

Fault analysis in grid-connected solar photovoltaic systems based on multi-objective grey wolf optimisation

Vanam Satyanarayana, Vinoth Krishnamoorthy

Department of Electrical and Electronics Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai, India

Article Info

Article history:

Received Nov 3, 2022

Revised Apr 28, 2023

Accepted May 6, 2023

Keywords:

Artificial bee colony algorithm

Genetic algorithm

Maximum power point tracking

Multi objective grey wolf optimization

Particle swarm optimization

Photovoltaic model

Sag and swell

ABSTRACT

The renewable energy resources depend on environmental concerns. Photovoltaic (PV) systems are an interesting form of renewable energy resource. The two main problems associated with PV systems are non-uniformity of irradiation and temperature change. PV achieving maximum power point tracking are dependent on power electronics converters. Emissions are a key challenge for the future of conventional renewable energy resources, which play an important role in the generation system. It is crucial in applications and industry because the primary goal of optimization is to discover specific research. We offer using the population of search agents based on fitness, the multi-objective grey wolf optimizer, a more modern meta-heuristic based on the hunting habits and social structure of grey wolves, for optimizing adaptive controllers for failures in grid analysis and power system integration various faults in the grid cause several power quality issues. Harmonics, voltage sag and swell imbalances, and many power conditioning topologies. This was carried out using MATLAB/Simulink, and the results showed a superior and flexible performance in reducing voltage sag and voltage swell problems and imperfections at various loading situations.

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



Corresponding Author:

Vanam Satyanarayana

Department of Electrical and Electronics Engineering

Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology

Chennai, Tamil Nadu, India

Email: veltechsatya@mail.com

1. INTRODUCTION

Grid integrating photovoltaic (PV) systems because they concern various faults based on the normal operating conditions of the system [1]. PV is a reliable renewable energy source that provides numerous advantages. PV benefits include the reduction of operating costs. Uniform through these advantages, there may be some stability issues when utilizing PV [2]. As a result, operators should consider improving stability issues in order to improve the predictable improve the stability of grid-integrated PV systems [3]. The basic block diagram of a grid-connected solar PV system is shown in (Figure 1 in Appendix). The analysis of voltage sag, swell and analysis of total harmonics distortion various control method fault duration tine reducing this formulation can approximate the true pareto-optimal solutions of multi-objective problems effectively.

2. MODELING OF SOLAR PV CELL

The maximum power point tracking, the use of power electronics converter equipment, and load changes produce multiple power quality (PQ) concerns many types of controllers are available in power

electronics converters the standard equivalent circuit of the PV cell is shown in Figure 2. However, electrical parameter adjustment should be taken into account [4]. The problem considered by maximum power point tracking (MPPT) methods to find the voltage and current based on PV array delivers temperature and irradiance. In perturb and observe (P&O) method, the MPPT method based on the calculation of the PV output power and the power change by sampling both the PV array current and voltage [5].

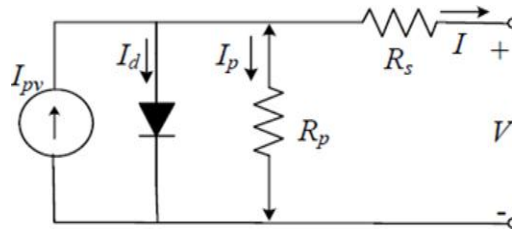


Figure 2. Equivalent circuit of solar PV cell

The tracker operates by periodically incrementing or decrementing the solar array voltage is based on environmental conditions [6]. Furthermore, various faults nonlinear load in inverter to grid cause several PQ issues. Harmonics, voltage sag and swell inequities, and many power conditioning topologies, such as transient voltage, filters, interruptive power supplies, and so on, have been employed in the past to improve the PQ of power networks [7]. PV cell characteristics based on solar irradiation shown in Figure 3.

