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Maximum Power Point Tracking For Photovoltaic Systems

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***Abstract*— Renewable energy generation has experienced consistent growth in the last two decades, motivated by the concerns of climate change and high oil prices, and supported by renewable energy legislation and incentives, with a close to $150 billion investment in 2010. Solar photovoltaic is one of the fastest growing energy technologies, with an average annual growth of about 40% in the past decade. The 2.6GW installed capacity in 2009 implies an increase of more than 50% compared to the previous year and has lead to a total capacity of 7.8GW photovoltaic power worldwide (Figure.1). Similarly high grow rate has been registered in the past few decades for the wind power industry as well, with an approximately 30% increase in 2009 [13].**

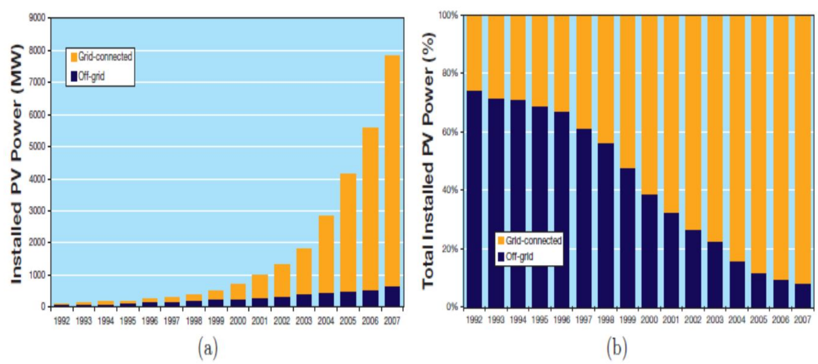

Figure.1: Cumulative installed (a) and percentage of grid connected and off-grid (b) PV power in the 'International Energy Agency - Photovoltaic Power Systems Programme' (IEA-PVPS) reporting countries [9]

Despite the technological advances and governmental incentives, the cost of energy produced by PV systems is still relatively high and cannot compete yet with traditional wholesale electricity prices. This motivates the research for creating not only improved solar panels but also more efficient power converters which can extract close to 100% of the available power from the photovoltaic array.

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I. INTRODUCTION to MPPT System

A MPPT, or maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar array (PV panels), and the load. It is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. MPPT system varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. Additional power harvested from the modules is then made available as increased battery charge current.

A MPPT looks at the output of the panels, and compares it to the battery voltage. It then uses an algorithm to calculate what is the absolute best power that the panel can put out. It takes this and converts it to the best voltage to get maximum AMPS into the battery. Most MPPT's are around 92-97% efficient in the conversion. We typically get a 20 to 45% power gain in winter and 10-20% in summer over using a standard PWM regulator.

The output characteristics of PV-module are nonlinear and each curve only has one MPP. Figure.2 shows that the output current of PV module is mainly affected by irradiation variation, whereas the output voltage of PV-module is mainly affected by temperature variation. Therefore, to efficiently use PV module, in case the atmospheric conditions are varied, the MPP tracking of PV-module should be implemented.

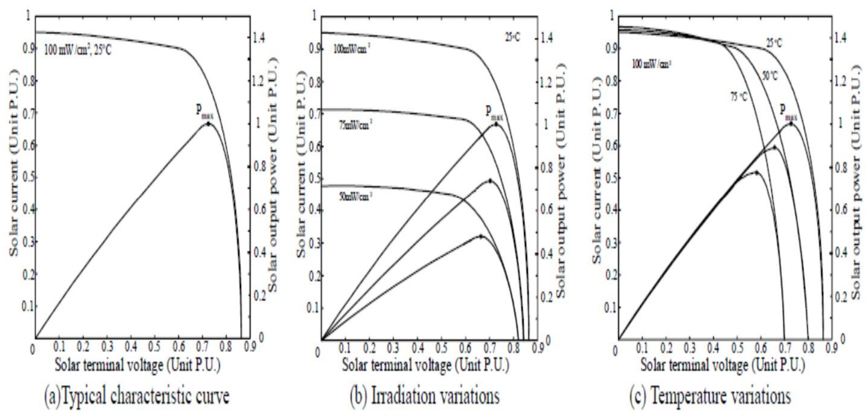

Figure.2: A typical I-V curve for varying Temperature and Irradiation [6]

