# A Comparative Study of Conventional and Soft Computing Based MPPT Techniques for PV Systems under different Operating Conditions

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***Abstract*—This study compares conventional and soft computing-based Maximum Power Point Tracking (MPPT) techniques for photovoltaic (PV) systems under various operating conditions. The analysis focuses on efficiency, adaptability, and reliability, revealing significant advantages of soft computing methods in dynamic environments.**

***Index Terms*—MPPT, photovoltaic systems, soft computing, conventional techniques, efficiency, adaptability**

## I. INTRODUCTION

More recently, various soft computing MPPT techniques have been proposed in the literature, all of which have their own unique advantages, and disadvantages. In general, it performs better using soft computing based MPPT control methods, methods based on fuzzy logic control, ANN, ACO, were seen to be highly precise and stable when the cell parameters changes, as perturbation based methods have the problem to oscillate the system around MPP [1]. As a result, this study provides a comprehensive comparison based on experimental findings of various soft computing methods, such as ANFIS based systems, ANN based systems, GWO based systems and PSO based systems for MPPT techniques of PV systems. It also analyses the impact of the nature of load and the climate upon the output variables of photovoltaic systems. The comparison discusses the outcomes of these techniques based on the tracking speed, efficiency, accurate MPP and the stable MPP in the course of assignment changes. In all, soft computing based methods are a better choice over conventional methods based on the outcomes discoursed and the comprehensive comparative study of various MPPT techniques for productivity.

Photovoltaic panels have a nonlinear voltage-current characteristic which is described by the Shockley diode equation and contains one peak, called maximum power point (MPP) [2]. The PV panel can generate maximum output electrical power if it operates exactly at the point where the resistance is equal to the characteristic load resistance. Therefore, for maximum power transfer to be achieved, an MPPT controller is used. There has been a significant amount of research performed on MPPT over the past three decades. Conventional MPPT methods, such as hill climbing and perturb and observe, have been thoroughly studied and examined for possible enhanced performance. A design for a high step perturbation value to track the MPP quickly during rapidly changing atmospheric conditions was proposed. However, unfortunately, the PV cell voltage consumption reduces the efficiency. Furthermore, conventional MPPT controllers are manually designed and can sometimes lead to higher oscillations around MPP and thus hysteresis between modes which are not switching off under changing atmospheric conditions..

## II. CONVENTIONAL MPPT TECHNIQUES

In the Inc regental Conductance (IC) method , output power is maximized by matching the module's output conductance to the conductance of the incremental change in voltage, that is; dP=dt0 dI=d(t-dt)/ dt=0. This algorithm will accurately track the MPP and will not remain in the Cementous Region. The disadvantage of the IC technique is that it becomes complex and requires more computation time and more microcontroller architecture. This algorithm is also more costly and consumes more power. MPP tracking can also be hampered by changes in solar radiation and temperature [3].

The P' and O' algorithm is the simplest algorithm for MPPT. It works by perturbing the voltage at the module terminals and comparing the output power of the PV module under consideration. When the output power is less than that obtained before the perturbations, it implies that the operating voltage of the module is greater than the MPP and, thus, the operating voltage of the module is decr eased. Conversely, when the output power is greater than that obtained before the perturbations, it implies that the operating voltage of the module is less than the MPP. The value of the operated voltage of the module is then increased. The algorithm is robust, easi ly implemented and has a simple control structure [4].

Conventional MPPT techniques are necessary for maximizing the power generation in PV systems. These conventional techniques are based on classical control and power electronic theories. These techniques compare the voltage and/or current characteristic of PV system to locate the operating point where the maximum power is generated by desiring to track the maximum power point (MPP) continuously. These conventional techniques make use of algorithms of control technique such as Proportional-Integral (PI), Proportional-Resonant (PR), State-space, timer, Compensators etc. The techniques are as follows: Perturb and Observe (P&O) technique, Incremental Conductance (IC) technique, Fractional Open Circuit Voltage (FOCV) technique, Fractional Short Circuit Current (FSCC) technique, Fuzzy Logic Control Technique, etc.

