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A Technical Review of MPPT Algorithms for Solar Photovoltaic System: SWOT Analysis of MPPT Algorithms

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Abstract

To continuously operate the Photovoltaic (PV) system at its Maximum Power Point (MPP) under changing weather is a challenging task. To accomplish this, multiple MPP Tracking (MPPT) algorithms have been proposed, which can be portioned into two: 1) Conventional algorithms, have the strengths of a simple structure, fewer computations, and low memory requirement, and cheap implementation. Whereas, trapping under Partial Shading Conditions (PSC), steady-state oscillations, and system dependency are the associated drawbacks. Conversely, 2) Soft computing algorithms, perform efficiently under all weather conditions with zero steady-state oscillations, and are system independent. The structural complexities, giant computations, huge memory requirements, and expensive implementation, are the accompanying concerns. The core contribution of this study is to present a deep analysis of all the MPPT algorithms at the standard benchmarks defined in the published literature, for the readers so they could decide which algorithm to choose under certain circumstances.

Index Terms: *Global Maximum Power Point Tracking, Partial Shading Condition, Photovoltaic System, Uniform Weather Condition, MPPT Algorithms.*

I. INTRODUCTION

Energy systems encounter problems of generation shortage, swelling demand, instability, emissions, and high prices [1]. The statics presented here have shown that energy demand is growing rapidly which causes the depletion of fossil fuels and cost inflation. In the conventional power grid paradigm, a shortage of energy may be addressed by adding fossil fuel-based power generation plants along with the expansion of transmission and distribution network capacity [2]. However, such a measure results in huge capital investment, an increase in maintenance cost, and extended energy networks. Large networks in turn become more difficult to manage, terror as well as cyber security attacks, and fault-prone.

However, in a smart grid, there are central or distributed configurations [3]. Small-sized renewable energy distributed generators (DGs) exist on customer premises. Therefore, outage on such small DGs does not cause voltage and frequency instability. Therefore, smart grid energy networks are preferred [4]. Renewable DGs present in smart distribution system function in two ways: 1) In grid-connected mode, DGs will serve the customer-owned load and export surplus power to the national grid, and 2) In standalone mode, DGs feed an isolated community under a situation, where it is difficult or financially infeasible to connect the load to the national grid. Off-grid renewable energy systems are suitable for remote areas and applications where other power sources are either impractical to use [5]. Among renewables, solar energy is one of the most abundant natural resources available on our planet [6] and [7]. However, large solar energy potential exists over most parts of the globe. Moreover, solar Photovoltaic (PV) technology has minimum energy conversion losses due to the direct conversion of illumination to electrical energy using the photoelectric effect [8]. It is reliable, environment-friendly, pollution-free, cheaply maintainable, and easy to install anywhere [9]. The effective life of a PV cell is almost 25 years with six years’ payback time, which makes it more cost-effective than other renewable resources [10]. The performance of a PV system depends on the material of a PV cell, facing the sun, the efficiency of the converter, and MPPT efficiency [11]. This has been an ongoing area of research, however; this work does not concentrate on it. The second method termed 'mechanical tracking’ rotates the panel to receive maximum insolation at its surface. The amount of illumination that falls at the surface of the PV cell is directly proportional to the amount of electric power production [12]. The third method is improving the electronic converter's efficiency which already exceeds about 95 % [13]. The fourth is MPPT efficiency [14]. To get the maximum power the PV system should operate at its Maximum Power Point (MPP), and therefore MPP trackers governed by algorithms are employed [15]. The MPPT is the simplest, easiest, cheapest, and most effective way of optimizing the efficiency, power output, covered area, and payback time of the PV system. The MPPT algorithms can be categorized into, (1) Conventional techniques are incremental scanning algorithms. These scans the P-V curve of a PV array in a sequence and consider the first detected peak as an MPP without scanning the rest and are unable to identify the Global Maximum Power Point (GMPP) among the multiple peaks created in the characteristic curve of a PV cell created due to the Partial Shading Conditions (PSC). Therefore, these techniques are not suitable for the Global Maximum Power Point Tracking (GMPPT) under Partial Shading Conditions (PSCs) [16]. Whereas, (2) Soft computing algorithms use the concept of randomization. These algorithms perform the optimal use of random numbers to solve non-linear problems like Global MPPT (GMPPT) under PSCs [17].

