

Maximum Power Point Tracking Using Fuzzy Logic Control in Constant Voltage for Different Environmental Conditions

R. Shalaby¹, M. Shabaan², B. Abuzalam¹, M.A. Younes.²

¹The Faculty of Electronic Engineering, El Menoufia, Egypt

²National Water Research Center, Cairo, Egypt

Abstract: Maximum power point tracking (MPPT) is a real problem in harvesting power of photovoltaic (PV) solar cells. Constant voltage method (CV) has been used to get MPP. Unfortunately, to determine the reference maximum voltage in CV method, the photovoltaic module should be regularly disconnected to measure the open circuit voltage and calculate the new operating point; this causes power losing rather than time consuming. This paper introduces a fully electronic system that automatically generates a reference maximum voltage which allows the PV modules to produce all the power they are capable of. Unlike the approximated calculations of reference values of traditional CV; the charge of this accurate reference-generator is to generate an expected operating point over wide range of weather variations without disconnecting the PV modules. A T-S based fuzzy logic controller has been utilized to calculate the maximum operating voltage (V_{mpp}) of the PV module according to weather variations i.e. temperature and irradiation.

Keywords: Constant Voltage; Photovoltaic module; MPPT and Automatic V_{mpp} generation

I. Introduction

The photovoltaic energy is increasing interest in electrical power applications. It is crucial to operate PV energy conversion systems near maximum power point to increase the output efficiency of PV. However, the nonlinear nature of PV systems is apparent from Figure. 1. i.e. the current and power of PV array depend on the array terminal operating voltage. In addition, the maximum power operating point is changing with Irradiation level and temperature. Therefore, the tracking control of maximum power point is a complicated problem. To overcome these problems, many tracking control strategies have been proposed such as perturb and observe (P&O) which depends on increasing or decreasing a step of power. However when the environment condition changes rapidly, a fast decision of a step change is important since the MPP tracking velocity is delayed as discussed in [1][2]. In [3] the incremental conductance that needs high effectiveness CPU due to many computational complexities and it increases the system unit cost was discussed. The constant

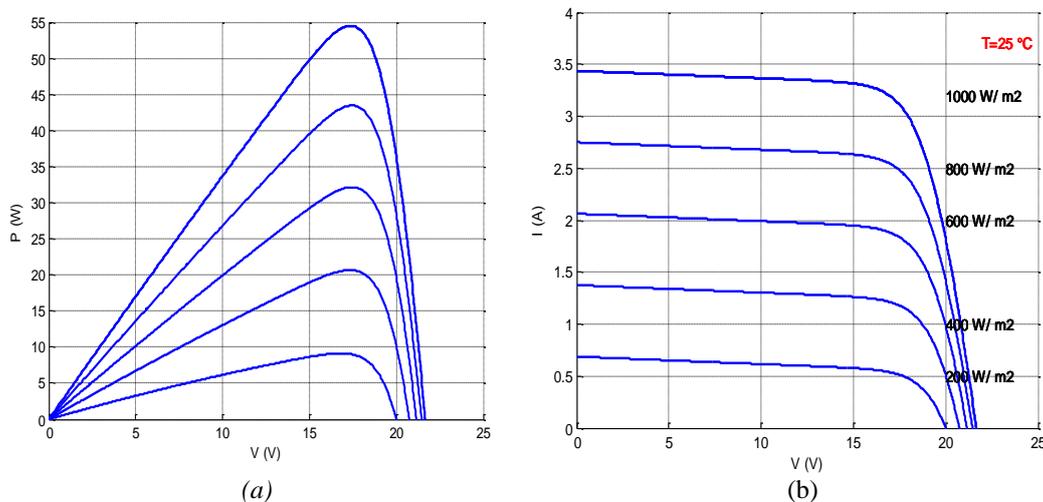


Figure 1 PV characteristics (a) Current vs. voltage (b) Power vs. voltage

Voltage assumes that individual Irradiation and temperature variations on the array are insignificant, and that the constant reference voltage is an adequate approximation of the true MPP. Operation is therefore never exactly at the MPP and different data has to be collected for different geographical regions as [4] pointed. Artificial neural network (ANN) methods employ back-propagation (BP) training algorithm. Larger number of hidden nodes yield more accurate results, but at the expense of longer computational time. Hence, in rapid fluctuations of environment, the ANN MPPT may not be able to respond quickly enough to cope with the fast

