# Maximum Power Point Tracking and Power Fluctuation Control in Grid- Connected Solar Photovoltaic Systems: A Comprehensive Review

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***Abstract:*** Conventional electric power frameworks are intended in vast component to use extensive base load control plants, with the constrained capacity to quickly incline yield or decrease yield beneath a specific level. In any case, the solar Photovoltaic (PV) framework emerges as the reasonable choice during the significant power framework epoch due to its low-effectiveness vitality adaptation characteristic requires as well as the proficient power transformation framework. Likewise, the expansion in popular fluctuation constructed by discontinuous sources, for example, PV focuses to enhance the power yield via tracking the Maximum Power Points (MPPs). Alternatively, it is necessitate controlling the power fluctuations by means of Battery Energy Storage Systems (BESS) that can commendably manage power control yield altitudes and battery State of Charge (SOC). In this paper, we expect to display a concise review on Maximum Power Point Tracking (MPPT) algorithms and power fluctuation control algorithms that are accessible in the literatures. Notwithstanding that, a widespread comparative investigation along side with the pros and cons of each algorithm is featured.

***Index Terms* - Solar energy, Grid connected solar PV systems, MPPT, Power fluctuation control**

## I. INTRODUCTION

In recent years, solar vitality is one of the indispensable Renewable Energy Sources (RES) that have been gaining expanded consideration, which is ample along with having the best accessibility contrasted with different assets [1]. As a result of quick development within the semiconductor as well as the power electronics strategies, PV vitality remains the most important RES that generates the electricity from the solar radiation can be installed in developed countries as the fastest growing sector which is in the form of distributed, grid-connected, rooftop systems [2]. PV is one of the developing advancements owing to its innovative advancement, consistent price decrease, clean, pollution free, higher efficiency, compact size, the absence of moving/rotating parts and inexhaustible [3]. PV frameworks are regularly associated with the circulation grid (low-voltage network) otherwise the user-end grid to outline the Grid-Connected PV system (GCPV). The GCPV framework stands for an electricity power-producing solar PV power framework that remains appended to the utility grid and has several inverters [4]. The GCPV can be able to determine the ideal measuring proportion of the PV array competence, contrasted with the ostensible inverter input limit from two points of view: energetic and economic [5]. The request of PV production frameworks appears to be expanded for mutually independent as well as the grid-connected modes of PV frameworks. The attributes of the solar cell are essentially impacted by insolation, temperature, partial shading condition, and so forth.

In the direction of separating the maximum accessible power from PV module that displays a current-voltage trademark through a distinctive point, called MPP under certain conditions such as varied radiance and temperature, the system utilizes an efficient algorithm called MPPT, in which following the MPP of a PV array remains habitually a fundamental ingredient of a PV framework to maximize the output power [6]. The most ordinarily utilized MPPT strategy is the Perturbation and Observation (P&O) method because of its easier implementation, nevertheless, oscillation is unavoidable [7]. The primary function of MPPT is to regulate its input voltage, which is additionally the PV panel input voltage, all together that it compares with the voltage where the panel conveys the maximum power [8]. The task of MPPT depends on the accompanying standards:

- If the working purpose of PV has advanced on the way to the MPP, subsequently the working voltage must be annoyed in a similar way.
- Otherwise, the working point has budged far from the MPP and for that reason; the trail of the working voltage irritation must be switched [9].

One of the significant issues standing up to the users and designers of PV vitality frameworks is the arbitrary, fluctuating nature of the energy sources [10]. Enterprises are broadly influenced when there is a network aggravation. For the most part, the yield intensity of PV fluctuates as a result of shifting irradiation as well as the temperature, power or voltage variation, power production preserve, and framework frequency stability; as an outcome, the fluctuation of the produced control from PV source in light of DG (Distributed Generation) influences nearby loads associated with the framework [11]. The variance in the grid revolutionizes the voltage and frequency parameter that influences sensitive equipment in the manufacturing units. Because of this issue battery reinforcement as well as the local generators are commonly used to secure sensitive equipment and control frameworks [12]. Subsequently, attenuating this power fluctuation throughout putting away the produced control amid peak loads with utilizing it later amid peak loads expand the dependability of the DG framework, which causes the power framework to be more solid and stable [13]. The decrease of the fluctuation is frequently acknowledged via utilizing many limits of expensive vitality stockpiling otherwise introducing a dump load.

Several algorithms are used for analyzing the MPPT and power fluctuation control; for example, Incremental Conductance (INC), P&O, Artificial Neural Networks (ANNs), as well as fuzzy logic control is utilized toward locating the best working point. Conversely, the Fuzzy Inference System (FIS) based MPPT likewise examined. Coordinating FIS with ANN results in a powerful AI strategy recognized as an Adaptive Neuro-Fuzzy Inference System (ANFIS).

## II. PV SYSTEM

PV framework [14] remains a solid-state semiconductor gadget that produces electricity while it is exposed to the light. Solar panels ingest the sunlight as a wellspring of vitality toward generating the electricity or warmth. PV modules comprise the PV arrays of a PV framework that produces and contributes solar power in commercial and residential applications. The solar panel is comprised of the solar cell, solar array mounting racks, array DC disengage, battery pack, control meter, utility meter, kilowatt meter, reinforcement generator, charge controller. A single PV module is framed through interfacing numerous solar cells in successive and parallel.

