International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Enhancing Distribution Network Efficiency and Symmetry via Optimal Sizing and Location of Photovoltaic DG Using PSO

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Submitted:11/03/2024 **Revised**: 26/04/2024 **Accepted**: 03/05/2024

Abstract: With the increasing integration of Distributed Generators (DGs) into distribution networks, their effectiveness in reducing power losses, stabilizing voltage levels, and improving power supply reliability is being widely acknowledged. This paper employs a Particle Swarm Optimization (PSO) algorithm, specifically adapted to handle random constraints, for the optimal sizing and placement of photovoltaic DG (PVDG) units to minimize phase asymmetries within the grid. The proposed approach is designed to enhance system performance by reducing losses, maximizing cost-effectiveness, and supporting voltage symmetry. The model's performance is validated on an IEEE 33-bus radial distribution network using MATLAB simulations, both with and without PVDG, showing encouraging results. The PSO-based PVDG model outperforms other methods, including the Teaching-Learning Artificial Bee Colony (TLABC) algorithm, by achieving active power loss reductions of 17.60%. Additionally, it reduces reactive power losses by 23.16% compared to TLABC and provides cost savings of 15.21% over TLABC. Significantly, it improves the voltage profile of the distribution system by 3.48%.

Keywords: *Distributed generators (DG), Enhancement of voltage profiles, Economic benefits, Reduction of power losses, Particle Swarm Optimization (PSO) algorithm, photovoltaic distributed generators (PVDG).*

1. Introduction

The need for electricity is rising because of the increase in world population and the growing reliance on electrical appliances in daily life. Addressing this demand necessitates the generation of additional electrical power. However, it's imperative that this power generation comes from sources that are sustainable and do not contribute to global warming. Consequently, renewables such as PV, biomass, wind turbines, and microturbines are favoured choices for electricity generation. Solar power-based distributed generators (DGs) have seen a notable increase in adoption within this context. The incorporation of DGs into power distribution networks is increasing because of its advantages in technology, finances, and the environment. DGs, operating on a smaller scale (ranging from kW to MW), are typically implanted within these networks. Their presence aids in enhancing system efficiency by reducing losses, improving voltage profiles and reliability [1,2].

Biogeography-based optimization algorithm to integrate multiple PVDGs into distribution network. Integration of PVDGs into radial distribution systems (RDS) promises a host of benefits, including reduced power losses, better voltage profiles, and improved voltage stability [3]. Numerous optimization algorithms such as, TLABC and PSO have been explored for defining the size and placement of DG within RDS. These algorithms leverage evolutionary principles and learning mechanisms to achieve superior results in terms of robustness and efficiency. Furthermore, simulation studies have been conducted on actual PV systems to evaluate their performance and energy production. These studies validate the feasibility and efficacy of PVDGs in contributing to the grid. However, improper sizing and placement of DG can adversely affect the technical balance of existing systems [4,5,6]. Hence, the development of effective techniques for optimal sizing and placement of DGs is essential. In this context, PSO algorithm emerges as a promising approach for optimizing the placement and size of DGs. Unlike traditional methods, PSO requires minimal information about the problem and is capable of handling various types of optimization problems. Although PSO exhibits advantages such as faster convergence and ease of implementation, it still presents opportunities for further improvement.

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To summarize, the contributions of this paper include the incorporation of photovoltaic PVDG into the distribution system. PSO algorithm is used for optimal location and sizing problem and employment of the FBSM load flow approach for calculating losses and voltages, injection of PVDG at optimal locations to minimize losses and improve voltage profiles, demonstration of effectiveness on an IEEE 33 RDS, and comparison of results with existing algorithms. This paper offers an extensive overview of the research, covers the problem formulation, proposed optimization technique, simulation results, and concluding remarks [7,8].

