Comparison between Neuro-Fuzzy Inference System (ANFIS) Based MPPT Controller and ANN based MPPT controller for Standalone Solar Energy Generation System

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Abstract

In this paper, an ANFIS-based MPPT controller for a DC-DC converter is developed and its performance is analyzed. There are two power sources, a DC-to-DC booster converter, and a load in the proposed system. The proposed algorithm utilizes neural networks and fuzzy logic. The MPPT controllers use Adaptive Neuro-Fuzzy Inference System (ANFIS) to enhance converter performance. As a result of high oscillations in conventional algorithms such as Perturb and Observe (P&O), the paper proposes AI-based methods for enhancing efficiency. ANFIS is more efficient in tracking MPP than ANN-based controllers with fewer settling times, overshoots, oscillations, and delays. To demonstrate the ANFIS controller's ability to follow reference voltages and currents, its performance is simulated and compared with the MPPT controller based on artificial intelligence techniques. The simulation results show that MPPT controllers based on ANFIS provide better performance than MPPT controllers based on Artificial Intelligence Techniques under various operating conditions.

Keywords—*ANFIS, P&O, ANN, MPPT, DC to DC boost converter*

1.INTRODUCTION

As a substitute for conventional energy sources, renewable energy sources (RES) are now more frequently used. In the current scenario of depleting fossil fuel reserves, global warming, greenhouse gases, and increasing environmental pollution, photovoltaic energy (PV) is becoming increasingly popular as a renewable source of energy. Generally, the MPPT controller is composed of a DC–DC power converter which is controlled by an algorithm to drive the panel's operating point to the MPP. The MPPT techniques can be grouped into two categories: conventional techniques, such as perturbation and observation (P&O) [1–3], incremental conductance (IC) [4,5], and open-circuit voltage (OCV) method [6, 7], Artificial neural networks (ANNs) are AI-based techniques [8], fuzzy logic (FL) [9], particle swarm optimization (PSO) [10], and adaptive neuro-fuzzy inference system (ANFIS) [11]. The advantage of the AI-based model is the fast Maximum Power Point (MPP) approximation according to the parameters of the PV panel. The Artificial Neural Network (ANN) is the component of AI. The advantage of ANN based algorithm is this is that there is no need to solve the complex mathematical relation between output power, irradiance of solar PV system, temperature of solar PV system. The proposed ANN based MPPT system can search the MPP quickly and exactly in accordance with the change in environmental conditions. A multilayer neural network with one or more hidden layers can approximate any continuous nonlinear function. Neural networks are parallel in design and have a simple structure comprised of many processing elements. Furthermore, ANNs generalize the learning experience and even provide predictions for new knowledge, reducing online learning time and improving learning effectiveness. The main objective is to achieve fast and stable response for the real power, controlled by an ANN based controller. The solar system uses ANN based technique to achieve effective maximum power point tracking.

This paper presents a comparison of two popular artificial intelligence techniques ANN and ANFIS based controllers under non-linear changing solar irradiation conditions. ANFIS has more efficiency than ANN based controller in tracking MPP with less settling time, better efficiency, accuracy and fast response making the system more effective.

A simple block diagram of DC-DC converter for SECS using ANFIS based MPPT Controller is shown in Figure 1. Proposed system consist of PV array, power electronics interfacing devices such as DC-DC Boost converter, load arrangement and ANFIS based MPPT Controller. In order to improve the performance of maximum power point tracking of solar PV system, an effective ANFIS based MPPT Controller is developed and compared with the conventional ANN based MPPT controller.

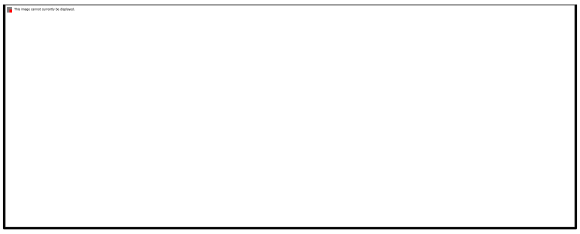


Fig. 1: Block Diagram of DC-DC Converter for SECS using ANFIS based MPPT Controller

2. PV System Model

PV module is composed of solar cells. Individual solar cells are connected in series and parallel and mounted on a single panel. Single diode model of PV cell is most widely used model. Output power can be calculated by current voltage relationship. This current voltage relationship is based on electrical characteristics of the model. An equivalent circuit of a single diode model is shown in the figure 2.

