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Research Application of ANFIS Controller to Determine and Maintain the Maximum Capacity Working Point of the Grid-Connected Solar Power System

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***Abstract** - Solar energy is a clean and endless source of energy that nature bestows on man. Since ancient times, people have been able to utilize this energy source for themselves. There are medium and large scale solar power plants connected to the grid or buildings using solar power at the household scale family. Grid-connected solar power systems are increasingly being used to exploit this infinite renewable energy source. In this system, the maximum power emitted by photovoltaic (PV) panels depends on the sun's radiation intensity and the working temperature of the equipment. For each value of solar radiation intensity and photovoltaic panel temperature, there is one point of maximum power emitted by the panel, called the maximum power point (MPP). To improve the device's efficiency, it is necessary to maintain the system working in accordance with the maximum power point when the radiation intensity of the sun and the panel temperature change. This paper presents a method for determining and maintaining the maximum power working point of a grid-connected solar PV system using an adaptive neural-fuzzy inference system (ANFIS). The simulation results show that with different intensity of solar radiation and temperature change, the system's working point always stick to the point with maximum power.*

Keywords - *ANFIS, Maximum power point, MPPT, PV System.*

I. INTRODUCTION

With outstanding advantages such as infinite reserves, solar energy does not change climate and does not adversely affect the environment, attracting the attention of many countries around the world. Currently, many countries worldwide have taken specific steps to gradually replace traditional fossil energy sources with renewable energy sources in which the amount of solar is an appropriate choice. The main direction to exploit renewable energy is to turn them into electricity to connect to the national grid or from a local power grid [1]. Nowadays, a popular method to harness and utilize solar energy attracting many countries is to convert them into AC and connect them to common grids based on electronic converters. That system is called a grid-connected solar power system. A grid-connected solar power system includes components: Photovoltaic cells, DC-DC converters, DC - AC converters, power grids, maximum power point tracking (MPPT), and controller (Fig. 1).

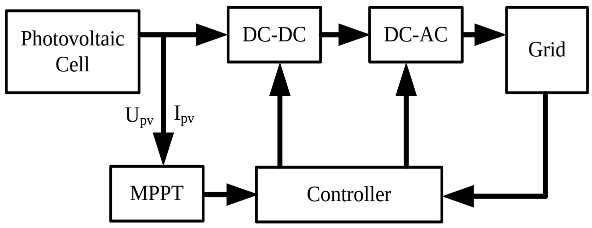

Fig. 1 Grid-connected solar power system

The corresponding electrical schematic diagram of a photovoltaic (PV) cell is shown in Fig. 2.

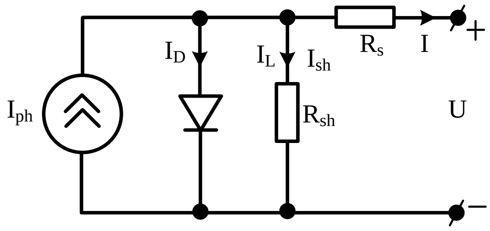

Fig. 2 Electrical diagram of a photovoltaic cell

The relationship between current, voltage, and power (I, U, and P) of photovoltaic (PV) cells that depend on solar radiation intensity and their temperature is explained in equation (1), [6, 7, 8, 10].

$$I = I_{pv} - I_0\left(e^{\frac{U-IR_s}{AV_t}} - 1\right) - \frac{U-IR_s}{R_p} \qquad (1)$$

Inside: I_{pv}: photoelectric current (A); I_0: saturated reverse current (A); R_s: series resistance of cell (Ω); R_p: parallel resistance of cell (Ω);

$V_t = \frac{N_s K T_c}{q}$; N_s: the number of continuous photovoltaic; K: boltzmann constant ($1{,}338.10^{-23}$J/^{0}K); T_c: working temperature of photovoltaic cell (^{0}C); q: charge of electronic ($1{,}602.10^{-19}$C).

The relationship between I(U) and P(U) of the photoelectric cell is shown in Fig. 3, and they have a nonlinear relationship with each other.

