

Golden Section Search Optimization Technique For Maximum Power Point Tracking

Ajay Patel*, Vikas Kumar, Yogendra Kumar*****

* (Department of Electrical & Electronics Engineering, OIST College, RGPV University, Bhopal-462021)

** (Department of Electrical & Electronics Engineering, OIST College, RGPV University, Bhopal-462021)

*** (Department of Electrical & Electronics Engineering, MANIT University, Bhopal-462051)

ABSTRACT

The performance of solar photovoltaic (PV) array is affected in conditions like Array tilt (optimum = latitude), Array tracking (1-axis, 2-axis), Array azimuth/orientation (optimum = 180° or South), Array temperature, Array "soiling" (dust/dirt, snow, foreign matter etc.), Array shading (trees, clouds, buildings, chimneys, dormers, utility and telephone poles etc.), Array configuration, Array age, solar insolation. If large PV installations exist then these factors affect considerably. In partial shading condition, the PV characteristics get more complex with multiple peaks. Yet, it is essential to understand and predict them to yield the maximum possible power. Present work illustrates a MATLAB-based M file programming scheme suitable for monitoring the I-V and P-V characteristics of a PV array under a nonuniform insolation due to partial shading condition for different configuration (modules in series-parallel) of solar PV. It is used for developing and evaluating new maximum power point tracking techniques, especially for partially shaded conditions.

Keywords - Maximum power point (MPP), maximum power point tracking (MPPT), golden section search (GSS), photovoltaic (PV)

I. INTRODUCTION

The non-renewable energy sources like oil, coal, natural gas, nuclear etc. are sinking fast and the price of energy is increasing. Renewable energy resources will be an even more vital part of power production in the new millennium [1]. The renewable energy sources like wind, solar, biomass, water, geothermal etc. become an alternate for energy. With erupt in the use of non-conventional energy sources, photovoltaic (PV) setting up are being more and more employed in numerous application systems [2]. Sun is the eventual sources for photovoltaic energy. Photovoltaic technology is engaged for directly converting solar energy to DC electrical energy. With the help of an inverter DC power is converted to AC

power. The generated electricity can be utilized for different applications directly or through battery storage system. It has many merits such as little maintenance, cleanness, unlimited resource and no noise.

A most important test in using a PV source is to take on its nonlinear output characteristics, which differ with atmospheric temperature and solar irradiation [2][4][9][10]. When a classic city home is prepared with a PV power generation system, the PV modules are usually installed on the roof. In addition to shadows formed by clouds, those created by adjoining homes, trees, utility and/or telephone poles, and power line cables sometimes incompletely cover these PV modules [6]. The characteristics get more multifarious if the complete array does not get uniform insolation, as in partially shaded (cloudy) conditions, resulting in many peaks. The attendance of many peaks reduces the effectiveness of the existing maximum power point tracking (MPPT) scheme due to their inability to distinguish between the local and global peaks [5][11].

It is not simply the size of the PV array but also its prototype (i.e., the number of modules in series and parallel) that substantially have an effect on its power output and the performance of the system. Therefore, in PV generation system a maximum power point tracking (MPPT) control to take out maximum power from the PV arrays at actual time becomes indispensable. In recent years, for tracking the maximum power point (MPP) a large number of techniques have been planned. Incremental conductance, perturbation and observation (P&O) and hill climbing, ripple correlation, etc. methods are widely functional in the MPPT controllers due to their simplicity, fast response and easy implementation. Several MPPT algorithms have been anticipated from time-to-time [3]. MPPT of a photovoltaic array is essential part of a PV system. The method vary in cost, sensors required, complexity, range of effectiveness, convergence speed, implementation hardware, popularity, and in other respects [8].

