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A Review of different MPPT algorithms for PV System

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***Abstract*— At the present time, for fulfilling the rising power demands and to ensure minimization in rapid global warming increase, there is a marked development of renewable energy dependentsystems. The solar PV system is the most trending system among several renewable sources based systems. For generation of electricity, one of the principal renewable energy sources used is solar energy. Nonetheless, it is important to maximize energy extracted from the PV system, because it has low conversion efficiency.Also major disadvantage is that the temperature of the solar cell affects the performance and durability of the photovoltaic panel.Therefore, to ascertain extraction of maximum power, PV system must contain MPPT controller. The PV system efficacy can be significantly enhanced with the help of MPPT.To keep an efficient check on MPP, several techniques have been suggestedand these MPPT algorithms are reviewed in this paper. This paper gives a review of the various MPPT based approaches such as INC, P&O, ANN, Fuzzy Logic and PSO based MPPT algorithms.**

Keywords—Solar PV system, MPPT, MPPT algorithms

I. INTRODUCTION

With the gradual decline in natural resources available on earth, the power sector is searching for alternate energy sources in order to meet the rising demand of power. The utilization of sources of renewable energy ensures minimization in the amount of carbon present in the earth's atmosphere which further contribute to address the rising global warming issue. **The solar PV system is the most trending system among several renewable sources based systems.** It is widely used because it has a simple structure. The PV (photovoltaic) system which usessolid-state semiconductor, on exposure to the light develops electric power. Solar cells are used to built the solar panel in which the both serial and parallel connection of large count of solar cells is established leading to the formation of PV module.In order to attain the highest output voltage these modules are connected in serial manner and to attain the highest output current parallel connection have been made. Many countries have been commercializing Solar PV systems because of their advantages such as maintenance free and sustainable in the long term. Though, dealing with nonlinear characteristics of PV array of PV systems remains the major concern. PV characteristics depends upon two major factors which are temperature and irradiance. The cause of level of irradiance can be passing clouds, trees or neighbor buildings.In figure 1, the PV generation systems block diagram is represented.

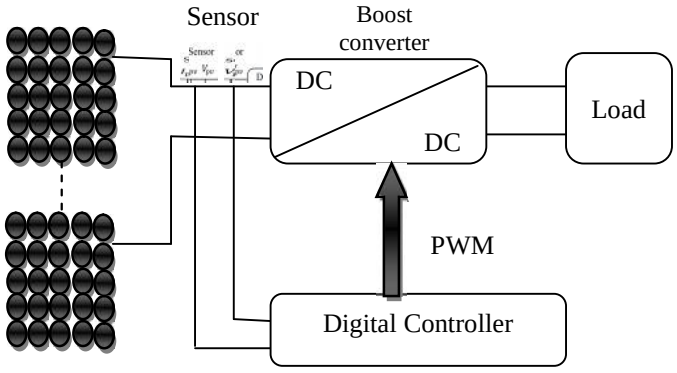

Fig. 1: Block Diagram of PV Generation System

The major categories of PV Generation System are as follows:

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- Grid-connected systems
- Standalone systems

To assure AC and DC service, these systems were developed for the purpose of operation ensuring no dependency on utility gridconnected with another source of energy and storage system.
The efficiency of PV system efficiency can be improved by applying the electronic power appliances along with the MPP (maximum power point) controller.For extraction of optimal power from the PV module, MPPT controller is used. With the help of MPPT, the efficiency of the PV system has been improved to a large extent.

