

Optimal Sizing and Siting of Distributed Generators by Hybrid Particle Swarm Optimization-Grey Wolf Optimization Algorithm

Mahendran M V

Tamilnadu Transmission corporation (A subsidiary of TNEB Limited)
Madurai, Tamil Nadu, India
mahendranmv3@gmail.com

Vijayan V

St' Joseph's College of Engineering Affiliated to Anna University
Chennai, Tamil Nadu, India

Abstract: In operation of the power system, minimization in loss of the power for Distributed System has implication in minimization of cost of operation. In this work, a new Hybrid Particle Swarm Optimization (PSO), and the Grey Wolf Optimization (GWO) technique, is examined in order to determine the optimal sizing, location, and quantity of Distributed Generators units in Distributed System. The aim of optimal positioning of the Distributed Generators issue is to reduce the loss of power in Distributed System because to experience the restraints like current limits, balance in power, Distributed Generators capacity limits, bus voltage limits, and Distributed Generators penetration limit. In order to solve the issue, the hybrid PSO-GWO algorithm is examined to concurrently discover the optimal sizing and siting of Distributed Generators units. Additionally, the optimal amount of Distributed Generators units can be attained through evaluating optimal consequences from various Distributed Generators in the issue. Finally, the developed approach is examined on the IEEE 33- bus, 69-bus, bus, and 118-bus Radial Distributed System (RDS). The consequence evaluations show that the developed approach can attain superior quality solutions than the conventional approaches for the represented scenarios for the test systems. Furthermore, the hybridization of the proposed method consents to accomplish the search procedure at superior speeds. Hence, the proposed technique is a capable technique in order to solve the issue of the optimal position of Distributed Generators units in Distributed System.

Keywords: Distributed Generators; Distribution System; Power Loss; Operating Cost; IEEE Bus System

Nomenclature

Abbreviations	Descriptions
PSO	Particle Swarm Optimization
GWO	Grey Wolf Optimization
DG	Distributed Generation
APL	Active Power Loss
GA	Genetic Algorithm
SA	Sensitivity Analysis
VM	Voltage Magnitude
OPF	Optimal Power Flow
RDS	Radial Distribution Systems
DN	Distribution Networks
WOA	Whale Optimization Algorithm
BESS	Battery Energy Storage System
ABC	Artificial Bee Colony
DS	Distribution Systems
IDSA	Improved Differential Search Algorithm
DE	Distributed Energy
SG	South Geopolitical
DG	Distribution Grid
ODGP	Optimal DG Placement

1. Introduction

The DG is a novel manner to convene a few of the electrical system load which is ahead impetus because of the numerous features. Amongst these could be revealed the minimization of losses in distribution and transmission lines, delaying savings in infrastructure, via reactive power injection the voltage is controlled and enhanced energy effectiveness by means of utilizing heat supplied through the generation. Nevertheless, there are a few points that require to be considered, for instance, minimum revenues from effectiveness costs, inducement to clean energy producers, logistics associated with the fuel supply and apparatus costs and continuation [6].

The extensive employ of DG is the result of the maximum effectiveness in its applications such as trigeneration; co-generation; flexibility in the choice of these applications and the lessening burden on transmission and distribution network [7]. The incorporation of DG influences the line losses; short circuit current; system stability voltage output; and reliability [20]. Consequently; before placing DG in the system these parameters are necessary to be examined [12]. The study's demeanor until now has shown that the non-optimal DG positioning can exceed the line losses that can surpass the line losses without DG [11]. If DG sizing is improved; it can minimize the line losses although promote an increase in size can consequence in a raise in losses [17] [18]. Furthermore; at a particular bus if the DG is positioned at that voltage is least; it can enhance the voltage although if it is positioned at a node whereas the voltage is already maximum; it can reason an infringement of allowable voltage restrictions. The suitable and optimal positioning of DG can be performed by exploiting intelligent techniques, analytical techniques; and numerical techniques [8].

