RENEWABLE ENERGY BASED BATTERY CHARGING SYSTEM

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***Abstract*— Many MPPT algorithm and soft computing techniques have been employed. These all techniques perform well only in uniform irradiation condition, however, during partial shaded conditions; these are not able to search the global maximum power point (GMPP). These are highly efficient in searching, but in every algorithm, it requires two inputs (voltage and current), which are sensed by voltage and current sensors. These two sensors make system costly. These all things motivate for developing a single sensor based MPPT. In this paper, a new stochastic mathematics-based hybrid Cauchy and Gaussian sine cosine optimization (CGSCO) algorithm is proposed for single sensor based battery charging scheme from SPV array in all types of weather conditions. The main objective of this MPPT algorithm is to maximize the charging current and efficiently performs during partial shading condition.**

***Index Terms*— MPPT, Lead-acid battery, PV, Partial shaded, Sine cosine optimization, Gaussian distribution function, Cauchy density function, GWO, LIPSO.**

INTRODUCTION

The solar energy is one of the most important renewable energy sources that have been gaining increased attention in recent years. Solar energy is plentiful; it has the greatest availability compared to other energy sources. The amount of energy supplied to the earth in one day by the sun is sufficient to power the total energy needs of the earth for one year. Solar energy is clean and free of emissions, since it does not produce pollutants or by-products harmful to nature. The conversion of solar energy into electrical energy has many application fields.

Photovoltaic panels are used to convert the solar energy into electrical energy. PV has nonlinear internal characteristics. The voltage-power characteristics of the PV panel is varied which depends upon irradiance and temperature. Considering the high initial installation cost of the PV system, it is always necessary to operate PV at its Maximum Power Point (MPP). For this purpose dc-dc converter interface is required between PV and battery. The installation cost of the battery is low compared to PV panel. But the lifetime cost of the battery is high compare to the PV installation because of its limited service time. Battery life time is reduced if there is low PV energy availability for longer period or improper charging discharging. So the battery charging needs control for achieving high State of Charge (SOC) and longer battery life. MPPT algorithms are used to obtain the maximum power from the solar array based on the irradiation and temperature variations. They are based on the simple logic that, MPPT calculates the output of PV module, compares it to battery voltage then fixes what is the optimum power that PV module can produce to charge the battery and converts it to the optimum voltage to get maximum current into battery. Here, during charging, constant current flows, this current is equal to the MPP current.

However, when the charging is exceeded the limit, then the control switch to the constant voltage mode. This process is good, only for a fixed solar irradiation and temperature, but in practical, this is not possible because of the variable nature of solar irradiation and temperature, then the current at the MPP also varies. Therefore, by maintaining the constant current or voltage at different solar irradiance or temperatures a power loss occurs.

The MPPT controller has employed by various methods and soft computing techniques. They are, Perturb and Observe (P&O), Incremental conductance, Hill climbing, Fuzzy logic, hybrid fuzzy, Neural network, Particle swarm optimization (PSO), Grey wolf optimization (GWO), Lagrange interpolation particle swarm optimization (LIPSO), Improved PSO, Hybrid P & O and model based MPPT, etc. In these existing systems, the voltage and current are measured to control the duty cycle. Moreover, in the case of two sensors, the computational stored data is more for comparison and decision making process, as well as the accuracy of the final decision, is depended on the perfection of two sensors. All techniques perform only in uniform conditions and not efficiently in partial shading. They require two inputs (V, I), which are sensed by voltage and current sensors. The computational stored data is more. Accuracy is low and Costly. More power loss. Oscillations occur. In his paper, a new stochastic mathematics-based CGSCO algorithm is proposed for MPPT. This is the hybrid of Cauchy density and Gaussian distribution function (CGF) with sine cosine optimization (SCO) algorithm. Here, the SCO generates population and, through follows a path, which moves towards the MPP. The combined effect of both algorithms (CGSCO), converges the MPP only in few steps with the minimum computational burden. Moreover, its performance doesn't depend on the initial value and algorithm-specified parameters. In this proposed system, the PV model, battery model and the battery charging system is implemented. A simple model structure for lead-acid batteries is used to facilitate the battery model part of the system model. The complete system is simulated using MATLAB-SIMULINK and the results are presented.

