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Comparative Analysis of Various MPPT-Techniques for Optimization of Solar-PVEC System

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Abstract

The paper aims to provide a comprehensive analysis of various MPPT Technique under various environmental condition. The photovoltaic array having non-linear power voltage characteristic and under non-uniform irradiances. It shows a many peaks which have many local peaks and one global peak. For getting a global peak among all local peaks, MPPT play an important role in PV system. Therefore a technique like maximum power point tracking (MPPT) is required to optimize the performance. Here the comparison of hill climbing perturb and observe (P&O) algorithm technique, incremental and conductance (I&C) control algorithm, the drift free P&O algorithm technique are discussed in detail with simulation and simultaneously some other intelligent control techniques comparison are given briefly which help the researcher to ease in selecting the appropriate algorithm for specific application.

Keywords: MPPT Technique, Traditional and Intelligence based Controller

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1. Introduction

Solar energy is one of the vital renewable energy in spite of the non-renewable sources such as coal, gasoline. This energy is clean, never-ending and available absolutely free. Any variation in atmospheric condition change reliability and quality of power and create a challenge in integration of renewable energy and become a most promising challenge in most of the developed and developing country like India. Historic commitment of COP 21 commits the world to holding the rise of global temperature to well below 2^0 C above pre-industrial levels, and pursuing efforts to limit this increment to 1.5^0 C, is a much more ambitious goal. India submitted a stronger commitments through Intended Nationally Determined Contribution (INDC) to the UNFCCC to increase the contribution of non-fossil fuel to 40% in the total installed capacity by 2030. Increase contribution of PV generation through India's Jawaharlal Nehru Solar Mission is one of the instruments to fulfill this ambitious commitment.

In a solar PV system generally the tracing of maximum power and corresponding point is a biggest challenge and one of the very important parts of photovoltaic energy conversion systems. For getting this many of the researchers and research community developed a lot of algorithm. Out of all, each technique have some merits and demerits[1] and some variation in terms of implementation complexity, required sensors which are used in parameter sensing, convergence speed, cost, and range of effectiveness which are addressed in various research articles. In photovoltaic solar energy conversion system tracing of maximum power point and corresponding operating point is important other for any change in isolation system goes in unstable region[2,3]. For any given set of conditions to efficiency increase of a photovoltaic conversion array, the photovoltaic modules are operated at maximum power point[4,5].

From the nonlinear characteristics of PV module, tracing of maximum power play a vital role for any photovoltaic system. In literature review, different maximum power point tracing techniques have been reported[5].

2. MPPT Algorithm and Techniques

In this paper most of the MPPT schemes available in literature are considered and tried to describe briefly with the help of flowchart and comparison table. These are the following MPPT Technique.

(a) Constant Voltage (CV) Method.
(b) Short – Current Pulse Method.
(c) Open Voltage (OV) Method.
(d) Perturb and observe (P&O) Method.
(e) Incremental Conductance Method.
(f) The artificial Neural Network (ANN) based Method.
(g) The Fuzzy Logic Controller (FLC) based Method.

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2.1 Constant Voltage Method

It is used to take number of step (n^{th}), and the operating points of the PV array. Keep 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. In CV method it is assumed that insulation and temperature variation of PV array have trivial effect on $V_{MPP,}$ & reference voltage V_{REF} is an adequate estimation of the real V_{MPP} and different data have to be adapted for different geological regions. The flow chart of the CV method is given Figure 1

2.2 Short Current Pulse Method

In this method MPP is achieved the by giving the current I_{REF} to the controller of converter. It is true that the operating current to get maximum power is proportional to the I_{SC} under different conditions of the irradiance level (S)is given as-

$$I_{REF}(s) = K_I . I_{SC}(S) \tag{1}$$

Where K_I is constant, I_{SC} is short circuit current.

This particular algorithm involves the measurement of the I_{sc}. To obtain this short circuit current, it is essential to use a static switch in shunt to PV array, to create the short- circuit situation. The SC method require measurement of the array current I_{PV} in order to control the duty cycle of the boost converter. When the voltage V_{PV} = 0 i.e no power is delivered by the PV system and hence no energy is being produced.