A. Perturb and Observe (P&O)

This approach has been widely adopted for the simplicity and low cost of impel- mentation algorithms in digital embedded systems, the absence of sensors, and the ease of identifying the MPP. However, when considering the problems that arise operating conditions different as the presence of perturbations, the low tracking speed and the ease of establishing oscillations around the highest point of power (HMP). The limitations of the P&O algorithm can be improved by introducing new techniques such as IARV [5]. Different adaptive algorithms can also be introduced, although they have the disadvantage of needing sensors, the con-. However, when considering the problems that arise under different operating conditions, simply the presence of disturbances, the low tracking speed, and the ease with which oscillations are established around the maximum point of power (MPP), these limitations can be improved by introducing new techniques such as incremental conductance [added: c419f8cf-f41c-45a7-beb8-52f3278bdeff].

Perturb and Observe (P&O) was one of the first algorithms implemented in MPPT controllers. The general concept of the P&O algorithm is to perturb the operating voltage of the PV array and observe the change in the array power, dP, due to the perturbation [6]. Based on the sign of the voltage perturbation, the algorithm can determine whether or not to continue adjusting the array voltage until the MPP is found. There are some limitations of the P&O algorithm. That are: (1) oscillations around the MPP in the P&O are reduced by introducing large perturbations when the MPP is getting closer; (2) operating close to a local disturbance or cloud edge in Partial Shading Conditions (PSC) may cause convergence to an undesired point in the MPP search space; (3) Fast Irradiance changes can cause the P&O algorithm to shoot over the global MPP. These limitations greatly affect the performance of the P&O under different operating conditions and its performance is degraded notably in PSC and also under high dynamics of the solar radiation.

B. Incremental Conductance (INC)

The traditional INC method needs a high frequency of observation to make the decision, but at the same time, it is not only computationally expensive but also a cause of high-power loss due to the frequent switching ON and OFF of boost DC/DC converter. It also increases the voltage and current oscillations beyond the intend limit. That is why, to mitigate the problems faced due to the traditional INC method; the concept of the modified or improved perturb-nulling incremental conductance (M/PINC and INC2) method is repeatedly proposed. The concept of modified or improved perturb-nulling incremental conductance (M/PINC and INC2) method is presented in literature as the amalgamation of both P&O and INC referred to INC2 method and it is a perturb and observe type MPPT algorithm, the only distinction is that unlike traditional INC, it perturbs the array voltage slightly and the tracking decision is made from the third inequality by comparing the first and second-instantaneous output power behaviors. The ratio of dtg/2 (δshown in the figure 5 and is called the hysteresis width or switching width) is equivalently set to the inverse of the sampling frequency DSP and thus without interrupting the switching of the power or the control of the booster for any DC/DC, ts, δ, dtg, and the power switching frequency fs has inevitably been interrelated. The significant expressions which are important in MPPT control and are directly related with INC are Ivand Is shown in Eq. (19) and (20) and Omega (ω) is shown in Eq. (24).

The incremental conductance (INC) maximum power point tracking (MPPT) technique has learned considerable popularity in recent years due to its numerous advantages [6]. Incremental conductance (INC) MPPT algorithm is a perturb and observe type algorithm which compares both instantaneous and incremental conductance to track the maximum power point [7]. The circuit structure for the MPPT is straightforward, and parameters can easily be configured, making it simple to model and simulate. Unlike P&O, it has the capability to conduct a new search for MPP when the tracking error is low. When the change in the power-voltage (P-V) characteristics of the given solar array is observed the INC, method performs considerably without oscillations around the MPP under rapidly changing temperature and solar radiations. The INC method, not like the FC (fixed step size), is able to respond quickly and robustly to the rapid changes in the PV terminal in real time, resulting in smooth and consistent responses when the environmental conditions are both unstable such as under variations in solar irradiance with temperature, is noticed. Despite of the fixed and adaptive configuration, it executes constant and speedy monitoring. The INC algorithm is tried and tested, and it provides for maximum power extraction efficiency in a laboratory setting in a variety of atmospheric environments [8].

