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Performance Enhancement of PV System using Artificial Neural Network (ANN) as a Maximum Power Point Tracking

***Abstract**. Since the generalization of the use of electricity, energy consumption, conversion and energy storage has led to research and development of new sources of supply. This interest has increased due to the depletion of fossil fuels, their impact on the environment and the waste they generate. Photovoltaic (PV) technology is an attractive solution as a replacement or complementary to conventional sources of electricity supply due to its many advantages. This work focuses on studying, modeling and designing of an advanced controller for a step up converter that uses an artificial neural network (ANN) as a maximum power point tracking (MPPT) algorithm to generate maximum power. The effectiveness was proved for climatic conditions variation. A comparative study between the proposed method and the conventional ones was carried out using Matlab/Simulink software*

***Streszczenie.** Od czasu uogólnienia wykorzystania energii elektrycznej jej zużycie, konwersja i magazynowanie energii doprowadziły do badań i rozwoju nowych źródeł zaopatrzenia. Zainteresowanie to wzrosło ze względu na wyczerpywanie się paliw kopalnych, ich wpływ na środowisko i generowane przez nie odpady. Technologia fotowoltaiczna (PV) jest atrakcyjnym rozwiązaniem jako zamiennik lub uzupełnienie konwencjonalnych źródeł zaopatrzenia w energię elektryczną ze względu na swoje liczne zalety. Praca ta koncentruje się na badaniu, modelowaniu i projektowaniu zaawansowanego sterownika do przetwornicy podwyższającej, która wykorzystuje sztuczną sieć neuronową (ANN) jako algorytm śledzenia punktu mocy maksymalnej (MPPT) do generowania maksymalnej mocy. Skuteczność została wykazana przy zmienności warunków klimatycznych. Badanie porównawcze proponowanej metody z metodami konwencjonalnymi przeprowadzono z wykorzystaniem oprogramowania Matlab/Simulink (**Zwiększenie wydajności systemu fotowoltaicznego przy użyciu sztucznej sieci neuronowej (ANN) jako śledzenia punktu maksymalnej mocy**)*

Keywords Solar energy, Step up Chopper, Intelligent MPPT controller, Artificial Neural networks.
.**Słowa kluczowe:** Energia słoneczna, Step up Chopper, Inteligentny sterownik MPPT, Sztuczne sieci neuronowe..

Introduction

In recent decades, energy consumption has been on the rise in all regions of the world, following the considerable advancement of technology and industry. This had the negative consequence of climatic upheaval and notable natural disasters. The solution is to use renewable energies which offer the possibility of producing electricity that meets ecological requirements, such as photovoltaic energy, but unfortunately this issue encounters economic constraints, high cost and low yield. The maximum power pursuit problem is among the problems of photovoltaic systems. This observation is confirmed by the large number of works oncerning this problem encountered in the literature. Different MPPT methods have been used in the literature in order to achieve optimal performance. The most popular algorithm is perturb and observe (P&O) [1,2]. The incremental conductance is [3,4]. The open-circuit voltage [5], fuzzy logic method [5], genetic algorithm [6]. and MPPT algorithms based on neural networks in [7,8]. Intelligence techniques play an important role in performance analysis, prediction, and control of renewable energy systems.

The main objective of this work is to study the performance of a solar system integrating an ANN MPPT technique considered for power maximization. For atmospheric condition variation, the behavior and performance of PV panels using this algorithm are analyzed

PV panel description and modelling

A single solar cell can be modeled by using a current source, a diode, and two resistors [9,10]. This model is known as a single diode model. A PV array is a group of several PV cells which are electrically connected in series and parallel circuits to generate the required current and voltage (Figure 1).
Photonic generated current basically depends on irradiance and temperature.

