

## Roof top PV for charging the EV using hybrid GWO-CSA

Dhamodharan Selvaraj, Dhanalakshmi Rangasamy

Department of Electrical and Electronics Engineering, Dayananda Sager College of Engineering, Bangalore, India

### Article Info

#### Article history:

Received Sep 1, 2021

Revised Mar 16, 2022

Accepted Mar 28, 2022

#### Keywords:

Electric vehicle charging

Hybrid GWO-CSA

On the go charging

Partial Shaded Condition

PV panels

### ABSTRACT

In this paper, a novel idea of charging the vehicle on the go while using the solar panels on the roof of the vehicle is introduced. The use of electric vehicles has increased among people as the vehicles are affordable. Electric vehicle charging is one of the major problems faced by most manufacturers today. The PV panels take the energy from sunlight, and it can charge the vehicle battery. When the vehicle is moving on the road, the power extraction for charging may not be proper due to the partial shaded condition. To extract sufficient power for charging, a hybrid optimization algorithm has been introduced. In this paper, an electric vehicle model that uses the hybrid optimization algorithm of grey wolf optimization and cuckoo search algorithm (GWO-CSA) is developed and compared with the conventional particle swarm optimization (PSO) algorithm. The extraction of maximum power and the performance of the vehicle are analysed using MATLAB/Simulink, and the simulation results are discussed. To test the effectiveness of the algorithm, it is compared with the other three algorithms.

*This is an open access article under the [CC BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.*



### Corresponding Author:

Dhamodharan Selvaraj

Department of Electrical and Electronics Engineering, Dayananda sager college of engineering

Shavige Malleshwara Hills, 91st Main Rd, 1st Stage, Kumaraswamy Layout, Bengalore, Karnataka

560078, India

Email: dhamu.winner@gmail.com

## 1. INTRODUCTION

Throughout this decade, numerous manufacturers have introduced energy-efficient and cost-effective electric automobiles. However, developing countries such as India continue to be underserved when it comes to billing requirements. There may be a significant demand for charging stations or alternative charging solutions in the near future. Solar energy has recently emerged as one of the simplest and most environmentally friendly energy sources [1]. Numerous articles concern the tracking of solar panels' maximum power points. Maximum power tracking for EV on-the-go charging in partially shaded settings is a significant difficulty. Additionally, due to these partially shadowed conditions, a hot spot in the photovoltaic cells results in power loss.

There are several articles that discuss how to overcome this partially shaded state through reconfiguration of photovoltaic panels or cells, as well as using optimization algorithms and intelligent strategies. The following articles describe the answer to this problem: The article [2] examines the photovoltaic cells contained within the panels. pixel-wise voting network PVNet is a pascal programme developed at the European communities' joint research centre in Ispra to simulate the electrical behaviour of solar cell interconnection networks. Article [3] describes an approach for simulating and modelling solar cells and photovoltaic modules that are partially shaded in the Pspice environment. The article [4] investigates the functionality of a photovoltaic array. These properties stated in [2]-[4] demonstrate that when

the IV curves are shaded, they have many peaks. To address this issue, the work in [5] explores the available interconnections between the modules in a shadowed solar field and how they affect power generation.

The work in [6] proposes a novel distributed maximum power point tracking DMPPT technique that is both simple to apply and accurate, resulting in precise maximum power point tracking (MPPT). The research in [7] proposes a global maximum power point tracking strategy based on shade detection and the trend of slopes out of each segment of the curve. Article [8] discusses topologies for PV panels such as total cross-tied, bridge link, and honeycomb. The authors present a straightforward and accurate model of photovoltaic arrays operating in partial shadowing conditions, based on the one-diode equivalent circuit of a photovoltaic cell and mathematical advances addressed in the literature [9]. The array status evaluation is critical for guaranteeing the safe operation of large-scale photovoltaic power plants, since it may result in the severity of partial shadowing increasing. Then they discovered [10] that a variety of indicators accurately represent the status of photovoltaic panels. The performance assessment approach was developed using the k-means clustering algorithm [10]. The technology performs a reconfiguration by detecting the voltages and irradiances of the photovoltaic cells or panels [11]. Charge redistribution through a switched capacitor achieves power balancing in mismatch circumstances, such as partial shade [11]. Hot spot identification is performed between [12]–[14]. A straightforward technique for identifying hot zones has been discussed. Additionally, an excellent method is employed to guard against hot spots on the panels. The detection method is based on the equivalent DC impedance of the panel's strings, which provides valuable properties for hot spot identification.