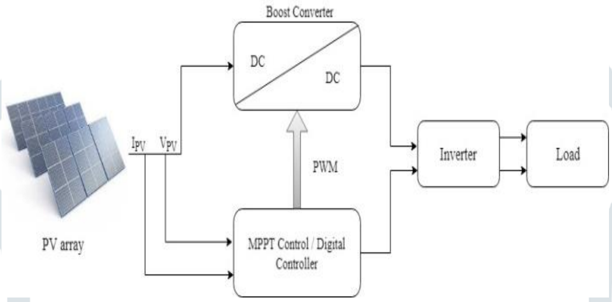

**Figure 1:** Block diagram of the PV system

## III. MPPT ALGORITHM

MPPT algorithm includes in charge controllers used for extracting maximum available power from PV module under certain conditions. MPPT algorithms are essential in PV applications since the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in an effort to obtain the maximum power from a solar array.The MPPT algorithms are most common as they have the advantage of convenient implementation. In normal conditions the PV curve has only one maximum point. However, if the PV array is partially shaded, there are more than one maxima in these curves [15]. Under these conditions, the MPP of the PV array changes continuously; consequently the PV system's operation point must change to maximize the energy produced.

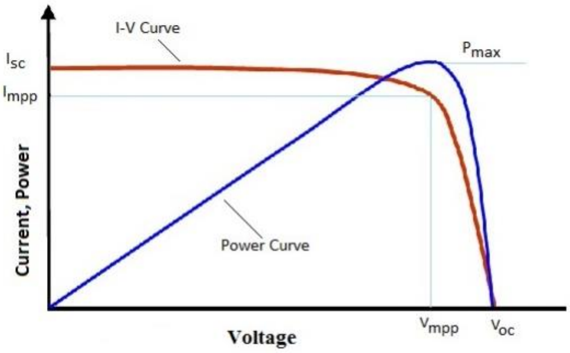

**Figure 3:** P-V and I-V characteristic curve

The power generation execution of a PV framework has regularly portrayed by an electrical characteristic curve, such as the power-voltage (P-V) curve [16], and in such curve, a point demonstrating that the PV framework creates the maximal power yield. Preferably, the PV framework can be controlled to accomplish the MPP over its life- expectancy if the characteristic curve is settled. In any case, by and by, the characteristic curve shifts nonlinearly with the variety of natural conditions, for example, the sun oriented irradiance and PV cell temperature, so it is trying to get the MPP. To address the enhancement of the PV control creation, MPPT algorithms have been produced to control PV frameworks to approach MPPs.

A MPPT system is in this manner used to keep up the PV clusters working point at its MPP. There are many MPPT methods available in the literature; the most widely-used techniques are described in the following sections, starting with the simplest method [17].

### 3.1 **Hill Climbing Techniques**

The hill climbing algorithm [18] locates the MPP via relating the alterations in the power to changes in the control variable which is used to control the array. Hill-climbing techniques are the most popular MPPT approaches due to their ease of implementation and better performance when the irradiation is constant. It involves a perturbation in the duty ratio of the power inverter. In the case of a PV array connected to a system, perturbing the duty ratio of power inverter perturbs the PV array current and hence perturbs the PV array voltage. In this method, by incrementing the voltage, the power increases when operating on the left of the MPP and decreases the power when on the rightof the MPP. Therefore, if there is an increase in power, the subsequent perturbation is kept at identical point to reach the MPP. If there is a decrease in power, the perturbation is reversed. This process is repeated periodically until the MPP is reached. The oscillation of the system is minimized by reducing the perturbation step size. The hill climbing based procedures are so named in light of the state of the power-voltage (P-V) curve. This technique is sub-categorized into two types,

1. Perturb and Observe (P&O).
2. Incremental Conductance (INC).

Both P&O and INC algorithms are based on the “hill-climbing” principle, which consists of moving the operation point of the PV array in the direction in which power increases.

### 3.2 Perturb and Observe (P&O) Algorithm

The P&O algorithm [19] is also called hill-climbing but both names refer to the same algorithm depending on how it is implemented. The most ordinarily utilized MPPT algorithm is the P&O because of its effortlessness of execution. In MPPT, the P&O algorithm is based on the calculation of the PV output power and the power change by sampling both the PV current and voltage. The tracker works by intermittently increasing or decrementing the sun based cluster voltage. On the off chance that a given annoyance prompts an expansion or reduction in the yield intensity of the PV, at that point, ensuing irritation is created in the equivalent or inverse heading. So, the duty cycle (D) of the DC chopper is changed and the process is repeated until the MPP has been reached. Actually, the system oscillates about the MPP. Lessening the annoyance step size can limit the wavering. Be that as it may, little advance size backs off the MPPT. .

Then the duty-cycle can be calculated as,

$$D = D + \Delta D \text{ and} \tag{1}$$

$$D = D - \Delta D \tag{2}$$

The major drawback of P&O algorithm is that if there is any shadow on any of panels (because they have been in series or parallel) then the P-V curve of the PV is going to have several peak and it can't find the real peak. It can be overcome by the following MPPT algorithms.

