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A Two-Stage Tracking Algorithm for PV Systems Subjected to Partial Shading Conditions

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Abstract- This paper proposes a golden section search (GSS) based global maximum power point tracking (GMPPT) algorithm to track the global peak of the PV array under partial shaded conditions. Partial shading is a common scenario in building integrated PV systems where shading is cast by clouds, birds, nearby structures, trees, etc. The conventional MPPT algorithms fail to track the maximum power as, under partially shaded conditions, multiple peaks characterize the voltage-power curve. These algorithms oscillate around the first peak they detect resulting in lower harvest efficiency. Sophisticated algorithms that can detect the global peak are necessary to address such conditions and many multi stage tracking algorithms have been proposed in the literature. This paper proposes a new two stage GMPPT algorithm that can track the maximum power under all irradiation conditions. The first stage of the algorithm shrinks the search interval to the neighbourhood of the global peak and the second stage detects it accurately. The reliability of the algorithm is tested for various partial shading conditions and the simulated outcomes are presented to exemplify the effectiveness of the proposed GSS based GMPPT algorithm.

Keywords - Photovoltaic array, partial shading, global MPPT, two stage algorithm, golden section search.

1. Introduction

Fast depletion of non-renewable energy sources, rise in oil price, general awareness and concern about the carbon footprint level have opened a wide opportunity for power generation using Solar PV systems. The conversion efficiency of PV cell is relatively less and hence, it is essential to operate the PV panel at its optimal operating point called the maximum power point to ensure maximum harvest efficiency. The electrical characteristics of a PV cell are non_linear and depend on factors like temperature, irradiation, shade pattern and intensity [1]. As these environmental factors change, the electrical characteristics and in turn the peak power also changes. Literature reports many tracking algorithms and techniques with varied intricacies and efficiencies. The broadly adopted techniques include fractional voltage [2, 3], fractional current [4], perturb & observe [5], incremental conductance [6] and ripple correlation [7] algorithms. Modified algorithms based on line search [8] and heuristic search [9] have also been proposed to increase the accuracy and speed. These algorithms are time tested and widely adopted owing to their simplicity. Many of these algorithms [10-15] work well under homogeneous irradiation conditions but fail under partially shaded conditions. Under inhomogeneous irradiation or partially shaded conditions, the voltage-current and voltage-power characteristics exhibits multiple steps and peaks respectively due to the activation of bypass diodes connected across the shaded PV panels. The conventional MPPT algorithms fail under these conditions as they cannot distinguish between the local and the global maximum. Accurate tracking of global peak requires modifications in the conventional algorithms. Many global peak detecting algorithms including modified versions of the conventional algorithms and algorithms based on soft computing and other sophisticated techniques that can accurately identify the global maximum have been proposed in literature. Generally, the GMPPT algorithms employ multiple stages so that the region of global peak is identified in the initial stages and the global peak is located precisely in the final stage [16-25]. This paper presents a two stage GMPPT algorithm to reliably detect the global peak under all irradiation conditions.

2. Review of the Extensively used MPPT Algorithms

The fractional voltage method relies on the actuality that the ratio between the peak power point voltage and the open circuit voltage is almost constant ('k'). In the fractional current algorithm, the ratio 'k' is considered between the current at the maximum power point and the short circuit current. These algorithms are quite simple. However, dependency of 'k' on temperature and irradiation and detachment of PV array for measurement results in lower efficiency [10, 11]. Though usage of pilot cells alleviates the power loss due to disconnection during measurement, the technique fails under partial shaded conditions, as the value of 'k' and the position of global peak are dependent on the shade intensity and geometry. Lookup table based algorithms, makes use of the database that includes the position of MPP for a wider range of irradiation and temperature conditions to identify the actual peak for the prevailing conditions. This strategy involves sensors to measure the temperature and irradiation and also require a substantial database. A perturbation is introduced in the array voltage and the corresponding change in the power is measured in hill climbing based algorithms [12,13]. If the change in power is positive, the disturbance is preceded in the similar direction. If the change is negative, the course of disturbance is reversed. These algorithms get trapped at the first crest they notice and move back and forth around it.

The line search algorithms like Fibonacci search and golden section search are suited for unimodal functions and hence fail under partial shaded conditions. Though these existing, deep-rooted and time tested algorithms successfully track the MPP under homogeneous conditions, they fail to track the MPP under partially shaded conditions. Intelligent peak detecting algorithms utilizing fuzzy and neural networks have also been proposed [14,15]. Though these algorithms are efficient, the correctness relies on the rule base and data set employed for training the neuron layers.

One way to track the global peak is to search the entire voltage range (from short circuit to open circuit) periodically with a relatively small sweep step. This improves the tracking accuracy but reduces the tracking speed as the entire range is to be swept. Generally, the conventional algorithms are modified or combined with other algorithms to track the global peak. Many such algorithms have been proposed in literature. The algorithm proposed by Patel [16] is a two stage algorithm where the first stage finds the region of global MPP and the second stage uses P&O algorithm to locate the actual MPP. It is based on the assumption that the magnitude of the crests increases towards the global peak and decrease beyond that, which is not always the case. Algorithm based on Fibonacci numbers has been proposed in [17] for partially shaded conditions. This algorithm however, does not guarantee tracking under all irradiation scenarios. The multi stage algorithm presented in [18] adopts P&O with bigger step size in the first stage to make out the region of global peak. However, larger step size may let pass the global peak and the smaller step size slow down the tracking. Many algorithms that utilize soft computing and other advanced techniques [19-25] have been proposed and compared, however it is difficult to adjudge the best.