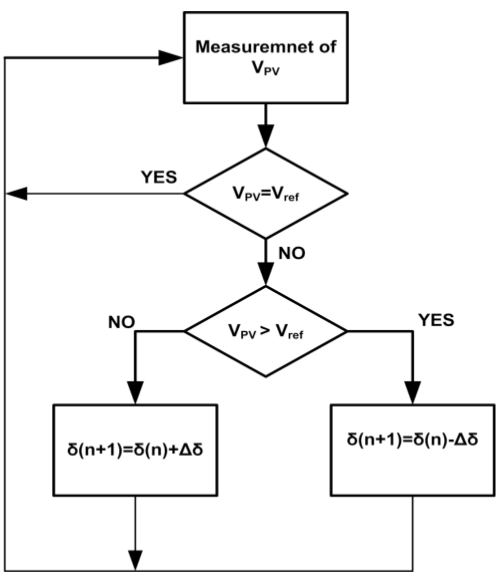

Figure 1. Flow chart of the CV method.

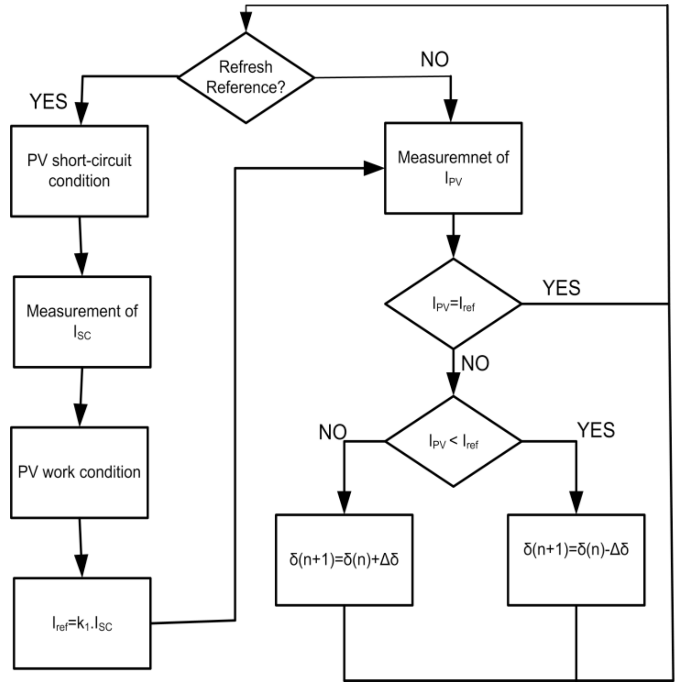

Figure 2. Short current Pulse Method.

2.3 Open Voltage Method

The Open Voltage method is based on the criteria such that V_{MPP} is constantly near to a specific (fix) percentage of $V_{OC.}$

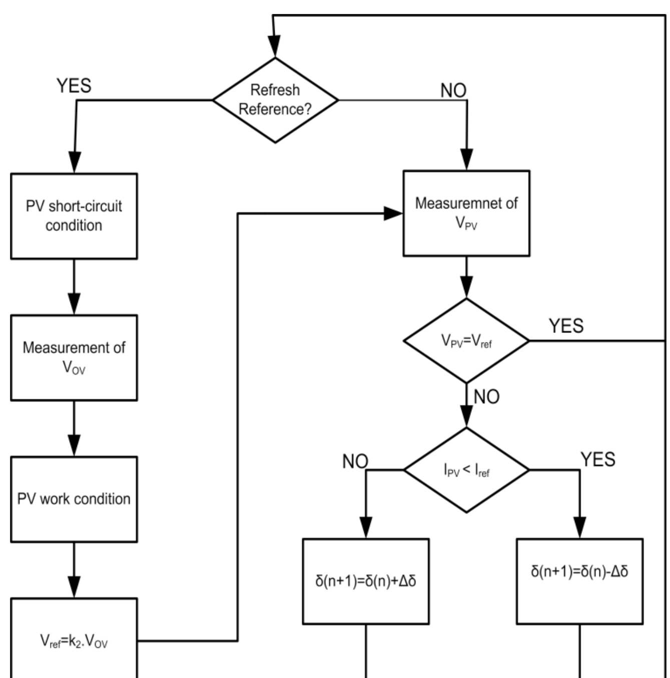

Figure 3. Open voltage method.

