Application of fuzzy logic technique to track maximum power point in photovoltaic systems

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ABSTRACT

The use of photovoltaic (PV) systems for generating electric power is increasing in our everyday lives but since the generated voltage and current vary non linearly it has been very difficult to trace the maximum power point (MPP) of the PV systems so to overcome with this problem many power tracking methods were introduced out of which fuzzy logic technique was found to be one of the easy and efficient maximum power point tracking (MPPT) method. In this paper, various MPPT algorithms are observed how they help in improving the efficiency of PV systems by adjusting the duty ratio of the power interface, and also understand why the fuzzy logic control (FLC) technique is preferred over other algorithms. The system was established using MATLAB/Simulink.

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1. INTRODUCTION

Over years we have been acquainted with using energy sources that had adverse effects on the environment. We are still relying on those fossil fuels and extracting them which will soon end in these recent years and this directed to the rapid growth of renewable energy sources (RESs) because the energy produced by them is clean and less hazardous [1]. Solar energy being the most abundant resource of energy can help us rely less on these non-renewable energy sources. Here come the photovoltaic (PV) systems playing the key role as they help in converting this light energy to electrical energy [2]. The basic requirement for a PV system is a PV cell which is nothing but a P-N junction diode. PV cells have a very low voltage so to obtain more voltage we use a PV module which is a result of a series and parallel combination of many PV cells. These PV modules help in the formation of a PV array when in a series and parallel fashion. All these arrays joined together lead to a solar panel, the solar panel along with many other components complete a PV system [3], [4]. The current-voltage (I-V) and power-voltage (P-V) curves generated by a PV array being non-linear in the structure are affected due to various factors such as solar irradiation and array temperature [5], [6].

To design an efficient PV system a PV array needs to operate at maximum power point (MPP). We are performing this maximum power point tracking (MPPT) to ensure that the functioning point of the PV array is always equal to the MPP or near that point. The functioning point is the result of the intersection of the V-I characteristics curve with the load line [7]. We should ensure that this point always coincides with the maximum power point and for this to happen we go for a power interface that has a control input given in such a way that thermal resistance is kept constant [8]. The function of this power interface is that if the resistive load changes then accordingly control input also changes such that irrespective of the load resistance (R_o), the thermal resistance (Rt) is always constant because of which load line sees that maximum power point is drawn [9]. Here, the load is DC so the power interface is a DC-DC converter and the control input for these converters is the duty cycle. If the load requires ac voltage then we opt for a DC-AC converter (inverter). DC-DC converters can be of any topology i.e., isolated or non-isolated topology according to our requirement such that the input/thermal impedance of the PV module is controlled [10]. Here, a boost converter is used that comes under a non-isolated topology. Now we will look into how this control input is given generically as shown in Figure 1 such that (R_t) is regulated.

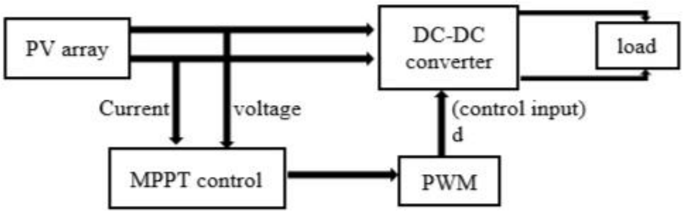

Figure 1. Block diagram representing MPPT topology of a PV system

The current and terminal voltage of the PV array are considered which are processed appropriately using different algorithms from which we obtain a reference generator and that reference is compared with another variable (power variable mostly) called the feedback variable [11]. Now the reference and feedback variables are monitored and the fault is passed to a proportional-integral (PI) controller which ensures that the error goes to zero so that the feedback matches the reference and under this condition, MPPT is achieved [12], [13]. The output of the PI controller generates the pulse width modulation (PWM) such that the DC-DC converter gets the required duty ratio. Many MPPT methods were executed like perturb & observe (P&O), incremental conductance (IO), fuzzy logic controller (FLC) technique, and many more where the functioning point of the PV curve was equivalent to the maximum power of the curve [14], [15]. In this paper, we will study how these different algorithms help in extracting maximum voltage from the PV array, their behavior under various environmental conditions, and how these algorithms vary among themselves serving us to find the most efficient technique.