### 3.3 Incremental Conductance (INC) Algorithm

The INC algorithm [20] was designed based on an observation of PV characteristic curve. This algorithm was intended to overcome some drawback of P&O algorithm. In the INC method the array terminal voltage is always adjusted according to the MPP voltage it is based on the incremental and instantaneous conductance of the PV module. This technique misuses the presumption of the proportion of progress in yield conductance is equivalent to the negative yield conductance as well as momentary conductance. We have,

$$P = V \times I \tag{3}$$

Concerning the chain statute for the subordinate of items respects,

$$\frac{dP}{dV} = \frac{d(V \times I)}{dV} \tag{4}$$

The MPP can be computed by utilizing the connection between $\frac{dI}{dV}$and $-\frac{I}{V}$. If $\frac{dP}{dV}$ is negative then MPPT is lies on the right side of recent position and if the MPP is positive the MPPT lies on the left side. The equation of INC method is:

$$\frac{dP}{dV} = \frac{d(V \times I)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} \tag{5}$$

$$\frac{dP}{dV} = I + V\frac{dI}{dV} \tag{6}$$

$$\text{MPP is reached when } \frac{dP}{dV} = 0 \text{ and} \tag{7}$$

$$\frac{dI}{dV} = -\frac{I}{V} \tag{8}$$

## IV. OPTIMIZATION TECHNIQUES

The optimization techniques [21] deal to overcome the partial shading effects, tracking the global MPP in order to maximize the power extraction of the PV arrangements. Some of the optimization algorithms are,

1. Modified firefly algorithm under partial shading.
2. Lagrangian Interpolation (LI) and Particle Swarm Optimization (PSO) algorithm.
3. Grey Wolf Optimization (GWO) technique.
4. Particle Swarm Optimization (PSO) based algorithm under partially shaded conditions.
5. Glowworm Swarm Optimization (GSO) algorithm.

### 4.1 **Modified Firefly Algorithm under Partial Shading**

The firefly algorithm [22] is ameta-heuristic algorithm that has been shown to successfully track the Global Maximum Point (GMP) under the partial shading conditions. The proposed algorithm has three fundamental assumptions.

Firstly, all fireflies are unisex and can move closer to the brighter and more attractive ones until all of them have been compared (except for itself).Secondly, the attractiveness of a firefly is related to its brightness, which depends on the distance between itself and other flies. However, because of the light absorption of the air, the attractiveness decreases as the distance increases. Finally, the brightness or light intensity of a firefly is determined by the value of the objective function of a given problem.

The primary issue of the normal algorithm is that the position of every single firefly is converted in a stepwise manner towards the brighter fireflies. This is because of the fact that the entire flies have got to compare with each other, and every comparison accompanies a movement. Consider an example; there are four fireflies in the space. Assume that flies 2, 3, and 4 are brighter than fly 1. Since quantitatively it is difficult to describe the lightness. So hue gradation is used to indicate the brightness level of the flies. Hence, fly 4 is the brightest, fly 3 is brighter than 2, and fly 1 has no brightness. Fly 1 change its position towards flies 2, 3 and 4, respectively, and the brightness of fly 1 also changes as its position changes. The zigzag trajectories may cause the tracking time of the GMP to be excessively long. To overcome this problem, the modified algorithm use the average of the coordinates of all the brighter fireflies as the representativepoint, and the firefly will only move towards the spot with no meandering near all the more brilliant flies. The lightness levels of the four flies and the original position of fly 1 are the same as those in the initial stage. However, it only takes one step for fly 1 to move to the final position. The firefly algorithm can be expressed by three equations. The attractiveness, $\beta$ can be quantitatively expressed as,

$$\beta(r) = \beta_0\, exp(-\gamma d^m) \tag{9}$$

Where $\beta_0$ is the initial attractiveness at $d = 0$, $d$is the distance between two fireflies, $\gamma$ is an absorption coefficient controlling the reduction of the light intensity, $m$ is an integer, and is set to 2. The distance between two fireflies $i$ and $j$, at positions $x_i$ and $x_j$ can be evaluated as Euclidean distance. It can be expressed as,

$$d_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{n}(x_{ik} - x_{jk})^2} \tag{10}$$

Where $x_{ik}$ and $x_{jk}$ are the$k^{th}$ component of the spatial coordinates of the $i^{th}$ and $j^{th}$ firefly, and $n$ is the number of the dimensions.

### **4.2 Lagrangian Interpolation (LI) and Particle Swarm Optimization (PSO) Algorithm**

The PSO algorithm is an improved procedure that can be connected utilizing multivariable capacity enhancement by means of numerous nearby ideal focuses. The LI-PSO algorithm [23] estimates the voltage value$V_{mpp}$ of the PV module I–V characteristic in the first step, using the Constant Voltage (CV) method approximation. The CV strategy algorithm is the most straightforward MPPT controller and generally triggers a speedy reaction. This technique assumes the value of $V_{mpp}$ at different irradiance points is approximately equal. $V_{oc}$ represents the open circuit voltage of the PV panel, the ratio between the PV module maximum output voltage, and its open circuit voltage, which are equal to consistent $C$ , and accepting that it marginally modified with the sun oriented radiation,