2.4 Perturb and Observe (P&O) Algorithm Technique

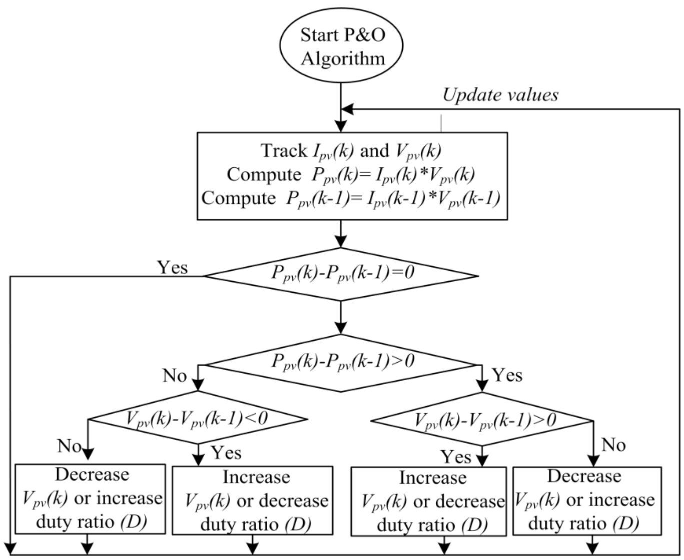

Figure 4. Perturb and Observe algorithm.

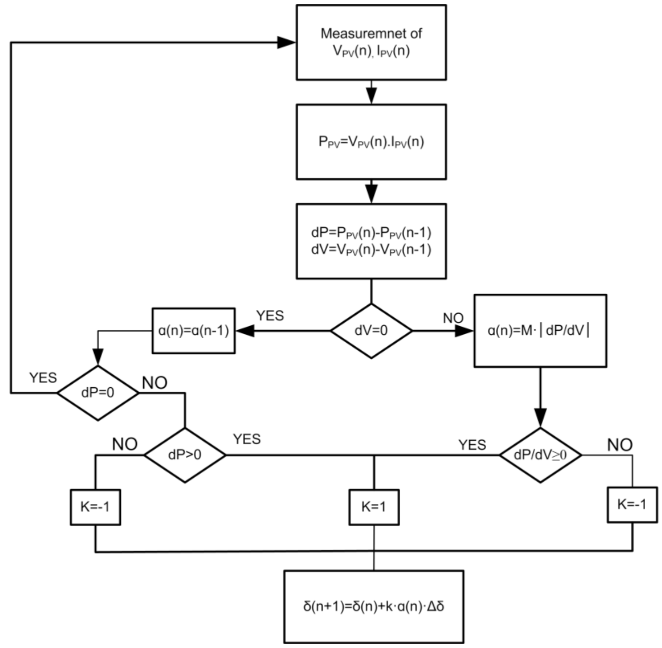

Figure 4(b). Optimized P&O, b.

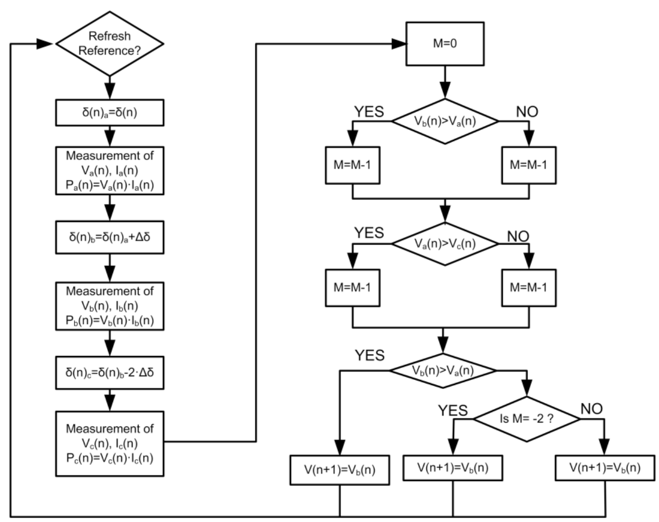

Figure 4(c). Optimized P&O,c.