Fig. 2: Equivalent Circuit of Solar PV Cell

The voltage-current relationship can be written as:

$$I = I_L - I_D = I_L - I_s\left\{ e^{\frac{q(V+\mathrm{Re})}{AKT}} - 1 \right\} - \frac{V + IR_e}{R_{sh}} \quad (2.1)$$

It is possible to enumerate I_L:

$$I_L = \frac{\varphi}{\varphi_{ref}}\left[I_{L,ref} + \mu_{sc}\left(T_C - T_{c,ref} \right) \right] \quad (2.2)$$

Saturation current I_s can be expressed at the reference condition as:

$$I_s = I_{C,ref}\left(\frac{T_{C,ref} + 273}{T_C + 273} \right)^3 \exp\left[\frac{e_{gap} N_S}{q_{ref}} \left(1 - \frac{T_{C,ref} + 273}{T_C + 273} \right) \right] \quad (2.3)$$

$I_{s,ref}$ can be expressed as:

$$I_{s,ref} = I_{L,ref} \exp\left(-\frac{V_{oc,ref}}{a_{ref}} \right) \quad (2.4)$$

The value of open circuit voltage at reference condition is given by manufacturer.

Value of α_{ref} can be calculated by:

$$a_{ref} = \frac{2V_{mpp,ref} - V_{oc,ref}}{\frac{I_{sc,ref}}{I_{sc,ref} - I_{mpp,ref}} + ln\left(1 - \frac{I_{mpp,ref}}{I_{sc,ref}}\right)} \quad (2.5)$$

The value of α can be calculated by following equation:

$$a = \frac{T_c + 273}{T_{c,ref} + 273} a_{ref} \quad (2.6)$$

The value of series resistance is provided by some manufacturers. To estimate the value of R_s following equation can be used:

$$R_s = \frac{a_{ref} \, ln\left(\frac{I_{mpp,ref}}{I_{sc,ref} - I_{mpp,ref}}\right) + V_{oc,ref} - V_{mpp,ref}}{I_{mpp,ref}} \quad (2.7)$$

After the study of the PV module, it can be said that the temperature plays an important role in the performance of PV module. It is necessary to design a thermal module for the PV system as temperature is major aspect to be considered. Temperature of PV module varies when there is a change in irradiance, its output current and voltage, and the equation can be expressed as:

$$C_{pv} \frac{dT_c}{dt} = k_{a,PV} \varphi - \frac{VI}{A} - k_{loss}(T_c - T_a) \quad (2.8)$$

3. Flowchart for ANFIS based MPPT Controller

In order to improve the efficiency of MPPT controllers, AI techniques are widely used due to the nonlinear output characteristics of PV systems. The PV array parameters as well as the ambient parameters are used to determine the maximum operating voltage. To design MPPT controller using ANFIS, first task is to gather the input–output dataset for training purpose. The training data is generated using the efficient PV model. A step-by-step process of data generation is illustrated in the flowchart shown in Fig. 3.

Fig. 3: Flowchart of Dataset for ANFIS

4. MATLAB/Simulink Model of 2 kW DC-DC Converter for Solar Energy Conversion System with ANFIS based MPPT Controller

In this study DC-DC boost converter for Solar Energy Conversion System with ANFIS MPPT Controller. Simulations using MATLAB R2020a software have been carried out to evaluate the performance of the system with implemented control scheme. The overall simulation model for DC-DC boost converters with MPPT controllers based on ANFIS is discussed in this section.

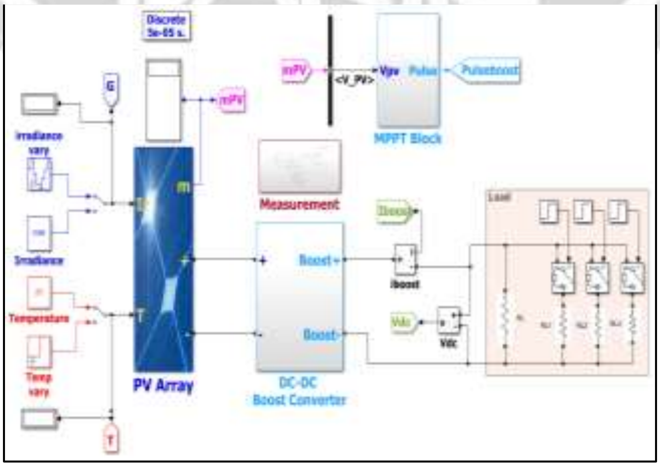


Fig. 4: Simulink Model of DC-DC boost converter for Solar Energy Conversion System with ANFIS MPPT Controller

4.1 ANFIS Training Results

Figure 5 (a) displays ANFIS model structure. There are two inputs are taken and one output is derived. The two inputs are PV voltage and PV current and one out is the duty ration for the boost converter.