Nevertheless, this paper proposes a two-stage algorithm to track reliably the maximum power point under shaded, partially shaded and non-shaded conditions. The search is based on 'divide and eliminate technique', where the search range is shrunk by the first stage and the peak is located by the second stage. Based on the critical observations made from the comprehensive shading analysis [26], this work proposes to search for the local peaks at specific locations in the first stage rather than the entire span. This ensures good tracking speed. Further, the second stage, which is based on golden ratio search technique, ensures faster convergence and good accuracy.

3. Tracking The Maximum Power

Maximum power is tracked by matching the impedance of the PV source with the load. As the source impedance varies with environmental conditions, impedance is matched by adjusting the duty cycle of gate pulses to the boost converter operating in continuous current mode. The typical PV system with MPPT is presented in Figure 1. The proposed two stage MPPT algorithm tracks the global MPP by observing the array voltage and current. The power is estimated and global MPPT (GMPPT) algorithm generates the reference voltage and the PI controller controls the PV array voltage.

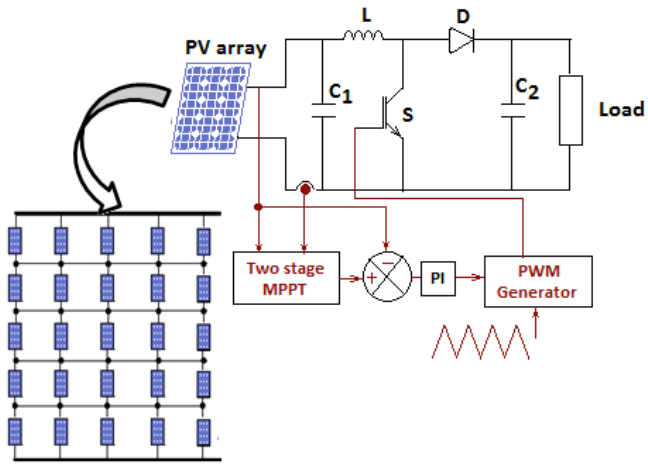


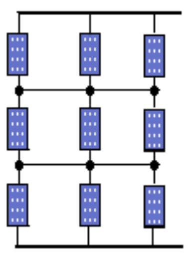
Fig.1. Schematic circuit of PV system with MPPT

A 3 × 3 PV array is considered in this work. The panels are arranged in TCT configuration where 3 panels are linked in parallel and 3 such parallel strings are linked in series. Each of the PV panel (Solkar make 37 W_p Panel) has 36 series connected poly crystalline PV cells and provided with single bypass diode. The specifications of the panel at STC (1000 W/m^2, 25^{o}C and air mass 1.5) are given in Table 1.

Table 1. Specifications of PV panel and array

Specifications	PV panel	PV Array
Open circuit Voltage V_{oc}	21.24 V	63.72
Short circuit Current I_{sc}	2.55 A	7.65
Maximum Power P_{max}	37.08 W	333.72 W
Voltage at maximum power V_{mp}	16.55 V	49.55
Current at maximum power I_{mp}	2.245 A	6.735

The characteristics of the 3×3 TCT array under full irradiation conditions are presented in Figure 2.



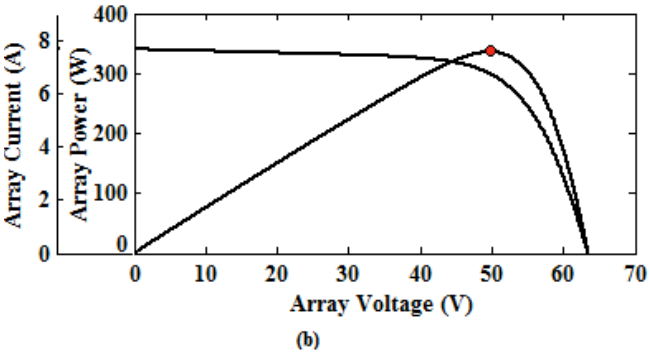


Fig.2. (a) PV array in TCT (b) Electrical characteristics

The maximum power is 333.75 W and the V_{mp} and I_{mp} are 49.55 V and 6.735 A respectively. The V-P curve displays distinct peak as the irradiation received by all the nine panels are the same (full irradiation).

4. The Proposed MPPT Algorithm

The proposed algorithm is a two stage algorithm where the first stage identifies the region of global MPP and the second stage locates the actual MPP. The entire voltage range is swept to identify the region of global peak. To speed up the process, only significant regions are searched for local peaks. The maximum number of peaks for a given m × n TCT array ('m' series connected rows with 'n' panels in a row) is 'm' and the voltage range extends from 0 to $m \times V_{oc\_module}$. The peaks are likely to occur at multiples of $k \times V_{oc\_module}$ (single bypass diode per panel is considered). The range of 'k' lies between 70% - 85% depending on the environmental conditions. Initially, the reference voltage V_{ref1} is set as $k \times V_{oc\_module}$. The corresponding power (P_1) is estimated by multiplying the voltage and current. Now the voltage perturbation is applied and the new reference voltage is set as $V_{ref\,i} = V_{ref\,i-1} + k\,V_{oc\_module}$. If the power measured at this new reference $P_i > P_{i-1}$, then $P_{max} = P_i$ else $P_{max} = P_{i-1}$. The disturbance is proceeded in the same direction until V_{ref} reaches $m \times k \times V_{oc\_module}$. Thus at end of first stage, with 'm' voltage perturbations, the location of global peak is narrowed down to V_{ref_max}. The assumption that the peaks occur at multiples of 80% of $V_{oc\text{-}module}$ is not true always and hence the second stage is initiated by expanding the search interval around the reference voltage obtained from the first stage. Further, the interval fixed for the second stage will have a unique peak and GSS algorithm is used to track the global peak (GP). The search interval for the second stage is fixed as V_{ref_max} - 20% of V_{oc_module} and V_{ref_max} + 20% of V_{oc_module}. GSS algorithm divide and eliminate region within this interval to locate the exact location of the global peak.