The defined benchmarks chosen from the published literature are:

1. Tracking Speed
2. Ability to Track the GMPP under PSC
3. Ability to Detect the change in Weather Conditions
4. Structural Complexity
5. Computational Complexity
6. Efficiency
7. Steady-State Oscillations
8. Array Dependence
9. Number of Tuning Parameters
10. Number of Sensors
11. Memory Requirement

The tracking speed defines the ability of an algorithm that how quickly it reaches the MPP to save time. The ability of GMPP tracking under PSC defines the success of the algorithm. The Structural complexity creates the implementation difficulties of the algorithm. Computational complexity defines the tracking speed and implementation difficulties. The efficiency of an algorithm describes how quickly and accurately it extracts the maximum power from PV cells. The stability of power is described by steady-state oscillations. Array dependence affects the tracking speed, efficiency, and GMPPT ability of the algorithm.

II. CONVENTIONAL MPPT ALGORITHMS

Conventional algorithms are simple structured techniques and use the real-time data of the solar PV system to track the MPP. These techniques are very effective under Uniform Weather Conditions (UWC) but fail in PSC due to the formation of various peaks in the P-V curve. These techniques create confusion and cannot differentiate between Local Maximum Power Point (LMPP) and Global Maximum Power Point (GMPP). The reason for success in UWC is the occurrence of just one power peak. The conventional algorithms include; Perturb and Observe (P&O), Incremental Conductance (InC), Hill Climbing (HC), Fractional Short Circuit Current (FSCC), Fractional Open Circuit Voltage (FOCV), and Global Maximum Point technique.

A. Perturb and Observe (P&O) Algorithm

It is one of the most used conventional algorithms in the market. It tracks the MPP by perturbing the value of the single variable (mostly voltage). Its implementation is cheap and easy due to its simple structure but the steady-state oscillations around the MPP are the disadvantage. Additionally, it fails in tracking the GMPP under PSC. An improved P&O algorithm using variable step size was introduced [18]. Initially, it operates using a big perturbation step size and decreases as gets closer to the MPP. This improvement speeds up the tracking process but the issue of oscillation is still there. Various improved versions of the P&O algorithm are summarized, including the improved P&O algorithm for the application of micro-grid [19]. The Delta P&O algorithm is presented, where the conventional perturbation step size is replaced with a fixed step size to get the improved results [20]. This time the value of perturbation step size is set optimally to get better results.
The research comes up with a result that there is an inverse relationship between the perturbation and efficiency of the PV module and a new approach of constant duty ratio perturbation rate is proposed which successfully reduces the oscillations. The P&O algorithm with all its improved versions is very successful in UWC but fails in PSCs [21].

B. Hill Climbing (HC) Algorithm

It is the same approach as the P&O algorithm. The only difference in the P&O and HC algorithms is the selection of perturbing variables. The variable used for perturbation in the HC technique is D. The HC algorithm changes the D and checks for the change in power of the PV array. If the change is positive, it continues its perturbation in the same direction else it reverses the direction of perturbation. It starts oscillations when reaches the MPP [22]. Improvement in the HC algorithm is made in terms of tracking accuracy by using an interleaved boost converter. A new approach using the DSP controller was used to develop a hardware model and test it under different illumination conditions [23]. A further 17.5 % improvement in convergence speed is noted. A similar approach is used for a grid-connected approach and compared with the P&O technique. The HC algorithm has the drawback of oscillations around the MPP and fails to track GMPP in PSC [24].

C. Incremental Conductance (InC) Algorithm

It has the same basic idea as the P&O technique but with a different check for perturbation. Initially, the change in a variable (mostly voltage) has made after recording the value of "P", 'V", and current. The ratio of change in power (ΔP) for the change in the voltage (ΔV) is calculated. If the ΔP is positive, it keeps changing the voltage in the same direction else it reverses the direction. Improvement has been made by introducing the variable step change in voltage to increase the tracking speed [25]. Experimentation is performed with two different approaches Variable Frequency Constant Duty (VFCD) is employed by one converter and the Constant Frequency Variable Duty (CFVD) is employed by the other converter, both are well managed and produce good results for the standalone PV system [26]. A hybrid of Fuzzy Logic Controller (FLC) with the InC algorithm is implemented using Cuk-converter [27]. Improvement in response and reduction in error is evolved. Further, this hybrid approach is also implemented using a boost converter. An incremental conductance algorithm is suitable for low power applications and is very effective for the steady change in illumination [28]. However, the problem of oscillations of OPP around the MPP remains unresolved.

