PSO based Effective Maximum Power Tracking of Solar Photovoltaic System

Pavan Pathak, Dr. Amita Mahor

***Abstract*— Renewable energy sources are the most important and emerging energy sources as the non renewable sources are depleting day by day. Solar energy or the photovoltaic (PV) energy is gaining popularity since it is clean, pollution free and long lasting. For maximum output power from a solar cell various tracking (MPPT) method are developed and adopted but the hunt for a better one is still on. In the same context this paper presents a Particle swarm optimization (PSO) based generalized PV model using Matlab/ Simulink software. The major advantage of this paper is that we can use it for the maximization of the PV output power or for the minimization of difference (or error) between the maximum power and power obtained in each trial. Furthermore, the developed algorithm is simple and the proposed model can be quite easily implemented on the test system. To estimate the effectiveness of the proposed model it was tested on Matlab/Simulink environment for 6 different population sizes and for each pop size 30 trails are carried out. Its results are compared with the Hill climbing and Look up table method and the competence of PSO based method in terms of convergence speed and maximum power is highlighted using simulation results.**

Index Terms— Hill climbing, Particle swarm Optimization (PSO), Photovoltaic (PV), Maximum power point tracking (MPPT).

INTRODUCTION

As the energy requirements are increasing on a regular basis, the use of more sustainable and alternative source is gaining importance. The power generation from solar PV is expected to grow for reduction the global warming. The PV power is likely to be used in distributed generation, transportation purposes and certain mobile application. The main reason behind this is that PV system possesses non linear relationship and the output power depends on the type and nature of the connected load. Because of this kind of direct connection with the load their overall efficiency is very low. One of the major problems associated with the solar system or panels are that they are still costly so to make them cost effective is an important point to be considered. To encounter some of these objectives the directly connected photovoltaic systems are being replaced with the PV systems and a maximum power point tracker (MPPT) in between.

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The PV power principally depends on solar temperature and solar irradiance. As solar irradiance and temperature are time dependent so it is very much important to have control logic that will continuously look after the terminal voltage & current and updates the control signal accordingly. The terminal voltage of PV module should also be equal to the maximum power point value. To achieve all these goals a particle swam optimization (PSO) based maximum power point tracking method has been proposed and developed for extracting maximum output power from a solar PV array under various pop sizes and trails. It is based on the two different stopping criteria. One is on the number of iterations and the other on the difference between the maximum power and PV power in each trial.

LITERATURE REVIEW

A maximum power point tracking algorithm is absolutely necessary to increase the efficiency of the solar panel. It has been found that only 30-40% of energy incident is converted into Electrical energy so it is very important to track Maximum power points. Over the last one decade many researchers have worked on MPPT, still it is an open research area. Work done by some of the researchers is listed below:

Miyatake, M et al. [1] presented multiple photovoltaic modules form of power distribution used in solar PV systems. Normally in such systems individual maximum power point tracking schemes for each of the PV modules increases the cost. Also V-I characteristic exhibits multiple local maximum power points during partial shading. Due to this it is difficult to find the global MPP using conventional single-stage tracking. Proposed algorithm solved this difficulty by introducing a particle swarm optimization technique.

Kashif Ishaque et al.[2] have proposed an improved maximum power point tracking approach for the photovoltaic system using a modified particle swarm optimization algorithm. Advantage of the method is the reduction of the steady state oscillation once the maximum power point is located. Also, the proposed method has the ability to track the MPP for the extreme environmental conditions. The algorithm is simple and can be computed very fast.

Kuei-Hsiang Chao et. al.[3] investigated the output characteristics of photovoltaic module arrays with partial module shading. They have presented a maximum power point tracking method that can efficiently track the global optimum of multiple peak curves. Proposed method was based on particle swarm optimization. The concept of linear decreases in weighting was added to improve the tracking performance of the maximum power point tracker. Simulation results verified that proposed method can successfully track maximum power points in the output characteristic curves of photovoltaic modules with multiple peak values.

Malathy S. and Ramaprabha R.[4] proposed lookup table based model for solar photovoltaic module. Insolation level and temperature greatly influenced the performance of a solar PV module. The experimental data including voltage and current of the PV module are obtained for various insolation conditions. These data are then used to develop a lookup table to mimic the behavior of the actual PV module. This work can be extended to study the impact of partial shading conditions in different types of configurations.

