# GRAVITATIONAL SEARCH BASED NEURAL NETWORK TRACKING FOR EXTRACTION OF MAXIMUM POWER UNDER PARTIAL SHADING CONDITIONS IN PV SYSTEM

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***Abstract***:

*The output power produced by the solar cells shows a nonlinear current-voltage characteristic with respect to varying solar irradiance and ambient temperature. Maximum Power Point Tracking (MPPT) is utilized in Photovoltaic (PV) systems to maximize its output power. By monitoring the voltage and current of the PV system and controlling the duty cycle of the DC/ DC converter, a new MPPT controller is proposed in this paper. The design of MPPT is framed as an optimization problem whose solution is reached by using Gravitational search algorithm (GSA) to obtain the optimal parameters for the controller. Simulation results have shown that the proposed technique is delivering maximum power of photovoltaic system under different irradiance and ambient temperature. The performance of the developed GSA algorithm is comparable to Particle Swarm Optimization (PSO), Ant colony Optimization (ACO) for different conditions to validate its robustness.*

***Keywords:*** *Partial Shading, PV panel, GSA, RNN, power, voltage, current, MPPT*

## 1. INTRODUCTION

The increasing power demand in the world is being met by more power production. The depletion of natural conventional sources induces the search for the new techniques; hence the power demand is met by renewable sources like wind, solar, hybrid etc. Among these renewable sources, solar photo voltaic system is the very powerful. According to the research and studies, the PV power is influenced by many factors, such as temperature and irradiance; hence PV arrays still have relatively low conversion efficiency. And the characteristic curve of a solar cell exhibits a nonlinear voltage current characteristic; a maximum power point tracker (MPPT) controller is required to match the solar cell power to the environmental changes [1] .To increase the efficiency of PV system, the MPPT controller has to track the MPP operating voltage point of the PV panel, thus optimizing the production of electricity. As a consequence, many research works are set to the control of these systems in order to improve their efficiency.

In general to achieve the maximum power the source impedance should be made equal to load impedance, in a typical PV system, which is achieved by the adjusting the impedance of DC–DC converter by controlling the duty cycle using a power switch. In this paper, an intelligent technique based maximum power point tracking (MPPT) is proposed for maximizing output power of the photovoltaic (PV). The intelligent technique is the combination of gravitational search algorithm (GSA) and recurrent neural network (RNN).

According to these parameters, the maximum power is tracked and generates the control signal for the converter. By applying the proposed MPPT technique, the maximum power is evaluated. Here, the objective function is the minimization of the difference between the maximum power and the actual power. The proposed technique is implemented in MATLAB/Simulink and their outcomes are evaluated under the variation of solar irradiance. Based on the solar irradiance, the performances are analysed in the different time instants and considered as the three different cases. The performance of the proposed technique is analysed and compared with the existing techniques such as Particle Swarm Optimization (PSO), Ant colony Optimization (ACO) for different disturbances to confirm its robustness.

There are numerous MPPT algorithms reported in the literature; they are broadly classified into two categories, namely (1) the conventional and (2) soft computing methods. For conventional MPPT, the widely used methods include Perturb and Observe (P&O) and Incremental Conductance (IC) [2, 3]; there are some simpler methods also available [4].To improve some of the problems available in the conventional techniques, the MPPT techniques based on soft computing (SC) are proposed [5,6,7].

## 2. PROBLEM DEFINITION

From the literature reviews, the tracking method plays a significant role to extract maximum power from the PV system. To achieve maximum power from PV module, it must be operated at the voltage corresponding to the MPP. Numerous MPPT methods that exist in literature are scanty by the difficulty in the measurements of PV temperature and irradiation characteristics and they fail in solving certain variant optimization problems. To overcome these problems, the need for an effective hybridization algorithm is proposed. Therefore, in this paper, an intelligent technique based MPPT is proposed for tracking the maximum power of PV system.

## 3. SYSTEM DESCRIPTION

The photovoltaic system consists of following main blocks: PV panel, MPPT controller, DC/DC converter and the load[19]. The subsequent sections will describe the component of the PV system. Fig. 1shows the block diagram of a PV system equipped with the MPPT controller.

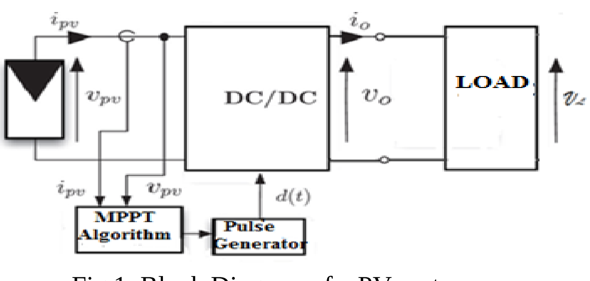



Fig.1. Block Diagram of a PV system

### 3.1. Mathematical Model of Photovoltaic Module

The open circuit voltage of a typical PV cell is about 0.5 to 0.7 volts depending on the Semiconductor used. Hence, to form an array of desired voltage and current, series and parallel configurations of PV modules are employed. [8]

For simulation of photovoltaic module, mathematical model of single diode equivalent circuit is used, which is developed based on current-voltage relationship of a solar cell. An ideal PV cell consists of a current source and an anti-parallel diode, whereas a practical PV cell includes an equivalent series and a shunt resistance parameter to an ideal PV cell.