The GSS algorithm [27] locates the maximum or peak of a unimodal function (function with single peak) in the given interval (a, b) by repeated division and elimination. Two search points x_1 and x_2 are inserted initially in the interval (a, b) as shown in Figure 3 and this results in two search sections (a, x_1) and (x_2, b). The width of both the sections should essentially be the same to ensure good convergence speed.

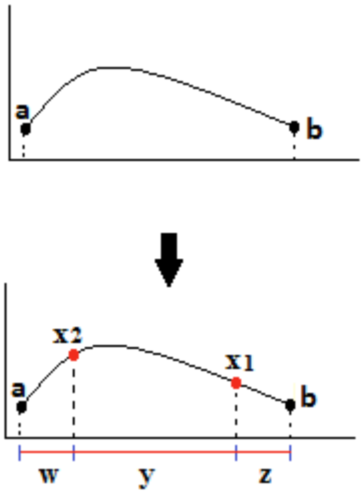


Fig.3. Search interval and search points in GSS algorithm

One section is eliminated at the end of the iteration and the search continues with the remaining one. To eliminate the section, the function is evaluated at the two search points. If $f(x_2) > f(x_1)$, the section (x_1, b) can be eliminated as the maximum lies in the region (a, x_1). If $f(x_1) > f(x_2)$, section (a, x_2) is eliminated and the maximum lies in the region (x_2,b). Thus, a section is eliminated at the end of each iteration and new search points are introduced in the narrowed interval for further iterations in such a way that the two resulting sections are equally wide. The search points of j^{th} iteration are calculated as follows

$$x_{2j} = a+L_j^* \qquad (1)$$

$$x_{1j} = b-L_j^* \qquad (2)$$

where, $Lj^* = L_0/\ \gamma^j$, L_0 being the initial search range and γ the golden ratio.

In the example presented in Figure 4, the first iteration reduces the interval from (a, b) to (a, x_1) as $f(x_2) > f(x_1)$. The section (x_1, b) is eliminated and the new interval is (a, b) where $b = x_1$. Two new search points, x_3 and x_4 are introduced in the new interval such that section (a, x_3) is as wide as section (x_4, b). Moreover, the search point x_4 is found to be equal to x_2 and hence it is enough if the function is evaluated at new search point x_3. The section (x_3, b) is eliminated as $f(x_4) > f(x_3)$. The second iteration reduces the interval further to (a, x_3). The iteration is thus repeated until the search interval reduces to a smaller section that the new point inserted be treated as the maximum point.