2. MODELLING OF PV ARRAY

When light falls on a solar cell the photons having energy more than that of bandgap energy create several electron-hole pairs, these carriers when subjected to the electric field are drifted apart giving rise to photocurrent I_{ph} which is dependent on solar irradiation. The following equations help us in building the V-I characteristics of a solar cell [16]. The equation of photocurrent which is dependent on solar irradiation is [17],

$$I_{ph} = [I_{sc} + K_i\,(T - 298)] * \frac{G}{1000} \tag{1}$$

where I_{sc} indicates the short circuit current in amperes (A), K_i indicates short circuit current temperature coefficient in (A/ °C) at 25 °C and 1000 W/m^2. T is the temperature at which the array operates in (K), G denotes solar irradiation in (W/m^2). It is the radiation supplied to the PV solar cell so that it absorbs the solar energy from the sun [18].

$$I_o = I_{rs}\left(\frac{T}{T_n}\right)^3 * \exp\left[q * \frac{E_{g0}\left(\frac{1}{T_n} - \frac{1}{T}\right)}{nK}\right] \tag{2}$$

I_o is the saturation current (A), I_{rs} is the reverse saturation current in (A), T_n is the nominal temperature in (K), E_{g0} is bandgap energy of an electron in eV, n is the ideality factor of the diode, q is electron charge in coulomb, K is the Boltzmann constant in (J/K) [19]. Reverse saturation current is given by,

$$I_{rs} = \frac{I_{sc}}{e^{\left[\frac{qV_{oc}}{nNsKT}\right]-1}} \tag{3}$$

V_{oc} is open-circuit voltage, N_s is the number of cells in series [20]. Current through the shunt resistor is given by,

$$I_{sh} = \left[\frac{V+I_{rs}}{R_{sh}}\right] \tag{4}$$

R_{sh} is the shunt resistance in ohm. The output current is given by,

$$I = I_{ph} - \mathrm{I}_o \left(\exp\left(\frac{q(V+I_{rs})}{nKN_sT}\right) - 1\right) - I_{sh} \tag{5}$$

where R_s is the resistance in series, N_p is the number of cells in parallel, P_{mp} is the rated power, V_{mp} is the maximum power voltage, I_{mp} is the maximum power current. Parameters considered while designing the PV array are represented in Table 1.

Table 1. Data used for construction of array

Specifications	Values	Specifications	Values
q(C)	$1.6 * 10^{-19}$	E_{g0}	1.1ev
V_{oc}	32.9V	N_s	54
I_{sc}	8.21A	N_p	1
n	2	R_s	0.221 ohm
K	$1.38 * 10^{-23}$	R_{sh}	415.405 ohm

There are many traditional MPPT techniques such as Perturb and Observe (P&O) method, IC method, fractional short circuit current, fractional open-circuit voltage, and hill climbing [21], and this work will be looking into some of the popular methods. P&O algorithms are the most preferred ones in tracking MPPT as it is easy to implement because of their non-complicated structure. Here the voltage obtained by the solar PV array is advanced with the support of Boost converter by suitably selecting the values of L, C, and duty ratio.

