A Simulated Annealing MPPT Approach for Partially Shaded PV System

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***Abstract*-Solar energy is one of the most abundant renewable energy sources, capable of producing electricity with the help of a PV cell. PV cell exhibits a non linear power-voltage (P-V) characteristics leading to a unique point referred as maximum power point(MPP). This MPP varies depending on environmental conditions. This project proposes a Simulated Annealing based Global Maximum Power Point Tracking (GMPPT)** technique designed for photovoltaic (PV) systems experiencing partial shading conditions (PSC).Simulated Annealing (SA) has been applied to PV MPPT and is very effective at locating global maxima with limited implementation complexity.The proposed method performs faster convergence speed, higher tracking accuracy and continuously tracking of the global Maximum Power Point (GMPP) under climate changes when compared with the existing system of Cauchy and Gaussian sine cosine optimization (CGSCO). This work produces the simulation results of proposed MPPT algorithm. The simulation of Solar PV using SA algorithm is carried out using MATLAB software.

***Index Terms*—Maximum power point, photovaltic, energy resources, Simulated Annealing**

I. INTRODUCTION

Energy is the primary and most universal measure of all kinds of work by human beings and nature. Everything that happens in the world is the expression of flow of energy in one of its forms Energy is an important input in all sectors of a country's economy. The standard of living is directly related to per capita energy consumption. Due to rapid increase in the population and standard of living; we are faced with energy crisis. Conventional sources of energy are increasingly depleted. Hence, Non-Conventional Energy Sources have emerged as potential source of energy in India and world at large. During the past decades, the electric power industry has undergone significant changes in response to the rising concerns of global climate change and volatile fossil fuel prices. For more efficient, reliable, and environmentally friendly energy production, it is critical to increase the deployment of distributed generation, especially from Renewable Energy resources (RE), as well as distributed Energy Storage (ES).Renewable energy based generations such as wind or Photovoltaic (PV) have been used to generate power in the past few years.

Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis. It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air. The large magnitude of solar energy available makes it a highly appealing source of electricity.

Photovoltaic power capacity is measured as maximum power output under standardized test conditions (STC) in "W_p" (Watts peak). The actual power output at a particular point in time may be less than or greater than this standardized, or "rated," value, depending on geographical location, time of day, weather conditions, and other factors. Solar photovoltaic array capacity factors are typically under 25%, which is lower than many other industrial sources of electricity.

Simulated Annealing (SA) is a probabilistic technique for approximating the global optimum of a given function. Specifically, it is a metaheuristic to approximate global optimization in a large search space. It is often used when the search space is discrete. For problems where finding an approximate global optimum is more important than finding a precise local optimum in a fixed amount of time, simulated annealing may be preferable to alternatives such as gradient descent.

In this thesis, the area of focus is to formulate a PV system integrating an energy storage system, design and simulate a DC/DC Converter to interface a battery-bank and develop a smart battery energy management system to coordinate the operation of the battery bank along with the PV system, considering the utility grid connection. Long-term energy storage battery such as Lead acid battery is used to shave the midday PV power peak and provide a complementary power supply during the night. This system is more advantageous with the view of increasing the lifespan of the battery.

II. RELATED WORK

In S. Mohanty, and P. K. Ray et al., [1] presented a maximum power point tracking (MPPT) design for a photovoltaic (PV) system using a grey wolf optimization (GWO) technique. The GWO is a new optimization method which overcomes the limitations such as lower tracking efficiency, steady-state oscillations, and transients as encountered in perturb and observe (P&O) and improved PSO (IPSO) techniques. The problem of tracking the global peak (GP) of a PV array under partial shading conditions (PSCs) is attempted employing the GWO-based MPPT technique. The proposed scheme is studied for a PV array under PSCs which exhibits multiple peaks and its tracking performance is compared with that of two MPPT algorithms, namely P&O-MPPT and IPSO-MPPT.