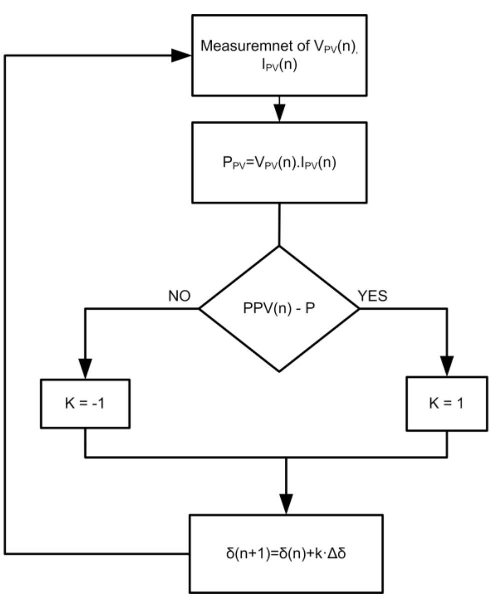

Figure 4(a). Optimized P&O,a.

The flow chart for controlling the solar Photo Voltaic energy conversion array voltage is given in Figure 1. The duty cycle is generated by comparing it with the saw-tooth waveform and it is adjusted in such a way so as to trace the maximum power-point of the solar Photo Voltaic energy conversion array power Vs voltage curve. In this MPPT scheme, the Photo Voltaic energy conversion voltage and Photo Voltaic energy conversion current are obtained at each iteration and the corresponding power is calculated. If product of solar PV current and voltage is more than the last iteration product then the value of solar PV voltage is increased and new value is given. Updated otherwise PV voltage value is decreased and new value of voltage is updated.

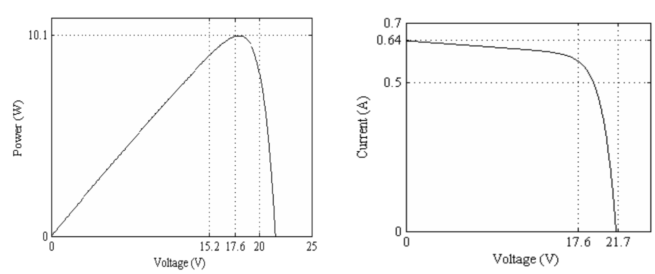

Figure 5. Power- Voltage and Current-Voltage graph for one module.

A 4500 W solar PV array is designed. For this purpose a solar module consisting of 36 cells of open circuit voltage (V_{oc}) of 21.6Vand 0.64A short circuit current (I_{sc}) is designed to give above rating by connecting N_{ser} series connected module number and N_{par} is the parallel connected module numbers.

$$P_{mpp} = \left(N_{ser} \times V_{mpp}\right) \times \left(N_{par} \times I_{mpp}\right) = 4.5\,kW \tag{2}$$

Where V_{mpp}=solar PV voltage at maximum power and I_{mpp}=solar PV current at maximum power. Here 10W, 17.6V (V_{mpp}), 0.58A (I_{mpp}) module is selected for this purpose as shown in Figure 2.It has been examined that V_{mpp}=0.85*V_{oc} and I_{mpp}=0.90*I_{sc}. Hence P_{mpp} for one module is given by P_{mpp}=V_{mpp}*I_{mpp}. Now V_{oca}=600V. Hence number of series connected module (N_{ser})=600/21.6≈29 and number of parallel connected modules are (N_{par}) = 4500/ [(0.85*600)*0.58]=15.25≈15.

By this way connecting 29 modules in series and 15 modules in parallel one can achieve 4500W solar PV array.