The photovoltaic array is partially shadowed, and other issues associated with solar panel integration on the vehicle are explored in [15]. And the articles discuss the solutions proposed for the partial shaded circumstances, utilising meta-heuristics and intelligent approaches. In articles [16], [17], a comparison of the perturb and observe method with the PSO algorithm under partial shadow situations is discussed in the grid-connected photovoltaic system. This article [18] provides a method for MPPT of a photovoltaic panel array with partial shadowing using an improved pattern search method. The firefly algorithm (FA) [19] is a control mechanism for switching patterns in non-homogeneous shading profiles that follows the largest global peak of power generated by many switching patterns. The article then introduces a novel, intelligent, bio-inspired meerkat optimization algorithm [20] (MOA) capable of finding the global power peak and assuring maximum power supply. The research article [21] proposes a technique for tracking the global maximum power point (GMPPT) of partially shadowed photovoltaic (PV) systems using simulated annealing (SA). The proposed strategy for GMPPT is compared to both the widely used perturb and observe MPPT methodology and the particle swarm optimization method. As an alternative to standard photovoltaic MPPT approaches, the work given in [22] uses an opposition-based learning firefly algorithm (OFA) to improve the performance of solar systems under both uniform irradiance changes and partial shade circumstances. This article [23] proposes using the chimp optimization algorithm (ChOA), a metaheuristic algorithm inspired by chimps' natural social behaviour, to track the MPPT of solar PV strings. The article [24] discusses kinetic gas molecular optimization in terms of MPPT and maximum number of iterations (KGMO). This contrasts with ant colony optimization (ACO). In comparison to the KGMO technique, ACO requires more iterations to achieve the specified partially shaded irradiation conditions. The article [25] examines the performance of the PSO and grey wolf optimization algorithms in a photovoltaic power plant's battery maintenance. Sathyanarayana *et al.* [26], the multi-objective function is utilised to track MPPT and its performance is compared to that of single and multi-objective tracking.

Numerous papers fail to describe hybrid meta-heuristic algorithms and hill climbing strategies that use meta-heuristics. The research presents partly shaded optimization of artificial bee colonies using perturb and observe [27], hybrid whale optimization using simulated annealing [28], and PSO with sliding mode control [29]. Several papers examine the application of intelligent techniques such as neural networks [30] and artificial neuro-fuzzy inference systems [31] to the regulation of power generated by photovoltaic (PV) panels. The PSO is compared with P & O and IC in [32], [33]. The enhanced PSO is compared with PSO in [34]. Then the modified PSO is used in [35]. Benefits are discussed. The new architecture of PV is discussed in [36]. Multilevel control is implemented and discussed in [37]. Salvi *et al.* [38], fuzzy logic is used to analyse the problem of partial shaded conditions in PV. And [39] discusses the genetic algorithm in comparison with the fuzzy logic for the partial shaded problem in PV.

In this paper, PV roof-top on electric vehicles is proposed with 2 kW panels and on-the-go charging facilities. To extract sufficient power for charging, a hybrid optimization algorithm has been introduced. An electric vehicle model which uses the hybrid optimization algorithm of grey wolf optimization and cuckoo search algorithm (GWO-CSA) has been developed and compared with the conventional particle swarm optimization (PSO) algorithm for maximum power efficiency. The extraction of maximum power and the performance of the vehicle are analysed using MATLAB/Simulink.

2. METHOD

The proposed system shown in Figure 1 has five PV panels with the connection of retractable aluminium bars, which are hinged vertically to the surface of the roof of the car model. The panels are movable and can also be detached from the roof. The five PV panels are arranged in a circular pattern on the roof of the vehicle. For simplicity, the connecting wires are not shown in Figure 1 for simplicity.

Figure 2 shows the battery and charger with the motor drive as the load on the battery. The Figure 3 shows the expansion part of Figure 2. The charger takes the input from the PV panels.  $V_{pv}$  and  $I_{pv}$  are the measured voltage and current at the PV output terminals. The on-the-go charger is connected to the Li-ion battery. This battery is connected to the inverter, and the inverter drives the permanent magnet brushless DC motor (PMBLDC). The hybrid GWO-CSA or PSO based MPPT algorithm predicts the reference voltage. And the PWM is generated according to the current reference generation for constant current charge.