SitiRahimah Osman, et al., [2] present a Maximum power point tracking (MPPT) and battery charging control are two important functions for a solar battery charger. The operation of a solar battery charger for standalone street light systems is investigated. Using only one voltage sensor, the solar charger is able to operate in both MPPT and constant voltage (CV) charging mode, hence providing high performance at a low cost.

Y. Mahmoud et al., [3]proposes a photovoltaic circuit model featuring lower computational time and comparable accuracy. The model utilizes the accuracy of the practical PV model and reduces the computational time by replacing the model series resistance with a third-degree-polynomial voltage-dependent source. The proposed model mimics the accurate characteristics of the practical model without being dependent on a transcendental implicit equation, thus providing low computational time.

Y. Mahmoud et al., [4] The only photovoltaic (PV) model in the literature featuring low computational effort is the ideal PV circuit model because it uniquely relies on a simple nontranscendental equation. Unfortunately, it suffers from a deteriorated accuracy at low irradiance levels. This letter enhances the accuracy of the ideal PV model at low irradiance levels without affecting its simplicity. The proposed approach modifies the equation of the saturation current such that it takes the irradiance variations into consideration. The effect of the proposed modification on the complexity of the model is shown to be negligible.

T. K. Soon et al., [5] proposes a simpler fast-converging MPPT technique, which excludes the extra control loop and intermittent disconnection. In the proposed algorithm, the relationship between the load line and the I-V curve is used with trigonometry rule to obtain the fast response. Theproposed algorithm is four times faster than the conventional incremental conductance algorithm during the load and solar irradiation variation. Consequently, the proposed algorithm has higher efficiency.

III. SYSTEM IMPLEMENTATION

The propose 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. Therefore, in this project, a new Simulated Annealing algorithm is proposed for MPPT.

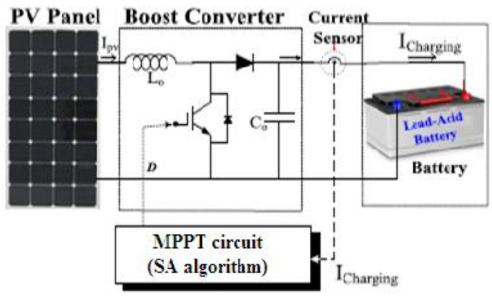

Fig. 3.1 SPV Operating Model for Battery Charging

The complete working of a solar PV array with a battery is shown in Fig.4. 1. Here, the output of the PV panel is supplied to the battery through a boost converter. The switching of the boost converter is decided by Simulated Annealing algorithm by using the information of charging current.

B) MODELLING OF SOLAR PV (SPV) MODULE

For modeling, various techniques are available, but in this work, for simplicity, a single diode model is taken and shown in Fig. 4.2.

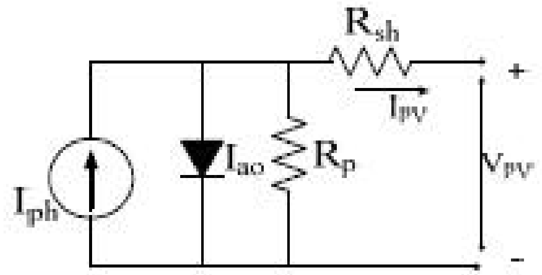

Fig. 3.2 PV Array Configuration

The mathematical formulation of the output current (I_{pv}) of the PV module is described as

$$I_p = I_{ph} - I_a \left[e^{\left(\frac{(V_p + R_{sh}.I_p) \times q}{N_c\ k\ {}_c a_f}\right)} - 1\right] - \frac{V_p + R_{sh} I_p}{R_p} \text{______ (1)}$$