II. MODELLING OF PROPOSED SYSTEM

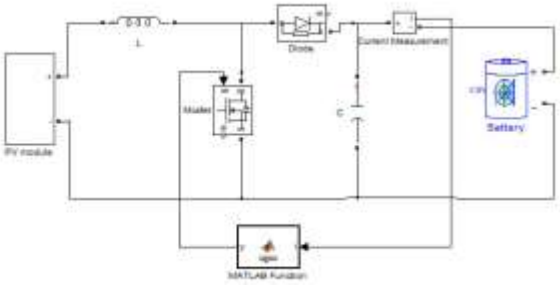

Fig 1. Simulink model of proposed system.

The circuit consists of solar PV system, boost converter, battery and CGSCO MPPT control technique. In this PV system, the controllable voltage source is used to give the solar voltage to the battery. The output voltage is fed to the boost converter. It has a MOSFET as power semiconductor switching device. The MOSFET’s gate signal is controlled by the CGSCO based MPPT control. The output of boost converter is connected to the battery.

A. Modeling of solar PV System

The PV module contains a single solar cell as a resistance Rs that is connected in series with a parallel combination of the following elements: Current source, Two exponential diodes, Parallel resistor Rp. The output current I is

$$I = I_{ph} - I_s\left(e^{(V+I\times R_s)/N\times V_t} - 1\right) - \frac{V+I\times R_s}{R_p} \text{ ……… (1)}$$

Where, Is is the diode saturation current. V is the voltage across the solar cell electrical parts. Vt is the terminal voltage, kT/q, k is the Boltzmann constant. T is the device operating temperature. q is the elementary charge on an electron. N is the quality factor of the first diode. Rs, Rp are equivalent series and parallel resistance.

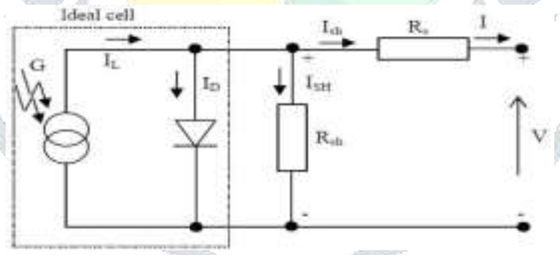

Fig 2. Equivalent circuit of PV system

The basic eq. of the elementary PV cell does not represent the I–V characteristic of a practical PV array. Cells connected in parallel increase the current and cells connected in series provide greater output voltages. Practical arrays are composed of several connected PV cells and the observation of the characteristics at the terminals of the PV array requires the inclusion of additional parameters to the basic equation.

Partial shading of solar PV system

The partial shading effect on PV modules in a PV string s analyzed by performing the simulation for PV string which has 3 series connected PV modules. Different irradiation values are applied to each of the modules by maintaining the temperature value as constant for all the 3 modules. The irradiation values applied to the modules are G (PV1) = 1000 W/m2, G (PV2) = 600 W/m2 and G (PV3) 800 W/m.

B. Modeling of Lead-Acid battery

The energy output from the Solar PV systems is generally stored in a battery or in a battery bank depending upon the requirements of the system. Mostly batteries or used in the stand-alone system and in the case of grid connected system, batteries are used as a backup system. The primary functions of the battery in a PV system are:

(a) Energy Storage Capability and Autonomy: to store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed or on demand.

(b) Voltage and Current Stabilization: to supply power to electrical loads at stable voltages and currents, by suppressing or 'smoothing out' transients that may occur in PV systems.

(c) Supply Surge Currents: to supply surge or high peak operating currents to electrical loads or appliances

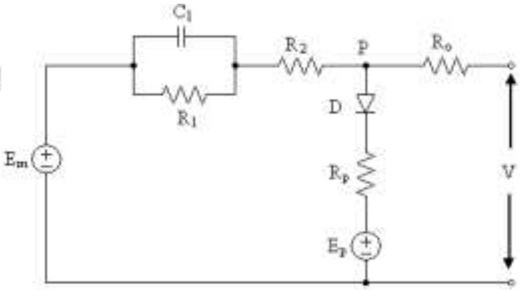

Fig 3. Equivalent circuit of battery

The implementation of State of charge battery using MATLAB/SIMULINK is presented in this section. This simulation focuses on knowing the state of charge of a battery by connecting it to a load with constant charging and discharging.