A. Artificial Intelligence Techniques used for MPPT Tracking

Three different types of artificial intelligence algorithms used for tracking the MPP are as follows,

a. Particle Swarm Optimization Technique
b. The Perturbation and Observe (P&O) Method
c. Genetic Algorithm

Particle Swarm Optimization Technique

Particle swarm optimization has parallel processing, good robustness characteristics, and high probability of finding the global optimal solution and higher computational efficiency than the traditional random method. Its greatest advantage lies in its simple realization, easy and fast convergence. Due to its good performance in the multi-peak function optimization, particle swarm optimization is applied to the PV array. First of all, particle swarm optimization initializes the variables randomly in a given space. The number of decision variables determines the dimension of space. Each optimization problem is to search the solution space of a particle, each particle runs at a certain speed in the search space, the speed of particles is in accordance with its own flight experience and flight experience of other examples with dynamic adjustments. In the optimization space, each particle has decided to adapt the fitness value, and recorded their own best position Pi found so far, and the entire group of all particles found in the best position Pbest. Velocity and position are update using (1) and (2).

The Perturbation and Observe (P&O) Method

This is also called as 'hill-climbing' MPPT methods, which are based on the fact that, on the voltage-power characteristic, on the left of the MPP the variation of the power against voltage dP/dV > 0, while on the right,

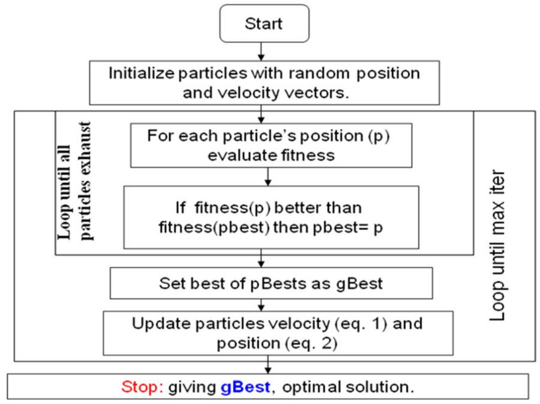

Figure.4: Flow chart of PSO technique [3]

dP/dV < 0. If the operating voltage of the PV array is perturbed in a given direction and dP/dV > 0, it is known that the perturbation moved the array's operating point toward the MPP. The P&O algorithm would then continue to perturb the PV array voltage in the same direction. If dP/dV < 0, then the change in operating point moved the PV array away from the MPP, and the P&O algorithm reverses the direction of the perturbation. The Figure.6 shows the details about P&O method [12].
From figure 5, it can be observed that at a given irradiation the power calculated is P_k at a voltage V_p, with the increase in the irradiation there is an increment in the voltage $(k+1)T_p$ and the power calculated at that instant is P_{k+1}

Genetic Algorithm
The genetic algorithm is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution. We can apply the genetic algorithm to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is discontinuous, non - differentiable, stochastic, or highly nonlinear. The genetic algorithm uses three main types of rules at each step to create the next generation from the current population,

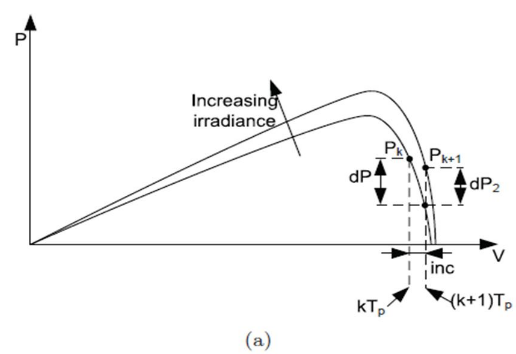

Figure.5: Tracking of MPP using P&O method [12]

- Selection rules select the individuals, called parents, which contribute to the population at the next generation.
- Crossover rules combine two parents to form children for the next generation.
- Mutation rules apply random changes to individual parents to form children [10]

The figure 6 shows the flow chart for the above stems implied in GA.

