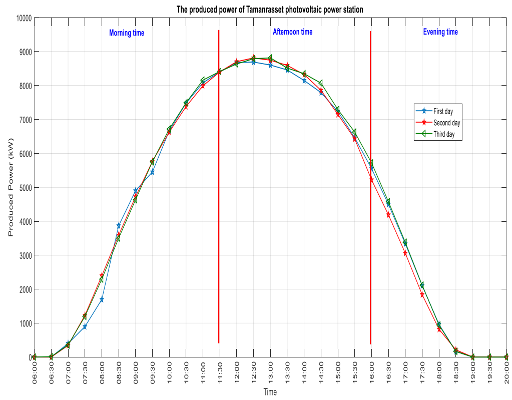

Fig. 6. The produced power at Tamanrasset photovoltaic power station

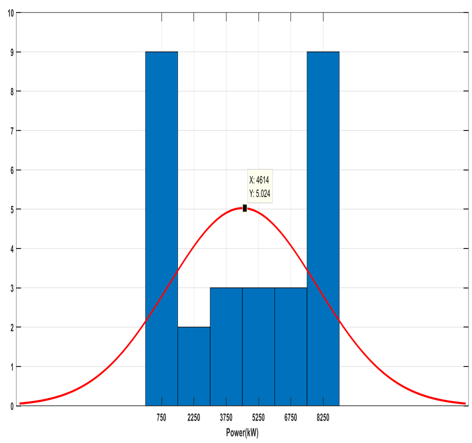

Fig. 7. The average of produced power during three days at Tamanrasset photovoltaic power station

4. PHOTOVOLTAIC SYSTEM DIAGNOSTIC SYSTEM BASED ON NEURAL NETWORKS

The photovoltaic system affected with two mains factors, internal parameters such as the series and shunt resistances, therefore, the series resistors affect the curve (I, V) that can result a deviation of the slope from the maximum power point. where the shunt resistance increase lead to increase the produced power, and the externs parameters such as the temperature and solar radiance, where the lower solar irradiance affect the (P, V) curve that decrease the maximum power, and the increasing of the temperature lead to decrease the maximum power.

Diagnostics of photovoltaic systems have become a challenge, especially to avoid sudden failures that appear in the system. Therefore, artificial neural networks become one of the most commonly used diagnostic approaches in the nonlinear system due to their strong self-learning ability, generalization ability, and high fault tolerance. The proposed diagnostic system based on the artificial neural network model is shown in Figure 8.

The developed diagnostic approach based on artificial neural networks is divided on two parts, the first part consists to generate the residual by compare the real output with the neural network model , then the second part with compare the amplitude of the generated residual with the threshold in order to evaluate the generated residual with the alarm.

The artificial neural network collects the real measurements data and divided it into training, validation and testing, it's divided the real data into 70% for training, 15% for validation, and 15% for testing, furthermore, the scheme of the proposed multilayer neural networks is shown in figure 9.

The neural network applied for the diagnosis of the photovoltaic system uses multilayer networks. It has an input layer containing solar radiation and the ambient temperature, a hidden layer, and an output layer containing the power produced. The hidden layer with a non-linear 'sigmoid' activation function and a linear activation function for the output layer. The multilayer neural network uses a retro propagation algorithm and a learning rule to minimize the squared error given by the following equation:

$$E = \frac{1}{2}\sum_i (d_i - y_i)^2 = \frac{1}{2}\sum_i \left(d_i \sum w_{ij} x_j\right)^2 \tag{7}$$

Where w_{ij} the change in weight w_{ij} by a quantity Δw_{ij} must be proportional to the error gradient given by:

$$\Delta w_{ij} = -\eta \frac{dE}{dw_{ij}} = \eta \sum_i (d_i - y_i) x_i \tag{8}$$

The weighted sum of inputs will be calculated using the following expression:

$$a_j = \sum_{j=1,n} w_{ij} x_j \tag{9}$$

From this value; the activation function calculating the value of the neuron state that it is sent to downstream neurons.

$$y_i = \phi(a_i - \theta_i) \tag{10}$$

The gradient algorithm is used to calculate the derivatives of the photovoltaic system entities with respect to all its inputs, this output defined as

$$u_j = f_1\Big(\sum_{i=1} w_{ij}^1 x_i + w_{ki}^1 x_k + b_j^1\Big)$$
$$y_k = f_2\left(\sum_{i=2}^{N} u_1 + b_k^2\right) \tag{11}$$

Where $f_1(v) = \frac{2}{1+e^{-2v}} - 1$, $f_2(v) = v$ are respectively the sigmoid activation function, k is the output layer index, i is the input layer index, j is the hidden layer index, w_{kj} is the synaptic weight, w_{ji} is the synaptic weight between the layers Inputs and hidden, w_{ki} the synaptic weight between the output and input layers, x_i is the connection between the input and hidden layers and b_j^1 is the bias of the neuron j.

