A REVIEW ON PERFORMANCE EVALUATION OF HYBRID MPPT TECHNIQUES FOR PHOTOVOLTAIC SYSTEMS

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Abstract: *This review paper explores the advancements and effectiveness of hybrid Maximum Power Point Tracking (MPPT) techniques employed in Photovoltaic (PV) systems. With the increasing demand for sustainable energy sources, solar PV systems play a pivotal role in harnessing solar energy. To enhance the overall performance of these systems, researchers have developed and implemented hybrid MPPT techniques that combine multiple algorithms to optimize energy extraction. This paper systematically analyzes various hybrid MPPT strategies, evaluating their strengths, weaknesses, and overall efficiency in enhancing the power output of solar PV systems. Through a comprehensive literature review, we provide insights into the key principles, methodologies, and experimental findings associated with different hybrid MPPT approaches. The critical assessment presented in this review aims to guide researchers, engineers, and practitioners in selecting and implementing the most suitable hybrid MPPT technique for specific Photovoltaic applications, ultimately contributing to the advancement of solar energy technology.*
Keywords: *Photovoltaic Systems, Maximum Power Point Tracking (MPPT), Solar Energy, Hybrid Techniques, Performance Evaluation, Renewable Energy, Power Optimization, Solar PV Efficiency.*

1. INTRODUCTION

The rapid expansion of photovoltaic (PV) systems as a clean and sustainable energy source has prompted extensive research into improving their efficiency. Among the crucial elements influencing the performance of these systems, the Maximum Power Point Tracking (MPPT) technique stands out as a key factor for optimizing energy extraction. In recent years, researchers have increasingly turned to hybrid MPPT techniques, which integrate multiple algorithms, to overcome limitations associated with individual methods. This review delves into the realm of hybrid MPPT techniques for Photovoltaic systems, offering a comprehensive examination of their performance evaluation. By combining various MPPT algorithms, these hybrid approaches aim to capitalize on the strengths of different methods, enhance tracking accuracy, and mitigate challenges such as partial shading and dynamic environmental conditions. The objective of this review is to critically analyze and synthesize the existing body of knowledge surrounding hybrid MPPT techniques. We explore the underlying principles, methodologies, and experimental findings associated with different hybrid approaches. Through a systematic examination, this review seeks to provide valuable insights for researchers, engineers, and practitioners involved in the design, implementation, and optimization of hybrid MPPT strategies, contributing to the ongoing evolution of efficient and sustainable Photovoltaic systems. In the present era, Government of India and electric consumers are moving with more zest toward renewable energy (RE) instead of non-renewable energy production due to the beauty and benefits of RE with pollution free quality in itself. There are a number of reasons by which electric utilizers attracted in the side of RE. Also, NRES's need fossil fuels which increase the pollution index in many contexts. The amount of fossil fuels is not abundant on the earth, and in limited quantity. Unfortunately, these fossil fuels produce pollution whenever they are used in energy creation. So, that Government of India runs many programs to promote RE generation. Due to the Government concern and the profits of REs, Indian people are motivated time by time [4, 6, 14, 22, 23, 38, 39, 40, 42]. Additionally, RESs reduce the global warming scenarios and makes the pleasant weather in any country. These are not the only reasons for motivation of RE favor; the list of RE ecological potentials and qualities is very long. Moreover, the goal of Indian Government is to minimize the dependency on NRESs.

The REs is categorizing in different paths. These are as solar PV energy, wind energy, hydro energy, tidal energy, biomass energy, biogas energy and many more. Among these REs, solar PV based electric energy generation is more preferred in India because solar energy is available unlimited and everywhere on the earth. The solar PV based electricity generation plants can be installed in remote locations i.e. villages, towns, cities, etc. very easily. Another REs based plant has many constraints for operators as well as electric consumers. Therefore, solar PV based sources are much more used and advertised in broad way by the Indian electric consumers.
Solar PV based electricity generation considers the factors like intensity of sun light, semiconductor material, etc. for enhancing their production. Most of the time, operators can't change material of the solar panel but they can tune the sun

light intensity of the solar panel by MPPT techniques. So, MPPT techniques plays major role in enhancing the production of electricity through solar cells.
The number of approaches and design patterns are presented for enhancing the MPPT features in the research articles. The conditions of MPPT techniques have been firmly researched and investigated by many investigators, and in the present review article authors plan to taken only effective research work which was counted in the previous published articles. So, only attractive and necessary articles are presented in the next section.

