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Maximum Power Extraction from PV System Using Fuzzy Logic

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Abstract— One of the most popular renewable energy is solar energy due to its large availability. Major benefit of PV system for adopting solar energy is due to less maintenance cost, no moving parts and small limitations for installation. However, photovoltaic system has poor conversion efficiency as output performance of PV system is dependent on solar irradiation and temperature which are not consider as constant input source to system. The main objective is to extract maximum power from PV system Various techniques are to be used as mechanically as well as electrically to extract maximum power. Conventional Perturb and Observation (P&O), incremental conductance, adaptive Perturb and Observation, fuzzy logic based algorithm has implemented for extraction of maximum power. Boost converter is used for power interface as well as to step up the output voltage. Fuzzy logic based algorithms finds successful role to track maximum power even in rapidly changing climatic conditions. The proposed model has been implemented in MATLAB/Simulink and validated with experimental data of commercial PV panels.

Keywords— PV(photovoltaic) module, Mathematical Modeling, Maximum power extraction, Perturb & Observation, Incremental conductance, Adaptive Perturb and Observation, Fuzzy logic algorithm, Simulation.

I. INTRODUCTION

Among all available renewable energy sources (RES), solar energy is widely available in nature and can be obtained without any expenses. As PV system is semiconductor device, it has less maintenance cost due to absence of moving parts. Maximum power point extraction from PV system is the most essential part of a photovoltaic system. The main objective of MPPT is to extract maximum output power for particular solar irradiance and temperature. MPPT algorithms helps to maximize the amount of power delivered to load from PV module. A various MPPT algorithms [2] have been investigated and differ from various characteristics like sensors convergence speed, range of effectiveness, cost, sensors popularity, efficiency or complexity.

The proposed system with block diagram is presented in section II. A mathematical modeling of a PV cell is described in Section III, concept of maximum power extraction with different MPPT algorithms like Perturbation and Observation (P&O), Incremental conductance, Adaptive Perturb and Observation and a Fuzzy logic based method is presented in section IV. All proposed algorithms are implemented in MATLAB/ Simulink. Comparison between described algorithms for power and required tracking time is presented in Section V.

II. PROPOSED SYSTEM

The basic block diagram [3] in Fig. 1 represents proposed system. It consists of a PV system, DC-DC (boost) converter [10], and load. DC-DC converter is used for power interface between array and load. DC-DC voltage converter selection depends on the required voltage level on load side.

For MPPT, output voltage and current of PV module are taken as input. In order to extract maximum from PV system, MPPT algorithms defines resultant change in particular variable either voltage or current or power. In this proposed system, output of algorithm generates change in duty ratio and is fed to PWM generator which generates switching for boost converter.

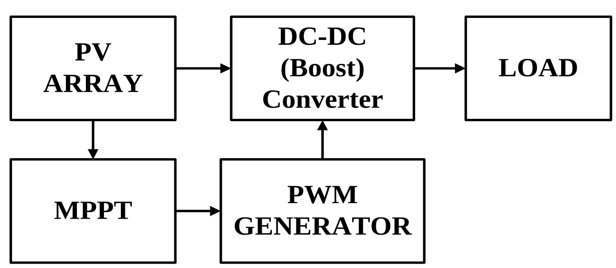

Figure 1. Block diagram of maximum power extraction strategy

III. Mathematical Modeling of PV Array

The PV cell is a semiconductor diode in which p-n junction is fabricated in forms of wafers [1]. When a photovoltaic cell is exposed to light, electromagnetic radiation is converted to direct current without any environmental hazards. PV modules contain series and/or parallel connections of PV cells.

The studied model consists of polycrystalline PV cell module a total power capacity of 330 W. The electrical parameters are given in Table 1, taken from a manufacturer's datasheet. The parameters are given under Standard Test Conditions (STC) with a solar irradiance of 1000 W/m^2 and module temperature of 25 ºC.

An ideal PV cell is modeled by a current source in parallel with a diode [4]. Since no solar cell is ideal [1] therefore shunt and series resistances are added to the model as shown in Figure 2. R_P is the equivalent shunt resistance which has a very high value. R_S is the intrinsic series resistance whose value is very small.