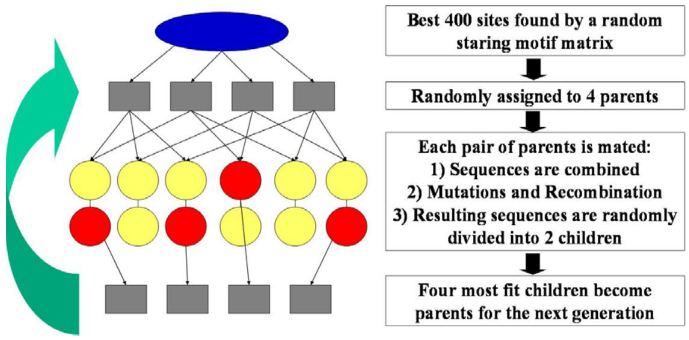

Figure.6: Flow chart of the genetic algorithm [10]

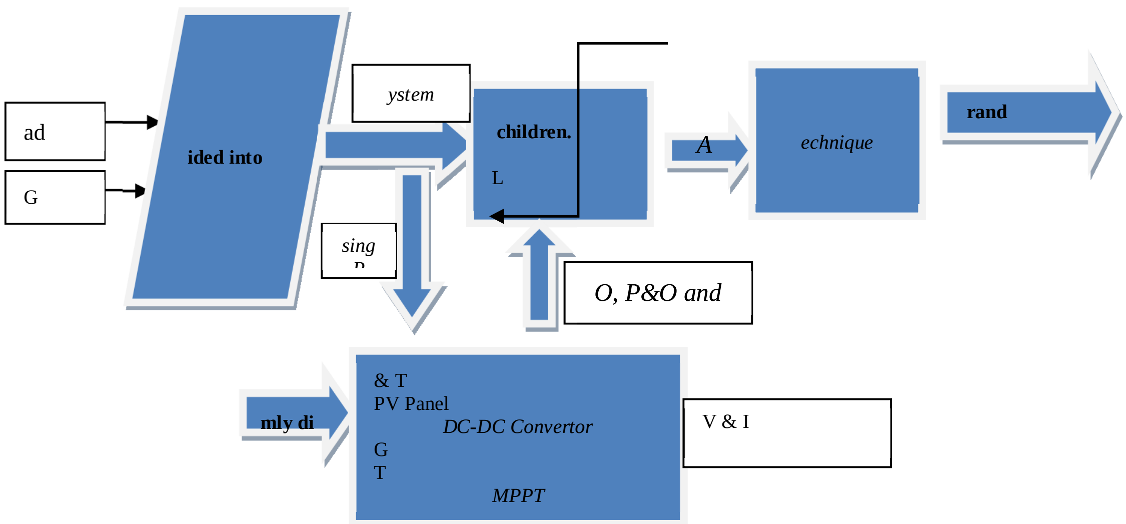

Figure.7: Functional Block Diagram of proposed MPPT Control of Photovoltaic System Based on PSO Algorithm

From Figure 7, we can see that solar panel generates the voltage and current depending upon the temperature T and irradiation G. Now using the reference voltage and current along with the current temperature T and irradiation G is given to MPPT block. Here using the PSO, P&O and GA techniques optimal operating voltage and current of PV module is found at which maximum power is obtained. Maximum power can be transferred when the impedance of solar panel is equal to connected load impedance.

II. MODELLING OF SOLAR CELL

The standard five parameter model of SPV module is shown in Figure.9.

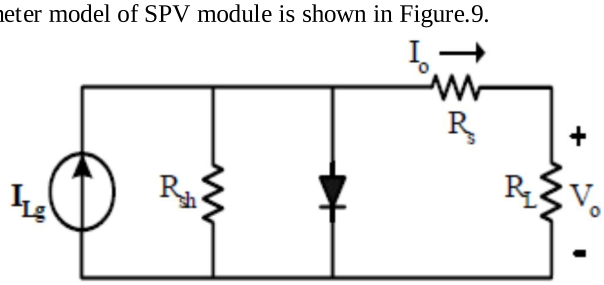

Figure.8: Electrical Equivalent Circuit model of single diode SPV module [9]

Equivalent circuit diagram shown on Figure.8 consists of a constant current source, in parallel with a shunt resistance and a diode, which includes an ideality factor to account for the recombination in the space-charge region. This model accounts for the losses due to the module's internal series resistance, as well as contacts and interconnections between cells and modules. It has a relatively good approximation precision and it is perhaps the most suitable model for the diagnostics of PV arrays, as it offers good compromise between approximation precision and simplicity.

Improved model equation (3) to (14) is used to model SPV cell.

