CUCKOO SEARCH ALGORITHM BASED MAXIMUM POWER POINT TRACKING FOR SOLAR PV SYSTEMS

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Abstract— Solar radiant energy accounts for majority of usable renewable energy on the earth. Photovoltaic systems convert energy from the sun directly into electricity. Photovoltaic modules have a single operating point which results in the maximum output power. A Maximum Power Point Tracking (MPPT) system is utilized to take the full advantage of solar energy. Conventional MPPT algorithms fail to track the optimum power under rapidly changing atmospheric conditions. Thus an intelligent method based on genetic algorithm, Cuckoo Search Algorithm (CSA) is used to track the optimum power. This algorithm, which is inspired by the parasitic reproduction strategy of cuckoo birds ensures the ability to find the global MPP and also provides a simpler control scheme and lower overall system cost.

Keywords— Cuckoo Search Algorithm, MPPT, Photovoltaic module, Solar energy

I. ` INTRODUCTION

With the advent of industrial revolution, the demand of electricity has increased tremendously. Currently, majority of power generated in the world is from fossil fuelled power plants. Majority of the greenhouse gases in the world are emitted by fossil fuels, contributing 3/4th of all carbon, methane and other greenhouse gas emissions. Also, world's fossil fuel reserve is being depleted drastically. Within a short span of time, world will have to depend on renewable energy sources to meet most of its electricity demand. Renewable energy sources are clean sources of energy having a much lower environmental impact than conventional energy technologies. Renewable energy technologies generally require less maintenance than conventional energy generators. Their fuel is derived from natural and available resources which reduces the costs of operation. They produce little or no waste products such as carbon dioxide or other pollutants, so has a minimal environmental impact [1].

Solar energy is one among the promising renewable energy sources for the future. Solar energy is light and heat radiant from the sun which is harnessed using a range of evolving technologies such as solar heating, solar photovoltaics, solar

thermal energy, solar architecture and artificial photosynthesis. Solar energy is a clean form of energy. It emits very small amount of carbon gases or sulphur oxides. Other advantages of solar energy ate that it is affordable, reliable and flexible [5].

Solar PV systems convert energy of sun directly into electricity by making use of the photovoltaic effect. The solar energy is converted into electricity by making use of a semiconductor device that is called a solar cell. For practical applications requiring a particular voltage or current for their operation, a number of solar cells are to be connected together in series and parallel to form a solar panel, also called as PV module. For large-scale generation of power, the solar panels are connected together in series and parallel to form a solar PV array.

The PV panels exhibit nonlinear V - I characteristics as their output supply depends mainly on the nature of connected load. Hence, it is necessary to find optimal power point of the panel so that the overall efficiency of the photovoltaic system is increased. Therefore, a Maximum Power Point Tracking (MPPT) algorithm is used for extracting maximum available power from a PV module under various environmental conditions. A power conditioning circuit transfers maximum power from the solar PV module to the load. A dc-dc converter can serve this purpose whose duty cycle is varied so as to keep the operating power at its constant maximum value and thus we can operate the PV system at its maximum efficiency.

More than thirty MPPT algorithms have been proposed, among that the Perturb and Observe (P&O) method and Incremental Conductance (IC) method are the commonly used methods for MPPT. These methods however fail to track maximum power under partial shading conditions. This brings out the necessity of intelligent methods like Fuzzy Logic Control (FLC), Artificial Neural Network (ANN), Particle Swarm Optimization (PSO), Ant Colony optimization (ACO), Cuckoo Search Algorithm (CSA) etc. for MPPT.

In this paper, a comparatively novel algorithm known as Cuckoo search algorithm is being discussed about. Due to its advantages, it is gaining its place in the optimization of wide variety of problems.

II. MODELLING OF A PV SYSTEM

A solar cell can be typically modelled by a current source with an inverted diode which is connected in parallel to it. It has its own series and parallel resistance. Series resistance occurs due to hindrance in the path of electrons from n to p junction in the p-n junction diode and parallel resistance is due to the presence of leakage current. An ideal solar cell has series resistance equal to zero and shunt resistance equal to infinity .Equivalent circuit of a solar cell is shown in fig.1 [4].