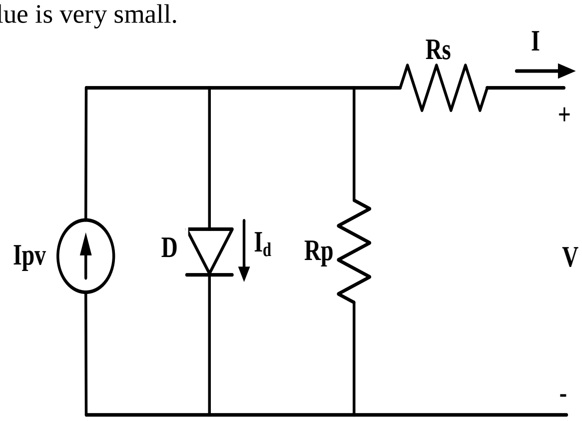

Figure 2. Equivalent circuit of single–diode PV cell

By using Kirchhoff's Current Law, the output current delivered by PV module is given by

$$I = I_{pv} - I_o \exp\left[\left(\frac{V + R_s I}{V_t a}\right) - 1\right] - \frac{V + R_s I}{R_p} \quad (1)$$

The module photo-current I_{pv} can be calculated by

$$I_{pv} = (I_{pv,n} + K_i \Delta T)\frac{G}{G_n} \quad (2)$$

Where, $I_{pv,n} \approx I_{sc}$, ΔT = T- T_n (T and T_n being the actual and nominal temperatures (Kelvin), respectively), G is the irradiation (W/m^2) on the PV cell surface, and G_n is the nominal solar irradiation.

The reverse saturation current or leakage current is given by

$$I_o = I_{o,n}\left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qEg}{ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \quad (3)$$

The diode ideality factor 'a' depends on the PV cell structure; e.g., for polycrystalline silicon cells a =1.3.[3]

Where, $I_{o,n}$ is nominal reverse saturation current which can be expressed by

$$I_{o,n} = \frac{I_{sc}}{\left[\exp\left(\frac{V_{oc}}{V_t a}\right) - 1\right]} \quad (4)$$

$V_t = N_s kT/q$ Thermal voltage of cell(V)
Q=1.602*10^{-19} Electron charge (C)
k=1.38*10^{-23} Boltzmans constant (J/K)
I_o: Saturation current of diode (A).
a: Diode ideality factor
I_{sc}: Short circuit current of PV cell (A)
K_i: the cell's short-circuit current temperature coefficient
V_{oc}: Open circuit voltage of PV module (V)
N_s: Number of series connected cell

Table 1. Electrical Parameters of Photovoltaic module at STC

Rated Power(P)	330W
Open-circuit voltage (V_{oc})	45.50 V
Short-circuit current (I_{sc})	9.65 A
Voltage at Maximum power (V_{mp})	36.90 V
Current at Maximum power (I_{mp})	8.95 A
Number of cells connected in series (N_s)	72
Temperature coefficient of I_{sc} (K_i)	0.0154 I/°C
Temperature coefficient of Voc (K_v)	-0.2775 V/°C
Diode ideality factor (A)	1.3

Figure illustrates the characteristic of proposed module in which I-V and P-V characteristics curve validates the parameters value with manufacturer datasheet at Standard Test Conditions (STC).

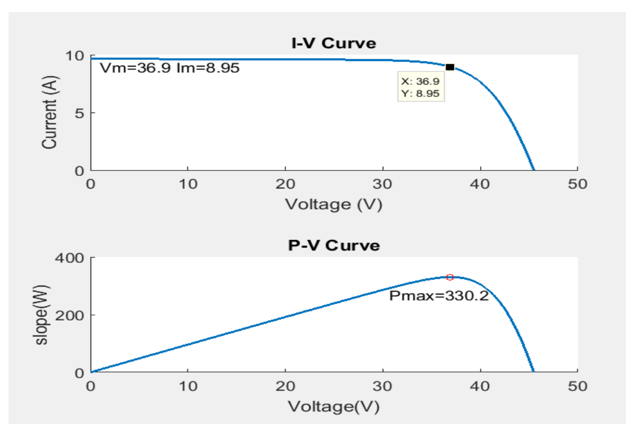

Figure 3. Characteristics I-V and P-V curve of Panel

IV. MAXIMUM POWER POINT TRACKING

As per maximum power transfer theorey, when source impedance matches load impedance, maximum amount of power is transferred to load [7]. So, MPPT problem can be treat as a impedance matching problem. The problem considered by MPPT algorithms is to automatically detect the voltage V_{mp} or current I_{mp} at which a PV array should operate to extract the maximum output power P_{mp} at given temperature and irradiance.