Where, I_{ph} is the photovoltaic current. $I_{\alpha o}$ is cell reverse saturation current or diode leakage current. $V_{pv}$are the module output voltage. R_{sh}(0.221Ω) and R_p(415.5Ω) are equivalent series and parallel resistance, N_{cs} is the number of series cells,q is the charge (of an electron) [1.60217646×10-19 C], the Boltzmann constant is k [1.3806503×10-23J/K], temperature of the cell's is T_c, α_{fd} is ideality factor of the diode (in general its value is 1≤α≤1.5).
The mathematical details of I_{ph} and $I_{\alpha o}$are described as,

$$I_{ph} = \left(\frac{R_P + R_{sh}}{R_P} I_S + K_i(T_c - T_r)\right)\frac{S}{S_r} \text{______ (2)}$$

$$I_a = \frac{I_S + K_i(T_c - T_r)}{e^{\left(\frac{V_O + K_v(T_c - T_r)}{N_c\ k\ {}_c a_f} \times q\right)} - 1} \text{______ (3)}$$

Where, I_{sc} and V_{oc} are short circuit current and open circuit voltage, K_i and K_v are coefficient of current (0.0032A/K) and voltage (-0.123V/K), T_c and T_{ref} are cell's working and reference temperature (25℃), S and S_{ref} are the working and reference irradiation (1000W/m2).

(i) SOLAR PV SYSTEM UNDER PARTIAL SHADING CONDITIONS

Due to the shadow of clouds, trees or tall buildings, a non uniformity of the insolation arises on the PV panel. In this situation, some modules receive direct irradiance and some are under partially shaded. The partially shaded modules generate less amount of current in comparisons to other modules. All modules in PV array are in series, so the current through the parallel resistance of partially shaded modules, leads to a voltage drop. This drop reduces the maximum output power and creates hotspots. This problem can be resolved by bypassing currents of all modules through a bypass diode (Dby).

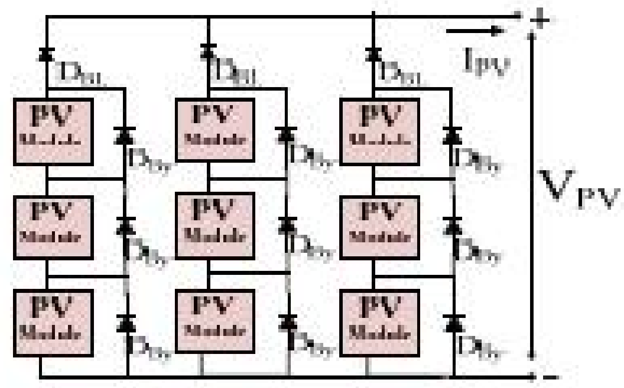

Fig. 3.3 Circuit Configuration of PV Module

In the case of parallel connections of the string, the shaded string draws current from rest of the parallel connected strings. This circulating current reduces the efficiency of the PV panel. This problem can be resolved by using a blocking diode (DBL). The arrangement of bypass diode (Dby) and blocking diode (DBL) in a series-parallel combination of modules is shown in Fig. 4.3. In this partial shaded condition, the power-voltage (P-V) characteristic of the PV panel consists of multiple peaks. Out of all peaks, the power of the top most peak is maximum, that is known as GMPP.

C) SIMULATED ANNEALING

The Simulated Annealing (SA) method is a powerful optimization technique and it has the ability to find near global optimum solutions for the optimization problem. SA is applied in many power system problems. However, appropriate setting of the control parameters of the SA based algorithm is a difficult task and the speed of the algorithm is slow when applied to a real power system. SA is a method for finding a good solution to an optimization problem. If you're in a situation where you want to maximize or minimize something, your problem can likely be tackled with simulated annealing. Simulated Annealing (SA) is motivated by an analogy to annealing in solids. The algorithm in this paper simulated the cooling of material in a heat bath. This is a process known as annealing. If you heat a solid past melting point and then cool it, the structural properties of the solid depend on the rate of cooling. If the liquid is cooled slowly enough then large crystals will be formed, However the liquid is cooled quickly (quenched) the crystals will contain imperfections. Metropolis's algorithm simulated the material as a system of particles. The algorithm simulates the cooling process by gradually lowering the temperature of the system until it converges to a steady, frozen state.

