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RESEARCH ARTICLE - ENGINEERING (MISCELLANEOUS)

Optimizing Power System Performance: The Significance of Placement and Sizing of Battery Energy Storage Systems

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Abstract

The Battery Energy Storage System (BESS) has become a key tool for improving power system performance. However, the use of BESS in a distribution grid has several problems including deciding where to position it and how much capacity should be used to maximize its benefits. The purpose of this study is to optimize the siting and sizing of BESS for enhanced voltage profile and reduced power losses across the distribution system. To do this, two meta-heuristic optimization algorithms are suggested in this paper, Particle Swarm Optimization (PSO) and Dragonfly Algorithm (DA). Two cases have been presented. The first case includes 33 buses, while the second has 85 buses. The results of both cases are successfully effective in reducing system losses and improving the voltage profiles in power systems. It is observed that losses reduce by 45.59% compared to the base case for Case 1. The value in Case 2 decreases by 40.09% compared to the base case. The voltage profiles in Case 1 show an increase, with a minimum voltage of 0.95 PU, compared to the base case where the minimum voltage was at 0.904 PU. In Case 2, the minimum voltage becomes 0.95 PU instead of 0.874 PU in the base case.

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Keywords: BESS Placement; BESS Sizing; Voltage Profile Improvement; Loss Reduction; Battery Energy Storage System.

1. Introduction

In recent years, the usage of BESS has become more widespread within the electrical power industry. This is due to their capability to improve power system stability and flexibility, providing ride-through capabilities during generation loss, performing energy arbitrage, and mitigating the effects of intermittency caused by Renewable Energy Sources (RWs) [1, 2]. BESS is a new technology that plays an important role in facilitating adaptation to the environment. It is also expected to solve many problems associated with the smart grid [3-5]. Efficient planning for the size and placement of BESS holds paramount importance in expansive networks [6]. Furthermore, installing BESS on a larger scale than necessary may increase utility investment costs [6, 7]. Determining BESS optimal location and capacity is a complex problem categorized as a non-deterministic polynomial-time problem. Furthermore, there is no one-fit-all solution for the placement and sizing of BESS in a power grid due to different technologies as well as requirements. The complexity of this problem is explained by many aspects including overall load demand, generation capacity and cost relating to the network topology [8]. This study suggested determining the optimal placement and capacity of BESS in radial distribution networks to minimize power loss [9]. Under normal operating conditions, a power system usually maintains a stable voltage profile but if fault or disturbance occurs, it may become unstable leading to an uncontrolled gradual decline in voltage. Load dynamics play a key role in voltage stability. In recent years, voltage instability and collapse have occurred more frequently due to changing patterns of system loads. Voltage stability analysis studies how the power system responds to fluctuations in generator and load dynamics to maintain stable and reliable operation of the electric power system [10, 11]. The proposed method utilized Second-Order Cone Programming (SOCP) to achieve optimal power flow [12]. To optimize the performance of the electricity distribution network, it is important to determine the sizes and locations of the Energy Storage System (ESS). The study found that optimal placement of ESS reduces the need for massive distribution generator (DG) control and eliminates large control facilities. This article discusses the daily load of wind and solar energy on a power grid node. The focus is on identifying sites and determining the capacity of BESS to reduce the average daily loss in distribution networks connected to RWs and the load on the power grid node. A model was developed to accomplish this, and a modified simulated annealing Genetic Algorithm (GA) was used to address it [13]. Proposed in [14], is a solution to minimize electricity costs on the distribution system by finding the optimal placement for a BESS. The BESS placement is calculated to reduce costs during normal, off-peak, and peak hours throughout the day, taking into account varying electricity prices. The results indicate the optimal BESS placement constricted in reducing the electricity costs on the distribution system, both with and without photovoltaic systems. In [15], a radial power grid with a new approach was suggested to determine the optimal position and capacity of BESS through clustering and sensitivity analysis.

