Simulation and Control of Photovoltaic Panel Using Nonlinear Autoregressive Moving Average (NARMA Controller)

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Abstract. Recently, the photovoltaics (PVs) is considers as one of important renewable energy systems. Generally, The PVs cell is detecting the solar radiation and converted it into a power electric DC current. In this paper, the PV has designed to produce power electrical of certain power and it has given that power with standard temperatures conditions designed at (1000 W/m², 25 °C) for temperature and solar radiation. In case of increase or decrease in the temperature values and solar radiation the power value will be reduced. Besides, the control systems has utilized to control the power value that effected by the radiation and temperature of the PV system. An artificial neural network (ANN) technique which is nonlinear autoregressive moving average (NARMA) has used to the purpose of get the high efficiency and controlling the maximum power point (MPP) at different conditions of radiation and temperature. This control will be carried out by applying a PV model using the equivalent circuit of the PV. MATLAB-based modelling will be used for simulation and compared between results before and after using NARMA controller.

1 Introduction

Renewable energy plays an important role in generating energy because of the increase in electricity consumption. The average worldwide consumption of this energy was up by 2.2% per years between 2008 to 2013 [1]. Renewable energy is a supply that will feed the future sufficiently efficiently without environmental degradation through greenhouse gas emissions. The solar energy is more and more clean energy available, the sun was used to provide light, heat and electric power etc. for domestic and industrial applications through solar energy technologies [2]. In recent years, renewable energy sources and photovoltaic cells have grown significantly [3]. The problem of energy is one of the most important problems facing the world today, this problem is caused by an increase in the demand for electricity and added to the high prices of fossil fuels. Other problems in the world are the increase in global climate change, and because of these problems, alternative technologies for electricity generation have received more attention. And to solve these problems requires the creation of other sources of energy and one of these resources is renewable energy [4]. Photovoltaic cells (PVs) plays an important role for converting solar energy into electrical energy and most recognized methods for using solar energy. The efficiency of typical photovoltaic cells was about 15%, which means that these cells can convert 1/6 of solar energy into electrical energy [5]. In the present work used Artificial Neural Networks Technique (ANN) is used for controlling of the PV panel to improve the efficiency [6].
2 Modeling and Simulation of PV Panel

2.1 Mathematical Formulation of PV module

This part focuses on the modeling and simulation of PV Panel. It presented the mathematical equation of electrical and thermal performance of PV [7]. The characteristics and behavior of the PV module under different operating conditions has been mathematically represented and simulated in MATLAB Simulink. These models are different in some respects, such as the number of parameters in the current voltage, accuracy and calculation procedure [8]. The most commonly used model to describe PV is the four parameters (N), the diode electric circuit with the diode as shown in Figure 1. The equivalent circuit of the photovoltaic cell consists of a current source connected in parallel to the diode, two alternating current resistors and a series to show the losses [9].

![Figure 1: PV equivalent circuit](image)

By applying the Kirchhoff law to currents in the equivalent circuit above, we can obtain the mathematical description of the voltage output characteristics of photovoltaic cells, which results in equation 1.

\[ I_{PV} = I_{ph} - I_{D} - I_{sh} \]  

(1)

The diode internal diffusion current is expressed as:

\[ I_{D} = \frac{I_{ph} n D_{j} R_{sh}}{N_{v}} \]  

(2)

Where \( I_{D} \) is Reverse saturation current of the diode, \( I_{ph} \) photo current (A), \( m \) is Electron charge (1.602 \times 10^{-19} \text{Coulomb}), \( N \) ideality factor, \( K \) Boltzmann constant (1.381 \times 10^{-23} \text{J/K}), \( R_{sh} \) is shunt resistance (\( \Omega \)) and \( R_{s} \) is series resistance (\( \Omega \)).