(1) $$I_{ph} = I_{sc} + k_i(T - T_{ref})(\frac{G}{1000}$$

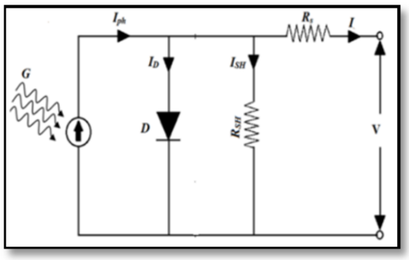


Fig. 1. Photovoltaic cell

The short-circuit current Isc is defined by: $I_{sc=}I_{s=}I_{ph}$

The module-reverse saturation current Irs and I_0 which varies with cell temperature are given by:

(2) $$I_{rs} = I_{sc}/[\exp\left(\frac{qV_{oc}}{N_s knT}\right) - 1]$$

(3) $$I_o = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{qE_g}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right]$$

The current voltage characteristics will be:

(4) $$I = I_{ph} - I_s\left(e^{\frac{q(V+IR_S)}{nKT_C}} - 1\right) - \frac{V+IR_S}{R_{sh}}$$

Table 1. Parameters of The Solar Module

Open circuit voltage (Voc)	36.3 V
Short-circuit current (I_{sc})	7.84 A
Voltage at MPP (V_{mp})	29 V
Current at MPP (I_{mp})	7.35
Maximum Power (P_m)	213.15 w
N_s	96

Datasheet of the pv panel **1Soltech 1STH-215-P** implemented in matlab Simulink software and its parameters are listed in Table 1. Simulation was carried out for climatic condition variation for pv panel with 2 series modules and 2 parallel strings. Figure 2 shows **I-V** and **P-V** characteristics for different level of irradiance and temperature. It is clear that by varying irradiance the open circuit voltage Voc has a small variation, contrary to the short-circuit current Isc which varies a lot which causes a huge variation in the power of the photovoltaic panel. Unlike the variation in irradiance, the variation in temperature mainly affects the open circuit voltage Voc. It decreases with temperature rise. Maximum power is obtained for a maximum irradiance and a minimum temperature. So in STC conditions (G=1000 w/m^2, T= 25° C) this panel generates a maximum power of 852.6w corresponding to pv voltage of 58 V and a current of 15.68A.

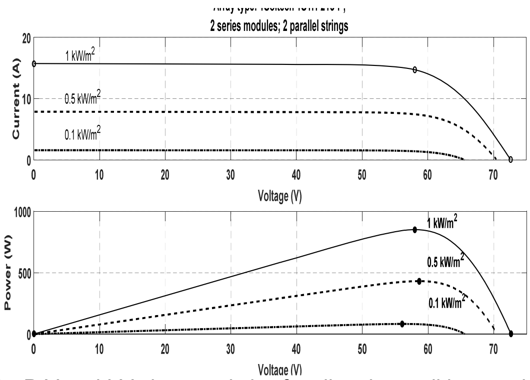


Fig. 2. P-V and I-V characteristics for climatic conditions variation

The Maximum Power Point (MPP) of a solar panel varies with irradiation and temperature. Maximum power point tracking is a technique applied to the control of a power converter attached to a solar panel which optimizes the output power by varying the operating point in terms of voltage and current. Because of their ease of implementation, the (P & O) and INC algorithms are the most commonly used [11,12]. Usually, in order to extract at all times, the maximum power available at the terminals of the photovoltaic module and transfer it to the load, an adaptation stage DC-DC converter is used. The proposed model incorporates a PV array and a step-up converter, which is used as an interface device connecting the PV panel to the load.

Step up DC-DC converter is composed of two semi-conductor switches (controlled and uncontrolled) and an energy storage element. The output voltage ripples are reduced by connecting a capacitor to the converter output. Relationship between inputs and outputs voltage and current are given by equation 5.

$$\frac{V_{out}}{V_{in}} = \frac{I_{in}}{I_{out}} = \frac{1}{1-D} \quad (5)$$

Perturb and observe P&O technique

The basic idea behind this technique is perturbing (increasing or decreasing) the array terminal voltage and observing the impact on the PV output power, then comparing it with the previous iteration's value. If the power is increased, the perturbation will continue in its current direction; otherwise, it will reverse. The operating point begins to oscillate around the maximum power point (MPP) after it is achieved. This technique presents some limitations, such as an increase in power losses as a result of the steady state condition oscillation around the MPP, particularly in the case of big steps [13]. The (P&O) algorithm is sluggish during a quick change of atmospheric conditions.