2. Methodology

Fig 1. illustrates the solar-based Distributed Generators (DGs) placed optimally within the radial distribution system. The control system utilizes PSO to ascertain the optimal placement and sizing of DG. It also computes key metrics such as power losses, voltage profiles and cost savings within the distribution network. The methodology develops a model with PSO algorithm in MATLAB Primarily, an analysis of the current system is conducted to evaluate numerous economic and technical factors. Subsequently, the PSO is employed to identify the optimum size and placement of the Photovoltaic Distributed Generation (PVDG). Once these optimal parameters are determined within the radial distribution system, an in-depth comparison among different methodologies is conducted [9,10].

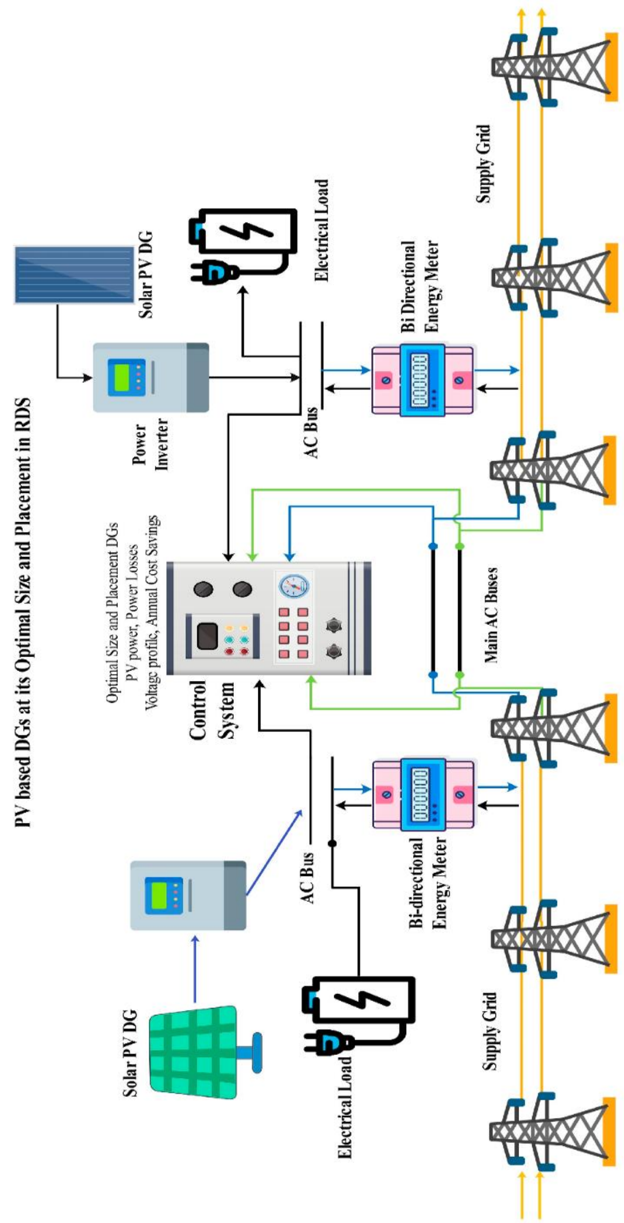

Fig 1. IEEE 33 Bus Distribution network using PVDG.

3. Problem formulation

This study aims to optimize several key objectives including reducing power losses, enhancing voltage profiles, and achieving cost savings within the radial distribution network. Constraints such as min. and max. voltage magnitudes, as well as power balance, are incorporated to confirm the anticipated outcomes of the optimization issue [11,12].

3.1. objective function

According to literature data approximately 13% of electrical power is lost within distribution systems out of the total power generated. The primary aim in determining the optimal location and sizing of PVDG within a distribution system is to maximize benefits by enhancing system efficiency, mainly through reductions in losses, enhancements in voltage profiles. The calculation of losses and voltages has been facilitated by the employment of BFSM. The objectives of minimizing power losses are expressed in below equations Eq. (1) and Eq. (2) [13].

$$\text{Min.}\, Q_L = \sum_{i=1}^{N} Q_{loss} = \sum_{i=1}^{N} {I^2}_{br,i} * X_I \text{ for } i = 1,2..N \quad (1)$$

$$\text{Min.}\, P_L = \sum_{i=1}^{N} P_{loss} = \sum_{i=1}^{N} {I^2}_{br,i} * R_I \text{ for } i = 1,2..N \quad (2)$$