When p-n junction is not illuminated the equation for diode current is given by,

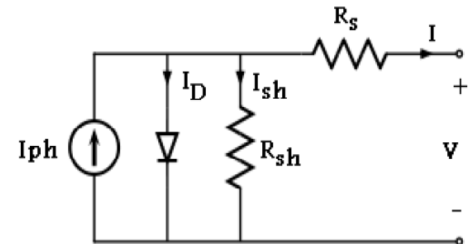

FIG.1 Equivalent Circuit of a Solar Cell

$$I_D = I_o\left(e^{\frac{V}{V_t}} - 1\right) \qquad (1)$$

Where,

$$V_t = \frac{kT}{q} \qquad (2)$$

Here, V_t is the thermal voltage, T is the operating temperature, q is the charge of an electron and I_o is the diode saturation current. When p-n junction is illuminated, the diode characteristics shift as shown in fig.2. By applying KCL to the equivalent circuit, the net current from the PV cell is given by,

$$I = I_{ph} - I_D - I_{Rsh} \qquad (3)$$

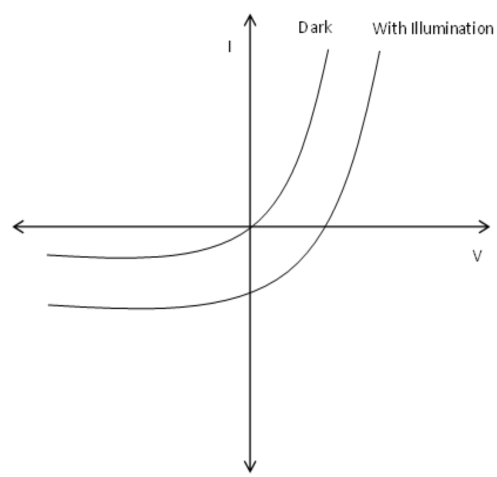

FIG.2 Diode characteristics under dark and illuminated conditions

Considering the intrinsic series and shunt impedances, the net current from the diode is given by,

$$I = I_{ph} - I_o\left[\exp\left(\frac{V + IR_s}{V_t}\right) - 1\right] - \left(\frac{V + IR_s}{R_{sh}}\right) \qquad (4)$$

The last term in the above equation can be neglected since $R_s >> R_{sh}$. So it can be written as,

$$I = I_{ph} - I_o\left[\exp\left(\frac{V + IR_s}{V_t}\right) - 1\right] \qquad (5)$$

Equation 5 gives the net current from a PV cell. The module saturation current I_O is given by,

$$I_o = I_{rs}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{qE_{go}}{BK}\left(\frac{1}{T_r}-\frac{1}{T}\right)\right] \quad (6)$$

Here, I_{rs} is the reverse saturation current and is given by,

$$I_{rs} = \frac{I_{sc}}{\exp\left[\frac{qV_{oc}}{N_s KAT}-1\right]} \quad (7)$$

I_{sc} is the short circuit current and is specific for a particular cell. The equation for photo-generated current I_{ph} is given by,

$$I_{ph} = I_{sc} + K_i(T-T_r)\frac{\lambda}{1000} \quad (8)$$

Where,

- λ : PV module illumination
- A : P-N Junction ideality Factor
- T_r : Reference temperature
- R_S : Series impedance
- R_{sh} : Shunt impedance
- V_{oc} : Open Circuit voltage
- K_i : Short Circuit current temperature coefficient

Equation (5) can be used for obtaining the I-V characteristics of the solar cell. Typical I-V and P-V characteristics of the solar cell can be obtained as shown in fig.3.