D. Fractional Short Circuit Current (FSCC) Algorithm

The FSCC algorithm is a simple approach also known as short current pulse MPPT [29]. A short and simple path is adopted in this technique by using the information of the Short Circuit Current (Isc) of the PV array. It was calculated that in UWC the Optimal Current (IMPP) of a PV system always equals 0.9 times of Isc of that PV system. Therefore, a factor is introduced whose value should be less than one so the IMPP could be used as a reference for the controller to find MPP in the relationship described in Eq. 1.

$$I_{MPP} = k_1 * I_{SC} \tag{1}$$

Term k1 varies from 0.78 to 0.92. The FSC MPPT technique needs just one sensor it is clear from Eq. 1 that it is a guess therefore it does not guarantee the MPP. Whereas, the continuous measurements for the whole day result in power loss. The FSC algorithm is suited for high voltage low current applications. Not much effort has been spent on this technique. A countable work presented with this thought is limited. The efficiency of 90 % is claimed for the FSC technique [30]. An intelligent version of the FSC technique is presented where the usage of current limits for the decision of measuring a new value of I_{SC} is introduced [31]. Another improvement in the FSC technique is the use of a lookup table here the comparison of computed and calculated values is made to feed the error to the PI controller [32].

E. Fractional Open Circuit Voltage (FOCV) Algorithm

The FOCV algorithm is another simple approach used for MPPT [33]. A short and simple path is adopted in this technique using the information of open-circuit Voltage (Voc) of the PV system. It was calculated that in UWC, the Optimal Voltage (VMPP) of a PV system always equals the 76 % of Voc of that PV system. Therefore, a factor is introduced whose value should be less than one, So the VMPP could be used as a reference for the controller to find MPP in the relationship described in Eq.2.

$$V_{MPP} = k_2 * V_{OC} \tag{2}$$

Term k2 is a factor with a value less than one. Normally it varies from 0.71 to 0.8. The V_{OC} is continuously compared with the Input Voltage (V_{PV}). The difference between these parameters is sent to the PI controller to tune the value of the duty cycle accordingly. The FOC MPPT technique needs just one sensor to perform. It is suitable for high current and low voltage applications [30]. It is clear from Eq.2 that it is a guess, therefore it does not guarantee the MPP whereas the unremitting measurements result in power loss.

F. Analysis of Conventional MPPT Algorithms

Conventional algorithms are acknowledged for simplicity and stress-free application. In recent years, the performance of conventional algorithms enhanced to a broader extent. Conventional algorithms are now able to perform in the grid-connected PV systems as well. SWOT analysis for conventional MPPT algorithms in terms of opportunities, threats, strengths, and weaknesses can be found in Table I. The performance assessment of conventional MPPT techniques is presented in Table II.