## III. SOFT COMPUTING BASED MPPT TECHNIQUES

Several works have been published recently yet the SC and dimension reductions (DR) models such as functional approximate SC, decision trees, ANN, and nonlinear mapping have gained emphasized on aspects in the MPPT advancement and of inherent unpredictability, environmental stress and also designed to function in wide range of working conditions. Kang et al. proposed a P&O MPPT technique based on SC NM which is designed through algorithm improvement to lessen the hunting actions and the perturbations aspects that leads to tracking the stability and efficiency of the MPP. Another SC-based MPPT technique, ELBC MPPT was developed whereby a fuzzy inference with a low computation power was investigated for the interaction between the PV panel terminal voltage and perturbation value. The exponential output scale ratio was modeled and NM is used because of its reliable drive towards global MPPs. Additionally, the active fuzzy system was introduced and the controllers were modified to maximize the models' efficiency and also guaranteed the fast-faster model than the other methods. Recently, a wind-driven SC tracking the global catastrophe was ready and NM is used for locking MPP, produced on the base on the highest possible power function gradient. The SC is used because of its reputation in the applications and potential global maximum that leads to MPP tracking by PWM converter. Besides the SC model-based MPPT methods, the methodologies based on combination of DR and SC models have been given particular attention, due to its broad range of adaptability for non-linear mapping, potential to remove sensitive burden of model re-training and HV-prohibited model collaborations. In [3].

Maximum power point tracking (MPPT) is essential to the photovoltaic (PV) power generating system as MPPT stands for the enhancement of the PV panel efficiency [9]. Conventional MPPT methods such as IW, P&O, and HC use extreme point measurements to catch MPP, which increase the overall efficiency of PVS on wasting of time. Diverse soft computing (SC) based MPPT methods have gained a lot of importance as alternatives to conventional MPPT techniques. Soft computing methods include FLC-based techniques, ANN-based methods, etc because of their benefaction of trial-and-error process clinging to converters' non-ideal characteristics and system imperfections [10].

### A. Artificial Neural Networks (ANN)

Figure 3 shows the basic organogram of the ANN [3]. There are many layers in an ANN, but as shown in the figure a three-layer model is used. The input neurons I in, V in and structure parameters are akin to ambient temperature (T a), solar irradiance (G m) and panel temperature (T m) etc. The hidden neurons perform

the major function, that is, function approximation like F (I in, V in) and the output layer is responsible to produce the specific value of the function, such as the output power (P out). The weights in the neurons are tuned using different optimization algorithms, and in training mode the input-output mapping is performed. So, finally the ANN is able to forecast the voltage, current, and power of the solar modules on the basis of structure parameters, without using any simplified or approximate model of the solar modules.
An Artificial Neural Network (ANN) is a system that is made of large number of highly interconnected simple computational units called as neurons which work in harmony to solve problems by preparing and refining the models on the basis of available data [11]. So, typically researchers in diverse electrical, electronic and computer engineering fields use ANNs to predict the I, V, and P curve of the solar modules without using classical equivalent model of the solar module. The implementation of the ANN is quite simple and user adaptive, hence it is used in MPPT [12].

B. Fuzzy Logic Control (FLC)
The transfer functions are selected by the design purposes of the PV system, all phenomena are modelled with changing variable temperature and obtaining constant illumination [13]. Unsurprisingly, it is difficult for the characteristic of the PV power system of the function-based modelling to be anticipated. With the help of such classical tests, the simulated results of the power system’s dynamic rules should be gathered and furnished. To all modelling, the voltage-based approach of the PV power system is carried out with the Matlab package for correctness of anticipated transient variable-based modelling rules. In such studies, hard computing methods are applied since they can help to improve the development of the methods FLC, ANN, ANFIS, and so on, of the power filtering operation, and the ability of these methods to optimize the parameters of the control [14]. The performances of the mentioned techniques are compared with this study and their advantages and disadvantages are evaluated. As a result, it is newly revealed in the literature to show great success in the application of these techniques to the modeling of natural constant changing processes such as PV power systems at full load.
In this study, FLC strategy based MPPT technique is presented for the PV system. The output power reference p* values, focus on operational voltage, Ge control of the pv system by means of a general power modelling approach employed using the possibilities of the PV systems. The operation of the PV power system is controlled by tracking the maximum-power point (MPP) using the irradiation and temperature sensing. The MPP characteristics of the PV system at various temperature and insulation values are determined. These assumed voltage and current transfer functions are intended to provide specific parameter-adjustable filtration effect so that the various curves of the PV system operating would actually be approximated by conventional PV modeling [15].