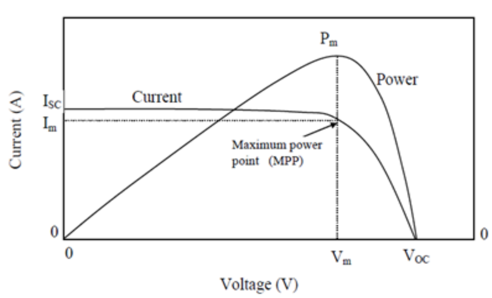

FIG.3 Typical I-V and P-V Characteristics of a Solar Cell

It is clear from the equations that the I-V and P-V characteristics change with insolation and temperature. Matlab based simulations can be done inorder to validate the theoretical concept. Since a reasonable power output can only be obtained by the series and parallel combination of cells, the actual current from the PV module is given by,

$$I = N_p I_{ph} - N_p I_o\left[\exp\left\{q\left(\frac{V+IR_s}{N_s KAT}\right)\right\}-1\right] \quad (9)$$

Where N_s is the number of cells connected in series and N_P is the number of cells connected in parallel. The validation of these concepts using simulation is described in the following sections.

III. MAXIMUM POWER POINT TRACKING

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that allows the Photovoltaic (PV) modules to operate in a manner to produce all the power they are capable of producing. According to Maximum Power Transfer theorem, the power output from a circuit is maximum when the source impedance of the circuit matches with the load impedance. Hence the problem of MPPT is basically an impedance matching problem. Maximum power point tracking technique is used so that the efficiency of the solar panel is improved. The irradiance on a PV panel and its operating temperature changes during a day. The power output from a PV module is dependent on the insolation. Variation of P-V characteristics with insolation and temperature is shown in fig.4.

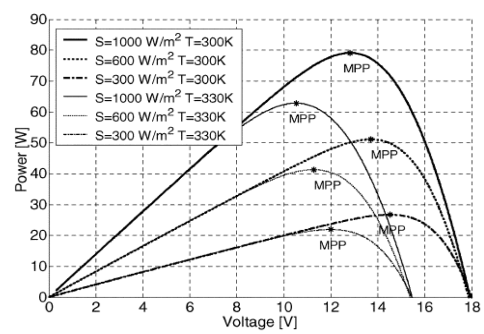

FIG.3 Variation of PV Characteristics with Temperature and Insolation

The basic work by MPPT is to find out the PV output voltage or output current at which the PV array can produce maximum possible output power at a given temperature and irradiance and that conjointly will increase the in operation time period of the PV system. A basic Module of a PV system consist of PV panels and Load where a DC/DC converter is used between them used for extracting the maximum power from the PV module and transfer it to the load. The load impedance is varied by varying the duty cycle to match the maximum supply power. In practical cases load impedance will be a constant. So in order for maximum power tracking, the panel output should automatically adjust so as to give maximum power for all the conditions. This can be achieved using a power conditioning circuit which is basically a dc-dc converter. A boost converter is normally employed.

There exists a wide variety of MPPT techniques that are in practise nowadays. Those MPPT methods are widely classified as (i) Conventional Methods and (ii) Computational Intelligent Based Methods.

Conventional Methods include Perturb and Observe (P&O) and Incremental Conductance methods. A system with embedded computational intelligence is considered as an intelligent system that has learning, self-organisation and generalization capacity. The computational intelligence based methods employed in MPPT include Fuzzy Logic Control (FLC), Artificial Neural Network (ANN), Particle Swam Optimization (PSO), Ant Colony Optimization (ACO), Cuckoo Search Algorithm (CSA) etc.

IV. CUCKOO SEARCH ALGORITHM

Many nature inspired evolutionary algorithms have been developed for optimization in the past few years. These algorithms usually work based on a random search in some acceptable search region depending on the problem to be optimized. But the search is not truly random because there will be some mechanism in the algorithm which guides the search so that the solution vector gets improved with iterations. Two crucial basic characteristics of these modern meta-heuristic algorithms are intensification (exploitation) and diversification (exploration).

