An Extensive Study on Online, Offline and Hybrid MPPT Algorithms for Photovoltaic Systems

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ABSTRACT:
To moderate global warming, conventional fossil fuels are depleted. As the population increased with the rising standard of living and industrial growth, the global environment is affected and cause the greenhouse gases occurrence, which are frequently increased by unlimited use of fossil fuels. The generation of electric power loads increases the power demand on the basics of modern power technology development. Several benefits can be attained by installing the distribution generation with the quality and reliability of power delivered. However, the global energy problem can be resolved by renewable energy sources as an alternative energy generation. Technological developments in the last decade have increased the use of renewable energy sources. In worldwide, several renewable energy sources are used to attain their own power demand. The photovoltaic (PV) generation is the essential renewable energy source to serve the increasing electrical loads. The fastest-growing PV system has the naturally available energy sources of robust evolution with elegant benefits. The foremost objective of this paper is to examine the performance of the PV system with various Maximum Power Point Tracking (MPPT) algorithms. The solar irradiance and temperature make it complex to track the MPPT of PV systems. This review is about various MPPT algorithms like online, offline, and hybrid methods. The selected algorithms from each discussion are simulated in MATLAB/Simulink environment to match their performance in footings of the dynamic response and efficiency of the PV system under the variations of solar irradiance and temperature. An explanation and discussion of the PV system are achieved with the study of different types of MPPT algorithms of PV systems.

KEYWORDS: MPPT Algorithms, Solar Power, Renewable Energy, Hybrid System, PV System.

1. INTRODUCTION

As the continuous increase in the population in the worldwide atmosphere and the rigid greenhouse occurrence are pointedly frightening all the breathing creatures on earth, which is most threatened by the unrestricted use of fossil fuels [1]. The development of power electronics components increases power demand by the use of domestic loads, commercial loads and industrial loads. An alternative energy source is essential as a precise solution to overcome this energy problem by renewable energy sources. As a concern to this, a survey on renewable energy sources has been raised. The International Renewable Energy Agency (IRENA) in 2019 released the statistics of its renewable capacity reported as 171 GW is added in the world as an overall renewable energy capacity in 2018. Asia alone is accounted for 61% of the total renewable energy installation in 2018 with a growth rate of 11.4%.

As of 2018, on the basis of global power generation capacities installed, five renewable energy sources are listed by the power technology. Hydropower installed capacity of 1295 GW, is higher than 18% of the total power generation capacity installed worldwide and

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54% of the global renewable power generation capacity. Among these China is the biggest hydro generation capacity of 22.5 GW. The second most renewable energy sources are wind as installed power capacity 563 GW in 2018 is 24% of world generation capacity where China has the highest installed capacity as 184 GW followed by the US as 94 GW by the end of 2018. The third biggest renewable energy source is solar with more than 486 GW of installed capacity in the world. During the past five years, the average growth rate of solar energy is 25%, which is the cause of fastest growing solar energy. In the world, China, Germany, US, Italy, Japan, and India are the most biggest solar power capacity. In the present world, UAE having 1.17 GW is the biggest solar power plant. Bio-power with 117 GW is the fourth biggest renewable energy sources [2]. As of 2018, India, China, and UK possess above 50% of the entire bioenergy capacity development of the world. The geothermal power generation is the fifth biggest renewable source of the capacity of 13.2 GW in 2018. The geothermal capacity increased by 539 MW in 2018, out of this Turkey has a share of 40% and US with 900 MW are the biggest geothermal power plants in the world [3].

India is one among the countries which has largest energy production from renewable sources. As of 2019, India has 35% of installed capacity and 17% of total electricity that is 83.38 GW of the installed renewable energy capacity [4]. This includes 37.09 GW from wind, 31.69 GW from solar, 9.95 GW bio-power, and 4.65 GW hydropower [5]. In recent years, development in technology increases the electrical demand which deploys usual renewable energy sources like solar, wind, biomass, geothermal, hydropower, etc. The devotion of renewable energy sources solves prompt development in the modern periods.

The solar PV system is the fastest-growing field with elegant benefits and the natural energy source with a robust evolution in renewable energy sources, which makes the reviewer's choice to choose the solar PV system as a study. The abundant availability of natural energy sources, leads solar PV generation as robust evolution in the last few years over the world. The elegant beneficial of PV [6] is shown in Fig.1.

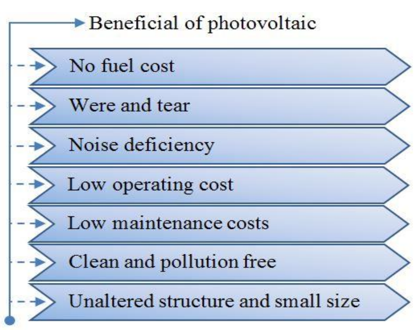

Fig. 1. Benefits of PV Cell.

This review paper comprises of various details under several sections observed from the literature survey that has been done in various sections. Section 2 comprises of the different parts of PV solar cells. The applications of the MPPT algorithm by the various researchers have been portrayed in Section 3. Simulation results and discussion are presented in Section 4. This study is carried out by the limited access of online publication and it is not our intention to omit any of the publication which is relevant to it.

2. MODELLING OF SOLAR PV CELLS

In 1839, Edmon Becquerel had observed the basic physical process of converting solar energy to electric energy which is the foundation of solar cells [7], [8]. This cell is a P-N junction which absorbs photons in the light energy to give electric energy known as the PV effect. The fabrication of the solar cell adopts different techniques but their characteristics will differ from one type to another. Commonly crystalline silicon solar cells are used for solar power generation. A P-N junction of solar cells is identical as diode junction, in case the diode forward bias allows the current to flow between p-type to n-type. Similarly, when the junction is exposed to sunlight, a photo-current is generated which is proportional to the incident radiation (G) produced. This arrangement is easily represented with the help of relevant electrical circuits. The two popular models of equivalent circuits are Single Diode Model (SDM) and Double Diode Model (DDM).

2.1. Single Diode Model (SDM)

SDM shown in Fig.2 comprises of current source (I_{ph}) with parallel diode, series resistance (R_s) and shunt resistance (R_{sh}) [9]–[12]. R_s denotes the resistance of inner cells that depends on the semiconductor material as well as contact resistance. R_{sh} denotes junction leakage current (I_{sh}) which produces the thin manufacturing fault within solar cell. The relation between the current (I_d) and the voltage (V) of the solar cell can be mathematically deduced from the equivalent circuit model refer to (1).