II. Maximum Power Point Tracking (MPPT)

The MPPT control approach is mainly utilized to extract the highest available power possessed by PV modules in regard to temperature and solar irradiance at a specific time instant with the help of an MPPT Controller. **To keep an efficient check on MPP, several techniques have been suggested.** Many of these algorithms track very slowly which reduces the utilization efficiency. In order to enhance the efficiency of solar energy, different kinds of MPPT control approaches are utilized like, Particle Swarm Optimization (PSO), Perturbation and Observation (P&O), Incremental Conductance (INC), Fuzzy Logic Controller and Artificial Neural Network (ANN) applied with backpropagation technique, etc.
In [1], the author stated that the output attained using a PV system is regulated, then provided to DC inverter and converter by the MPPT. If the PV output voltage is greater as compared to MPP, in this case, the power transmitted to load is increased.
The author in [2] conferred the MPPT approaches for various applications for various systems. According to the fill factor and temperature of the cell, the efficiency of MPPT differs.
The MPPT performance that enhances the PV system temperature was proposed in [3]. In this, it has been analyzed that the 4% efficiency is affected due to fill factor variation with geographic areacharacteristicsand climatic conditions.
The MPPT modeling comprising of buck converter having oscillations which use0.5% less output power was presented in [4]. Kadri et al. [5] described the MPPT containing voltage control for minimizing the loss of power that occur due to errors in dynamic tracking under conditions of quick weather variation. Moreover, an alteration in power is reflected using irradiation variation by PI outer voltage regulation using the signal error and for reflection of power grid side, the components of grid current are used in order to detect the exact MPP direction.
Another technique in respect to the controller had been introduced in which the PV single-phase system possessing grid-connection with 1 kW of rated power for the enhanced performance of PV array MPP that regulates the voltage of DC link as well as meets the unity power parameter whiletemperature and solar irradiance changes suddenly [6].

2.1 Incremental Conductance (INC) Based MPPT Techniques:

For the purpose of attainingthe point of operation of MPP for flexible voltage step variations on the basis of the PV curve slope, different methods were introduced. For changing the voltage step value of the PV curve,the deceleration and acceleration parameters are implemented in the subsequent iteration steps. The PV system having flexible voltage step variation are able to keepa check on the environmental changes rapidly. Therefore, the PV energy systems ensure further production of solar energy. Moreover, due to non requirement of I-V characteristics knowledge belonging to particular PV panels, it is easily implemented whereas tuning of parameters is also not difficult [7–9].
The MPP tracking is done initiating search of P-V curve peak. This procedure makes use of two instantaneous conductance that is I/V and dI/dV for the MPPT and the location of the PV module operating pointare identified by these values in the P-V curve representing the operation of PV module is performed at the MPP havingits left and right sides in the P-V curve [10, 11].
The INC (Incremental Conductance) algorithm having a variable step size was presented in [12] for enhancing the speed of tracking of MPPT controller. This approach defines the radiation direction in order to make changes in voltage under a fast varying environment. Moreover, MPP is calculated. Hence, it results into elimination of the oscillation problem of the P&O algorithm of MPP.
Liu et al. [13] introduced an enhanced INC algorithm in which voltage with variable step size is used for estimating the trade-off among variable responses among steady-state oscillation in and variable response in terms of step size.
The contrast among 4 basic MPPT approaches under stable and changing environmental situations with the MATLAB model has been explained in [14].INC has optimal and robust performance respective of varying conditions, among these existed techniques.

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The INC suggested for the PV modules was tested under a quick-varying environment with the help ofa DC-DC converter ensuring PV at the required maximum power point voltage with connection of theisolation stage via load[15]. Saving of 15% of energy extraction losses is assured.

2.2 Perturbation and Observation (P&O) Based MPPT Algorithm (P&O MPPT):

Perturbation and Observation (P&O) Based MPPT approach can be implemented easily and it is based on PV array that is insufficient for radiation of direction. A turn of operating point in the direction of MPP occurs enabling voltage working in identical direction in case of rise in the power taken from the PV array. In contrast, A turn of operating point away from the MPP occurs in case of reduction in the power taken from the PV array and hence, results into overturning the direction of the working voltage perturbation [16-18].
Go et al. [19] discussed the P&O algorithm power oscillation that interfered with each MPPT cycle by array terminal voltage.
In order to resolve the issue of oscillation, a solution was proposed in [20] of decoupling the fluctuations of PV power that occurs due to Hill Climbing P&O in regard to the irradiance changes.
[21] presents the use of P&O algorithm in analog circuit applications.
A multivariable P&O MPPT technique is discussed by Petrone et al. [22] in respect to single-stage PV inverter. Its performance is good, however, due to the requirement to control more than one variable, the operation complexity increases.
The enhanced P&O approach has been proposed in [23] with the adaptive algorithm for adjusting the step size of reference voltage and hysteresis in steady or slowly changing climatic conditions for the purpose of minimization of the PV output power of up to 5% in contrast to conventional P&O in the dynamic environment scenario.
With the aim of enhancing the potential of MPPT, the biological swam chasing PV MPPT algorithm has been proposed [24].
The PV array mathematical models based on the P&O approach is being suggested in [25].
Tomaximize the output power of the array by continuous tracking of MPP, the P&O approach-based PV system was modeled and scrutinized by the authors in [26].