Assumptions

- The internal resistance is maintained constant during the charge and the discharge cycles and does not vary with the amplitude of the current.

- The parameters of the model are deduced from discharge characteristics and assumed to be the same for charging.

- The capacity of the battery doesn't change with the amplitude of current.

- The model doesn't take the temperature into account.

- The Self-Discharge of the battery is not represented. It can be represented by adding a large resistance in parallel with the battery terminals.

- The battery has no memory effect.

Limitations

The minimum no-load battery voltage is 0 V and the maximum battery voltage is equal to 2*E0. The minimum capacity of the battery is 0 Ah and the maximum capacity is Qmax.

III. CGSCO ALGORITHM BASED BATTERY CHARGING

A new stochastic mathematics-based CGSCO algorithm is proposed for MPPT. This is the hybrid of Cauchy density and Gaussian distribution function (CGF) with sine cosine optimization (SCO) algorithm.

The overall performance of the charging process is dependent on charging current. In this situation, the main objective of the charging is, to maximize the charging current in safety region. Therefore, in this project, the main objective of the MPPT algorithm is to maximize the charging current in every type of dynamic conditions. Around 95% voltage of the voltage rating\ is maintained by battery and slight voltage variation as well as current maximization is taken into the account by MPPT algorithm, so the combined results reach the MPP. It means, the overall responsibility of maximizing the charging current or reaching the MPP, is on the shoulder of MPPT algorithm

A. Sine Cosine Algorithm

SCA is population based optimization technique, found the optimization process with a set of random solution. These random solutions are repeatedly calculated over the course of iterations by an objective function. The probability of finding global optima is increased, with the sufficient number of random solutions.

$$Xti+1=Xti+r1 \text{ x } \sin (r2) \text{ x } r3Pti - Xti \qquad \ldots (2)$$

$$Xti+1=Xti+r1 \text{ x } \cos (r2) \text{ x } r3Pti - Xti \qquad \ldots (3)$$

Where Xti is the position of current solution in i-th dimension at t-th iteration, r1, r2, r3 are the random numbers, Pi is position of the destination point in the i-th dimension.

$$Xti+1=Xti+r1 \text{ x } \sin (r2) \text{ x } r3Pti - Xti \quad r4<0.5 \qquad \ldots. (4)$$

$$Xti+1=Xti+r1 \text{ x } \cos (r2) \text{ x } r3Pti - Xti \quad r4 \geq 0.5 \qquad \ldots (5)$$

Where r4 is a random number in [0, 1]

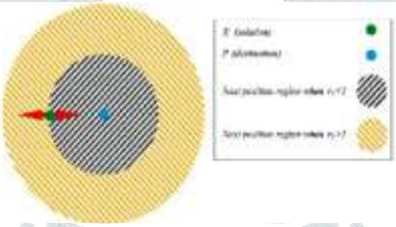

Fig 4 Effect of sine cosine in eqn. (1) and (2)

In the above equations there are four main parameters r_1, r_2, r_3 and r_4. The parametersr1 states that the next position region between solution and destination or outside it. Parameter r_2 tells how far the movement should be towards or outwards the destination. The parameter r_3 brings the random weight for destination in order to stochastically force ($r_3 > 1$) or deemphasize ($r_3 < 1$) the effect of destination in defining the distance. And parameter r_4 equally switches between sine and cosine component in eqn. (3)

Fig. 4 shows that in the search space how the proposed equations define space between the two solutions. The cyclic pattern of sine and cosine function describes the position of solution around another solution. Also this can give guarantee exploitation of the space between two solutions. We can explore the search space by changing the range of sine and cosine function.