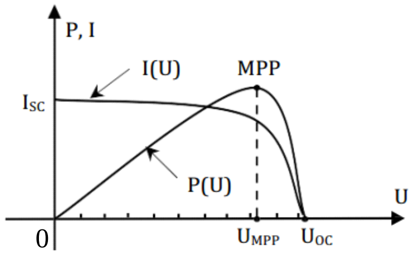

Fig. 3 Graph showing the relationship I(U) and P(U) of PV

On the P(U) curve, there exists a point where the solar panels provide maximum power called the maximum PowerPoint. Assuming that a PV photovoltaic cell with properties I(U) and P(U) corresponds to the defined value of solar radiation and temperature as shown in Fig. 4, the load characteristic of PV is a straight line 0m passing through the origin, the working point of PV is the intersection point between the I(U) characteristic of the PV and its load characteristics. If the PV module is to work at point C, it has maximum power. The essence of detection is to change the gradient of the load property (line 0m) to cross the curve I(U) at point C.

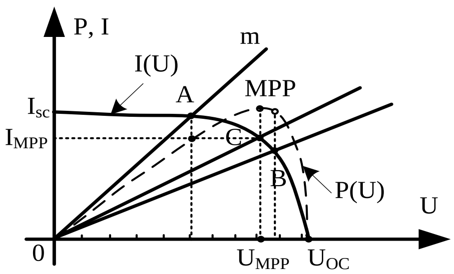

Fig. 4 V-A characteristics of the load and solar cell

During operation, due to solar radiation and the random adjustment of solar power panel temperature, the maximum power point (MPP) of PV is changed randomly. To efficiently utilize the power produced by a solar cell at any time, the system must contain the maximum power point tracking and ensure that the system works at maximum power point incessantly. The search algorithm for maximum power point normally carried out in DC-DC converter, for the system without DC-DC converter, MPPT is implemented in DC - AC converter. There are a variety of researches about MPPT such as perturb and observe (P&O) [2], fractional open - circuit voltage [3]; genetic algorithm [4], neural network and neuro-fuzzy approaches [5]; the constant voltage method [8, 9]; the disturbance and observation methodology [9]; the incremental conductance methodology [9]; the fuzzy control method [6, 10, 11]. This research proposes applying the Adaptive Neural - Fuzzy Inference System (ANFIS) to determine and maintain the maximum power point for a grid-connected solar power system. The following parts present a mathematic algorithm, modeling and simulating, report and conclusion.

II. THE ADAPTIVE NEURON – FUZZY INFERENCE SYSTEM

The ANFIS controller is an inference combining the Sugeno fuzzy model and artificial neural network. ANFIS carries the advantages of a fuzzy system, including a clear structure, a simple design but offers the benefit of an enhanced priority in the Neuron network's learning capabilities. ANFIS has a 5-layer structure, as shown in Fig. 5 [8]. The first layer is responsible for blurring the input variables, and a neuron describes each fault function. The fault function can be a triangle, a trapezoid, or a Gauss function ... The output of ANFIS can be a constant. or linear function. Invisible classes 2, 3, 4 are responsible for fuzzy inference; neurons in grade 5 complete the fuzzy resolution. ANFIS can have multiple inputs but a single output; The output variable is defined by the expression (2).

$$\sum_i \underline{w_i} f_i = \frac{\sum_i \underline{w_i} f_i}{\sum_i \underline{w_i}} \tag{2}$$

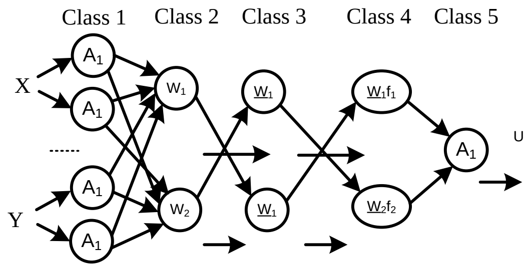

Fig. 5 Structure of ANFIS network

There are two possible training algorithms for ANFIS: Backropa and Hybrid.

III. ESTABLISHING MPPT BASED ON ADAPTIVE NEURON – FUZZY

This section presents an algorithm to indicate the maximum power point based on the ANFIS platform. The main contents include: selecting the control structure, setting up training and verification data, setting the neural network - fuzzy network, performing the training and calibration of the network to achieve the desired error, modeling, and simulation.