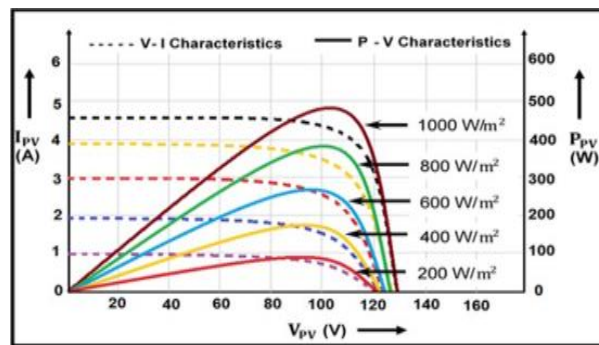


Figure 3. PV cell characteristics based on solar irradiation

Mathematical model PV cell: the photovoltaic cells are mathematically constructed using (1)-(5) of the PV cell is comparable to a single diode and different solar irradiance as shown in Figure 3. The following equations were utilized techniques of the PV cell. When we use KCL to analyses obtain [8].

$$I = I_{ph} - I_d - I_{rp} \tag{1}$$

As shown in Figure 2, the determined the equation, where I_{rp} is the current flowing through resistance R_p (3):

$$I_d = \left(\exp \left(\frac{V + I R_s}{n V_t N_s} \right) - 1 \right) * I \tag{2}$$

where N_s is the cells are connected in series shunt resistance is given by (3), and current in solution is given by (4).

$$I_{rp} = \left(\frac{V + I R_s}{R_p} \right) \tag{3}$$

$$I_{ph} = [\mu_{sc} (T_c - T_{ref}) + I_{sc}] \tag{4}$$

The reverse saturation current is an (5) generally MPPT is installed in between PV system to load. There is a different power output at the level of solar insolation and temperature.

$$I_o = I_{sc} / \left(\exp \left(\frac{q \cdot V_{oc}}{n \cdot k \cdot T_C \cdot v_t} \right) - 1 \right) \quad (5)$$

3. THE GREY WOLF OPTIMIZATION

This controller's reign is demonstrated using comparison optimization [9] different methods, such as genetic and artificial bee colonies and particle swarm optimization (PSO), a grey wolf optimization procedure with adaptive controller [10], the system response contributes to the preservation of system wolf optimization [11]. The powerful meta-heuristic are grey wolf optimizer (GWO). As a recently created optimization it may PSO, genetic algorithm (GA), and many others prevention of convergence [12].

The multi-model bench mark function, as shown in Figure 4. In general, the benchmark functions utilized are minimization functions and can be classified into four classes. Fixed-dimension multimodal and composite functions unimodal and multimodal. The GWO also produced very competitive results on the remaining composite benchmark functions. The social behavior of grey wolves suggests new optimization inspired by grey wolves and evaluates its abilities in tackling benchmark and real problems [13].

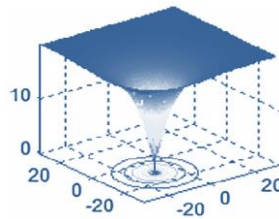


Figure 4. 2-D versions of multimodal benchmark function

3.1. Mathematical model GWO

The dominance of grey wolves in hunting prey is represented in (6) and (7) in the following subsection. Prayer by higher-ranked value wolves is modeled using hunting prey and encircling prey. Wolves attack their prey:

$$P_{loss} = \sum_{j=1}^{N_{br}} R_j (I_j^2) \quad (6)$$

$$f_1 = \text{Min} \sum_{j=1}^{N_t} P^t \text{ Loss} \quad (7)$$

the fittest solution can be described as the alpha-best solution, with beta and delta accordingly in the mathematical model of the GWO method. The rest of the potential solutions are regarded as Omega grey wolf optimization with hunting prey is represented in (8) and (9).

$$|\Delta V_2| = \sum_{i=1}^{N_d} |V_i - V_{base}| \quad (8)$$

$$f_2 = \text{Min} \sum_{t=1}^{N_t} |\Delta V_2^t| \quad (9)$$

3.2. Encircling prey

As previously stated, grey wolves encircle animals during the hunt in order to mathematically mimic encircling activity. The following equations are suggested, where t denotes the current iteration. The position vector of the prey is (X_p) , and \vec{A} and \vec{C} are coincident vectors. When \vec{X} represents the grey wolf's location vector, the vectors \vec{A} and \vec{C} are calculated as (10)-(13).