Cuckoo Search Algorithm (CSA) is one among such nature inspired optimization algorithms. The algorithm was developed by scientists Xin-She Yang and Suash Deb in the year 2009. It was inspired by obligate brood parasitism of some cuckoo species which lay their eggs in the nest of some other host bird species. Specific egg laying and breeding of cuckoos form the basis of this optimization algorithm. Cuckoos used in this optimization method exist in two forms as mature cuckoos and eggs. Mature cuckoos lay eggs in some host birds' nests and if these eggs are not recognized or killed by host birds, they grow into a mature cuckoo. Environmental features and the immigration of societies of cuckoos help them to converge and find the best habitat for breeding and reproduction. This best habitat is the global maximum of objective function [11].

Cuckoos are fascinating birds because of the beautiful sounds they can make and also because of their reproduction strategy. Some species such as the ani and Guira cuckoos lay their eggs in communal nests and remove others' eggs to increase the probability of hatching of their own eggs .Some species undertakes the obligate brood parasitism by laying their eggs in the nests of other host bird species. There are three basic types of brood parasitism: intraspecific brood parasitism, cooperative breeding, and nest takeover. Some host birds engage direct conflict with the intruding cuckoos. If a host bird discovers the cuckoo eggs it will throw these alien eggs away or abandons its nest and builds a new nest elsewhere. Some cuckoo species have evolved in such a way that female parasitic cuckoos mimic colour and pattern of the eggs of a few chosen host species. This increases the probability of egg hatching thus increasing their reproductivity.

A. *Levy Flights*

Searching for a suitable host bird's nest is an important part of cuckoo's reproduction strategy. Normally, the search for the nest is similar to the search for food, which takes place in a random or in a quasi-random form. In general, while searching for food, animals choose directions or trajectories that can be modelled by certain mathematical functions. One of most common model is the Levy flight. A Levy Flight can be thought as a random walk where the step size has a Levy probability distribution. In CS, nest searching is characterized by Levy flight. Mathematically, a Levy flight is a random walk where step sizes are extracted from Levy distribution according to a power law [7] as shown below:

$$y = l^{-\lambda}$$ [illegible]

where *l* is the flight length and λ is the variance. Since $1 < \lambda < 3$, y has an infinite variance. Fig. 4 depicts an example of Levy flight in a two dimensional plane. Due to the virtue of Levy distribution, the steps consist of many small steps and also large-step, long distance jumps. Comparing to other metaheuristic algorithms, these long jumps may increase the search efficiency of cuckoo search significantly especially for multimodal, nonlinear problems.

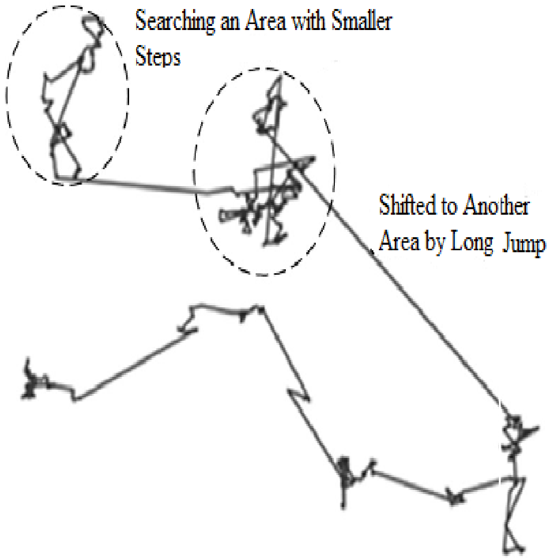

FIG.4 Levy Flight in a 2D Plane

B. *Method of Optimization*

The algorithm starts with an initial population of cuckoos. These initial cuckoos lay their eggs in some host birds' nests. Some of these eggs which are more similar to the host bird' eggs can grow up and turn into a mature cuckoo. Other eggs which are detected by host birds are killed. The grown eggs reveal the goodness of the nests in that area. The more eggs that survive in an area, more the profit is gained in that area. So the position in which more eggs survive will be the term that CSA is going to optimize [11].

Cuckoos search for the most suitable area to lay eggs in order to maximize their eggs survival rate. After remaining eggs grow and turn into a mature cuckoo, they make some societies. Each society has their habitat region to live. The best habitat of all societies will be the destination of the cuckoos in all other societies. Then they immigrate towards the best habitat. They will inhabit somewhere near to the best habitat. [20].