Table 1: SWOT Analysis of Conventional MPPT Algorithms

S. No.	Algorithms	Strengths	Weakness	Opportunities	Threats
1	Perturb & Observe	Structural, Computational Simplicity, Easy Implementation	Slow Tracking, Fail to Track GMPP under PSC, Tuning Required, Unable to diff among LMPP & GMPP	Easy implementation Available, a Good Choice for UWC, Suitable for the Area with Persistent Weather, Good Sale	Power Loss under PSC, Power Loss under Changing Weather, Permanent Failure for huge PV System
2	Hill Climbing	Structural, Computational Simplicity, Easy Implementation	Slow Tracking, Fail to Track GMPP under PSC, Tuning Required, Unable to diff among LMPP & GMPP	Easy Implementation Available, a Good Choice for UWC, Suitable for an Area with Persistent Weather, Good Sale	Power Loss under PSC, Power Loss under Changing Weather, Permanent Failure for huge PV System
3	Incremental Conductance	Easy To Implement, Stable Output	Slow Tracking, Fail to Track GMPP under PSC, Tuning Required, Unable to diff among LMPP & GMPP	Good Choice for UWC, Suitable for being with Persistent Weather, Low Price, Good Sale	Power Loss under PSC, Power Loss under Changing Weather, Permanent Failure for huge PV System
4	Fractional Open Circuit Voltage	Cheap, Easy, Simple, Fast Speed, Stable Output, Known Position, Reliable	Low Accuracy, Low Power Applications, Under PSC, Tuning Required, Unable to diff among LMPP & GMPP	Good Choice for UWC, Suitable for being with Persistent Weather, Low Price, Good Sale	Power Loss under PSC, Power Loss under Changing Weather Conditions due to slow MPPT speed
5	Fractional Short Circuit Current	Cheap, Easy, Simple, Fast Speed, Stable Output, Known Position, Reliable	Low Accuracy, Low Power Applications, Under PSC, Tuning Required, Unable to diff among LMPP & GMPP	Good Choice for UWC, Suitable for being with Persistent Weather, Low Price, Good Sale	Power Loss under PSC, Power Loss under Changing Weather Conditions due to slow MPPT speed

6	Global MPPT	Easy to Implement, Tracks GMPP under PSC, able to diff between LMPP and GMPP	Parameter's Tuning is Required, Tracking Speed is Dependent on the PV System	Good Choice, Easy Implementation, Cheap Implementation, Tracks GMPP under PSC	Power Loss due to Failure under PSC Tested for uniform Changing Weather

Table II: Performance Assessment of Conventional MPPT Algorithms

S.No.	Algorithm	Oscillations	Structural Complexity	Memory	Computational Complexity	Execute Time	Depend at Array	Parameter Tuning	Ref.
1	P&O	Average	No	Low	No	High	Yes	Yes	[18]
2	HC	Average	No	Low	No	High	Yes	Yes	[22]
3	InC	Reduced	No	Low	No	High	Yes	Yes	[25]
4	FSC	Zero	No	Low	Low	High	Yes	Yes	[29]
5	FOC	Zero	No	Low	Low	High	Yes	Yes	[33]

III. SOFT-COMPUTING MPPT ALGORITHMS

For solving non-linear problems, soft-computing techniques are a worthy choice. These algorithms are reliable and provide fast convergence. After struggling with the conventional algorithms the researchers turn towards soft-computing techniques to get help in MPP tracking of a PV system. These soft-computing techniques proved fruitful in tracking the GMPP of the PV system under PSCs. Unlike conventional algorithms, the soft-computing techniques do not have the drawbacks of slow tracking speed and failures in tracking GMPP under PSCs. The soft-computing techniques used for GMPPT under PSC include Genetic Algorithm (GA), Artificial Neural Network (ANN), Fuzzy Logic Control (FLC), Particle Swarm Optimization (PSO), Cuckoo Search (CS) algorithm, Ant Colony Optimization (ACO), Fire-Fly (FF) algorithm, Random Search Algorithm (RSA), Artificial Bee Colony (ABC), Nonlinear Method (NM), Differential Evolution (DE) algorithm, Grey Wolf Optimization (GWO) algorithm, Flower Pollination Algorithm (FPA).

A. Fuzzy Logic Control (FLC) Algorithm

Fuzzification, inference, and de-fuzzification are the three steps of Fuzzy Logic Control (FLC). The optimal performance of the PV system is decided by the second step of fuzzy inference and fuzzy rule designing, but deep training and huge knowledge are required for the designing of fuzzy rules [34]. In the FLC technique, MPP tracking is performed by reducing the error of the PV system. Based on the information of error and difference in error the FLC tracks MPP. Although FLC has proved its multiple advantages, it fails to remove steady-state oscillation around MPP. Additionally, an increase in the defined membership functions will increase the associated computational burden. Furthermore, defining fuzzy rules is a huge complex work. A three-input FLC was proposed for MPPT of a PV system to simplify the membership function and enhance the operating area [35]. This results in a faster convergence speed. An asymmetrical FLC for MPPT of a PV system is presented in which the optimization of the membership function is made using the heuristic approach to provide more accurate results [36]. A "new rule compressed fuzzy logic method" for MPPT of a PV system is presented to observe the performance evaluation using Simulink and hardware carried out and the results have shown noticeable improvement in MPPT accuracy and speed [37].