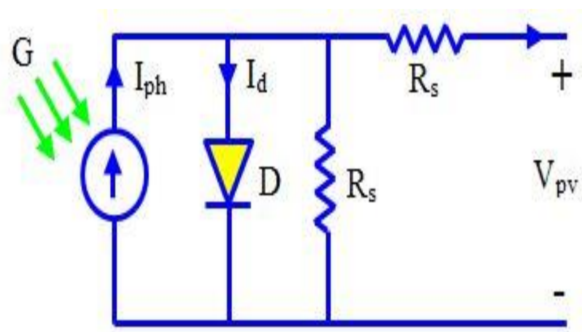

Fig. 2. Equivalent Electrical Circuit SDM of Solar PV cell.

$$I_d = I_s e^{\left(\left(\frac{V_{PV}+I_{PV}R_s}{nV_{tn}}\right)-1\right)} \quad (1)$$

Kirchhoff's laws as follows [11]: refer to (2)

$$I_{PV} = I_{ph} - I_d - I_{sh} \quad (2)$$

The relationship with V and R_{sh} causes the leakage current which is represented by current I_{sh} given as

$$I_{sh} = \left(\frac{V_{PV}+I_{PV}R_s}{R_{sh}}\right) \quad (3)$$

Now, refer to (2) for substituting the currents I_d and I_{sh}

$$I_{PV} = I_{ph} - I_s e^{\left(\left(\frac{V_{PV}+I_{PV}R_s}{nV_{tn}}\right)-1\right)} - \left(\frac{V_{PV}+I_{PV}R_s}{R_{sh}}\right) \quad (4)$$

Using, $V_{tn} = \frac{T_c K}{q}$ (5)

and $I_{ph} = I_{ph,n}\left(K_1(T_m - T_n)\left(\frac{G}{G_n}\right)\right)$ (6)

Where,
V_{PV} - is the output voltage of the PV cell (V)
V_{tn} - is the thermal voltage (V)
I_{PV} - is the generated PV current (A)
I_{ph} - is the cell photocurrent (A)
I_d - is the current through parallel diode (A)
I_{sh} - is the current through shunt resistance (A)
I_s - is the diode reverse saturation current (A)
$I_{ph,n}$ - is the nominal values of photocurrent (A)
R_s - is the lumped series resistance (Ω)
R_{sh} - is the lumped shunt resistance (Ω)
T_m - is the module temperature (° C)
T_n - is the nominal temperature (25° C)
T_c - is the temperature of operating cell (° C)
K_1 - is the temperature coefficient of the cell short circuit current (A K^{-1})
K - is the Boltzmann constant (k = 1.38 x 10^{-23} J/K)
n - is the quality factor of the diode which is between 1 and 2
q - is the charge of an electron (q = 1.6 x 10^{-19} C)
G_n - is the solar irradiance (1000 W/m^2)

The output current (I_{PV}) is multiplied with the number of parallel PV cells (N_p) in case of the PV module. Whereas the output voltage of the module equals the multiplication of (V_{PV}) with the number of series-connected cells (N_S).

2.2. Double Diode Model (DDM)

Fig. 3 shows DDM connected with the current source (I_{ph}) in parallel with two diodes (I_{d1} and I_{d2}) and two resistances (R_{sh} and R_s). Leakage current from R_{sh} is I_{sh} current and R_s denotes series resistance. The relation of current and voltage of solar PV cell is deduced mathematically from the equivalent circuit model and Kirchhoff's laws as follows [13]: refer to (7).

$$I_{PV} = I_{ph} - I_{d1} - I_{d2} - I_{sh} \quad (7)$$

The following equation describes the relationship between the current I_{d1} and I_{d2} with the voltage (V),

$$I_{d1} = I_{s1} e^{\left(\left(\frac{V_{PV}+I_{PV}R_s}{n_1 V_{tn}}\right)-1\right)} \quad (8)$$

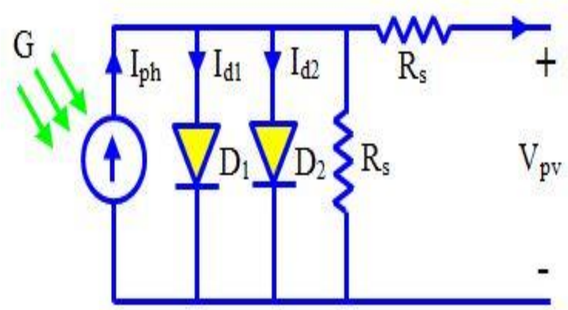

Fig. 3. Equivalent Electrical Circuit DDM of Solar PV cell.

$$I_{d2} = I_{s2} e^{\left(\left(\frac{V_{PV}+I_{PV}R_s}{n_2 V_{tn}}\right)-1\right)} \quad (9)$$

The relationship with the voltage (V) and shunt resistance (R_{sh}) causes the leakage current which is represented by current I_{sh}, that is similar to the SDM given as

$$I_{sh} = \left(\frac{V_{PV}+I_{PV}R_s}{R_{sh}}\right) \quad (10)$$

Now, refer to (7) for substituting the currents I_{d1}, I_{d2} and I_{sh}.

$$I_{PV} = I_{ph} - I_{d1} - I_{d2} - \left(\frac{V_{PV}+I_{PV}R_s}{R_{sh}}\right) \quad (11)$$

Using $V_{tn} = \frac{T_c K}{q}$ (12)

and $I_{ph} = I_{ph,n}\left(K_1(T_m - T_n)\left(\frac{G}{G_n}\right)\right)$ (13)

Where,
V_{PV} - is the output voltage of the PV cell (V)
V_{tn} - is the thermal voltage (V)
I_{PV} - is the generated PV current (A)
I_{ph} - is the cell photocurrent (A)
I_{d1} - is the current through parallel diode 1 (A)
I_{d2} - is the current through parallel diode 2 (A)
I_{sh} - is the current through shunt resistance (A)
I_{s1} - is the diode 1 reverse saturation current of diffusion phenomenon (A)
I_{s2} - is the diode 2 reverse saturation current of

recombination phenomenon (A)

$I_{ph,n}$ - is the nominal values of photocurrent (A)

R_s - is the lumped series resistance (Ω)

R_{sh} - is the lumped shunt resistance (Ω)

T_m - is the module temperature (° C)

T_n - is the nominal temperature (25° C)

T_c - is the temperature of operating cell (° C)

K_1 - is the temperature coefficient of the cell short circuit current (A K−1)

K - is the Boltzmann constant (k = 1.38 x 10^{-23} J/K)

n_1 - is the quality factor of the diode 1 of diffusion which is equal to 1

n_2 - is the quality factor of the diode 2 of recombination which is equal to 2

q - is the charge of an electron (q = 1.6 x 10^{-19} C)

G_n - is the solar irradiance (1000 W/m^2)

The above discussion explains the modeling analysis of SDM and DDM. The output of PV system gets affected by various ambient conditions. The performance of the PV system is influenced by the atmospheric factors like irradiance level, ambient temperature, dirt or dust, and installing conditions. So, the characteristic of the PV system is essential and can be seen in two ways with two parameters i.e *I-V* and *P-V* under constant irradiance and temperature.

