Maximum Output Power Control for PV Generation System based on Fuzzy Logic Algorithm

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Abstract: The paper presents implementation of a PV fuzzy logic power tracking controller. Using maximum power point tracker with the intermediate converter can increase the system efficiency by matching the PV system to the load. A new fuzzy MPPT is proposed, where fuzzy inputs parameters are dP/dI and the last incremental of duty of duty ratio LδD, and the output is the new incremental value (new δD) according to the maximum power point under various illumination levels.

Keywords: photovoltaic array, maximum power point tracking, fuzzy logic control.

I. Introduction

The P-V characteristics depend strongly on two environmental factors: illumination and temperature. Then, changes of these characteristics also yield changes in the location of the array's optimum operating point (MPP). To achieve maximum efficiency it is therefore necessary to constantly adjust the solar panel's operating point depending on its current state of operation.

There are two ways to increase the power coming from a photovoltaic array: One is to add more panels to the array, which means an increase in area requirements and a proportional increase in cost for material. Another way is to attempt, to make the existing array work at its highest possible efficiency. If the array is operated at this point, with its corresponding values for current Impp (current at the maximum power point) and voltage Vmpp (voltage at the maximum power point), the maximum possible efficiency is achieved. There are several ways of handling the parameters and controlling for operating photovoltaic panels as close as possible to the point of maximum power and maximum efficiency perturbation and observation (P&O), incremental conductance.[1] - [4]. In this paper, a novel strategy is proposed which only the current from the panels is used, as a control variable for the system, without computing the voltage and current product explicitly.

This paper proposes a method to track the maximum power point using fuzzy logic control, the method is efficient in case of changing the atmospheric conditions even though this change is sudden and sharp. The proposed FLC behavior depends on the membership functions, their distribution, and the rules that influence the different fuzzy variables in the system. It is important to mention that there is no formal method or accurate algorithm to determine the parameters of the controller. It means, choosing fuzzy parameters to obtain the optimum operating point depends on the experience of the system designer.

II. PV array characteristics

In figure 1 is shown the equivalent circuit for real solar cell. In real solar cells, a voltage loss on the way to the external contacts could be observed. This voltage loss could be expressed by a series resistor R_S. Furthermore leakage currents could be observed, which could be described by a parallel resistor R_{Sh}.

The mathematical modeling for the PV equivalent circuit can be deduced using the principle current equation.

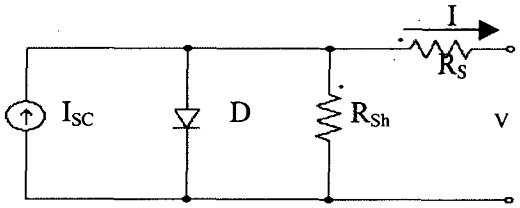


Fig. 1 Equivalent circuit of photovoltaic array.

Equation (1) relates the I-V characteristics of a real diode to a number of device parameters[5-8]:

$$I = I_{SC} - I_o \{\exp[q(V + IR_S)/KT_k] - 1\} - (V + IR_S)/R_{Sh} \quad \ldots\ldots(1)$$

where V and I represent the output voltage and currant of the PV, respectively; Rs and R_{Sh} are the series and shunt resistance of the cell (Fig. 1); q is the electron charge; Isc is the light-generated current; Io is the reverse saturation current; K is the Boltzman constant, and Tk is the temperature in K.

Equation (1) can be written in another form :

$$I = I_{SC}\{1 - K1\,[\exp(K2V^m) - 1]\} \ldots\ldots(2)$$

where the coefficient K1, K2 and m are defined as:

$K1 = 0.01175$; $K4 = \ln((K1+1)/K1)$;
$K2 = K4/(V_{OC})^m$;

$K3 = \ln[(I_{SC}(1+K1)-I_{mpp})/K1\ I_{SC}]$;
$m = \ln(K3/K4)/\ln(V_{mpp}/V_{OC})$.

and:

I_{mpp}- is current at maximum power
V_{mpp} -is voltage at maximum power
I_{SC}- is short circuit current.
V_{OC}- is open circuit voltage of array.