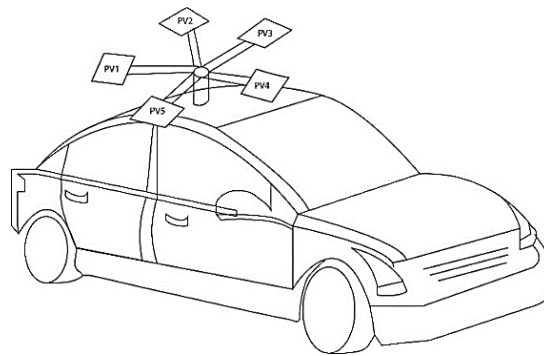


Figure 1. Proposed on-the-go charger car model

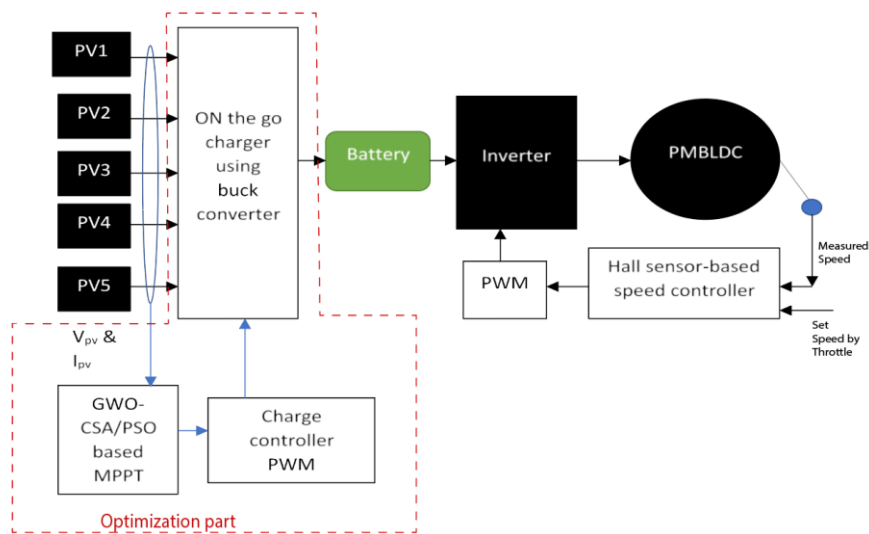


Figure 2. On-the-go charger model with battery and PMBLDC motor

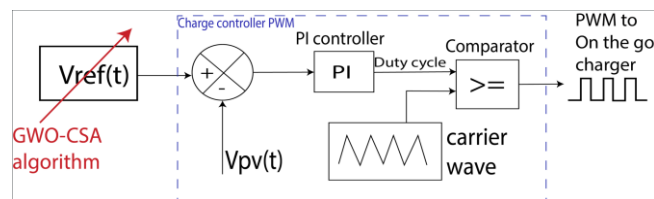


Figure 3. Expansion of the optimization part from Figure 2

### 2.1. Problem formulation

The PV power extraction must be maximized for charging the electric vehicle battery. The following objective function is used for the selection of proper  $V_{ref}$ . The objective function with constraint is represented as,

$$F(V_{ref}(t)) = \max(P(t)) \quad (1)$$

where,

$$P(t) = V_{pv}(t) \times (I_{pv}(t)) \quad (2)$$

inequality constraints

$$V_{ref\ min}(t) \leq V_{ref}(t) \leq V_{ref\ max}(t) \quad (3)$$

where,

F – fitness function

Vref – reference voltage for MPP

P(t) – measured PV power

$V_{pv}(t)$  = measured PV voltage in V

$I_{pv}(t)$  = measured PV current in A

t – simulation time in secs

The is optimally selected by the hybrid GWO-CSA algorithm. This is set as the set point voltage for the charge controller. The measured PV voltage is taken as feed forward and then passed through the PI controller. This PI controller regulates the error voltage as a proportional duty cycle. Then it is compared with the carrier wave to create the pulse width modulation (PWM). This PWM is used for the extraction of maximum power.

### 2.2. Algorithm

Individually the gray wolf optimization algorithm (GWO) as well as cuckoo search algorithm (CSA) both performs well. The GWO produces fast convergence and CSA make 100 % success rate. A hybrid GWO-CSA is developed by combing both the algorithm, to get much better performance. In this  $X_\alpha, X_\beta$  and  $X_\delta$  is the Vref which is used for the control. The Flowchart is shown in Figure 4. Levy is the random generation function. According to GWO algorithm encircling the prey, hunting the prey and attacking the prey are the steps. For encircling it uses,

$$D = |C \cdot V_{p,ref}(it) - V_{ref}(it)| \quad (4)$$

$$V_{ref}(it) = V_{p,ref} - A \cdot D \quad (5)$$

Here, (it+1) represents the next iteration,  $V_{p,ref}$  represents the position of one wolf, A & D are the coefficient vectors. It can be calculated using,

$$A = 2a \cdot r_1 - a \quad (6)$$

$$C = 2r_2 \quad (7)$$

Here, 'a' is the value between 2 and 0 which decreases linearly while iterating, r1 and r2 are the random numbers between (0,1). For Hunting the prey following equation is used,

$$V_{ref}(it + 1) = \frac{(V_{ref1} + V_{ref2} + V_{ref3})}{3} \quad (8)$$

Where

$$V_{ref1} = |V_{ref\ \alpha} - A_1 \cdot D_\alpha| \quad (9)$$

$$V_{ref2} = |V_{ref\ \beta} - A_2 \cdot D_\beta| \quad (10)$$

$$V_{ref3} = |V_{ref\ \gamma} - A_3 \cdot D_\gamma| \quad (11)$$

$V_{ref\ \alpha}$ ,  $V_{ref\ \beta}$  and  $V_{ref\ \gamma}$  are the best three solutions so far. And  $D_\alpha$ ,  $D_\beta$  and  $D_\gamma$  are the values from in (5) after substituting the updated  $V_{ref\ \alpha}$ ,  $V_{ref\ \beta}$  and  $V_{ref\ \gamma}$ . For attacking the prey,

$$A = 2 - 2 \left( \frac{it}{max} \right) \tag{12}$$

Here ‘it’ is iteration count, ‘max’ is maximum iteration count. For cuckoo search the levy flights updation equation is used. And the Levy function can be represented as,

$$Levy \sim u = it^{-\lambda} \text{ here, } 1 < \lambda < 3 \tag{13}$$

$$V_{ref,i}(it + 1) = V_{ref,i}(it) + \alpha \oplus Levy(\lambda) \tag{14}$$

Here,  $i=1,2,\dots,n$  is the population count.