The photocurrent \( I_{ph} \) mainly associated to the working temperature of cell and solar radiation, which is described as

\[ I_{ph} = (I_{SC} + G_{ref} \cdot \mathcal{C}_{ref} \cdot (T_{ref} - T)) \]  

(3)

Where \( I_{SC} \) is Short circuit current of solar cell, \( G_{ref} \) reference solar radiation in (1000 W/m²), \( G \) is Solar radiation (W/m²), \( T \) Cell temperature, \( T_{ref} \) Cell reference temperature (298 K), \( K_{i} \) is Short circuit current temperature coefficient (A). The Short circuit current is measured under (STC) of reference temperature 25 °C and solar radiation of 1000 W/m². The open circuit voltage can be given by [18]

\[ V_{oc} = \frac{V_{oc} + K \cdot V}{(T - T_{ref})} \]  

(4)

Where \( V_{oc} \) is open circuit voltage at (STC), \( K \) open circuit voltage temperature coefficient.

\[ I_{S} = I_{Rs} \cdot \frac{(T/T_{ref})}{3} \cdot e^{\left(e^{-\left(\frac{E_{g}}{kT}\right)}\right)} \]  

(5)

Where, \( I_{S} \) is Reverse saturation current of cell at a reference temperature and a solar radiation, \( E_{g} \) Band-gap energy of the monocrystalline-Si solar cell equal 1.12 eV, \( N \) diode ideality factor which is depend on PV technology.

The reverse saturation current of cell at reference temperature can be approximately calculated as [5].

\[ I_{rs} = \frac{q}{nN_{v}kT_{ref}} \]  

(6)

The current of PV and shunt current determine as:

\[ I_{PV} = I_{ph} - I_{D} - I_{sh} \]  

(7)

\[ I_{sh} = \left(V + I \cdot R_{sh}\right) \]  

(8)
2.2 Simulation of PV Panel
The strategy of PV module modeling is not different from PV cell modeling. It uses the same parameters of PV cell model, but only the open-circuit voltage is different and must be divided by the number of cells in series. In order to simulate the performance of PV cells and to make a good model, it is necessary to take into account all the factors that affect the PV cell such as solar radiation, the operating temperature, ideality factor, Series resistance and neglect the effect of because the effect is very small on single module. The simulation is based on the datasheet of (Monocrystalline, SR-100S, and 100W) photovoltaic module [10] and the parameters required for the simulation of this PV panel are illustrated in Table 1.

Table 1: Technical specification of the proposed PV panel

| MODEL       | SR-100S |
|-------------|---------|
| Maximum power | 100W    |
| Open circuit voltage | 21.8V    |
| Short circuit current | 6.4A    |
| Rated voltage | 17.2V    |
| Rated current | 5.82A   |
| Short circuit current temperature coefficient | 2.1 mA/K |
| Open circuit voltage temperature coefficient | -0.79 V/K |
| No. of series cells | 54 |
| No. of parallel cells | 1   |
| Dimensions | 1250*808*35mm |
| Test condition | 1000 W/m², 25 °C |

The procedure of simulation is as following:
Step 1 using equation 3 to compute photocurrent, and step 2 using equation 6 to calculate reverse saturation current. In addition, using step 3 the equation 5 of the cell’s saturation current of the diode. Moreover, using step 4 equation 2 to find diode internal diffusion current. Carrying out all the above equations, this will leads to obtain the output PV current in equation 7 as figure 1.

2.3 Implementation and Simulation of Model
The proposed model of single solar photovoltaic cell is implemented and shown in figure 2 to figure 7.

Figure 2: Shunt Current Simulation System.
Figure 3: Reverse Saturation Current.

Figure 4: Saturation Current Simulation System.

Figure 5: Photo Current simulation system.
2.4 Design of NARMA in PV Panel

The closed loop diagram of the control system for the PV cell by NARMA controller has been applied using Matlab program. Figure 9 show the PV model with NARMA Controller and after design NARMA, as well as add a step to sense any change in power then go to system to give a results or not by adjust a power by a gain.
3 Results and Discussions
3.1 Results of Simulink Model
The plots of I-V characteristic bends have been delivered by changing certain parameters each one, in turn, keeping different parameters steady at STC executed in MATLAB Simulink. Figure 10 outlines the I-V normal for fluctuating sun based irradiance (G). On watching the bend delineate the expansion in irradiance esteem cell current esteem likewise increments relatively however cell voltage increments exceptionally less. Figure 12 clarify I-V characteristic for shifting temperature (T). It is seen that as temperature expands cell current additionally builds marginally and cell voltage demonstrates a huge abatement in its esteem.