2.1. P&O algorithm using a boost converter for photovoltaic array

The duty ratio is controlled by the P&O algorithm using the MPPT technique. MPPT controller generates duty cycle (period of the system in which the signal is active) so that switching signals are created for the converter. These switching signals help the boost converter such that the resulting PV system always works at maximum voltage and power. This algorithm works on the perception that the derivative of power at maximum power point with respect to voltage is 0 [22]. The output power of the solar array and its disturbance is observed here. With the support of the previous values, the duty cycle (increased or decreased) is adjusted accordingly [23]. The values taken into consideration for the working of Boost converter are portrayed in Table 2 and the algorithm used for building the module is shown in Figure 2. If $dP > 0$ and $dV < 0$ duty ratio is increased [24]. If $dP > 0$ and $dV > 0$ duty ratio is decreased. Leading to a change in the direction of the operating point, if $dP < 0$ and $dV < 0$ duty ratio is decreased, and if $dP < 0$ and $dV > 0$ duty ratio is increased. Here comes the next MPPT algorithm called incremental conductance which modifies the Perturb & Observe algorithm by comparing the power derivative with respect to voltage with instantaneous (I/V) and incremental (dI/dV) conductance of the PV array [25].

Table 2. Parameters used for the boost converter

Parameters	Values
Inductance	100 microhenry
Capacitance	1,000 microfarad
Resistance	100 ohm

2.2. Incremental conductance MPPT using boost converter

Here MPPT technique is used so that maximum power is transmitted from solar PV array such that utilization of PV array is maximum. In this paper, the incremental conductance algorithm is used. An MPPT system is used to ensure that the switching pulses to the switch (here we are using a MOSFET) will be adjusted such that it ensures maximum power is being tracked from the solar system consequently output voltage increases to the value suitable to our requirement. We will first design a solar module and the generated output is fed as the input to the boost converter using a voltage-controlled source at the solar module interface [26].

The parameters used for building a boost converter are stated in Table 2. The voltage controller produces a signal which is connected to the voltage obtained as output from the PV module. Boost converter helps in the advancement of dc voltage obtained, the system is designed such that we get the output based on our requirement. Now we need an MPPT algorithm [27], the output of which is given as the gating pulses. The algorithm generates the gate pulses such that power extracted from the PV module would be extreme. The incremental conductance algorithm is the derivative of power output obtained by the PV array with respect to voltage [28]. The algorithm used for the construction of the module is represented in Figure 3.