Equation (2) is only applicable at one particular illumination, G, and cell temperature, T_C. When the illumination and temperatures changes, the change in above parameters can be calculated using:

$$\Delta T_C = T_C - T_{STC} \quad \text{.......................................(3)}$$

T_C is the cell temperature and T_{STC} is the temperature at the standard test conditions.

$$\Delta I = \alpha_{SCT}(G/G_{SCT})\,\Delta T_C + ((G/G_{STC})-1)\,I_{SC,STC} \quad \text{...............(4)}$$

G is the illumination, G_{STC}, $I_{SC,STC}$ and α_{SCT} are the illumination, short circuit current and short circuit temperature coefficient at the standard test condition test respectively.

$$\Delta V = -\beta_{SCT}\,\Delta T_C - R_S\,\Delta I \quad \text{.............................(5)}$$
$$V_{new} = V_{SCT} + \Delta V; \quad I_{new} = I_{SCT} + \Delta I \quad \text{........... (6)}$$

The cell temperature can be calculated by knowing the illumination, G, and the ambient temperature, T_a, by the equation:

$$T_C = T_a + (NOTC - T_{a,Ref})\,G/800 \quad \text{...............(7)}$$

Equation (2) is used in Matlab software to get the I-V and P-V characteristics for various illumination and fixed temperature (25 °C) shown in Fig. 2 and Fig. 3 respectively. Figure 4 and 5 show the I-V and P-V for various temperature and fixed illumination level.

It is clearly seen in Fig. 2 that as the irradiance levels increases the current also increases. The maximum power point increases with a steep positive slope, proportional to the illumination, as shown in Fig. 3. Higher illumination levels result in associated higher power maxima and in higher voltage maxima, if the cell temperature is still constant.

The cell temperature of PV array is a function of illumination level, the ambient temperature, the rate at which the cell is cooled, and the way the PV panel is constructed. An increase in cell temperature will result in a lower open-circuit voltage and maximum power point, but with an associated slightly higher short-circuit current. The effect of cell temperature on V-I characteristics of the same array described in fig. 2 is plotted in Fig. 4.

It is clearly seen, the reduction of maximum available PV power and lower voltage of this peak power point, as a function of higher cell temperatures.

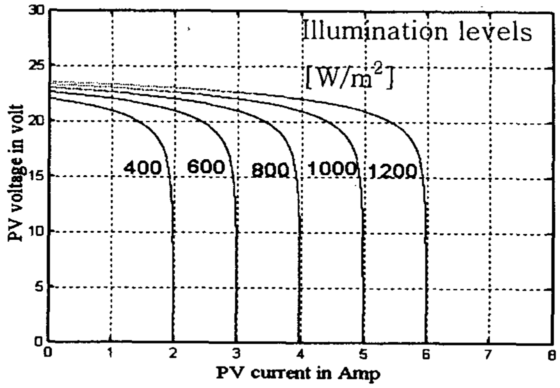


Fig. 2 V-I Characteristic of PV array at constant temperature [25 °C].

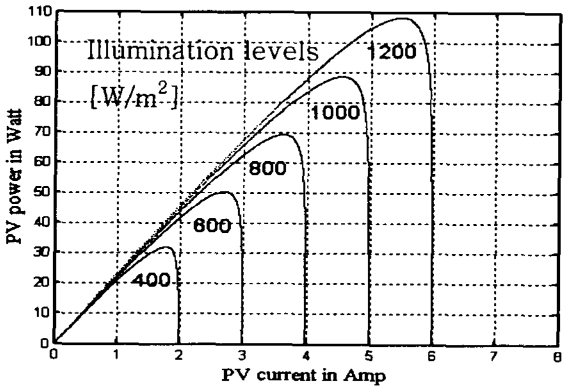


Fig. 3 P-I Characteristic of PV array at constant temperature [25 °C].