### 3. RESULTS AND DISCUSSION

The simulink diagram for the proposed on-the-go charging is developed based on the objective function using the hybrid GWO-CSA optimization algorithm. The solar PV is connected to an on-the-go charger, and the charger is connected to the battery. The battery powers the PMLBDC motor, which is driven by the hall sensor.

Here, four cases are analysed. In the first case, the irradiation considered for each panel differed by 100. PV1 is exposed with  $1000\ W/m^2$ , PV2 with  $900\ W/m^2$ , PV3 with  $800\ W/m^2$ , PV4 with  $700\ W/m^2$ , and PV5 with  $600\ W/m^2$ . The second case is designed like PV1 is exposed with  $1000\ W/m^2$ , PV2 is exposed with  $1000\ W/m^2$ , PV3, is exposed with  $900\ W/m^2$ , PV4 is exposed with  $900\ W/m^2$ , and PV5 is exposed with  $800\ W/m^2$ . In the third case, PV1 is exposed to  $700\ W/m^2$ , PV2 is exposed to  $700\ W/m^2$ , PV3 is exposed to  $500\ W/m^2$ , PV4 is exposed to  $500\ W/m^2$ , and PV5 is exposed to  $400\ W/m^2$ . And for the last case (case 5), PV1 is exposed with  $800\ W/m^2$ , PV2 is exposed with  $600\ W/m^2$ , PV3 is exposed with  $600\ W/m^2$ , PV4 is exposed with  $400\ W/m^2$ , and PV5 is exposed with  $400\ W/m^2$ .

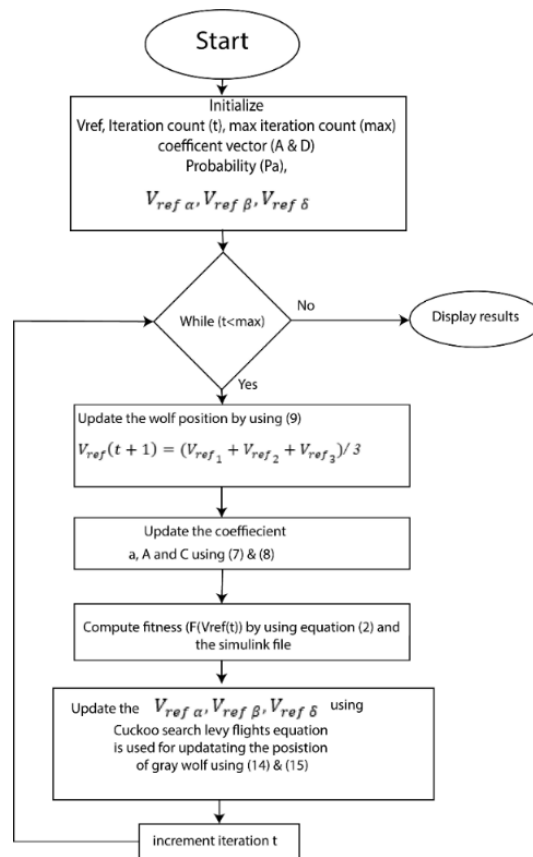


Figure 4. Flowchart of hybrid GWO-CSA

Figure 5 depicts the PV characteristic curve for Case 1. Then the PV curves of Case 2 are depicted in Figure 6. Then Figure 7 shows the PV curves of Case 3. Figure 8 depicts Case 4. The marker is marked for the X and Y axis in the graph. Here, the X axis is voltage, and the Y axis is power. The table shows the actual value of the tracking power comparison between PSO and the hybrid GWO-CSA. Table 1 shows the reference voltage selected by the PSO and hybrid GWO-CSA. Then Table 3 shows the tracking efficiency comparison. Table 4 shows the voltage reference selection error. From the Tables 1-4, it is observed that the charging system with hybrid GWO-CSA performs better under different conditions, and it extracts a good amount of power from PV.