C. *Cuckoo Search via Levy Flights*

Three idealized rules for CS based on cuckoo's brood parasitic behavior: (1) Each cuckoo lays one egg at a time and laces it in a randomly chosen nest (2) The best nest with the highest quality of eggs will be carried over to the next generation (3) The number of available nests is fixed and the number of cuckoo eggs discovered by the host bird maintains a probability Pa, where 0 < Pa < 1 [9].

For maximization problems, the fitness of a solution can be proportional to the value of the objective function. For simplicity, we can use the following representations that each egg in a nest represents a solution, and a cuckoo egg represents a new solution. Our aim is to use the new and potentially better solutions (i.e. cuckoos) to replace a not-so-good solution in the nests.

When generating a new solution for a cuckoo, a Levy flight is performed as in the following expression:

$$x_i^{t+1} = x_i^t + \alpha \oplus Levy(\lambda) \qquad (10)$$

where x_i^t is samples/eggs, i is the sample number, t is the number of iteration and α is the step size, which is related to the scales of the problem of interests. In most cases, we can use α = 1. A random walk is a Markov chain whose next location depends only on the current location (the first term in the above equation) and the transition probability (the second term). The product ⊕ means entry wise multiplications.. In most cases α is used as in the following equation, i.e.

$$\alpha = \alpha_0 (x_i^{t+1} - x_i^t) \qquad (11)$$

where α_0 is the initial step change. In this equation, the difference between two samples is used to determine the subsequent step size.

V. MPPT USING CSA

To use CS for designing MPPT, appropriate variables have to be selected for the search. First are the samples; in this case, they are defined as the values of the PV voltages, i.e. Vi (i = 1, 2. . .n). The total number of samples is defined as n. Second is the step size, denoted by α. The fitness function (J) is the value of PV power at MPP. Since J is dependent on the PV voltage, thus J = f (V). Initially, the generated samples are applied to the PV modules and the power is set as the initial fitness value. The maximum power provided by its corresponding voltage is considered as the current best sample. Thereafter the Levy flight is performed consequently new voltage samples are generated based on the following equation [6]:

$$V_i^{t+1} = V_i^t + \alpha \oplus Levy(\lambda) \qquad (12)$$

Where $\alpha = \alpha_0 (V_{best} - V_i)$. A simplified scheme of the Levy distribution can be explained by:

$$s \approx \kappa \frac{u}{v^{\left(\frac{1}{\beta}\right)}} (V_{best} - V_i) \qquad (13)$$

where β = 1.5, is the Levy multiplying coefficient (chosen by the designer), while u and v are determined from the normal distribution curves. The respective power for the new voltage samples are measured from the PV modules. By comparing the power values, the maximum power given by the voltage is selected as the new best sample. Besides this best sample, others are randomly destroyed with a probability of Pa-such process emulates the behaviour of the host bird discovering the cuckoo's eggs and then destroying those. Then new random samples are generated to replace the destroyed ones. Consequently, the powers for all samples are measured again and the current best is selected by evaluating J. The iteration continues until all the samples have reached the MPP.

A. *Overall Setup for Implementing MPPT*

The set-up that is used to realize the MPPT algorithm is shown in fig.5.The boost converter is selected due its superiority among other converters. The converter is designed to operate in the continuous inductor current mode. The switch used is a power MOSFET. At the input side, the PV voltage and current is measured using voltage and current sensor, respectively. Using these measured values, the MPPT algorithm generates Vout. Then Vref is subtracted from the Vout. The difference is the error voltage Verror, which is then fed to a controller. The output of the controller is compared to sawtooth waveform to produce the duty cycle for the converter. This duty cycle forces the converter to operate at desired voltage, i.e. at Vmpp.