The MPPT not only increases the power delivered to the load from the PV module, but also improves the operating lifetime of the PV system.

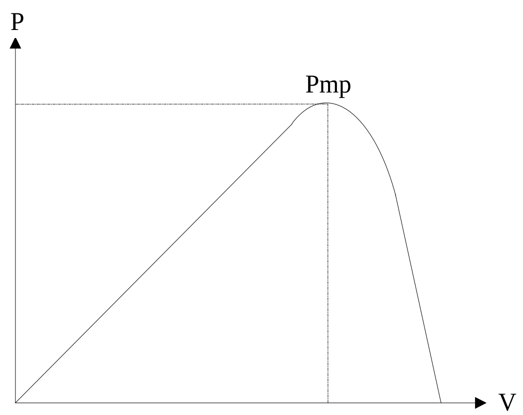

Figure 4. P-V curve characteristics of a PV array

A. *Perturb And Observation*

Perturb and Observation (P&O) is one of the most commonly used algorithm due to its easy implementation [3]. As it name implies, this method works based on perturb given in duty ratio of power converter, results in perturbation in the PV panel voltage of the power converter and consequently perturbation in the PV panel current [2]. This process is repeated periodically until maximum power point is reached. The flowchart of Perturb and observation algorithm is shown in Figure 5.

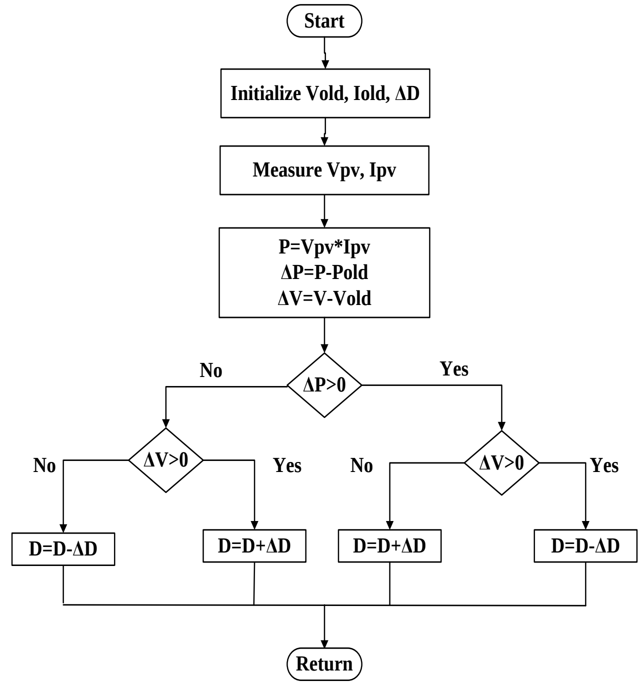

Figure 5. Flowchart of Perturb & Observation algorithm

A common problem in P&O algorithms is that the PV module terminal voltage is perturbed at every MPPT cycle; thus after tracking maximum power, it keeps continuously oscillating in both the side of MPP.

This algorithm is less complex to track maximum power but after tracking the maximum power it doesn't give constant value of power. In other words, it doesn't stop and continuously perturbs on both the left and right side of MPP as per the value of the perturb size. Thus due to continuous variation in MPP, there is a multiple point of maximum power at same time. Hence when there is a sudden change in solar irradiance as well as in atmospheric condition, maximum power deviates from its normal operating position on PV curve. Thus when solar irradiance changes, it takes more time to reach at maximum power point and makes more oscillation after also tracking MPP. This fluctuation in power causes loss and can be reduced by reduction in perturb size.