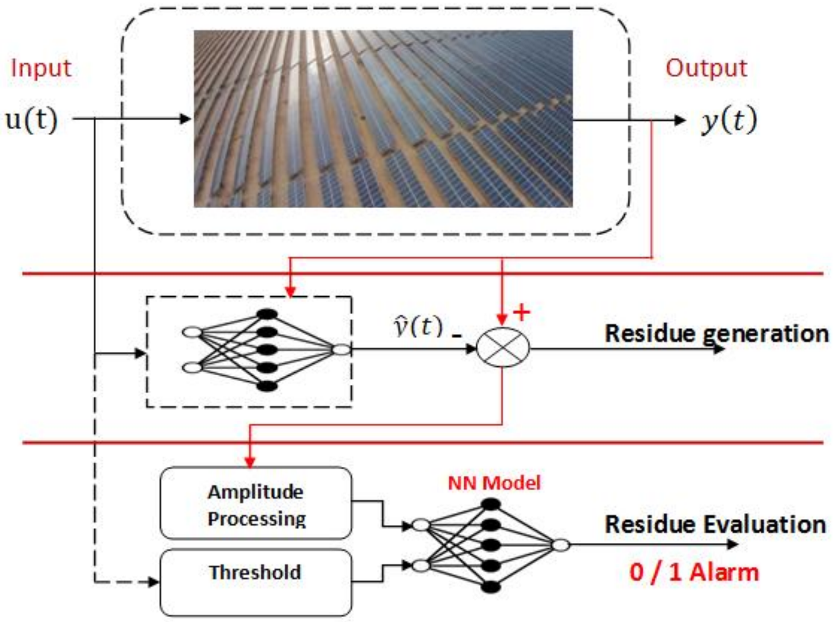

Fig. 8. Proposed diagnostic system based on artificial neural networks model

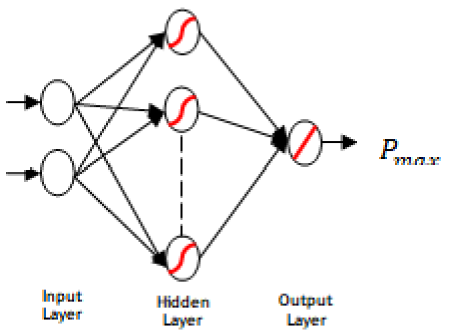

Fig. 9. The proposed artificial neural networks

The algorithm used to minimize the cost function E is based on the gradient method, are given as follows

$$E_p(W) = \frac{1}{2}\sum_{i=1}^{m}[y_i^d(k) - \hat{y}_i(k)]^2 \tag{12}$$

The proposed flowchart shows the fault diagnostic of the photovoltaic power station, which is divided into two parts, the first consist to generate the residue

$$r(k) = y(k) - \hat{y}(k) \tag{13}$$

Where the $y(k)$ is the real measured output of the system, and $\hat{y}(k)$ is the neural network estimated model of the system, therefore, the second part aims to evaluate the characteristic of the generated residue is presented as follows:

$$P = NN\ (G, T) \tag{14}$$

5. RESULTS AND DISCUSSION

This paper aims to simulate the behavior of the studied photovoltaic plant in Tamanrasset, with real measurement data obtained from an intelligent model based on an artificial neural network to detect and locate the faults that appear in the system. So, the objective is to compare the reference model with the proposed intelligent model in a healthy state, and then in order to assess and identify the faults occurring under different weather conditions.

The average power output over three days in a healthy state is shown in Figure 10. The root-mean-square error is of order 10^{-3}, presented in Figure 11.