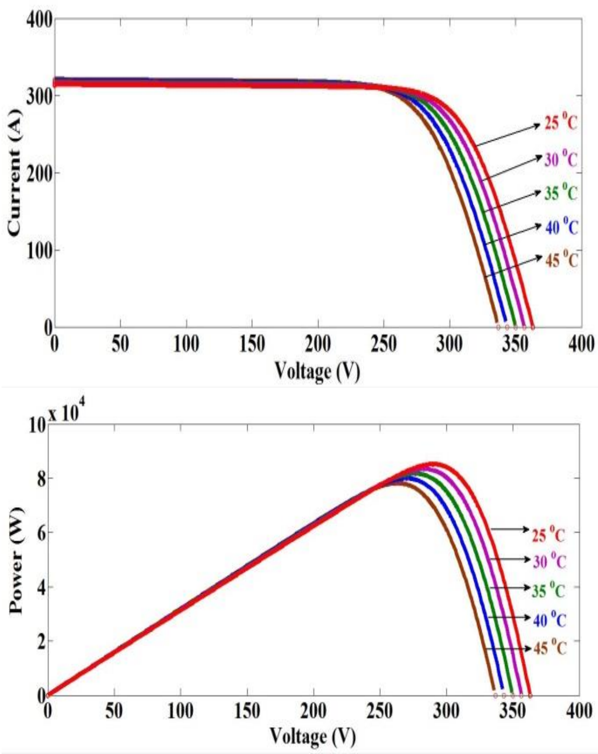

Fig. 4. *I-V* and *P-V* characteristics at constant irradiance.

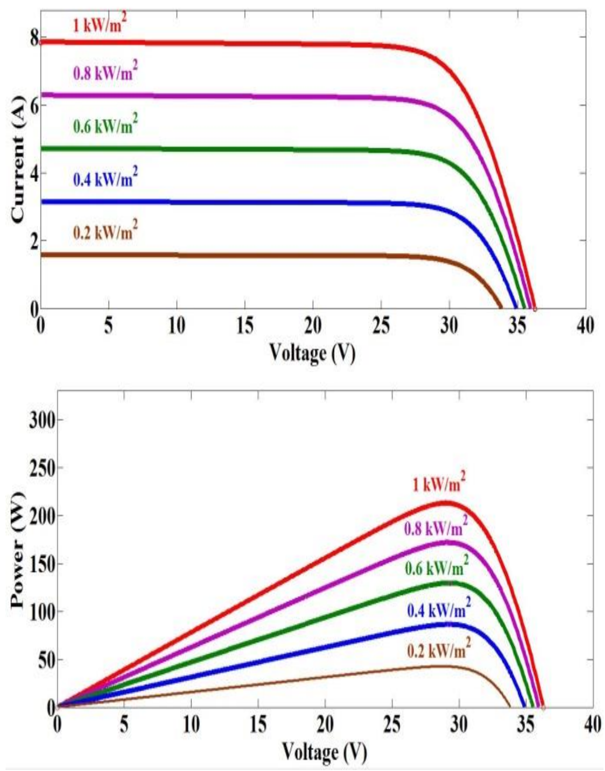

Fig. 5. *I-V* and *P-V* characteristics at constant temperature.

This *I-V* and *P-V* curves are used to recognize the precision of electrical factors in a PV cell providing information for designing, installing, and maintaining PV systems. *I-V* attribute is considered as the quality as well as performance of each PV generator [14]–[18]. The major points of *I-V* and *P-V* curves attributes are short-circuited current (I_{sc}) or maximum current at zero voltage and the open-circuited voltage (V_{oc}) or maximum voltage at zero current. Fig. 4 and Fig. 5 show *I-V* and *P-V* features at constant irradiance and constant temperature, respectively.

3. MPPT CONTROLLERS

Despite the benefits presented in solar PV systems, the implementation cost is high and the efficiency of PV generation is low. The maximum utilization of power or voltage in the PV systems is interrelated with different factors. The output power of PV modules depends upon the enactment of PV generation with subjective to temperatures and solar irradiation intensity of PV cells [9], [19]. As shown in Fig. 4 and Fig. 5, the PV features are non-linear, with the variation in temperature and level of solar irradiation. The variation of weather conditions and partial shading environments are common challenges for solar PV systems. These problems decrease the output of PV modules [1]. To assure maximum power for PV systems, Maximum Power Point (MPP) is required.

The intersection of *I-V* curve is considered to be the operating point of PV systems [20], single point on curve is called MPP. The tracing of the MPP is called MPP tracking (MPPT). To track this MPP, numerous approaches were developed. Since 1954, the researchers are focused to improve the MPPT with efficiency and develop the performance of PV systems [21], [22]. The traditional algorithms used are Incremental Conductance (IC), Perturbation and Observation (P&O), Current Sweep, Constant Voltage, and Temperature Method.

The control algorithms methods of MPPT are partitioned as online, offline, and hybrid methods. The online (termed as direct) control methods are P&O and IC which uses the value of voltage and/or current of the PV system. The suitable point of analysis is by perturbing the operating points, but it has a continuous oscillation around MPP. The benefits are that they are not affected by the variable of PV characteristics. The offline (termed as indirect) methods are Constant Voltage (CV), Constant Current (CC), Look-Up Table (LUT) and Pilot Cell (PC). Whereas these methods use some data by mathematical equations or directly from the obtained results of the PV system namely Short-Circuit Current (SCC), Open-Circuit Voltage (OCV), temperature and irradiation [23]. There are several research techniques [24], [25] developed by the researchers to enhance the efficiency of PV systems as shown in Table. 1.

Table 1. Various MPPT Techniques for Solar PV Cell.