Incremental conductance (INC) technic

In this technique, the incremental conductance (ΔI/ΔV) and the instantaneous conductance (I/V) are compared. The terminal voltage of the PV array decreases if the slope of the P-V curve (ΔP/ΔV) is negative, indicating that the operating point is to the right of the MPP. If the slope is positive, the operating point is to the left of the MPP and the terminal voltage of the PV array is raised; if the slope is zero, the MPP is attained and the instantaneous and incremental conductances are equal [14].

The P&O and INC algorithms are simulated first. Results have been established for temperature T = 25°C and variable irradiations to analyze the behavior of each technique (Fig.5). Figure 6 to Figure 11 show the duty cycle, generated power P_{pv} compared to reference power P_{ideal} , voltage and current of the PV panel and load.

At standard test condition STC, the PV system performance using P&O and INC MPPT algorithms is shown. It is clear that for constant irradiation G=1000 w/m^2, P&O find MPP quickly but oscillate at MPP. While, as shown in Fig. 13, INC finds MPP after a time delay. But the oscillations at constant irradiation are less as compared to P&O. Duty cycle dynamics of both algorithms for variable climatic conditions show that for P&O, D is perturbed continuously and results in greater oscillation at MPP with better tracking performances for instantaneous variation or quick slope of irradiance. While for INC, D presents less oscillation at MPP and more time to reach steady state.

Thus, in order to overcome these limitations of conventional MPPT techniques, an efficient MPPT algorithm is needed. For this reason, a Neural Network MPPT algorithm is proposed.

Basic structure of neural network

An artificial neural network ANN is a form of artificial neural network intelligence that tries to imitate the behavior of the human brain and nervous system. Basically, the architecture consists of three types of neuron layers: the input layer, the hidden layer, and the output layer. A simple neuron model is shown in Figure 12. There are different activation functions that can be used [15,16]. A mathematical model of the output of a neuron k can be written as mentioned by Equations (6,7).

The output neuron is obtained by summing each of the input signals after they have been multiplied by the connection weights. The proposed ANN in this study is a feed-forward neural network. The input layers represent the irradiance and temperature. The output layer is the voltage Vmpp corresponding to the maximum power generated by the panel. A duty cycle signal is then applied for adjusting PV voltage through the boost converter.

The topology proposed and simulated in Matlab/Simulink is presented in figure 13. The gate signal of the DC-DC converter is given from the NN algorithm. The algorithm takes irradiation and temperature from the solar PV module and after optimizing voltage value, a referenced duty cycle is generated, which is given to the dc-dc boost converter.

The success of the ANN was measured using mean square error (MSE) and regression coefficient [17,18]. Figure 14 shows validation performance graph obtained for the optimal value of the objective function of the network where training data, testing data and validation data are very close to each other. Best validation value is MSE= 1.802e-10 obtained at epoch 1000.