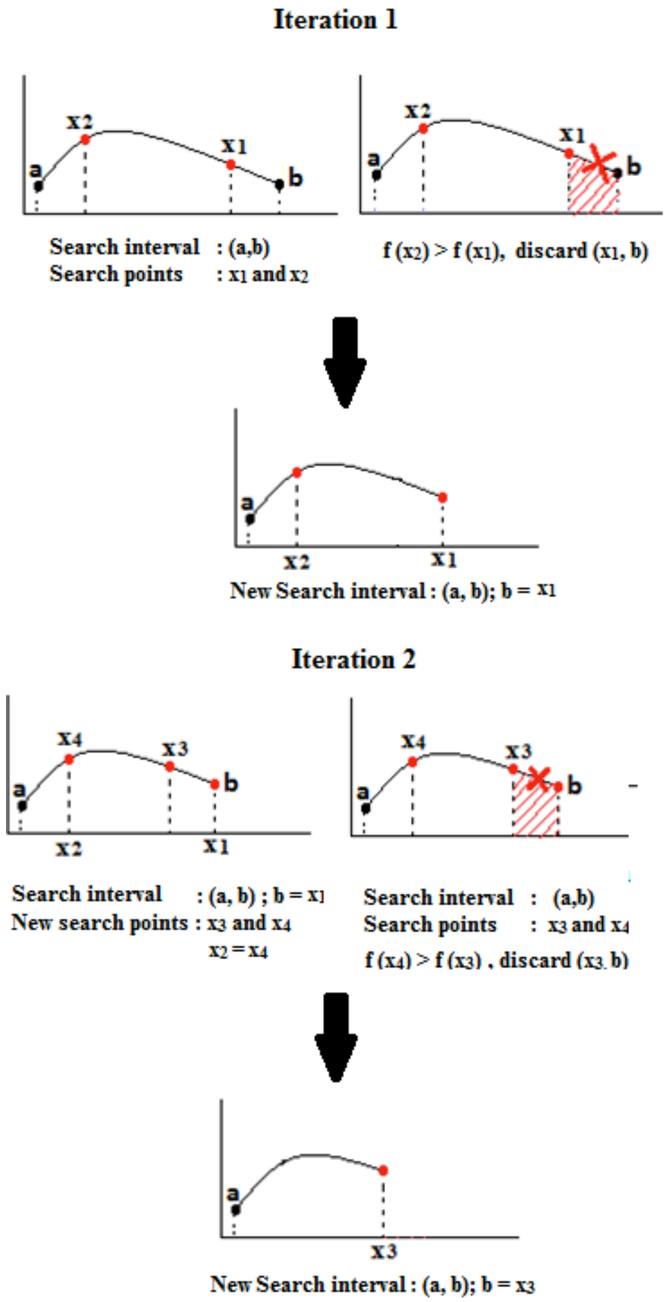


Fig. 4. Reduction of search interval in GSS algorithm

The efficiency of the GSS algorithm is measured by its reduction ratio (RR) which is defined as the ratio of length of search interval after 'n' iterations to the length of initial search interval.

$$RR = (0.618)^{n-1} \tag{3}$$

where n is the number of iterations. Using equation 3, it can be shown that only 15 iterations are required for GSS to achieve an error tolerance less than 0.1%. The flow chart of the proposed two stage MPPT algorithm is presented in Figure 5.

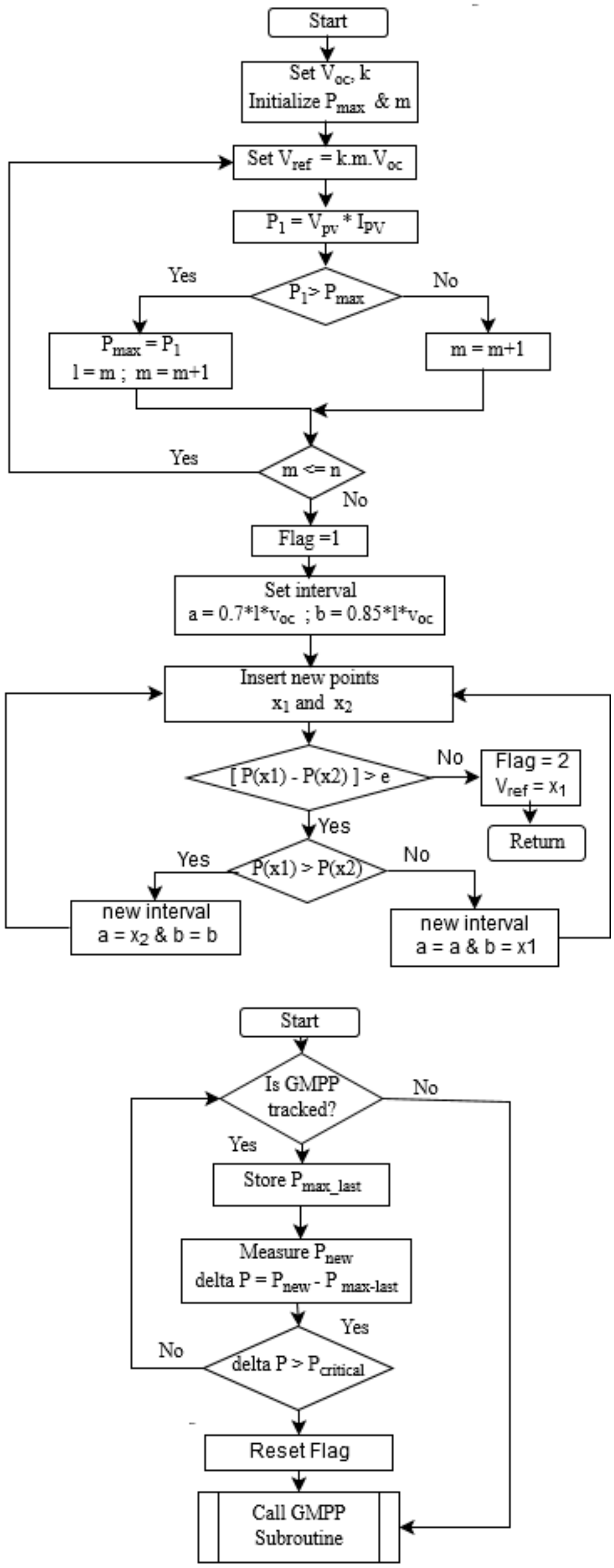


Fig. 5. Flow chart of the proposed GSS based GMPPT algorithm

Flags indicate the completion of the stages. The algorithm searches for the global peak and after locating, it terminates the search by setting the flag to 2. The reference voltage remains unaltered until the irradiation or shading conditions change. The algorithm senses changes of this sort by calculating the deviation in peak power (ΔP) periodically. If there is a change in environmental conditions or shade pattern and distribution, the deviation is large. Smaller deviation can however be neglected. If $\Delta P > P_{critical}$, new search is initiated and the main program calls the GMPP subroutine to rescanning the entire range and track the new peak.

5. Results and Discussion

The algorithm is first tested for standard test conditions. The V-I and V-P characteristics are presented for non-shaded case presented in Figure 2 (V_{mp}=49.55 V, P_m =333.75 W). The V-P curve exhibits single peak and the proposed algorithm has tracked the peak effectively. The change is reference voltage as the algorithm tracks and the controlled PV array voltage are shown in Figure 6.