It seems very hard to decide which technique among them is the best one. However, the Golden Section

Search (GSS) MPPT algorithm is proposed in this paper, because of advantages of its fast response, robust performance, and guaranteed convergence. A disadvantage of GSS MPPT method is that, it fails at partial shading and rapid changing environmental condition because of this it cannot track the MPP instantly when the weather condition is changing and cannot identify the global and local maxima. Due to this, the MPP give rise to the waste of several amount of obtainable energy. A number of improvements of the GSS algorithm have been deliberate in order to decrease the number of peaks in the region of the MPP in partial shading, but this slows down the speed of response of the algorithm to changing atmospheric situation and lowers the algorithm effectiveness during dull days.

This paper looks at the MPPT for PV system using GSS technique where the maximum power value is reorganized. The main compensation connected with PV arrays is that it consists of no moving parts. Do not produce any noise, robust and maintenance costs are minimal. In this paper, a MATLAB-based simulator cum learning tool, which can be used to improve the understanding and calculate the $I-V$ and $P-V$ characteristics curve of large PV arrays. This can be used to learn the result of temperature and insolation variation, varying shading patterns. The reason for using MATLAB is that it is simple, robust and less time consuming. It provides numerous features that can be used to simulate electronic and power electronic circuits and systems, high complex systems, and distributed generation power systems.

II. SYSTEM STRUCTURE

A PV system consists of a solar array which is a group of series-/parallel-connected modules, the solar cell rated power varies between 1 and 2 W depending on the material of solar cell and the surface area; thus, to design a solar module, the solar cell power is measured, and then, the modules are connected in series based on the desired output. Fig. 1 shows a PV array system.

Its characteristics control the terminal voltage and terminal current of a PV array. Under a specific environmental condition, the nonlinear I-V characteristics can be represented by following function:

$$V_a = f(I_a, E, T) \quad (1)$$

where V_a and I_a are the terminal voltage and current respectively of the PV, E is the irradiation level, T is the temperature, and $f(\)$ is the assumed characteristic function. The estimated model which has been developed below is engaged to produce the above function. Then the PV output power P_{out} can be calculated through:

$$P_{out} = V_a * I_a = f(I_a, E, T) * I_a \quad (2)$$

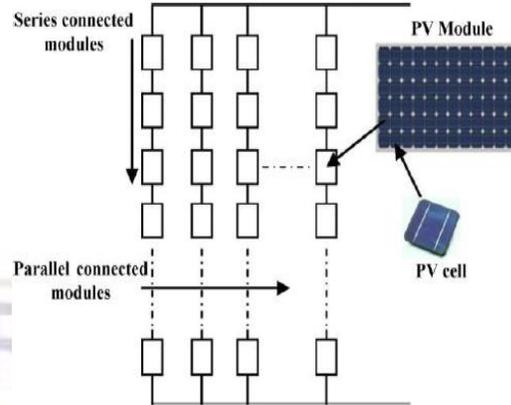


Fig. 1 PV array system

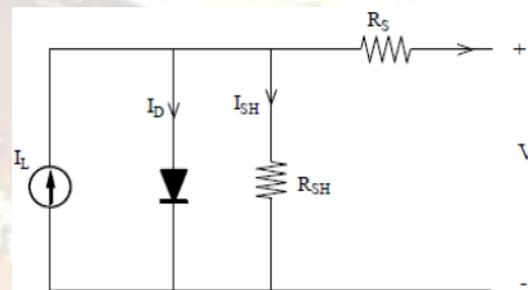


Fig. 2 Equivalent Circuit for solar PV cell

The electrical characteristics of the PV system are represented by P-V and by I-V curve. The characteristic curves of the solar cell are nonlinear because of equipped physical phenomena. By using the corresponding circuit of the solar cell shown in Fig. 2, the mathematical model of the generated current in a PV system is represented by