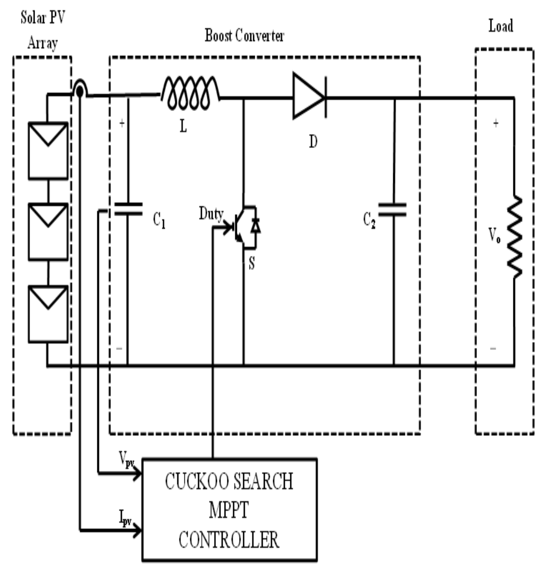

FIG.5 Circuit for Realizing MPPT

B. *Flowchart of CSA MPPT*

The flowchart of the proposed method is shown in fig. 6. First, all constants and variables, namely the voltage, current, power, number of samples and the value of b is initialized. Using the present value of voltage and current, the power is calculated. The new value of voltage and power are stored in the voltage and fitness arrays, respectively. Furthermore, before the start of every iteration, a check is performed to determine if the samples have already achieved convergence or otherwise. If the samples have converged to MPP, they will merge as a same value and so does the respective power [10].

If the samples do not converge, all the power values of the corresponding samples are measured and are stored in the fitness array. By evaluating the array, the sample with highest power is chosen as the best sample. Thereafter all other samples are forced to go towards this best value. The step sizes are calculated by performing the Levy flight as described by equations 12 and 13. Consequently, a new set of samples are found. Afterwards the corresponding powers of these new samples are measured from the PV panel. On the other hand, if any samples results in a lesser power, then that particular sample is discarded and a new sample is generated. This iteration continues until all the samples converge to the optimum point, i.e. MPP [10].