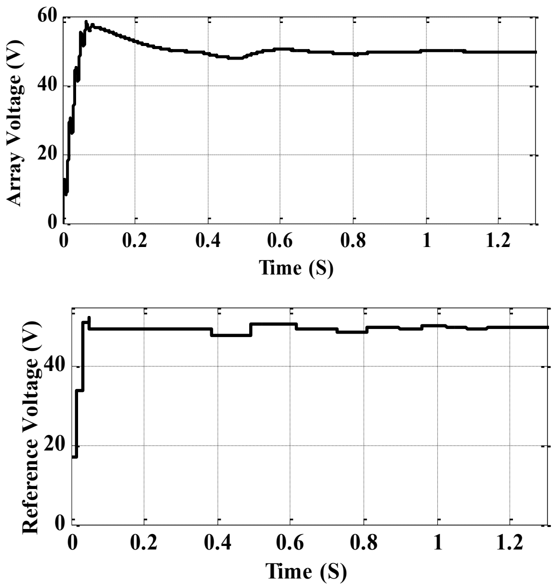


Fig.6. Change in array voltage and reference voltage for non_shaded case.

The proposed two stage GMPPT algorithm is tested for few shading patterns presented in Figure 7 and Figure 9. The test shade patterns are chosen to illustrate the efficacy of the proposed algorithm in locating the global peak on both the left and right side of the load line. In test shade pattern given in Figure 9, the local peak and the global peak occur next to each other with a small difference in power. The simulation results including the change in reference voltage, array voltage and power are presented for three different shade patterns are presented. The first stage locates the region of global peak in 3 iterations as the size of the array considered is 3×3 and the golden section search algorithm searches for the global peak in the reduced interval. The search further reduces the interval at the reduction rate of $(0.618)^{n-1}$, where n is the number of iteration.

The first shading pattern is given in Figure 7 where panels are subjected to two different irradiation levels. Three panels receive irradiation G_1= 1000 W/m^2 and the remaining six panels are shaded and receive irradiation of G_2= 628 W/m^2. The number of shaded panels in each row is unlike though the shade intensity remains the same. The row currents are hence different and $I_{row1} > I_{row2} > I_{row3}$. Consequently, the V-P curve exhibits three different crests with the global peak of 224.2 W occurring at the voltage 51.14 V as shown in Figure 7.

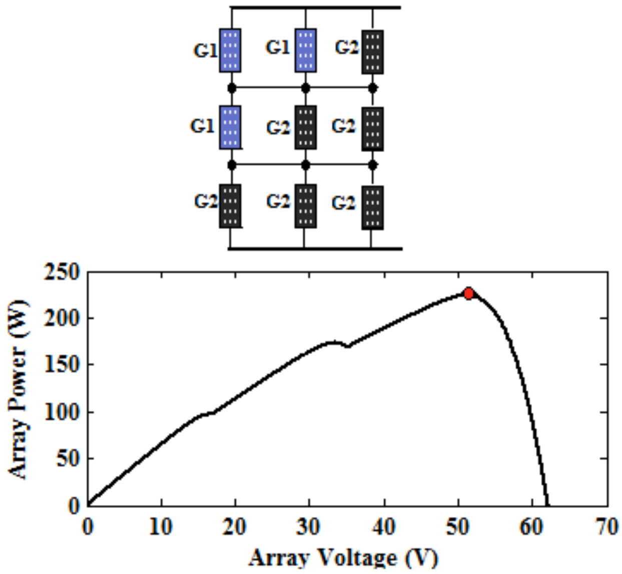


Fig.7. Shade pattern 1 and the electrical characteristics

The region of the global peak is identified by first stage of the algorithm at t= 0.075 s and the second stage is then triggered. At t=1.6 s, the global peak is tracked by the GSS algorithm and the array voltage settles at 51.13 V. The tracked maximum power is 224 W.

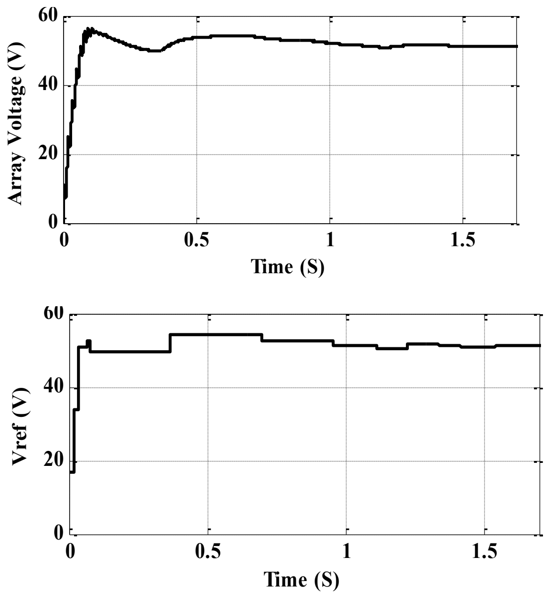


Fig. 8. Change in array voltage and reference voltage for shade pattern 1

The second shade pattern as given in Figure 9 is subjected to three different shade intensities. Three of the panels are not shaded while the others receive irradiation of 500 W/m^2, 800 W/m^2 and 900 W/m^2. As the row currents are different, the V-P curve exhibits three peaks. The shade pattern along with the V-P curve is shown in Figure 9. The global peak in this case lies on the left side and the power variation between the global peak (202 W) and one of the local peaks (184 W) is relatively small (18 W).