$$\vec{D} = |\vec{C} \cdot \vec{X}_p(t) - \vec{X}(t)| \quad (10)$$

$$\vec{X}(t+1) = \vec{X}(t) - \vec{A} \cdot \vec{D} \quad (11)$$

$$\vec{A} = 2\vec{a} \cdot \vec{r1} - \vec{a} \tag{12}$$

$$\vec{C} = 2 \cdot \vec{r2} \tag{13}$$

3.3. Hunting prey

The modeling hunting behavior average position moves the direction of goal [14]. The equation of hunting strategy is formulated as follows and $\vec{C}1$, $\vec{C}2$, and $\vec{C}3$ are three coefficient vector aids in adjust distance vector and it is computed using (3). Position of vector of other grey wolf (omega) is (14)-(17).

$$\vec{X}(t + 1) = \frac{\vec{X1} + \vec{X2} + \vec{X3}}{3} \tag{14}$$

$$\vec{X1} = |\vec{Xa} - \vec{A1} \cdot \vec{Da}| \tag{15}$$

$$\vec{X2} = |\vec{Xb} - \vec{A2} \cdot \vec{Db}| \tag{16}$$

$$\vec{X3} = |\vec{Xd} - \vec{A3} \cdot \vec{Dd}| \tag{17}$$

The population of search agents [15], [16] α , β , δ , ω of based on fitness where $\vec{D} \alpha$, $\vec{D} \beta$, and $\vec{D} \delta$ are the modified distance vector between the alpha, beta, and delta position to the other wolves (18)-(20).

$$\vec{Da} = |\vec{C1} \cdot \vec{Xa} - \vec{X}| \tag{18}$$

$$\vec{Db} = |\vec{C2} \cdot \vec{Xb} - \vec{X}| \tag{19}$$

$$\vec{Dd} = |\vec{C3} \cdot \vec{Xd} - \vec{X}| \tag{20}$$

3.4. Wolves attack the prey

As a result, the equation that describes how grey wolves behave (21):

$$A = 2 - 2 \left(\frac{t}{Max} \right) \tag{21}$$

where t is a string of numbers between 0 and max (the maximum amount of iterations), indicating the number of times current:

The pseudo code of the GWO

Prepare based on the population of fit grey wolves X_i ($i=1, 2, n$)

Prepare a , A , and C

Determine optimization search by using this equation.

$X\alpha$ =Alpha is the best element of the population is responsible for decision making

$X\beta$ =beta is ensuring that all subordinate should obey the order and feed back to alpha

$X\delta$ =wolves dominates omega and report to alpha and beta

While ($T < 1$ wolves attack the prey)

For each search wolves update the position by using

End for

Update a , A , and C

Fittenes of search wolves

Update $X\alpha$, $X\beta$, and $X\delta$

$T=T+1$

($T > 1$ wolves get away from the prey)

End while

Return $X\alpha$.

The complexity of this approach is comparable to that of other computational complexity of N objectives in-heuristic optimization method. A flow chart of multi objective grey wolf optimization as shown in Figure 5.

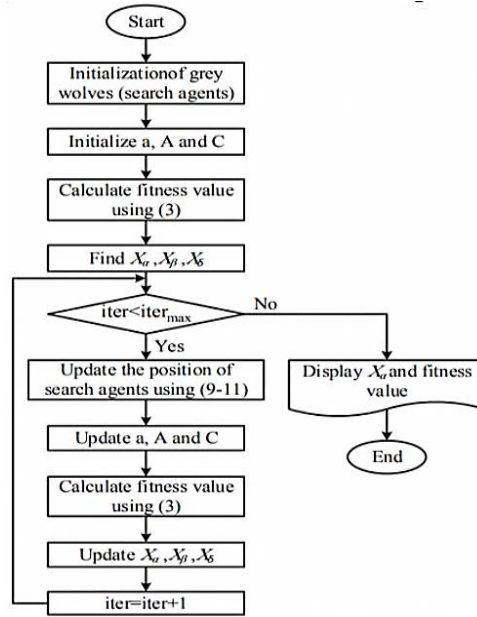


Figure 5. Flowcharts of multi-objective grey wolf optimizer (MOGWO)