MPPT Techniques
Hill Climbing or Perturbation and Observation (P&O)
Incremental Conductance (IC)
Fractional Open-Circuit Voltage (FOCV)
Fractional Short-Circuit Current (FSCC)
Constant Voltage and Temperature Method. (CVT)
Artificial Neural Network (ANN)
Particle Swarm Optimization (PSO)
Ant Colony Optimization (ACO),
Genetic Algorithm (GA)
Artificial Neural Network (ANN)
Fuzzy Logic Control (FLC)
Slide mode Control (SMC)
Fuzzy Logic Controller Intelligent Control (FLCIC)
Ripple Correlation Control (RCC)
DC-Link Capacitor Droop Control
Load Current or Load Voltage Maximization
dP/dV or *dP/dI* Feedback Control
Continuous Conduction Mode
Discontinuous Conduction Mode
Feedback of Power Variation with Voltage Technique
Feedback of Power Variation with Current Technique
Phase Shift – PWM Based Feed Forward Method

3.1. Online Methods

The online method is called a model-free method. The instant values of PV output voltage and current are utilized in generating control signals. This technique works on the basis of optimal control theory [26] and includes P&O along with IC. In 1983, Wasynezuk discovered IC techniques [21], [22] which is based on the slope of PV array power curve as shown in the Fig. 6

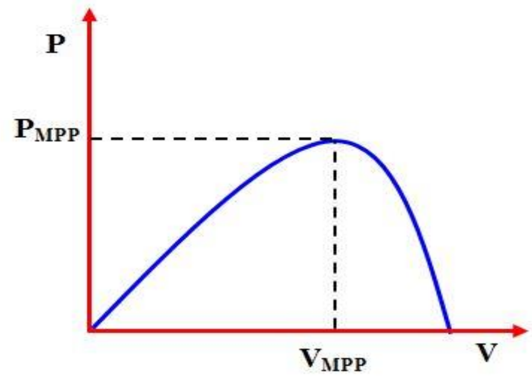

Fig. 6. Power curve of PV array.

Quantity of incremental variations in PV array measures voltage and current for predicting the effects due to these variations. The ratio of current and voltage is called a conductance i.e *I/V* = a conductance. The change in a conductance known to be IC is the fact that the power curve slope is zero as shown in Fig. 7. The maximum power is obtained when *dP/dV* = 0. It can be expressed as

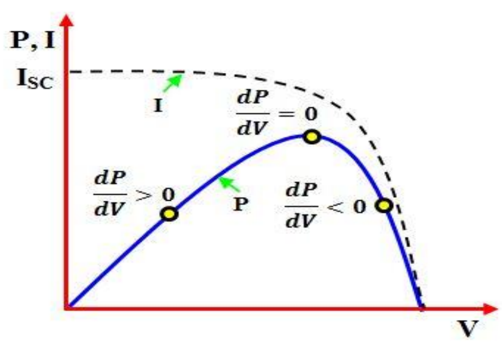

Fig. 7. PV curve by IC.

$$\frac{dP}{dV} = \frac{d(VI)}{dv} = I\frac{dV}{dV} + V\frac{dI}{dV} \quad (14)$$

$$\text{At MPPT, } \frac{dP}{dV} = 0 \quad (15)$$

$$0 = I\frac{dV}{dV} + V\frac{dI}{dV} \quad (16)$$

$$\frac{dI}{dV} = -\frac{I}{V} \quad (17)$$

$$\frac{dI}{dV}\ is \begin{cases} = -\frac{I}{V}\ at\ MPP \\ > -\frac{I}{V}\ below\ MPP \\ < -\frac{I}{V}\ above\ MPP \end{cases} \quad (18)$$

(or)

$$\frac{dP}{dV}\ is \begin{cases} = -\frac{dP}{dV}\ at\ MPP \\ > -\frac{dP}{dV}\ below\ MPP \\ < -\frac{dP}{dV}\ above\ MPP \end{cases} \quad (19)$$

MPP is achieved when IC equals negative of instantaneous conductance. The IC algorithm is shown in Fig. 8. The tracking conditions are more rapid than P&O but when a continued oscillation occurs nearby MPP involves heavy computation in controller. So, this method has obliged complex control circuitry that results in a high-cost system. This drawback of IC give raises the popularity of P&O methods.

In 1979, Fox et al. have said the important principle of P&O used in fundamental hill climbing techniques [21], [22]. P&O or hill-climbing implemented by adjusting voltage or current in PV array and measure to the power. If power is either increased or decreased in further variation, it will be continued till there is no change in power. The output power is measured at each perturbation, if it is greater value in the power of the previous stage, the power moves towards MPP (left of PV curve). When the preceding stage gives the smaller value of power it will deviate from MPP (right of PV curve). The voltage perturbation has the same value power in the preceding stage as it reaches the MPP. The algorithm of P&O is shown in Fig. 9. Since the perturbation is occurring continuously, there will be an oscillation near MPP and controlling the convergence is required to reach output to the MPP.

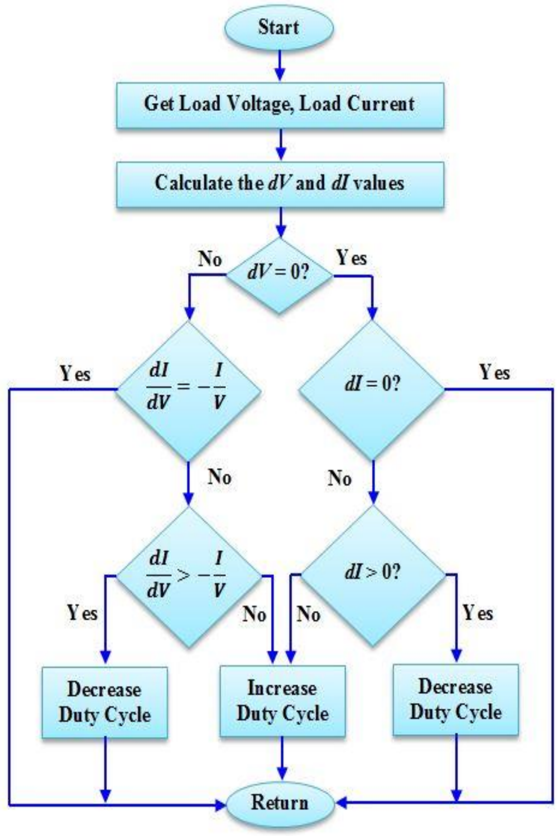

Fig. 8. Flowchart of IC algorithms for MPPT.