The typical I-V output characteristics of PV-cell are represented as following Eq. 3

$$I_{pv} = I_{ph} - I_r\left[exp\left\{\frac{V_{pv}+I_{pv}R_{se}}{V_t}\right\} - 1\right] - \frac{(V_{pv}+I_{pv}R_{se})}{R_{sh}} \tag{3}$$

Where, $I_{pv} = \{I_{ph,ref}[1 + \alpha(T - T_{ref})]\}\frac{G}{G_{ref}}$, (4)

$$I_{pv,ref} = I_{sc,ref}\ , \tag{5}$$

$$I_{ph,ref} = \frac{R_{sh}+R_{se}}{R_{sh}} \times I_{sc,ref} \tag{6}$$

$$I_r = \frac{I_{sc,ref}+\alpha(T-T_{ref})}{exp\frac{V_{oc,ref}+\beta(T-T_{ref})}{nV_t}-1} \tag{7}$$

$$I_{r,ref} = \frac{I_{sc,ref}}{exp\left(\frac{V_{oc,ref}}{V_{t,ref}}\right)-1} \tag{8}$$

$$V_t = V_{t,ref}\frac{T}{T_{ref}} \tag{9}$$

$$V_{t,ref} = \frac{n_{ref}\ k\ T_{ref}}{q} \tag{10}$$

$$R_{sh} = \frac{4.6}{G-0.086} \quad \text{(Obtained by curve fitting)} \tag{11}$$

$$I_m = I_{m,ref} \times G \tag{12}$$

$$V_m = V_{m,ref} + \{\beta(T - T_{ref})\} \tag{13}$$

$$n = n_{ref}\ \frac{T}{T_{ref}} \tag{14}$$

III. Implementation of MPPT Algorithms

A. MPPT using PSO

➢ **Algorithm for PSO Implementation**

Step 1- Set the number of particles and searching parameters.

Step 2- Set the limit for position and velocity

Step 3- Position and velocity of each particle is initialized randomly in two separate matrix

Step 4- Set Local best (pBest) for each particle with respect to the corresponding position matrix

Step 5- The pBest of each particle is put in the objective function and the power is computed. Values obtained from these computations are compared with the particle having the maximum fitness value out of these is set as Global best (gBest) and the value obtained after the computation with respect to this particle is set as gBest value. This gBest gives the values of Voltage and Current.

Step 6- Using the equation 1 and 2, update the values of position and velocity of each particle and obtain the new pBest and gBest values

Step 7- Repeat Step 6 for number of iterations to get the optimized value of Voltage & Current.

Step 8- gBest at the end of the last iteration gives the optimized value.

Step 9- Compute the Duty-cycle using equation 15.

$$D=\frac{1}{1+\sqrt{\frac{R_{in}}{R_{out}}}} \quad (15)$$

Where R_{in} is the input resistance and R_{out} is the output resistance.

B. MPPT using Perturb and Observe (P&O) method

Perturb-and-observe (P&O) method is dominantly used in practical PV systems for the MPPT control due to its simple implementation, high reliability, and tracking efficiency. Figure.11 shows the flow chart of the P&O method. The present power *P(k)* is calculated with the present values of PV voltage *V(k)* and current *I(k)*, and is compared with the previous power *P(k-1)*. If the power increases, keep the next voltage change in the same direction as the previous change. Otherwise, change the voltage in the opposite direction as the previous one

The aim of this function is to pick the peaks of PV power curves shown before; as the objective function and out two variables as arguments x(1), and x(2) (Vmp, and Imp). This efficient function is implemented by maximizing the power with the voltage and current as optimizing variables, and with bounds for them by the values of Voc, and Isc from the PV module data sheet, also with nonlinear constraints with the aid of Voc, and Isc obtained from I-V curves for each irradiances, and temperatures values. Both the objective function and constraint function are implemented using the previous modelling relations in the form of MATLAB m-files.

Function MPP = *f* (x)

MPP = x(1) * x(2)

Function Constraints: This optimizing variable (x(1)) is bounded by [0 V_{ocref}].

This optimizing variable (x(2)) is bounded by [0 I_{sc_ref}].

The nonlinear constraint: Function [c,ceq] = *f* (x) c = [z1-$V_{ocModule}$ (For Each Irradiance & Temperature Values);

z2 - I_{sc_module} (For Each Irradiance & Temperature Values)]

C. Algorithm for MPPT implementation

Following algorithm is used to find the maximum power point for a PV panel.