B. *Incremental Coductance*

The incremental conductance method works on the position of slope from maximum power point, as slope at MPP is zero, positive on left side of MPP and negative on right side of MPP, which can be represented as

$$\begin{cases} \frac{\Delta P}{\Delta V} = 0, \text{ at MPP} \\ \frac{\Delta P}{\Delta V} > 0, \text{ at left side of MPP} \\ \frac{\Delta P}{\Delta V} < 0, \text{at right side of MPP} \end{cases} \quad (5)$$

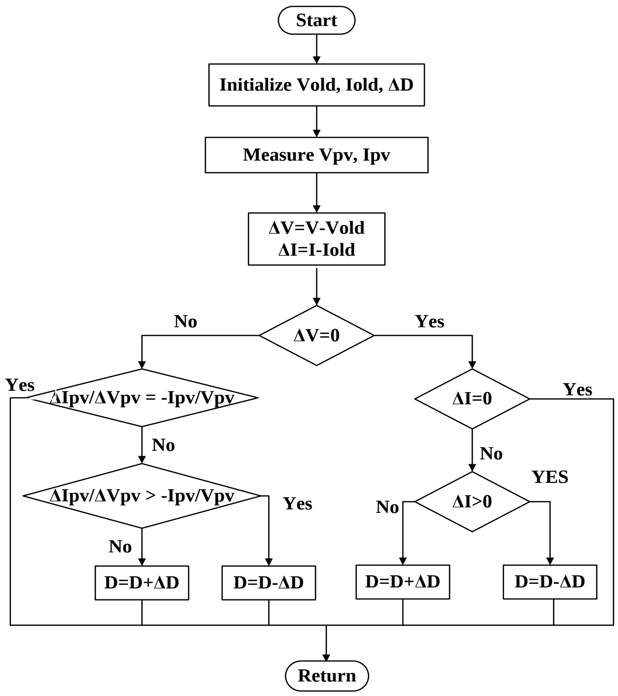

Figure 6. Flowchart of Incremental Conductance algorithm

Since

$$\frac{\Delta P}{\Delta V} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \approx I + V\frac{\Delta I}{\Delta V} \quad (6)$$

Equation (5) can be written as

$$\begin{cases} \frac{\Delta I}{\Delta V} = -\frac{I}{V} \text{ ,at MPP} \\ \frac{\Delta I}{\Delta V} > -\frac{I}{V} \text{ ,at left side of MPP} \\ \frac{\Delta I}{\Delta V} < -\frac{I}{V} \text{ ,at right side of MPP} \end{cases} \quad (7)$$

The MPP can thus be tracked by comparing the instantaneous conductance (I/V) to the incremental conductance (ΔI/ΔV) as shown in the flowchart in Fig. 6. Once the MPP is reached, the operation of the PV array is maintained at this point unless a change in ΔI is noted, indicating a change in atmospheric conditions and the MPP [2].The algorithm decrements or increments ΔD to track the new MPP.

C. Adaptive Perturb and Observation

The operation of perturb and observation mainly depends on the size of perturb. Amount of perturb decides the speed of response to track maximum power point. When small perturb size is to be selected, the resultant change in output is also small thus it tracks more time to achieve maximum power point but it has advantage of reduction in oscillation. As well as large perturb size reaches to MPP fast but it oscillates in either direction of MPP.

Now to avoid these situations, variable perturb size is adopted in which operation of perturb is based on the position of power from MPP. When power is far from MPP, increasing perturb size tracks the MPP very fast, as well as after MPP tracking, to avoid oscillation around MPP, perturb size is reduced. Thus by adaptive perturb and observation, maximum power point is achieved without any oscillation hence power losses also reduced.

D. Fuzzy Logic based MPPT

Fuzzy logic control based algorithm is one of the most efficient control techniques for tracking of maximum power point, which is the research topic in the filed of artificial intelligence. Fuzzy Logic control method do not require an accurate mathematical model and can easily operate with imprecise inputs [2]. It has also the ability to operate nonlinear systems and control unstable systems.

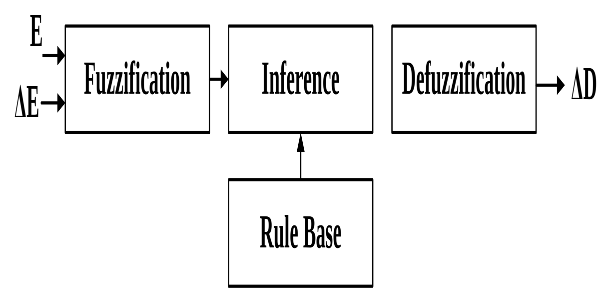

Figure 7. Functional block diagram of Fuzzy logic based algorithm

The fundamental structure of any fuzzy logic controller is shown in Fig. 7 which consists of the following stages: fuzzification, rule base and inference, and defuzzification [9]. In this proposed model inputs are the slope (E) and the change in the slope (ΔE) of the photovoltaic module. The resultant output of the fuzzy logic controller is the change in the duty ratio ΔD [2] .