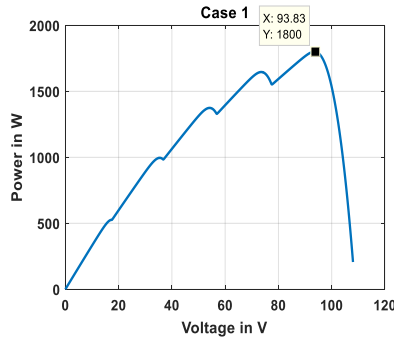


Figure 5. PV curves of case 1

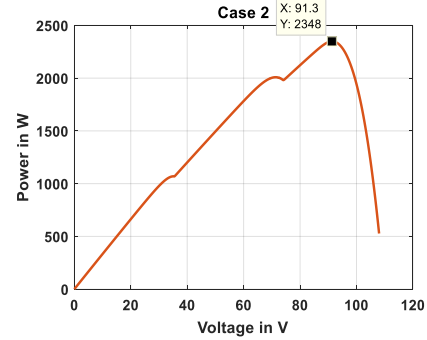


Figure.6. PV curves case 2

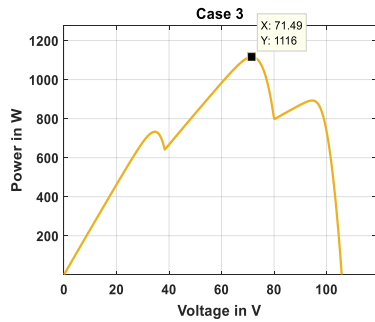


Figure 7. PV curves of case 3

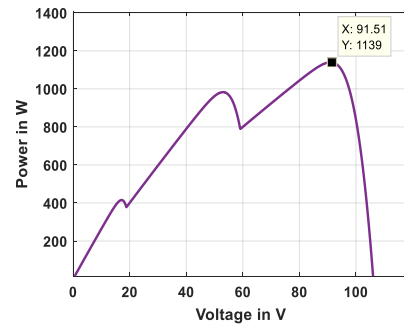


Figure 8. PV curves of case 4

Table 1. Tracking power comparison

Cases	Actual power in watts	Power extracted in watts using PSO, EL-PSO [32], [33]	Power extracted in watts using GA, FL [38], [39]	Power extracted in watts using hybrid GWO-CSA
Case 1	1800	1791.6	1791.5	1792.1
Case 2	2348	2323.9	2323.7	2328.45
Case 3	1116	1106	1105	1109.63
Case 4	1139	1135.7	1135.4	1135.8

Table 2. Selected reference voltage comparison

Cases	Actual value of reference voltage in Volts	Reference voltage in Volts using PSO, EL-PSO [32], [33]	Reference voltage in Volts using GA, FL [38], [39]	Reference voltage in Volts using hybrid GWO-CSA
Case 1	93.83	93.506	93.8	92.2592
Case 2	91.3	89.348	89.3	89.8026
Case 3	71.49	71.932	70	70.7502
Case 4	91.51	89.803	89.1	89.3475

Table 3. Tracking efficiency comparison

Cases	Efficiency in % with PSO, EL-PSO [32], [33]	Efficiency in % with GA,FL [38], [39]	Efficiency in % with hybrid GWO-CSA
Case 1	99.53333	99.4	99.56111
Case 2	98.97359	98.7	99.16738
Case 3	99.10394	99	99.42921
Case 4	99.71027	99.6	99.71905

Table 4. Voltage reference selection error

Cases	Voltage error in volts with PSO, EL- PSO [32], [33]	Voltage error in volts with GA, FL [38], [39]	Voltage error in volts with hybrid GWO-CSA
Case 1	0.05993	0.06	1.274264
Case 2	1.955448	1.98	1.4566
Case 3	1.17018	1.18	0.491983
Case 4	1.86537	1.88	2.36313

It is shown that the voltage regulation is better in hybrid GWO-CSA and the efficiency is also better in the proposed algorithm. Figure 9 shows the state of charge of the battery in all the cases using the proposed algorithm. The state of charge of the battery is kept at 50% of its initial charge. Without the on-the-go charger, the battery is discharged by 50%. But the results from all four cases show that the on-the-go charger improves the state of charge (SOC) of the battery. Figure 10 shows the voltage of the battery in all the cases. It is observed that the voltage levels change according to the power level. The voltage is lower when the battery is not charged. Figure 11 shows the reference current of the battery in all the cases. The current is negative when the charger is not connected. The charge current is high when there is a large amount of power available. So, from the simulation results, it is observed that the on-the-go charger is successful. As the battery is loaded with the PMBLDC motor driven by the inverter, the motor performance is analysed here. The speed of the PMBLDC motor shaft is shown in Figure 12 The proposed hybrid GWO-CSA maintains the system reliably for PV panel dynamics.