At present, the issue of DG sizing and placement is of significance [13]. At non-optimal places, with non-optimal sizing, the installation of DG units can cause instability of the system, higher power losses, power quality issues, and escalating operational costs. For a given distribution network, optimization techniques are able to indicate the optimal solution. In the distribution power system, there are numerous techniques to assign and size the DG [19]. At each load bus, the power flow approach can be exploited to discover the optimum DG size by presumptuous each load bus is capable to have a DG unit [14] [15]. This technique is incompetent because of the obligation of a huge number of load flow calculations. One more technique to decide the positioning and sizing of DG is to exploit optimization techniques like the GA. GA is appropriate for multi-objective issues like DG allocation and presents acceptable solutions. Nevertheless, the calculation time for GA is high, with a tremendously lengthy convergence time. Also, analytical techniques can be exploited to assign the DG in meshed or radial systems. In this approach, separate expressions for radial and meshed network systems are required [9]. In addition, complex processes on the basis of the phasor current are exploited to resolve the position issue. Nevertheless, this approach only optimizes the position by taking into consideration of a fixed size of DG [16] [17]. For a similar reason, an amalgamation of the SA approach and other heuristic approaches are usually exploited. In these methods, the position of the DG is determined during SA and the sizing of the DG is determined during heuristic techniques [10]. The benefit of this approach is the minimization of the search space that ultimately augments the overall speed of optimization procedures.

The major objective of the work is to propose a hybrid PSO-GWO method to assure the attained near-optimal solutions for the issue. Also, to show enhancement of the method in estimating optimal DG sizing and siting, an approach on the basis of the obvious separation among sizing and siting is used for outcome evaluation. Since an evaluation of this separation approach, the factor of the loss sensitivity is initially exploited to discover a priority list of the possible positions whereas DG units have the ability to deploy and subsequently optimization technique is used to discover the optimal DG unit's size by means of a fixed count of DG units. In order to attain the optimal amount of DG units, proposed approach is examined for the issue with diverse quantities of DG units and the scenario by means of practicable solution equivalent to the minimum loss of power between the examined scenarios is represented as the optimal solution with the optimal quantity of DG units. The proposed approach is examined on the IEEE 33, 69, and 118-bus systems, and the consequence attained using the proposed approach are examined by evaluating those from the renowned optimization techniques.

2. Literature Review

In 2019, Jose Iriaa et al [1], presented a new optimization method to aid operators of DS planning future medium voltage DN described using significant diffusion of over-the-meter resources of DE. Moreover, the optimization method describes the optimal combine, position, and sizing of on-load tap charger transformers and energy storage devices by means of aims of explanatory network technical issues and reducing both costs of investment and operation. The proposed optimization method eases the non-convex clarification for the OPF to an inhibited second-order cone programming algorithm.

In 2019, Ling Ai Wong et al [2] developed a method for optimal sizing and placement of BESS to decrease the losses of power in the DG. To carry out the optimization, a meta-heuristic optimization approach called WOA was developed. Here, two different algorithms were developed to attain the optimal allotment of BESS. The primary algorithm was to attain optimal sizing and a location in two steps when the subsequent algorithm optimizes both sizings and location concurrently.

In 2019, Choton K. Das et al [3], developed a stratagem for optimal sizing and allocation of distributed ESSs via Q and P injection using the ESSs to a DN. The examination was performed in a renewable-penetrated (solar and wind) voltage IEEE-33 bus DN for two diverse cases such as exploiting non-uniform and uniform ESS sizes. Moreover, a hybrid metaheuristic optimization technique, for instance, a fitness-scaled chaotic ABC technique was used to optimize objective model parameters. Also, The ABC technique was used to validate the outcomes obtained from the fitness-scaled chaotic ABC technique.

