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MPPT-based fuzzy logic controller under partially shaded PV arrays and rapidly variation conditions

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Abstract— One of the main causes of reducing energy yield of photovoltaic (PV) systems is partially shaded conditions. Under these conditions, the power-voltage characteristics get more complex with multiple peaks. As well known classical MPPT algorithms such as P&O, IncCond, etc fail to track the global maximum power point effectively if the PV array is partially shaded. Recently some published papers state that artificial intelligence techniques (fuzzy logic, ANN, GA etc) are very suitable to solve this problem. In this paper, a MPPT-based fuzzy-logic controller is developed under Matlab/Simulink. In order to show the effectiveness of this technique, static and dynamic load have been used. With respect to the results, it has been demonstrated that the fuzzy logic technique is success to track the real MPP with rapidly variation of insolation and with partially shaded PV arrays but the efficiency of the fuzzy algorithm depends to the type of load.

Keywords— PV array, MPPT, fuzzy-logic, rapidly variation, Photovoltaic load, Partially shaded condition.

I. Introduction

Solar energy is one of the most important renewable energy sources, it base on photovoltaic effect which converts the light to the electricity from photovoltaic cell. The produced of this energy is used either directly or associated with a storage in batteries or in an energy reserve, e.g. hydraulic. In connected PVG, it may be associated with inverters and voltage step-up or step-down systems (i.e. choppers)[1].

The photovoltaic cell (array) has a highly non-linear current-voltage characteristic varying with the irradiance and temperature. Under uniform irradiation the characteristic presents a unique point, called the maximum power point (MPP), at which the array operates with maximum efficiency and produces maximum output power. But on account of chimney, tree, cloud, etc insolation will be no uniform and power-voltage characteristic have multiple local maximum power point. To get the maximum power from the PV, a maximum power point tracker (MPPT) is used.

Several MPPT techniques have been proposed in the literature from 1968, date the first publication of a MPPT command [2], [3] .The modern commands are based on artificial intelligent techniques like neural network and fuzzy logic.

In this article, a MPPT technique with fuzzy logic method is developed at Matlab/Simulink. In order to test the influence of no uniform insolation (Partial shading) and the rapidly variation of insolation on fuzzy based MPPT, static and dynamic load are using.

II. GPV Model

An ideal solar cell consists of a single diode connected in parallel with a light generated current source (IPV) is shown in Fig. 1(a). The single diode model which includes the series resistance, Rs is depicted in Fig. 1(b)[4].

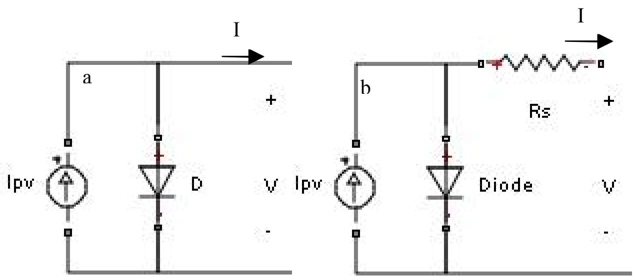

Fig. 1 (a) An ideal solar cell and (b) single diode model with Rs.

The output current in Fig. 1(b) is $I = I_{pv} - I_D$. It can be written as

$$I = I_{pv} - I_0 \left[\exp\left(\frac{V + VR_s}{a V_T} \right) - 1 \right] \quad (1)$$

where IPV is the current generated by the incidence of light, Io is the reverse saturation current, $V_T = \frac{N_s kT}{e}$ is the thermal voltage of the PV module having Ns cells connected in series, q is the electron charge, k is the Boltzmann constant, T is the temperature of the p–n junction in K and a is the diode ideality factor[4].