The travelling salesman problem is a good example: the salesman is looking to visit a set of cities in the order that minimizes the total number of miles he travels. As the number of cities gets large, it becomes too computationally intensive to check every possible itinerary.

(i) PROCEDURE FOR SA ALGORITHM

1. Generate a random solution
2. Calculate its cost using defined cost function
3. Generate a random neighboring solution
4. Calculate the new solution's cost
5. Compare them:
   - If $C_{n} < C_o$: move to the new solution
   - If $C_{n} > C_o$: *maybe* move to the new solution
6. Repeat steps 3-5 above until an acceptable solution is found or you reach some maximum number of iterations.

(ii) PSEUDO CODE FOR SA ALGORITHM

The following pseudo code presents the simulated annealing heuristic as described above. It starts from a state s_0 and continues to either a maximum of k_m steps or until a state with energy of e_m or less is found. In the process, the call neighbour(s) should generate a randomly chosen neighbour of a given state s; the call random (0, 1) should pick and return a value in the range [0, 1], uniformly at random. The annealing schedule is defined by the call temperature(r), which should yield the temperature to use, given the fraction r of the time budget that has been expended so far.

- Let $s = s_0$
- For $k = 0$ through k_m (exclusive):
- $T \leftarrow$ temperature(k/k_m)
- Pick a random neighbor , $s_m \leftarrow$ neighbour(s)
- If $P(E(s), E(s_{n}), T) \geq$ random (0, 1), move to the new state:$s \leftarrow s_{n}$
- Output: the final state s

(iii) IMPLEMENTATION OF SA ALGORITHM

The Simulated Annealing algorithm is implemented as follows:

- 1. Select a local search scheme
- 2. Determine the cooling schedule
- 3. Understand the result

(iv) ACCEPTANCE CRITERIA

The law of thermodynamics state that at temperature, t, the probability of an increase in energy of magnitude, δE, is given by

$$P(\delta E)= \exp(-\delta E / kt) \quad (3.1)$$

Where k is a constant known as Boltzmann's constant.

The simulation in the Metropolis algorithm calculates the new energy of the system. If the energy has decreased, the system moves to this state. If the energy has increased then the new state is accepted using the probability returned by the above formula. A certain number of iterations are carried out at each temperature and then the temperature is decreased. This is repeated until the system freezes into a steady state. This equation is directly used in simulated annealing, although it is usual to drop the Boltzmann constant as this was only introduced into the equation to cope with different materials. Therefore, the probability of accepting a worse state is given by the equation

$$P = \exp(-c/t) > r \quad (3.2)$$

Where

c = the change in the evaluation function

t = the current temperature

r = a random number between 0 and 1

The probability of accepting a worse move is a function of both the temperature of the system and of the change in the cost function. This was shown in the lectures and a spreadsheet is available from the web site for this course which shows the same example that was presented in the lectures. It can be appreciated that as the temperature of the system decreases the probability of accepting a worse move is decreased. This is the same as gradually moving to a frozen state in physical annealing. Also note, that if the temperature is zero then only better moves will be accepted which effectively makes simulated annealing act like hill climbing.

(v) SIMULATED ANNEALING ALGORITHM

1. k = 0;

2. Search (i→ j), performance differenceΔ;

3. If Δ≤ 0 then accept, elseif exp(-Δ/T(k)) > random[0,1) then accept;

4. Repeat 1) and 2) for L(k) steps;

5. k = k+1;