$$\text{i.e., } \frac{V_{mpp}}{V_{oc}} = K \tag{11}$$

The algorithm starts by getting the present estimation of$V(k)$as well asutilizing the past esteem, put away toward the end of the former cycle $V(k-1)$. Then the value of the duty cycle $d_{mpp}$ at $V_{mpp}$is estimated, using the Lagrangian interpolation formula, for which four points selected from the I-V characteristic are used. The PV module I-V curve can be described by the quadratic interpolation function. The interpolation nodes $n_1$and $n_2$ represent the voltage values at the two sampling points $(V_1 and\ V_2)$, while $n_2$ represents the voltage $V_0$ of the short circuit current, which is equal to 0, and $n_3$ represents the open circuit voltage provided by the PV module data sheet. The function values$f_1$ and $f_2$ correspond to the voltage values, representing the duty cycle$(d_1, d_2)$, the values of the sampling points, and $f_0$, $f_3$ represents the duty cycle$\left(d|_{I_c} and\ d|_{V_0}\right)$ at the $I_c\ and\ V_0$points, which are equal to 1 and 0, respectively. Once the values of $V_0$,$V_1$, $V_2$,$V_3$ have been obtained using the aforementioned process, the value of the duty cycle at MPP $d_{mpp}$ at $V_{mpp}$ can be estimated using the Lagrangian Interpolation (LI) formula, given as,

$$f(n) = \frac{(n-n_1)(n-n_2)(n-n_3)}{(n_0-n_1)(n_0-n_2)(n_0-n_3)} f_0 + \cdots + \frac{(n-n_0)(n-n_1)(n-n_2)}{(n_3-n_0)(n_3-n_1)(n_3-n_2)} f_3 \tag{12}$$

Where$n$ is the value of $V_{mpp}$ .The PSO algorithm computes the value of initial particles $d_{mpp}$ (duty cycle at MPP) based on the voltage at maximum power. Along these lines, the algorithm can begin the streamlining procedure with an underlying quality that is as of now near the MPP. The underlying estimation of particles can be characterized as:

$$d_i^k = [d_1, d_2, \cdots, d_N] \tag{13}$$

Where $N$ is the number of particles and $k$ is the number of iterations.

### 4.3 Grey-Wolf Optimization Technique

The GWO algorithm [24] mimics the initiative progressive system and chasing component of grey wolves in nature. Grey wolves are viewed as at the highest point of natural way of life and they want to live in a pack. Four sorts of grey wolves, for example, alpha ($\alpha$), beta ($\beta$), delta ($\delta$), and omega ($\omega$) are utilized for reenacting the initiative pecking order. With the end goal to scientifically demonstrate the social pecking order of wolves while outliningthe GWO, we think about the fittest arrangement as the alpha ($\alpha$). Thusly, the second and third best arrangements are named as beta ($\beta$) and delta ($\delta$), individually. Whatever is left of the competitor arrangements are thought to be omega ($\omega$). The fundamental strides of the GWO algorithm, to be specific, chasing, pursuing, and following for prey, enclosing prey, and assaulting prey which is actualized to plan GWO for executing optimization. Grey wolves encircle a prey amid the hunt and the encircling conduct can be demonstrated by the accompanying conditions,

$$\overrightarrow{C_1} = \left|\vec{C}_2 \cdot \vec{X}_p(t) - \vec{X}_p(t)\right| \tag{14}$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{C}_3 \cdot \vec{C}_1 \tag{15}$$

Where $t$means the present iteration,$\vec{C}_1$ $\overrightarrow{C_2}$, and $\vec{C}_3$signifies the coefficient vectors, $X_p$is the position vector of the prey, and $X$demonstrates the position vector of the grey wolf.

### 4.4 Particle Swarm Optimization (PSO) based Algorithm under Partially Shaded Conditions

The PSO technique [25] is currently connected to understand the MPPT algorithm for PV framework working under partially shaded conditions, wherein the P-V curve exhibits numerous neighborhoods MPPs. Because of the uniqueness of this issue, the standard form of PSO will be altered to meet the down to earth thought of PGS under PSC. Definite outline systems which consider the equipment impediment will be displayed in the accompanying. The introduced framework comprises an arrangement associated PV module, a DC–DC converter and an advanced controller wherein the proposed MPPT algorithm has actualized. A straightforward boost converter has utilized to interface the voltage from the PV module to the load.

### 4.5 Glowworm Swarm Optimization (GSO) algorithm

The GSO algorithm [26] is another sort of stochastic and metaheuristic improvement algorithm. GSO utilizes a swarm of glowworms as its agents, which are viewed as the potential solutions for an issue. The fitness of optimality is estimated by the target work characterized by clients. In the present work, GSO is adjusted to produce an ideal reference voltage that shifts with radiance to separate the most extreme power from the PV module. GSO is an optimization technique that is anything but difficult to execute with a rapid convergence speed and a couple of parameters to adjust.

#### 4.5.1 Description of the Algorithm

The GSO algorithm depends on glowworms, every one of which is viewed as a potential solution for the given target issue. In the first iteration, a swarm of glowworms is arbitrarily dispersed in a hunt space with an underlying luciferin esteem, which decides the brightness of the glowworms. The luciferin is refreshed by the objective function value at the present position of the glowworm. Every glowworm, which has its own choice sweep $0 < r_d^i < r_s$ ($r_s$ is the largest detecting span of glowworms), looks for asplendid individual with high luciferin in its neighborhood-decision range and advances toward such person. After such development, the decision radius of this glowworm remains refreshed by the number of ideal people in a choice sweep. At long last, the vast majority of the glowworms accumulate at the peak point after a few iterations. Every iterations comprises a luciferin-refresh stage, a development stage dependent on a transition rule, and a nearby-decision range refresh stage.