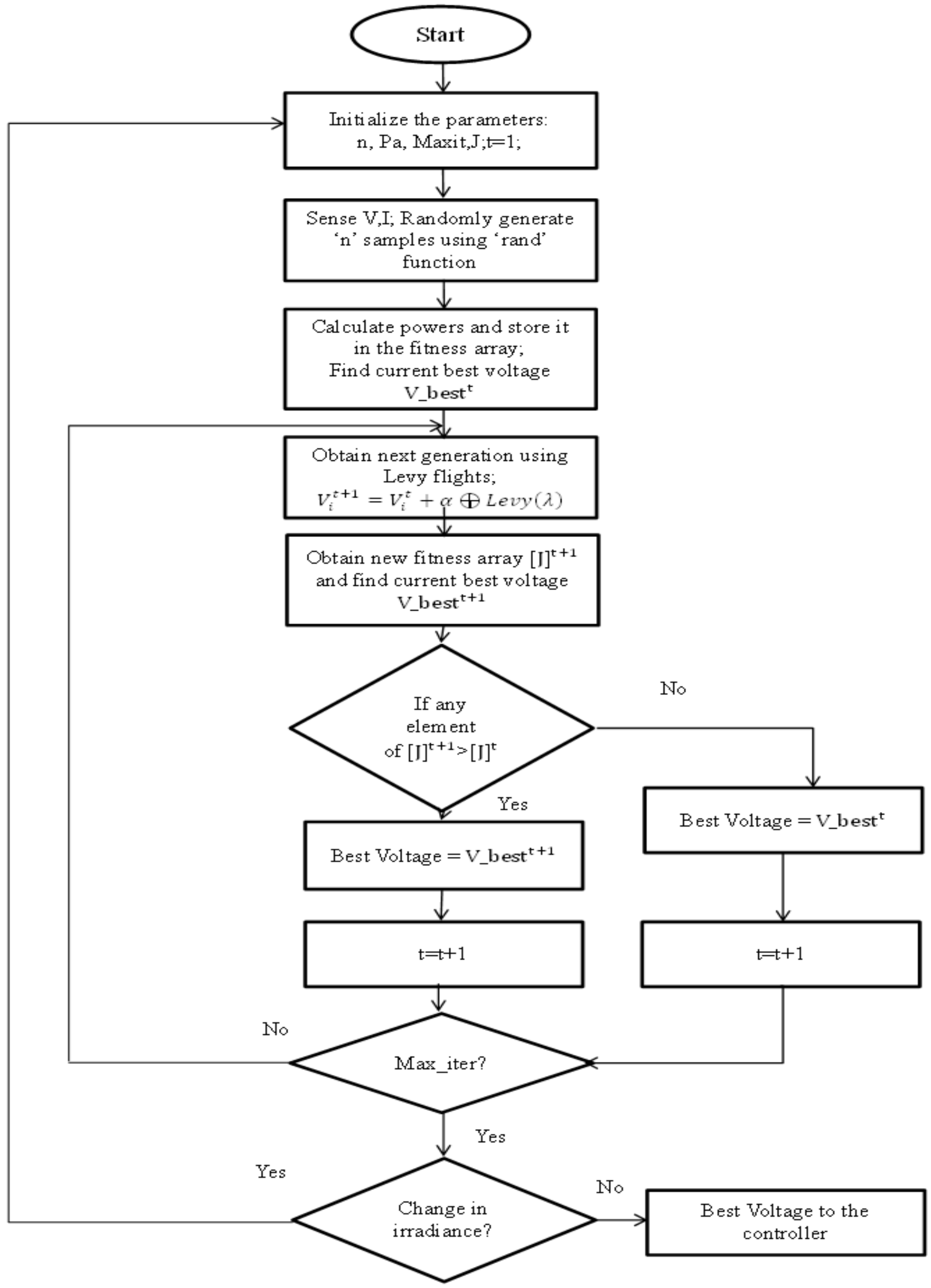

FIG.6 Flowchart of Cuckoo Search Algorithm

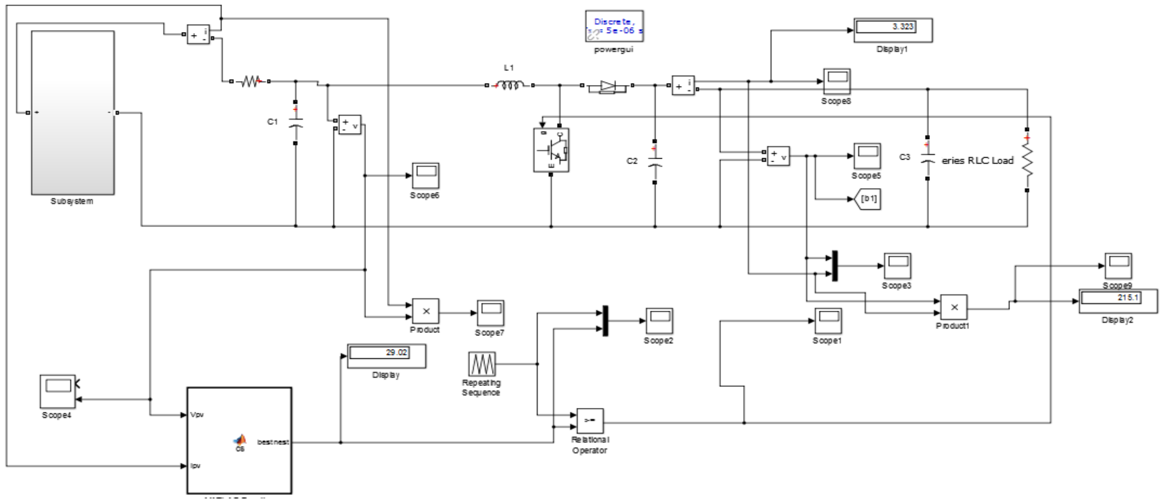

FIG.6 Flowchart of Cuckoo Search Algorithm

VI. SIMULATION STUDIES

First of all a solar PV system is modeled and simulated. The specifications used are that of an EMVEE DIAMOND PV module. Simulink model of the complete system using CSA is shown in the fig 6. It can be seen from the waveform that the power from the PV module is tracked at its maximum value with minimum oscillations. The MPPT algorithm is implemented in code form and incorporated in the system as an embedded function. The voltage and current from the panel are sensed and the MPPT algorithm gives the best value of voltage, i. e, the voltage at which maximum power is generated. This value is then fed to a controller which can generate the pulses for the operation of the switch so that the maximum power is tracked effectively. Various results obtained after simulation under standard test conditions are as shown in the following figures.