Here, $I_{br,i}$ - ith branch Current and

X_i - ith branch reactance

$I_{br,i}$- ith branch Current and

R_i- ith branch resistance

Issue of voltage profile within the distribution system is closely linked with power quality. Historically, this aspect has been deemed less critical from a utility perspective compared to power losses. However, with the increasing incorporation of intermittent renewable DG into distribution systems, there is a growing attention in the voltage patterns within the distribution network. Variations in load and generation requirements can lead to discrepancies in voltage levels across different nodes.

$$\Delta V = 0.95 \leq V \leq 1.05 \text{ p.u} \quad (3)$$

$$V_{Profile} = \sum_{i=1}^{n_i} (V_i - V_{rated}) \quad i = 1,2..n \quad (4)$$

Here, V_i- ith bus voltage and

ΔV = Change in voltage

3.2. constraints

Constraints are two categories, inequality limits and equality limits [14].

3.2.1. Equality constraints

$$P_{Grid}+P_{DG}=P_{loss}+P_{Load} \quad (5)$$

$$Q_{Grid}+Q_{DG}=Q_{loss}+Q_{Load} \quad (6)$$

Here, $Q_{Grid}+Q_{DG}$ and $P_{Grid}+P_{DG}$ are the total reactive and reactive power supplied respectively. Q_{loss} and P_{loss} are reactive and active power losses, Q_{Load} and P_{Load} are the reactive and active power loads, respectively.

3.2.2. Inequality Constraints

Current limits:

To maintain adequate current in all branches, the rating limits must not be exceeded.

$$|\mathbf{I_{ij}}| \leq |\mathbf{I_{ij}}|_{\mathbf{max}} \quad (7)$$

Voltage Limits:

To maintain stable voltage throughout the system, the total voltage values throughout every point in the distribution network must follow to defined constraints.

$$V_{min} \leq |V_i| \leq V_{max} \quad (8)$$

Thermal limits:

$$|\mathbf{S_{li}}| \leq |\mathbf{I_{li}}|_{\mathbf{max}} \quad (9)$$

3.3. DG model based on photovoltaic

PVDG modules harness sunlight to generate electrical power directly. The total power generated is contingent upon sunlight intensity. Power generated is DC, is consumed by the Load is AC. Converter is employed to convert DC to AC, ensuring compatibility with the AC utility distribution system [15]. PVDG output power capacity (Pcpv) is determined by Equation (10):

$$P_{cpv} \rightarrow f(A_{sp}, I_{solar}, \mu_{sp}) \quad (10)$$

Here, Asp-area of the solar panel; I_{solar} - solar radiation; μ_{sp}-solar cells efficiency in PVDG. Calculate P_{cpv}(ât) at a specific time using the equation.

$$P_{cpv}(\Delta t) = A_{sp} \text{ x } I_{solar} \text{ x } \mu_{sp}(\Delta t) \quad (11)$$

Thus, the power generated from solar photovoltaic panels is treated as originating from a non-dispatchable source. Moreover, this source can provide both active and reactive power, with its power factor being either stable or unity, contingent upon the usage of the converter. If a constant P.F is required, a converter is employed. The extreme power valuation of the DG is calculated using the following equation.

$$P_{max} = \frac{1}{m \rightarrow n} \sum_{m=1}^{n=24} P_{cpv}(\Delta t)_{mn} \quad (12)$$

4. PSO Algorithm

The PSO algorithm is a potent solution for optimization problems, this technique is favored for its robustness, ease of implementation, and versatility across various applications. the PSO algorithm operates by initializing a population (swarm) of particles within the search space. Separately particle possesses an individual momentum and velocity, which are adjusted based on the particle's historical performance and that of its neighbors. This adjustment directs particles towards the optimal solution within the search region [16,17]. The algorithm operates in a search space (N-dimensional), with velocities and particle positions updated using Equations following equations:

$$T_P^{k+1} = T_P^k + \gamma * V_P^{k+1} \quad (13)$$

$$V_P^{k+1} = \omega V_P^k + C_1 * rand_1 * (P_{best} - T_P^k) + C_2 * rand_2 * (g_{best} - T_P^k) \quad (14)$$