Eq. (1) does not adequately represent the behaviour of the cell when subjected to environmental variations, especially at low voltage. A more practical model can be seen in Fig. 2, where Rs and Rp represent the series and parallel resistances, respectively. An output current equation using this model can be written as [4]

$$I = I_{pv} - I_0\left[\exp\left(\frac{V + IR_s}{aV_T}\right) - 1\right] - \frac{V + IR_s}{R_p} \quad (2)$$

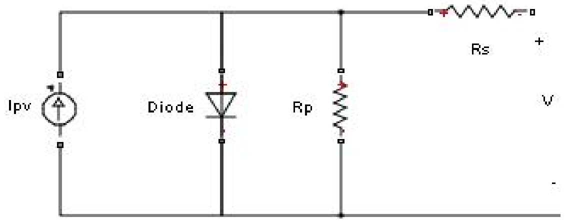

Fig. 2 Single diode model with Rs and Rp.

III. Fuzzy Logic Algorithm

Fuzzy controller was based on fuzzy logic principle developed by Zadeh in 1965 [5]. This principle is basing on two inputs variables: the error E and a change in error ΔE, and one output variable ΔD (duty ratio variation). ΔD value can be looked up in a rule base table such as Table I [2].

Fuzzy logic control generally consists of three stages: fuzzification, rule base table lookup, and defuzzification. During fuzzification, numerical input variables are converted into linguistic variables based on a membership function similar to Fig. 3. In this case, five fuzzy levels are used: NB (negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big). In Fig. 3, a and b are based on the range of values of the numerical variable.

Our simulation is based on genetic algorithm (GA) which chooses optimally and simultaneously both membership functions and control rules for the fuzzy logic controller as doing in [9].

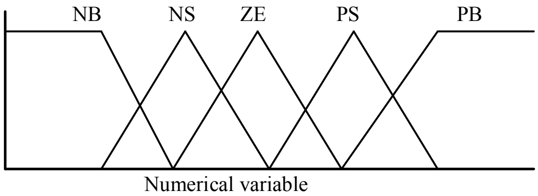

Fig. 3 Membership functions for inputs and output of fuzzy logic controller.

The inputs to a MPPT fuzzy logic controller are usually an error E and a change in error ΔE. The user has the flexibility of choosing how to compute E and ΔE. Since dP/dV vanishes at the MPP, [7], [10] uses the approximation

$$E(n) = \frac{P(n) - P(n-1)}{V(n) - V(n-1)} \quad (3)$$

and

$$\Delta E(n) = E(n) - E(n-1) \quad (4)$$

Once E and ΔE are calculated and converted to the linguistic variables, the fuzzy logic controller output, which is typically a change in duty ratio ΔD of the power converter, can be looked up in a rule base table such as Table I [8].

TABLE .I

FUZZY RULE BASE TABLE

E \ ΔE	NG	NP	EZ	PP	PG
NG	EZ	EZ	NG	NG	NG
NP	EZ	EZ	NP	NP	NP
EZ	NP	EZ	EZ	EZ	PP
PP	PP	PP	PP	EZ	EZ
PG	PG	PG	PG	EZ	EZ

The linguistic variables assigned to ΔD for the different combinations of E and ΔE are based on the power converter being used and also on the knowledge of the user. Table I is based on a boost converter. If, for example, the operating point is far to the left of the MPP , that is E is PB, and ΔE is ZE, then we want to largely increase the duty ratio, that is ΔD should be PB to reach the MPP.

IV. Simulation Results

To test the performance of fuzzy technique, a photovoltaic generator with four modules was using, shown fig.4. Photovoltaic panel specifications are shown in table II.