B. Artificial Neural Network (ANN)

After observing the behavior of neurons, a technique known as Artificial Neural Network (ANN) is developed. It is an intelligent technique and can decide itself. A great amount of knowledge is required to train the neuron of the ANN algorithm [38]. The ANN used for MPPT in the PV system involves three layers. The three-layer model of ANN depicted is preferably the ANN and is used in hybrid with conventional MPPT techniques due to its expanded optimization scope [39], and [40]. ANN uses a backpropagation approach for accurate tracking. Researchers have implemented a hybrid of ANN with FLC for MPP tracking of a PV system [41]. Experimentation is also performed under UWC, PSC and suddenly changing weather conditions with different configurations of PV array bridge link, total cross ties, and series-parallel configuration. Highly improved results are obtained with this hybrid of ANN and FLC. A unique MPPT approach in a Neutral Point Clamped (NPC) in a grid-connected PV system using the ANN technique is presented [42]. It tests the accuracy of the PV system and the results have proved that the ANN technique is dependent on the type of weights age of the hidden layer.

Although the ANN is highly capable of solving non-linear problems the technique has huge computations and needs huge data training and memory.

C. Genetic (GA) Algorithm

The GA is one of the best choices for stochastic search. It is very effective for wide data search and is not bound to any specific application instead has been successfully applied in a wide range of applications. The Solar PV system displays multiple power peaks under PSC. Therefore, it is very difficult to track GMPP. A wide range of data analyses is required to solve this non-linear problem of GMPP tracking. The GA is properly tuned to get efficient results; mutation is fixed at 80 % while the crossover is at 10 %. Results of GA compared with the binary search algorithm. The GA proves its superiority against the binary search algorithm in tracking GMPP under PSC. GA is preferred in combination with other algorithms due to its high initial population requirement to increase its reliability [43]. Further, a hybrid of GA with a variable step size P&O algorithm is implemented and the obtained results are compared with the P&O algorithm [44]. A huge improvement was shown by this hybrid algorithm against the conventional P&O algorithm in tracking speed and efficiency. No improvement was ever introduced in the structure of GA for MPPT purposes. Multiple times it is implemented in a hybrid with conventional or biotic MPPT techniques to achieve the target more effectively.

D. Particle Swarm Optimization (PSO) Algorithm

The strategy of the Particle Swarm Optimization (PSO) algorithm for solving non-linear optimization problems is very effective. This searching technique is developed by observing the behavior of swarms [45]. For almost one decade, PSO remains the most preferred GMPP tracking algorithm. In the PSO algorithm, initially, the particles were selected randomly within the defined limits. These particles start the movement in the defined space. Multiple improvements had so far been implemented in the PSO MPPT technique. The PSO is used for MPPT and GMPPT tracking under uniform and PSCs [46]. It performed well but it was noticed that the random calculation of inertia constant and weight affects the performance capability of the PSO algorithm. Hence, to remove this calculation load improvements were made in the PSO algorithm, which shows valuable progress in MPP tracking under UWC and GMPP tracking under PSC. Further, multiple improvements have been introduced by the researcher to increase the convergence speed and tracking accuracy of the PSO algorithm [47]. Reduction of steady-state oscillations and GMPP tracking ability under extreme weather conditions are the targets achieved by the improved PSO algorithm [46]. Results were verified using the MATLAB simulation and hardware implementation. A modification in the PSO MPPT algorithm was made for the selection of particles. This modification improves the performance of PSO techniques by achieving almost zero steady-state oscillations, more accurate GMPPT under PSC, and faster response [48]. Performance verification was confirmed with simulation and hardware implementation using a low-cost Arduino microcontroller. A deterministic PSO MPPT technique was introduced in which the role of random numbers for the generation of acceleration factor was removed [49]. Moreover, the change in velocity was controlled. This concept of altering the PSO method brings positive effects on MPPT which includes the reduction in the number of tuning parameters, reduction in structural complexity, and achievement of a consistent solution instead of less quantity of particles.