changes as in [5][6]. the fuzzy logic control which depends a lot on the knowledge of the user or control engineer in choosing the right error computation and coming up with the rule base table has been discussed in [7][8]. All These challenges made it crucially to modify simple and low cost method as constant voltage method.

II. Constant Voltage Method

The Constant Voltage algorithm is the simplest MPPT control method. The operating point of the PV array is kept near the MPP by regulating the array voltage and matching it to a fixed reference voltage (V_{ref}) equal to the V_{mpp} of the characteristic PV module or another pre-validated best voltage value [9]. The CV method assumes that Irradiation and temperature variations on the array are insignificant on the V_{mpp} , and that the constant reference voltage V_{ref} is an adequate approximation of the real MPP. Therefore, the operating point is never exactly at the MPP and different data have to be adopted for different geographical regions. The CV method needs the measurement of the PV array voltage V_{pv} in order to set up the duty-cycle (D) of the DC/DC converter. It is important to observe that when the PV panel is in low Irradiation conditions the CV technique is generally more effective than either the P&O method or the IC method [10]. The CV control method has the disadvantage that it is unable to track the MPP in rapidly changed solar irradiation so that the power efficiency is reduced. However, there is the advantage of reducing the sensor of an array. There is a near linear relationship between maximum voltage and open circuit voltage (V_{oc}) of the cell which is described by the equation:

$$V_{mpp} \approx K V_{oc}$$

Where k is a constant ranged from 0.71 and 0.78. Firstly k can be computed by measuring V_{mpp} and measure V_{oc} then calculate k from the above relation. by repeating this procedure and take the average of all k values as in [11], then V_{oc} can be measured periodically by disconnecting the load regularly. But this method will make a power loss. [12] proposed a solution for this problem by connecting PV pilot cell in parallel with the main PV module and that PV pilot has the same characteristics of the main module, momentarily the pilot cell is swept and V_{oc} is measured without losing the power. [13] were introduced a new solution using neural networks and genetic algorithm to get V_{mpp} based on irradiation and temperature but this method is time consuming and need a high effectiveness CPU due to many computational complexities and it increases the system unit cost. Another drawback in this method is that the relationship that describes V_{mpp} an approximation of the real value so it won't ever reach the maximum power point but it will be close to it as in [10]. since environmental variations have a clear effect on voltage in special and on PV characteristics in general, Fuzzy logic controller (FLC) have been introduced to calculate the exact maximum voltage point. Consequently exact maximum power point can be obtained based on the environmental variations and the nonlinear characteristics of PV cells. A FLC is applied to generating a maximum possible voltage (V_{mpp}) of PV modules which is corresponding to the maximum obtainable power point. The proposed FLC take the weather conditions into account through the application of temperature and Irradiation as fuzzy inputs.

III. System Structure

Figure 2 is showing the simple structure of the proposed constant voltage method. It consists of PV panel, buck DC-DC converter and proportional-integral (PI) which is responsible for controlling the duty cycle of the converter where reference voltage of PI controller is the output of FLC. V_{mpp} is the desired point of the PV module which can be acquired by watching the system, and the load is a resistor. The PV module that was used here is Solar module SM55, its technical characteristics at standard test condition is shown in Table 1.