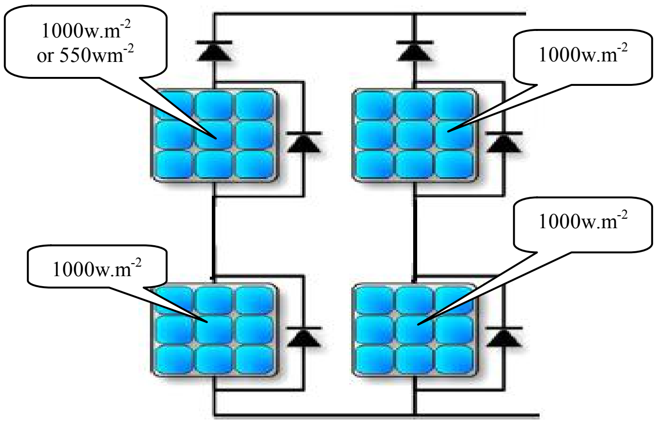

Fig.4 Photovoltaic generator

TABLE II

PV MODULE SPECIFICATIONS

Designation	BP SX150
Maximum power (P_{max})	150 W
Voltage at P_{max} (V_{PPM})	34.5 V
current at P_{max}(I_{PPM})	4.35 A
Open-circuit voltage (V_{oc})	43.5 V
Short-circuit current (I_{cc})	4.75A

The various parts of the fuzzy technique have been modelled using the Matlab/Simulink model as shown in Fig.5

A. Response for Uniform and no Uniform Insolation During Operation

In the case where the first module receives irradiance of 550 W.m-2 and the others modules receive standard conditions(G=1000W.m-2 and T=25C°), two peaks in power characteristic have been observed as shown in Fig.6., with regard to fig.6 the global and local maximum power points are located at 353W and 299W, respectively. The produced output power of the fuzzy algorithm under uniform irradiation and no uniform irradiation (partial shading condition) are shown in Fig.7. (a) and (b), respectively. The response times of the system in the two conditions are 0.6s, 0.26 s with resistive load and 0.24 s, 0.23s with battery load, respectively. According to fig. 7.(a) and (b), it is clearly shown that the fuzzy algorithm can search the real MPP and force the photovoltaic generator to operate at this point with good performance. We can also note that the response times of the fuzzy algorithm are different for the same irradiance according to the type of load.

B. Response for Rapidly Changing Insolation During Operation

Figs.8.(a) and (b) show the irradiation variations and the generated output power of the fuzzy algorithm corresponded for both loads (resistive and battery). We changed irradiation intensity of first module, while the others intensity rest at the standard conditions (T=25C° and G= 1000w.m-2). From fig. 8, in the case of battery, it can be observed that the fuzzy algorithm reach shortly the MPP, whereas in the case of resistive load the algorithm takes more time to reach the MPP with small static error. It can be concluded that the load type influenced the performance of the algorithm.

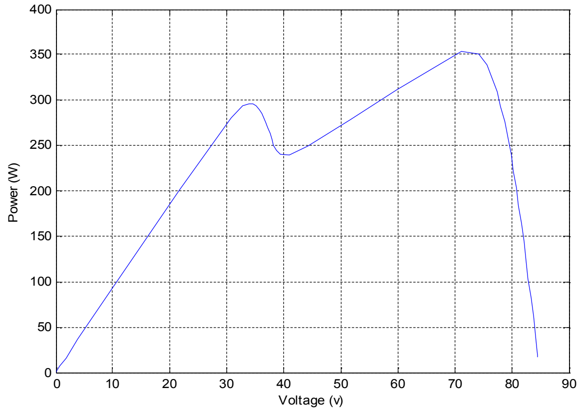

Fig.6 P-V characteristic for PVs array under no uniform insolation conditions

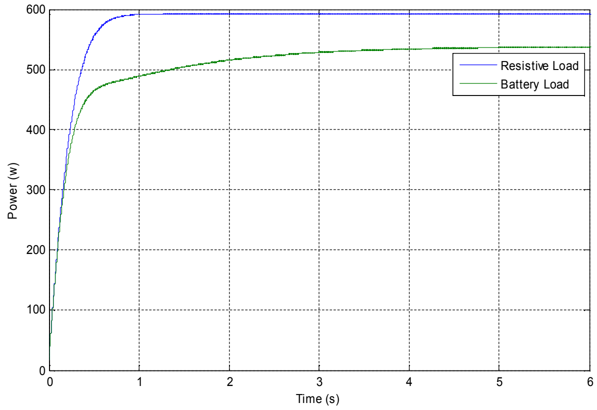

Fig.7.a The generated output power of the fuzzy algorithm under uniform condition (T=25C° , G= 1000w.m^{-2})