Moacyr A. G. de Brito, et. al.[5] presented a comparisons among the most usual MPPT with respect to the amount of energy extracted from the photovoltaic panel, PV voltage ripple, dynamic response and use of sensors. In presented work models are first implemented via Mat Simulink, and after a digitally controlled boost DC-DC converter was implemented and connected to an Agilent Solar Array simulator in order to verify the simulation results.

Using different MPPT techniques modeling and simulation of PV system in Matlab/Simulink software has been done in [6]-[10]. The main focus of literature review is to survey and summarize the use of PSO and its application to MPPT of solar PV system problems reported in literature along with other non-conventional and conventional methods. It has been also observed that application of PSO in various real world problems outperforms other state of the art of non-conventional or conventional mathematical algorithm.PSO has been accepted widely for obtaining the global optimal solution because of its simplicity and low constraints on objective function. Although PSO approach is capable of providing good quality results at faster rate, but when compared with other evolutionary optimization methods, their ability to fine tune the optimum solution is comparatively weak, mainly due to the lack of diversity at the end of search. Hybridization of PSO with conventional mathematical approaches are the major areas which need further research to increase the global optimal ability of PSO

MAXIMUM POWER POINT TRACKING

Maximum Power Point Tracking of a photovoltaic array is an essential part of a Photo Voltaic system. Renewable sources of energy acquire growing importance due to its enormous consumption and exhaustion of fossil fuel. Also, solar energy is the most readily available source of energy and it is free. The rapid increase in the demand for electricity and the recent change in the environmental conditions such as global warming led to a need for a new source of energy that is cheaper and sustainable with less carbon emissions.

- **Maximum Power Point Tracking Methods**

Maximum Power Point Tracking algorithms are necessary in Photo Voltaic applications because the Maximum Power Point of a solar panel varies with the irradiation and temperature. Use of Maximum Power Point Tracking algorithms is required in order to obtain the maximum power from a Solar Photo Voltaic Array. Over the last decades many methods have been developed and published to find the Maximum Power Point. These methods differ in many factors such as required sensors, complexity, cost, range of effectiveness, convergence speed, correct tracking when irradiation and or temperature change, hardware needed for the implementation or popularity, among others.

Among various methods, the Perturb & Observe methods are the most common. These techniques have the advantage of an easy implementation, although they also have drawbacks. Other methods are based on different principles like fuzzy logic control, neural network, fractional open circuit voltage or short circuit current, current sweep, etc. Almost these methods yield a local maximum and some, like the fractional open circuit voltage or short circuit current, give an approximated MPP, not the exact one. In normal conditions the V-P curve has only one maximum, so it is not a problem. However, if the PV array is partially shaded, there are multiple maxima in these curves

SIMULINK MODELLING

In this work maximum power point tracking of PV cell has been done by using 3 different methods look up method, Hill Climbing and PSO based MPPT method.

Here Matlab/Simulink version R2010 environment has been used to develop a Simulink model of solar PV system along with maximum power point tracking method. Detailed methodology of various MPPT based PV systems and its Simulink models are given in subsequent section.

- **Methodology**

To develop a solar PV system mathematical equations are designed using SIMULINK. After this, the subsystems were created and connected with each other. Similarly the designing of Buck converter has been done. Both the models were connected using a constant voltage source. As the solar insolation and temperature is changed model runs and gives the result accordingly. To change the duty ratio of the DC-DC BUCK converter an embedded function is created, which regulates the duty ratio of converter automatically.

- **Simulink Model**

The detailed simulink model of the proposed work has been designed to track the maximum power point and can be operated in a buck mode is shown below.

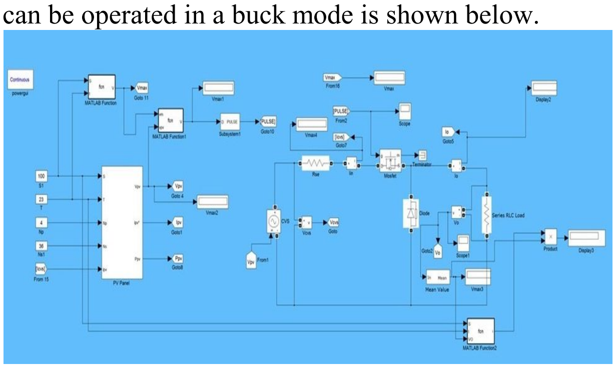

Fig.1:Simulink model of Look up based MPPT

As shown in Fig.1 the block diagram consists of solar PV panel, DC-DC BUCK converter and MATLAB function block. PV panel is the life of this diagram. The functioning of theses blocks are described in subsection below.

