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A Review of Maximum Power Point Tracking Algorithms for Photovoltaic Systems under Uniform and Non-Uniform irradiances

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Abstract

The global demand for electrical energy is constantly increasing while the production of fossil fuel based energy is declining and therefore the obvious choice of clean energy source which is abundant and could provide security for the future development is sun's energy. This paper summarizes the modeling of PV module and PV characteristics under shaded conditions. The power-voltage characteristic of photovoltaic array is non-linear and it exhibits multiple peaks including many local peaks and one global peak under non-uniform irradiances. In order to track the global peak, MPPT is the important component of PV systems. Though many review papers discussed the conventional techniques such as P&O, incremental conductance, ripple correlation control and only very few attempts have been made with intelligence MPPT techniques. This paper also discusses the various algorithms based on Fuzzy Logic, Artificial Neural Network, Ant Colony Optimization, Genetic Algorithm and Particle Swarm Optimization applied to maximum power point tracking in photovoltaic systems under changing irradiance conditions. This paper is intended to introduce a conceptual MPPT technique based on Firefly Algorithm (FA).

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Keywords: Maximum power Point Tracking (MPPT) Techniques, Photo Voltaic (PV) Array

1. Introduction

Solar PV power systems have been commercialized in many countries due to its merits such as long term benefits, maintenance free and environmental friendly. To ensure the optimal utilization of PV arrays, maximum power point tracking is used in conjunction with the power converters. The power voltage characteristic is non-linear and it exhibits many local peaks and one global peak. The major challenge lies in using the PV power generation systems is to tackle the non-linear characteristics of PV array. The PV characteristics depend on the level of irradiance and temperature. PV array experiences different irradiance levels due to passing clouds, neighbor buildings or trees

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To date, though there are many review papers which discusses the various conventional MPPT techniques such as Perturb and Observe, Incremental Conductance, short circuit current, open circuit voltage and ripple correlation control approaches[1] –[5]. These methods are applicable only under uniform radiances. This paper discusses the various intelligence based MPPT techniques which include Fuzzy Logic Control (FLC), Artificial Neural Network (ANN), Ant Colony Optimization (ACO), Genetic Algorithm (GA), Particle Swarm optimization (PSO) algorithms. At the end, this paper is intended to introduce a conceptual MPPT technique based on Firefly Algorithm (FA).

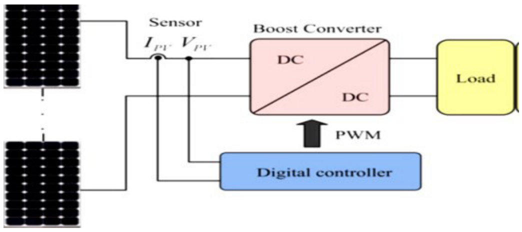


Fig.1. Block Diagram of PV Generation systems

2. Modeling of PV module

2.1 PV panel modeling

Various models have been used for depicting the PV module and two-diode model is found to be very accurate but it requires computation of seven parameters [7].

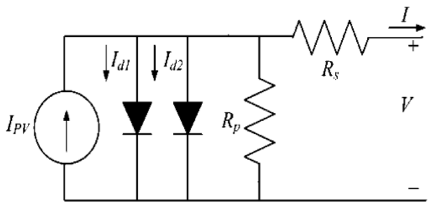


Fig.2. Two-diode model of the PV cell

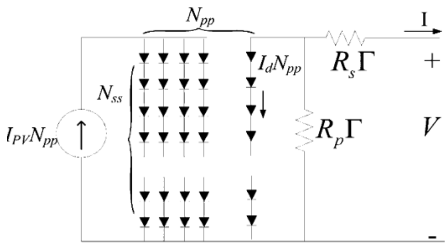


Fig.3. Series Parallel combination of the PV array

The output current of the module is given by

$$I = I_{pv} - I_{d1} - I_{d2} - \left(\frac{V+IR_S}{R_p}\right) \quad (1)$$

where

$$I_{d1} = I_{o1}\left[exp\left(\frac{V+IR_S}{\alpha_1 V_{T1}}\right) - 1\right] \quad (2)$$

and

$$I_{d2} = I_{o2}\left[\exp\left(\frac{V+IR_S}{\alpha_2 V_{T2}}\right) - 1\right] \quad (3)$$

In the paper [6] suggests a fast and simple two diode model which requires only five parameters to be computed. For this model, current equation is simplified as

$$I = I_{pv} - I_o(I_p + 2) - \left(\frac{V+IR_S}{R_p}\right) \quad (4)$$

where

$$I_p = exp\left(\frac{V+IR_S}{V_T}\right) + exp\left(\frac{V+IR_S}{(p-1)V_T}\right) \quad (5)$$

and

$$p = 1 + \alpha_2 \quad (6)$$

2.2 Characteristics of PV Cell under PSC

During partial shading conditions i.e., when the PV array is operating at non uniform irradiance, the PV curve is characterized by several local peak and one global peak as shown in the figure