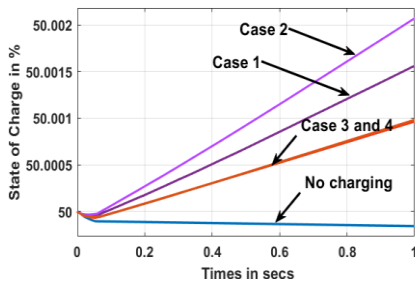


Figure 9. State of charge using hybrid GWO-CSA of battery in all the cases

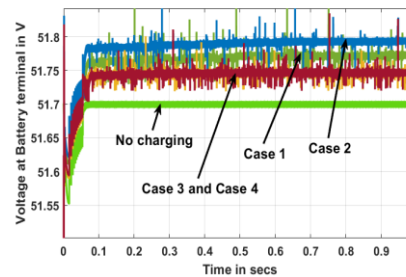


Figure 10. Voltage of battery using hybrid GWO-CSA in all the cases

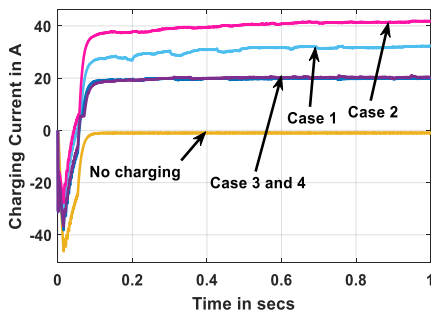


Figure 11. Reference current of battery using hybrid GWO-CSA in all the cases

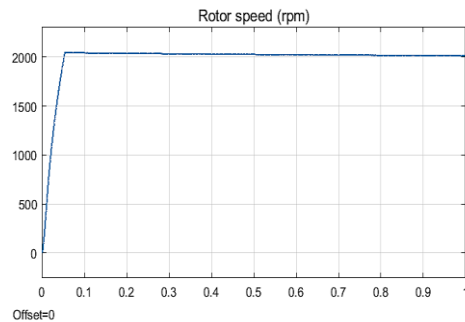


Figure 12. Shaft speed of the PMBLDC motor using hybrid GWO-CSA

4. CONCLUSION

The on-the-go roof-top PV charger in an electric vehicle is developed with the objective of maximum power extraction using the hybrid GWO-CSA optimization algorithm. The simulation results show that the hybrid GWO-CSA algorithm is better in all the aspects like voltage reference error, power extraction, voltage levels, and tracking efficiency. The simulation results of the charging system are compared with the PSO algorithm. And it is evident that the performance of the PMBLDC motor is better with this charging system. The results of the PV power test were also satisfactory after implementing the new algorithm. The

various cases show the reliability of the on-the-go charger in various PV irradiance conditions. The proposed hybrid GWO-CSA algorithm performs well compared to the PSO algorithm, FL and GA and maintains system reliability.

## ACKNOWLEDGEMENTS

Author thanks Dr. Dhanalakshmi for her valuable suggestions and Mr. Ganeshan Vishwanathan, Viswajothi Technologies Pvt Ltd, Bangalore for providing the resources.