$$I = I_{ph} - I_0(e^{q(V+IR_s)/nkT} - 1) - (V+R_s I)/R_{sh} \quad (3)$$

$$I_{ph} = I_{ph(T1)}(1 + K_0(T - T_1)) \quad (4)$$

$$I_{ph(T1)} = G * I_{SC(T1;nom)}/G_{(nom)} \quad (5)$$

$$K_0 = (I_{SC(T2)} - I_{SC(T1)})/(T_2 - T_1) \quad (6)$$

$$I_0 = I_0(T1) * (T/T1)^{3/n} * e^{-qV_g/nk*(1/T-1/T1)} \quad (7)$$

$$I_0(T1) = I_{SC(T1)} / (e^{qV_{oc(T1)}/nkT1} - 1) \quad (8)$$

$$R_s = -dV/dI_{V_{oc}} - 1/X_V \quad (9)$$

$$X_V = I_0(T1) * q/nkT1 * e^{qV_{oc(T1)}/nkT1} \quad (10)$$

Where I_{pv} and V are PV array output current and voltage respectively. Diode saturation current I_0 . Light generated current I_{ph} . Solar cell series resistance R_s , which gives a more accurate shape between the maximum power point and the open circuit voltage. This represents the internal losses due to the current flow. Solar cell shunt resistance R_{sh} , in parallel with the diode, this corresponds to the leakage current to the ground and it is commonly neglected. Either allowing the diode quality factor n to become a variable parameter (instead of being fixed at either 1 or 2) or introducing two parallel diodes with independently set saturation currents. In an ideal cell

$R_s = R_{sh} = 0$. q is the electron charge (1.6×10^{-19} C), k is Boltzmann's constant (1.38×10^{-23} J/K).

Table: 1 Electrical parameters of Solarex MSX60 60W PV array

At Temperature	T	25	$^{\circ}C$
Open Circuit Voltage	V_{oc}	21.0	V
Short Circuit Current	I_{sc}	3.74	A
Voltage max power	V_m	17.1	V
Current max power	I_m	3.5	A
Maximum Power	P_m	59.9	W

III. STEPS OF GSS ALGORITHM

MPPT is naturally a maxima-finding process. The measures for judgment a maximum with GSS technique is illustrated in Fig. 3. The goal is to find the maximum functional value of $f(x)$ within the input interval $(x1, x2)$.

The penetrating step is described as below:

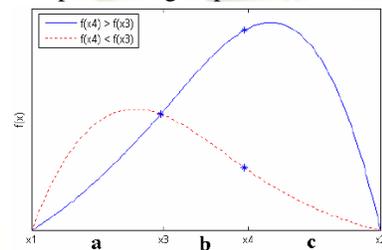


Fig. 3 Explanatory diagram for GSS

- At first, the values of $f(x1)$, $f(x2)$ and $f(x3)$ are previously recognized. Because $f(x3) > f(x1)$ and $f(x2)$, the maximum must recline within the part of $(x1, x2)$.
- The value of $f(x4)$ at a point $x4$ is being evaluated.
- The maximum point lies inside the section $(x3, x2)$ if $f(x4) > f(x3)$ as shown on the solid line in Fig. 3 The new point $x4$ is then inserted and $x1$ is unused to make a new narrower search section $(x3, x2)$ with still 3 known points $x4, x3, x2$.
- If $f(x4) < f(x3)$ as shown on the dashed line in Fig. 3 the maximum point lies within the section $(x1, x4)$. The new point $x4$ is still inserted, but $x2$ is unused to create another new narrower search section $(x1, x4)$ with another set of 3 known points $x1, x3$ and $x4$.
- Repeat the steps during 2 to 4 for a definite number of times, or until the search section is sufficient to make sure that the new inserted point can be measured the maximum point.

Obviously, for every iterating action there are two possible search sections like $(x1, x4)$ and $(x3, x2)$ in Fig. 3. Merely one will be selected to be the next search section. It is necessary that the two possible sections are evenly extensive. Otherwise, the convergence speed would be slowed down when the wider sections being engaged more frequently in some worse cases. Thus, the choice of the new point $x4$ must suit the condition: width of $(x3, x2) =$ width of $(x1, x4)$, that is $a + b = b + c$ in Fig. 3. As a result, it becomes feasible that all the search sections of the iterations can have the similar section of spacing between the three points such that the algorithm converges at a regular speed, i.e.