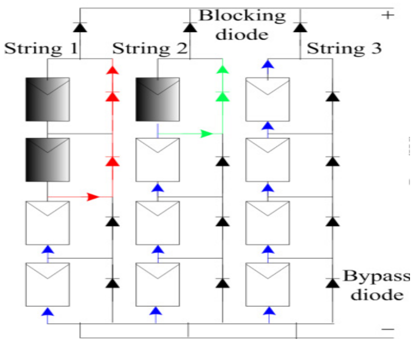


Fig.4. Operation of PV array under partial shading

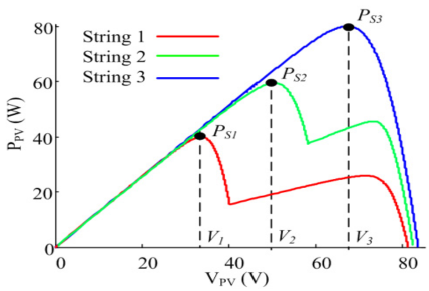


Fig.5. PV curves for each string

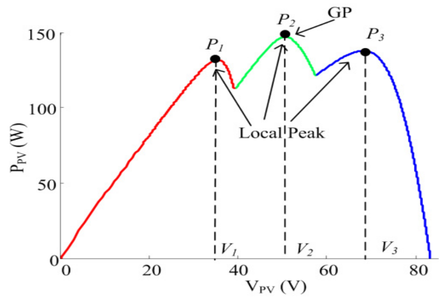


Fig.6. PV curve of the entire array

3. Conventional MPPT Techniques

The following are some of the MPPT techniques which are suitable for uniform irradiance conditions. They are Perturb and Observe, Hill Climbing algorithm, Incremental Conductance, short circuit current, open circuit voltage and ripple correlation control approaches [4],[5]. Even though these techniques are simple and easy to implement, they cannot be used under partial shading conditions.[1]-[3]

4. Intelligent MPPT Techniques

4.1 FLC based MPPT

Fuzzy logic based MPPT does not require the knowledge of the PV panel. It has two inputs and one output. Mamdanis method is used for fuzzy inference and centre of gravity method for defuzzification and the duty ratio is computed [16],[17].

Table 1 Fuzzy Logic Based Rules

E &ΔE	Small	Medium	Large
Small	ZO	NS	NB
Medium	PS	ZO	NS
Large	PB	PS	ZO

4.2 Artificial Neural Network based MPPT

The three layer RBFN NN is adopted for implementing the MPPT. The number of input units in the input layer is three while the hidden layer has nine input units and the output layer has one unit. To control the duty cycle of the switch, PWM pulses are generated using PV module. Enhancement of weight of links and adjustment of parameters used for learning will enhance the performance of the system.[11]-[12].ANN based methods is suitable for the systems that can get sufficient training data.

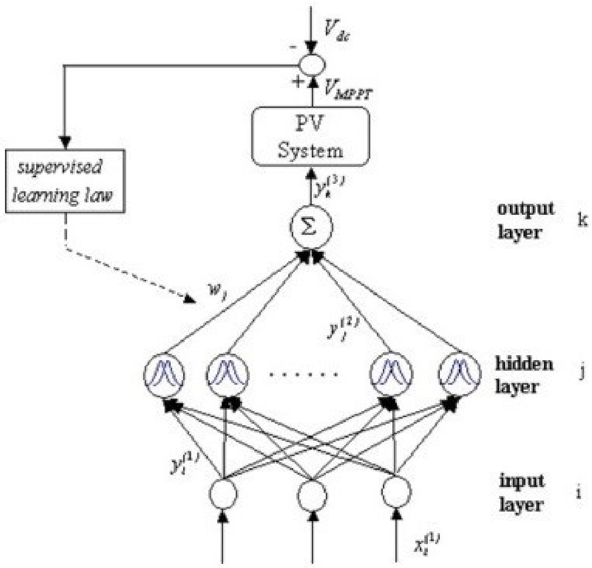


Fig.7. ANN based MPPT

4.3 PSO based MPPT

To demonstrate the application of PSO for MPPT, a solution vector of duty cycles with Np particles is to be determined. The algorithm transmits three duty cycles di (i=1,2,3,4,….Np) to the power converter. The value of duty cycle is approximately a constant after subsequent iteration and hence the operating point will be maintained. [8]-[11]. PSO method is efficient for non-uniform irradiance conditions but its convergence depends on the initial place of the agents.