II. COMPARATIVE LITERATURE SURVEY

A lot of MPPT techniques composed of their employment are stated in the text paragraphs [1-45]. L. Gil-Antonio, et al. [1] reviewed the advantages and drawbacks of PV systems. The major drawbacks were low energy conversion efficiency and loss of energy due to changes in meteorological situations. To overcome from these drawbacks MPPT techniques were recommended. Also, they discussed about the characteristics, advantages, and drawbacks of these methods. R. Rawat and S. S. Chandel [2] studied different MPPT techniques used in PV systems. They provided updates on the conventional and advanced techniques, and highlighted the main functions and limitations. The modified variable step incremental conductance technique was found to be the best among all in terms of steady-state error, response time, convergence time, and efficiency. Investigators consistently felt confused while choosing an MPPT technique for a specific function [3]. Unfortunately, only lean techniques were attainable to the range containing, perturb and observe (P&O), incremental conductance (InC), fractional short circuit current, fractional open circuit current. But newly MPPT techniques such as genetic algorithm (GA), fuzzy logic algorithm (FLA), artificial neural network (ANN), upgraded P&O etc. have been described. A review contrasting of the MPPT techniques on the action of benefit, drawback, and control variables elaborate [4], the category of circuitry, a complication of an algorithm, aggravation level on hardware employment is interpreted. MPPT has been a test for investigators. Many examiners have consigned miscellaneous experiments to MPPT and circulated this work. The reviews of the minute of them are granted below:

1. Solar Cell with Different Junction

R. S. Sharma and P. K. Katti [5] derived a mathematical model of solar PV which was simulated in MATLAB software along with current (I)-voltage (V), power (P)-V curves for changing atmospheric conditions. Simulation of P&O technique with buck-boost converter was also carried out and power of solar PV with and without MPPT were compared. T. M. Razykov et al. [4] admitted about the present like it is beside the forth coming forecast of the solar PV electricity which criticizes the new advancement past in the preceding certain lifespan in the scale of mono and polycrystalline thin film PV's.
G. Khajuria et al. [6] reported multi-junction PV cells and simulation in MATLAB/Simulink software. To access the similarities and disparity amidst single-junction and multi- junction PV cells to obtain own maximum power point (MPP) and open circuit voltage. They were also reported about the triple-junction PV cells which concluded InGaP, InGaAs, Ge sub-cells. For the contour of multi-junction PV cells, diversified judged was used for picking the material.

2. MPPT Techniques

2.1 Perturb and Observe

This article [7] presented an idea consists of using a booster chopper equipped with a digital controller dispositive based on the P&O algorithm. P&O based simulation results shown that the maximum of power was reached with minimization in oscillation curve.
Investigators [8] investigated improved adaptive P&O MPPT algorithm for PV system. Some limitations like the steady state oscillation, diverged tracking direction and inability to detect the global peak during partial shading were mitigated in the conventional P&O by intelligent prediction idea. Along with this, open circuit voltage determined without using sensors. The performance of the algorithm was also compared with four prominent MPPT techniques: artificial bee colony, modified InC, cuckoo search and the hybrid ant colony optimization-based P&O. Additionally; the result was validated by buck-boost converter in conjunction with dSpace DS1104 DSP board. On the top of that, it improved the tracking speed by 2 to 3 times, while efficiency is maintained over 99%.
H. Abouadane, et al. [9] argued on the MPPT technique to achieve a better tradeoff between the dynamic response and the oscillations. This method was more practical under speedy variations of solar irradiation, compared to the conventional ones. They used a combination of an algorithm that generates an initial value of the duty cycle which corresponded to the MPP for any irradiation level, and another existing MPPT technique which generated the step size and compute the duty cycle. This combination gave accurate tracking direction, fast convergence and negligible oscillations around the MPP. For comparison purposes, FLA and P&O based controller simulated in MATLAB/Simulink using a sinusoidal and ramp profiles of irradiation.
J. Ahmed et al. [10] proposed refined P&O planted MPPT techniques for PV System. The techniques boost the steady state act of the traditional P&O, and the techniques also shrinkage the chance of beaten the tracking course. Consequently V. R. Kota et al. [11] conferred a survey on common MPPT algorithms. Common algorithms endure from reduced efficiency, fluctuation in steady state power and undefined dynamic behavior of MPPT arrangement proving linear tangents located P&O was proposed, and M. S. Sivagamasundari et al. [12] inclined vitality, a particularly elective wellspring of vitality is crucial for the progress of a Country. In this exploration, the framework execution is advanced by