4. RESULTS AND DISCUSSION

We have fault analysis of grid connected solar PV system comparison of various optimization algorithm based on power quality issues. Simulation results line-ground (LG) fault and line-line-line-ground (LLLG) faults in power delivery at nonlinear load [17], [18]. Figure 6 shows three-phase voltage sag LG faults based on GA-PSO proposed method in Figures 6(a)-6(c) presents various time durations. Three-phase voltage sag LG faults MOGWO methods. There phase Inverter to utility grid voltage faults at nonlinear load. Voltage sag LG faults comparison to simulation results.

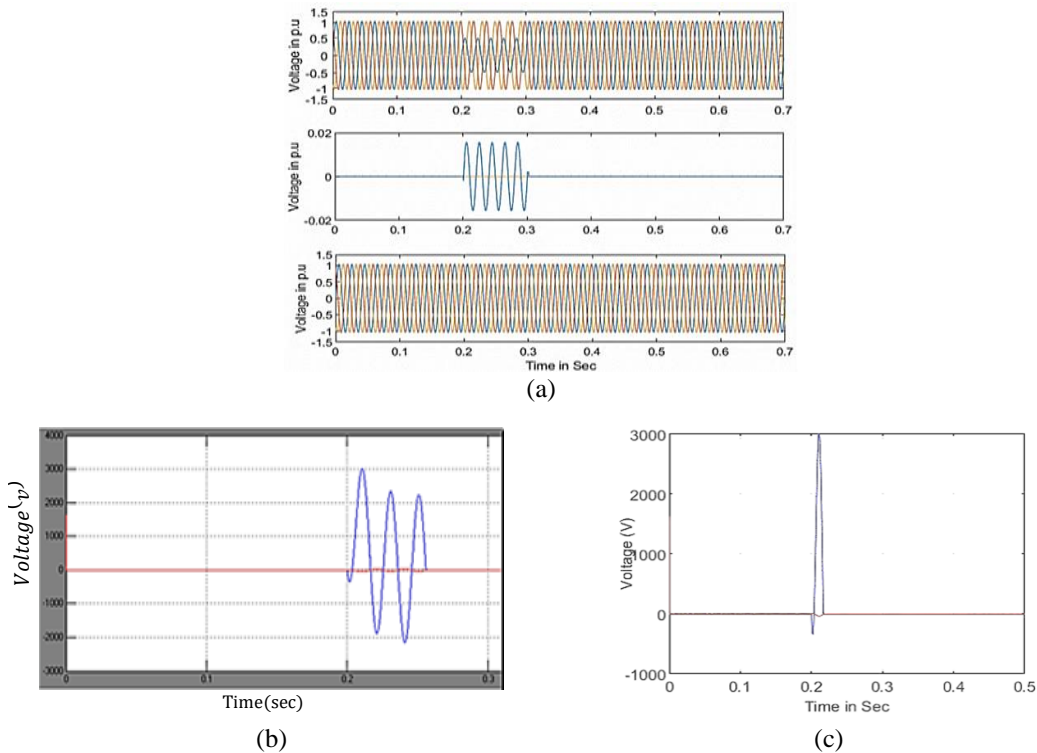


Figure 6. Three-phase voltages sag LG faults (a) GA-PSO, (b) artificial bee colony (ABC), and (c) MOGWO

The renewable energy source that provides numerous advantages PV benefits of no pollution and the reduction of operating costs there may be some stability issues [19]–[21]. Figure 7 represents the simulation results for a three-phase voltage swell LLLG faults duration time references, which includes three sub figures. The voltage swell LLLG faults response is displayed in Figure 7(a) while the response of GA-PSO algorithm is respectively given Figures 7(b) and 7(c).