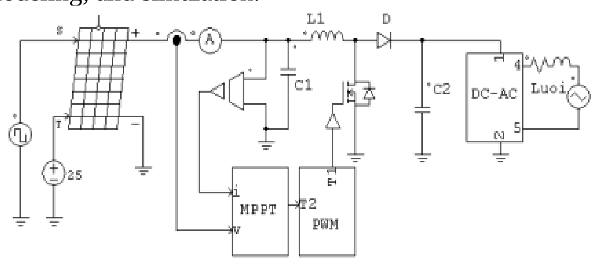

Fig. 6 Schematic diagram of grid-connected solar power system

The algorithm for determining and maintaining the maximum power point is performed by modifying an incremental voltage DC -DC converter's operating conditions. Therefore, the output voltage and output current of the solar panel must be measured. The ANFIS controller has two inputs: the photovoltaic cell voltage and current. The output of ANFIS is fed to the pulse width control controller (PWM) to change the working regulation of voltage increase. Therefore, the load characteristic can be adjusted to overcome the I(U) characteristic of the solar cell at the maximum PowerPoint. Select the ANFIS controller with the photoelectric cell voltage and current input. Six fuzzy chains blur the voltage input in the form of a Gauss function; the current input is blurred by the Gauss function's eight fuzzy chains. The fault functions are selected similarly and separately, and the output opacity is linear. Training data includes 300 data, 200 pieces of data for the test. Tables 1 and 2 illustrate some values of training data, and Table 2 shows some values of test data.

Table 1. Values of training data

u	i	u_{dk}
13.75167	3.747421	-3.34833
14.68876	3.746101	-2.41124
15.62247	3.717419	-1.47753
16.54304	3.635333	-0.55696
17.43195	3.456673	0.531952
16.59632	3.62848	-0.50368
16.99887	3.552842	0.098866
17.01408	3.537665	0.114079
17.29628	3.460079	0.396282
17.47939	3.391673	0.579386
17.19056	3.443852	0.29056
17.20692	3.413048	0.306918
16.97866	3.43067	0.078655

Table 2. Values of test data

u	1.000000	u_{dk}
16.754242	2.146848	-0.345758
17.107153	2.101330	0.207153
16.700232	2.161279	-0.199768
17.040278	2.128492	0.040278
17.293020	2.102262	0.393020
17.040849	2.163080	-0.059151
17.572851	2.087284	0.672851
16.756802	2.252328	-0.343198
17.313973	2.199298	0.213973
16.688942	2.327389	-0.311058
17.265768	2.281062	0.165768
16.773211	2.397109	-0.126789

According to the hybrid method with 100 training times, we get a training error of 0.68564 and a test error of 0.06861. The trained parameters of the ANFIS controller are shown in Fig. 7 – Fig. 11, where Fig. 7 illustrates the ANFIS input and output data. Fig. 8 shows the difference after each stage. Fig. 9 and Fig. 10 describe the following types of inference functions trained, and Fig. 11 shows the input-output relationship after the training. It can be seen that after training, the fuzzy sets for the voltage variables rarely change; however, a significant modification was recorded for the current dimming sets in both their form and position.