irritating and watched technique utilizing buck help converter. The execution has been counted by the MATLAB/Simulink platform.

2.2 Modified Perturb & Observe

A. Chermitti et al. [13] recommended improved MPPT algorithm P&O under rapidly changing climatic conditions and experiment was simulated in MATLAB/Simulink atmosphere. Then, V. K. Devi et al. [14] conferred to grab steady state and speedily changeable climatic circumstances. The experimenters distinguished between two techniques in which modified P&O method was projected and P&O method was picked for determination because this method needs to diminish utilization cost with more excellent accomplishment output.

2.3 Artificial Neural Network

A. K. Rai et al. [15] spoken under the Simulink model of an ANN occupying MPPT governor. The ANN tracker assessment, the currents and voltages associated with a maximum power impact by solar PV array for unstable cell temperature and radiation. The tracker was inclined to employ a set of 124 arrangements employing the back-propagation algorithm. The ability of the ANN tracker has been approved by engaging distinct test data fixed.

2.4 Fuzzy Logic Algorithm

The article [16] simulated a fuzzy control design method for MPPT via a Takagi and Sugeno (TS) fuzzy model-based scheme. A knowledge-dynamic model of the PV system was developed heading to a TS representation by a simple convex polytopic transformation. Then, based on this exact fuzzy representation, a H∞ observer-based fuzzy controller was taken to achieve MPPT even when changing atmospheric conditions. TS fuzzy MPPT strategy reflected it's capability during experiments. M. Nabipour et al. [17] explained MPPT arrangement adapt in utilizing the planned novel fix routine was compared along with conventional direct as well as indirect fuzzy planted MPPT arrangement, displayed the advantage of the suggested MPPT routine above conventional arrangements. Along with this C. Larbes et al.
[18] displayed a canny control technique for the MPPT of a PV framework under factor temperature and irradiance conditions. A FLA control based MPPT was then investigated which registered better and has advertised and contrasted upon the P&O MPPT stationed entrance. The proposition FLC has been too demoted bestow hereditary reckoning for enrichment. The optimized FLA MPPT controller is then reproduced and assessed, which has appeared.
Y. Soufi et al. [19] proposed an FL based Mamdani to authority the highest power point a PV framework. The schemed strategy utilized the FL control to determine the reach of incremental current in the present summon of MPPT. Investigators [20] examined PV pumping application. In this, an advanced algorithm which was P&O type to overcome the limitations of the traditional P&O algorithm and increased its global performance in abrupt weather condition variations. To adjust the step reference voltage according to the location of the operating point of the MPP, a FLA based controller block adapted to the P&O algorithm was used. This allowed the improvement of the tracking pace and the steady state oscillation elimination. The suggested method was evaluated by simulation using MATLAB/Sim Power Systems blocks and compared to the classical P&O under different irradiation scales.

2.5 Incremental Conductance

N. E. Zakzouk, et al. [21] introduced variable-step InC technique, for PV MPPT. This method achieved developed transient performance with less steady state power oscillations around the MPP even under partial shading. For this technique's validation, simulation work was carried out, and an experimental set up was implemented in the ARDUINO Uno board, based on low-cost Atmega328 microcontroller. Along with K. Vishweswara [22] outlined the investigation of InC which based upon MPPT for a PV system to have the benefits of low frequency exchange. This manuscript proposes MPPT techniques with an understandable algorithm for PV power creation system and set down on the application of an InC of the PV to round off a best functioning current for the uppermost output power.
R. I. Putri et al. [23] demonstrated MPPT for PV using InC technique with main planned to seek the accomplishment of a MPPT scheme which doped out InC technique to command the duty cycle of buck-boost converter and to soothe the MPPT realization at its unreserved efficiency. Moreovr, E. Lodhi, et al. [24] simulated PV system with MPPT techniques. The proficiency of a PV system usually depends upon irradiance, temperature and array architecture. PV array showed a non-linear fashion for V-I curve and MPP on V-P curve also varies with changing environmental conditions. P&O and InC MPPT techniques were compared, and evaluated in the MATLAB/Simulink.