- **Solar PV cell model**

Modeling of solar PV cell has been done by using the mathematical eq.(1)-(8) . The detailed Simulink model is shown in fig.2 given below:

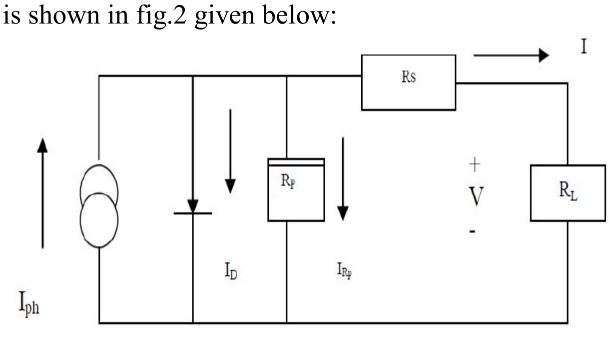

Fig.2:Equivalent circuit of a PV cell

$$I_{ph} = I_D + I_{Rp} + I \qquad (1)$$

Above equation can be rewritten as

$$I = I_{ph} - I_{Rp} - I_D \qquad (2)$$

$$I = I_{ph} - I_o \cdot \left[\exp\left(\frac{V + I.R_s}{V_T}\right) - 1\right] - \left[\frac{V + I.R_s}{R_p}\right] \qquad (3)$$

Where, I_{ph} is the Insolation current, I is the Cell current, I_0 is the reverse saturation current, V is the Cell voltage, R_S is the series resistance, R_P is the parallel resistance, V_T is the thermal voltage, K is the Boltzmann constant, T is the temperature in Kelvin, q is the charge of an electron.

The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity: it has an equivalent circuit as shown below in Fig.3

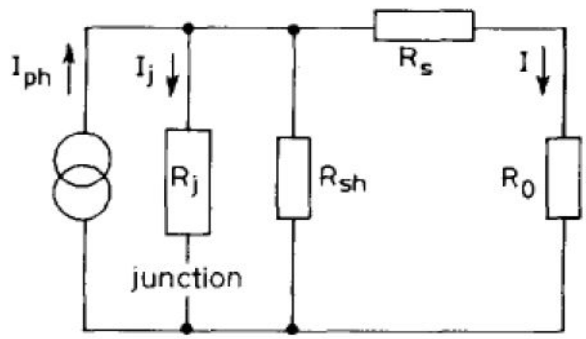

Fig.3:Equivalent circuit of a PV cell

The current source I_{ph} represents the cell photo voltaic current; R_j is used to represent the non-linear impedance of the p-n junction; R_{sh} and Rs are used to represent the intrinsic series and shunt resistance of the cell respectively. Usually the value of R_{sh} is very large and that of Rs is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays or PV generators .The PV mathematical model used to simplify our PV array is represented by the equation:

$$I = n_p I_{ph} - n_p I_{rs} \left[\exp\left(\frac{q}{KTA} * \frac{V}{n_s}\right) - 1\right] \qquad (4)$$

Where, I is the PV array output current; V is the PV array output voltage; n_s is the number of cells in series and n_p is the number of cells in parallel; q is the charge of an electron; k is the Boltzmann's constant; A is the p-n junction ideality factor; T is the cell temperature (K); I_{rs} is the cell reverse saturation current. The factor

A in eq. (5) determines the cell deviation from the ideal p-n junction characteristics; it ranges between 1-5 but for present case A=2.46.

The cell reverse saturation current I_{rs} varies with temperature according to the following equation:

$$I_{rs} = I_{rr}\left[\frac{T}{T_r}\right]^3 \exp\left(\frac{q\,E_G}{K\,A}\left[\frac{1}{T_r}-\frac{1}{T}\right]\right) \qquad (5)$$

Where, T_r is the cell reference temperature, I_{rr} is the cell reverse saturation temperature at T_r and E_G is the band gap of the semiconductor used in the cell.