1. Initialize random elite group. Iteration=0.
2. Initialize random generation of individuals in the population including elite group. Generation =0, & Itteratio=iteration + 1.
3. Evaluate the fitness function, power P= V_{pv} * I_{pv}
   a. max(Power)

b. $0 < V_{pv} < V_{ocr\_ref}$

c. $0 < I_{pv} < I_{sc\_ref}$

4. Perform sharing, roulette wheel selection, cross-over and mutation, then go to step 3.

IV. Results and Discussions

A. Specification's of Panel

- Max output Power: 210 W
- Open circuit voltage: 47.8 V
- Short circuit Current: 5.7 A
- Temperature coefficient of open circuit voltage:0.0028mA/ ^{0}C
- Temperature coefficient of short circuit current:0.00039mA/ ^{0}C
- No. of series connected cells: 72

Table 1 shows the simulated results using PSO, P&O, and GA technique. To highlight the proposed system performance, irradiation and temperature variations were applied in steps. The said artificial intelligence techniques were successfully able to track the maximum power point for a PV panel at any given Irradiation G & Temperature T respectively. The simulation results confirm that the PSO based MPPT controller is simple, fast, efficient and has faster convergence in finding the maximum power point. The MPPT's discussed are around 92-97% efficient and can yield upto 10% to 30% power gain

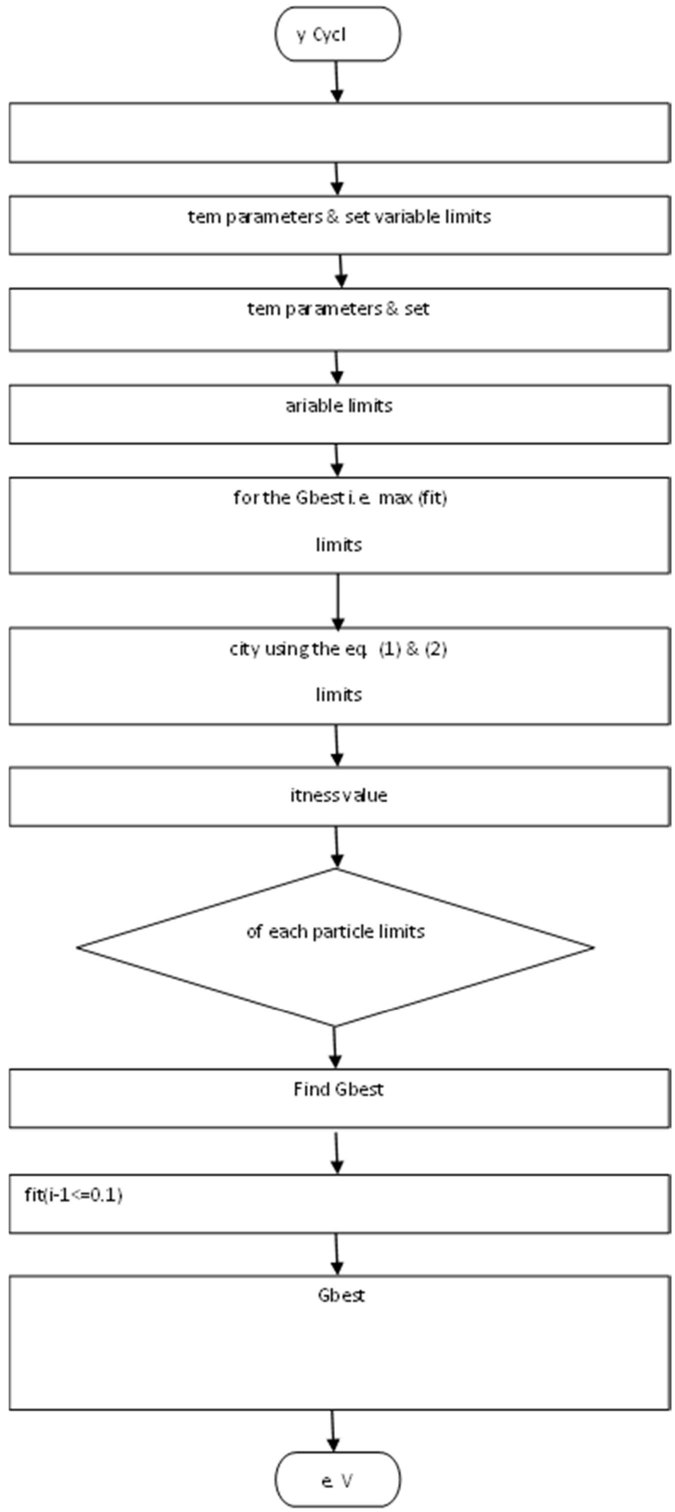
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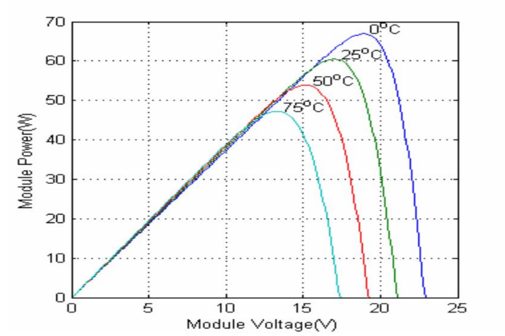
Figure 12 and 13 show P-V characteristics of a module as function of irradiation and temperature, respectively. It can be observed that with the decrease in irradiation and increase in the temperature the output power of the PV panel decreases.