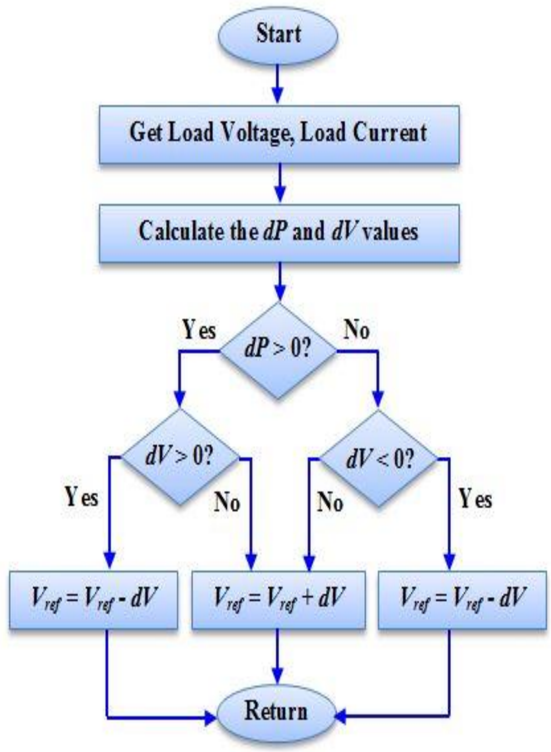

Fig. 9. Flowchart of P&O algorithms for MPPT.

Fig. 10 shows the summary of the P&O and IC techniques proposed by the researchers. The recent MPPT algorithm by the various researches has been discussed in this section.

In [27], authors have tested the PSO based MPPT approach for PV system. The inertia weight of the earlier velocity in the current calculation of speed is helpful for the global optimum. The large value of inertia weight gives the global optimum and the less value gives local examination. The output reference voltage (V^{*}_{dcn}) given by [28] is chosen for PSO convergence to reach the G_{best}. But, in [29], authors have developed the Xbee-PRO as ZigBee devices which are connecting in every PV module to central controller. ZigBee devices and analog controller are proposed for MPPT system with step-up converters. The voltage and current are calculated from the individual PV panels, it converts into UART data format which is transmitted through ZigBee module to host in every sampling period. After then, host controller rapidly executes P&O at central Digital-Signal Processor (DSP) for achieving efficient MPPT of every module.

In [30], the Teaching-Learning Based Optimization (TLBO) method is proposed . This process contains the student stage and teacher stage. Initially, teacher conveys knowledge directly to the students [31]. The knowledge is transferred to students by discussing among themselves in the next stage [32]. The appropriate variable is chosen; the strength of students as '*n*', the learners as initial duty cycles, then PV current and voltage are estimated. The fitness values of learner '*I*' is evaluated by the teacher group to find the best fitness which is the optimal duty cycle in relation to global MPP. Whereas the Improved TLBO (ITLBO) method is introduced in [33] for MPPT. The modifications are denoted as teacher phase and learner phase. In the former, first learner discusses with teacher whereas in the latter, learner performs the role of a teacher. This helps a fast response to determine the best fitness function from random learners to the teacher based learners.

In [34], the Artificial Bee Colony (ABC) technique is implemented comprising of three groups namely scouts, employed and onlooker. At first, employed bees produce initial food sources. Employed bees are observed by onlooker who selects one of their sources. Scouts find new food sources which are exchanged with abandoned food sources. Best food source represents the optimal MPP. Here comes, the researches that explain the Human Psychology Optimization (HPO) algorithm in [35] which depends on mental and psychological states of motivated individuals [36]. It is based on the factor self-motivation, excitement, lesson and inspiration [37]–[43]. The HPO algorithm chooses the duty cycle of PV power using [44]–[46]. The energy level is verified with all factors used in [47], new duty cycles are produced for subsequent iteration. This continues in the chain process to reach the optimum duty cycle at MPP.

In [48], a novel Divide and Conquer Algorithm with Ternary Ratio algorithm (DCA-TR) is proposed for