## IV. COMPARATIVE ANALYSIS

In [22], initial data model about the ANN parameters are not optimal and also converged more slowly. The P&O method tracking performance is better than the other two. The best solar battery self-learning MPPT algorithm is Hill Climbing, and the average conversion efficiency of the whole point is 99.70%. Therefore, when there is no special need for fast switching, select radiation MPPT, Hill Climbing is the best MPPT algorithm for optimal economic operation. When the radiation changes greatly, the battery and the solar panel output voltage will be partly mismatched. For partial pressure sorting, when one of the solar panels is seriously shadowed, the traditional MPPT algorithm may fall into local extremes. At this time, learning MPPT can make up for the defect and find the global extremum in the short term. MPPT research at home and abroad has shifted from traditional control and intelligent control to learning MPPT.
Conventional MPPT techniques are based on direct programming whereas Soft computing techniques are based on the both human learning and nature inspired techniques so, they are more adaptive to the curve changes as well as uncertainties in the system. Some of the other state of art techniques applied are FLC, BBO, BPO, WOA, CSA, ACO, AQ, etc. On the basis of the simulation results, each algorithm’s merits and demerits are discussed in the literature which includes algorithm complexity, convergence rate, steady state time, and its suitability and adaptability for different environmental conditions [8].

Maximum Power Point Tracking (MPPT) plays a vital role in the improvement of photovoltaic (PV) systems in extracting maximum energy when varying environmental conditions like solar radiation, load changes, partial shading, temperature fluctuations, etc. The performance of PV system highly depends on the PV module characteristics which becomes very non-linear with varying environmental conditions [2]. Few important MPPT techniques based on conventional and soft computing techniques are discussed here. A comparative analysis by experimental testing of the Perturbation and Observation (P&O), Incremental Conductance (IC), Hill Climbing (HC) MPPT techniques; and Firefly Algorithm (FA), Particle Swarm Optimization (PSO), Horseshoe Bat Algorithm (HBA), and Squirrel Search Algorithm (SSA) as soft computing techniques are analyzed.

A. Performance Evaluation Metrics

The evaluation of operating condition of different converters is presented under many conditions. They considered eight conditions i.e. [1] step change in irradiance, and [2] nuclear reactor-power light, [3] cloudy in irradiance, [4] fixed irradiance, [5], [6] and 11 NSST-NSCT interval condition, the global as standard irradiance and room environment condition, [7] variation from standard panel efficiency, Pmp, outside temperature, and wind speed for efficiency up, [8] reduction of panel efficiency for recession of panel efficiency and lastly a variation from unity power factor to 0.85 and 0.95 power factor lagging for inverter cop-factor.C-Simulation has been done for load condition variation in the response of each of the selected MPPTs. Pre-diode and tails of current island is not equal for the Osceola MPPT values shown in the Fig. To diagnose converging or tracking we can only see identifying the current tunnel before MPPT but not used. Full-diode conductance relies on the type of panel and temperature, which calculates it very inaccurate or misleading during start-up. The derived Full Diode: ERDAFF depends on the relative accurate value of ERDAFF, voltage panel Vdc, diode temperature Td and temperature T with respect to Working condition parameters of each MPPT.

There are many performance parameters which are to be considered while comparing the performance of different MPPT algorithms. These performance parameters vary with the site of installation and the disturbance present in the operating environment of PV System. The most common performance parameters are steady state, dynamic conditions, AC, and DC side harmonics as well as overall system output. The maximum Zew der Line is one of the most important performance metrics for an MPPT for both static and dynamic response. The lower maximum dcdc voltage regulation error leads to the improvement of the maximum system power output and the reliability of power process. Another research article found by different author is for evaluating the dynamic performance where they claim there are four factors which are to be considered: reducing the power losses, start-up time, overshoot, special settling time. The dynamic performance is measured by comparing power responses to different parameters of the active function and then computing the suggested coefficients from the overshoots, start-up times, and settling times. Area determination between optimal power curve and estimated power curve as a function of time. Total absolute error more than 0.5% is an accepted settling time error. Situation 1 error overcomes the reversed settling time which is critical. In our system, global maximum will be found which is not the true maximum if P-V curve is under partial shading among multiple local peaks [18]. In the case of simultaneous tracking of multiple global maxima of P-V curve, in PSO the convergence rate is faster than other algorithms in terms of time.