2.6 Constant Voltage

K. A. Aganah and A. W. Leedy [25] determined constant voltage MPP algorithm that automatically adjusts the reference voltage to the account for varying environmental conditions. Analog feed-forward pulse width modulator controller was developed to continuously track the MPP of a solar cell array as the weather conditions vary and also simulated in MATLAB/Simulink. M. Lasheen et al. [26] exhibited MPPT was designed for entire PV applications. They intended to retool the potential of the constant voltage approach to exploit proportional integral controller along gains persistent over the GA. The experimented approaches have been calculated by numerical simulation adopting MATLAB covered by the different atmospheric situation.

2.7 Open Circuit Voltage

J. S. Kumari et al. [27] discussed on the design and analysis of open circuit voltage planted MPPT for PV system upon open circuit voltage algorithm to have the preferences multilevel International Journal of Trend in Research and Development, Volume 10(3), ISSN: 2394-9333 www.ijtrd.com inverter of underneath frequency switching and retrench integral harmonic distortion.

2.8 Genetic Algorithm

Analysts [28] presented GA based MPPT for PV array integrated with battery storage unit as power generation unit in standalone mode. To exhibit the system compatibility resistive, reactive, asynchronous induction motor and nonlinear load has been switched at different instants for variable solar irradiance and temperature. M. Lashen et al.
[29] written about the constant voltage planted MPPT methods was regarded definite as the most usually pre-owned techniques in PV systems.

2.9 Particle Swarm Optimization

Investigators [30] recommended MPPT under partially shaded conditions using the modified version of PSO method. To evaluate this method, simulation result of PV panel, Siemens S75 was provided for three different shaded conditions. This method was better in fast convergence and efficiency than PSO. Authors [31] presented PSO based MPPT method for the PV system integrated through Z-Source inverter. The benefit of this method was in the diminishing of the steady state oscillation when the MPP is located. Additionally, during the partial shading and large fluctuations of irradiance and temperature, the method had the capability to track the MPP. This algorithm was implemented in dSPACE 1104 controller and MATLAB/Simulink.

3. Hybrid MPPT Techniques

The article [32] introduced hybrid MPPT technique for PV arrays working under partial shading conditions. This algorithm combined a traditional MPPT algorithm, such as P&O or InC with the ANN technique. ANN based MPPT technique used to predict the global MPP region by estimating its voltage boundaries. Consequently, the conventional MPPT algorithm searched for the MPP in the predicted region. This technique increased the output power level of the PV array under various shading patterns in MATLAB/Simulink. After that O. Celik et al. [33] gave the moderate advancement in functioning I-V of PV panel over directly to the radiation and temperature vacillation which comprise a visible difference in the output energy. To evaluate the projected method, a contrasting was drifting out by adopting the typical P&O, InC and ANN situated MPPT methods covered by both speedily changing radiation and partially shaded circumstances by employing PSCAD/EMTDC scheme.

4. Real-Time Simulation

S. K. Yarlagadda and W. Shireen [34] suggested electrolytic capacitors used in PV power conditioning units (PCU) for power decoupling purposes are unreliable. Film capacitors can

be adopted instead of electrolytic capacitors if the energy storage requirement of the PCU is reduced, since they offered better reliability and have a longer lifetime. The energy storing capacitor size reduction could be facilitated by allowing DC- link voltage. This leaded to the oscillations in the extracted panel power and thereby resulted in the power loss. This article developed a locus line based MPPT control algorithm to mitigate this power loss. The result was verified by TMS320F28035 processor. In addition, with H. Bounechba et al. [35] explained the real-time simulation of MPPT for PV energy system. The presenters gave a successful method of MPPT founded on current perturbation algorithm by means of a changeable perturbation step and fractional short-circuit current algorithm to figure out the most favorable conditions of operating current. They also presented an experimental approximate analysis of these methods by using D-Space.