- T^k - present search point; T^{k+1} -altered search point
- V^k- present speed; V^{k+1} -changed speed.
- C_1, C_2 - weight coefficients
- $C_1 = C_2 = 2$;
- $rand_1$ and $rand_2$ - random numbers [0, 1];
- The inertial weight is $\omega = \omega_{max} - k(\omega_{max} - \omega_{min})/k_{max}$ and $\omega_{min} = 0.4$, $\omega_{max} = 0.9$
- There are K and k_{max} and maximum number of iterations respectively.

PSO algorithm flowchart, depicted in Fig 2. PSO algorithm to find the best place and size for distributed generation (DG). The approach allows the model to converge towards a best resolution. The process initiates by configuring input parameters and acquiring bus and line data for the IEEE 33-bus system. At each iteration, BFSM is employed again to compute losses and voltages. The resulting model yields the best size and placement of DG, leading to reduced losses, cost savings, and enhanced voltage profiles. The fitness value of the DG confirms the improvement in the above-mentioned issues [18,19,22].

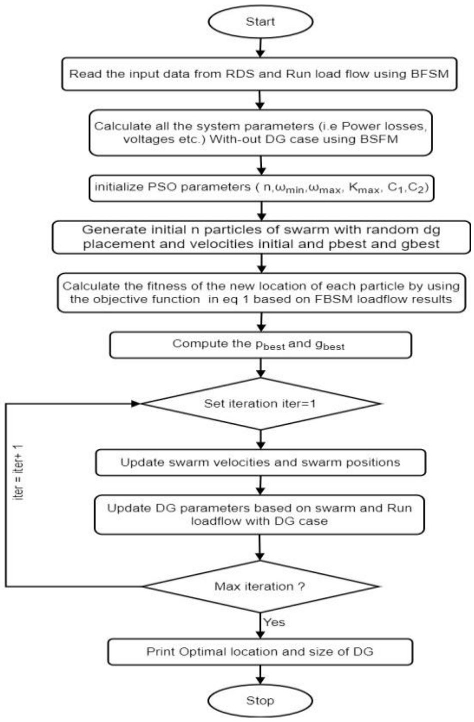

Fig 2. PSO algorithm Flowchart

5. Results and Analysis

Initially, an analysis was conducted on a base distribution network. Subsequently, compared the RDS with and without DG. The proposed methodology is implemented using MATLAB 2022a.

5.1. IEEE 33 Bus system without DG performance Analysis

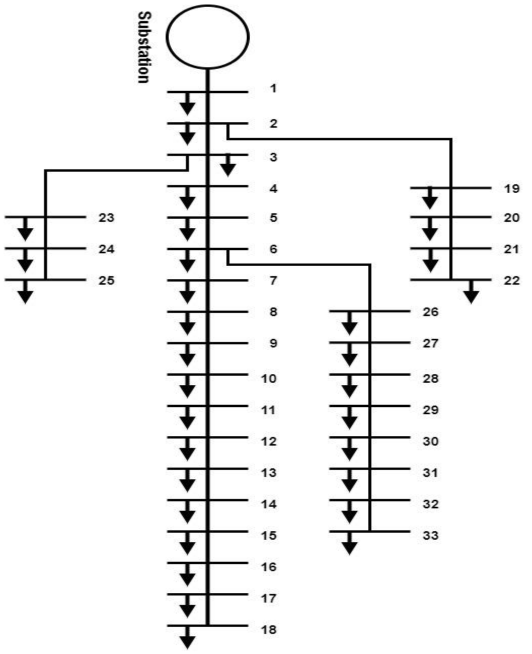

Fig 3. IEEE 33 Bus Radial distribution system

To validate the efficacy of proposed method, 33-bus RDS (IEEE) system is used, it is illustrated in Fig 3. contains 32 lines and 33 buses. Voltage limits were set uniformly at 5 for all buses, with a 12.66 kV voltage level across all buses and total loads of reactive power and active power is 2.3 MVAR and 3.715 MW respectively, Fig 4. depicts the real power distribution across the system, highlighting variations from bus to bus. Notably, the peak active power at bus number 24 and 25 each at 415 kW. Peak reactive power at bus number 3, 600 kVAR.