**Table 1:** Summary of optimization algorithms

| S. No. | Optimization Algorithms | Techniques employed in the algorithms |
|---|---|---|
| 1 | Modified firefly algorithm under partial shading. | 1. Firstly, all fireflies are unisex and can move closer to the brighter and more attractive ones until all of them have been compared (except for itself).<br>2. Secondly, the attractiveness of a firefly is related to its brightness, which depends on the distance between itself and other flies. However, because of the light absorption of the air, the attractiveness decreases as the distance increases.<br>3. Finally, the brightness or light intensity of a firefly is determined by the value of the objective function of a given problem. |
| 2 | Lagrangian Interpolation (LI) and Particle Swarm Optimization (PSO) algorithm. | 1. Parameter selection.<br>2. PSO initialization.<br>3. Fitness evaluation.<br>4. Determination of individual and global best fitness.<br>5. Updating the velocity and position of each particle.<br>6. Convergence determination.<br>7. Re-initialization. |
| 3 | Grey Wolf Optimization (GWO) technique. | 1. Initialization<br>2. Fitness evaluation<br>3. Computation of best position<br>4. Updating the position, radius and the coefficient vectors. |

| | | |
|---|---|---|
| | | 5. Convergence determination<br>6. Re-initialization |
| 4 | Particle Swarm Optimization (PSO) based algorithm under partially shaded conditions. | 1. Parameter selection.<br>2. PSO initialization.<br>3. Fitness evaluation.<br>4. Update Individual and Global Best Data.<br>5. Update Velocity and Position of Each Particle.<br>6. Convergence determination.<br>7. Re-initialization. |
| 5 | Glowworm Swarm Optimization (GSO) algorithm. | 1. Initialization.<br>2. Luciferin-Update Phase.<br>3. Movement Phase.<br>4. Local-Decision Range Update Phase.<br>5. Irradiance determination<br>6. Re-initialization |

## V. POWER FLUCTUATION CONTROL ALGORITHM

The PV output power from a grid connected array can change rapidly in view of the movement of overhead clouds.One of the main characteristics of PV systems is the high variability of their output power [38]. This variability stems from the fact that these systems are static, and thus, any instantaneous change in the irradiance reaching the PV arrays leads to a corresponding change in their output power.

The main issue associated with large PV systems is the fluctuation of their output power. Because the output power generated from solar PV is variable in nature, due to frequent change in solar radiation level caused by cloud passing. It does not deliver the constant power continuously like nuclear, thermal or gas-fired plants. These variances can adverselyaffect the execution of the electric systems to which these frameworks are associated, particularly if the infiltration levels of these frameworks are elevated. Besides, the changes in the intensity of PV frameworks make it hard to foresee their yield, and in this manner, to think of them as when booking the creating units in the system. The fluctuation in the grid changes the voltage and frequency parameter which affects sensitive equipments in manufacturing units [39].

Mitigating solar PV fluctuation is a challenge since solar PV penetration with high ramp-rate introduces significant voltage fluctuation in weak radial distribution network. There are many ways suggested in the literature such as use of dump load, operate PV below its MPP and use of storage technology to counter PV output power fluctuation. Use of (i) battery technology, (ii) dump load and (iii) PV generator curtailment to smooth the output power from solar PV plant is presented. Utilization of vitality stockpiling advancements, for example, Battery Energy Storage (BES), Electric Double Layer Capacitor (EDLC), Superconducting Magnetic Energy Storage (SMES) as well as the energy unit has been proposed to smooth out here and now sun based PV yield control variances successfully. These methods give extra importance to the past history data than the present value of the fluctuating value [40]. This problem is referred as memory effect. There are many techniques to investigate and to reduce the fluctuations in the power generated from a large customer-owned PV system, in the order of megawatts.

### 5.1 Battery Energy Storage Station (BESS) Based Smoothing Control

The BESS [33] is the current and typical means of smoothing solar-power generation fluctuations. Such BESS-based hybrid power systems require a suitable control strategy that can effectively regulate power output levels and battery SOC. This method proposes a new control strategy for smoothing of PV power fluctuations by means of feedback control of SOC and a large-scale BESS. First, the smoothing problem is formulated based on the power fluctuation rate. The power fluctuation rate can be considered as an assessment indicator for PV generation equipment that is connected to the power grid. the power fluctuation rates over the investigated time period are used to evaluate the control effect of PV smoothing both with and without the BESS. It can be represented as,

$$r_{PV}^{T} = f_{PV}\left[\frac{P_{PV}^{max}-P_{PV}^{min}}{P_{PV}^{rated}}\right]_{T} \text{ and } \tag{16}$$

$$r_{hybrid}^{T} = f_{hybrid}\left[\frac{P_{hybrid}^{max}-P_{hybrid}^{min}}{P_{hybrid}^{rated}}\right]_{T} \tag{17}$$

## VI. COMPARATIVE ANALYSIS

### 6.1 MPPT Algorithms

**Table 2: Merits and demerits of hill climbing techniques**

| S. No | Algorithm | Merits | Demerits |
|---|---|---|---|
| 1 | Perturb and Observe (P&O) [19] | • Simplicity as well as high convergence speed.<br>• Reduces the oscillation. | • Slow response speed.<br>• Oscillations in steady state.<br>• Changes in solar irradiance. |
| 2 | Incremental Conductance (IC) [20] | • Improves PV efficiency.<br>• Produces more energy on a vast irradiation changes environment<br>• Reduces power loss and system cost. | • Low tracking time.<br>• Error in voltage increment & decrement. |