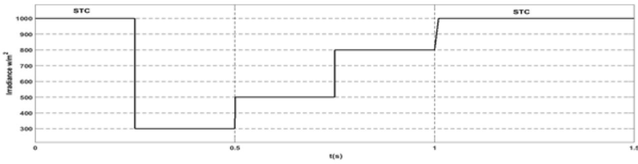


Fig. 5. Irradiance variation

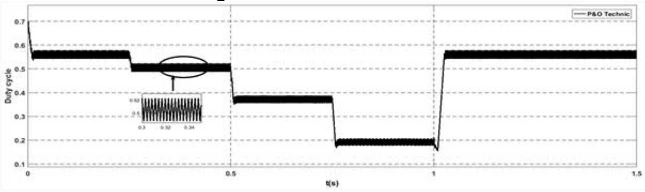


Fig. 6. Duty cycle for P&O technique

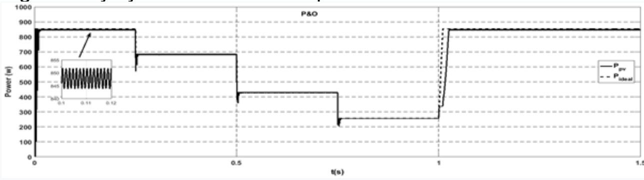


Fig. 7. PV power with P&O algorithm

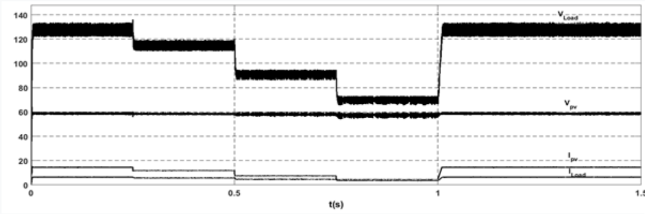


Fig. 8. PV and load voltage and current with P&O algorithm

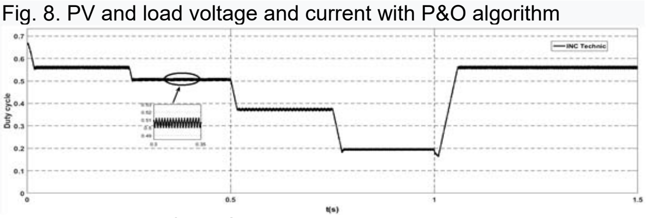


Fig. 9. Duty cycle for INC technique

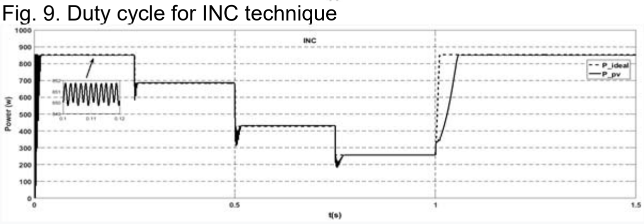


Fig. 10. PV power with INC technique

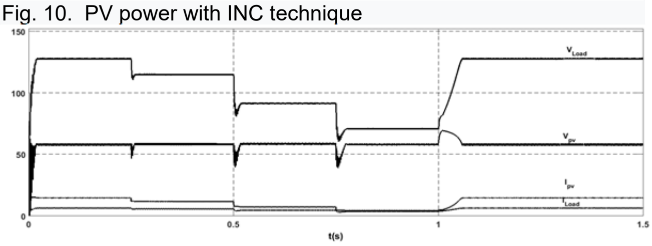


Fig. 11. PV and load voltage and current with INC technic

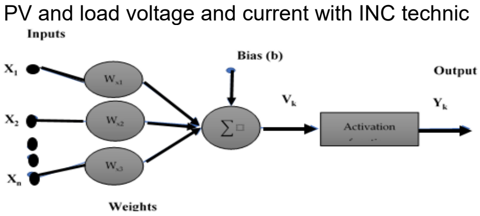


Fig.12. Basic structure of neuron

(6) $V_k = \sum_{i=1}^{n} x_i w_{kj} +$

(7) $y_k = f(V_k)$

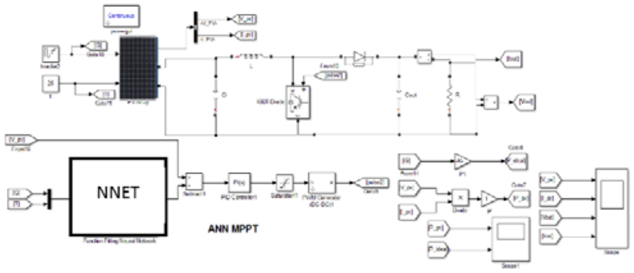


Fig. 13. Matlab/simulink model of pv panel with ANN Algorithm

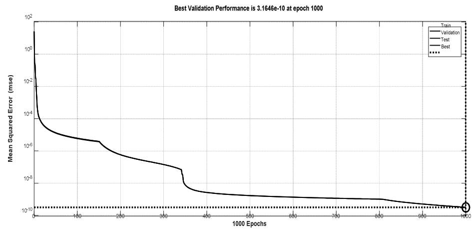


Fig. 14. validation performance graph

Results and discussion

The three methods were tested and compared under different scenarios. Figure 15 shows generated power and Figure 16 shows input and output voltages and currents. Variations in solar irradiance and temperature are applied to check and evaluate the robustness of the proposed controller.