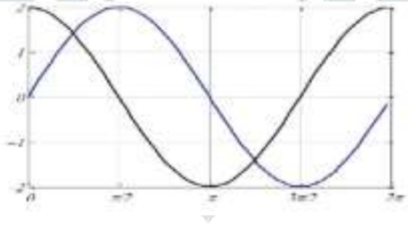

Fig.5 sine cosine with ranges of [-2, 2]

The Sine Cosine function [-2,2] operation is illustrated by conceptual model as shown in the fig. 4.2. By changing the ranges of Sine Cosine function we can find the promising region in the search space. Also it ensures the exploration and exploitation of search space. To make balance between exploration and exploitation, the range of sine and cosine in eqn. (1) to (3) is changed adaptively using the below equation:

$$r1= a - t\, a/T \qquad \ldots\ldots (6)$$

Where **t** is current iteration, **T** is maximum number of iterations and **a** is constant.

SCA explores the search space when ranges of sine and cosine function are in [-2,-1] and (1,2] and exploits the search space when ranges are in [-1,1].

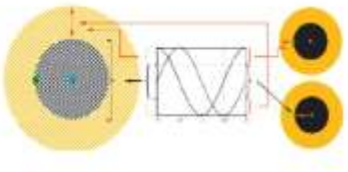

Fig.6 Sine and Cosine with the ranges in [- 2,2]