2.3 Artificial Neural Network (ANN) Based MPPT Techniques:

ANN-MPPT approach utilizes an artificialneural network which has multilayered feedback with a reverse propagation trained network. The 2-stage offline trained MPPT based on ANN with 2 cascaded ANNs,evaluates the irradiance and temperature level from the current and voltage signals shown by thePV array. This approach performs better under the quickly varying climatic conditions also for both the constant and variable instants with generally minimizing the training set; the 3-layer RBF NN is used for the implementation of MPPT.Home energy management system has been presented in [27] in which the neural network is used which is responsible for monitoring the home loads, predicting the generation of PV andutilization of home, and depending upon the choice of energy persuasion of the consumers. The implementation of the 2-stage MPPT was done for enhancing the PV modules' nonuniform irradiance [28].
The MPPT 2-stage approach based on ANN was presented for MPP [29]. This approach does not depend upon time and trade featuresbecause of which the MPP tracking is assumed to be done with no any time increment via characteristics variations of PV.
The issue of PV array nonlinear characteristics with the quickly varying temperature and irradiation has been overcome by utilizing DE (Differential Evolution) and ANN with the traditional MPPT for tracking the MPP [30].
A novel MPPT algorithm based on ANN has been presented by Xu et al. [31] by making use of conventional INC utilizing sensors to enhance the performance.
The MPPT based on 2-stage ANN has been proposed in [32] for estimating the irradiance and temperature level from the current and voltage signals for determining the optimal maximum operating point.
In [33],MPPT controller based on ANN designed in regard to the PV system has been presented to order to exceed the limitations as slow and inaccurate tracking and performingits operation at optimum point and minimize oscillations while quickly varying climatic conditions.
The 3-layered ANN based MPPT with a reverse propagation approachwas presented [34] in respect to the boost converter designed for the PV system for reduction of lasting system losses and for enhancement of conversion efficiency. It provides optimal output voltage under changing temperature conditions also.

2.4 Fuzzy Logic Controller Based MPPT Techniques:

The**MPPT technique based on** fuzzy logic control is an appropriate meansto map an input space with the output space. Fuzzy set theory acts as the basis ofFuzzy logic. This theory specifies that the variable belongs toone or numerous sets, having a degree of defined membership. Fuzzification, inference, and defuzzification are the 3 blocks of fuzzy logic controller. The hybrid adaptive neuro-fuzzy inference system has been implemented with the purpose of identification of the operating point which is close to the MPP [35]. In [36], the fuzzy logic has been implemented for obtaining the operating voltage fluctuations of MPP utilizing the Mamdani method. In this approach, the tracking of MPP is done quickly in contrast to the previous algorithm.
In order to followthe MPP which belong toPV system in respect to changing insolation and temperature terms, Hossain et al. [37] introduced an intelligent method.
The MPPT based on fuzzy logic has been proposed in [38] for extracting the MPP and for feeding the 3-level NPC (Neutral Point Clamped) VSI from PV system, in which this provides the output waveforms' highest number of levels with the minimum dV/dT, low harmonic distortion, and less switching frequencies.
Chin et al. [39] dicussed optimization of PV system following the P&O algorithm in partly shaded situations to overcome the low precision of the fuzzy logic algorithm which was implemented for obtaining rapid control of MPP and balanced output power in respect to variable and constant conditions.
For controlling the DC-DC buck converter via providing duty cycle to this converter, the ANFIS controller for the PV system was presented [40].
The convergence processis longer under disturbances and uncertainties. To overcome this drawback, the sliding mode control has been presented [41]. It performs online tuning of ANN and FNN algorithms. The Sugeno fuzzy MPPT approach has been developed for thePV system [42]. In this, the control based on MPV (maximum power voltage) DMP (direct MP) was utilized for controlling the PV voltage output to a PV voltage reference Vref from the MPP decision-maker and for the power slope control.
Because of changing irradiance and temperature, the PV output exhibits nonlinearity property. In order to overcome this nonlinearity, thefuzzy logic controller has been proposed in [43].