In 2017, Satish Kumar Injeti [4], worked on the selection of optimal positions and sizes for Distributed Generators in RDS to reduce losses, reduce operating costs and enhance voltage profile. IDSA was exploited to resolve the optimization issue by means of Pareto optimal technique by taking into consideration of financial and technical advantages of DGs as objectives. The developed technique was examined on IEEE 69-bus and 33-bus RDS, and outcomes, were evaluated by means of conventional techniques. The proposed technique was able to produce a high-quality solution with fulfilled constraints.

In 2018, E.O. Diemuodeke et al [5], presented optimal mapping of hybrid energy systems that were on the basis of the PV and wind, using a backup diesel generator and a deliberation of energy storage, for households in 6 positions in the SS area of Nigeria. For each of the positions, a hybrid energy system was optimally selected on the basis of the TOPSIS multi-criteria decision-making approach and HOMER software computation which regarded as economic, technical, environmental, and socio-cultural criteria.

3. Objective Function

In this paper, the purpose of the ODGP issue is to reduce total real losses of power in DS fulfilling all system constraints and DG units. Scientifically, ODGP issue is devised as below:

In a distribution system, the objective model for reduction of the total APL is stated in eq. (1).

$$F = \min(P_1) \quad (1)$$

In eq. (1), P_1 indicates the total APL of the system stated in eq. (2).

$$P_1 = \frac{R_{ij}}{U_i U_j} \left(\sum_{i=1}^N \sum_{j=1}^N \cos(\Delta_i - \Delta_j) (L_i L_j + M_i M_j) \right) \quad (2)$$

In eq. (2), Δ_i and U_i indicates the angle and VM at bus i , correspondingly; R_{ij} indicates distribution line resistance linking buses i and j ; Δ_j and U_j indicates the angle and voltage magnitude at bus j , correspondingly; M_i and M_j indicates net reactive power at buses i and j , L_i and indicates net active power at buses i and j , correspondingly. In addition to the system, N indicates a number of buses.

The optimal sizing and the location of DG, which require to assure all of the constraints operational for instance the constraints of power balance, DG capacity limitation, branch currents, bus voltages, and DG penetration as below.

- Constraints of power balance: In the ODGP issue, the equations of power flow are stated as equality constraints. The formulation is devised in eq. (5) and (6).

$$L_{G,i} - L_{H,i} = |U_i| \sum_{j=1}^N |X_{ij}| |U_{ij}| \cos(\Delta_i - \Delta_j - \phi_{ij}) \quad (3)$$

$$M_{G,i} - M_{H,i} = |U_i| \sum_{j=1}^N |X_{ij}| |U_{ij}| \sin(\Delta_i - \Delta_j - \phi_{ij}) \quad (4)$$

In eq. (3) and (4), $M_{G,i}$ and $L_{G,i}$ indicates output of reactive power and output of active power for the generator at bus i ; $L_{H,i}$ indicates at bus i active power of load; $M_{H,i}$ indicates at bus i reactive power of load; and ϕ_{ij} and X_{ij} indicates angle and modulus of i^{th} element in system entry matrix associated with bus i and j , correspondingly.

- Constraints of bus voltage: At each bus, VM should be controlled in their upper and lower limits:

$$U_{i,\min} \leq U_i \leq U_{i,\max}; \quad i = 1, \dots, N \quad (5)$$

In eq. (5), $U_{i,\max}$ and $U_{i,\min}$ indicates at the bus i the maximum and minimum voltage levels, correspondingly.

- Constraints of branch current: In branches flow of current must not surpass their restrictions.

$$|B_{br,k}| \leq |B_{br,k}^{\max}|; k = 1, \dots, N_{br} \quad (6)$$

In eq. (6), $|B_{br,k}^{\max}|$ indicates the maximum allowable current flows during k^{th} branch, $|B_{br,k}|$ indicates the branch current of k^{th} system branch; and N_{br} indicates the quantity of system branches.