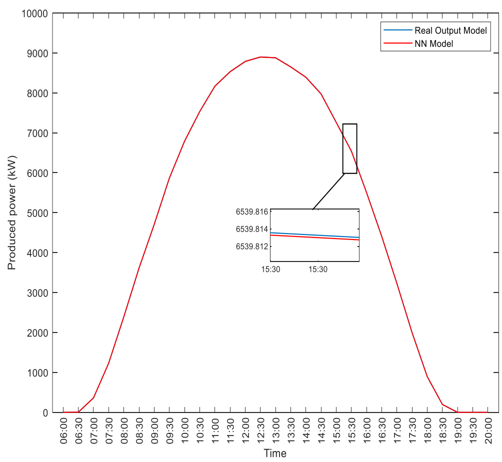

Fig. 10. Real and neural network output model

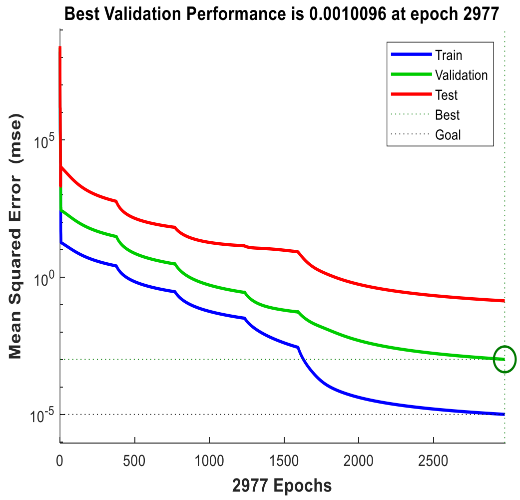

Fig. 11. Neural network performance model

The neural network inputs used in this study are (solar irradiance and ambient temperature) and an output (power output). In addition, I used two processes in the preprocessing of the data, normalization where the input values are rescaled to a uniform scale, and normalization (Min-Max) where normalize the inputs/targets are between [1, -1]. The neural network is trained and validated against the training, validation, and testing dataset, where 70% of the data is used for training, 15% for validation, and 15% for testing. The neural network hyperparameters used are the two-input neural network and a ten-neuron hidden layer with a non-differentiable activation function (sigmoid) and a single-neuron output layer (linear), weight initialization, learning rate, and the number of epochs.

An automated system has been designed to diagnose these faults based on artificial neural networks. The implementation of a diagnostic system based on neural networks is carried out, with tests and several parametric studies on the choice of the type of network, the choice of inputs as well as the choice of outputs. After verifying the good learning performance of the RNA, the faults are studied and tested in the PV system are Mismatch faults, where various illumination intensities during the day and abrupt temperature changes due to different weather conditions and geographical locations. Finally, the results obtained from the neural network tests confirmed the effectiveness of artificial neural networks in automating the diagnosis of these faults in the investigated PV plant.

However, the neural network model learns from the reference model until it reaches the selected mean square error (MSE) in the hyperparameters in a normal operating state, which has the ability to instantly detect the defect between the reference model and the neural model.

Another test of robustness applied of the proposed is obtained by determining the statistical coefficient as shows in Figure 13.

The figure 14 shows the reference model with the unhealthy operation state due to the high temperature which reached until 35 C, therefore, the residual evaluation in Figure 14 shown the system fault detection as "1" and with normal operation state as "0", which indicate the robustness and the effectiveness of the proposed diagnostic approach.

6. CONCLUSION

This paper deals with the diagnosis of the solar power plant of Tamanrasset in the Algerian south with a new intelligent approach based on artificial neural networks. Indeed, photovoltaic stations are influenced by two main factors; internal factors such as shunt and series resistances, and external factors such as solar radiation and temperature. In this work, external factors are studied. The faults studied and tested in the PV system are Mismatch faults, where various irradiance intensities during the day and abrupt temperature changes are due to different weather conditions and geographical locations. Therefore, the developed diagnostic approach based on artificial neural networks is divided into two parts. The first part is to build a reference model for three days of normal operation, and then the second part is to compare the new days with the reference to generate the residual, comparing the actual output with the reference model in order to evaluate and process the characteristics of the generated residuals. The proposed neural network-based approach can avoid nonlinear behaviors and has shown interesting results with high accuracy.