to go around the destination

General steps of the SCA Algorithm

```
Initialize a set of search agents (solutions) (X)
Do
    Evaluate each of the search agents by the objective function
    Update the best solution obtained so far (P=X*)
    Update $r_1$, $r_2$, $r_3$, and $r_4$
    Update the position of search agents using Eq. (4.3) & (4.4)
While (t< maximum number of iterations)
Return the best solution obtained so far as the global optimum
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B.Cauchy Density and Gaussian distribution Function (CGF)

For reduction of the exploration and enhancement of the exploitation of the search space, the CGF is integrated with SCO during position updating stage. The Cauchy density and Gaussian distribution function are described as

$$\mathrm{fc}(V) = \frac{\gamma}{\pi * (\gamma^2 + (v - vo)^2)} \qquad \ldots\ldots\ldots (7)$$

$$\mathrm{fn}(V) = \frac{1}{\sqrt{2\pi}\sigma} * e^{-(V-\mu^2)/2\sigma^2} \ldots\ldots\ldots. (8)$$

Where, σ^2= the variance? μ=the mean value, and N(μ, σ^2) is the normal distribution. γ is the proportional parameter, V_0 is the peak position of the Cauchy distribution (C(V_0, γ^2)). N (0, 1) and C (0, 1) are Gaussian and Cauchy random number.

C. CGSCO Algorithm

In CGSCO, first SCO finds the optimal place for all variables, after that in the second stage, the positions or values of the all variables are again analyzed by Cauchy density and Gaussian distribution function then final location updating process is completed. Both stages are described as,

Stage 1

$$\Phi = D_j^k + \alpha \times \cos(\beta) \times (\psi \times P_j - D_j) \quad \phi \geq 0.5 \qquad \ldots..(9)$$

$$\Phi = D_j^k + \alpha \times \sin(\beta) \times (\psi \times P_j - D_j) \quad \phi < 0.5. \qquad \ldots.. (10)$$

Stage 2

$$D_j^{k+1} = \Phi * [1 + \delta * (\eta * N(0, 1) + (1-\eta) * C(0, 1))]. \qquad \ldots... (11)$$

Where, Dj (k+1) is the updated duty cycle of the jths population in the k+1th iteration. Pj k is the obtained power, corresponding to Dj(k). ψ and φ are the random numbers in [0, 1]. β is the random number in [0, 2π]. λ is sinusoidal nature constant. K is the maximum number of iteration. δ is inertia constant and

$$\eta = k/K. \qquad \text{----- (12)}$$

Moreover, in CGF, Cauchy density function enhances the global exploration ability, which can very effectively inhibit the loss of population diversity as well as avoid the trapping into local minima, and Gaussian distribution enhances the local exploitation ability, which increases the rate of convergence. The combined effect of both algorithms (CGSCO), converges the MPP only in few steps with the minimum computational burden. Moreover, its performance doesn't depend on the initial value and algorithm-specified parameters. The complete flowchart of CGSCO algorithm is shown in Fiq.

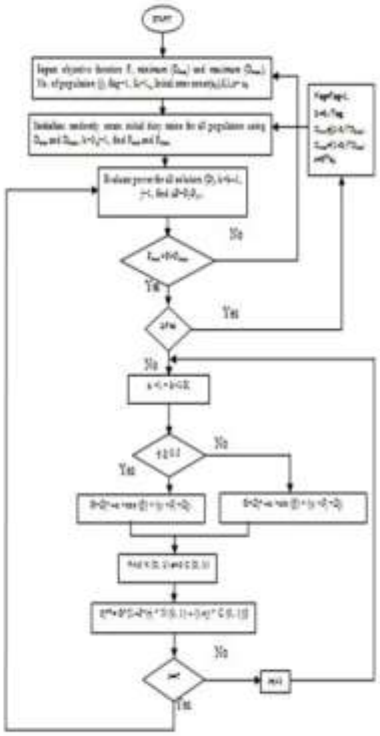

Fig 7. Flow chart of CGSCO algorithm

V.RESULTS

The performance evaluation of the proposed CGSCO-S1 based MPPT for lead-acid battery charging scheme is performed by using a boost converter', which is shown in Fig.1(a). The algorithm parameters of all techniques are given in Table I. Moreover, the circuit parameters are given in Table II.

TABLE I. CIRCUIT PARAMETERS

Circuit parameter	**Selected Value**
Inductor of boost converter	**3.5 mH**
Commutation frequency of boost converter	20KHz
DC bus capacitor (Co)	**500 µF**
dSpace functional frequency	**50 kHz**
Mode of operation	**Continuous**

TABLE I. CONSTANTS OF ALL ALGORITHMS

Algorithm	**WODE**	**GWO**	**LIPSO [24]**