- Constraints of DG capacity: The exploited DG units ought to contain permissible size in their below range:

$$L_{DG,i}^{\min} \leq L_{DG,i} \leq L_{DG,i}^{\max}, i = 2, \dots, N \quad (7)$$

In eq. (7), $L_{DG,i}^{\max}$ and $L_{DG,i}^{\min}$ are, correspondingly, the maximum and the minimum output of power constraints in DG at bus i and $L_{DG,i}$ indicates at bus i output of DG power.

- Constraints of DG penetration: In the distribution system, this constraint is to restrict the total count of DG power output to be established indicated using eq. (8).

$$\sum_{i=1}^{N_D} L_{DG,i} \leq \sum_{j=1}^N L_{D,j} + \sum_{k=1}^{N_{br}} L_{l,k} \quad (8)$$

In eq. (8), $L_{D,j}$ indicates the active power demand at bus j ; $L_{DG,i}$ indicates the power output of the i^{th} DG; $L_{l,k}$ is the APL in k^{th} branch, and N_D indicates the count of DG units.

- Constraint of DG candidate position: Assigning few DG units in similar bus is unreasonable; therefore a constraint for site of exploited DG units shown in eq. (9).

$$Cl_{DG,i} \neq Cl_{DG,j}; i, j \in N \quad (9)$$

In eq. (9), $Cl_{DG,i}$ indicates the candidate locations for DG units.

4. Hybrid PSO-GWO Algorithm

For heuristic variants, numerous researchers have proposed some hybridization variants. In [14], two variations are hybridized in high or low level by means of transmits else co-evolutionary approaches as homogeneous else heterogeneous. Here, the hybridization of PSO [15] with the GWO [16] technique exploiting low-level co-evolutionary integrating hybrid is presented. As the functionalities of both variants are integrated the hybrid is low level. This method is considered as co-evolutionary here both variants do not use one after the other conversely, they run in parallel. It is integrated due to there are two different variations that are included in creating concluding the issues solutions. Based on this alteration, the capability of exploitation is improved in PSO by means of the capability of exploration in GWO to make both variations potency.

In the proposed method, in the search space first, three agents' location is updated using the proposed below equation.

As opposed to exploiting common mathematical equations, the exploitation and exploration of the grey wolf are controlled using inertia constant in the search space. The enhanced set of leading formulation as stated below:

$$\bar{d}_\alpha = |\bar{c}_1 \cdot \bar{y}_\alpha - w \cdot \bar{y}| \quad (10)$$

$$\bar{d}_\beta = |\bar{c}_2 \cdot \bar{y}_\beta - w \cdot \bar{y}| \quad (11)$$

$$\bar{d}_\delta = |\bar{c}_3 \cdot \bar{y}_\delta - w \cdot \bar{y}| \quad (12)$$

So as to hybridize PSO and GWO variants, the velocity and updated equation are developed as below:

$$u_i^{k+1} = w \cdot (u_i^k + c_1 r_1 (y_1 - y_i^k) + c_2 r_2 (y_2 - y_i^k) + c_3 r_3 (y_3 - y_i^k)) \quad (13)$$

$$y_i^{k+1} = y_i^k + u_i^{k+1} \quad (14)$$

5. Results and Discussions

5.1 Experimental Procedure

The proposed algorithm experimented on the IEEE 33-bus, 69-bus, and 118-bus RDS. The control parameters of the proposed algorithm like the maximum diffusion number, number of points, and the maximum count of iterations, are chosen by simulations of the test systems. For each system, the proposed algorithm was run 10 independent trials to attain an optimal solution. Here, both the optimal and fixed count of DG units in favour of the deployment of bus systems was contemplated. In support of scenario by means of a fixed number of DG units, outcomes attained using the proposed technique for systems were evaluated and verified to those from conventional algorithms such as GA, Teachers Learning Optimization Algorithm (TLBO), PSO and GWO algorithm.