E. Cuckoo Search (CS) Algorithm

The CS algorithm is derived from the behavior of a cuckoo bird. Intelligence and behavior of cuckoo bird explained and implemented for MPPT of a solar PV system [50]. The behavior of a cuckoo bird is that it lay eggs in the nest of a host bird. The CS algorithm is compared with P&O and PSO algorithms under PSCs and showed less steady-state oscillation than the P&O and PSO algorithms [50].

F. Ant Colony Optimization (ACO) Algorithm

Another bio-inspired technique known as the ACO algorithm is developed based on the movement analysis of ants for searching the food. The ACO algorithm has multiple applications in different fields such as data mining [51], redundancy allocation problems [52], and weapon target optimization [53]. Usually, the movements of ants for searching for food happen in N-dimensions. During the search, process ants change the pheromone lay phenomenon. In the ACO algorithm, the pheromone lay phenomenon means the quality of a solution and the interaction of ants moves the searching process from poor to the good solution [54]. The ACO algorithm is avoided to be used individually, mostly it is used in hybrid with other soft-computing techniques to get efficient results [55]. The flowchart of the ACO technique is present [56].

The ACO MPPT algorithm was introduced with the new pheromone updating strategy (ACO-NPU). After the development of the design steps, it is tested for different weather conditions. Improvement in tracking speed and accuracy achieved is compared to the conventional ACO technique. Additionally, high robustness and zero steady-state oscillations are the achievements of the ACO-NPU MPPT algorithm [57].

G. Random Search (RSM) Algorithm

Anderson proposed a unique method for solving the global optimization problems named RSM [58]. Later this RSM is used for hyperparameter extraction [59]. As the name implies RSM tracks the optimal solution using randomness. It randomly produces the solutions within the defined limits and searches for the best. For the MPP tracking, the RSM algorithm generates random solutions in the range of "0-1" and sends these values to the DC-DC converter to calculate the power against each input [58]. These values are updated continuously after each iteration until the MPP is reached. The performance of the RSM algorithm in tracking GMPP is tested under different PSCs. Compared to the PSO algorithm, RSM possesses better convergence speed and valuable improvement in the tracking speed of GMPP is observed [60]. Further improvement in RSA was made in several fields such as binary operations, image classification, etc. No further improvement was noticed in this technique for MPPT of the PV system.

H. Artificial Bee Colony (ABC) Algorithm

Another biotic algorithm developed from the behavior of bees is called an Artificial Bee Colony (ABC) algorithm. Bees target different colonies for searching the food. The ‘Employers’ and ‘Onlookers’ are the two species of bees that are very actively involved in food searching. The job of the onlooker bee is to choose the source of food and employer bees are searching for the food. These characteristics of bees are studied and analyzed deeply to use in MPP tracking of the solar PV system [61]. A successful modification is introduced to improve the accuracy and tracking speed of the conventional ABC technique. The ABC algorithm is used to design the PI controller for MPPT purposes. Optimal parameter selection for designing the PI controller is necessary to get optimum results and for this purpose the ABC algorithm is used. The ABC technique is mostly used in hybrid for MPPT. There is not much research on the improvement in the structure of this technique.

I. Differential Evolution (DE) Algorithm

Implementation of the DE algorithm for MPPT begins with the initialization of a set of target vectors. All the vectors in the population then pass through the fitness test. A fitness test is the measure of power production by the solar PV array. After the fitness evaluation of vectors, the mutation and crossover process is executed. For each target vector, two more vectors mutant and trial are generated using mutation and crossover respectively. Further, a comparison between the trial and target vectors was made one by one. The vector with better or matching fitness will propagate to the next iteration. The process keeps repeating until the achievement of MPP or to meet the termination conditions [62], and [63]. Simplification of the mutation process by removing the complex terms for mutant vector calculation and using the Φ for this purpose. Additionally, the perturbation of the duty cycle and the direction of perturbation is defined through Φ, which guarantees the generation passage and the convergence of operating power-point towards GMPP. The proposed technique is validated through simulation and hardware implementation. Reduction in complexity and increase in accuracy is achieved with the MDE MPPT technique [64].