**Table 3: Merits and demerits of optimization techniques**

| S. No | Algorithm | Merits | Demerits |
|---|---|---|---|
| 1 | Modified Firefly Algorithm Under Partial Shading [22] | • Lessen the quantity of computation tasks.<br>• Lessenthe ideal opportunity for combining with the GMP.<br>• Effectively suppress the power and voltage fluctuations. | • Fails to track MPP.<br>• Can be tracked in local optima.<br>• Need for proper settings. |
| 2 | Lagrangian Interpolation (LI) and Particle Swarm Optimization (PSO) Algorithm [23] | • Enhances the stability.<br>• Fast tracking capability. | • Easy to fall into local optimum.<br>• Low convergence rate. |
| 3 | Grey Wolf Optimization Technique [24] | • Overcomes the limitations such as lower tracking efficiency, steady-state oscillations, and transients as encountered in P&O and improved PSO (IPSO) techniques. | • lower tracking efficiency<br>• Oscillations generated in the PV output power. |
| 4 | PSO based algorithm under partial shading conditions [25] | • Easy to implement,<br>• System-independent.<br>• High tracking efficiency. | • Low tracking speed.<br>• Possesses steady-state errors<br>• It is system dependent |
| 5 | Glowworm Swarm Optimization algorithm [26] | • High performance and tracking speed.<br>• Do not require an accurate mathematical model.<br>• Entail training a large amount of data. | • Calculation is complex<br>• Large storage space is necessary |

**Table 4: Merits and demerits of other MPPT algorithms**

| S. No | Algorithm | Merits | Demerits |
|---|---|---|---|
| 1 | Fuzzy Logic Control [27] | • Yields more power.<br>• Allows the connection of PV modules.<br>• Offers a cost savings. | • Unable to respond quickly.<br>• Issues of wrong judgment. |
| 2 | Neural Networks [28] | • Near accurate in predicting the MPP.<br>• Controls the on goings of the Buck Boost Converter. | • Necessitates a load for training and cases.<br>• Low accuracy. |
| 3 | Current Sweep Algorithm [29] | • Maintains the output voltage constant.<br>• Non linear duty ratio change is avoided. | • Doesn't use global information.<br>• Doesn't maintain the search tree. |
| 4 | Fractional Open Circuit Voltage (FOCV) Algorithm [30] | • Simple Method.<br>• Easy to implement.<br>• Low expensive. | • PV array remains detached from the heap.<br>• The sampling time frame is too extended. |
| 5 | Fractional Short Circuit Current (FSCC) Algorithm [31] | • Needs only a current sensor.<br>• Less expensive.<br>• Easy to implement. | • Intermittent loss of intensity while estimating the short circuit current. |
| 6 | Two-Mode Control Algorithm [32] | • Improves the efficiency.<br>• Excellent performance.<br>• Cost effective. | • Requires deterministic model.<br>Increased oscillation. |

### 6.2 Power Fluctuation Control Algorithms

**Table 5: Merits and demerits of power fluctuation control algorithms**

| S. No | Algorithm | Merits | Demerits |
|---|---|---|---|
| 1 | Battery Energy Storage Station (BESS) based smoothing control [33] | • Improves the smoothing performance.<br>• Effectiveness of battery SOC control. | • A trade-off amongthe battery exertionas well as the level of smoothness. |
| 2 | Fuzzy based method [34] | • No deterministic model is required.<br>• Compellingwhile the numerical articulations are troublesome. | • Significant loss.<br>• Irradiance changes.<br>• Variations in duty cycle. |
| 3 | DSTATCOM [35] | • Low cost.<br>• Reduces the tap changing frequency.<br>• Comfort voltage regulation. | • Having power quality issues.<br>• Changes in load voltage. |
| 4 | Energy capacitor system [36] | • Unlimited life cycle, not have any harmful materials, notrequiring a defensive circuit.<br>• Quickincriminating time.<br>• Simple charging method. | • Lifespan is restricted as a result of the utilization of electrolyte.<br>• Electrolyte may leak.<br>• Have high internal resistances. |
| 5 | Optimal dispatching method [37] | • Fast and reliable convergence.<br>• High computing speed.<br>• High calculation accuracy. | • Smoothness of power curve leads to abandoned. |

We have presented the two types of techniques of grid connected solar PV systems namely, MPPT and power fluctuation control. Both the techniques consist of different types of algorithms and implementation methods. Each algorithm and implementation methods has its own merits and demerits. So we cannot conclude that which is the best algorithm or implementation method for both the MPPT and power fluctuation control.

## VI. CONCLUSION

PV array is an aggregate power-producing unit, comprising many numbers of PV modules as well as the panels. The execution of PV modules, as well as arrays, is by and large appraised by their most extreme DC control yield (watts) under Standard Test Conditions (the STC). It has both MPPT to minimize the similarity between the PV panels and power fluctuation control to smoothen the yield control produced as a result of the PV arrays. In this paper, we had summarized those two techniques and different types of algorithms, implementation methods. We have also examined the merits and demerits of each algorithm and finally, we have provided the comparison for those different types of algorithms.

## REFERENCES

**[1]** Kesraoui, Mohamed, Aldjia Lazizi, and Ahmed Chaib. "Grid connected solar PV system: modeling, simulation and experimental tests." Energy Procedia, vol.95, pp.181-188, 2016.

**[2]** Kuo, Yeong-Chau, Tsorng-Juu Liang, and Jiann-Fuh Chen. "Novel maximum-power-point-tracking controller for PV energy conversion system." IEEE transactions on industrial electronics, vol.48, no.3, pp.594-601, 2001.