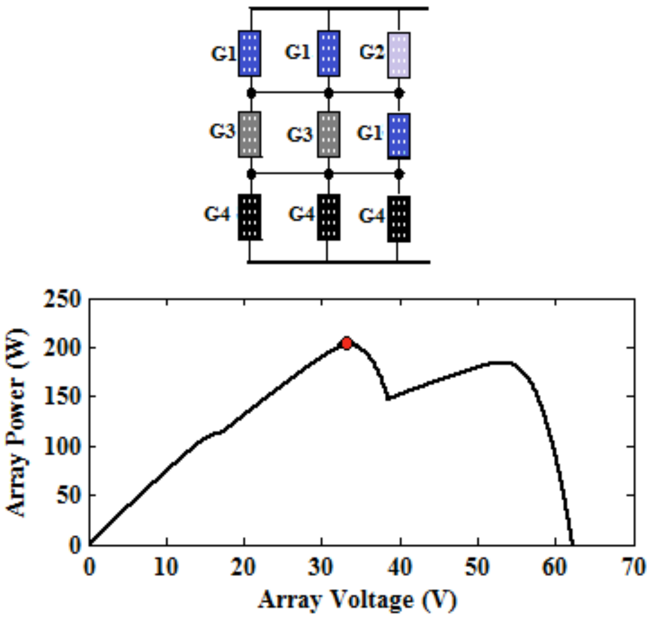


Fig. 9. Shade pattern 2 and the electrical characteristics

The change in reference voltage and the array voltage are presented in Figure 10. The algorithm differentiated the peaks and tracked the global peak effectively. The algorithm has shrunk the interval at t= 0.1s and the GSS based second stage located the global peak after 10 iterations at t = 1.6 s.

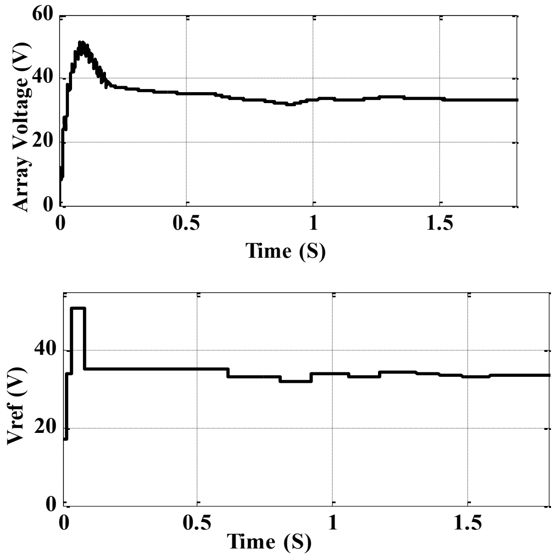


Fig. 10. Change in array voltage and reference voltage for shade pattern 1

Finally, the effectiveness of the proposed algorithm is tested for varying environmental conditions as presented in Figure 11. The array is subjected to dynamic shading scenarios where the first shade pattern exists for 2 s. The shade pattern is changed to the second in the time range of 2-4 s and then to the third thereafter as presented in the Figure 11. The irradiation received by the shaded panels in the three patterns is 628 W/m^2, 628 W/m^2 and 310 W/m^2 respectively. The V-P curves that correspond to these shade patterns are presented in Figure 12 with the global peaks marked red.

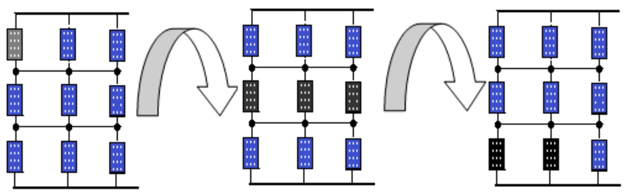


Fig.11. Dynamic shading patterns

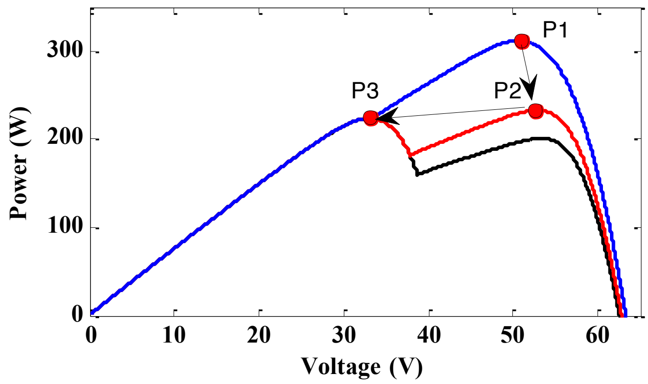


Fig. 12. Electrical characteristics for the shading conditions given in Figure 11.

The algorithm starts scanning the initial search interval at t= 0 s from the left side. The region of global peak is detected at the third iteration and the second stage continues the search with GSS algorithm and generates the reference voltage as 50.66V. The maximum power point is tracked at t = 1.2 s. The algorithm periodically checks for the change in peak power periodically. It senses the deviation at t = 2 s when the second shade pattern is applied. The deviation is more and as $\Delta P > P_{critical}$, the algorithm calls the GMPP subroutine to rescan the voltage range for the new peak. The peak occurs at 53.2 V which is on the right side of the previous peak. The next disturbance is made at t=0.4 s with the third shade pattern. The algorithm recognizes the change in irradiation received by checking ΔP. In this case, the peak lies to the left of the previous one and is tracked at t=6.1s. The variation in the reference voltage generated by the proposed algorithm and the resultant change in the array voltage are shown in Figure 13.