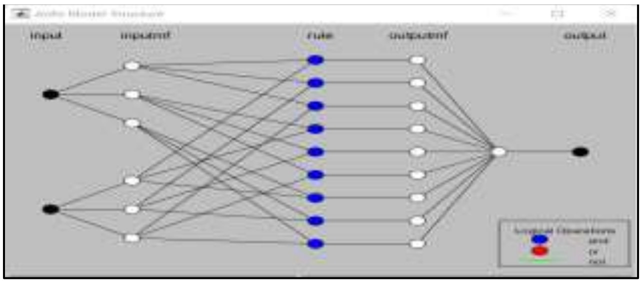


Fig. 5 (a): ANFIS Model Structure

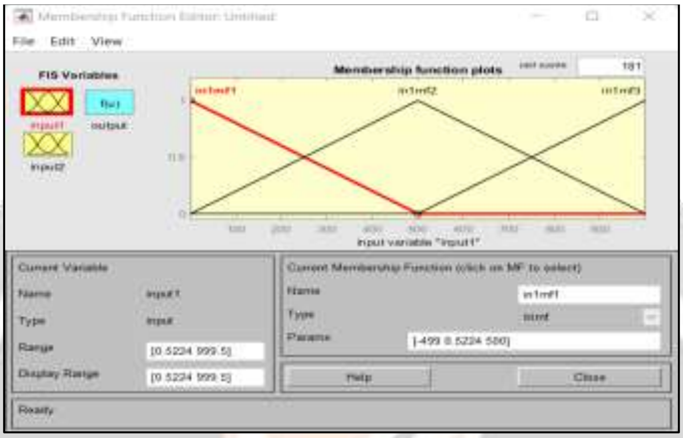


Fig. 5 (b): Membership Function for ANFIS based MPPT Controller

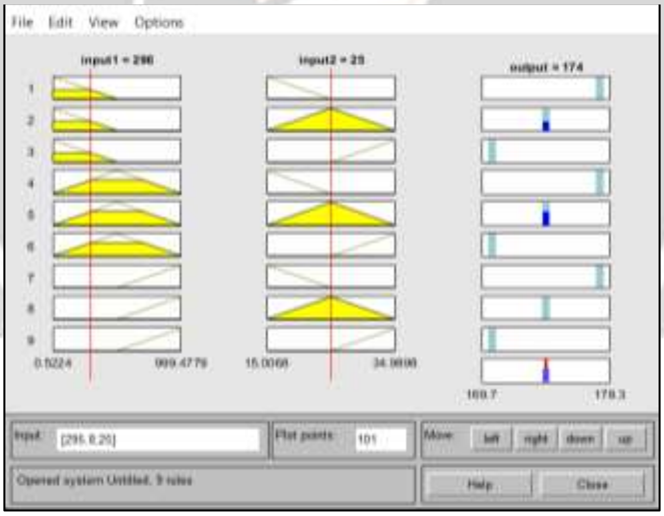


Fig. 5 (c): Rules for ANFIS based MPPT Controller

5. Simulation Result

This section shows the comparative study of proposed MPPT controller. It shows comparison performance of between Levenberg based ANN MPPT Controller and ANFIS based MPPT Controller. For each controller simulation is carried out for 4 seconds and with the same input irradiance and temperature. Details study is shown in following subsections.

5.1 PV Array Results Comparison

Figure 6 shows the simulation results of PV array with Levenberg based Artificial Neural Network MPPT Controller and ANFIS based MPPT Controller. Waveform of PV output voltage, PV output current and PV output power with Irradiance shown in this Figure 6.1. Temperature is kept constant at 25° C and Irradiance step change from 600-1000 W/m^2.

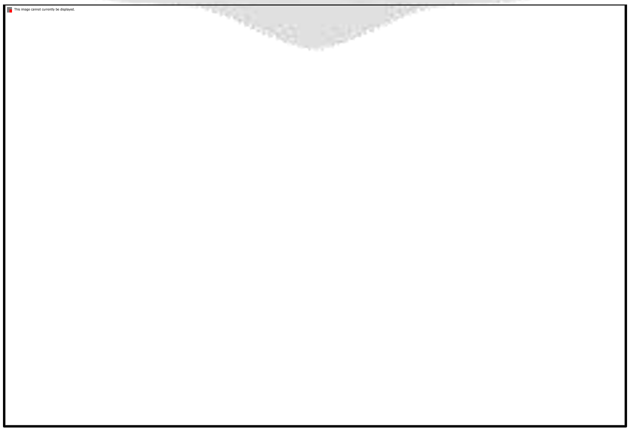
Figure 5.1 (a) shows the PV voltage comparison of Levenberg based Artificial Neural Network MPPT Controller and ANFIS based MPPT Controller. It is clearly seen that PV voltage performance by ANFIS based MPPT Controller is superior than Levenberg ANN MPPT Controller. During the time interval 1s to 1.5s from Levenberg based Artificial Neural Network MPPT Controller PV output voltage is 172, whereas ANFIS based MPPT Controller gives 175V.