In the fuzzification stage, numerical input variables are converted into suitable linguistic variables or sets, and divided into both positive and negative range as NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small) and PB (Positive Big) using basic fuzzy subset.

Table 2. Fuzzy Logic Rules

E/ΔE	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

Inference engine mainly consists of fuzzy rules. The inputs variable are fuzzified and fed to the inference process which evaluates the rules for control. The output fuzzy set is identified using fuzzy implication method. The fuzzy rules for proposed fuzzy logic controller is shown in table 2 [2].

Since ΔP/ΔV becomes zero at the MPP, equation for input as

$$E(n) = \frac{P(n) - P(n-1)}{V(n) - V(n-1)} \quad (8)$$

And

$$\Delta E(n) = E - E(n-1) \quad (9)$$

The fuzzy inference formulates the mapping from input to output according to rules and generates the linguistic output. In the defuzzification stage, output linguistic variable is to be converted again into crisp variable. The centroid method [9], is the most commonly used for defuzzification. The resultant output ΔD is then added to the previous output of D to obtain new value of the duty ratio.

V. Results and Discussion

First, a MATLAB simulation for all four MPPT algorithm is determine which gives more accurate output when suddenly changes in solar irradiation. In this paper, algorithms are simulated for 1000 W/m^2, 800 W/m^2 and 600 W/m^2 with one second time duration for each level. 25˚C is consider for all algorithms.

Although in real system, solar irradiation never changes as fast as in reality, the response time taken by each algorithms represents time required to track maximum power and The photovoltaic output power for all four different studied MPPT algorithms is illustrated in Fig(8).

The incremental conductance method has the same features and results with that of the P&O method. The following table represents mean value of power for all algorithms, the advantage of fuzzy logic based algorithm to track maximum power point quickly and without any oscillation even during rapidly changing climate condition.

Table 3. Comparision of results for all MPPT algorithms

	P&O	IC	Adaptive P&O	Fuzzy Logic
P_{mp} (W)	330.09	330.09	330	330.1
Tracking Time(Sec)	0.6	0.6	0.5	0.02

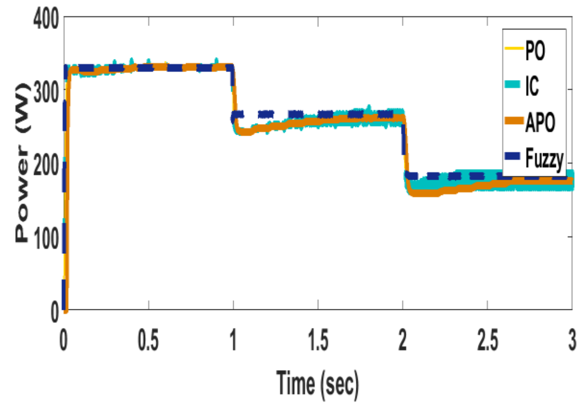

Fig 8. Comparison of power for different MPPT algorithm

VI. Conclusion And Future Scope

In this paper, a PV system with maximum power point extraction algorithm is achieved. Firstly, mathematical modelling of PV cell has been carried out. Then, maximum power point extraction concept with four different algorithms namely perturb and observation, incremental conductance, adaptive perturb and observation, fuzzy logic based have been presented.

The results shows that perturb and observation, incremental conductance, adaptive perturb and observation fails to track fast when there is sudden change in solar irradiance. In Adaptive perturb and observation method, oscillation is reduced as compared to P&O and incremental conductance but it takes time to track maximum power point when solar irradiance changes. Fuzzy logic control based algorithm can track maximum power fast and accurately as compared to other algorithm. Perturb and observation, incremental conductance, adaptive perturb and observation takes time to track MPP and after achieving steady state, there is oscillation around MPP which results in power loss. On, the other hand, fuzzy logic is advantageous due to absence of power loss as well as low tracking rime even in rapidly changing climate condition. Hence fuzzy logic based MPPT proves its better performance as compared to other conventional methods. Moreover to enhance performance and accuracy other artificial intelligence based techniques like Artificial Neural Network, Genetic algorithm and/or combination of these techniques can be use in future.

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