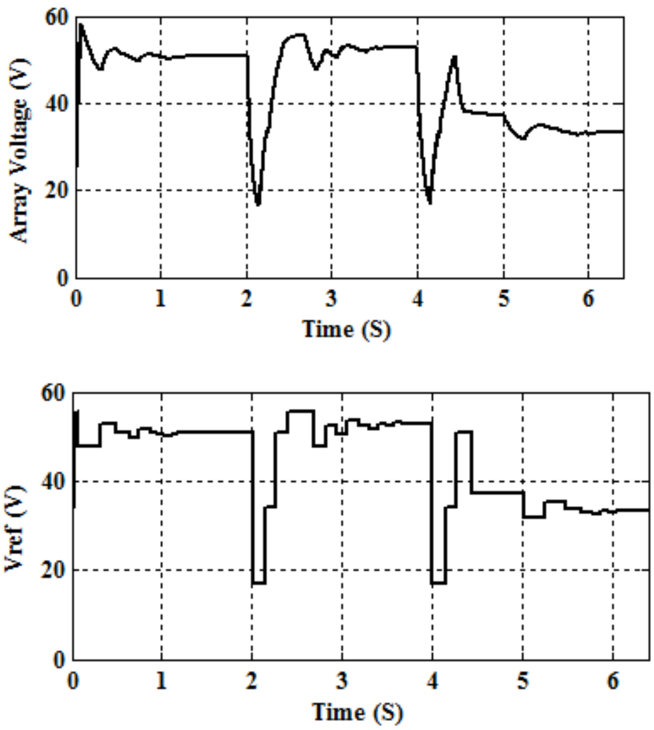


Fig.13. Change in array voltage and reference voltage for the dynamic shading

The tracing capability of the proposed GSS based GMPPT algorithm can verified by comparing the actual peaks tracked by the algorithm with the peaks obtained from the V-P curves. The comparison is presented in table 2.

Table 2. Comparision of simulated results with V-P curve.

Shade pattern	V-P curve		Proposed algorithm	
	V_{mp} (V)	P_{mp} (W)	V_{mp} (V)	P_{mp} (W)
1	50.91	311.8	50.66	311.8
2	52.6	233	52.9	232.4
3	33.21	223.6	33.25	223.7

It can be inferred from the above table that the proposed GSS based GMPPT algorithm is effective and has tracked the global peak for all the test shading scenarios simulated. The proposed GMMPT algorithm checks for the global peak at only strategic locations in the first stage rather than scanning the entire region. Further, the RR of the GSS algorithm is better thus, enabling the identification of the global peak in less iteration (15 iterations to converge within +0.1% error tolerance limit). Hence, the proposed algorithm is is faster than the other multi stage algorithms.

6. Conclusions

In this paper, a reliable two stage GSS based GMPPT algorithm has been proposed. It initially scans only the significant regions in the entire voltage range and narrow down the region of GP. This reduces the search time and second stage locates the actual global peak by searching in the new interval fixed around the vicinity of the global peak by the first stage. After tracking the GMPP, the algorithm checks for the environmental changes by periodically checking the deviation in power and initiates new search if deviation is more. The proposed algorithm converges quickly with the convergence rate of $(0.618)^{(n-1)}$ that with 15 iterations, the reference voltage converges with an error tolerance of 0.1%. The efficiency of the algorithm was tested for different test shade patterns and the simulated results presented comply with that of the V-P curve data.

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References

[1] M. G. Villalva, J. R. Gazoli, and E. R. Filho. "Comprehensive approach to modelling and simulation of photovoltaic arrays", IEEE Transactions on Power Electronics, Vol. 24, No. 5, pp. 1198–1208, 2009.

[2] Kumari, J., and Babu, Ch., "Comparison of maximum power point tracking algorithms for photovoltaic system", International Journal of Advances in Engineering and Technology, Vol.1, pp.133–148,2011.

[3] J. Ahmad, "A fractional open circuit voltage based maximum power point tracker for photovoltaic arrays," 2010 2nd International Conference on Software Technology and Engineering, San Juan, PR, 2010, pp. V1-247-V1-250.

[4] El-Khozondar, Hala J., Rifa J. El-Khozondar, Khaled Matter, and Teuvo Suntio. "A review study of photovoltaic array maximum power tracking algorithms." Renewables: Wind, Water, and Solar , Vol.3, no. 1, 2016.

[5] Villalva, Marcelo G., and Ernesto Ruppert. "Analysis and simulation of the P&O MPPT algorithm using a linearized PV array model." In Industrial Electronics, 2009. IECON'09. 35th Annual Conference of IEEE, pp. 231-236. IEEE, 2009.

[6] Liu, Fangrui, Shanxu Duan, Fei Liu, Bangyin Liu, and Yong Kang. "A variable step size INC MPPT method for PV systems." IEEE Transactions on Industrial electronics, Vol. 55, no. 7 , pp. 2622-2628, 2008.

[7] Casadei, Domenico, Gabriele Grandi, and Claudio Rossi. "Single-phase single-stage photovoltaic generation system based on a ripple correlation control maximum power point tracking." IEEE Transactions on Energy Conversion, Vol. 21, no. 2, pp.562-568, 2006.

[8] Kheldoun, A., Rafik Bradai, R. Boukenoui, and A. Mellit. "A new Golden Section method-based maximum power point tracking algorithm for photovoltaic systems."