The temperature dependence of the energy gap of the semi conductor is given by

$$E_G = E_G(0) \quad \frac{\alpha T^2}{T+\beta} \qquad (6)$$

The photo current I_{ph} depends on the solar radiation and cell temperature as follows:

$$I_{ph} = [I_{scr} + K_i\,(T - T_r)]\,\frac{S}{100} \qquad (7)$$

Where, I_{scr} is the cell short-circuit current at reference temperature and radiation K_i is the short circuit current temperature coefficient, and S is the solar radiation in $\frac{mW}{m^2}$. The PV power can be calculated using equation (8) as follows:

$$P = IV = n_P\, I_{ph}\, V\, [(\frac{q}{KTA} * \frac{V}{n_s}) - 1] \qquad (8)$$

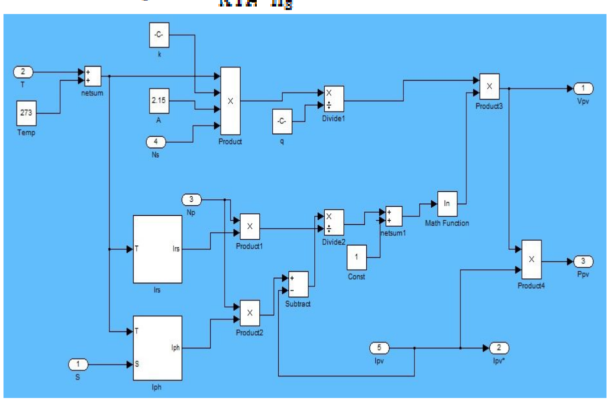

Fig.4: Simulink model of Solar PV Cell

In above Simulink model there is two sub systems Irs and Iph in the above Fig. These subsystem measures the reverse saturation current and Photovoltaic current of PV cell respectively. There model shown as below

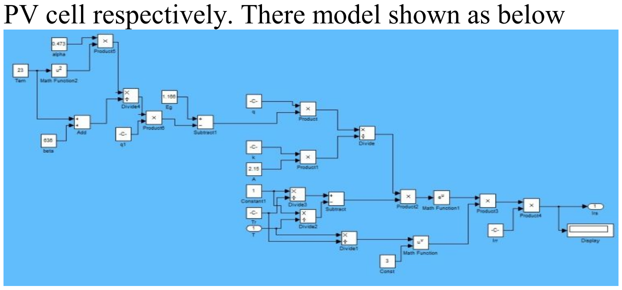

Fig.5: Simulink model of Irs (Reverse Saturation Current)

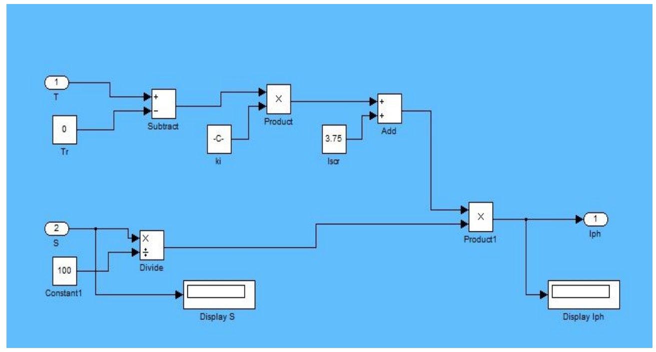

Fig.6: Simulink Model of Iph (Phase Current)

- **Modeling of MPPT block**

The maximum power point of PV cell is achieved by using PSO based method & coded in matlab function as mentioned in Appendix I, further the output of matlab function & solar panel output voltage have been compared in new MATLAB function and based on comparison of these two inputs duty ratio of BUCK converter has been calculated. The MATLAB function is shown below.

```
function V = fcn(vm,vpv)
 %#codegen
 if vm<vpv
 alpha=abs(vm/vpv)
 else
 alpha=abs((vm-vpv)/vpv)
 end
 V = alpha;
```

EXPERIMENTAL SETTINGS

In present work PSO method has been used to track the maximum power point of the PV system. To simulate the results for the system solar Insolation has taken as 100 mW/m^2 and Solar cell temperature has taken as 23°F.

Program has been run on MATLAB version (R2010A) on a Dual core 32-bit OS 1GB RAM Hard disk 160GB.

RESULTS AND DISCUSSION

Simulink model of maximum power point tracking based photovoltaic system has been successfully developed in MATLAB R 2010 environment and results are taken at solar irradiation of 100 mW/m^2. The output voltage, output power and current at load side is observed and results are simulated for conventional hill climbing and lookup table MPPT algorithms. These results are compared with the proposed evolutionary computation based particle swarm optimization method.