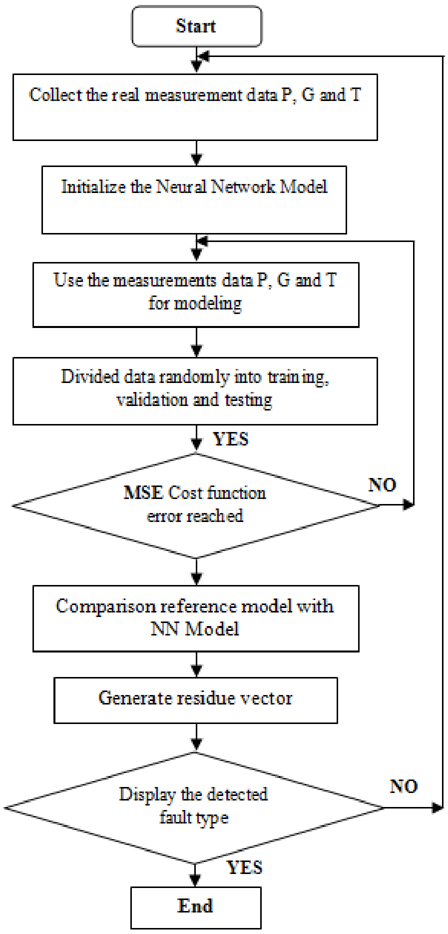

Fig. 12. The flowchart of neural networks modeling system

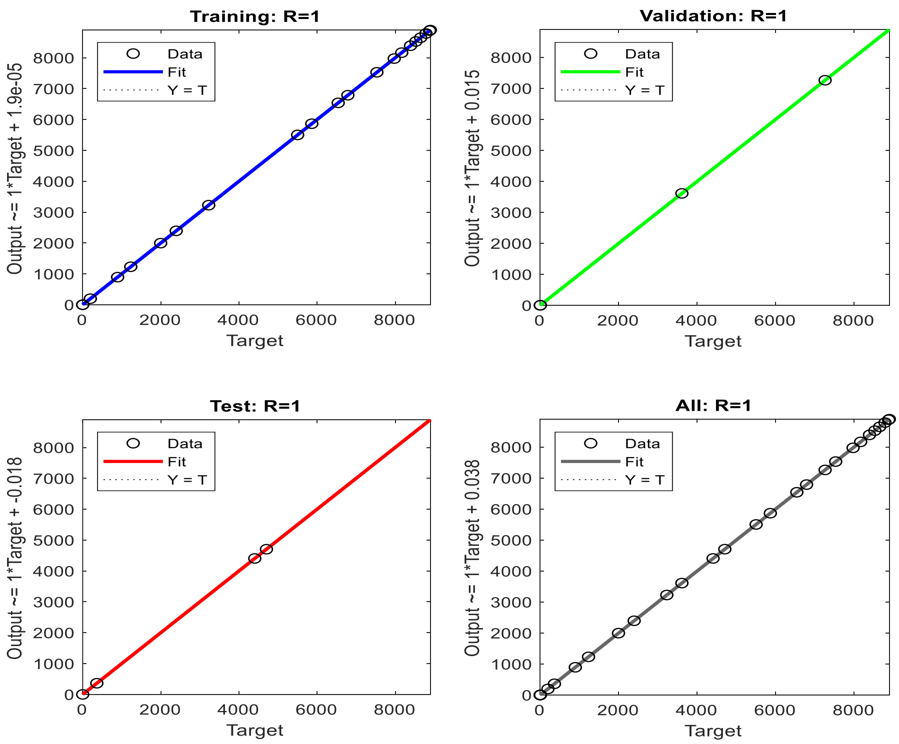

Fig. 13. Correlation of the neural model

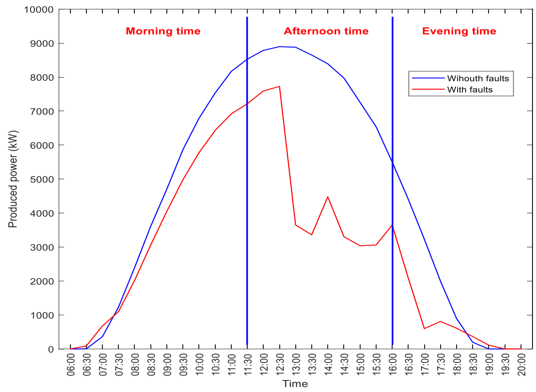

Fig. 14. The reference model and unhealthy model of produced power

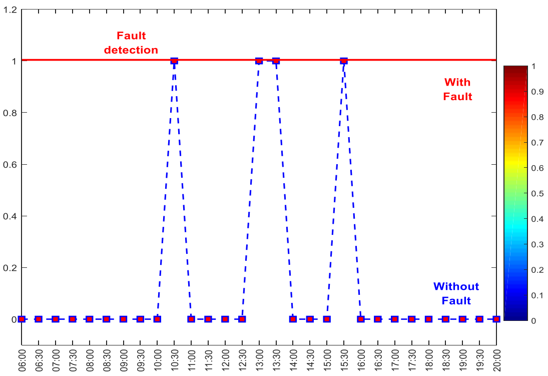

Fig. 15. The evaluation of the characteristics of the residue of the produced power

Author contributions: *research concept and design, M.B.R.; Collection and/or assembly of data, M.B.R.; Data analysis and interpretation, A.S.A., A.H., I.C.; Writing the article, M.B.R., I.A.; Critical revision of the article, A.I., A.S.S.A.H., I.C.; Final approval of the article, A.H.*

Declaration of competing interest: *The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.*

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