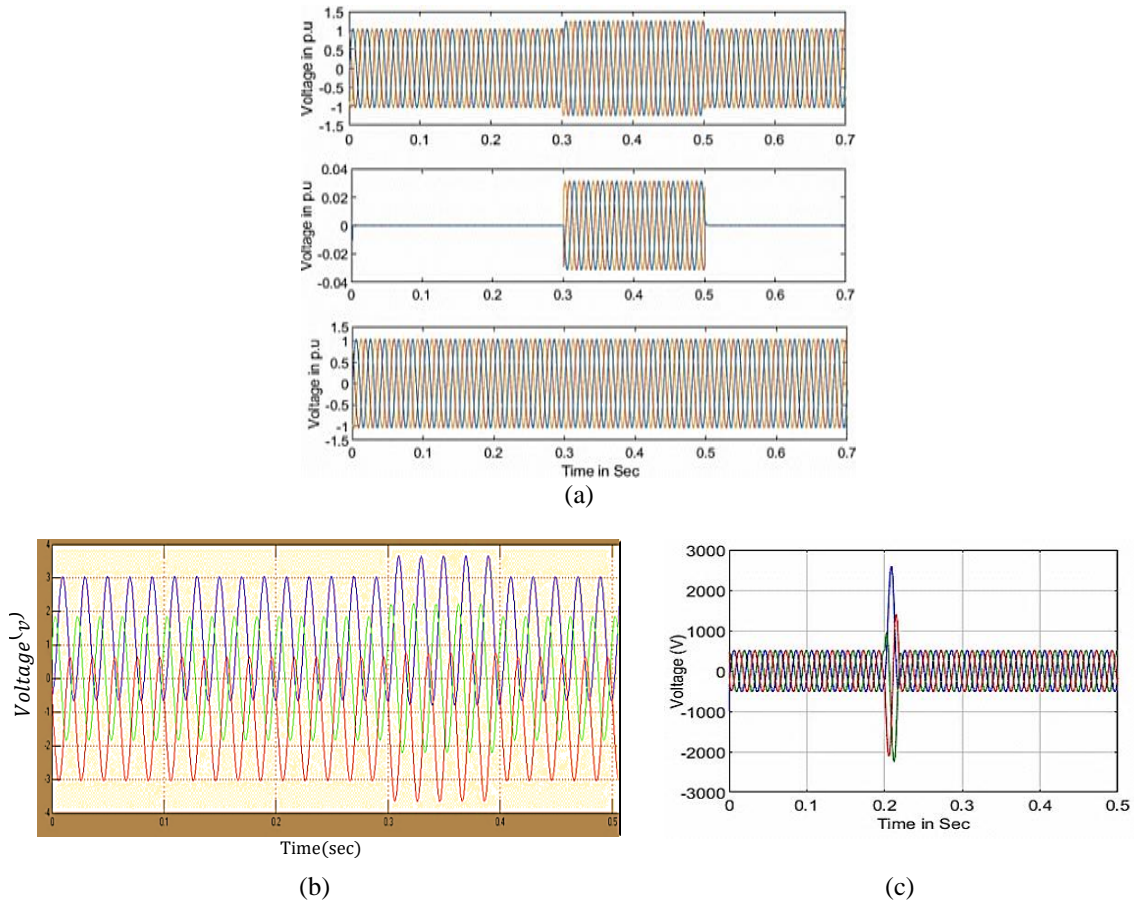


Figure 7. Three-phase voltages swell LLLG faults (a) GA-PSO, (b) ABC, and (c) MOGWO

Through results three-phase voltage swell LLLG faults MOGWO method conditions three-phase voltage swell LLLG faults comparison to simulation results [22]–[26]. Figure 8 shows and analysis of total harmonics distortion. When utilizing considers improving stability issues improve overall performance of the faults analysis the MOGWO is based on the proposed GWO, GA-PSO and ABC, MOGWO, reducing duration faults time and harmonics also increasing power factor. This research several simulation modeling and optimization control method for grid-connected solar PV systems as shown in Table 1.