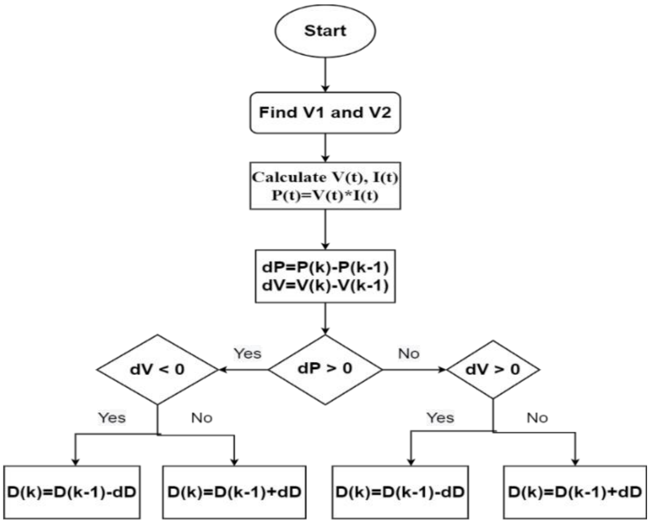

Figure 2. Algorithm used for the implementation of Perturb and Observe algorithm

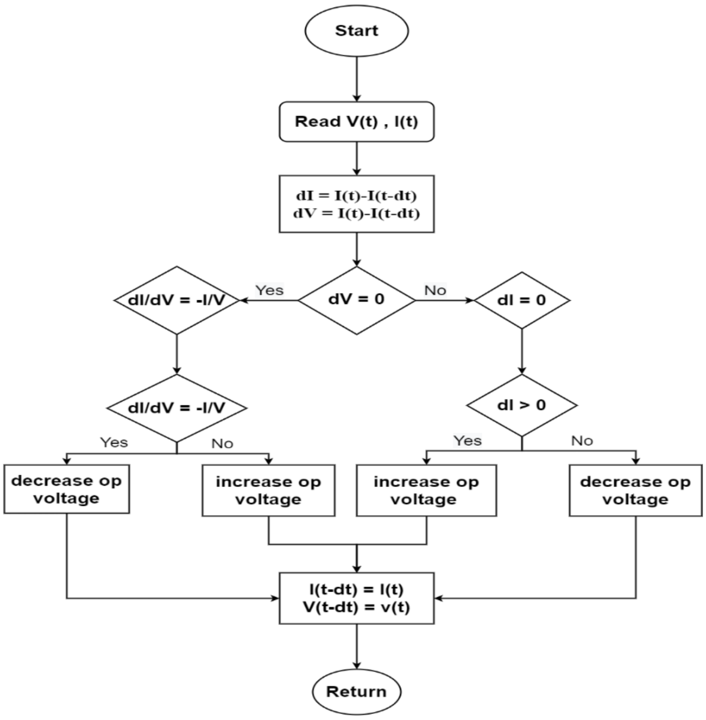

Figure 3. Flow chart representing incremental conductance (I/C) algorithm

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = \frac{VdI}{dV} + \frac{IdV}{dV} = I + \frac{VdI}{dV} \quad (6)$$

For the solar array to operate at maximum power point at any condition.

$$\frac{dP}{dV} = 0 \quad (7)$$

$$I + \frac{VdI}{dV} = 0 \quad (8)$$

$$\frac{dI}{dV} = -\frac{I}{V} \quad (9)$$

2.3. Fuzzy logic based MPPT: a modern technique

This is an efficient technique compared to the previously mentioned methods here the current and voltage generated as output by the PV array are interfaced with the boost converter. The previous and instantaneous values of power are given to multiplexer (MUX) which generates the fault signal. This is now fed to an FLC which works on a fuzzy rule as illustrated in Table 3, from here the output is fed to gate pulse. This technique is preferred over other algorithms because it keeps a track of every change in the value [29]. The deviation w.r.t every membership function we have mentioned is considered and the output is adjusted accordingly leading to a new operating voltage which is given to the switching pulses as duty ratio.

Table 3. Fuzzy rule

$\Delta Vpv * (o/p)$		$\Delta Vpv(i/p)$				
$\Delta Ppv\ (i/p)$		nb	ns	ze	ps	pb
	nb	ps	pb	nb	nb	ns
	ns	ps	ps	ns	ns	ns
	ze	ze	ze	ze	ze	ze
	ps	ns	ns	ps	ps	ps
	pb	ns	nb	pb	pb	ps

Where ΔPpv , ΔVpv variation in power and variation in voltage are input parameters. (*) is a reference value, it checks if there is any deviation in the output terminals and adjusts the values according to the defined logic. Membership functions such as nb, ns, ze, ps, pb are responsible for deciding the operation of that particular logic [30]. Where nb is negative big, ns is negative small, ze is zero, ps is positive small and pb is positive big [31]. Parameters measured while designing the module are represented in Table 4, and the algorithm used for the implementation of FLC is depicted in Figure 4.

Table 4. Parameters used for the construction of the module

Parameters	Values	Parameters	Values
T(K)	298	I_{sc}	7.84A
G(W/m^2)	800	N_s and N_p	1
V_{oc}	36.3V		