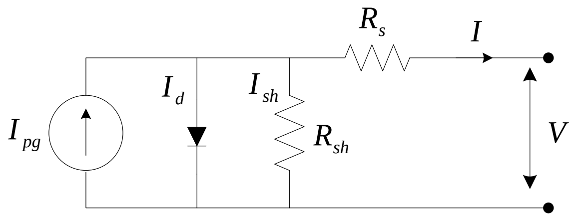



Fig.2. Ideal and practical PV cell of single diode model.

For practical PV cell,

$$I = I_{pg} - I_d - I_{sh} \quad (1)$$

$$I_{sh} = \frac{V+IR_S}{R_{Sh}} \quad (2)$$

The general equation for connecting n number of cells in series in PV module can be written as,

$$\mathrm{I} = \mathrm{I_{pg}} - \mathrm{I_0}\left[\exp\left(\frac{\mathrm{V+IR_S}}{\mathrm{nNV_{th}}}\right) - 1\right] - \frac{\mathrm{V+IR_S}}{\mathrm{R_{sh}}} \quad (3)$$

Where,

| | | |
|---|---|---|
| $I_{pg}$- | Photon-generated current | (A) |
| $I_{sh}$ - | current through shunt resistor | (A) |
| $I_0$ _- | reverse saturation current at reference temperature | (A) |
| $R_{sh}$ - | Shunt resistance | (Ω) |
| $R_s$ - | Series resistance | (Ω) |
| K - | Boltzmann's constant ($1.3806503 \times 10^{-23}$) | J/k |
| q - | Electron charge ($1.60217646 \times 10^{-19}$ ) | C |
| $V_{th}$ - | Thermal voltage of module at reference temperature | (V) |
| V - | Open circuit voltage at | |

| | | |
|---|---|---|
| | reference temperature | (V) |
| N - | Diode ideal factor | |
| $I_r$ - | Irradiation | ($W/m^2$) |

### 3.2. Characteristics of Photovoltaic Module

The performance of the PV voltage, current and power characteristics curve for uniform and partial shaded condition is illustrated in figure 3.The V-I and P-V curves are nonlinear in nature and its maximum power occur at the knee point of the V-I characteristic curve, where the product of voltage and current reaches the maximum value .

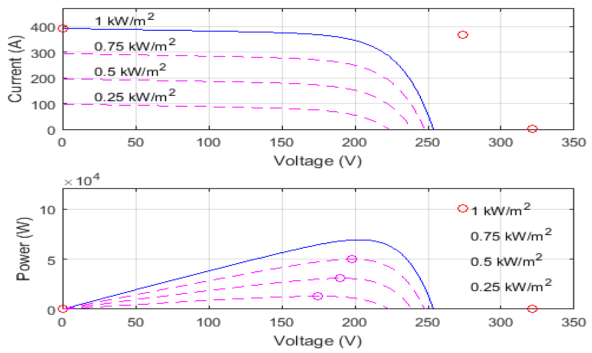



Fig.3. I-V and P-V curve for different irradiation condition

In practical the output voltage and current are affected by temperature and irradiance, hence the output MPP also changes which creates the need of MPPT algorithm to track maximum power and efficiency.

### 3.3. MPPT Controller

Photovoltaic system consists of a PV module and electrical loads. By changing duty cycle of the DC-DC converter the PV source impedance can be matched with that of load impedance which is the condition for maximum power transfer. In this regard, numerous MPPT methods have been analysed.

#### 3.3.1. MPPT Control with Incremental Conductance

Maximum power point tracking by incremental conductance method with Integral regulator is proposed. According to this method the maximum power point is obtained when differentiating the PV array power with respect to voltage and setting the result equal to zero [9, 10]. This is revealed in equation (9),