5.2 Performance Analysis

Tables 1, 2 and 3 summarize the performance analysis of the performance of the proposed and conventional method for IEEE 33, 69, and 118 bus systems. The higher quantity of DG units and a large amount of complex issue likelihood of imprecise solutions in complex issues; and lack of sturdiness is obtained. As a result, conventional approaches might be tricky to manage with complex and large-scale optimization issues taking into consideration the incorporation of a huge count of DG units. Hence, it is able to finalize that the performance of proposed algorithm has equivalent or superior to the conventional methods in order to deal with the fixed count of DG unit's scenario for the examined IEEE 69, 33, and 118 bus systems.

Table 1. Analysis of the Proposed Algorithm for IEEE 33 Bus System

Method	Power loss (kW)	Total DG size	Loss reduction (%)
GA	83.43	1.23	65.34
TLBO	83.45	1.33	65.78
PSO	83.46	1.432	65.43
GWO	83.49	1.325	64.56
Proposed algorithm	83.32	1.232	65.99

Table 2. Analysis of the Proposed Algorithm for IEEE 33 Bus System

Method	Power loss (kW)	Total DG size	Loss reduction (%)
GA	73.12	2.43	71.12
TLBO	73.45	2.89	72.22
PSO	72.16	2.78	71.23
GWO	74.12	2.67	71.16
Proposed algorithm	73.02	2.14	72.76

Table 3. Analysis Of The Proposed Algorithm For IEEE 118 Bus System

Method	Power loss (kW)	Total DG size	Loss reduction (%)
GA	61.22	3.13	67.14
TLBO	61.12	3.24	69.73
PSO	63.76	3.24	69.23
GWO	63.89	3.67	66.16
Proposed algorithm	66.12	3.73	69.91

6. Conclusion

In this work, the hybrid PSO-GWO algorithm was effectively executed in order to solve the optimal positioning of the DGs issue in DS. In this work, the considered issue comprises the optimal size, position, and the amount of DG unit's determination in an RDS for reducing the total APL fulfilling the system and constraints of DG. To resolve the issue, each individual contemplated as a candidate solution comprises of two variables of size and a location for the execution of the proposed technique. As a result, both the optimal size and the location of DG units were concurrently obtained. As exposed from the experimented outcomes aforesaid, this method assures the capability to discover the improved near-optimal solution than the separation mechanism of DG sizing and siting. Moreover, the work presents a novel precise procedure for estimating the optimum DG number by means of the assist of the proposed hybrid PSO-GWO algorithm. The viability and efficiency of the proposed algorithm in order to solve the

ODGP issue were shown on the IEEE 33, 69, and 118-bus systems. Finally, attained outcomes were examined through evaluating to those from the conventional algorithms.