J. Grey Wolf Optimization (GWO) Algorithm

The GWO MPPT algorithm is derived from a chasing strategy followed by grey wolves for hunting and leadership pyramid [65]. To simulate the leadership pyramid, four different grew wolves are employed such as beta (β), omega (ω), alpha (α), and delta (δ). The α is reserved as the best solution, β is the second-best solution, δ is the third-best solution and ω represents the remaining wolves.

K. Flower Pollination (FPA) Algorithm

The FPA is a recently introduced biotic technique presented by researchers [66]. The FPA initially generates five random pollens (duty cycles) between “0-1” and calculates the power for each. Pollen with the maximum power designated as P_{best}. Then a new randomly generated number between "0-1" is equated with the switching probability "P" (normally set at 0.8) to decide whether the pollens will pass through the local pollination or global pollination. After passing through the local or global pollination a new set of pollens is received which is tested and provides a new P_{best}. After completion of 25 iterations, the P_{best} with the highest value is selected as a G_{best} (global best) [67].

The FPA technique is implemented for MPP under changing weather conditions and PSC [68]. Results have equated with P&O and PSO techniques. The FPA outperformed both in all weather conditions in terms of efficiency, tracking speed, and convergence speed. The drawbacks of FPA are its complex structure, high computation time, procedural complexity, difficulty to tune parameters [69], and the decision of selecting a fixed value for switching probability so the local and global pollination can be used effectively and efficiently [70]. A Modified FPA (MFPA) was proposed for MPPT of a solar PV system [71]. The structure of FPA is amended to a more complex form but the performance improvement is obtained. The performance of both techniques is checked using simulation and hardware implementation. The tracking speed and efficiency of MFPA are better to be compared to the conventional FPA algorithm.

L. Analysis of Soft-Computing MPPT Algorithms

The soft-computing MPPT algorithms have great potential to solve non-linear optimization problems. These soft-computing techniques can perform in all weather conditions and can efficiently track GMPP in the PSC, unlike conventional MPPT techniques. A detailed analysis of all soft-computing techniques has been made which includes their performance analysis, pros, and cons, improvements made in them, and their hybrid is used with other techniques. SWOT analysis for soft-computing MPPT algorithms is explained in Table III in detail having Opportunities, Threats, Strengths, and Weaknesses. From the oldest GA to the recent FPA, all effective soft-computing techniques are analyzed. A comprehensive comparison of mentioned soft-computing MPPT algorithms is presented in the table below i.e., Table III:

Table II1: SWOT Analysis for Soft-Computing MPPT Algorithms

S. No.	Algorithms	Strengths	Weakness	Opportunities	Threats
1	FLC	Accuracy, Speed, Easy, Flexible, Validated, Zero Oscillations	User & Sensor Dependent, Complex, Huge Computations	Metaheuristic Technique, Weak in Steady-State Oscillations	Huge Computations and Complex Working Problems
2	ANN	Accuracy, Speed, Easy, Flexible, Validated, Zero Oscillations	Sensor Dependent, High Memory Required, Need & Training, Tough & Time Taking	Metaheuristic Technique, Reduction in Required Memory could make ANN Demanding	The huge size of the PV System, Memory Requirements, for Small Systems
3	GA	Accuracy, Speed, Flexibility, Zero Oscillations	Complex, Parameter Tuning, Huge Initial Populations Required, Sensor Dependent	Metaheuristic Technique, weak in Steady-State Oscillations	Same and much Familiar to both ANN and FL
4	PSO	Need Low Memory, Quickly Tracks GMPP, Optimal Results, Reduced Oscillations	Complex Structure, Difficult, Sensor Dependent, huge Computations	Metaheuristic Technique, Reduction in Required Memory could make ANN Demanding	Complex Structure Resist using PSO for MPPT under UWC, no Improvement to Reduce Complexity
5	CSA	High Tracking Speed, Improved Randomness, Reduced Steady-State Oscillations	Complex, huge Calculations, Training Required, Sensor Dependency	The Multipurpose Technique, Tuning Parameters Reduced, Metaheuristic Technique	The Complex Structure makes Implementation Difficult, and the Burden of huge Computations