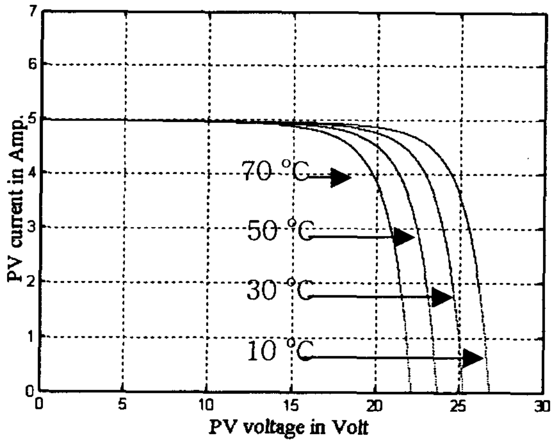


Fig. 4 V-I Characteristic of PV array at constant illumination [1kW/m²].

The main parameters which influence the illumination levels on a surface at a fixed tilt on earth are the daily and seasonal solar path, the presence of clouds, smug and dust between the surface and the sunlight, and the shade of any object positioned such that the illumination level is reduced.

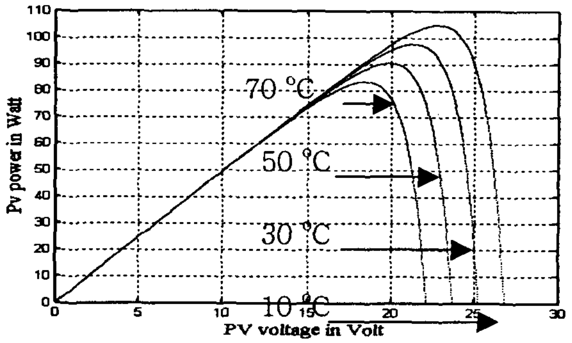


Fig. 5 P-I Characteristic of PV array at constant illumination [1kW/m^2].

III. Fuzzy logic control for MPPT.

The control objective is to track the maximum power point from the PV arrays for a certain solar insolation level. The maximum power corresponding to the optimum operating point can be achieved by well choosing the FL controller input and output membership functions and rule bases[9-10].

Instead of tracking the maximum power via the tracking of the changing in the output power, this paper introduces a method for calculating and implementing a tracker for the changing in the power with respect to the current (dP/dI) and the corresponding changing in the duty ratio LδD, according to the changing of these variables, the new duty ratio δD is determined in the same direction of maximum power point as shown in Fig. 6

The variables dP/dI, LδD and δD are described by triangular membership functions, as shown in Fig. 7, and the control laws are given in Table. I.

TABLE I Rules of the fuzzy logic controller.

	nb	nm	ns	zz	ps	pm	pb
N	pb	pm	nm	ns	ns	nm	nb
Z	ns	-	ns	zz	pm	-	pm
P	nb	ns	ns	ps	pm	pm	pb

The following fuzzy levels are chosen for controlling inputs and output of FLC: n(negative), nb(negative big), nm(negative medium), ns (negative small), z(zero), p(positive), ps(positive small), pm(positive medium, and pb(positive big).

Figure 9 indicates the operation of fuzzy controller, if, for example, the illumination level is G1 and the output power at the point A for the PV voltage V1, the output power can be raised for maximum at B by increasing the voltage to V2. If the illumination level now increases to G4, the output power jumps to the point C.