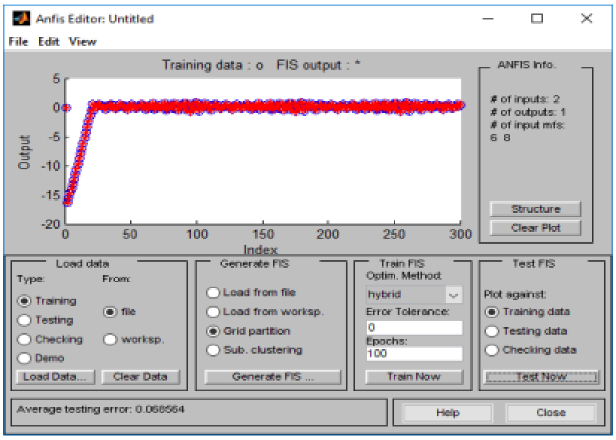

Fig. 7 Data set for training and testing

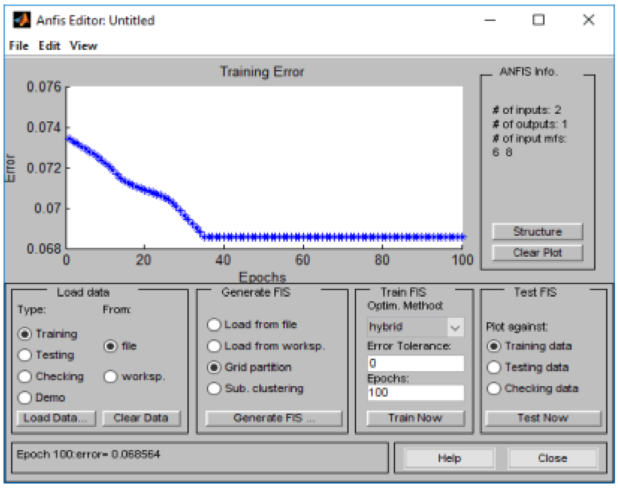

Fig. 8 Error curve during training

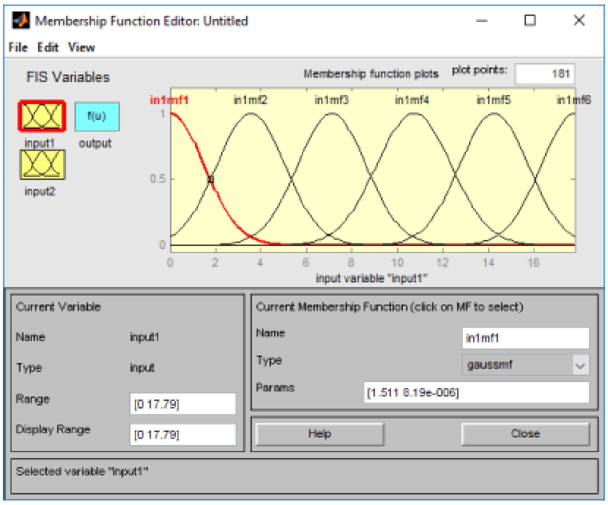

Fig. 9 Trained voltage variable inference functions

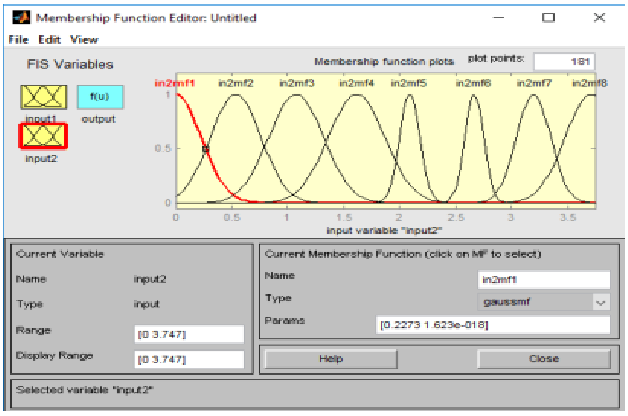

Fig. 10 Inference function of the current variable after being trained

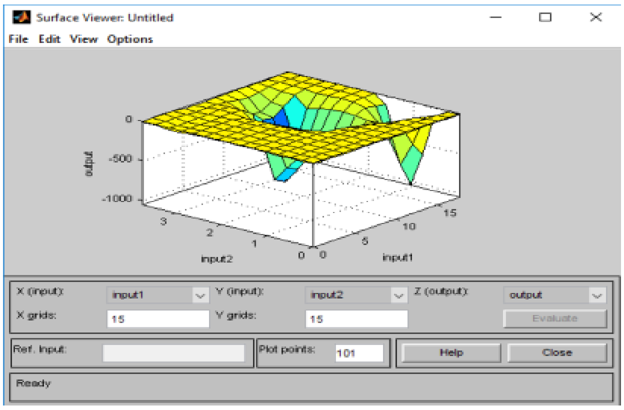

Fig. 11 ANFIS input-output relationship after training

Table 3. Parameters of photovoltaic cells

Parameter	Values
The number of cell pin (cell pin)	72 cell
Alternate range of solar radiation	from (800-1000)W/m
The operating temperature of solar cell	25^0C
A parallel resistor of solar cell	1000Ω
Continuous resistor of solar cell	0,008Ω
Short-circuit current	3,8A
Saturated current of diot (I_{s0})	2.10^{-8}A
Energy band E_g	1,12
Form factor A	1,2
Temperature affection coefficient	0,0024