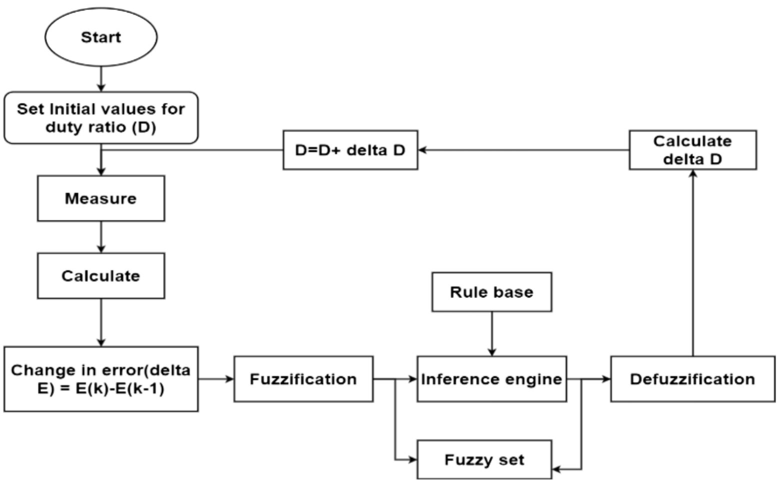

Figure 4. Fuzzy logic-based MPPT algorithm

3. RESULTS AND DISCUSSION

First, the simulation model of the PV array was built using the equations that help in explaining the current and power characteristics of the solar cell at a temperature of 25 °C. Then we have simulation results for P-V and I-V curves that change with irradiation [32]. Figure 5 represents P-V and I-V for different irradiation values. Figures 5(a) and 5(b) represent P-V and I-V curve at irradiation of 600 W/m^2 followed by Figures 5(c) and 5(d) representing P-V and I-V curves at irradiation of 1,000 W/m^2.

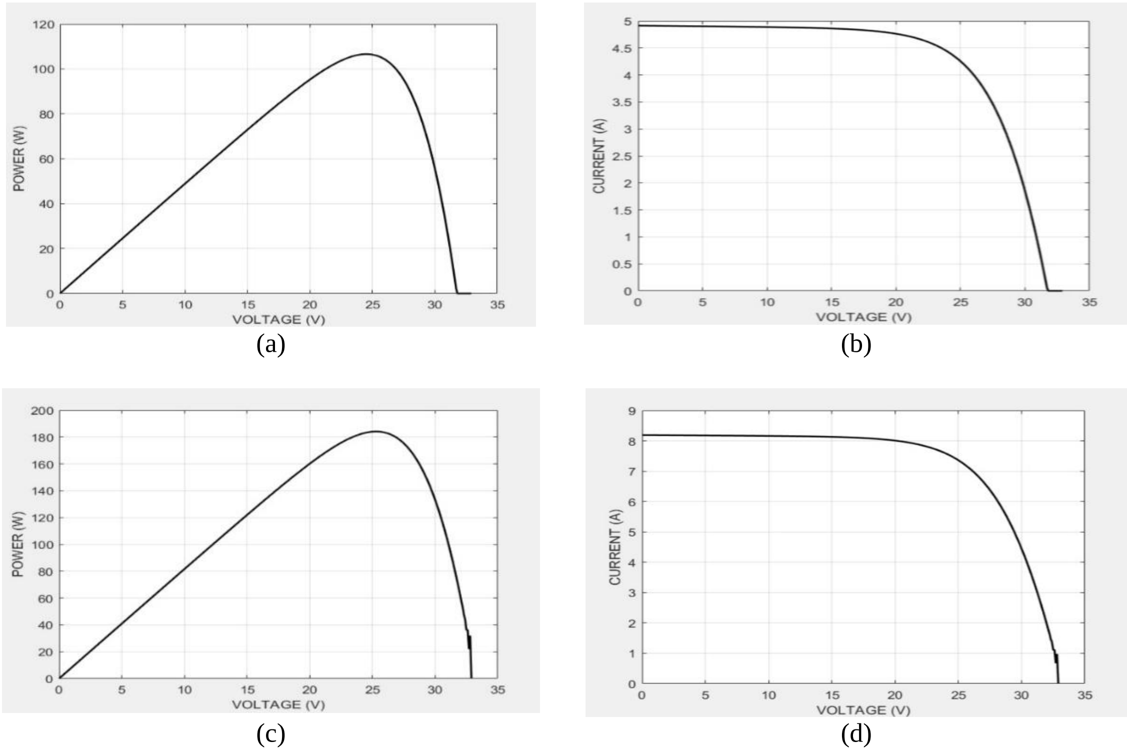

Figure 5. P-V and I-V characteristics, (a) P-V characteristics at 600 W/m^2, (b) I-V characteristics at 600 W/m^2, (c) P-V characteristics at 1000 W/m^2, and (d). I-V characteristics at 1000 W/m^2

Not only irradiance, but we also have ambient temperature and load operating conditions affecting the module [33]. We can control the load conditioning by carefully controlling the switching of a converter but we cannot control the other two factors.