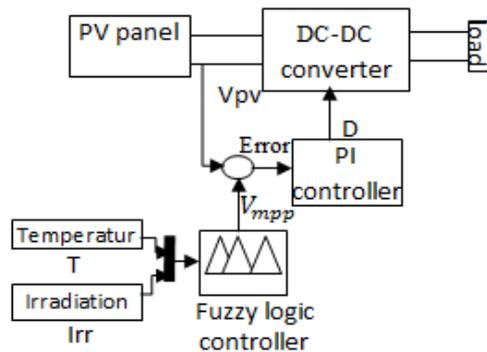


Figure 2 system structure containing the proposed method

IV. Fuzzy Logic Controller Design

Fuzzy inference system (FIS) contains the following stages: fuzzification interface, a rule base, a database, a decision-making unit, and finally a defuzzification interface. A FIS with five functional block described in Figure 3. The function of each block is as follows:

- Rule base containing a number of fuzzy rules (IF–THEN rules).
- Database defines the membership functions of the utilized fuzzy sets.
- The decision-making unit performs the inference operations on the rules
- The fuzzification interface is transforming the crisp input values into degrees of match with linguistic values
- Unlike fuzzification, the defuzzification interface is transforming the fuzzy values resulting from the inference engine into a crisp output.

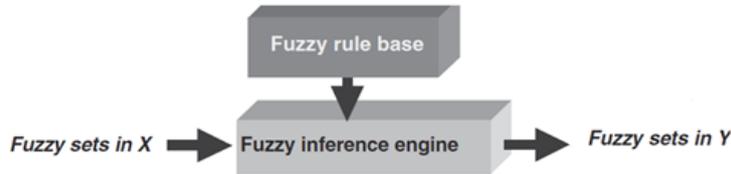


Figure 3 structure of fuzzy logic control

Table 1 Parameters of the solar array Solar module SM55 25°C, 1000W/m2.

Characteristics	SM55
Number of cells in series	36
Number of cells in parallel	1
Maximum Power (Pmax) in watt	55
Open Circuit Voltage (Voc)	21.7 V
Short-circuit Current (Isc)	3.45 A
Maximum power point Voltage (V _{mp})	17.4 V
Maximum power point Current (I _{mp})	3.15A
Temperature Coefficient of Voc	-0.077V/°C
Temperature Coefficient of Isc	1.2mA/°C

In this system a linear change in V_{mpp} (the output of FLC) has been noticed so Takagi-Sugeno FLC is preferred here to get accurate and easy calculations.

1.1 Fuzzification

Temperature and Irradiation the inputs of this system are converted from crisp values to fuzzy values in this phase represented in membership functions in Fig. 5.

1.2 Fuzzy Inference Engine

This phase provide the system with the suitable control rule that governs this operation using rule table which define the relationship between inputs and output using “IF ... Then” rules as depicted in figure 4.

For example: Rule 1:

If $Input_1 = x$ and $Input_2 = y$, then

Output is $Z = ax + by + c$.

The output level Z_i of each rule is weighted by the firing strength w_i of the rule. For example, for an AND rule with Input 1 = x and Input 2 = y, the firing strength is

$$w_i = \text{AND} (F_1(x), F_2(y))$$

Where $F_{1,2}(\cdot)$ are the membership functions for Inputs 1 and 2. The final output of the system is the weighted average of all rule outputs. Five Fuzzy sets describing irradiation [Very Small (VS), Small(S), Medium (M), Big (B) and Very Big (VB)], and Temperature [Low (L), Medium (M), Normal (N), Upper Normal and High (H)] were proposed as shown in Table 2,