$$a / b = c / b = (b + c) / a = \phi \quad (11)$$

where $\phi =$ Golden ratio

Solve eq. to yield:

$$\phi = (1 + \sqrt{5}) / 2 = 1.61803398 \dots$$

Where ϕ is the golden ratio. That is the reason why this search strategy is called GSS

IV. FLOW CHART FOR GSS

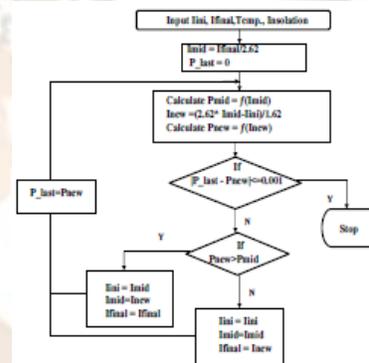


Fig. 4 Flow chart for GSS

V. GSS PROCEDURE

According to the golden ratio, point at $I_a = 2.35$ A is certain as the third initialized point. Then the following points can be generated as shown in Fig. 5 and Table 2 by next the searching scheme. It is seen that the GSS algorithm can arrive at the very close position to MPP after only 6 iterations. In fact, it can be logically imitative that it takes only 15 iteration steps for GSS to reduce in size the search interval to 0.1% of its original length. This means, for a digital control system with 0.1% resolution matching to a 10-bit A/D converter, not more than 15 iteration steps are essential for the GSS to get the best valid solution. Therefore, the GSS always converges extremely fast.

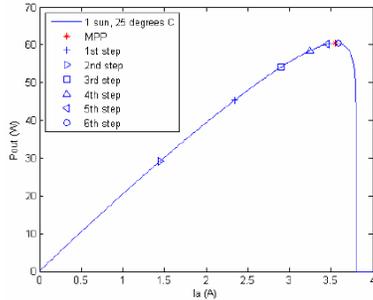


Fig. 5 GSS procedures for MPPT

Table: 2. Evaluated point of each step in GSS

Step	1 st	2 nd	3 rd	4 th	5 th	6 th	...	MP P
I _a (A)	2.3	1.4	2.9	3.2	3.4	3.5	...	3.5
P _{out} (W)	45.	28.	53.	57.	59.	59.	...	59.

In addition, with GSS the MPP can be start for certain as long as the preliminary search section is set suitably. The section through 0 to open circuit voltage when voltage acts as the search variable or section from 0 to short circuit current when current acts as the search variable can be surely a safe initial section to get the guaranteed MPP.

VI. MATLAB PROGRAMING

```
functiontemp=PVprog2(Sun,T,No_of_modules,Subass_no,Gr_no)
%PVprog2.m model for the MAX-^0 solar array returns
%current, voltage and power for the given illumination and temperature
%I,V are array current and voltage
%Sun=num of suns where 1 Sun =1000W/m^2
col=['b' 'g' 'r' 'c' 'm' 'y' 'k'];
k= 1.38e-23; %Boltzman's constant
q=1.6e-19; %charge of an electron
V=1; %Initialisation of the array voltage
I=0; % and array current so that one enters into while loop atleast once
x=0; %initialisation
while (V>0);
I=I+.001;
x=x+1;
% enter the following constants here, and the model will be
A=1.2; % 'diode quality' factor = 2for crystalline and <2 for amorphous
Vg=1.12; % band gap voltage , 1.12eV for xtal Si, 1.75 for amorphous Si
Ns=36; % number of series connected cells (diodes)
T1=273+25;
```

```
Voc_T1=21.06/Ns; % open ckt voltage per cell at temp T1
Isc_T1=3.8; % short ckt current per cell at temp T1
T2=273+75;
Voc_T2=17.05/Ns; % open ckt voltage per cell at temp T2
Isc_T2=3.92; % short ckt current per cell at temp T2
Tak = 273 + T; %array working temp
Trk = 273+25; %reference temp
Iph_T1=Isc_T1*Sun;
a=(Isc_T2-Isc_T1)/Isc_T1*(1/(T2-T1));
Iph=Iph_T1*(1+a*(Tak-T1));
Vt_T1=k*T1/q; % =A*kT/q
Ir_T1=Isc_T1/(exp(Voc_T1/(A*Vt_T1))-1);
Ir_T2=Isc_T2/(exp(Voc_T2/(A*Vt_T1))-1);
b=Vg*q/(A*k);
Ir=Ir_T1*(Tak/T1)^(3/A).*exp(-b.*(1./Tak-1/T1));
X2v=Ir_T1/(A*Vt_T1)*exp(Voc_T1/(A*Vt_T1));
dVdI_Voc=-1.15/Ns/2; %dV/dI at Voc per cell from manufacturer graph
Rs=-dVdI_Voc-1/X2v; %series resistance per cell
Vt_T=A*1.38e-23*Tak/1.6e-19; % =A*kT/q
bracket=(log((Iph-I)/Ir+1));
flg=(isreal(bracket)& (bracket>0));
if (flg)
Vtemp=Vt_T*bracket-I*Rs;
if (Vtemp>0)V=Vtemp; end
else
V=V-0.001;
I= Iph - I0(eq(V +IRs)/nkT - 1) - (V+RsI)/Rsh;
End
```