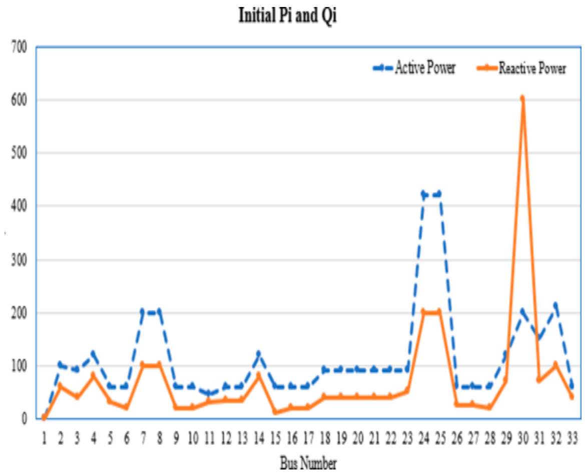

Fig 4. IEEE 33 bus system load data

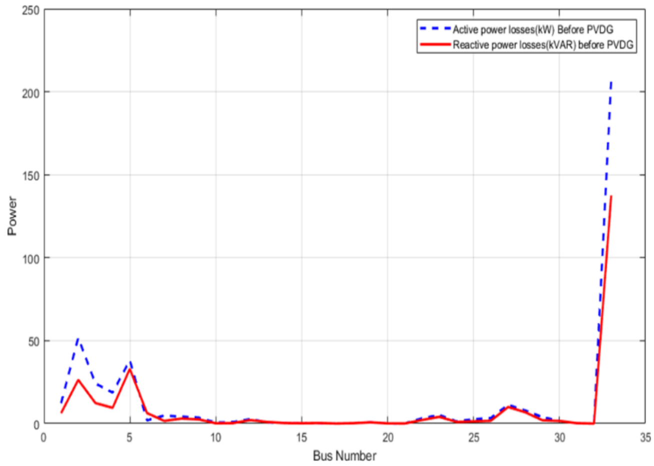

Fig 5. Reactive and Active power losses without DG

Fig 5. depicts the reactive active power loss without DG. Bus 33 is shown to have the extreme reactive and active power losses are 205.90 kW and 136.60 kVar.

5.2. IEEE (33bus) system with PVDG performance Analysis

This segment explores the impact of integrating PVDG into the radial distribution system, focusing on optimal placement and sizing considerations. All bus bars, except bus number 1, were considered as potential integration points for PVDG.

Fig 6. showcases the optimal PVDG within the IEEE (33bus) system. Upon implementation, it was observed that integrating a 2440 kW PVDG unit at node number 9 led to minimized electrical losses and enhanced voltage levels.

The optimized PVDG significantly reduces Active and reactive power loss from 205.90 kW to 91.70 kW, and from 136.60 kvar to 64.75 kvar, as shown in Fig 7.