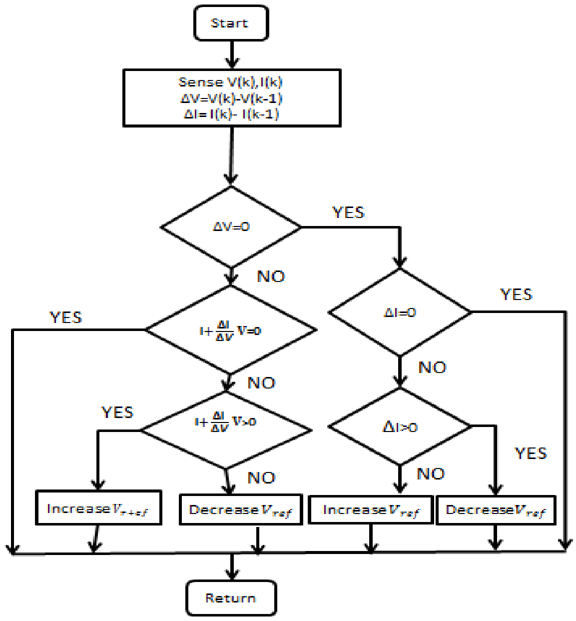



Fig.4. Flow chart of Incremental conductance

At maximum power point dP/dV=0 therefore,

$$\frac{d(V*I)}{dv} = I + V * \frac{dI}{dV} = 0 \tag{4}$$

Rearranging equation (4) gives as,

$$\frac{dI}{dV} > \frac{-I}{V}; V_{ref} = V_{ref} + dV \tag{5}$$

$$\frac{dI}{dV} < \frac{-I}{V}; V_{ref} = V_{ref} - dV \tag{6}$$

The MPP can thus be pursued by associating the instantaneous conductance $(I/V)$ to the incremental conductance $(dI/dV)$.
The integral regulator minimizes the error and the regulated output is given for duty cycle correction based on which pulse generator gives a signal to the DC/DC converter. The P and O technique sporadically fails to track the rapid changing maximum power point in the correct direction throughout fast changing atmospheric condition and the response is more oscillatory and unstable. For this reason, incremental conductance technique is utilized to offer the training patterns rules (data generation) obligatory to the projected MPPT controller.

### 3.3.2. MPPT Control with Optimisation methods

#### 3.3.2.1 Particle Swarm Optimization (PSO) Algorithm

PSO is used to find the optimised maximum power point of solar power system based on the collective behaviour of swarm while searching for food which follows the rule that, the bird which is closer to the food is the effective leader and a group of birds will follow the leader. PSO optimization starts with some arbitrary

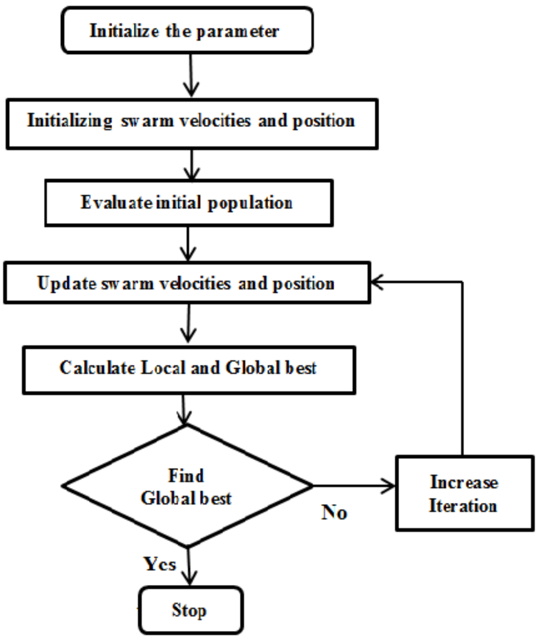



Fig.5. Flow chart of PSO Algorithm

solutions which is utilised from Incremental conductance technique and the search for optimum solution is carried out through generating updates. Every particle in the swarm is categorised by its own position and velocity of the particles flight. The fitness value of each particle is calculated based on their positions and velocities and thus represents the solution for the given optimization problem. [18]

At the end of iteration, local best and global best solution for every particle is updated. In PSO technique there is a weak local search and slow convergence problems. On the other hand, they require a large number of iterations to optimize the solutions thereby leading to increased computational cost.

#### 3.3.2.2 Ant Colony Optimization (ACO)

ACO algorithm is used to find the optimum solution for maximum power point of solar system using the behaviour of ants by selecting a path with a higher trace of pheromone left over by ants which found the food previously and leave the path again with their own pheromones with this optimal shortest path can be found. The pheromone levels disappear gradually and reduce its trace along a particular path which is very important in converging to the optimal path. In ACO algorithm, continuous time systems are divided into multiple regions forming the local nodes for artificial ants and the fitness for every region is calculated.

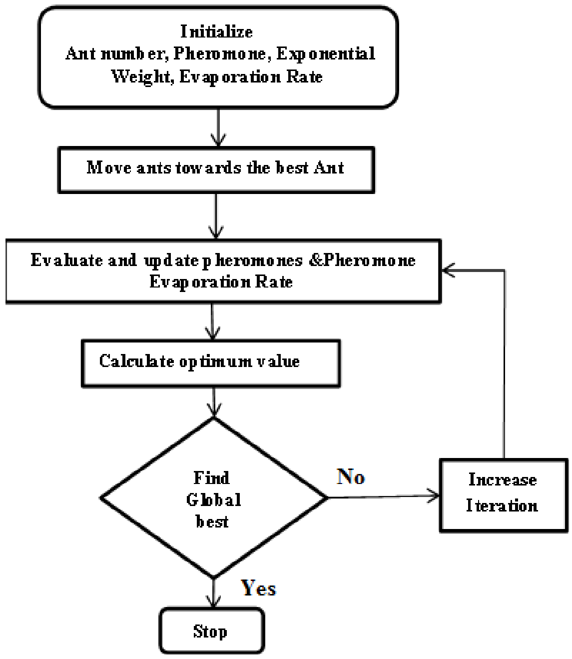



Fig.6. Flow chart of Ant Colony

#### 3.3.2.3 Gravitational Search Algorithm (GSA) (Proposed technique)

The GSA calculation, which depends on Newtonian laws of gravity and mass connection, has a possibility to drive forward improvement strategy created by Rashedi et al. [11]. The best solution is measured by their masses and these heavier masses cause forces of attraction.

