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Steady state oscillations reduction using neural network IC-based variable step Size MPPT

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Abstract - *This paper deals with the development of neural network IC-based variable step size MPPT controller. The proposed neural network MPPT controller is firstly, developed in offline mode required for testing different set of neural network parameters and architectures, and used secondly in the online mode to track the output power of the PV system composed of Solarex MSX 60W PV module fed by a DC-DC boost converter drived using the proposed ANN MPPT controller. The proposed neural network MPPT controller is tested and validated using Matlab/Simulink environments. Simulation results and analysis are presented showing good performances for the proposed controller compared to the conventional fixed or variable step size algorithms.*

Résumé - *Cet article traite le développement d'un contrôleur MPPT à pas variable basé sur un réseau neuronal. Le contrôleur MPPT proposé est d'abord développé en mode hors ligne pour tester différents ensembles de paramètres et architectures de réseaux neuronaux puis utilisé en second lieu en mode en ligne pour suivre la puissance de sortie d'un système photovoltaïque composé du module Solarex MSX 60W alimenté par un convertisseur boost DC-DC piloté à par le régulateur ANN MPPT proposé. Le contrôleur MPPT proposé est testé et validé en utilisant l'environnement Matlab/Simulink. Les résultats de simulation et d'analyse sont présentés montrant de bonnes performances pour le contrôleur proposé par rapport aux contrôleurs conventionnels à pas fixe et à pas variable.*

Keywords: PV System - MPPT - Incremental Conductance - IC - Neural Network - Variable Step Size.

1. INTRODUCTION

Solar energy is a clean energy since it fuses hydrogen atoms into helium to radiate light and heat. It has been harnessed by human beings since ancient time using a range of ever-evolving technologies. Solar radiation, along with secondary solar- powered resources such as wind and wave power, hydroelectricity and biomass, is accounted for most of the available renewable energy on the Earth.

These use infinite sources as a basis for energy supplies and can ensure a full supply with a suitable combination of different technologies such as biomasses, photovoltaic's, wind power, and so on. A particular role in the number of renewable energies is played

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by photovoltaic's; they permit an emission-free conversion of sunlight into electrical energy and, will be an important pillar in future energy systems[1-2].

Photovoltaic systems can provide clean power for small or large applications. They are already installed and generating energy around the world in individual homes, housing developments, offices and public buildings. Although PV systems can operate as stand-alone systems, where it is difficult to connect to the grid or where there is no energy infrastructure, they are mostly connected to the grid for homes and businesses in developed areas.

Unfortunately, the performance of a solar cell is measured in terms of its efficiency at turning sunlight into electricity. A typical commercial solar cell has an efficiency of about 15%. The amount of power produced by a solar power installation depends on the location of the sun in the sky and on the amount of cloud cover. In addition, the source of solar power is not controllable and hence there is a need to maximize the power generated from the sunlight. This can be done with MPPT strategies implemented at an appropriate stage of power processing [3].

Over the past decades many methods to find the MPP have been developed. These techniques differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, correct tracking when irradiation and/or temperature change, hardware needed for the implementation or popularity, among others.

Some of the most popular MPPT techniques are: Perturb and Observe (PO) [4], hill climbing method (HC) [5], Incremental Conductance method (IC) [6], Fractional short circuit current (FSCC) [7], Fractional open circuit voltage (FOCV) [8], Fuzzy logic (FL) [9], Neural networks (NN) [10], genetic algorithm (GA) [11], particle swarm optimisation (PSO) [12], artificial bee colony (ABC) [13], etc.... Among several techniques mentioned, the Perturb and Observe (P&O) method and the Incremental Conductance (IC) algorithms are the most commonly applied algorithms.

The advantages of both methods are simplicity, easy implementation and requirement of low computational power. The drawbacks are: oscillations occur around the MPP and they get lost and track the MPP in the wrong direction during rapidly changing atmospheric conditions.

This paper deals with the development of neural network IC-based variable step size MPPT controller. The proposed neural network MPPT controller is firstly, developed in offline mode required for testing different set of neural network parameters and architectures, and used secondly in the online mode to track the output power of the PV system composed of Solarex MSX 60W PV module fed by a DC-DC boost converter drived using the proposed ANN MPPT controller.

The proposed neural network MPPT controller is tested and validated using Matlab/Simulink environment. Simulation results and analysis are presented showing good performances for the proposed controller compared to the conventional fixed or variable step size IC algorithms.