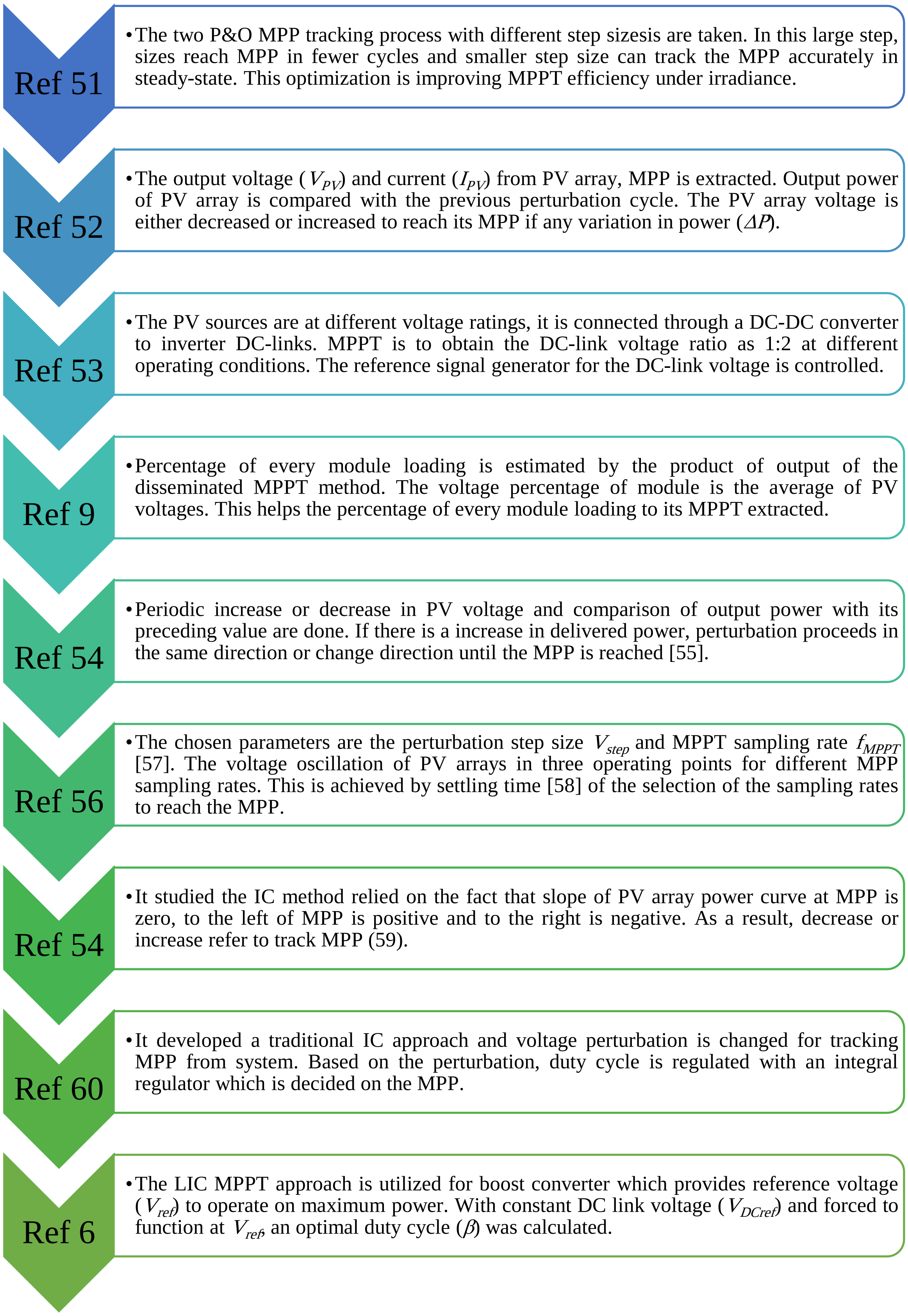

Fig. 10. Summary of P&O and IC techniques proposed by researchers.

PV systems. To optimize the function, PV voltage and panel power are considered as variables. The parameters V_1, V_2, P_1 and P_2 as voltage and power when $P_1<P_2$, the MPP exists in (V_1, Y) or (X, V_2). As the algorithm converges, the maximum voltage is attained at $V_{MPP} = (V_1 + V_2)/2$ until the PV system obtained 'V_{MPP}'. But, in [49] the Improved Chicken Swarm Optimization (ICSO) Algorithm is introduced for the MPPT in the PV system. As the initial value chaotic sequence is assigned for improving ergodicity and uniformity of population. The randomness and susceptibility for the initial value improves the performance of the algorithm [50]. To compute best fitness and individual's position which then replaces the best value in the final iteration.

In [61], the Overall Distribution Particle Swarm Optimization (OD-PSO) MPPT approach are explained for PV system under Partial Shading. The terms are given by the iteration number, the inertia weight, random numbers within [0, 1], and the cognitive and social coefficients. The particle i at k^{th} iteration is normally restricted below maximum v_{max} [62], and represents its position vector. Particles are updated by personal best (P_{besti}) particle position and global best (G_{best}) particle position.

In [63], the biological phenomenon is developed which has introduced as Crowded Plant Height Optimization tuned Proportional–Integral (CPHO-PI) controller with the tracking time is decreased but the traditional P&O-PI controller is increased with the initial irradiation. The proposed control scheme possesses stability and performs efficiently against time-varying solar insolation and various load conditions. However, a nature-inspired meta-heuristic approach was designed and Whale Optimization Algorithm (WOA) has been proposed in [64] which have two phases namely exploration and exploitation. The search space globally is explored which is then investigated. WOA replicate the hunting behavior of humpback whales. It was observed that it is done by humpback whales which produce distinctive bubbles over nine-shaped path. Whales denote search agents which is utilized to find the optimal value for PI controller gains that is determined after many iterations.

In [65], the performances of Integrated DC–DC Converter with Maximum power point tracker (IDCCM) are described in a hardware approach for the MPPT with the partial shading PV system. The IDCCM is connected in series and the MPPT controller is embedded in chip. The DC output voltage feeds the central inverter and the critical component controller are connected outside the device in which its AC output is connected directly to grid.

Along with this P&O methods, the Modified P&O (MP&O) method proposed by the researchers are also been discussed in this section.

In [54], MP&O technique decouples PV power fluctuations occurred due to the hill-climbing process which in turn was caused by irradiance change. This method includes an additional process for estimating this change during perturbation, measuring the energy variation caused by varying atmospheric conditions which then reimburse it for next perturbation process [66]. Whereas in [67], MP&O method for MPPT is implemented. This controller can track MPPs absolutely with fewer possibility of deviation from its tracking. This method was involved in tuning duty cycle of a boost converter whose convergence speed rises as well as average efficiency was enhanced by 4% when solar radiation conditions were varied.

In [54], *dP*-P&O algorithm was the enhanced version of traditional P&O with the ambition of preventing itself from tracking in a wrong way when changing rapidly in solar irradiance. Moreover, an additional power measurement is performed in the mid of MPPT sampling phase with no perturbation [68]. However, in [69], Enhanced Adaptive P&O (EA-P&O) MPPT approach is proposed for PV system. After initialization, it reads and calculates the voltage, current and power. The deviation is checked with normalized power and voltage. After a few samples of MPP, the MPPT is reached, the EA-P&O tracks MPP and continuously updates.

3.2. Offline Methods

The offline method is called a model-based method. The physical values like SCC (I_{sc}), OCV (V_{oc}), solar irradiance and temperature are references in offline methods. During operation, the control signal remains constant [70]. This offline technique includes SCC, OCV methods and artificial intelligence (AI). SCC is highly precise than OCV but depends on the value of I_{sc}. This increases complexity to measure I_{sc}, i.e due to exploitation of pilot cells or periodic shutting is enforced. OCV technique is a straight forward offline method and its relationship is linear with MPP voltage and V_{oc}. The pilot cells are used to estimate V_{oc} and it eliminates the power loss while shutting down the load for measurement of V_{oc}. The AI technique includes the Artificial Neural Network (ANN) and Fuzzy Logic (FL) [26]. In the look-up table method, it requires technical data of the PV panel and its characteristics to be stored. The look-up table is compared to the data with previous data to track the MPP. Here follows the discussion of offline techniques by the researchers.

In [70], the constant voltage technique is implemented whose factor value K varies from 0.7 to 0.95. The pilot panel is used to measure V_{oc}. The error signal generator through the PI block and the PWM fed the duty cycle till the PV panel voltage becomes equal to MPP voltage. In [26], the OCV techniques are analyzed with simulation. The result in terms of efficiency is 85% at high levels of illumination then the efficiency droops to 82% at low levels of illumination. Whereas the SCC shows a low efficiency at low levels of illumination. In [71], the new neural network MPPT for the PV system is explained. It has three layers called the input, hidden and output layers [72], the link between node are all weighted [73] between node i and j is named as W_{ij} as shown in Fig.1 1. The parameters are atmospheric data as temperature and solar irradiation, V_{OC} and I_{SC} as input variables to provide the duty cycle of converter as an output. To execute this data pattern of neural network are recorded over a time period to reach accurate MPP [73].