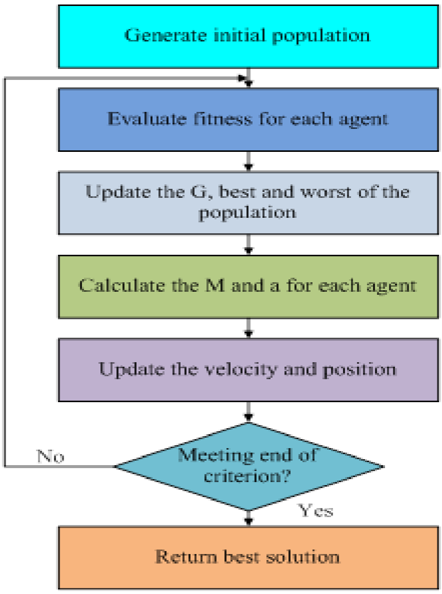


Fig.7. Flow chart of GSA Algorithm

These create ideal solution for the issue and they move gradually than lighter masses. In the proposed work, the GSA method is utilized to decide the MPPT preparing dataset of the ANN, i.e., minimization of difference between the present dc control and the greatest dc control. For GSA, the incremental conductance technique is designated to offer the training data generation to the projected MPPT controller. The DC voltage and current parameters of the PV panel is considered as the contribution of the GSA strategy.

### 3.3.2.3.1 Dataset Generation

Initially, the DC voltage and current of pv panel are considered as the input agents $X = V_{pv}, I_{pv}$. In GSA method, each mass has its position, its inertial mass ($M_i(t)$), its active gravitational mass ($M_{aj}$) and passive gravitational mass ($M_{pi}$). The position of the mass is equalled to a solution of the problem and its gravitational and inertial masses are identified by means of a fitness function [12]. The position of a system is defined with N (dimension of the search space) masses which are given by the equation (7), and the randomly generated agents are given in the following equation (8),

$$X_i = (X_i^1, \ldots, X_i^d, \ldots, X_i^n) \text{ for } i = 1,2,\ldots,n \qquad (7)$$

$$X_i^d = \begin{bmatrix} (V_{11}, I_{11}) & (V_{12}, I_{12}) & \cdots & (V_{1n}, I_{1n}) \\ (V_{21}, I_{21}) & (V_{22}, I_{22}) & \cdots & (V_{2n}, I_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (V_{n1}, I_{n1}) & (V_{n2}, I_{n2}) & \cdots & (V_{nn}, I_{nn}) \end{bmatrix} \qquad (8)$$

From the agents the objective function can be calculated which is given by the equation (9),

$$fit = Min\{P_k - P_m\} \qquad (9)$$

Where, $P_k$ is the DC power at any given time and $P_m$ is the maximum output DC power.

As per Newton's gravitation theory, a gravitational force from mass $j$ acts mass $i$ at the time $t$ is indicated as equation (10),

$$F_{ij}^d(t) = G(t)\frac{M_i(t) * M_j(t)}{R_{ij} + \varepsilon} * \left(X_j^d(t) - X_i^d(t)\right) \qquad (10)$$

Where, $M_i$ is the mass of the object $i$, $M_j$ the mass of the object $j$, $G(t)$ the gravitational constant at time $t$, $\varepsilon$ is a small constant and $R_{ij}(t)$ is the Euclidian distance between $i$ and $j$ objects which is defined as equation (11),

$$R_{ij}(t) = \left\| X_i(t), X_j(t) \right\|_2 \qquad (11)$$

The total force acting on the $i^{th}$ agent $F_i^d(t)$ is premeditated as equation (12),

$$F_i^d(t) = \sum_{j \in kbest, j \neq i}^{N} rand_j \left(F_{ij}^d(t)\right) \qquad (12)$$

Where, $rand_j$ is a random number between interval [0, 1] and $kbest$ is the set of first $K$ agents with the best fitness value and biggest mass.

In order to find the acceleration of the $i^{th}$ agent, at $t$ time in the $d^{th}$ dimension, law of motion is used,

$$a_i^d(t) = \frac{F_i^d(t)}{M_i(t)} \qquad (13)$$

It is to provide a randomized feature to the search, the next velocity of an agent is defined as a function of its current velocity added to its current acceleration which is given by the following equation (14) and (15),

$$V_i^d(t+1) = rand_i V_i^d(t) + a_i^d(t) \quad (14)$$

$$X_i^d(t+1) = X_i^d(t) + V_i^d(t+1) \quad (15)$$

Where, $V_i^d(t)$ is the velocity of an agent at time $t$ and $X_i^d(t)$ is the position of an agent at time $t$ in $d$ dimension.

The gravitational constant $(G)$ given as equation (16) and (17), at the starting which is initialized randomly, will be decreased with respect to time to control the search accuracy. $G$ is a function of the initial value $(G_0)$ and time $(t)$,

$$G(t) = G(G_0, t) \quad (16)$$

$$G(t) = G_0 e^{-\alpha \frac{t}{T}} \quad (17)$$

Where, $\alpha$ is a user specified constant, $t$ is the current iteration and $T$ is the total number of iterations.