**[3]** Roman, Eduardo, Ricardo Alonso, Pedro Ibañez, Sabino Elorduizapatarietxe, and Damián Goitia. "Intelligent PV module for grid-connected PV systems." IEEE Transactions on Industrial electronics, vol.53, no.4, pp.1066-1073, 2006.

**[4]** Seme, Sebastijan, Niko Lukač, Bojan Štumberger, and Miralem Hadžiselimović. "Power quality experimental analysis of grid-connected photovoltaic systems in urban distribution networks." Energy, vol.139, pp.1261-1266, 2017.

**[5]** Wang, H. X., M. A. Muñoz-García, G. P. Moreda, and M. C. Alonso-García. "Optimum inverter sizing of grid-connected photovoltaic systems based on energetic and economic considerations." Renewable Energy, vol.118, pp.709-717, 2018.

**[6]** Esram, Trishan, and Patrick L. Chapman. "Comparison of photovoltaic array maximum power point tracking techniques." IEEE Transactions on energy conversion, vol.22, no.2, pp.439-449, 2007.

**[7]** Ishaque, Kashif, Zainal Salam, and George Lauss. "The performance of perturb and observe and incremental conductance maximum power point tracking method under dynamic weather conditions." Applied Energy, vol.119, pp.228-236, 2014.

**[8]** Enslin, Johan HR, Mario S. Wolf, Daniel B. Snyman, and Wernher Swiegers. "Integrated photovoltaic maximum power point tracking converter." IEEE Transactions on industrial electronics, vol.44, no.6, pp.769-773, 1997.

**[9]** Femia, Nicola, Giovanni Petrone, Giovanni Spagnuolo, and Massimo Vitelli. "Optimization of perturb and observe maximum power point tracking method." IEEE transactions on power electronics, vol.20, no.4, pp.963-973, 2005.

**[10]** Ahmed, Nabil A., Masafumi Miyatake, and A. K. Al-Othman. "Power fluctuations suppression of stand-alone hybrid generation combining solar photovoltaic/wind turbine and fuel cell systems." Energy Conversion and Management, vol.49, no.10, pp.2711-2719, 2008.

**[11]** Ashique, Ratil H., Zainal Salam, Mohd Junaidi Bin Abdul Aziz, and Abdul Rauf Bhatti. "Integrated photovoltaic-grid dc fast charging system for electric vehicle: A review of the architecture and control." Renewable and Sustainable Energy Reviews, vol.69, pp.1243-1257, 2017.

**[12]** Shivashankar, S., Saad Mekhilef, Hazlie Mokhlis, and M. Karimi. "Mitigating methods of power fluctuation of photovoltaic (PV) sources–a review." Renewable and Sustainable Energy Reviews, vol.59, pp.1170-1184, 2016.

**[13]** Worku, Muhammed Y., M. A. Abido, and R. Iravani. "Power fluctuation minimization in grid connected photovoltaic using super capacitor energy storage system." Journal of Renewable and Sustainable Energy, vol.8, no.1, pp. 013501, 2016.

**[14]** Sampaio, Priscila Gonçalves Vasconcelos, and Mario Orestes Aguirre González. "Photovoltaic solar energy: Conceptual framework." Renewable and Sustainable Energy Reviews, vol.74, pp.590-601, 2017.

**[15]** Salas, V., E. Olias, A. Barrado, and A. Lazaro. "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems." Solar energy materials and solar cells, vol.90, no.11, pp.1555-1578, 2006.

**[16]** Huang, Chao, Long Wang, Ryan Shun-Cheung Yeung, Zijun Zhang, Henry Shu-Hung Chung, and Alain Bensoussan. "A prediction model-guided Jaya algorithm for the PV system maximum power point tracking." IEEE Transactions on Sustainable Energy, vol.9, no.1, pp.45-55, 2018.

**[17]** Ji, Young-Hyok, Doo-Yong Jung, Jun-Gu Kim, Jae-Hyung Kim, Tae-Won Lee, and Chung-Yuen Won. "A real maximum power point tracking method for mismatching compensation in PV array under partially shaded conditions." IEEE Transactions on power electronics, vol.26, no.4, pp.1001-1009, 2011.

**[18]** Alajmi, Bader N., Khaled H. Ahmed, Stephen J. Finney, and Barry W. Williams. "Fuzzy-logic-control approach of a modified hill-climbing method for maximum power point in microgrid standalone photovoltaic system." IEEE Transactions on Power Electronics, vol.26, no.4, pp.1022-1030, 2011.

**[19]** Abdelsalam, Ahmed K., Ahmed M. Massoud, Shehab Ahmed, and Prasad N. Enjeti. "High-performance adaptive Perturb and Observe MPPT technique for photovoltaic-based microgrids." IEEE Transactions on Power Electronics, vol.26, no.4, pp.1010-1021, 2011.

**[20]** Putri, Ratna Ika, Sapto Wibowo, and Muhamad Rifa'i. "Maximum power point tracking for photovoltaic using incremental conductance method." Energy Procedia, vol.68, pp.22-30, 2015.

**[21]** Ishaque, Kashif, Zainal Salam, Muhammad Amjad, and Saad Mekhilef. "An improved particle swarm optimization (PSO)–based MPPT for PV with reduced steady-state oscillation." IEEE transactions on Power Electronics, vol.27, no.8, pp.3627-3638, 2012.