Figure 17 and Figure 18 show simulation results of P&O, INC, and ANN algorithms for maximum power point tracking for atmospheric condition variation. It is clear that all of NN, P&O, and INC track MPP with varying degrees of efficiency and accuracy. The NN algorithm has a fast response; it takes less time to reach MPP with high efficiency and less oscillation compared with traditional methods.

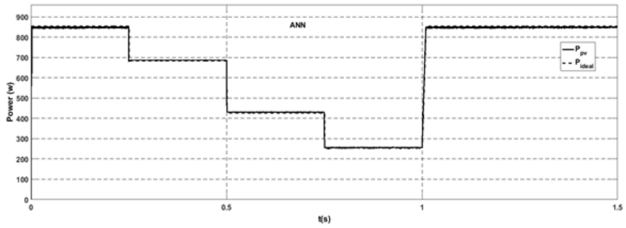


Fig. 15. PV power with ANN algorithm

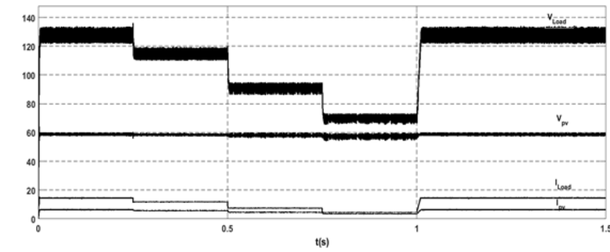
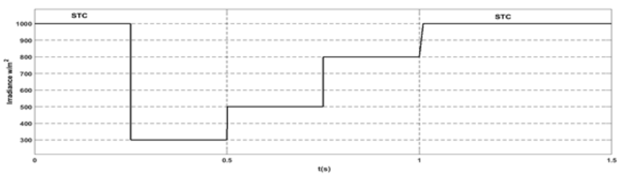


Fig. 16. PV and load voltage and current with ANN algorithm



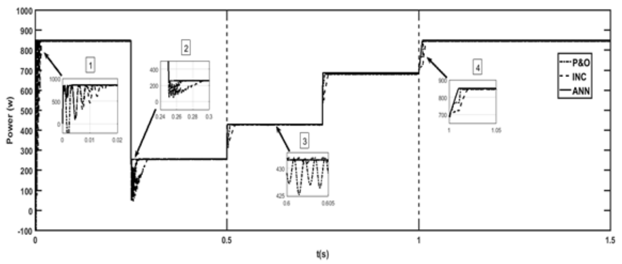


Fig. 17. PV Power obtained applying P&O, INC and ANN algorithm for irradiation variation

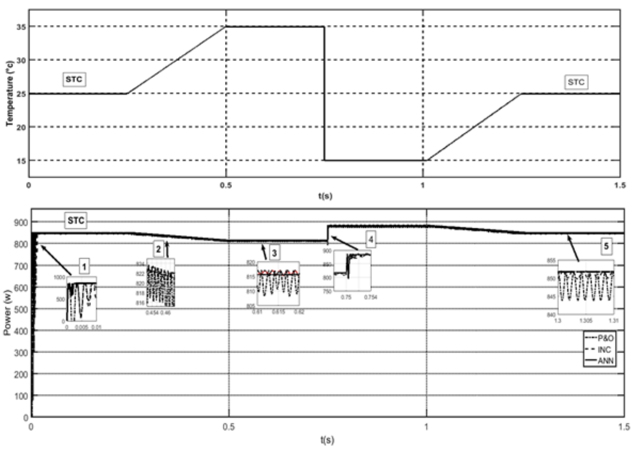


Fig. 18. PV Power obtained applying P&O, INC and ANN algorithm temperature variation

Conclusion

In this paper, a comparative study on maximum power point tracking techniques for photovoltaic generation systems operation under fast and slow changing atmospheric conditions is established. The behavior of a PV system is studied using conventional methods such as perturb and observe, incremental conductance, and the intelligent proposed ANN technique. The four steps of getting the network are data collection, selection of the network structure, training the network, and testing the network, which is the last step before using it. Simulation results show that all methods are stable at MPP but P&O and INC overshoot when irradiance changes rapidly. The ANN algorithm tracks the MPP faster with negligible oscillations, which increases efficiency, robustness and decreases power losses. The obtained results prove the superiority and effectiveness of the ANN controller.

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