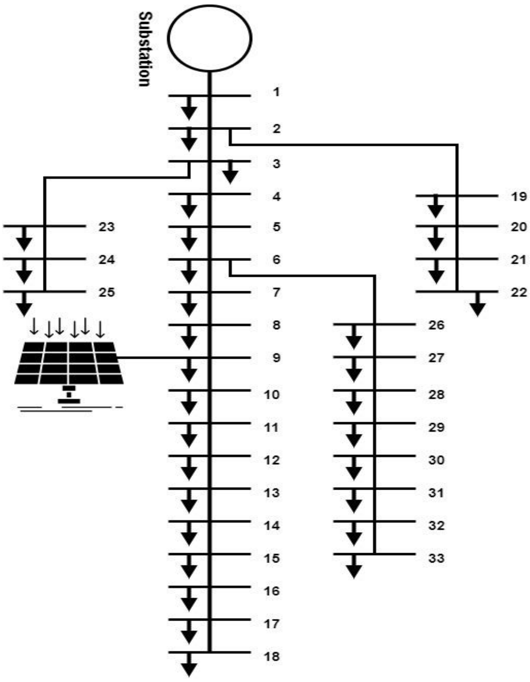

Fig 6. Radial distribution (IEEE-33 Bus) system with DG

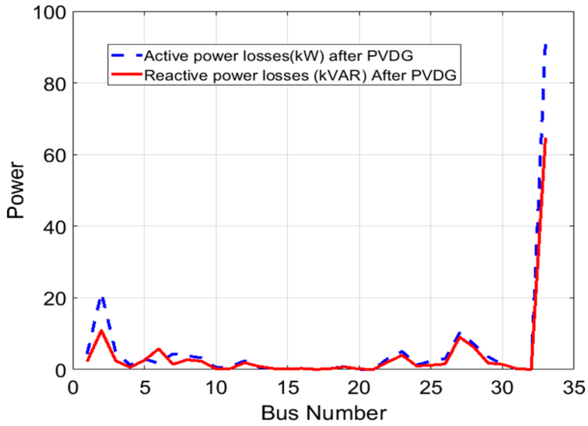

Fig 7. Reactive and active power losses with DG.

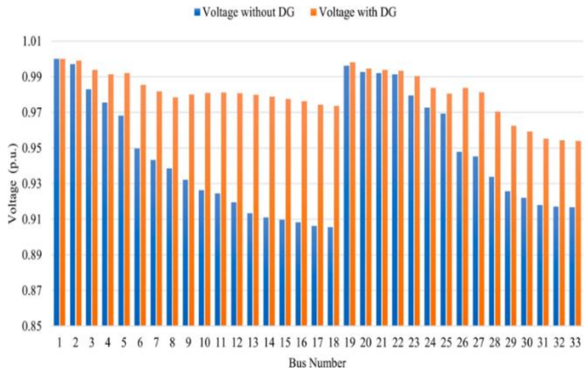

Fig 8. Voltage profiles without and with PVDG.

Fig 8. depicts result of the DG on the system voltage profile. You can compare the voltage profiles of systems with and without PVDG systems. A better voltage profile was noted upon integrating the PVDG into a 33-bus system. A voltage of 0.9116 per unit was observed at 18^{th} bus, which improved to 0.9575 p.u with PVDG, and overall system voltage profile is improved by 3.48%, resulting in improved performance.

Before integrating solar distributed generators, the total power loss of RDS reached, active power is 205.90 kW and reactive power is 136.60 kVAR. Table 1 shows the model outcomes, showing that the total reactive and active power losses are reduced by 52.60% and 55.47 % correspondingly, after incorporation of 2440 kW DG unit. Furthermore, the voltage level improved from 0.9116 pu. to 0.9575 pu.

Table 1. Key results obtained using the proposed model (IEEE system-33 Bus).

	Total Act. Power loss kW	**Total Rec. Power loss kVAR**	**Min. Volt. (pu.)**	**Max. Volt. (pu.)**	**Total DG (Size at Loc.)**
With out PV DG	205.90	136.60	0.9116 at bus 18	0.9970 at bus 2	-
With PV DG	91.70	64.75	0.9575 at bus 18	0.9985 at bus 2	2440 kW at bus 9

The energy cost savings results of the proposed system depict in Fig 9. The annual energy savings cost is INR 50,54,153, which is more annual cost savings compared to TLABC.

The optimal placement for the DG is at the 9th bus, with a capacity of 2440 kW. A notable reduction in active and reactive power loss, 55.47% and 52.60% is attained. The proposed method results lower power loss in distribution system compared to the TLABC method as mentioned in Table 2 [20,21].

Table 2. Illustrates a comparison between the proposed methodology and established algorithms.