**[22]** Teshome, D. F., C. H. Lee, Y. W. Lin, and K. L. Lian. "A modified firefly algorithm for photovoltaic maximum power point tracking control under partial shading." IEEE Journal of Emerging and Selected Topics in Power Electronics, vol.5, no.2, pp.661-671, 2017.

**[23]** Koad, Ramdan BA, Ahmed Faheem Zobaa, and Adel El-Shahat. "A novel MPPT algorithm based on particle swarm optimization for photovoltaic systems." IEEE Transactions on Sustainable Energy, vol.8, no.2, pp.468-476, 2017.

**[24]** Mohanty, Satyajit, BidyadharSubudhi, and Pravat Kumar Ray. "A new MPPT design using grey wolf optimization technique for photovoltaic system under partial shading conditions." IEEE Transactions on Sustainable Energy, vol.7, no.1, pp.181-188, 2016.

**[25]** Liu, Yi-Hwa, Shyh-Ching Huang, Jia-Wei Huang, and Wen-Cheng Liang. "A particle swarm optimization-based maximum power point tracking algorithm for PV systems operating under partially shaded conditions." IEEE Transactions on Energy Conversion, vol.27, no.4, pp.1027-1035, 2012.

**[26]** Hou, Wenhui, Yi Jin, Changan Zhu, and Guiqiang Li. "A novel maximum power point tracking algorithm based on glowworm swarm optimization for photovoltaic systems." International Journal of Photoenergy 2016 (2016).

**[27]** Patcharaprakiti, Nopporn, Suttichai Premrudeepreechacharn, and Yosanai Sriuthaisiriwong. "Maximum power point tracking using adaptive fuzzy logic control for grid-connected photovoltaic system." Renewable Energy, vol.30, no.11, pp.1771-1788, 2005.

**[28]** Messalti, Sabir, Abdelghani Harrag, and Abdelhamid Loukriz. "A new variable step size neural networks MPPT controller: Review, simulation and hardware implementation." Renewable and Sustainable Energy Reviews, vol.68, pp.221-233, 2017.

**[29]** Esram, Trishan, and Patrick L. Chapman. "Comparison of photovoltaic array maximum power point tracking techniques." IEEE Transactions on energy conversion, vol.22, no.2, pp.439-449, 2007.

**[30]** Montecucco, Andrea, and Andrew R. Knox. "Maximum power point tracking converter based on the open-circuit voltage method for thermoelectric generators." IEEE Transactions on Power Electronics, vol.30, no 2, pp.828-839, 2015.

**[31]** Sher, Hadeed Ahmed, Ali Faisal Murtaza, Abdullah Noman, Khaled E. Addoweesh, Kamal Al-Haddad, and Marcello Chiaberge. "A New sensorless hybrid MPPT algorithm based on fractional short-circuit current measurement and P&O MPPT." IEEE Transactions on Sustainable Energy 6, no. 4 (2015): 1426-1434.

**[32]** Yu, G. J., Y. S. Jung, J. Y. Choi, and G. S. Kim. "A novel two-mode MPPT control algorithm based on comparative study of existing algorithms." Solar Energy, vol.76, no.4, pp.455-463, 2004.

**[33]** Li, Xiangjun, Dong Hui, and Xiaokang Lai. "Battery energy storage station (BESS)-based smoothing control of photovoltaic (PV) and wind power generation fluctuations." IEEE Transactions on Sustainable Energy, vol.4, no.2, pp.464-473, 2013.

**[34]** Datta, Manoj, Tomonobu Senjyu, Atsushi Yona, and Toshihisa Funabashi. "A fuzzy based method for leveling output power fluctuations of photovoltaic-diesel hybrid power system." Renewable Energy, vol.36, no.6, pp.1693-1703, 2011.

**[35]** Yan, Ruifeng, Brandon Marais, and Tapan Kumar Saha. "Impacts of residential photovoltaic power fluctuation on on-load tap changer operation and a solution using DSTATCOM." Electric Power Systems Research, vol.111, pp.185-193, 2014.

**[36]** Jamehbozorg, Arash, Seyed Nasser Keshmiri, and Ghadir Radman. "PV output power smoothing using energy capacitor system." In Southeastcon, 2011 Proceedings of IEEE, pp. 164-168. IEEE, 2011.

**[37]** Li, Lili, Qia Ding, Hucheng Li, and Maohua Dan. "Optimal dispatching method for smoothing power fluctuations of the wind-photovoltaic-battery hybrid generation system." In Innovative Smart Grid Technologies-Asia (ISGT Asia), IEEE, pp. 1-6, 2012.

**[38]** Dursun, Erkan, and Osman Kilic. "Comparative evaluation of different power management strategies of a stand-alone PV/Wind/PEMFC hybrid power system." International Journal of Electrical Power & Energy Systems 34, no. 1 (2012): 81-89.

**[39]** Ahmed, Nabil A., Masafumi Miyatake, and A. K. Al-Othman. "Power fluctuations suppression of stand-alone hybrid generation combining solar photovoltaic/wind turbine and fuel cell systems." Energy Conversion and Management 49, no. 10 (2008): 2711-2719.

**[40]** Omran, Walid A., M. Kazerani, and M. M. A. Salama. "Investigation of methods for reduction of power fluctuations generated from large grid-connected photovoltaic systems." IEEE Transactions on Energy Conversion 26, no. 1 (2011): 318-327