## REFERENCES


[1] S. Chtita, S. Motahhir, A. El Hammoumi, A. Chouder et al., "A novel hybrid GWO–PSO-based maximum power point tracking for photovoltaic systems operating under partial shading conditions," 2022. ncbi.nlm.nih.gov

[2] C. Mai, L. Zhang, X. Chao, X. Hu et al., "A novel MPPT technology based on dung beetle optimization algorithm for PV systems under complex partial shade conditions," 2024. ncbi.nlm.nih.gov

[3] B. Newman, P. Kumar Choubey, and N. Rajani, "P-Adapters: Robustly Extracting Factual Information from Language Models with Diverse Prompts," 2021. [PDF]

[4] H. Sahraoui, H. Mellah, S. Drid, and L. Chrifi-Alaoui, "Adaptive maximum power point tracking using neural networks for a photovoltaic system according grid," 2021. [PDF]

[5] B. Satya Varun Sai, R. Mohanty, S. Mohanty, D. Chatterjee et al., "An efficient MPPT techniques for inter-harmonic reduction in grid connected hybrid wind and solar energy systems," 2024. ncbi.nlm.nih.gov
[6] Y. Cui, Z. Yi, J. Duan, D. Shi et al., "A Rprop-Neural-Network-Based PV Maximum Power Point Tracking Algorithm with Short-Circuit Current Limitation," 2018. [PDF]
[7] H. T. Yau, C. J. Lin, and Q. C. Liang, "PSO Based PI Controller Design for a Solar Charger System," 2013. ncbi.nlm.nih.gov
[8] Z. Li, W. H. Chen, J. Yang, and Y. Yan, "Dual Control of Exploration and Exploitation for Auto-Optimisation Control in Uncertain Environments," 2023. [PDF]
[9] H. Shareef, A. Hussein Mutlag, and A. Mohamed, "Random Forest-Based Approach for Maximum Power Point Tracking of Photovoltaic Systems Operating under Actual Environmental Conditions," 2017. ncbi.nlm.nih.gov
[10] Q. Lian, P. Han, and N. Mei, "A Review of Converter Circuits for Ambient Micro Energy Harvesting," 2022. ncbi.nlm.nih.gov
[11] S. Alias Sarang, M. Amir Raza, M. Panhwar, M. Khan et al., "Maximizing solar power generation through conventional and digital MPPT techniques: a comparative analysis," 2024. ncbi.nlm.nih.gov
[12] I. Ul Haq, Q. Khan, S. Ullah, S. Ahmed Khan et al., "Neural network-based adaptive global sliding mode MPPT controller design for stand-alone photovoltaic systems," 2022. ncbi.nlm.nih.gov
[13] S. Kumar, S. Gupta, V. Pratik, and P. Brunet, "Comparative Study of MPPT and Parameter Estimation of PV cells," 2023. [PDF]
[14] M. Shafiul Alam, F. Saleh Al-Ismail, M. A. Abido, and A. Salem, "High-Level Penetration of Renewable Energy with Grid: Challenges and Opportunities," 2020. [PDF]
[15] R. Sharmin, S. Shafayet Chowdhury, F. Abedin, and K. Mujibur Rahman, "Implementation of MPPT Technique of Solar Module with Supervised Machine Learning," 2021. [PDF]
[16] M. Ahmed, I. Harbi, R. Kennel, J. Rodríguez et al., "Maximum Power Point Tracking-Based Model Predictive Control for Photovoltaic Systems: Investigation and New Perspective," 2022. ncbi.nlm.nih.gov
[17] L. Zaghba, A. Borni, M. Khennane Benbiotur, A. Fezzani et al., "Enhancing grid-connected photovoltaic system performance with novel hybrid MPPT technique in variable atmospheric conditions," 2024. ncbi.nlm.nih.gov
[18] M. Amin Ghasemi, M. Parniani, S. Fariborz Zarei, and H. Mohammadian Foroushani, "Fast Maximum Power Point Tracking for PV Arrays under Partial shaded Conditions," 2018. [PDF]
[19] S. Mumtaz, L. Khan, S. Ahmed, and R. Bader, "Indirect adaptive soft computing-based wavelet-embedded control paradigms for WT/PV/SOFC in a grid/charging station connected hybrid power system," 2017. ncbi.nlm.nih.gov