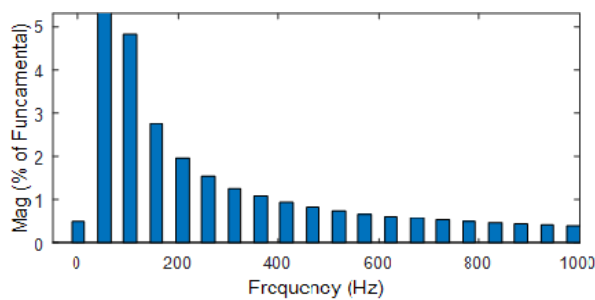


Figure 8. Analysis of Total harmonics distortion

Table 1. A comparison of optimization control method

Parameters	Description	GA&PSO	ABC	MOGWO
Voltage	Actual	415 v	415 v	415 v
	sag	430 v	450 v	450 v
	swell	340 v	390 v	390 v
Time	sag	0.1 sec	0.05sec	0.01 sec
	swell	0.2sec	0.1 sec	0.01sec
THD	THD	6.64 to 6.85%	3.51% to3.58%	2.20% to 0.78%
Power factor	Power factor	0.7	0.9	1 (unity)
Faults	Faults	LG, LLLG	LG, LLLG	LG, LLLG

5. CONCLUSION

The GWO method to provide a better understanding of how we can apply it to solve some optimization problems. We introduced this method it is quite effective, and simple enough to be easily understood. Model of grid operation made includes control voltage fluctuation, and total harmonics distortion. In addition, three main steps of hunting, searching for prey, encircling prey, and attacking prey, are implemented to perform optimization. Multi objective grey wolf optimization approach also adapted optimization. According to the simulation results, grid integrating renewable energy systems based on environmental conditions. Exclusion of harmonics and variation in voltage power losses and voltage fluctuations are reduced time duration of faults at nonlinear load. The grid interface system's overall harmonic distortions are 2.20% and 0.78.