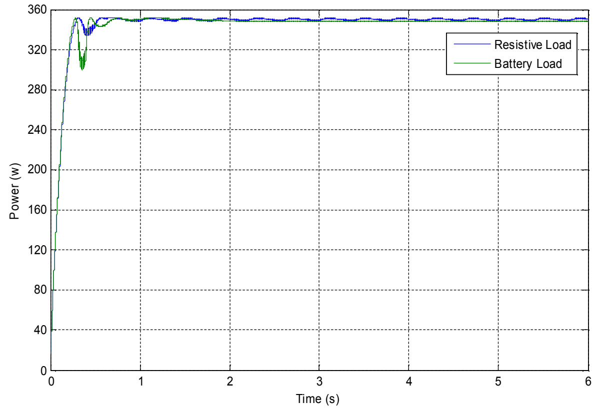

Fig.7.b The generated output power of the proposed algorithm under no uniform irradiation

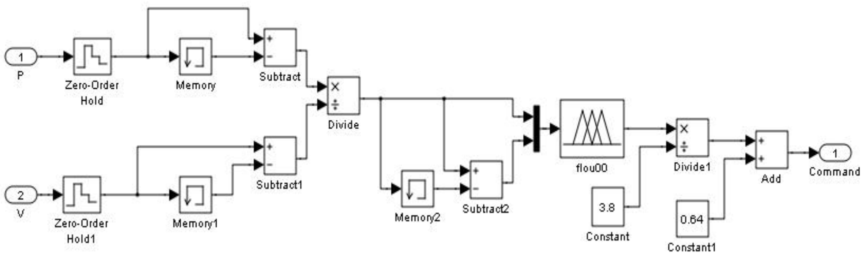

Fig.5 Subsystem simulation of the fuzzy MPPT algorithm

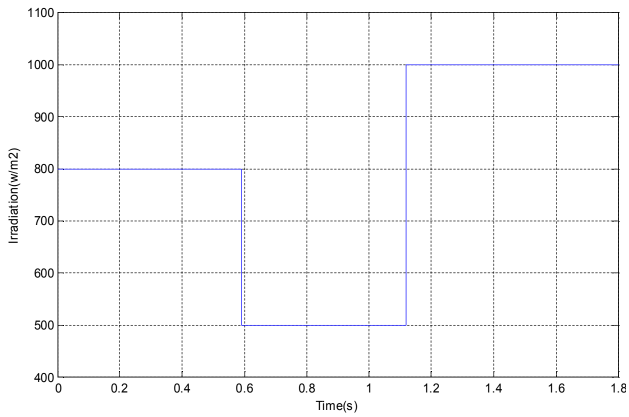

Fig.8.a Irradiation variations

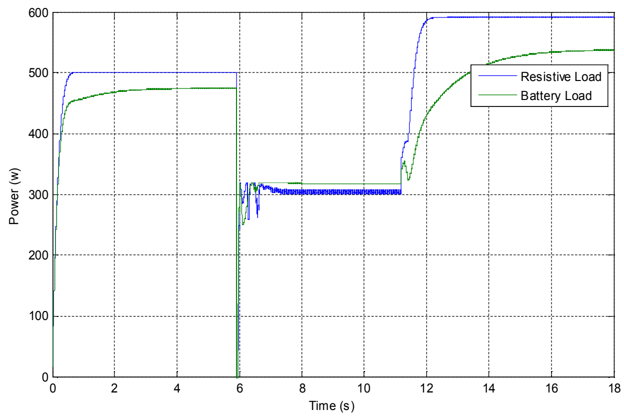

Fig.8.b The generated output power of fuzzy algorithm

V. Conclusions

In this paper, a MPPT-based fuzzy-logic controller for tracking a global MPP under partial shading and for rapidly changing conditions has been developed. In order to show the effectiveness of this technique, static and dynamic load have been used. With respect to the results, it has been demonstrated that the fuzzy algorithm avoids local MPPs and seeks rapidly the global MPP without oscillations. It has been observed that the efficiency of the fuzzy algorithm depends to the type of load at which the generator is connected.

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