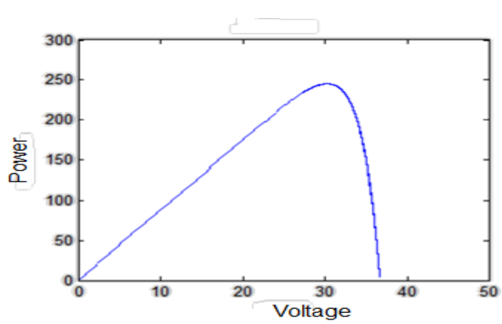

FIG.7 PV Characteristics at STC

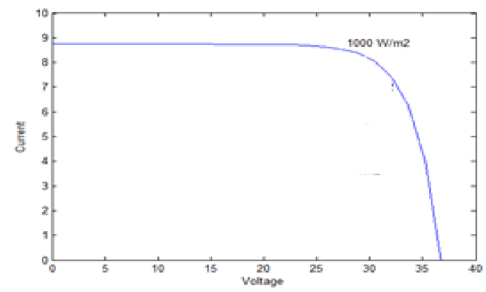

FIG.8 IV Characteristics at STC

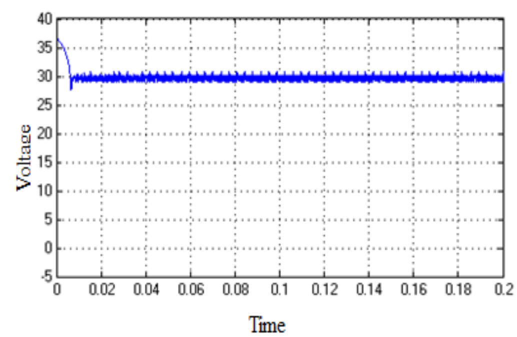

FIG.9 Voltage Output from PV Module

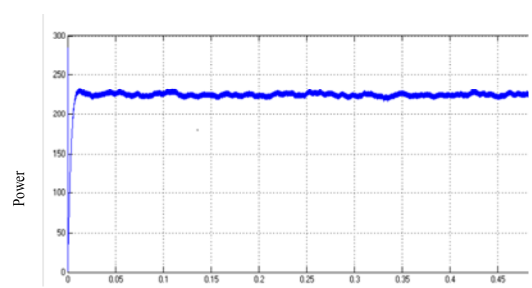

FIG.7 Power Output from PV Module at STC

The simulation for CSA based MPPT method is carried out here only for a few number of iterations because the simulation running time is too high. Even with low number of iterations the tracking time with this method is found to be very low compared to other methods.

VII. CONCLUSION

A PV system is modelled and simulated and optimum power from this module is tracked using conventional algorithms as well as a novel computational intelligence based Cuckoo Search Algorithm. Without MPPT the power obtained from PV module is considerably reduced and the PV panels operate at very low efficiency. MPPT increases the efficiency of the PV system. The MATLAB/SIMULINK environment is used for the simulation. The conventional MPPT algorithms fail to track optimum power under partial shading conditions and under rapidly changing environments. The Power conditioning circuit used is a dc-dc boost converter. The duty ratio of this converter is automatically changed by the controller so as to track the maximum power. To tackle the problem of partial shading this novel method can be effectively used. It is proved that CSA works better under varying atmospheric conditions and its convergence speed is faster compared to other algorithms. In the current method, the simulation running time is very high even for small number of iterations. This can be improved further by some methods in the future to make this algorithm more reliable. Also, in this work its efficiency under partial shading is not tested even though it is theoretically proved that this algorithm can work better under partial shading conditions.

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