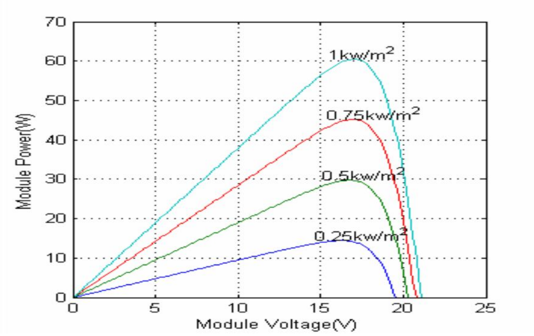


Figure.12 P-V characteristic at constant T=25^{0}C and varying irradiation

Figure.13 P-V characteristic at constant G=1000W/m^2 and varying temperature

Figure 14A, 14B, 14C shows the PV - IV characteristic of the DSP210D PV panel at STC i.e. 25 ^{0}C and 1000W/m^2 respectively using PSO, P&O and GA technique.

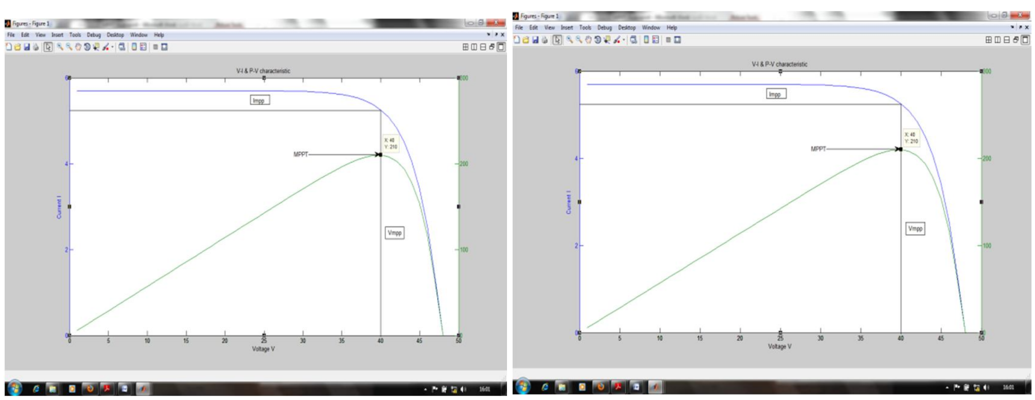
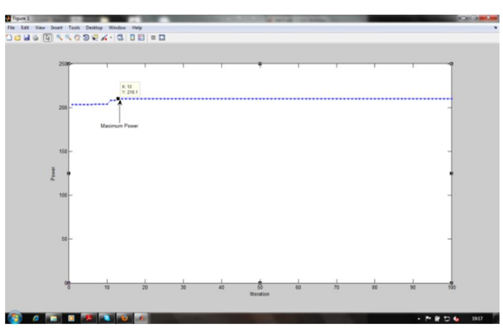


Figure.14A P-V and I-V Characteristic for a PV panel using PSO technique

Figure 14A shows the P-V and I-V characteristic of a DSP210 PV Panel. It can be observed that the PSO technique was successfully able to track the peak power of 210 W, with V_{mpp}, I_{mpp} of 39.70 V and 5.29 A respectively.