Algorithm Parameters	**λ=1,** **δ=0.1**	**'α', linearly decrement from** **2 to 0**	**C1=0.8,** **C2=1.2,** **w=0.4,** **Δp=1%** **and Δv=0.4**

A. Uniform SPV Panel Condition (Without Partial Shaded)

In uniform SPV panel condition, the environmental conditions and variations for all modules of the SPV panel are same. Therefore, in this situation, PV curve consists of a single peak (GMPP).

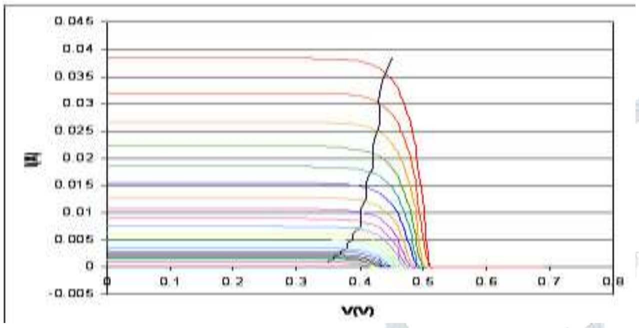

Fig 8 Solar array V-I characteristics at various temperatures

The performance of the SPV array is simulated by using MATLAB 2010a software on Intel core i3, 2.4 GHz processor, 2 GB of RAM memory and windows 7 operating system. For simulation, a solar panel of Voc=320 V, Isc=6A, PMPP=1.57 kW at 25oC with irradiation 1000 W/m2, and the battery rating: 324 V, 2.268 kWh (27 Cells of 12 V, 7 Ah) are considered.

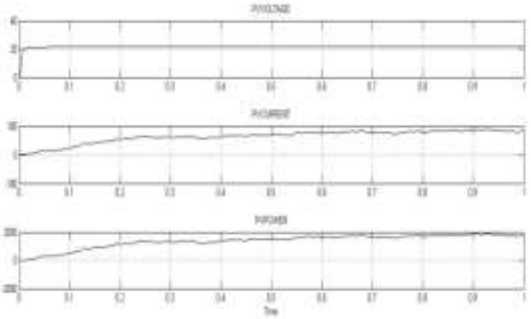

Fig 9. Output of SPV panel without partial shaded

In this proposed paper, the PV module has 3 x 2 arrays of solar cells. Totally 36 cells connected in series each array has 6 cells. The PV panel has a output voltage of 21.5v. The insolation of solar array has been tested in 1000W/munder normal condition.

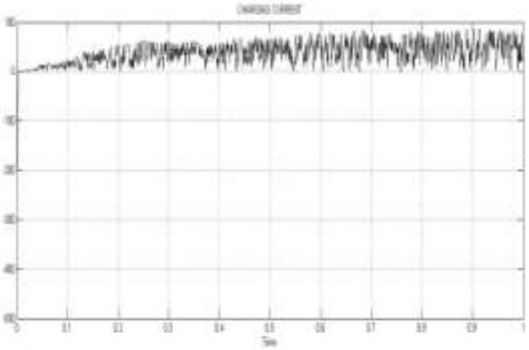

Fig 10. Battery charging current without partial shaded

Its average tracking efficiency is 97.98%, where the average tracking efficiencies of GWO, LIPSO and CGSCO-2S are 91.83%, 93.06% and 96.74%, respectively. These types of performances show the superiority over all other techniques. The battery charging current and voltage waveform achieved by CGSCO algorithms is shown in Fig.13.

B. Partially Shaded SPV Panel Condition

In partial shaded SPV panel condition, the environmental conditions and variations for all modules of the SPV panel are not same. Due to a shadow of any object on SPV panel, the solar insolation differs in shaded region w.r.t. other portions of the panel. Therefore, in this situation, PV curve consists of multiple peaks. The topmost peak is known as global maximum power point (GMPP) and rests all peaks are known as local maximum power point (LMPP). Here, 3 types of patterns. During partial shading, the PV module has been operated in various insolations. First 2 arrays have 1000W/m^2, next 2 arrays have 600W/m^2 and last 2 arrays have 800W/m^2.

The simulations of all algorithms are performed at the similar circuit and atmospheric conditions, which are shown in Fig.1, the average tracking efficiency of CGSCO-1S is 98.08%, which is much better w.r.t. all other techniques. The improvements in % tracking efficiency w.r.t. GWO and LIPSO are very significant, as well as the performance of CGSCO-1S w.r.t. CGSCO-2S is also improved.

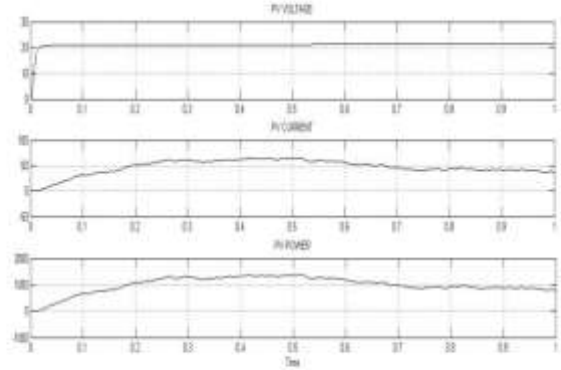

Fig 11. Output of SPV Panel with partial shaded

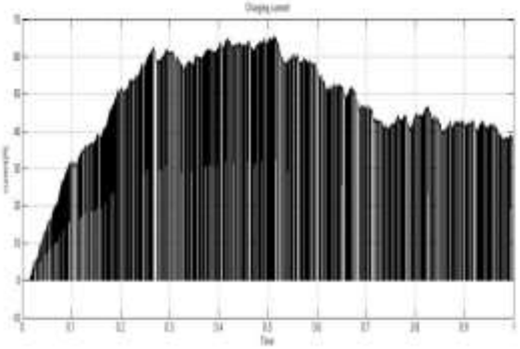

Fig 12. Battery charging current with partial shaded

Conclusion

In this proposed project, the MPPT algorithm is used to maximizing the battery charging current. This CGSCO algorithm is a single sensor based technique. The optimum duty cycle searching process for GMPP has been achieved by the CGSCO algorithm. It is highly robust, reliable, system independent and free from initial condition for MPPT, in all types of weather and shading conditions on the PV panel.

Moreover, on circuitry and economic level, the single sensor based GMPP tracking by using CGSCO is reliable, cheap and easy in maintenance, as well as the computational burden is also very less, so it is easy to implement on the low-cost microcontroller. The SCO algorithm becomes very useful tool to solve the unit commitment problems.

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