The remainder of the paper is organized as follows. Section 2 presents the photovoltaic system modelling. Section 3 describes the proposed neural network variable step size MPPT controller. Section 4 presents the simulations results and discussions. In Section 5, the conclusions are stated.

2. PV SYSTEM MODELING

The well-known and widely used model based on the well-known Shockley diode equation is presented below (figure 1) [14].

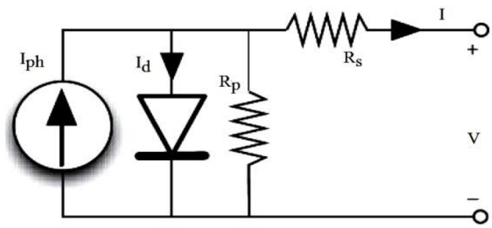

Fig. 1: Solar cell single-diode model

The output current I can be expressed by:

$$I = N_p I_{ph} - N_p I_{rs}\left(e^{\left(\frac{q(v+I R_S)}{A.k.T.N_S}\right)} - 1\right) - N_p\left(\frac{q(v+I R_S)}{N_S.R_p}\right) \quad (1)$$

where V is the cell output voltage, q is the electron charge (1.60217646 × 10^{-19} C), k is the Boltzmann's constant (1.3806503 × 10^{-23}J/K), T is the temperature in Kelvin, I_{rs} is the cell reverse saturation current, A is the diode ideality constant, N_p is the number of PV cells connected parallel and N_s is the number of PV cells connected in series.

The generated photocurrent I_{ph} is related to the solar irradiation by the following equation:

$$I_{ph} = \left(I_{sc} + k_i (T - T_r)\right)\frac{S}{1000} \quad (2)$$

where k_i is the short-circuit current temperature coefficient, S is the solar irradiation in W/m^2, I_{sc} is the cell short-circuit current at reference temperature and T_r is the cell reference temperature.

The cell's saturation current is varies with temperature according to the following equation:

$$I_{rs} = I_{rr}\left(\frac{T}{T_r}\right)^3 \exp\left(\frac{q.E_G}{k.A}.\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \quad (3)$$

where E_G is the band-gap energy of the semiconductor and I_{rr} is the reverse saturation at T_r.

3. PROPOSED NN IC-BASED MPPT ALGORITHM

3.1 Fixed step size IC MPPT

The Incremental Conductance is widely used MPPT methods for its simplicity and ease of implementation, high tracking speed and better efficiency [15-18]. This method focuses directly on power variations. The output current and voltage of the photovoltaic panel are used to calculate the conductance and the incremental conductance. The basic equations of this method are as follows:

$$\frac{dP}{dV} = 0 \quad (4)$$

Equation (4) can be rewritten as:

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{d(I)}{dV} = 0 \tag{5}$$

$$\frac{dI}{dV} = -\frac{I}{V} \quad \text{at MPP} \tag{6}$$

$$\frac{dI}{dV} > -\frac{I}{V} \quad \text{at left of MPP} \tag{7}$$

$$\frac{dI}{dV} < -\frac{I}{V} \quad \text{at right of MPP} \tag{8}$$

The flowchart of the Incremental Conductance method is illustrated in figure 2.

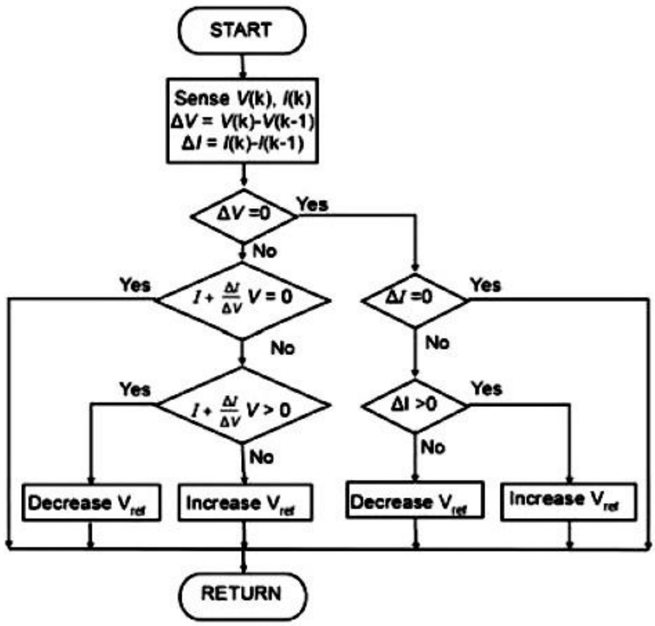

Fig. 2: Fixed step size IC algorithm flowchart

3.2 Variable step size MPPT

The performances of PV systems depends mainly on the IC MPPT algorithm step size. Therefore, a good calculation of step size provides a high performance of PV systems. The proposed variable step size IC MPPT algorithm is given as follows [19-21]:

$$D(k) = D(k-1) + SF \times \Delta D \tag{9}$$

where $D(k)$ and $D(k-1)$ are the duty cycle at instants k and $k-1$, SF is the scaling factor adjusted at the sampling period and ΔD is the fixed step size.

$$SF = \left| \frac{P_k - P_{k-1}}{V_k - V_{k-1}} \right| \tag{10}$$

where P_k, V_k and P_{k-1} V_{k-1} are the output power and voltage at instants k and $k-1$.

3.3 Proposed neural network variable step size MPPT

The brain processes information incrementally and learns concepts over time attaining a remarkable ability to make decisions and draw conclusions when presented with complex, noisy, irrelevant, or partial information.

Neural networks are popular because of their ability to imitate some of the brain's creative processes, albeit in a simplistic way, that cannot be imitated by existing mathematical or logical methods. Such capabilities are essential for solving many complex problems [22, 23].

In this study, we propose an ANN MPPT controller developed firstly in the offline mode required for testing different set of neural network parameters and architecture and used secondly in the online mode to track the output power of the PV system under different atmospheric conditions.

The inputs variables for ANN are the same as the IC algorithm inputs i.e. I I and V V, current and voltage of photovoltaic module, while the output power is the PWM ratio used to drive the DC-DC boost converter. Figure 3 show the architecture of the proposed ANN.

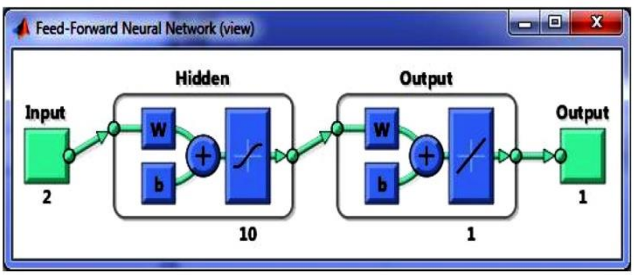

Fig. 3: Architecture of the proposed ANN

The training process uses the mean squared errors minimizing the overall error measure between the ANN output and data generated using the variable step size IC MPPT defined previously. Figure 4 shows the Simulink bloc of the trained ANN MPPT.

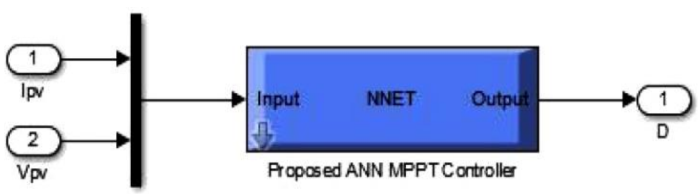

Fig. 4: Simulink bloc of the trained ANN MPPT

4. RESULTS AND DISCUSSION

The effectiveness of proposed variable step size neural network MPPT controller is analyzed and investigated using Matlab/Simulink.

The model of the system composed of Solarex MSX-60W PV module fed by a DC-DC boost converter drived using the propose controller is implemented.

Figure 5 shows the output power using the three MPPTs. While the figure 6 shows the corresponding generated duty cycle.

Table 1: Electrical Characteristics of Solarex MSX -60 (1kW/m², 25°C) [24].

Description _ MSX-60	**Description _ MSX-60**
Maximum Power (P_{MPP}) _ 60 W	Voltage open circuit _ 21.1 V
Voltage at P_{max} (V_{MPP}) _ 17.1 V	Temp. coeff of V_{oc} _ -(80±10)mV/°C)
Current at P_{max} (I_{MPP}) _ 3.5 A	Temp. coeff of I_{SC} _ -(0.065±0.01)%°C
Current short circuit (I_{SC}) _ 3.8 A	Temp. coeff of Power _ (-0.5 - 0.05)%°C
NOCT _ 47.2 °C	

Figure 5 shows the output power using the three MPPTs. While the figure 6 shows the corresponding generated duty cycle.