	Khasanov, 2019 [10]	**Proposed methodology, 2024**
Algorithm	**TLABC**	**PSO**
Min Voltage improved at bus	0.94237 at Bus 18	0.9575 at Bus 18
Active power loss reduction	43.37%	55.66%
Reactive power loss reduction	42.89%	52.78%
Cost savings (INR)	43,86,901	50,54,153

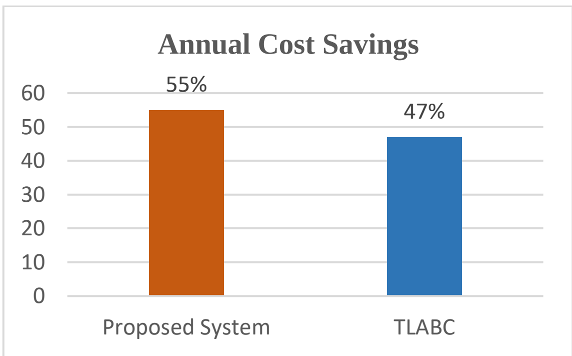

Fig 9. Comparison of annual energy loss reduction costs

6. Conclusion

The utilization of PSO is implemented to strategically location and regulate the magnitude of a PVDG with the objective of reducing energy losses and enhancing voltage stability. The performance evaluation of this method was conducted with the IEEE 33-bus system. The outcomes indicate a reduction in power losses, enhancement in the voltage profile, and optimization of cost benefits with the incorporation of PVDG units. Notably, the application of the PVDG PSO-based model demonstrates a notable decrease in power losses in comparison to the without-PVDG approach. This novel resolution exhibits superiority over alternative methodologies by accurately determining the optimal placement and scale of the PVDG, thereby establishing its indispensable utility. Moreover, the incorporation of PVDG into the 33-bus system results in substantial reductions in active and reactive power loss is 55.66% and 52.78% respectively, in comparison to the base case. In conclusion, PV-based DGs employing PSO algorithms represent a favourable option for mitigating electrical power loss, enhancing voltage profiles, and cost efficiencies within power distribution systems. Furthermore, the overall efficacy of the distribution network is enhanced, consequently reducing reliance on utility systems during periods of peak demand. The strategic installation of PVDG units is recommended in regions characterized by adequate sunlight intensity. Future investigations could delve into integrating PV and wind turbines within distribution systems, and incorporation of energy storage solutions. Furthermore, there is potential for exploring the development of wind-based DG models and conducting comparative analyses between solar and wind DG implementations

Author contributions

Ramavath Gnanendar: Conceptualization, Methodology, Software, Field study, Data curation, Writing-Original draft preparation, Software, Validation, Visualization, Investigation, Writing-Reviewing and Editing.

Dr. M. Sushama: Research supervisor.

References.

[1] Mohammedi, R.D.; Hellal, A.; Arif, S.; Mosbah, M. Optimal DG Placement and Sizing in Radial Distribution Systems Using NSGA-II for Power Loss Minimization and Voltage Stability Enhancement. Int. Rev. Electr. Eng. 2013, 8, 6.

[2] Barik, S.; Das, D. A novel Q-PQV bus pair method of biomass DGs placement in distribution networks to maintain the voltage of remotely located buses. Energy 2020, 194, 116880.

[3] Wang, Q.; Yao,W.; Fang, J.; Ai, X.;Wen, J.; Yang, X.; Xie, H.; Huang, X. Dynamic modeling and small signal stability analysis of distributed photovoltaic grid-connected system with large scale of panel level DC optimizers. Appl. Energy 2019, 259, 114132.

[4] Layadi, T.M.; Champenois, G.; Mostefai, M. Economic and ecological optimization of multi-source systems under the variability in the cost of fuel. Energy Convers. Manag. 2018, 177, 161–175.

[5] Vita, V. Development of a Decision-Making Algorithm for the Optimum Size and Placement of Distributed Generation Units in Distribution Networks. Energies 2017, 10, 1433.

[6] Duong, M.Q.; Pham, T.D.; Nguyen, T.T.; Doan, A.T.; Van Tran, H. Determination of Optimal Location and Sizing of Solar Photovoltaic Distribution Generation Units in Radial Distribution Systems. Energies 2019, 12, 174.