In figure 11 and figure, 13 are indicating P-V qualities of sunlight based cell through which we can find its pinnacle, for example, maximum power point with separate voltages for fluctuating irradiance and temperature individually. Moreover, it is being seen that as irradiance expands yield control that to increments ostensible power point at STC. Additionally, with the expansion in temperature, yield control diminishes.

In Figure 10 represents the relationship between output (I-V) characteristic of the solar cell and Figure 11 the relationship between output (P-V) characteristic of the cell without the use of the NARMA controller, moreover, we will note in the case of difference irradiation and temperature fixed will be values of the output power different from PV as shown in table 2.

Figure 9: PV model with NARMA Controller.

Figure 10: Output I-V Characteristic of the typical solar cell under different irradiance.
Table 2 represent the results in both of figure 11 and figure 10 which shows values between P-V & I-V varying on irradiation and temperature stability.

Table 2. The parameters between P-V and I-V varying on irradiation and temperature stability.

| Irradiation G (W/m²) | Temperature T (°C) | I_sc (Amp) | V_oc (volt) | P_m (watt) |
|----------------------|--------------------|------------|-------------|------------|
| 200                  | 25                 | 1.6        | 13.5        | 19         |
| 500                  | 25                 | 3.8        | 15.2        | 42         |
| 1000                 | 25                 | 7.2        | 19          | 96         |

Figure 11: P-V Characteristics of varying irradiance.

Figure 12: Output I-V Characteristic of the typical solar cell under different temperature.

Figure 13: P-V Characteristics varying temperature.
In figure 12 represents the relationship between output (I-V) characteristic of the solar cell and Figure 13 the relationship between output (P-V) characteristic of the cell without the use of the NARMA controller. Moreover, in the case of different temperature and irradiation fixed will be notice on the values of the output power different from PV as shown in table 3. Table 3 represent the results of figure 13 and figure 12, which shows values between (P-V), & (I-V) stability on irradiation and temperature varying.

Table 3: The result values between (P-V) & (I-V) stability on irradiation and temperature varying

| Irradiation (W/m²) | Temperature (°C) | I_sc (Amp) | V_sc (volt) | P_m (watt) |
|------------------|-----------------|------------|-------------|------------|
| 1000             | 25              | 7.5        | 18          | 100        |
| 1000             | 50              | 6          | 15          | 94         |
| 1000             | 100             | 7.4        | 10          | 78         |

3.2 Result with Controller

NARMA is one of the controller types working within the framework of the work of the neural network. NARMA controller divides data into three parts of the data until it reaches the desired results from NARMA. The closed loop diagram of the control system for PV by NARMA controller has been applied using Matlab program. There are two most important steps in the use of NARMA that contains a control identification system and design as figures from 14 to 18 represents the three parts in which NARMA controller operates until the searched desired results are achieved. In Figure 14, the first part of these data is the test data, and from Figure 15 to 17 it is the second part of the data and represents the training data.

The third part of NARMA control work is the validation data as in Figure 18, after which the NARMA gives the final results required to control it as shown in figure 19 illustrated the output power of PV cell with NARMA controller equal (100 watt) at temperature 25 °C, and irradiation value 1000 W/m².

Figure 14: Testing data of power in NARMA controller.

Figure 15: Training data of power in NARMA controller.
Figure 16. Input-Output data of power in NARMA.

Figure 17. Training data of power in NARMA controller.

Figure 18. Validation data of power in NARMA controller.
4 Conclusions
The conclusion show a comparison of the results in PV cell with controller and without controller. The uncontrolled case at different temperature and different radiation, after the addition of control and get the value of the capacity of attention and used the neural network of control because it is accurate to give the results in control by building a simulink model of the PV cell using artificial intelligence to reach the efficiency of attention means design efficiency For the PV cell.
The PV cell models applied to guess the attempt of controller vary of output of plant as well as controllers should contribute towards high reliability and performance in addition to cost effectiveness also by updating of controller parameters to maximize system output power and high efficiency. Utilization of training algorithm the Levenberg Marquardt (trainlm) which give the most efficient from the other types of the training algorithms by using neural networks. NARMA controller should be contribute to words high performance, cost effectiveness and reliability.

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