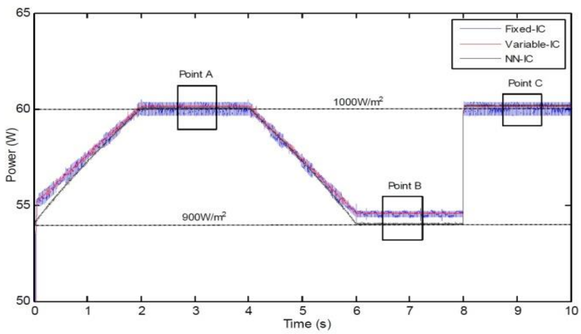

Fig. 5: Output power tracking

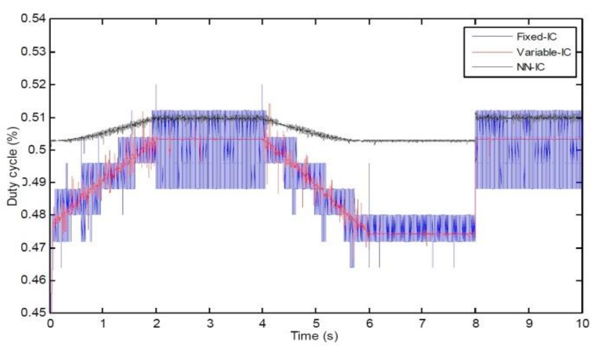

Fig. 6: PWM duty cycle

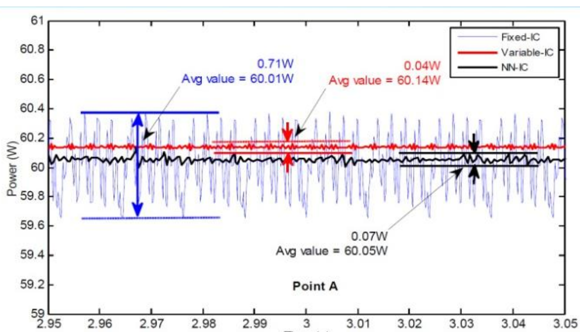

Fig. 7: Point A

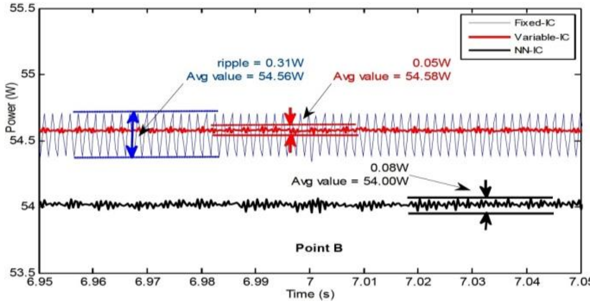

Fig. 8: Point B

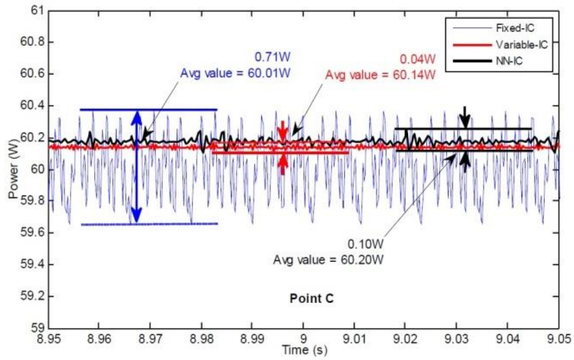

Fig. 9: Point C

From figures 7 to 9, we can see clearly that the proposed neural network outperforms the two conventional IC MPPTs in term of tracking, accuracy and steady state oscillations.

In addition, and compared to the conventional variable step size IC MPPT, the proposed neural network MPPT presents better performances especially in case of slow or linear variation of insolation.

5. CONCLUSION

In this paper a neural network IC-based variable step size MPPT controller has been proposed and investigated.

The proposed neural network MPPT controller is firstly, developed in off line mode required for testing different set of neural network parameters and architectures, and used secondly in the online mode to track the output power of the PV system composed of Solarex MSX 60W PV module fed by a DC-DC boost converter drived using the proposed ANN MPPT controller.

The proposed neural network MPPT controller is tested and validated using Matlab/Simulink environments. Simulation results and analysis are presented showing good performances for the proposed controller compared to the conventional fixed or variable step size algorithms.

For future works, we work currently on the experimental validation of the proposed present work using the hardware in the loop mode.

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