3.1. Simulation results of FLC based MPPT

The results obtained using this method are regarded as the most efficient ones as this technique keeps a record of every minute change in the input value. The simulation and results obtained using this technique are depicted in Figures 6 and 7.

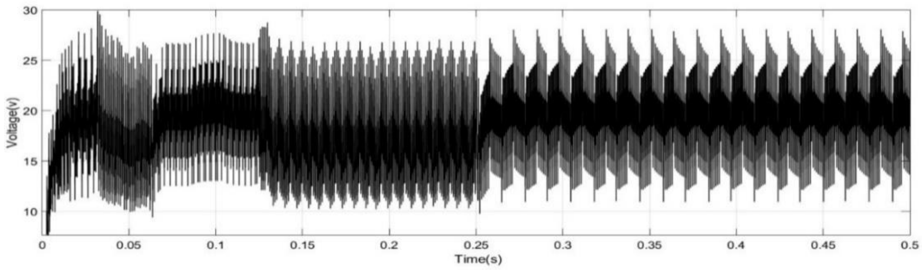

Figure 6. The output voltage of the PV array using the fuzzy logic technique

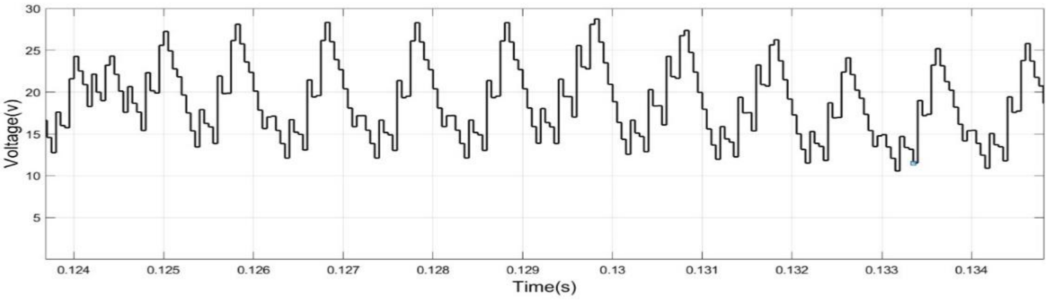

Figure 7. Variation of the output voltage of the PV array with a mean value of 20 V

We are trying to maximize the output voltage obtained by the PV array using various MPPT algorithms along with the boost converter out of which FLC-based MPPT methods are considered to be the most efficient ones. Figure 6 demonstrates the output voltage of the PV array obtained using FLC and Figure 7 represents how the obtained voltage changes with respect to maximum voltage. In this algorithm, we have two input signals and one output which is the change in duty ratio. This method is treated most efficient than the other two algorithms as the three processes involved in the fuzzy logic technique use different membership functions with the help of fuzzy rule to check for every small change in the input signals as observed in Figure 7 and accordingly change the output values by adjusting the duty cycle which helps in generating the gate pulses because of which the converter always operates at maximum voltage.

4. CONCLUSION

In this paper, a PV module is presented whose I-V, P-V characteristics are effected due to various environmental conditions. To increase its efficiency, various MPPT methods are considered, and by using which we ensure that the working voltage of the PV module always coincides with the maximum voltage or is near to that point to achieve this we have performed boost operation with the help of boost converter using different algorithms. As FLC keeps a note of every minute change in the input value as observed in the results and oscillates less around the MPP, this method is considered to be the most efficient one and preferred over other techniques.

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