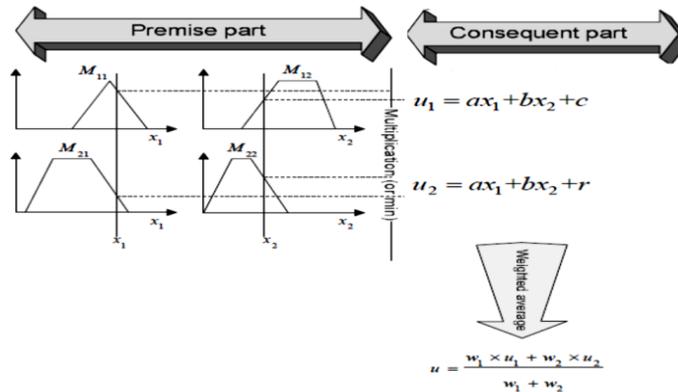


Figure 4 Fuzzy logic Incident and consequent diagram

According to Takagi-Sugeno a linear relations in the consequences enabled us to control this highly nonlinear system as in [14]. The output V_{mpp} is described by the relation $V_{mpp} = ax + c$ where x is the temperature and irradiation and a, c are constants. The voltage V_{mpp} is highly depending on temperature.

Table 2 Fuzzy rules

1.3 Defuzzification

In this phase the output is a fuzzy value it has to be converted into crisp or real value to be used in calculation, many methods were used for defuzzification for Sugeno-style inference, wtaver (weighted average) or wtsum (weighted sum). Weighted average, with the following equation, has been used.

$$\text{Final output} = \frac{\sum_{i=1}^N z_i}{\sum_{i=1}^N w_i}$$

Where N is the number of rules, z_i is the output level, w_i is firing strength of the rule

Irradiance \ Temperature	VS	S	M	VB
L	VS	VB	VVB	VB
M	VS	M	B	M
N	VS	M	S	S

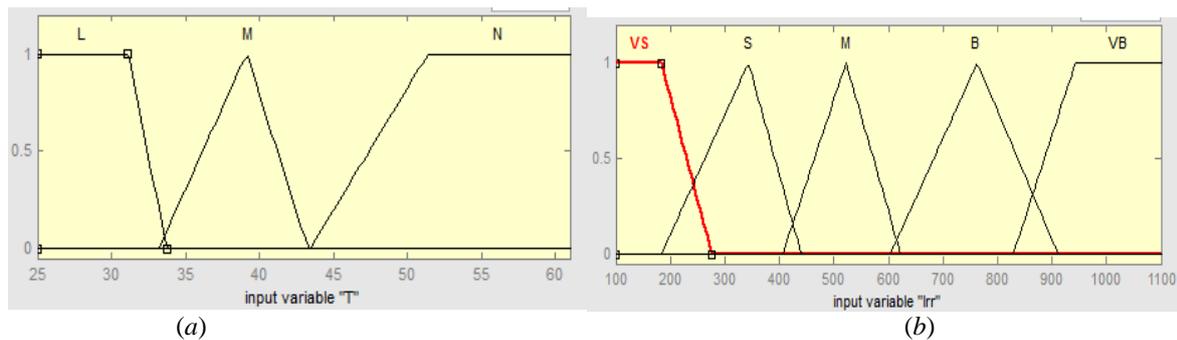


Figure 5. (a) Membership function of temperature (T) and (b) Membership function of Irradiation (I_{rr})

V. Simulation Results

Data sets for voltage and power covering a large range were aimed to be obtained to ensure operation of MPPT controller for a wide range of environmental conditions. Our proposed controller has proved its proficiency in tracking maximum power point. The dataset used to cover the range between 200 and 1000W/m², i.e. [200, 400, 600, 800, and 1000] for irradiation, and between 25 and 55°C for cell temperature as depicted in figures 6,7.

For the given environmental conditions (different irradiation and temperature values), in figure 6, irradiance levels were increased in a sudden steps manner from 200W/m² up to 1000W/m² and then decreased again. Results show the capability of the introduced fuzzy logic controller to harvest the maximum possible power of a photovoltaic module. Difference between figures (a) and (b) of different temperature is very clear. Figure 7 shows the ability of the proposed FLC to generate a reference value of the possible maximum cell voltage (V_{mpp}) at which the PV module can generate its maximum power. Values of V_{mpp} at 600, 800, and 1000 W/m² is very close to each other.