6	ACO	Good Convergence Speed Reduces SS Oscillations	Complex Structure, Difficult, Sensor Dependent, huge Computations	The Multipurpose Technique, Tuning Parameters Reduced, Metaheuristic Technique	Needs a lot of Improvement to Compute with other Soft-Computing Techniques
7	FF	Simple, can be Implemented at Cheap Microcontroller	Tracking Speed is not Fast, huge Computations, Sensor Dependent, Time Taking	Metaheuristic Technique, can be used, where only Quality Matters and Speed can be Ignored	It will Disappear from the MPPT field, a lot of Research is Required to Survive against Efficient Techniques
8	RSA	Easy Implementation, Low Memory	Low Speed, no proper Design, based on Uncontrolled Randomness, Sensor Dependent	It could be a Base for Developing Great Techniques	RSM in the Present Form is not Much Useful
9	ABC	Easy Implementation, Tracks GMPP under PSC	Complex Structure, low MPP Tracking Speed, Sensor Dependent	The Multipurpose Technique, Tuning Parameters Reduced, Metaheuristic Technique	Low Tracking Speed is a Resistive Part for its Selection for MPPT and GMPPT
10	NLM	Easy Implementation, Fast Speed	Unable to Perform under PSC, Complex, Vast Computations	Improve to able to perform under PSC	It Failed to get Attention as the MPPT Algorithm
12	GWO	Tracking Speed is Good, High Tracking Accuracy	Complex Structure, huge Computations, Parameter Tuning, Sensor Dependent	The Best Technique, Reduction of Computational Load, Metaheuristic Technique	Huge Calculations for MPPT under UWC.
13	FPA	Fast-Tracking Speed, Fast Convergence, High Tracking Accuracy, Effective use of Randomness	Complex Structure, huge Calculation, Large number of Tuning Parameters, Sensor Dependent	Vast Implications, Metaheuristic Techniques, Need Improved Structure	Huge Calculations for MPPT under UWC, huge Calculations should be used for PSC only

Table II1: Performance Assessment of Soft-Computing MPPT Algorithms

S.No.	Algorithm	Structural Complexity	Memory	Computational Complexity	Execute Time	Depend at Array	Parameter Tuning	Ref.
1	FLC	Average	Large	High	Average	Yes	Yes	[34]
2	ANN	High	Large	High	High	No	No	[39]
3	GA	No	Few	Average	Average	No	Yes	[43]
4	PSO	Average	Few	Average	Average	No	Yes	[45]
5	CS	High	High	High	Average	No	Yes	[50]
6	ABC	Average	Few	Average	Average	No	Yes	[61]
7	ACO	Average	Few	Average	Average	No	Yes	[51]
9	RSA	Average	Few	Low	High	No	Yes	[58]
11	DE	Average	High	High	Average	No	Yes	[62]
12	GWO	Average	High	High	Average	No	Yes	[65]
13	FPA	Average	Few	Average	Low	No	Yes	[66]

IV. DISCUSSION

The design and performance of each algorithm are evaluated at all the standard benchmarks and the results are summarized in Table I to Table IV. There is no such algorithm that can outperform the rest under all weather conditions. Each algorithm has its own strength and weaknesses under different conditions. The engineers have to select the optimal MPPT algorithm based on the prediction of weather conditions in that specific area by calculating the implementation complexities and performance of all the techniques under those predicted conditions.

V. CONCLUSION

After the detailed analysis of the performance, pros, and cons of all conventional and soft-computing techniques it can easily be said that there is no single MPPT technique that can be selected alone for all weather conditions. If one technique is simple, it cannot perform efficiently in PSC and if one can perform efficiently in PSC it has a problem of complexity and huge calculations. Criteria for the assessment of an algorithm are that the algorithm should be simple, easily implementable, ability to differentiate between LMPP and GMPP, quickly and accurately tracks MPP under uniform weather conditions and partial shading conditions, and also should not be dependent on the electric parameter of PV panels and zero steady-state oscillations.

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Authors Contributions

The author, Muhammad Mateen Afzal Awan, confirms sole responsibility i.e., study conception and design, data collection, analysis and interpretation of results, manuscript preparation, and technical implementation.

Conflict of Interest

The author declares no conflict of interest and confirms that this work is original and not plagiarized from any other source, i.e., electronic or print media. The information obtained from all of the sources is properly recognized and cited below.

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