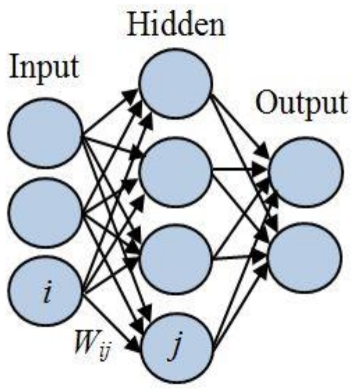

Fig. 11. Structure of neural network.

In [74], the RBF neural network learning algorithm is optimized by a huge variation Genetic Algorithm (GA). The data center, expansionary constant and weights are used to optimize by GA. The idea of huge variation operations is by expanding actual variance to realize. The GA enhances fitness function and modifies the operation accordingly by itself and thus solves the problem of prematurity.

3.3. Hybrid Methods

The integration of online and offline models is called hybrid methods. The ways of tracking are divided into two steps. The former, the local maximum power point (L_{MPP}) is found by any methods in offline by placing the operating point nearer to MPP. The latter, global MPP (G_{MPP}) is found by anyone of the online methods to fine-tune the operating point at MPP. Fig. 12 shows a summary of the hybrid techniques proposed by the researchers. At the ending of this section, offline methods need the basic knowledge of the solar panel. Online methods include the P&O and IC techniques and hybrid methods are the combination of both offline and online methods. From this MPPT method, each has its own merits and demerits; though the hybrid system is a recent development in researches, online methods have been considered in a wide area of PV systems.

4. SIMULATION RESULTS AND ITS DISCUSSION

Here, some of the MPPT methods are compared with the simulations of the PV system. Based on the MATLAB/Simulink software, comparison was done in terms of efficiency and dynamic response. The different MPPT methods have been used to develop the power generation competency of PV systems. However, online methods P&O and IC regularly use algorithms to recognize the MPPT with profitable existing inverters. To assess the MPPT method, there are some efforts to consider like control variable, complexity level, convergence speed, and efficiency as shown in Table 2 (online) and Table 3 (offline).

Table 2. Comparison of online MPPT Methods.

MPPT Method	P&O	IC
Type	Online	Online
Control Variable	V, I	V, I
Complexity	Low	Medium
Digital or Analog	Both	Digital
Convergence speed	Low	Depends
Prior tuning	No	No
Efficiency	High	High

Table 3. Comparison of offline MPPT Methods.

MPPT Method	OCV	SCC	ANN	FL
Type	Offline	Offline	Offline	Offline
Control Variable	Voltage	Current	Depends	Depends
Complexity	Low	Medium	High	High
Digital or Analog	Both	Both	Digital	Digital
Convergence speed	Medium	Medium	Fast	Fast
Prior tuning	Yes	Yes	Yes	Yes
Efficiency	Low	Low	High	High

A hybrid approach by joining two methods is called P&O (online) and ANN (offline). It is concentrated on the irradiance level, the measured irradiance is matched with identified value, i.e. increase or decrease in reference V_{MPP} value. This helps to control the slowness of convergence speed and decrease the oscillations of the traditional P&O MPPT methods. This hybrid method also differentiates with other hybrid approaches as shown in Table 4. Also, the hybrid MPPT method makes the system more complex and the number of controlled variables is taken into account for the evaluation to develop the MPPT methods.

Ref 34

- Presened a integration of P&O with PSO. The P&O method discovers Local Maximum Point (LMP) and further PSO will determine the Global Maximum Point (GMP).
- The operating voltage (V_{pv}) is perturbed by a small amount (V_c) [35], [36] every control cycle (T_{perb}) to determine the up or down in the P–V curve.

Ref 37

- Both online and offline MPPT are used. An online MPPT as P&O and FSCC as offline MPPT techniques are proposed.
- These methods start to track with the offline MPPT with the micro-stepping to near MPP and then change to online MPPT for the actual MPP.

Ref 38

- MPC for MPPT is comparatively studied with traditional IC approach. MPPT is enabled at 0.1 s, irradiance gradually decreases at 0.3 s from 1250 to 1000 W/m^2.
- It is observed that maximum power is tracked rapidly when the dual steps of MPC-MPPT is utilized than the traditional INC-MPPT approach.

Ref 39

- The controller is combination of linear OCV (LOCV) and Variable Step-Size-Incremental Conductance (VSS-INC) methods, where LOCV is an indirect method for low irradiation and VSS-INC is a direct MPPT method for higher irradiation.
- The LOCV requires V_{OC} in addition pilot cell is used to measure V_{OC}. It requires two parameters, namely dP/dV and multiplication factor (MF) to perform the MPPT.

Ref 40

- It combines P&O and ANN. This works on the irradiance level when the specified values exceed by average irradiance the reference voltage set loop of the algorithm.
- Thus, the number of oscillations and convergence speed will be less when compared with the commonly used P&O MPPT methods.

Ref 41

- Voltage reference enforced grid current *'d'* component i_{gd} for SMC controller by tracking the SMC.
- The value measured tracks to reference thoroughly which shows a good PI current controller adjustment to obtain maximum power from PV.

Ref 42

- Modified Particle Velocity-Based Particle Swarm Optimisation (MPV-PSO) approach for GMPPT was implemented. As a first step, three particles (V_1, V_2, V_3) suggesting as PV array reference voltages are initialized.
- Once the condition is satisfied, P&O algorithm [43] is executed to operate on PV array at the GMPP.

Ref 44

- The combined PSO-OCC MPP tracking is used. In this rather than duty ratio, PV panel current is considered as control parameter.
- The CCM operated at the input current refer to OCC which computes the power, array voltage and current. At the end of the iteration, P_{best} is the highest output power.

Ref 45

- SMC and artificial neural network (ANN) based MPPT was developed for a direct grid-connected PV system. ANN with three layers is used and two variables as solar temperature (T) and irradiation (G).
- The output voltage V_{mpp}, is the maximum power obtained from PV source.

Fig. 12. Summary of the hybrid techniques proposed by the researchers.

This hybrid method enhances partial shading conditions and design procedures for the energy production of the systems.

Table 4. Comparison of Hybrid MPPT methods.

MPPT Method	**Ref** [76]	**Ref** [77]	**Ref** [78]	**Ref** [79]	**Ref** [75]
Type	Hybrid	Hybrid	Hybrid	Hybrid	Hybrid
Control Variable	*V, I, G, T*	*V, I, G, T*	*V, I, G, T*	*V, I, G, T*	*V, I, G, T*
Complexity	High	High	High	High	High
Digital or Analog	Digital	Both	Digital	Digital	Digital
Convergence speed	Fast	Fast	Fast	Fast	Fast
Prior tuning	Yes	No	Yes	Yes	Yes
Efficiency	97.56%	98 %	98.02 %	98.11 %	98.26 %

4.1. Description of the PV System

The performance of the PV system is compared to the MPPT methods in simulations. The simulation parameters are shown in Table 5.