[7] Remha, S.; Chettih, S.; Arif, S. Optimal DG location and sizing for minimum active power loss in radial distribution system using firefly algorithm. Int. J. Energetica 2017, 4, 6–10.

[8] Matlokotsi, T.; Chowdhury, S. Optimal Placement and Sizing of Renewable Distributed Generation in Electricity Networks Considering Different Load Models. IEEE Conf. 2017, 1, 1–6.

[9] Prakash, D.; Lakshminarayana, C. Multiple DG placements in radial distribution system for multi objectives using Whale Optimization Algorithm. Alex. Eng. J. 2018, 57, 2797–2806.

[10] Kumar, M.; Nallagownden, P.; Elamvazuthi, I. Optimal Placement and Sizing of Renewable Distributed Generations and Capacitor Banks into Radial Distribution Systems. Energies 2017, 10, 811.

[11] Shaheen, A.M.; Elsayed, A.M.; Ginidi, A.R.; El-Sehiemy, R.A.; Elattar, E. A heap-based algorithm with deeper exploitative feature for optimal allocations of distributed generations with feeder reconfiguration in power distribution networks. Knowl. -Based Syst. 2022, 241, 108269.

[12] Jamil Mahfoud, R.; Sun, Y.; Faisal Alkayem, N.; Haes Alhelou, H.; Siano, P.; Shafie-Khah, M. A Novel Combined Evolutionary Algorithm for Optimal Planning of Distributed Generators in Radial Distribution Systems section. Appl. Sci. 2019, 9, 3394.

[13] Tamoor, M.; Bhatti, A.R.; Farhan, M.; Zaka, M.A.; ZakaUllah, P. Solar Energy Capacity Assessment and Performance Evaluation of Designed Grid-Connected Photovoltaic Systems. Appl. Sci. 2023, 37, 39.

[14] Urinboy, J.; Hasanov, M. Improvement Performance of Radial Distribution System by Optimal Placement of Photovoltaic Array. Int. J. Eng. Inf. Syst. 2021, 5, 157–159.

[15] Janamala, V. A new meta-heuristic pathfinder algorithm for solving optimal allocation of solar photovoltaic system inmulti-lateral distribution system for improving resilience. SN Appl. Sci. 2021, 3, 118.

[16] Ali, E.S.; Abd Elazim, S.M.; Abdelaziz, A.Y. Ant Lion optimization algorithm for optimal location and sizing of renewable distrib-uted generations. Renew Energy 2017, 101, 1311–1324.

[17] Eberhart, R.; Kennedy, J. A new optimizer using particle swarm theory. In Proceedings of the Sixth International Symposium on Micro Machine and Human Science, Nagoya, Japan, 4–6 October 1995; pp. 39–43.

[18] Bohre, A.K.; Agnihotri, G.; Dubey, M. Hybrid butterfly-based particle swarm optimization for optimization problems. In Proceedings of the First International Conference on Networks and Soft Computing (ICNSC), Guntur, India, 19–20 August 2014; pp. 172–177.

[19] Zeinalzadeh, A.; Mohammadi, Y.; Moradi, M.H. Optimal multi objective placement and sizing of multiple DGs and shunt capacitor banks simultaneously considering load uncertainty via MOPSO approach. Int. J. Electr. Power Energy Syst. 2015, 67,336–349.

[20] Haque, M. Efficient load flow method for distribution systems with radial or mesh configuration. IEE Proc. Gener. Transm. Distrib.1996, 143, 33–38.

[21] Salkuti, S.R.; Battu, N.R. An effective network reconfiguration approach of radial distribution system for loss minimization and voltage profile improvement. Bull. Electr. Eng. Informatics 2021, 10, 1819–1827.

[22] Eberhart, R.C.; Shi, Y. Comparing inertial weights and constriction factor in particle swarm optimization. In Proceedings of the International Congress on Evaluating Computation, La Jolla, CA, USA, 16–19 July 2000; pp. 84–89.