The masses of the agents are computed using fitness evaluation. According to Newton's law of gravity and law of motion, a heavier mass i has a higher pull on power and moves slower [13]. The masses are updated as equation (18) and (19),

$M_{ai} = M_{pi} = M_{ii} = M_i$ Where $i = 1,2,..., N$

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \quad (18)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \quad (19)$$

Where, $fit_i(t)$ represents the fitness value of the agent $i$ at time $t$, and the $best(t)$ and $worst(t)$ in the population respectively insist on the strongest and the weakest agent with regard to their fitness route. In this equation (20) and (21) is specified for a minimization problem,

$$best(t) = \min_{j \in \{\{1,...,m\}} fit_j(t) \quad (20)$$

$$worst(t) = \max_{j \in \{\{1,...,m\}} fit_j(t) \quad (21)$$

After finishing the above process the generated dataset using GSA is trained using the RNN.

### 3.3.2.4 Process for RNN Training

A RNN contains two layers and four stages, the preparation layer, testing layer and info stage, concealed stage, setting stage and yield stage. The topology is like a forward system, with the exception that the yields of the concealed layer are utilized as the input signals [19]. In this paper, the RNN is used to set up GSA, optimization of forces and the maximum power is accrued from the PV panel. The RNN is arranged to convey the yield vector. Once arranged, the RNN develops a link among all contributions through its concealed layers. The training diagram of a RNN with input and output parameters are shown in figure 8.

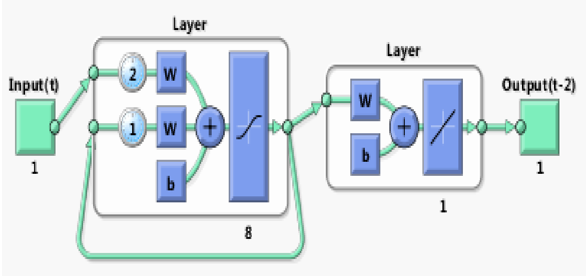



Fig.8. Training structure of proposed RNN

The anticipated RNN has the voltage ($V$) and current ($I$) as the input and the control signal is generated for regulating the pulses of converter as the output. RNN is trained by using back propagation through time delay (BPTT) algorithm with Bayesian regulation. It is used to make sure the weight adjustments $w_{bc}^3, w_b^2$ and $w_{ab}^2$ of the RNN by using the training datasets. In the GSA, the optimized parameter of RNN is realized while minimizing the BP error function. The fitness function of the projected algorithm is premeditated as equations (22) and (23),

$$f_i = \min(BP_{error}) \quad (22)$$

Where,

$$BP_{error} = \sum_{i=1}^{n} \left(P_{req}^i - P_{act}^i\right)^2 \quad (23)$$

In the above equation, $P_{req}$ is the required power of the node and $P_{act}$ is the actual power of the network.

### 3.4. MODEL OF DC/DC CONVERTER

The MPPT controller uses incremental conductance based GSA-RNN method to control the input voltage and the duty cycle of the boost converter (DC / DC converter) to deliver maximum power.

The basic structure of the boost converter is displayed in Fig. 9. When the switch is off, the solar energy is transferred to the output storage capacitor through the inductor. Changes in the duty cycle of switching time can regulate the input voltage and current.

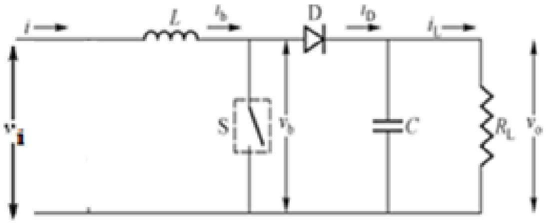



Fig.9. Basic boost converter

The duty cycle of the boost converter is,

$$D = \frac{T_{on}}{T_{on} - T_{off}} \tag{24}$$

The output voltage Vo is given by,

$$V_0 = \frac{V_i(T_{on} + T_{off})}{T_{off}} \tag{25}$$

$$V_0 = \frac{V_i}{1 - D} \tag{26}$$

## 4. SIMULATION AND RESULTS

To enhance the power gathering capacity, the proposed PV system has been simulated using MATLAB in Fig. 10.with different shading conditions. The MPPT was controlled by using proposed GSA and RNN technique. Simulink and Model-Based Design help to reduce development time of MPPT algorithm and organize it to hardware using automatic code generation. The system shown in Fig. 10 consists of a solar PV module, a DC/DC boost converter operating at switching frequency of 50 kHz. The performance analysis of the power of the PV is analysed based on the variation of the solar irradiance and temperature; the maximum output power is tracked. Here, the duty cycle of the converter is controlled by using the proposed technique, which is based on the voltage and current of PV panel.