APPENDIX

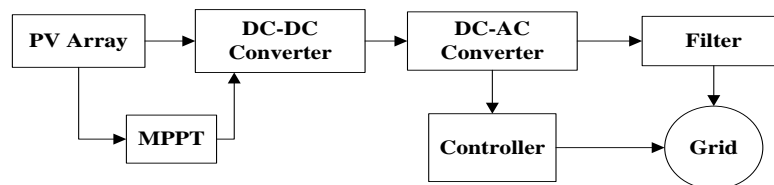


Figure 1. The block diagram of a grid-connected solar PV system





REFERENCES

- [1] N. Abas, S. Dilshad, A. Khalid, M. S. Saleem, and N. Khan, "Power quality improvement using dynamic voltage restorer," *IEEE Access*, vol. 8, pp. 164325–164339, 2020, doi: 10.1109/ACCESS.2020.3022477.
- [2] A. N. Alsammak and H. A. Mohammed, "Power quality improvement using fuzzy logic controller based unified power flow controller (UPFC)," *Indonesian Journal of Electrical Engineering and Computer Science (IJECS)*, vol. 21, no. 1, pp. 1–9, Jan. 2021, doi: 10.11591/ijeecs.v21.i1.pp1-9.
- [3] R. Martinez *et al.*, "Techniques to locate the origin of power quality disturbances in a power system: a review," *Sustainability (Switzerland)*, vol. 14, no. 12, p. 7428, Jun. 2022, doi: 10.3390/su14127428.
- [4] Y. M. Esmail, A. H. K. Alaboudy, M. S. Hassan, and G. M. Dousoky, "Mitigating power quality disturbances in smart grid using FACTS," *Indonesian Journal of Electrical Engineering and Computer Science (IJECS)*, vol. 22, no. 3, pp. 1223–1235, Jun. 2021, doi: 10.11591/ijeecs.v22.i3.pp1223-1235.
- [5] M. H. Qais, H. M. Hasanien, and S. Alghuwainem, "Transient search optimization for electrical parameters estimation of photovoltaic module based on datasheet values," *Energy Conversion and Management*, vol. 214, p. 112904, Jun. 2020, doi: 10.1016/j.enconman.2020.112904.
- [6] N. K. Rayaguru, S. Sekar, and S. S. Dash, "A fuzzy based custom power device for grid-PV system to improve power quality," *In 2020 International Conference on Computational Intelligence for Smart Power System and Sustainable Energy (CISPSSE)*, Jul. 2020, doi: 10.1109/CISPSSE49931.2020.9212299.
- [7] R. Alik and A. Jusoh, "An enhanced P&O checking algorithm MPPT for high tracking efficiency of partially shaded PV module," *Solar Energy*, vol. 163, pp. 570–580, Mar. 2018, doi: 10.1016/j.solener.2017.12.050.
- [8] T. Eswaran and V. S. Kumar, "Particle swarm optimization (PSO)-based tuning technique for PI controller for management of a distributed static synchronous compensator (DSTATCOM) for improved dynamic response and power quality," *Journal of Applied Research and Technology*, vol. 15, no. 2, pp. 173–189, Apr. 2017, doi: 10.1016/j.jart.2017.01.011.
- [9] Y. He, H. S. H. Chung, C. T. Lai, X. Zhang, and W. Wu, "Active cancelation of equivalent grid impedance for improving stability and injected power quality of grid-connected inverter under variable grid condition," *IEEE Transactions on Power Electronics*, vol. 33, no. 11, pp. 9387–9398, Nov. 2018, doi: 10.1109/TPEL.2018.2793459.
- [10] A. Naderipour, A. A. M. Zin, M. H. B. Habibuddin, M. R. Miveh, and J. M. Guerrero, "An improved synchronous reference frame current control strategy for a photovoltaic grid-connected inverter under unbalanced and nonlinear load conditions," *PLoS ONE*, vol. 12, no. 2, p. e0164856, Feb. 2017, doi: 10.1371/journal.pone.0164856.
- [11] V. F. Pires, A. Cordeiro, D. Foito, and J. F. Silva, "Three-phase multilevel inverter for grid-connected distributed photovoltaic systems based in three three-phase two-level inverters," *Solar Energy*, vol. 174, pp. 1026–1034, Nov. 2018, doi: 10.1016/j.solener.2018.09.083.