2.5 Incremental and Conductance (I&C) Control Algorithm

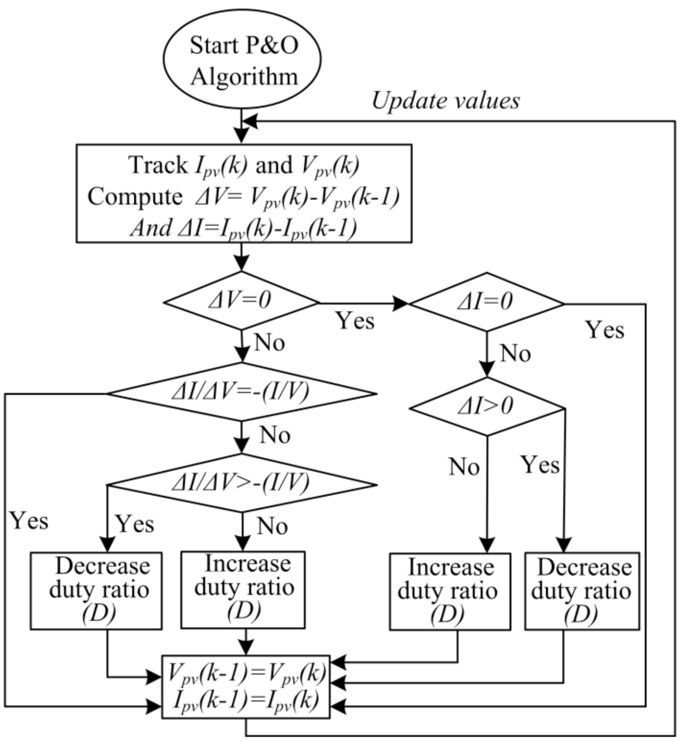

Figure 6. Incremental and Conductance algorithm.

The control algorithm for SPV array voltage is shown in Figure 1. There exists a nonlinear relation in power and voltage for PV array attribute. Many different MPPT methods have been reported in literature to trace operating point for optimal power, out of those P&O is easiest algorithm. Due to inherent demerit as oscillation at MPP and loss associated with it as discussed in last segment, I&C (incremental and conductance) algorithm is used[6].

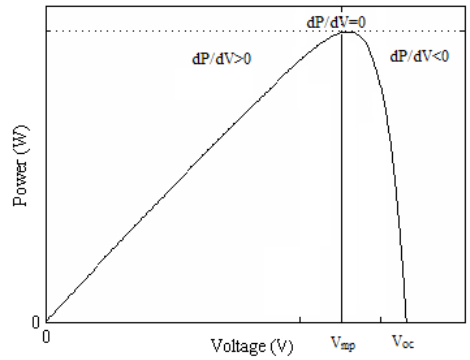

Figure 7. Incremental conductance approach.

$$P_{PV}(k) = V_{PV}(k) * I_{PV}(k) \tag{3}$$

$$\frac{dP_{PV}(k)}{dV_{PV}(k)} = I_{PV}(k) + V_{PV}(k) * \frac{dI_{PV}(k)}{dV_{PV}(k)} = 0 \tag{4}$$

$$\frac{dI_{PV}(k)}{dV_{PV}(k)} = -\frac{I_{PV}(k)}{V_{PV}(k)} \tag{5}$$

Where *V(k)* and *I(k)* are the values of voltage and current.

It is clear from the above equation that the slope at MPP should be zero. On the right of the MPP the slope is negative and on the left of MPP it is positive as shown in Figure 4.

2.6 The artificial Neural Network

A computing system is made up of a many simple, interrelated processing units, in which information is processed by their dynamic state response to peripheral inputs.

An artificial neural network (ANN) is a flexible mathematically organized structure which is able to identify composite nonlinear relationships among input and output data variables.

2.7 The Fuzzy Logic Method

A fuzzy logic is principally a nonlinear and an adaptive controller which provide robust performance for any linear or non-linear system with deviation in parameters. Fuzzy logic is a mathematical hypothesis combining multi valued probable judgment and simulated intelligence to imitate the human expertise to get solution of diverse problems by using a rough interpretation to relate diverse data and judgment. The FLC considered here is with scaling factors. These scaling factors are not exactly same for voltage and current controllers based on their input range, required output range, and interval of membership function defined for that particular controller. Initially, the scaling factors are selected based upon the approximate estimate of the input-output range for individual controller, as PI controllers, and are tuned individually to achieve the desired performanc[9].