6. Repeat 1 – 4 until stopping criterion is met

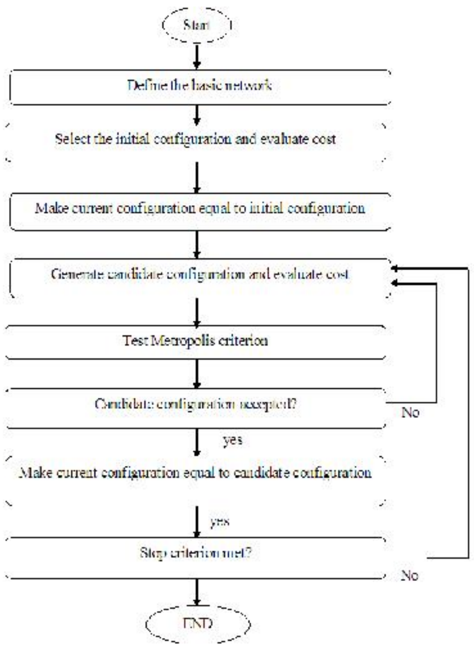

Figure 3.4:Flowchart of The Simulated Annealing Algorithm

Figure3.1 shows the flowchart of the Simulated Annealing algorithm which has the main advantage of the low time consumption. The main and the first step of this process were initializing all the necessary values. Then check the limitation of the power flow constraints. If it was satisfied then update all the initialized values. This process repeated again and again until the optimized values were obtained.

D)ENERGY STORAGE

Battery is a storage device which stores the excess power generated and uses it to supply the load in addition to the generators when power is required. The PV energy system (described in the previous chapters) is integrated i.e. connected to a common DC bus of constant voltage and the battery bank is also connected to the DC bus via a bidirectional converter. Any power transfer whether from PV array to battery bank or PV array to load or from battery bank to load or from load to load takes place via bidirectional converter. As the power flow associated with the battery is not uni-directional, a bidirectional converter is needed to charge and/or discharge the battery in case of excess and/or deficit of power respectively. Since batteries are dynamic in nature, the charging/discharging processes of battery reduces its lifespan. In PV systems, with the view to increase the lifespan of the battery, a battery energy storage system requires a battery energy management system. The objective of the energy management system is to maximize the power coming from the PV panel, minimize grid power, and minimize the charging and discharging of the battery and protect the battery from overcharging and discharging. It should also coordinate the power flow when the system is grid connected

IV. RESULTS AND DISCUSSION

The proposed work is completed on MATLAB software on the version of R2014a. The designed circuits were drawn and simulated using MATLAB Simulink and Sim power system toolboxes.

The figure 5.1 and 5.2 depicts the PV model that is designed in MATLAB Simulink platform and solar array respectively.

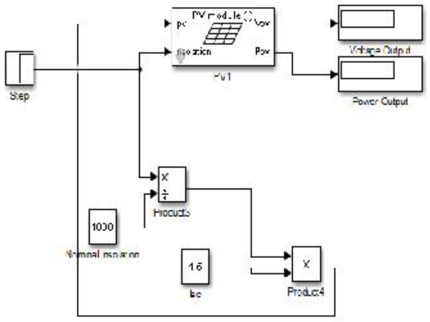

Fig 4.1 PV model

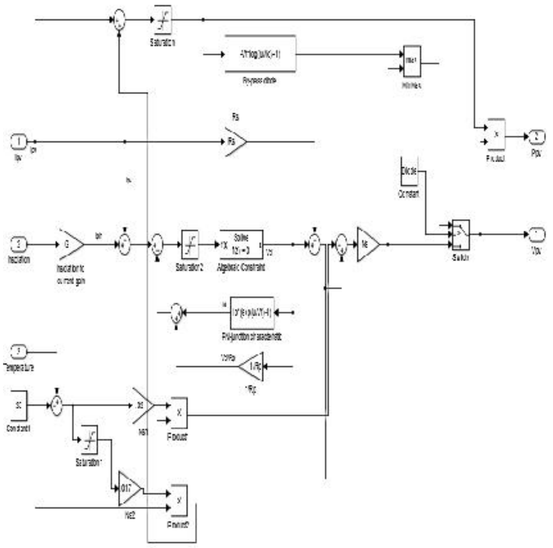

Fig 4.2 Solar cell module

The input source such as Photo voltaic source is designed as per the following Table 5.1 parameters.