PV output current performance is shown in Figure 5.1 (b). Simulation result shows that during the time interval 1 s to 1.5s, PV output current from Levenberg based Artificial Neural Network MPPT Controller PV output current is 8.7A, whereas ANFIS based MPPT Controller gives 9A.

Figure 5.1 (c) shows the PV power output comparison. During the time interval 1s to 1.5s ideal power output should be 15.70kW whereas from Levenberg based ANN MPPT Controller PV output power is 15.40kW and ANFIS based MPPT Controller gives 15.60kW during this irradiance change from 600-1000 W/m^2. ANFIS based MPPT Controller gives nearly ideal performance as seen from the figure 5.1 (c).

(a)

(b)

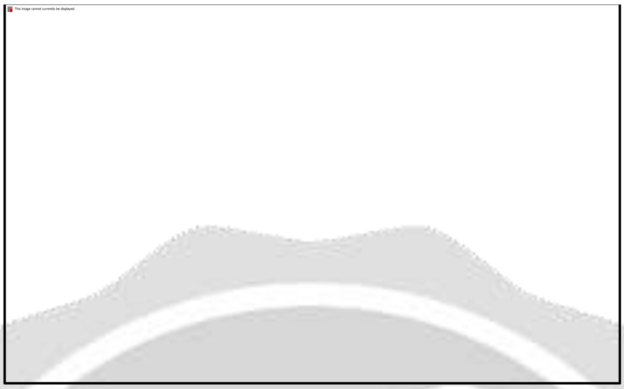


(c)

Fig. 6: Simulation Comparison Results of Incremental Conductance and Levenberg based ANN MPPT Controller at Irradiance Step Change from 600-1000 W/$m^2$with Resistive Load: (a) PV Output Voltage, (b) PV Output Current and (c) PV Output Power with Irradiance

5.2 Boost Converter Results Comparison

Figure 5.2 shows the simulation results comparison. Figure 5.2 shows the output current of boost converter which is kept constant at 500V.



(a)

(b)

(c)

Fig. 7: Simulation Comparison Results of Incremental Conductance and Levenberg based ANN MPPT Controller at Irradiance Step Change from 600-1000 W/m^2 with Resistive Load: (a) Duty Cycle of Boost Converter, (b) Dc Link Voltage, (c) Dc Link Current

Figure 7 shows the duty ratio comparison. Duty ratio generated by Levenberg based ANN MPPT Controller is pulsating whereas duty ration generated using the proposed ANFIS based MPPT Controller are smooth and shows better dynamic performance. As the boost converter output reference is set to 500V, the simulated result from both MPPT controller are shown in Figure 5.2 (b). Output from Levenberg based Artificial Neural Network MPPT Controller is shown in red, ANFIS based MPPT Controller is shown in blue. ANFIS based MPPT Controller shows the better performance compared with incremental conductance.

During the time interval 1s to 1.5s Levenberg based ANN MPPT Controller converter output voltage is 372V and ANFIS based MPPT Controller gives 380V and 3.9A shown in Figure 7 (b & c).

Fig. 8 Simulation Result Comparison of efficiency for Levenberg based ANN MPPT Controller and ANFIS based MPPT Controller.

Fig. 8: Simulation Result Comparison of efficiency for Levenberg based ANN MPPT Controller and ANFIS based MPPT Controller

Table 1: Simulation Result

Parameters	**Levenberg based ANN MPPT Controller**	**ANFIS based MPPT Controller**
	PV Array Parameters	
PV Current	8.7A	9A
PV Voltage	172	175V
PV Power	15.40kW	15.60kW
	Boost Converter Parameter	
Dc Link Voltage	372V	380V
Dc Link Current	3.8A	3.9A

7. CONCLUSION

This paper presents a DC-DC converter with maximum power point tracking (MPPT) technique for standalone solar energy conversion systems based on ANFIS. ANFIS algorithms for MPPT with Levenberg based Artificial Intelligence Technique based MPPT algorithms for PV system is compared. The model has been tested for different input and output conditions. Simulation results and real time applications show that for wide range of input irradiance ANFIS controller shows better performance than the Levenberg based Artificial Intelligence Technique based MPPT algorithms. Proposed ANFIS based MPPT controller shows 0.2 % improvement in PV power output compare to Levenberg based Artificial Intelligence Technique based MPPT algorithms. The average efficiency of Proposed ANFIS based MPPT controller is 99.9% and average efficiency of Artificial Intelligence Technique based MPPT algorithms is 99.7%. From the simulation results of the system, it is clear that ANFIS based MPPT controller for MPPT shows effective results as compared to Levenberg based Artificial Intelligence Technique based MPPT controllers.

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