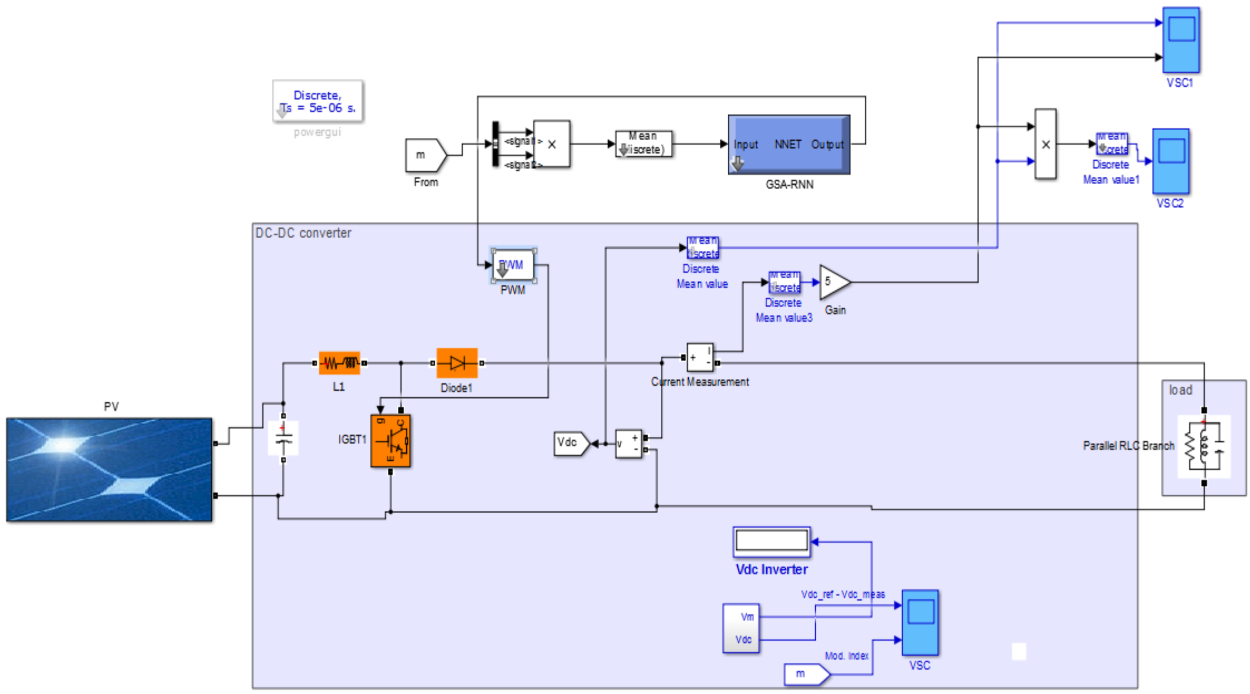
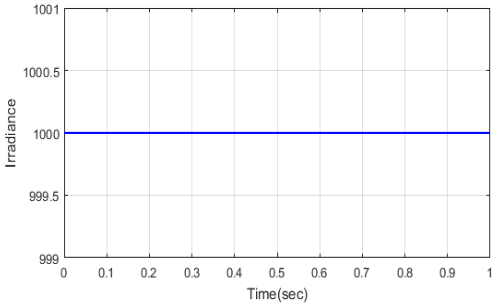



Fig.10. MATLAB/Simulink model of the proposed system

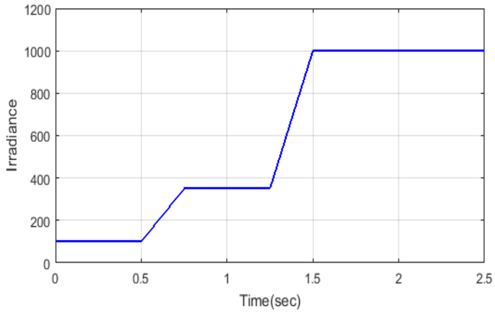
The proposed model is implemented to get maximum power from the PV module which is compared with methods like ACO-RNN and PSO-RNN. For different irradiance, the maximum power from the panel is yielded. The extracted power is generally given to the nonlinear load. Here, the gate of the converter is controlled by using the proposed procedure, which depends on the voltage and current of PV system. In the instance the systems reach an end, the GSA turns out to produce the ideal control pulse for the converter. The execution of the proposed method is depicted in a following segment.

### 4.1 Analysis and discussion of the simulation results

The dynamic response of the PV system due to changes in the irradiation and temperature are compared and studied using three MPPT techniques in simulation to validate the presented algorithm. In this simulation various step changes in solar radiation are performed. Fig. 11 indicates the solar irradiation profile used in simulation. The simulations were performed under exactly the same conditions and the change in irradiation is applied to study the response of each technique during partial shading conditions.




(a)




(b)

Fig. 11. (a) And (b) .Solar irradiation profile

In general with lower values of duty cycle the better performance can be achieved but for the fast response in partial changing radiation can be achieved with higher values of Duty cycle. So, a moderate value of duty cycle is selected for the better operation which will perform good both in steady and dynamic states.

The steady-state response and dynamic response of the PV system output power is studied using GSA-RNN based MPPT technique with different irradiance and change in temperature are shown in Figures 12 and 13 respectively. It is clear that this technique has good performance in both dynamic (partial shading) and steady-state response (constant radiation).