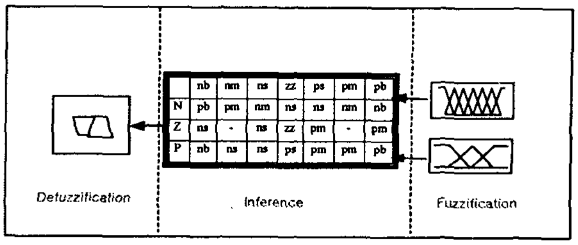
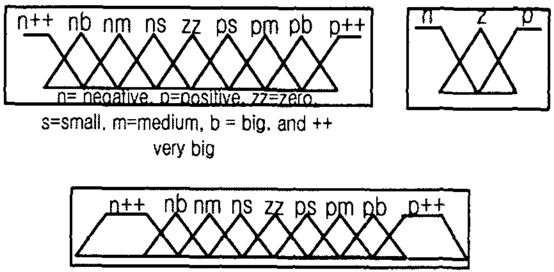


Fig. 6 Fuzzy logic controller.



s=small, m=medium, b = big, and ++ very big

n= negative, p=positive, zz=zero, s=small, m=medium , b = big, and ++ very big

Fig. 7 Membership functions for inputs and output.

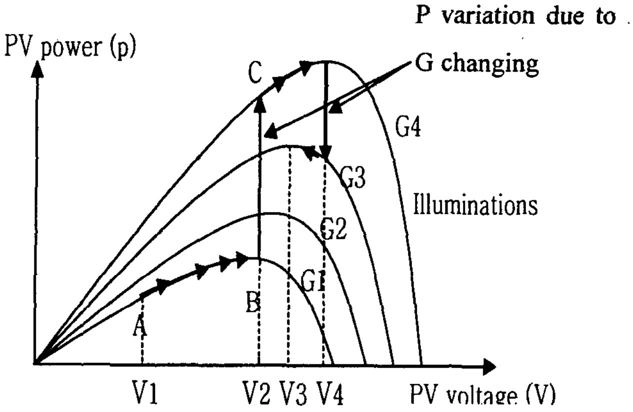


Fig. 8 Fuzzy controller performance.

However, at this illumination level, the maximum power point can be obtained by increasing the PV array voltage for V3. This means that, as the illumination level changes, the PV output voltage has to track this change to extract the maximum power.

The change in the PV array voltage is obtained by varying duty ratio of the boost converter according to the inputs of the FLC [11] & [12].

IV. System description

For the experimental investigation of the fuzzy MPPT technique, a microprocessor-based tracker shown in Fig.9 with the following details are constructed and used:

1- Silicon solar panel: series connection of two solar panels with maximum power output 53 watt each.
2- Maximum power tracker unit: a dc-dc boost converter tracks maximum power point of the solar panel based on PWM signal generated by the control unit.
3- Control unit: a personal computer PC , DSP board TMS320C33, interface circuit, and fuzzy logic controller algorithm are used to record and process measured voltage and current waveforms and to compute required signals for control and drive circuit of boost converter.
4- Load and sensors: a resistive load is connected to the solar panel via the boost converter, two sensors are used to measure the output voltage and current.

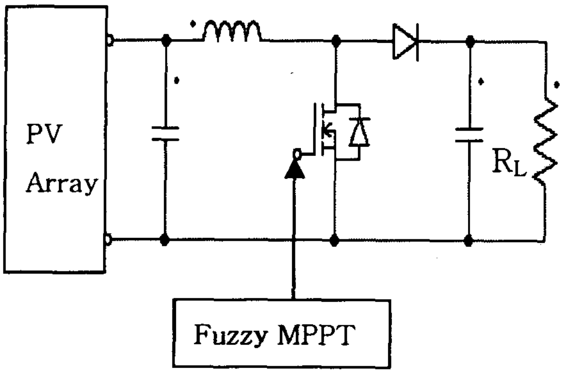


Fig. 9 The power circuit for boost converter loaded PV array.

VII. Conclusions

A photovoltaic generation system using fuzzy logic control has been installed at the laboratory and is being tested. Experimental results will be presented soon.

This work has been supported in part by EESRI (02-14-01), which is funded by MOCIE(Ministry of commerce, industry and energy)

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