## REFERENCE




- [1] H. A. Rub, M. Malinowski and K. Al-Haddad, "Energy, Global Warming and Impact of Power Electronics in the Present Century," *Power Electronics for Renewable Energy Systems, Transportation and Industrial Applications*, IEEE, 2014, pp.1-26, doi: 10.1002/9781118755525.ch1.
- [2] J. W. Bishop, "Computer simulation of the effects of electrical mismatches in photovoltaic cell interconnection circuits," *Solar Cells*, vol. 25, pp.73-89, 1988, doi: 10.1016/0379-6787(88)90059-2.
- [3] S. Silvestre, A. Boronat, and A. Chouder, "Study of bypass diodes configuration on PV modules," *Applied Energy*, vol. 86, no. 9, pp. 1632-1640, 2009, doi: 10.1016/j.apenergy.2009.01.020.
- [4] E. Díaz-Dorado, A. Suárez-García, C. Carrillo and J. Cidrás, "Influence of the shadows in photovoltaic systems with different configurations of bypass diodes," *SPEEDAM*, 2010, pp. 134-139, doi: 10.1109/SPEEDAM.2010.5542226.
- [5] L. F. L. Villa, D. Picault, B. Raison, S. Bacha and A. Labonne, "Maximizing the Power Output of Partially Shaded Photovoltaic Plants Through Optimization of the Interconnections Among Its Modules," *IEEE Journal of Photovoltaics*, vol. 2, no. 2, pp. 154-163, 2012, doi: 10.1109/JPHOTOV.2012.2185040.
- [6] P. Sharma and V. Agarwal, "Exact Maximum Power Point Tracking of Grid-Connected Partially Shaded PV Source Using Current Compensation Concept," *IEEE Transactions on Power Electronics*, vol. 29, no. 9, pp. 4684-4692, 2014, doi: 10.1109/TPEL.2013.2285075.
- [7] J. Gosumbonggot and G. Fujita, "Partial Shading Detection and Global Maximum Power Point Tracking Algorithm for Photovoltaic with the Variation of Irradiation and Temperature," *Energies*, vol. 12, no. 1, pp. 202-218, 2019, doi: 10.3390/en12020202.
- [8] R. V. Mahto, D. K. Sharma, D. X. Xavier, R. N. Raghavan, "Improving performance of photovoltaic panel by reconfigurability in partial shading condition," *Journal of Photonics for Energy*, vol. 10, no. 4, pp. 042004-1 to 042004-16, 2020, doi: 10.1117/1.JPE.10.042004.
- [9] A. B. Ben Abdelghani and H. B. A. Sethom, "Modeling PV installations under partial shading conditions," *SN Applied Sciences*, vol. 2, no. 1, pp. 1-9, 2020, doi: 10.1007/s42452-020-2458-0.
- [10] L. Liang, et al "Status evaluation method for arrays in large-scale photovoltaic power stations based on extreme learning machine and k-means," *Energy Reports*, vol. 7, no. 1, pp. 2484-2492, 2020, doi: 10.1016/j.egyr.2021.04.039.
- [11] K. A. N. Niazi, Y. Yongheng, T. Kerekes, and D. Sera, "Reconfigurable Distributed Power Electronics Technique for Solar PV Systems," *Electronics*, vol. 10, no. 9, pp. 1-16, 2021, doi: 10.3390/electronics10091121.
- [12] T. Ghanbari, "Hot spot detection and prevention using a simple method in photovoltaic panels," *IET Generation, Transmission & Distribution*, vol.11, no. 4, pp. 883-890, 2021, doi: 10.1049/iet-gtd.2016.0794.
- [13] O. W. M. Y. Narvios and Q. Nguyen, "Detection and mitigation system for shading-induced hot spots in household crystalline silicon photovoltaic modules," *AIP Conference Proceedings*, 2021, pp. 060003-1-060003-12, doi: 10.1063/5.0066564.
- [14] T. Ghanbari, "Permanent partial shading detection for protection of photovoltaic panels against hot spotting," *IET Renewable Power Generation*, vol. 11, no. 1, pp. 123-131, 2017, doi : 10.1049/iet-rpg.2016.0294.
- [15] P.R. Satpathy,A .Mahmoud,S.K Panigarhi, and R. Sharma, "Partial Shading Effect on the Performance of Electric Vehicle-Integrated Solar PV System," *Advances in Energy Technology*, vol. 1, pp. 169-178, 2020, doi: 10.1007/978-981-15-8700-9\_16.
- [16] S. Dhamodharan and R. Dhanalakshmi, "Comparative Analysis to the Solution of Partial Shaded Condition in Grid-Connected PV system," *Journal of Emerging Technologies and Innovative Research*, vol. 6, no. 6, pp. 1-6, 2019, doi: 10.1007/JETIR1906427.
- [17] A. Belkaid, U. Colak and K. Kayisli, "A comprehensive study of different photovoltaic peak power tracking methods," *IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA)*, 2017, pp. 1073-1079, doi: 10.1109/ICRERA.2017.8191221.
- [18] A. Tabon, J. P. Restrepo, J. Montano, M. Durango, J. Herrera and A. Ibeas, "MPPT of a Photovoltaic Panels Array with Partial Shading Using the IPSPM with Implementation Both in Simulation as in Hardware," *Energies*, vol. 13, no. 815, pp.1-17, 2020, doi: 10.3390/en13040815.
- [19] M. N. R. Nazeri, M. F. N. Tajuddin, T. S. Babu, A. Azmi, M. Malvoni and N. M. Kumar, "Firefly Algorithm-Based Photovoltaic Array Reconfiguration for Maximum Power Extraction during Mismatch Conditions," *Sustainability*, vol. 13, no. 1, pp. 3206-3212, 2020, doi: 10.3390/su13063206.
- [20] V. Srinivasan, C. S. Boopathi and R. Sridhar, "A new meerkat optimization algorithm based maximum power point tracking for partially shaded photovoltaic system," *Ain Shams Engineering Journal*, vol. 12, no. 4, pp. 3791-3802, 2021, doi: 10.1016/j.asej.2021.03.017.
- [21] S. Lyden and M. E. Haque, "A Simulated Annealing Global Maximum Power Point Tracking Approach for PV Modules Under Partial Shading Conditions," *IEEE Transactions on Power Electronics*, vol. 31, no. 6, pp. 4171-4181, 2016, doi: 10.1109/TPEL.2015.2468592.
- [22] A. G. A. Khalil, W. Alharbi, A. R. Al-Qawasmi, M. Alobaid, and I. M. Alarifi, "Maximum power point tracking of PV systems under partial shading conditions based on opposition-based learning firefly algorithm," *Sustainability*, vol. 13, no. 5, pp.1-18, 2021, doi: 10.3390/su13052656.
- [23] T. Nagadurga, P.V.R L. Narasimham, V. S Vakula, R. Devarapalli and F. P. G. Márquez, "Enhancing global maximum power point of solar photovoltaic strings under partial shading conditions using chimp optimization algorithm," *Energies*, vol. 14, no. 14, pp. 1-23, 2021, doi: 10.3390/en14144086.
- [24] R. S. Prasad and R. Thiyagarajan, "Kinetic Gas Molecular Optimization Method for PV System Under Partial Shaded Condition," *International Journal of Intelligent Engineering and Systems*, vol. 13, no. 4, pp. 33-43, 2020, doi: 10.22266/ijies2020.0831.04.