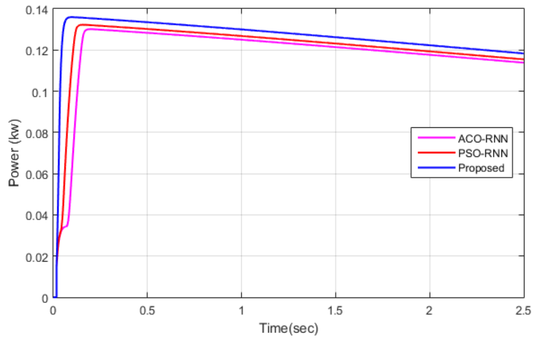
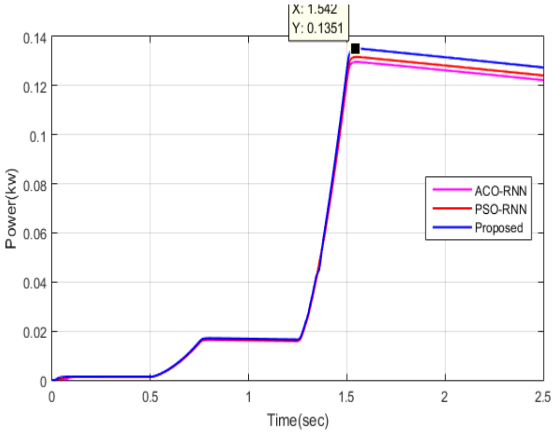



Fig.12. steady-state response (constant radiation)

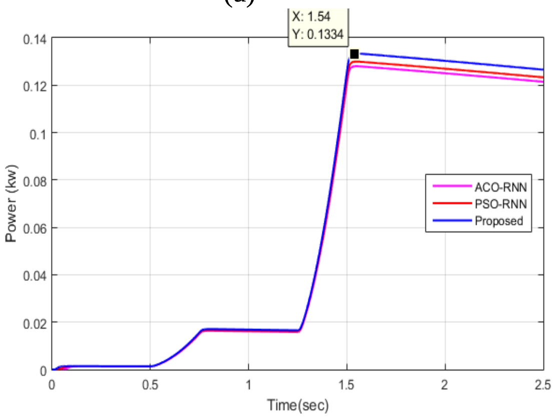
Figure 12 and 13 shows that the GSA based RNN technique has better performance than PSO, ACO technique in both the transient and steady state response. It is clear from results shown in Figs. 11 and 12 that the starting current for all the methods are almost the same.

In Figure 12 at time t = 0 to 2.5 sec the maximum power of the proposed model is illustrated at the constant irradiance.

The Maximum power point tracking is analysed under various PV irradiance and the different time instants. As observed from this figure the solar irradiance is decreased by about 60% from its normal irradiance and the power is not increased properly. Because, it depends on the MPPT working performance, if the MPPT control technique is not working properly, then the power is not maximized properly. By using the proposed technique, the maximum power is achieved which is shown in the figures. Then the performance of the proposed method is compared with the existing methods.




(a)




(b)

Fig.13.
(a) Response under Partial shading condition with 25°C
(b) Response under Partial shading condition with 40°C

From the simulated output shown in Figure.13, it is viewed that, variation of cell temperature has a net effect which is a decrease in output power with increase temperature. Compared to the effect of temperature, the effect of irradiance plays a major role of the PV output Power.

The problem is optimized by RNN based gravitational search algorithm with MATLAB. The relationship between the fitness of the objective function and the optimization of the iteration is shown in Figure 14.It is clear from plot that GSA-RNN method fits quickly with less number of iteration.

The performance of the proposed method is evaluated against three other established MPPT methods reported in the literature. Compared with a conventional method, such as incremental conductance [15], PSO and ACO based MPPT technique [16], the proposed method has higher yield power and lower steady-state oscillation.

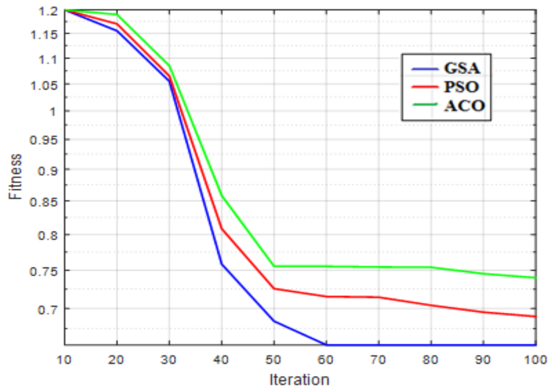



Fig.14. Variation of fitness function with iteration

## 5. REAL TIME IMPLEMENTATION AND RESULT

Figure 15 shows the experimental configuration and the converters set up of the proposed MPPT technique. The experimental verification is implemented by using a 37W solar panel having maximum voltage of 16.4v. The PIC16F882 microcontroller is used in this implementation. This microcontroller is equipped with 10-bit ADC, which is suitable for this project. A gate drive with a signal frequency of 20 kHz is designed to switch the converter, which regulates the output voltage and tracks the Maximum power point.