Table 4.1 PV panel parameters

V_{oc}	60 V
I_{sc}	6.5 A
Power(max)	45W
No. of solar cell	36
No. Of array	6
No. of cell per an array	6
Reference Insolation	$1000W/m^2$

The boost converter is designed with the following parameter specifications that is displayed on the table 5.2.

Table 4.2 Specifications of DC/DC Boost Converter

Inductor	5.6mH
Capacitor	100μ
Solid Switch	MOSFET
Switching Frequency	4k-Hz
Resistor (R_{load})	3KΩ

The designed SPV simulated anneling MPPT approach for partial shaded using boost converter topology is represented in the following figure 5.3

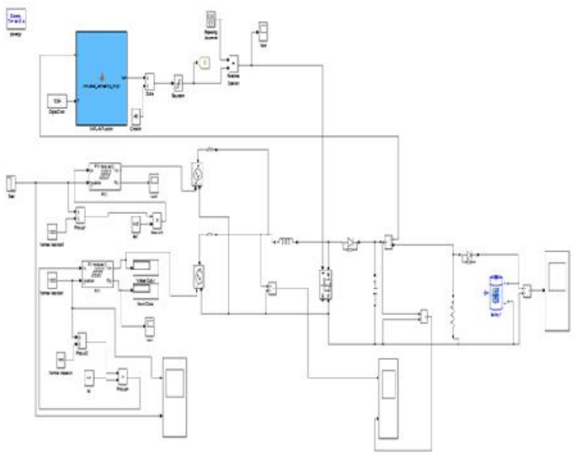

Fig 4.3 Simulink model for proposed PV system

The proposed Simulink work is incorporating the 200W PV panel for the MPPT analysis. The source side (i.e., PV side) voltage and current response with respect to the irradiance is shown in the following figure 5.7.