Energy Conversion and Management, 111, pp. 125-136, 2016.

[9] Salam, Zainal, Jubaer Ahmed, and Benny S. Merugu. "The application of soft computing methods for MPPT of PV system: A technological and status review", Applied Energy, 107, pp. 135-148, 2013.

[10] Kumari, Ms J. Surya, Ch Sai Babu, and Mr T. Raja Kullayappa. "Design and Analysis of Open Circuit Voltage Based Maximum Power Point Tracking for Photovoltaic System" ,International Journal of Advances in Science and Technology, Vol. 2, no. 2, pp.51-86, 2011.

[11] Kumari, J. Surya, Ch Sai Babu, and J. Yugandhar. "Design and investigation of short circuit current based maximum power point tracking for photovoltaic system." International Journal of Research and Reviews in Electrical and Computer Engineering, Vol. 1, 2011.

[12] Kjær, Søren Bækhøj, "Evaluation of the “hill climbing” and the “incremental conductance” maximum power point trackers for photovoltaic power systems" ,IEEE Transactions on Energy Conversion, Vol. 27, no. 4 ,pp. 922-929, 2012.

[13] Sera, Dezso, Tamas Kerekes, Remus Teodorescu, and Frede Blaabjerg. "Improved MPPT algorithms for rapidly changing environmental conditions", in Power Electronics and Motion Control Conference, 2006. EPE-PEMC 2006. 12th International, pp. 1614-1619. IEEE, 2006.

[14] Chaouachi, Aymen, Rashad M. Kamel, and Ken Nagasaka, "A novel multi-model neuro-fuzzy-based MPPT for three-phase grid-connected photovoltaic system." Solar energy, Vol. 84, no. 12, pp. 2219-2229, 2010.

[15] Bendib, B., F. Krim, H. Belmili, M. F. Almi, and S. Boulouma. "Advanced Fuzzy MPPT Controller for a stand-alone PV system." Energy Procedia, Vol. 50, pp. 383-392, 2014.

[16] Patel, Hiren, and Vivek Agarwal, "Maximum power point tracking scheme for PV systems operating under partially shaded conditions", IEEE Transactions on Industrial Electronics, Vol. 55, No. 4, pp. 1689-1698, 2008.

[17] Miyatake, Masafumi, Takeshi Inada, Isao Hiratsuka, Hongyan Zhao, Hisayo Otsuka, and Motomu Nakano, "Control characteristics of a fibonacci-search-based maximum power point tracker when a photovoltaic array is partially shaded", The 4th International on Power Electronics and Motion Control Conference IPEMC 2004, Vol. 2, pp. 816-821, 2004.

[18] Kheldoun, A., Rafik Bradai, R. Boukenoui, and A. Mellit. "A new Golden Section method-based maximum power point tracking algorithm for photovoltaic systems", Energy Conversion and Management, Vol. 111, pp. 125-136, 2016.

[19] M. Ben Smida and A. Sakly, “A comparative study of different MPPT methods for grid-connected partially shaded photovoltaic systems,” International Journal of Renewable Energy Research (IJRER), vol. 6, no. 3, 2016.

[20] S. Choudhury, P.K.Rout, “Adaptive Fuzzy Logic Based MPPT Control for PV System under Partial Shading Condition” International Journal of Renewable Energy Research (IJRER), Vol. 5, No. 4, 2015.

[21] Afef Badis, Mohamed Habib Boujmil, Mohamed Nejib Mansouri,"A Comparison of Global MPPT Techniques for Partially Shaded Grid-connected Photovoltaic System," International Journal of Renewable Energy Research.(IJRER), Vol. 8, No. 3, pp. 1442-1452 , 2018.

[22] B. Veerasamy, W. Kitagawa, and T. Takeshita, “MPPT method for PV modules using current control - based partial shading detection,” in 3rd International Conference on Renewable Energy Research and Applications (ICRERA), pp. 359–364, 2014.

[23] B. Veerasamy, A. R Thelkar, G. Ramu, and T. Takeshita, "Efficient MPPT control for fast irradiation changes and partial shading conditions on PV systems ,"In Renewable Energy Research and Applications (ICRERA), 2016 IEEE International Conference , pp. 358-363, IEEE, November 2016.

[24] R. Boukenoui, R. Bradai, A. Mellit, M. Ghanes and H. Salhi, 'Comparative Analysis of P&O, Modified Hill Climbing - FLC, and Adaptive P&O-FLC MPPTs for Microgrid Standalone PV System', 4th International Conference on Renewable Energy Research and Application (ICRERA), Palermo, Italy, pp. 1095 - 1099, Nov 22-25, 2015.

[25] Santi Agatino Rizzo, "Enhanced Hybrid Global MPPT Algorithm for PV Systems operating under Fast-Changing Partial Shading Conditions", International Journal of Renewable Energy Research.(IJRER), Vol. 8. No. 1, pp. 1800-1811,2018.

[26] S. Malathy and R. Ramaprabha, "Comprehensive analysis on the role of array size and configuration on energy yield of photovoltaic systems under shaded conditions", Renewable and Sustainable Energy Reviews, Vol. 49, pp. 672-679, 2015.

[27] Agrawal, Jyoti, and Mohan Aware, "Golden section search (GSS) algorithm for maximum power point tracking in photovoltaic system", IEEE 5th India International Conference on Power Electronics (IICPE), pp. 1-6, 2012.

[28] www. matlab.com