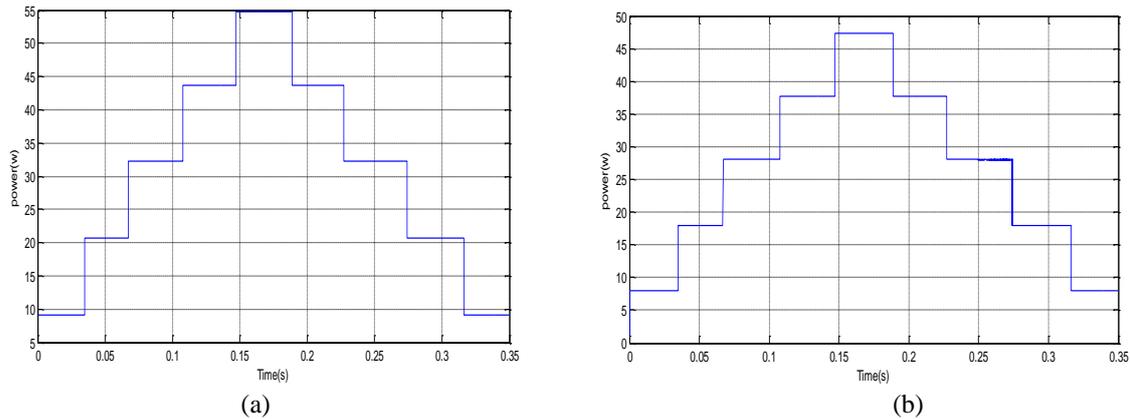


Figure 6 Maximum power gained for different irradiation at (a) $T = 25^{\circ}\text{C}$ (b) $T = 55^{\circ}\text{C}$

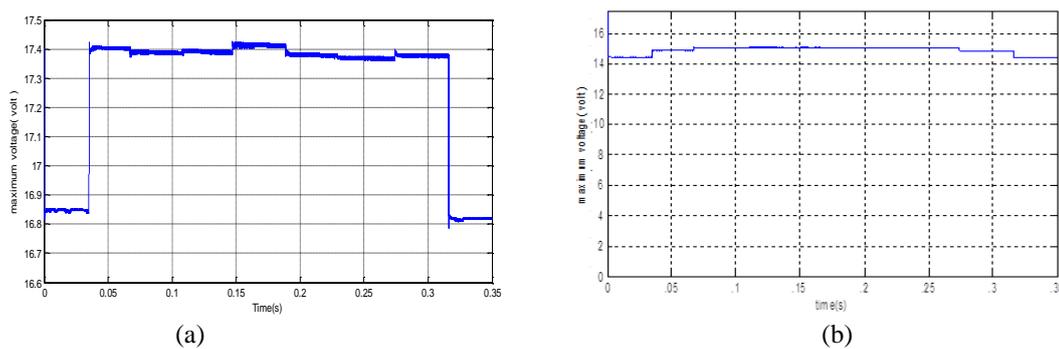


Figure 7 V_{mpp} is following different irradiation at different levels at: (a) $T = 25^{\circ}\text{C}$ and (b) $T = 55^{\circ}\text{C}$

Voltage at these irradiance levels may appear constant but isn't because of its characteristics as it is clear on the characteristic curve in figure 1 Fast and accurate tracking of maximum power was achieved.

VI. Conclusions

In this paper improvements have been added to the constant voltage method to track maximum power point in photovoltaic cells. In traditional method the load had to be regularly disconnected to measure V_{oc} , and a PV pilot cell was connected with the main module. Periodically, the pilot cell is swept and V_{oc} is measured. The proposed method applied fuzzy logic control to treat with the variation of temperature and irradiation which dramatically affect V_{mpp} of PV modules. The proposed Fuzzy logic controller shows its capability to instantaneously generate a desired reference for the maximum voltage according to the environmental variations (c.f. figure 7). Simulation results show also a good capability to track the maximum power point, which make it possible to avoid most of the drawbacks related to the application of traditional tracking strategies when weather conditions changes. The results have proved proficiency of the proposed method in tracking the maximum voltage point in different environmental conditions.

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