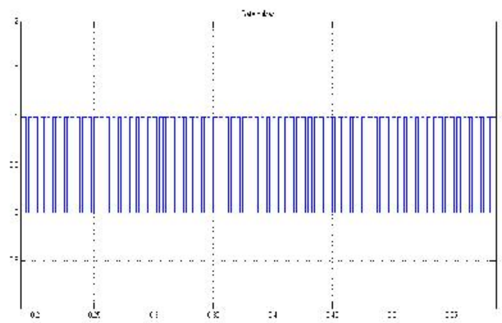

Fig 4.4 Gate Pulse For Boost Converter

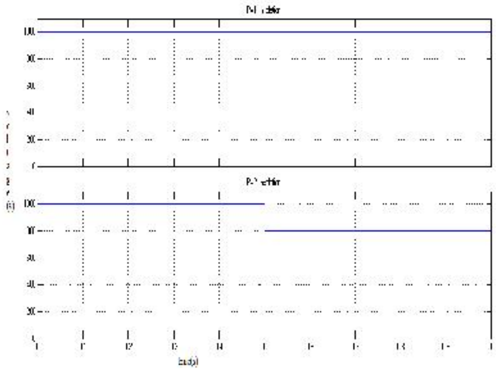

Fig 4.5 PV panel 1 insolation and PV panel 2 insolation

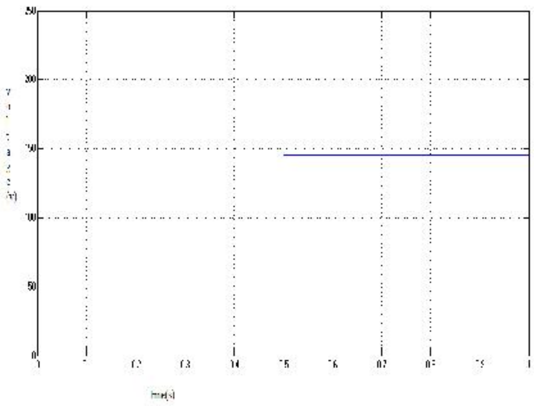

Fig 4.6 PV Module 1 Power Output

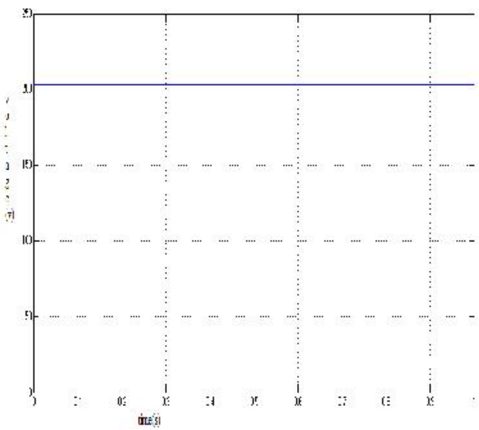

Fig 4.7 PV Module 2 Power Insolation

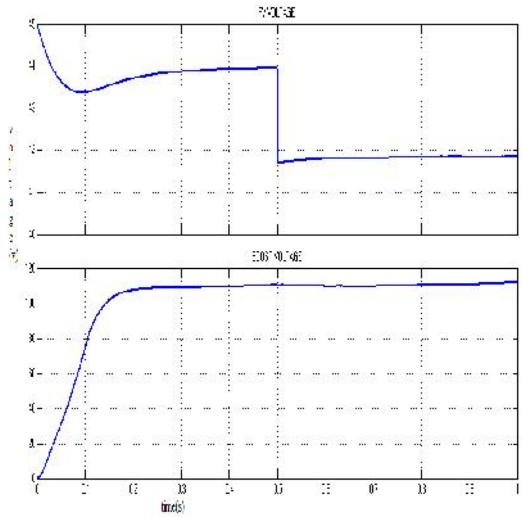

Fig 4.8 Solar PV Voltage And Solar PV Boost Voltage

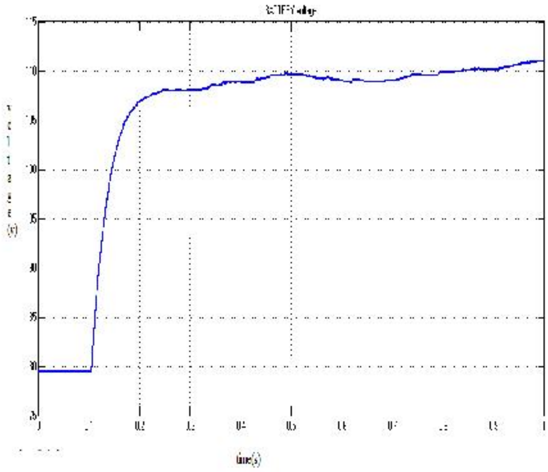

Figure 4.9 GMPPT Output Waveform for Constant Battery Charging

The work is mainly focusing about the SA based MPPT due to its outperforming capabilities when compared to other system. The efficient results obtained from the SA-MPPT is shown in the above figure

The above response is showing the maximum power achieved response in SA-MPPT implementation.

The solar panel was designed with the help of MATLAB simulation software. The panel is interfaced with the DC-DC converter and the converter is boosting the voltage up to maximum voltage efficiency of 95% the SA optimization algorithm is designed accordance the principles of the maximum power point tracking strategy. The efficiency comparison is done for the proposed MPPT based model.

V. CONCLUSION

The solar panel was designed with the help of MATLAB simulation software. The panel is interfaced with the DC-DC converter and the converter is boosting the voltage up to maximum efficiency of 79.2% for the existing MPPT algorithm. The simulated annealingalgorithm is designed accordance the principles of the maximum power point tracking strategy. The proposed algorithm responses to achieve global power point tracking in solar panels. The proposed algorithm tracking the maximum power form the solar panels and making an efficient boot conversion with 95% system efficiency

The future work may be extended in the way of implementing with Penguins Search Optimization Algorithminstead of simulated algorithm which is used now in project and also comparison of different algorithms will be done.

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