IV. SIMULATION RESULTS

To test the proposed MPPT algorithm, we have successfully modeled and simulated the grid-connected solar power system. The simulation was performed synchronously on Matlab - Simulink and Psim software. The photovoltaic cell parameters for investigation are listed in Table 3. The output voltage of the voltage increase is 300V. The Matlab simulation structure is shown in Fig. 13, and that of Psim is shown in Fig. 14.

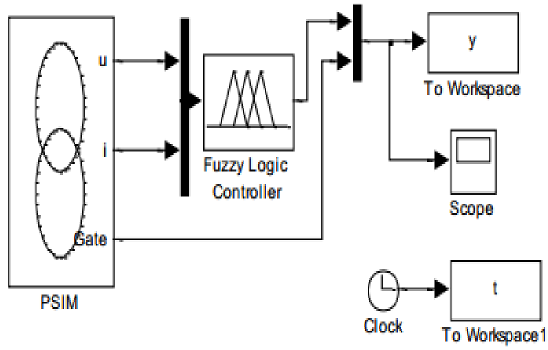

Fig. 12 Simulation diagram in Matlab-Simulink

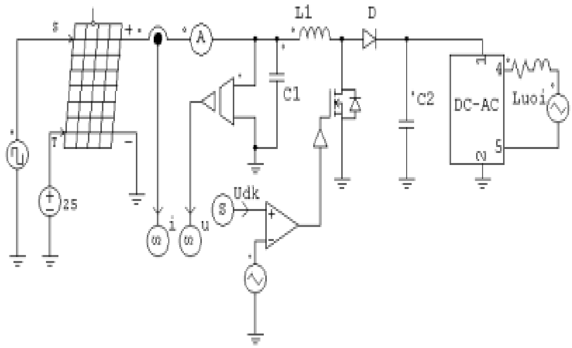

Fig. 13 Simulation structure in Psim

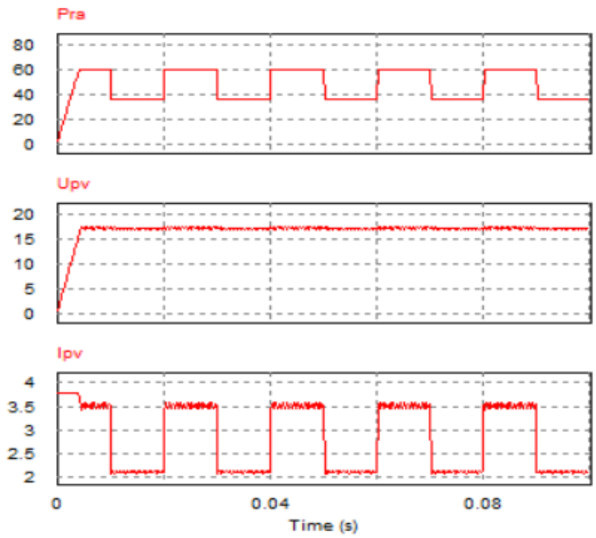

Fig. 14 System dynamic response

The simulation results in Fig. 14 show that the MPPT algorithm ensures the solar power system follows the point with maximum power while adjusting solar radiation.

V. CONCLUSION

Adopting Adaptive Fuzzy - Neural Networks can be trained to implement an algorithm to identify and exploit the maximum capacity operating point of grid-connected solar PV. An ANFIS based maximum power point tracking controller is developed to identify the MPP, subsequently, regulate the PV array to operate at different operating voltage. The simulation results obtained from Matlab - Simulink and Psim medium indicated that our proposed method is feasible.

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