2.7.1 Design Steps

The FLC design steps for voltage and current control of MPPT are given as -

- Identify input-output variables.
- Selection of MFs and defining control rules.
- Choose probable implication method.
- interpret fuzzy variable into crisp values.
- Tune the scaling factors for desired performance.

2.7.2 Selection of Membership Functions (MFs)

Five variables are selected for current controller: a) negative medium (NM); b) negative small (NS); c) zero (Z); d) positive small (PS); e) positive medium (PM) and are shown in Figure 8. In case of voltage controller7 linguistic variables are considered: i) negative large (NL);ii) negative medium (NM); iii) negative small (NS); iv) zero (Z); v) positive small (PS); vi) positive medium (PM); vii) positive large (PL), as shown in Figure 9.

Table 1. Type of MFs

	Type of MFs	Nos.	Interval
FVC	Triangular	7	[-15 15]
FCC	Triangular	5	[-2 2]

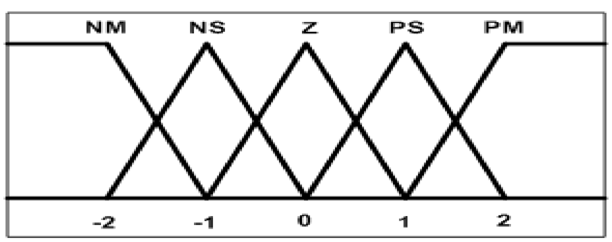

Figure 8. Membership functions for current controllers.

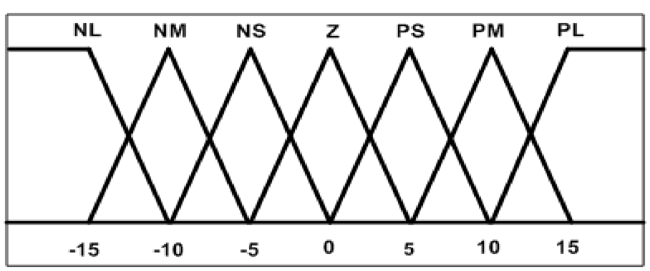

Figure 9. Membership functions for voltage controller.

To achieve high dynamic performance of MPPT these MFs and rules require tuning with different operating condition. Normalized inputs and output for FLC are obtained by using gain blocks as scaling factors G_e, G_{ce} and G_u as shown in Figure 10.

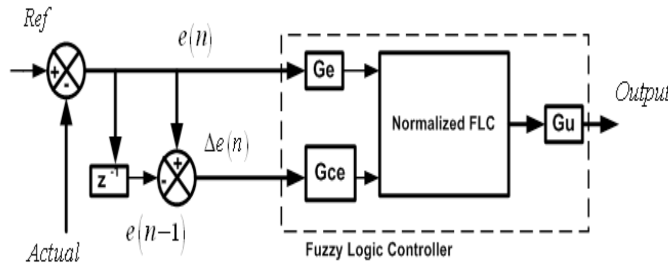

Figure 10. Block diagram of FLC.

After converting crisp set into fuzzy sets, fuzzy variables are process in an inference engine having control rules in (7 × 7) rule base for voltage and (5×5) rule base for current controller. The control rules are derived from experience. The fuzzy voltage controller (FVC), and fuzzy current controller (FCC) are designed with the same design steps, they differ in their parameters like numbers, range of membership function as given in Table-I and rules.

The control rules can also be formulated by behavior of solar PV system. Derivation of rules is normally based on following criteria for solar PV system. The rules for voltage controller are derived in similar way as of current controller.

- When current error is positive then reference current needs to be more.
- When current error is positive but small and change in current error is more than current reference has to be kept constant so that overshoot can be avoided.
- When current error is zero current reference kept constatnt.
- When current error is negative current reference has to be negative.

2.7.3 Performance Optimization by Tuning

Design of a robust controller needs tuning of FLC parameter. There are three-scaling factors G_e, G_{ce} and G_u used. The scaling factors are tuned depending upon the parameter of solar PV System, load, and current reference. The type, number and interval for each type of membership function are given in Table I.