2.5 Optimization Based MPPT Algorithm for PV System:

Several optimization techniques have been proposed by various authors, Particle Swarm Optimization (PSO) is one among them. With the aim of minimization of the constant oscillation to zero after MPP location, this algorithm is used.Also, it can track MPP for severe environmental situations such as partial shading and large insolation fluctuations. The PSO based MPP tracker for the PV module arrays can track the MPPs of the multipeak characteristic curvesglobally, in which algorithm weighingused fixed values and the performance achieved for tracking is not robust which leads to low success rates while global MPPs tracking.In this, the successful tracking of MPPs was done, however, the speed of dynamic response is slow. The MPPT controller algorithm based on IPSO for different environmental cases such as fully shaded and partly shaded conditions for identifying novel global MPP with the particle reinitialization can be observed [44]. The structure of PSO is simple, it can be implemented easily and its computational speed is fast. Despite the environmental changes, MPP can be traced for any kind of P-V curveand moreover,for tracking the PV system, the PSO search space can be minimized and reduction in convergence time can be observed. Though, the researchers [45-47] did not get succeeded in satisfying the speed of searching via flexible learning parameters and inertia weight, due to linearity in the line along with rising iteration numbers utilized for PSO formulas weighing. The MPPT based on IPSO can help in the P-V and I-V characteristics curves prediction while condition of partial shading can develop and demonstrates the PV system design encompassing a power converter and the MPPT controller [48–50]. The authors in [51] presented the loss of power because of partial sharing and reduction by PV systems division into small arrays by which it can control its own converter for each array.

Another optimization technique is suggested by the scholars in [52] as Whale Optimization Algorithm(WOA) which finds its base fromparticle swarm optimization. This approach is used to tune Maximum Power Point Tracking (MPPT) controllers possessed by solar Photovoltaic system specifying connected grid, also used MPPT controllers are Proportional-Integral (PI) based. The outcomes obtained from Incremental Conductance (IC) MPPT technique powered by PI are used for comparison in respect to both the Perturb & Observe (P&O) MPPT and the conventional incremental conductance techniques. A number of PI controller modes have been used. With the use of WOA, various parameters like Fractional order PI (FOPI), PI and I can be determined. In order to approximate the optimal PI controller parameters, performance measures are employed. Also, an enhanced performance of a grid-connected PV system of 400-kW is observed on operating MPPT controllers based on PI. The outcomes noted from simulation experiments have shown the potential of MPPT controllers typically based on PI which has enhanced PV system performance.

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Volume 6- Issue 1, Paper 43,January 2023

A controller based on modified Ant Colony Optimization (ACO) Algorithm is presented in [53] to be used by stand-alone photovoltaic (PV) system for Maximum Power Point Tracking (MPPT). In order to track accuracy and rapid speed of MPP, modification is done in A.CO algorithm. For the purpose of designing and modelling of MPPT controller based on modified ACO, MATLAB and SIMULINK is used. The enhanced simulated outcomes have illustrated that MPPT controllerbased on modified ACOis efficient for tracking of MPPT in the performance of standalone PV system.

III. CONCLUSION

Solar energy is used to overcome the environmental issues and to meet the rising energy demand. There is a huge development of enhancing the MPPT algorithm efficiency which encouraged the power domestic generation with the help of solar panels. The efficiency of PV system can be improved by utilizing the electronic power appliances along with the MPP controller.In order to enhance the efficiency of solar energy, different kinds of MPPT control approaches are utilized which are reviewed in this paper. In this review, various recent hybrid MPPT approaches are presented. It has been observed that P&O and INC approaches are simple and many researchers have used them however, there tracking speed is slow and their utilization efficiency is low. In order to overcome the limitations, fuzzy and ANN approaches are used presently with the help of which the efficiency can be enhanced.

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