Table 5. Simulation Parameters.

Parameters	**Values**
Voltage Source (V_{mpp})	330-370 V
Fundamental Frequency	50 Hz
Impedance of feeder	R = 0.134 Ω, X = 1.067 mH
Linear Load	P = 100 kW, Q = 10 kVAR
DC link voltage	700 V
DC link Capacitor	40 mF
Switching frequency	Converter 20 kHz Inverter 2.5 kHz
L filter	L_i = 2.2 mH
L boost	L_b = 2.5 mH
C boost	C_{in} = 1 mF

The demonstrated PV arrays are exposed to 1000 W/m^2, 800 W/m^2, 600 W/m^2 and 700 W/m^2 of solar irradiance, respectively. A signal generator is chosen as an irradiance source, it helps to change the irradiance value instantaneously and the MPPT methods performances were studied.

4.2. Simulation Results

The studies of various MPPT methods are implemented with the MATLAB/Simulink software. The performance of P&O and IC simulation is prepared in variations of irradiance and temperature as portrayed in Fig. 13 and Fig.1 4. As shown in Fig.13, it fails to track the MPPT voltage, when a major deviation arises due to a sudden change in irradiance voltage. The P&O algorithm gives to raise the oscillation of operating voltage at MPP, which is improved by the IC algorithm. As said in the early section, the operating voltage at MPP when dP/dV = 0, is grasped by the algorithm, and the oscillation of operating voltage is stopped. In Fig.14, the deviation in irradiance voltage is shown. Although the irradiance level is quickly varied, the IC algorithm fails to track MPP as in P&O methods.

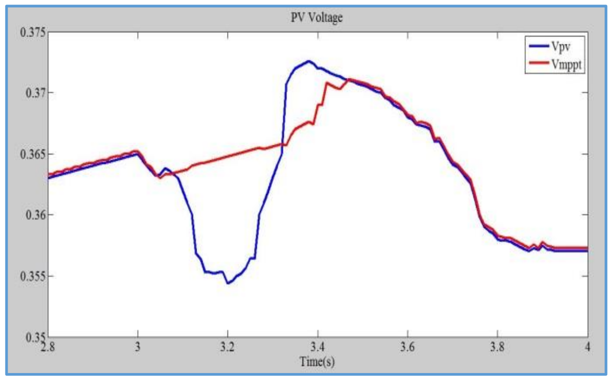

Fig. 13. Voltage behavior under irradiation by P&O algorithm.

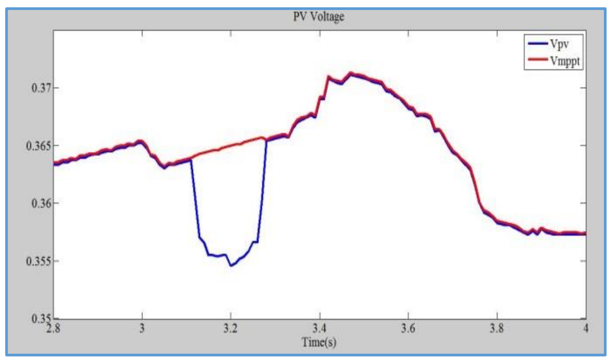

Fig. 14. Voltage behavior under irradiation by IC algorithm.

4.3. Dynamic Response

The performance of Hybrid MPPT methods is compared with P&O (online) and ANN (offline) based algorithms. The irradiation level of these algorithms is shown in Fig. 15. When compared with P&O and ANN algorithms, the present Hybrid MPPT methods performance will fall under the variable irradiance. The Hybrid algorithm has confirmed its robustness for variation of the irradiance even with a sudden drop of the irradiance. Subsequently, the outcomes clearly determine that the hybrid algorithm has a good tracking capability when compared to offline and online algorithms.

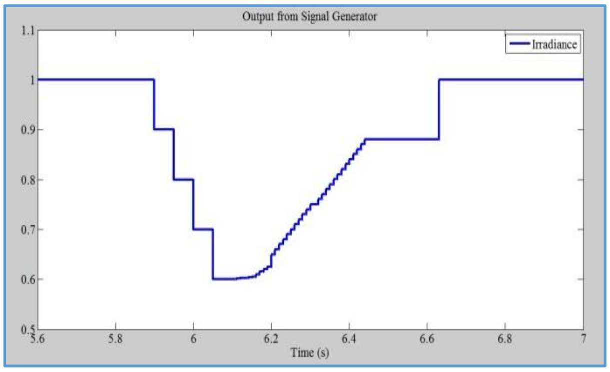

Fig. 15. Solar irradiance level used in Hybrid algorithms.

4.4. Computation of Efficiency

The efficiency of the MPPT method establishes the most significant initial consideration. The MPPT methods efficiency was evaluated based on the steady-state response of the system [77]. The efficiency can be calculated refer to (20)

$$\eta_T = \frac{1}{n}\sum_{i=0}^{n}\frac{P_i}{P_{max,i}} = \frac{1}{n}\sum_{i=0}^{n} 1 - \frac{P_i}{P_{max,i}} \quad (20)$$

Where, P_i is the solar panel power, $P_{max,i}$ is the maximum solar panel power, and 'n' is the number of samples. Moreover, the OCV and the SCC methods reveal low efficiency even if optimal constant (k) values are selected. This studied work specified that in terms of efficiency, the MPPT methods can be hierarchical as (1) Hybrid, (2) Online, and (3) Offline.

5. CONCLUSION

This paper has presented the study of a PV system in solar cells and MPPT techniques. The comprehensive review is achieved by the start of a detailed discussion of solar panel methods. It is mainly concentrated on MPPT algorithms that have involved in the input variable, control variable, circuitry, and its application. These MPPT methods are divided into online, offline, and hybrid methods. The online methods P&O and IC are said to be traditional MPPT algorithms, but recent research includes hybrid PV systems with different topologies. The MPPT algorithms are differentiated based on the simulation in the MATLAB/Simulink environment in footings of dynamic response and efficiency of the PV system. The result shows an impact on both the dynamic response and efficiency of the PV system. An application of offline and online methods reveal honestly poor dynamic response as well as efficiency. However, the applications of hybrid methods have better performances. This study gives useful information to researchers for those who select the area in PV systems. The main aim of this study is to disclose most topics in the PV system and the truthful information about renewable energy using the PV system has been successfully concluded.

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