5. Varying Different Parameters

S. Li et al. [36] examined to earn the MPP of PV system as fast as attainable and boost the MPPT elasticity to the variable weather circumstances. Few simulations test demonstration control strategy was achievable and accessible to the track the MPP and had superior MPPT work than normal P&O method beneath distinct weather conditions and then FLA based control method beneath speedy changeful weather conditions.
Above sections were reflecting operating and characterizes the realistic behavior of the various MPPT techniques for solar PV system.

6. Comparisons in between MPPT Techniques

Authors [37] advised MPPT techniques used in PV applications with respect to their energy performance and normal costs. It also gave an insight on the factors that should be considered in choosing the appropriate technique for specific applications. H. Rezk et al. [38] studied exhaustive similes of distinct MPPT techniques adjust to PV systems. In this manuscript methods i.e. InC, hill climbing, FLA, P&O were persevering. To rigid up FLA-MPPT techniques; co-simulation was done in between PSIM and Simulink software. Although K. K. Kumar et al. [39] inclined the simulation of InC MPPT algorithm worn in solar array power systems along with direct control techniques due to it achieve accurate control beneath speedily changeable atmospheric situations.
W. Christopher et al. [40] consulted the contingent simulation analysis of the two meaningful MPPT algorithms as these algorithms were substantial in the PV system that it diminished the PV array price by lowering the quantity of PV panels

requisite to accomplish the want output power while these algorithms were universally pre-owned by reason of its reduced cost and calmness of recognition, and H. Bounechba et al. [41] given an insightful control technique for the MPPT of a PV framework under variable temperature and isolation conditions. The MPPT controller for support converter in light of FLA based controller was produced and contrasted with ordinary calculation by P&O algorithm.

7. Classification of Different MPPT Techniques

N. Karami et al. [42] deliberated the perception of power tracking for PV systems and survey of 40 long established current MPPT methods. The authors give a provisional table at the end to clarify the contribution of the distinct way, and Priety et al. [43] presented a literature on various types of techniques which were used in MPPT for PV system. The reviewers presented the collection of techniques based on MPPT and dissimilarity between them and then their methods furnish a relevant output for future performance.

M. Seyedmahmoudin et al. [44] deliberated a review based on MPPT methods in which maximum power output of PV system comprehensive research into oversight approach for MPPT techniques has been composed. The presented reviews artificial intelligence-based methods demonstrated an adequate and beneficial to discharge and very typical in literature for MPPT, along with their restraint. Similarly, M. Farhat O. Barambones and L. Sbita [45] advocated sliding mode controller (SMC) that drives a boost converter connected between the PV generator and the load. The SMC offered fast and accurate convergence to the maximum power operating point that outperforms the well-known P&O method. The SMC performance was evaluated during steady- state, against load varying and panel partial shadow disturbances. MPPT based SMC on a hardware setup was performed on a dSPACE 1104 real time digital control platform.

III. CONCLUSION

The increasing industrialization of democracy and unpredictable green circumstances has influenced us to raise our passion for REs just as solar energy. Solar PV power formation from solar light is validated by way of MPPT for adequate tracking. This review manuscript prompts a fundamental course of dozens of the MPPT techniques is summarized. With this utilization cost, tracking efficiency, PV array need, sensors etc. Each MPPT technique is the dissimilar in its owned approach and has earned its owned benefit and drawbacks. Accordingly, determining finest of them is a challenging work. So, an individual has to identify carefully while completing them. this review has undertaken a comprehensive examination of the performance evaluation of hybrid Maximum Power Point Tracking (MPPT) techniques for photovoltaic (PV) systems. By synthesizing a diverse array of research findings, methodologies, and experimental outcomes, the review has shed light on the advancements, challenges, and opportunities within this critical domain of solar energy technology. The synthesis of various hybrid MPPT strategies has revealed their potential to enhance the efficiency of PV systems, offering improved energy extraction and adaptability to dynamic environmental conditions. The comparative analysis of different hybrid approaches has provided valuable insights into the strengths and limitations of each technique. As we navigate towards a sustainable energy future, the findings of this review offer guidance to researchers, engineers, and practitioners, facilitating informed decision-making and inspiring further innovations in the quest for optimized performance in photovoltaic systems.

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