The output voltage of solar PV system is given to the buck converter and the duty cycle of the semiconductor device is controlled with the MPPT algorithms where the output voltage of the solar PV and maximum voltage are compared with the adopted Lookup table, Hill Climbing and Proposed PSO methods and corresponding firing angles are calculated. As per these firing angles pulse are generated which are used to drive the device used in the buck converter. The detailed results obtained from each method are summarized as below:

MPPT Method	Vmax (Volt)	Voutput (Volt)	Poutput (Watt)	Ioutput (Amp)	Duty Ratio
Hill Climbing	16.29	14.54	208.6	14.35	0.7865

Table 6.1 Results for Hill Climbing Method

MPPT Method	Vmax (Volt)	Voutpu t (Volt)	Poutput (Watt)	Ioutput (Amp)	Duty Rati o
Look up	16.29	15.56	216.3	13.9	0.78 69

Table 6.2 Results for Look up Method

MPPT Method	Vmax (Volt)	Voutput (Volt)	Poutput (Watt)	Ioutput (Amp)	Duty Ratio
PSO	15.56	14.76	216.3	14.65	0.712 4

Table 6.3 Results for Proposed PSO method

- **Comparison**

In present work optimal power and voltage generation of test system has been obtained by PSO i.e. proposed Natural Exponential Inertia Weight method for MPPT. MATLAB programming to determine the optimal solution of test system using PSO has been done. Where PSO parameters $C_1 = 2$, $C_2 = 2$, no. of iterations = 180 are adopted. Generalized results for different approaches are mentioned in Table 6.1 The results for the MPPT incorporated solar photovoltaic test system using PSO method have been obtained for different population size 5, 10, 15, 20,25 and 30 as mentioned in Table 6.2. For each population size, 30 trials of individual test system are done and amongst all 30 trials best suitable results are considered. From results of different pop size it has been observed that population size 25 is giving best possible solution.

S.No.	Pop Sizes	Max. Power (W)	Min. Power (W)	Avg. Power (W)	Frequency of Convergence
1	5	171.3	110.8	128.0 9	9
2	10	208.6	126.8	174.2 3	13
3	15	208.6	157.7	187.6 6	14
4	20	208.6	170.7	199.7 2	13
5	25	216.3	170.7	201.1 4	15
6	30	208.6	197.4	204.9 1	20

Table 6.2.1: Result comparison of PSO approach for various pop sizes

MPPT Method	Vmax (Volt)	Voutput (Volt)	Poutput (Watt)	Ioutput (Amp)	Duty Ratio
Hill Climbing	16.29	14.54	208.6	14.35	0.786 5
Lookup	16.29	15.56	216.3	13.9	0.786 9
PSO	15.56	14.76	216.3	14.65	0.712 4

Table 6.2.2: Result comparison of different MPPT approaches

In optimal solar PV voltage and power generation problem of the test system modern heuristic optimization techniques especially PSO has gained popularity to solve such problems due to its simplicity.Mostly in PSO algorithm inertia weight ω is kept constant in one trial for all particles of the population.To increase the search ability movement of particles is governed by the value of objective function so that most fitted particle is found. In present work, PSO technique has been successfully applied for the test system

CONCLUSION & FUTURE SCOPE

1. Conclusion

This proposed method makes system more immune to spikes and fast temporary instability and reduces the quick step changing so it produces the much smooth response than standard methods.

PSO has been successfully used in each area of engineering for the optimization process. Mostly all PSO algorithms have been implemented according to work on specific situation and search spaces, therefore there is no generality and even their results vary in different scenarios. In present work linearly decreasing Inertia Weight PSO has been used to determine the optimal PV voltage and power as it can balance between convergence speed and convergence quality.
Modern heuristic optimization techniques especially PSO gained popularly to achieve maximum power point due to its simplicity. The performance of PSO is governed by its parameters like inertia weight, acceleration coefficients and personal and global experience of the particles. Here in present work PSO has been adopted to determine the optimal PV voltage and power. Results can be concluded as given below:
The results are obtained for different population sizes i.e. 5, 10, 15, 20, 25 and 30. It has been observed that population size 25 is giving best suitable value of objective function (216.3 W).

Results also show that PV output voltage of this test system corresponding to maximum power is maximum i.e. 14.76 volt.

2. Future Scope

The present work is based on PSO based approach. Here the change in insolation and temperature is considered to be negligible. Hence this work can be extended in the future directions.

- Development of different Simulink Models based on Look up table based MPPT controller for different algorithm such as Incremental Conductance, Parasitic Capacitance method etc can also be developed.
- Automatic recording and monitoring of the varying temperature and insolation level on the module to predict the maximum power of the module.
- PSO based existing MPPT method can also be hybridized using ANN.
- Development of a high Power Output MPPT system.
- Converting the whole system into a grid connected system.
- Two diode model of solar PV can also be used.

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