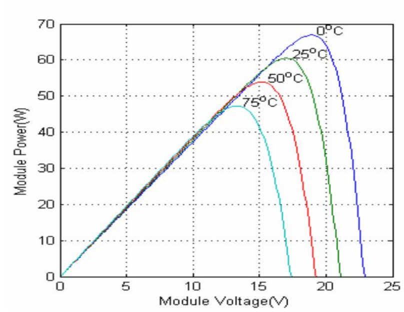


Figure.14B: Power Vs Iteration curve using GA method Figure.13 P-V characteristic at constant G=1000W/m^2 and varying temperature

Figure.14B shows the curve of Power Vs Iteration obtained using GA method. Here the convergence is obtained at 13th iteration giving the peak power of 210.1 W.

Figure 14A, 14B, 14C shows the PV - IV characteristic of the DSP210D PV panel at STC i.e. 25 ^{0}C and 1000W/m^{2} respectively using PSO, P&O and GA technique.

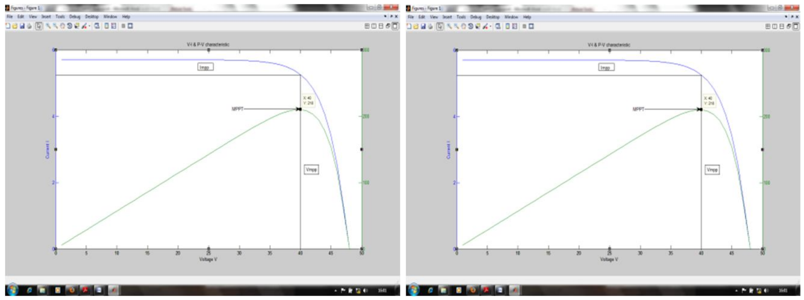


Figure.14A P-V and I-V Characteristic for a PV panel using PSO technique

Figure 14A shows the P-V and I-V characteristic of a DSP210 PV Panel. It can be observed that the PSO technique was successfully able to track the peak power of 210 W, with V_{mpp}, I_{mpp} of 39.70 V and 5.29 A respectively.

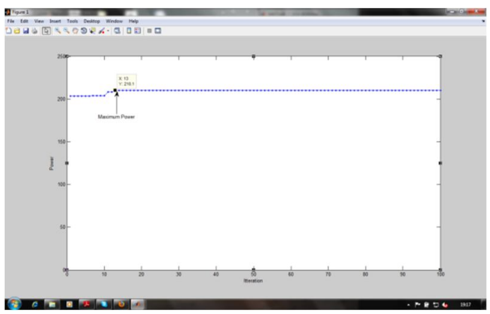


Figure.14B: Power Vs Iteration curve using GA method

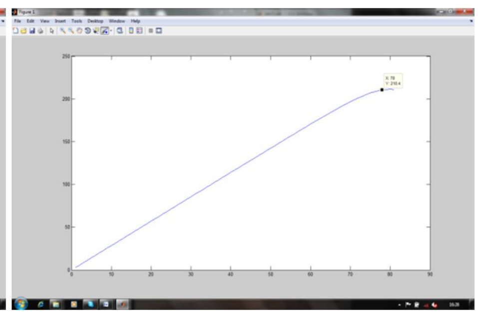


Figure.14C: Power Vs Iteration curve using P&O method

Figure.14B shows the curve of Power Vs Iteration obtained using GA method. Here the convergence is obtained at 13th iteration giving the peak power of 210.1 W.
Figure.14C shows the curve of Power Vs Iteration obtained using P&O method. Here the convergence is obtained at 78th iteration giving the peak power of 210.4 W.

V. CONCLUSION

The functional block diagram and the detailed MPPT algorithms using P&O, PSO and GA techniques are presented in the thesis. Solar cell is successfully modelled using MATLAB 07. To track the maximum power point P&O, PSO and GA methods are used. The performance of the proposed MPPT methods is tested by simulation at different irradiation and temperature. The results are analysed and compared. The simulation results conclude that PSO based MPPT controller is simple, fast, efficient, and has faster convergence. The MPPT's discussed are around 92-97% efficient. Typically 20 to 35% power gain in winter and 10-20% in summer can be achieved.

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