- [12] M. Ehtesham, M. Ahmad, and S. Kirmani, "Analyzing performance of stand-alone and grid connected PV systems for different power factor loads," *International Journal of Electrical Engineering and Technology (IJEET)*, vol. 12, no. 8, pp. 94–105, 2021.
- [13] M. A. Sameh, M. A. Badr, M. I. Marei, and M. A. Attia, "Enhancing the performance of photovoltaic systems under partial shading conditions using cuttlefish algorithm," in *8th International Conference on Renewable Energy Research and Applications, ICRERA 2019*, Nov. 2019, pp. 874–885, doi: 10.1109/ICRERA47325.2019.8996562.
- [14] A. A. Alabdalbari and I. A. Abed, "New robot path planning optimization using hybrid GWO-PSO algorithm," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 11, no. 3, pp. 1289–1296, Jun. 2022, doi: 10.11591/eei.v11i3.3677.
- [15] B. S. Revathi and M. Prabhakar, "Non isolated high gain DC-DC converter topologies for PV applications – a comprehensive review," *Renewable and Sustainable Energy Reviews*, vol. 66, pp. 920–933, Dec. 2016, doi: 10.1016/j.rser.2016.08.057.
- [16] H. Li, D. Yang, W. Su, J. Lu, and X. Yu, "An overall distribution particle swarm optimization MPPT algorithm for photovoltaic system under partial shading," *IEEE Transactions on Industrial Electronics*, vol. 66, no. 1, pp. 265–275, Jan. 2019, doi: 10.1109/TIE.2018.2829668.
- [17] N. Mishra, S. K. Yadav, B. Singh, S. Padmanaban, and F. Blaabjerg, "Flying capacitor voltage balance and neutral point voltage regulation of PV array fed active neutral point clamped converter in real-time HIL," *IET Power Electronics*, vol. 13, no. 13, pp. 2816–2823, Oct. 2020, doi: 10.1049/tet-pel.2019.1144.
- [18] S. Mirjalili, S. M. Mirjalili, and A. Lewis, "Grey wolf optimizer," *Advances in Engineering Software*, vol. 69, pp. 46–61, Mar. 2014, doi: 10.1016/j.advengsoft.2013.12.007.
- [19] N. Hashim, Z. Salam, D. Johari, and N. F. N. Ismail, "DC-DC boost converter design for fast and accurate MPPT algorithms in stand-alone photovoltaic system," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 9, no. 3, pp. 1038–1050, Sep. 2018, doi: 10.11591/ijpeds.v9.i3.pp1038-1050.
- [20] N. Singh and S. B. Singh, "Hybrid algorithm of particle swarm optimization and grey wolf optimizer for improving convergence performance," *Journal of Applied Mathematics*, vol. 2017, pp. 1–15, 2017, doi: 10.1155/2017/2030489.
- [21] I. K. Ibraheem and F. H. Ajeil, "Path planning of an autonomous mobile robot using swarm based optimization techniques," *Al-Khwarizmi Engineering Journal*, vol. 12, no. 4, pp. 12–25, Dec. 2017, doi: 10.22153/kej.2016.08.002.
- [22] I. A. Abed, M. M. Ali, and A. A. A. Kadhim, "Using particle swarm optimization to solve test functions problems," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 10, no. 6, pp. 3422–3431, Dec. 2021, doi: 10.11591/eei.v10i6.3244.
- [23] A. K. Mishra, S. R. Das, P. K. Ray, R. K. Mallick, A. Mohanty, and D. K. Mishra, "PSO-GWO optimized fractional order PID based hybrid shunt active power filter for power quality improvements," *IEEE Access*, vol. 8, pp. 74497–74512, 2020, doi: 10.1109/ACCESS.2020.2988611.
- [24] O. Lukačević *et al.*, "Optimal CONOPT solver-based coordination of bi-directional converters and energy storage systems for regulation of active and reactive power injection in modern power networks," *Ain Shams Engineering Journal*, vol. 13, no. 6, p. 101803, Nov. 2022, doi: 10.1016/j.asej.2022.101803.
- [25] V. Dabra, K. K. Paliwal, P. Sharma, and N. Kumar, "Optimization of photovoltaic power system: a comparative study," *Protection and Control of Modern Power Systems*, vol. 2, no. 1, Feb. 2017, doi: 10.1186/s41601-017-0036-2.
- [26] J. Ou and M. Wang, "Path planning for omnidirectional wheeled mobile robot by improved ant colony optimization," in *Chinese Control Conference (CCC)*, Jul. 2019, vol. 2019-July, pp. 2668–2673, doi: 10.23919/ChiCC.2019.8866228.

BIOGRAPHIES OF AUTHORS



Vanam Satyanarayana     is a research scholar in Electrical and Electronics Engineering Department at Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology Chennai, India. He received his B.Tech. M.Tech. Degrees in Electrical and Electronics Engineering and Power Electronics from University of Jawaharlal Nehru Technology Hyderabad. He is presently working as Assistant Professor in the Department of Electrical and Electronics Engineering Vaagdevi College of engineering, Warangal. His research area of interest is power systems, renewable energy systems, and power electronics applications. He can be contacted at email: veltechsatya@gmail.com.



Vinoth Krishnamoorthy     received the B.E. Degree in Electrical and Electronics Engineering from M.I.E.T Engineering college, Bharthidasan University, Trichy, India in 2002 and Post graduation in Power Electronics and Drives in Sastra University, Thanjavur, India in 2006 and completed Ph.D. at Anna University 2021. Working as an Associate Professor in VelTech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai. His area of interests is power electronics and smart grid. He can be contacted at email: vinothkrishna03@gmail.com.