The design of voltage controller is similar to current controller but the scaling factors are different, because input and output requirements of each controller are different. In present work for the linguistic variable of current controller triangular membership functions are used for current controller the interval is given in table I. To bring the error and change in error in the specified range for corresponding controller, gains blocks are used. The control rules will be executed only when the inputs E and CE are normalized using gain blocks, in the range specified for the corresponding controller. Max-min algorithm is considered for producing output variable by processed inputs through control rules[10].

Table 2. Comparison of Various MPPT Techniques

S.No	characteristic		MPPT Technique
1.	PV Array Dependent		Fractional V_{oc}, Fractional I_{sc}, Fuzzy logic Control ,Neural Network, Current Sweep, OCC MPPT
	PV array not Dependent		Hill Climbing or Perturb &Obseve, INC Conductance, RCC, DC-link Capacitor based droop control, Load V&I or Maximization, dP/dV&dP/dI based feedback-Control, Slide Control
2	MPPT True		Hill Climbing or Perturb &Obseve, Incremental Conductance, RCC, Fuzzy logic based Control ,Neural based Network, , RCC, Current Sweep, dP/dV&dP/dI feedback based Control, Slide Control
	Not		Fractional V_{oc}, Fractional I_{sc}, DC LINK Capacitor based droop control, OCC
3.	Periodic tuning Require		Fractional V_{oc}, Fractional I_{sc}, Fuzzy logic based Control ,Neural based Network, Current Sweep, OCC MPPT
	Not Require		Hill Climbing/P&O, INC, RCC, DC LINK Capacitor based droop control, dP/dV&dP/dI feedback Control, Slide Control
4	Digital		Fuzzy logic based MPPT Control ,Neural based Network, , Inc Conductance, dP/dV&dP/dI feedback Control, Slide Control, Current Sweep
	Analog		RCC MPPT
	Both		Hill Climbing/P&O, Fractional V_{oc}, Fractional I_{sc}, DC LINK Capacitor based droop control, OCC MPP tracing
5	Convergence speed	Fast	Fuzzy logic based Control ,Neural based Network, , RCC, Slide Control, OCC MPPT
		Medium	Fractional V_{oc}, Fractional I_{sc},
		Slow	Current Sweep
		Varies	Hill Climbing/P&O, Incremental Conductance
6	Implementation Complexity	Low	Hill Climbing/P&O, Fractional V_{oc}, RCC, DC LINK Capacitor droop control
		Medium	Incremental Conductance, Fractional I_{sc}, dP/dV&dP/dI feedback Control, Slide Control, OCC MPPT
		High	Fuzzy logic Control ,Neural Network, Current Sweep
7	Sensed Parameter	Voltage, Current	Hill Climbing/P&O, Incremental Conductance (INC), Slide Control
		Voltage	Fractional V_{oc}, DC LINK Capacitor based droop control
		Current	Fractional I_{sc}, OCC MPP tracing
		Varies	Fuzzy logic control ,Neural based Network, Current Sweep, RCC

3. Conclusion

The detail of the various algorithms used to trace maximum power point and its overall view is given in this paper. Advantage and disadvantage along with popularity, implementation complexity is also given here briefly. To mitigate the environmental challenge the tracing of maximum power from the photovoltaic energy conversion system is very significant. As per scenario, geographical condition and local situation the evaluation of MPP tracing algorithm cannot be done because these MPPT are slightly differ from each other in terms of performance. In the implementation of PV system, the most important and significant work is selection of particular MPP for specific task and this research article is tried to cover these all the issue. A comparative analysis is presented with characteristics of different MPPT algorithm along with FLC based controller, along with performance criteria is given in TABLE-II. A variety of MPP tracing algorithm is tried to discussed and explained here and corresponding flow chart also. In selecting the correct MPP tracing algorithm, for specific solar system, the comparison table is very fruitful.

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Annexure-I

Comparative Analysis of Various MPPT-Techniques for Optimization of Solar-PVEC System

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