VII. SIMULATION PROCEDURE

In this section the process used for simulation of the $P-V$ and $I-V$ characteristics of an incompletely shaded PV array is described. It is necessary to recognize how the shading pattern and the PV array arrangement are defined in MATLAB. This method consists of defining groups, assemblies, etc., for use with the MATLAB model developed corresponding to Fig. 6. This is explained with the help of explanation 1. Consider a simple case with just two unlike shades on the PV array.

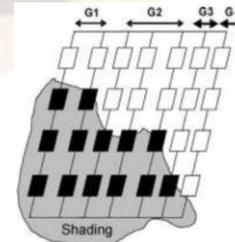


Fig. 6 PV array with groups G1 to G4
Explanation 1:

A PV array consisting of 1000 PV modules set into 100 series assemblies, linked in parallel, each one having 10 modules. It is chosen to obtain the $P-V$

and I-V curve of a variety of components of this PV array, which consists of three groups with unlike insolation patterns, as given in Table 3. Groups G1 through G3 have 40, 38, and 22 series assemblies, respectively. The complete PV array is shown in Fig. 7. As seen in Fig. 7 only two different insolation levels are considered for simplicity. Shaded modules, receiving an insolation, $\lambda = 0.1 \text{ kW/m}^2$, are indicated in dark color. It explains the method.

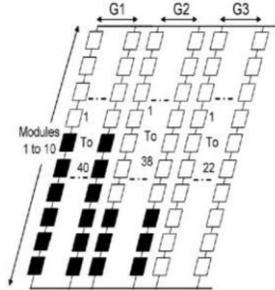


Fig. 7 PV array configuration for explanation 1, corresponding to the shading pattern of Table 2.

Table: 3 Insolation pattern

Group	No. of unshaded Modules in series Assembly ($\lambda=1$)	No. of shaded Modules in series Assembly ($\lambda=0.1$)	No. of series assemblies in a group
G1	4	6	40
G2	7	3	38
G3	10	0	22

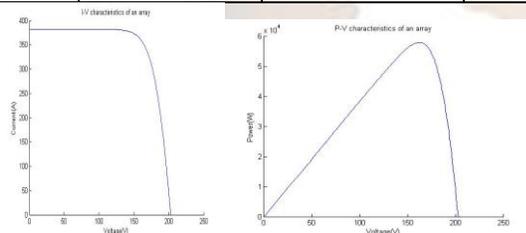


Fig. 8 (a) Without Shading (array 10x100, T=40, $\lambda=1$)