- [25] H. Kraiem, F. Aymen, L. Yahya, A. Triviño, M. Alharthi, and S. S. M. Ghoneim, "A Comparison between Particle Swarm and Grey Wolf Optimization Algorithms for Improving the Battery Autonomy in a Photovoltaic System," *Applied Sciences*, vol. 11 no. 16, pp. 7732-7742, 2021, doi: 10.3390/app11167732.
- [26] P. Sathyanarayana, R. Ballal, G. Kumar, S. Shaileshwari, "Maximum power point optimization for a grid synchronized PV system considering partial shaded condition using multi-objective function," *International Journal of Power Electronics and Drive Systems*, vol. 10, no. 3, pp. 1547-1555, 2019, doi: 10.11591/ijpeds.v10.i3.pp1547-1554.
- [27] D. Pilakkat and S. Kanthalakshmi, "Single phase PV system operating under Partially Shaded Conditions with ABC-PO as MPPT algorithm for grid connected applications," *Energy Reports*, vol. 6, no. 1, pp. 1910-1921, doi: 10.1016/j.egy.2020.07.019.
- [28] A. A. Z. Diab, "MPPT of PV System Under Partial Shading Conditions Based on Hybrid Whale Optimization-Simulated Annealing Algorithm (WOSA)," *Modern Maximum Power Point Tracking Techniques for Photovoltaic Energy Systems*, pp. 355-378, 2020.
- [29] C. C. Ahmed, M. Cherkaoui and M. Mokhlis, "PSO-SMC Controller Based GMPPT Technique for Photovoltaic Panel Under Partial Shading Effect," *International Journal of Intelligent Engineering and Systems*, vol. 13, no. 2, pp. 1-10, 2020, doi: 10.22266/ijies2020.0430.30.
- [30] A. S. Saidi, C. B. Salah, A. Errachi, M. F. Azzeh, J. K. Bhutto and V. P. T. Ijyas, "A novel approach in stand-alone photovoltaic system using MPPT controllers & NNE," *Ain Shams Engineering Journal*, vol. 12, no. 2, pp. 1973-1984, 2021, doi: 10.1016/j.asej.2021.01.006.
- [31] S. Sumana, R. Dhanalakshmi and S. Dhamodharan, "Validation of photovoltaics powered UPQC using ANFIS controller in a standard microgrid test environment," *International Journal of Electrical and Computer Engineering*, vol. 12, no. 1, pp. 92-101, 2022, doi: 10.11591/ijece.v12i1.pp92-101.
- [32] H. Chaieb and A. Sakly, "Comparison between P&O and P.S.O methods based MPPT algorithm for photovoltaic systems," *16th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering*, 2015, pp. 694-699, doi: 10.1109/STA.2015.7505205.
- [33] P. S. Gavhane, S. Krishnamurthy, R. Dixit, J. P. Ram and N. Rajasekar, "EL-PSO based MPPT for solar PV under partial shaded condition," *Energy Procedia*, vol. 117, pp. 1047-1053, 2017, doi: 10.1016/j.egypro.2017.05.227.
- [34] K. Ishaque, Z. Salam, M. Amjad and S. Mekhilef, "An Improved Particle Swarm Optimization (PSO)-Based MPPT for PV With Reduced Steady-State Oscillation," *IEEE Transactions on Power Electronics*, vol. 27, no. 8, pp. 3627-3638, 2012, doi: 10.1109/TPEL.2012.2185713.
- [35] H. Renaudineau *et al.*, "A PSO-Based Global MPPT Technique for Distributed PV Power Generation," *IEEE Transactions on Industrial Electronics*, vol. 62, no. 2, pp. 1047-1058, 2015, doi: 10.1109/TIE.2014.2336600.
- [36] M. Sarvi, S. Ahmadi and S. Abdi, "A PSO-based maximum power point tracking for photovoltaic systems under environmental and partially shaded conditions," *Progress in Photovoltaics: Research and Applications*, vol. 23, no. 2, pp. 201-214, 2013, doi: 10.1002/pip.2416.
- [37] C. Schaeff and J. T. Stauth, "Multilevel Power Point Tracking for Partial Power Processing Photovoltaic Converters," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 2, no. 4, pp. 859-869, 2014, doi: 10.1109/JESTPE.2014.2332952.
- [38] K. L. Shenoy, C. G. Nayak, P. M. Rajashekar, "Effect of partial shading in grid connected solar PV system with FL controller," *International Journal of Power Electronics and Drive System*, vol. 12, no. 1, pp. 431-440, 2021, doi: 10.11591/ijpeds.v12.i1.pp431-440.
- [39] A. E. Ibrahim, N. M. Nor, I. B. M. Nawi, M. F. Romlie and K. N. M. Hasan, "Genetic algorithm to improve power output of photovoltaic system under partial shaded condition," *International Journal of Power Electronics and Drive System*, vol. 10, no. 4, pp. 2182-2189, 2019, doi: 10.11591/ijpeds.v10.i4.pp2182-2189.

## BIOGRAPHIES OF AUTHORS



**Dhamodharan Selvaraj**    currently working as R&D manager in the division of Electrical and Electronics at ViswaJothi Technologies Pvt LTD, Bangalore. His area of interest is power electronics, power system, plugin electric vehicles with renewable energy resource. He is pursuing part time PhD in Electric vehicle charging. He can be contacted at email: dhamu.winner@gmail.com.



**Dhanalakshmi Rangasamy**    currently working as professor in the department of Electrical and Electronics Engineering at Dayananda Sagar College of Engineering, Bangalore. Her area of interest is Power system, Power electronics and renewable energy sources. She has many publications in reputed journals. He can be contacted at email: dhanalaxmisk@gmail.com.