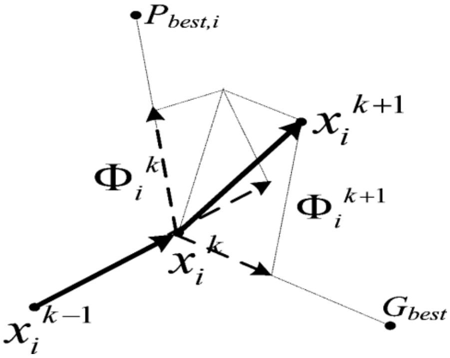
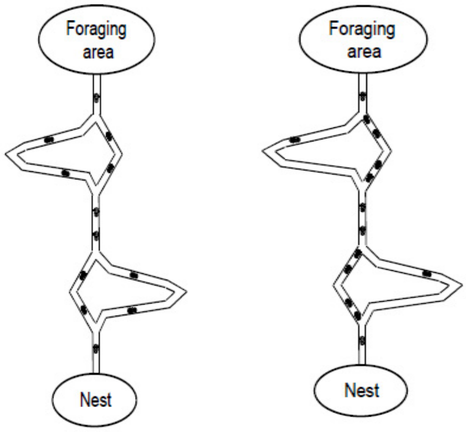


Fig. 8. Movement of particles in the optimization Process

4.4 ACO based MPPT

To apply the ACO based optimization technique for tracking maximum power modifications are required. In this algorithm [13], the parameters such as the number of ants (M), convergence speed (€), solution archive (K) and locality of search process (Q) are to be decided by the user. When choosing the number of ants, there will be tradeoff between convergence speed and tracking accuracy. More no. of iteration is required to converge when the value of Q is more.



(a) (b)

Fig. 9 (a) Ants using the double bridge (b) Ants chose the shortest path

4.5 Genetic Algorithm based MPPT

One of the adaptive metaheuristic search algorithm is Genetic Algorithm. In this, populations are initialized as given in equation (7) and generated power is the fitness function which is used to evaluate the members of the population.

$$[\text{parent}(1)\ \text{parent}(2)\ \text{parent}(3)\ \ \text{parent}(4)] = [0.8\ \ 0.6\ \ 0.4\ \ 0.2\ ].2\ V_{oc} \tag{7}$$

Crossover is performed in two steps as follows

$$\text{child}(k) = r.\text{parent}(k) + (1-r)\text{parent}(k+1) \tag{8}$$

$$\text{child}(k+1) = (1-r).\text{parent}(k) + r.\text{parent}(k+1) \tag{9}$$

If re-initialization is not implemented, then GA will stop at a local search and therefore re-initialization is done at the following conditions

$$|V(k+1) - V(k)| < \Delta V \tag{10}$$

$$\left|\frac{P_{pv}(k+1) - P_{pv}(k)}{P_{pv}(k)}\right| > \Delta P \tag{11}$$

Where P_{pv} is the generated power

Flowchart given below represents the steps involved in GA based MPPT for solar PV systems

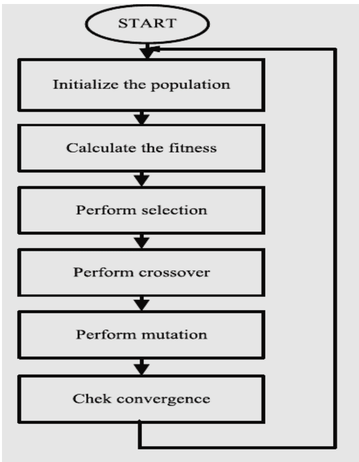


Fig. 10 Flowchart of GA based MPPT for PV system

4.6 Firefly Algorithm (FA) based MPPT

Firefly algorithm [14]-[15] is a new meta heuristic algorithm inspired by a flashing of fireflies, for optimization problems. It was introduced in the year 2009 at Cambridge University by Yang. In this algorithm, randomly generated solutions will be considered as fireflies. Brightness is assigned depending on their performance on the objective function. One important rule of this algorithm is all fireflies are unisex. It means that regardless of sex, any firefly can be attracted to any other brighter one. Second rule is that flashing light (brightness) is determined from the objective function. Light intensity at a particular distance ‘r’ from light source obeys inverse square law. Attractiveness is directly proportional to brightness and it decreases with distance.

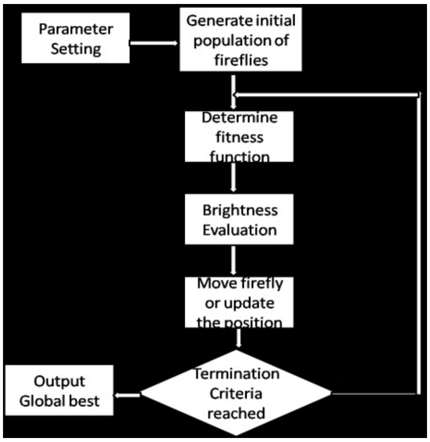


Fig. 11 *Flowchart of Firefly Algorithm based MPPT for PV system*

5. Conclusion

The intensive and massive use of energy from the solar cell is essential for providing solutions to environmental problems. Implementing the MPPT algorithm through digital controllers is easier if it is possible to minimize error functions. The differences between the various MPPT techniques are very slight and they can be evaluated according to the situation. For a particular application, selecting a particular MPPT is a tough task and this paper will be a good reference for the researchers who work with MPPT.

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