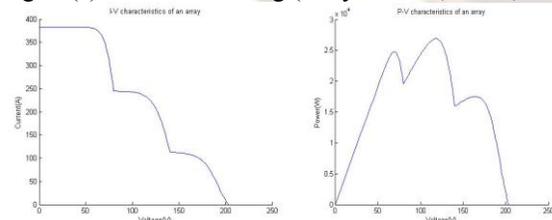


Fig. 8 (b) With Shading as per explanation 1 Explanation 2

Let us take a more complex case, it is desired to obtain the P-V characteristic of an array consisting of 1000 (10 × 100) modules and receiving insolation at several different levels. The array is arranged into five groups G1, G2, G3, and G4 with 40, 30, 20 and 10 series temperature, 1, 0.75, 0.5 and 0.1 insolation of the

different modules. A screen shot of the MATLAB command window, shown in Fig. 9, illustrates the manner in which one can feed the information into this generalized program. In this scheme, the array has four different groups and four different shades. But Fig. 10(a) and (b) shows five different peaks (or steps), indicating that the number of peaks, their magnitudes, and the overall nature of the PV curve is dependent on the temperature of the modules, the insolation level, the shading pattern, and the array configuration. A generalized program can provide a better solution to learning and understanding the behavior of a PV array in a complex scenario.

T=40; $\lambda=0.75$
T=30; $\lambda=0.5$
T=20; $\lambda=0.25$
T=10; $\lambda=0.1$

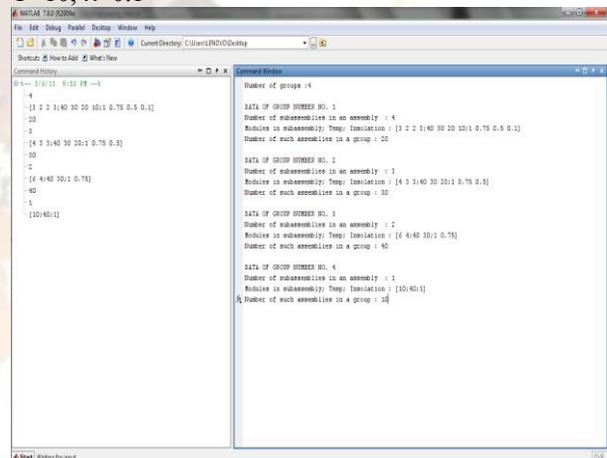
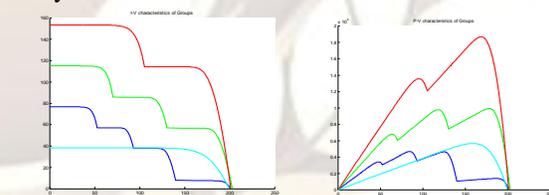
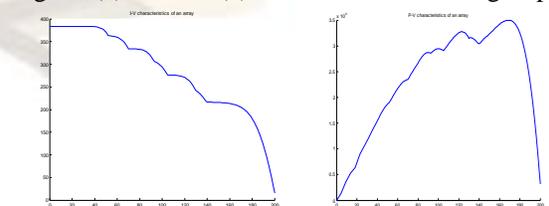


Fig. 9 Screen shot of the MATLAB command window showing how the input parameters are fed into the model to simulate a more complex and generalized array.



(a) I-V (b) P-V
Fig. 10 (a) I-V and (b) P-V Characteristic of groups



(a) I-V (b) P-V
Fig. 11 (a) I-V and (b) P-V Characteristic of an array
Now estimate Fig. 8(a), (b) and 11 (a), (b) we can see that PV curve in without shading has only one peak

but with shading having 3 groups, 2 different shadings and 2 different insolation gives 3 peaks.

VIII. CONCLUSION

The non-derivative GSS algorithm has fast convergence speed, and is quite robust and noise-resistant. Because of its good performances, it can be one of the competitive algorithms for MPPT methods in PV generation systems. Especially, when switching mode converters such as boost converter, buck converter, buck-boost converter, etc, are introduced in the applications, its robust capability makes it more important in the noisy switching environment. However, there are still some optimizations and experiments needed to be done as the future work. For example, the problems how it can track the MPP instantly when the weather condition is changing, and how it can identify the global maximum and local maxima, will be studied in the future.

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