References

- [1] Jose Iria, Miguel Heleno, Goncalo Cardoso, "Optimal sizing and placement of energy storage systems and on-load tap changer transformers in distribution networks", *Applied Energy*, Volume 250, 15 September 2019, Pages 1147-1157.
- [2] Ling Ai Wong, Vigna K. Ramachandaramurthy, Sara L. Walker, Phil Taylor, Mohammad Javad Sanjari, "Optimal placement and sizing of battery energy storage system for losses reduction using whale optimization algorithm", *Journal of Energy Storage*, Volume 26, December 2019.
- [3] Choton K. Das, Octavian Bass, Thair S. Mahmoud, Ganesh Kothapalli, Navid Mousavi, "An optimal allocation and sizing strategy of distributed energy storage systems to improve performance of distribution networks", *Journal of Energy Storage*, Volume 26, December 2019.
- [4] Satish Kumar Injeti, "A Pareto optimal approach for allocation of distributed generators in radial distribution systems using improved differential search algorithm", *Journal of Electrical Systems and Information Technology*, Volume 5, Issue 3, December 2018, Pages 908-927.
- [5] E. O. Diemuodeke, A. Addo, C. O. C. Oko, Y. Mulugetta, M. M. Ojapah, "Optimal mapping of hybrid renewable energy systems for locations using multi-criteria decision-making algorithm" *Renewable Energy*, Volume 134, April 2019, Pages 461-477.
- [6] F.J. De Sisternes, J.D. Jenkins, A. Botterud, "The value of energy storage in decarbonizing the electricity sector", *Appl. Energy*, Volume 175, page no: 368–379, (2016).
- [7] L.A. Wong, V.K. Ramachandaramurthy, P. Taylor, J. Ekanayake, S.L. Walker, S. Padmanaban, "Review on the optimal placement, sizing and control of an energy storage system in the distribution network", *J. Energy Storage*, Volume 21, page no: 489–504, 2019.
- [8] L.A. Wong, H. Shareef, A. Mohamed, A.A. Ibrahim, "Optimal battery sizing in photovoltaic based distributed generation using enhanced opposition-based firefly algorithm for voltage rise mitigation", *Sci. World J.* page no: 1–11, 2014.
- [9] A. Oudalov, D. Chartouni, C. Ohler, "Optimizing a battery energy storage system for primary frequency control", *IEEE Trans. Power Syst.* Volume 22, page no: 1259–1266, 2007.
- [10] Y. Yang, H. Li, A. Aichhorn, J. Zheng, M. Greenleaf, "Sizing strategy of distributed battery storage system with high penetration of photovoltaic for voltage regulation and peak load shaving", *IEEE Trans. Smart Grid* 5 page no: 982–991, 2014.
- [11] K.P. Kumar, B. Saravanan, "Day ahead scheduling of generation and storage in a microgrid considering demand side management", *J. Energy Storage*, volume no 21, page no 78–86, 2019.
- [12] N. Mousavi, G. Kothapalli, D. Habibi, M. Khiadani, C.K. Das, "An improved mathematical model for a pumped hydro storage system considering electrical, mechanical, and hydraulic losses", *Appl. Energy* volume: 247, page no: 228–236, 2019.
- [13] S.M. Hossain, C.K. Das, M.S. Hossain, S. Jarin, "Electricity from wasted energy of the moving vehicle using speed breaker", *J. Teknol. (Sci. Eng.)* volume 73 (1), page no 129–134, 2015.
- [14] Manoela Kohler, Marley M. B. R. Vellasco, Ricardo Tanscheit, "PSO+: A new particle swarm optimization algorithm for constrained problems", *Applied Soft Computing*, Volume 85, December 2019.
- [15] Di Miao, Wei Chen, Wei Zhao, "Tekle Demsas," Parameter estimation of PEM fuel cells employing the hybrid grey wolf optimization method", *Energy*, Volume 193, 15 February 2020.
- [16] E.-G. Talbi, "A taxonomy of hybrid metaheuristics," *Journal of Heuristics*, Volume. 8, issue. 5, page no. 541–564, 2002.
- [17] C.K. Das, S.M. Hossain, M.S. Hossain, "Introducing speed breaker as a power generation unit for minor needs, International Conference on Informatics", *Electronics Vision (ICIEV)*, IEEE, pp. 1–6, 2013.
- [18] J. Song, W. Yang, Y. Higano, X. Wang, "Introducing renewable energy and industrial restructuring to reduce GHG emission: application of a dynamic simulation model", *Energy Convers. Manag.* volume 96, page no 625–636, 2015.
- [19] P. Mazumder, M.H. Jamil, C.K. Das, M.A. Matin, "Hybrid energy optimization: an ultimate solution to the power crisis of St. Martin Island, Bangladesh", *9th International Forum on Strategic Technology (IFOST)*, page no 363–368, 2014.
- [20] P. Ariyaratna, K.M. Muttaqi, D. Sutanto, "A novel control strategy to mitigate slow and fast fluctuations of the voltage profile at common coupling point of rooftop solar PV unit with an integrated hybrid energy storage system", *J. Energy Storage*, volume 20, page no: 409–417, 2018.