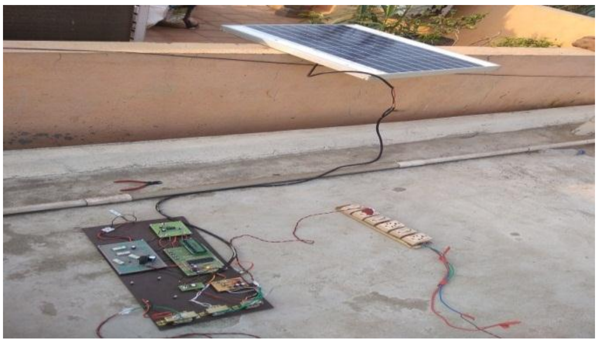


Fig.15 Experimental setup of boost converter connected with 37W solar panel

The dc–dc converter is a boost which is able to step up the input voltage and containing two semiconductor switches and, inductor as shown in Fig. 16. To reduce output voltage ripple, capacitor filters are added to the output of the converter. The converter is designed to operate in continuous conduction mode and is chosen on the basis of its wide range of operational region and based on irradiation, temperature, and output load.

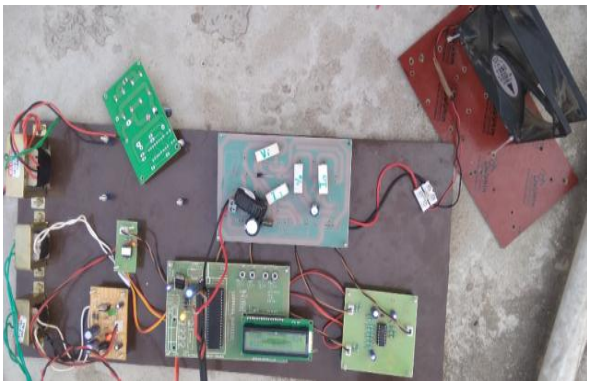
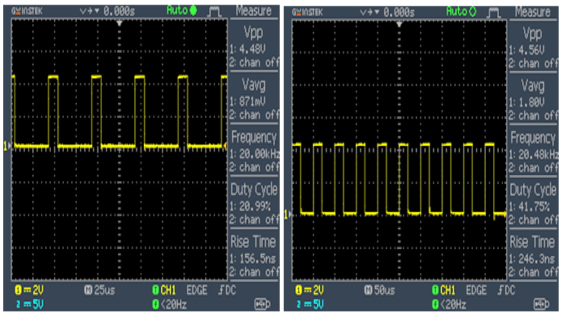


Fig.16 Boost converter connected with Fan load

Figure 17 gives the DSO output pulse of gate drive circuit controlled by PIC microcontroller, programmed with GSA-RNN for maximum extraction of power from the solar panel. It can be observed that on time and off time are varied in accordance with input profile and load requirement.




(a) (b)

Fig.17 Change in pulse produced by proposed algorithm for change in irradiation

Figure 18 shows the experimental output waveform of the system under shading effect which yields less output voltage and Figure 19 shows the experimental output waveform of the system under normal irradiation.

The entire tracking process takes around 4 s, and the MPP recognition of the global MPP occurs after 0.2 s from the start of the tracking. The proposed method continues searching until the stopping condition is met. As a result, in case of any change in weather conditions or output load, the algorithm considers this change and recognizes it during the running process.

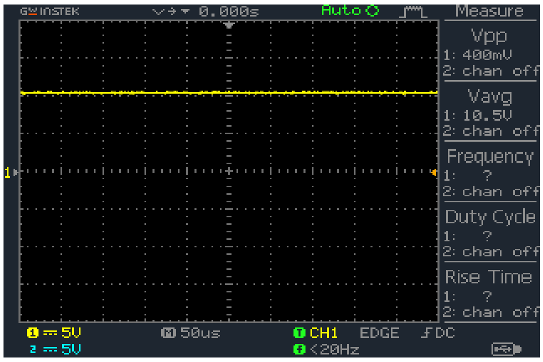



Fig.18 Converter output under partial shading

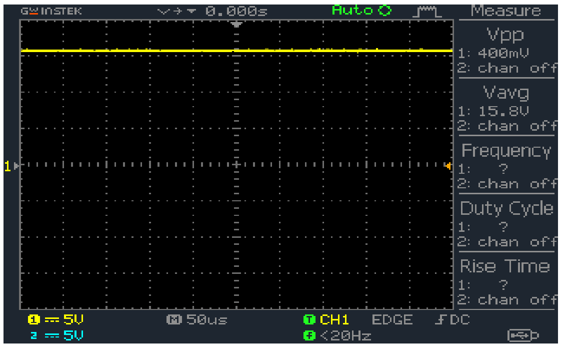



Fig.19 Converter output under normal condition

The proposed algorithm is tested with different load levels. Also the algorithm is tested for many times to prove its consistency and reliability.

## 6. CONCLUSION

Compared with other methods used in the literature, the proposed method is simple to implement and shows robust and reliable performance. This work is aimed to develop a reliable technique to track the MPP of PV system under partial shading conditions. A hybrid method called GSA, a combination of recurrent neural network, is employed to track the actual MPP in the output of the PV system. A sequential procedure of mathematical modelling is applied to model and simulate the behaviour of the PV system under partial shading conditions. The proposed MPPT method is verified through simulation and experiment under normal and partial shading conditions. Different conditions are verified to study the reliability, speed, and accuracy of the system. The proposed technique identifies the global MPP from local MPPs during mismatching conditions in any partial shading condition, and the technique is easily implemented in a low-cost PIC microcontroller.

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