Nomenclature & Symbols			
OF	Objective Function	WPTS	Wind Power Time Series
PSO	Particle Swarm Optimization	ESS	Energy Storage System
DA	Dragonfly Algorithm	PU	Per Unit
BESS	Battery Energy Storage System	DFs	Dragonflies
DG	Distribution Generator	RWs	Renewable Energy Sources
P_L	Real Power Demand	Q_L	Reactive Power Demand
ANN	Artificial Neural Network	SOCP	Second-Order Cone Programming
GA	Genetic Algorithm	BA	Bat Algorithm
FA	Firefly Algorithm		

The findings revealed that the BESS units were installed consistently at critical buses, regardless of the number of clusters considered. An optimal method for allocating ESS based on long-term (WPTS) was suggested to assign the ESS. It is vital to consider the cycles of charging and discharging of the ESS [16]. The proposed dynamic simulation method based on time-domain analysis requires less complex math equations, which reduces the amount of computation required. Additionally, a method proposed in [17] to optimize the allocation of BESS in low voltage grids can be achieved using the Receding Horizon Control and Benders decomposition algorithm. The BESS allocation problem was divided into a master problem and sub-problems using this algorithm; the optimization problem was complex, and the solutions were improved, resulting in better performance. This approach enhanced the efficiency of the optimization process. Additionally, it was recommended to use an ANN in [18] for optimal siting and control of BESS in solar energy and wind power applications. Various works have utilized PSO as a technique in [19-21] to achieve the best power output and system performance; it was essential to identify the ideal size and position of the ESS. A PSO was adopted to optimize hybrid photovoltaic and wind systems to minimize power losses in a radial distribution network [22, 23]. Moreover, researchers have conducted studies to determine the most efficient allocation of BESS in the electricity system using the Firefly Algorithm (FA) [24]. The position of BESS in the distribution system is very important for increasing its advantages. Ill-timed distribution and BESS capacity can lead to a decrease or increase in losses in the distribution network. Losses are also influenced by how close BESS is to load centers. Therefore, an optimal location to install BESS within a residential distribution system has to be identified. These are buses where losses can be reduced drastically if the BESS were installed on them. Several algorithms have been suggested by researchers for the sizing and placement optimality of BESS [25, 26]. This study aimed to identify the optimal location for BESS and DG by computing a loss sensitivity factor. This factor considers the power flow through the branches and the losses at the buses. The results show a minimization of the voltage deviation and actual power loss in the distribution grid [27]. The objective is to determine the optimal location and size for BESS and minimize costs associated with voltage deviations, power losses, and peak demands in the distribution network. This will help to improve the overall performance of the distribution network by using GA and PSO [28], and the Bat Algorithm(BA) [29]. However, algorithms like GA and FA are known for their tendency to become stuck in local optimal positions and their slow convergence rate.

This paper discusses the use of two optimization algorithms, namely PSO and DA [30, 31], to optimize the size and location of BESS in a distribution network. The algorithms are used to explore and exploit potential solutions for determining the optimal placement and size of BESS to reduce total system losses and improve the voltage profile. The performance of both algorithms is compared and analyzed using MATPOWER. The study is conducted on two cases: a 33 Bus Case 1 and an 85 Bus Case 2. PSO and DA are employed to solve the optimization problem.

2. PSO and DA Structures

2.1. Particle swarm optimization PSO

PSO is a promising approach for solving real-valued optimization problems. The algorithm works as follows: each particle in the swarm is represented by its coordinates, $X_i = (X_{il} \ldots X_{in})$ and its corresponding flight speed, $V_i = (V_{il}, \ldots, V_{in})$ in the search space. Each particle randomly adjusts its acceleration to find a better position based on its current velocity, its own experience, and the experience it has gained from other particles. The velocity of the particle is changed based on the relative locations of its personal best and the best experience of other particles. It is then accelerated in the directions of these locations with the highest fitness, as determined by the following equations [32, 33].

The position of individual particles is updated as in (1).

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{1}$$

With the velocity calculated as in (2).

$$v_i^{k+1} = W \times V_i^k + c_1 \times r_{d1} \times \left(Pbest_i^k - X_i^k\right) + c_2 \times r_{d2} \times (Gbest_i^k - X_i^k) \tag{2}$$

V_i^k: Velocity of particle i at iteration k, k is the number of iterations, $Gbest_i^k$ is the best position of the group, c_1 and c_2 are Acceleration factors, X_i^k is the position of particle i at iteration k, $Pbest_i^k$ is the best position of a particle, r_{d1} and r_{d2} are two random numbers generated independently each falling between 0 and 1, i is Number of particles, W is inertia weight factor.

2.2. Dragonfly algorithm DA

Mirjalili in 2015 proposed the DA [30]. Dragonflies (DFs) exhibit peculiar behavior in nature, which has been studied through the DA. This algorithm primarily focuses on how DFs search for food or evade predators. The mathematical model of the DA comprises five behaviors that are observed in DFs.

Separation: DFs are captivating insects that have been studied extensively using mathematical models S_i of the i^{th} individual is given by (3).

$$S_i = -\sum_{K=1}^{N} X - X_k \tag{3}$$

Here, the position of current DFs is represented, represents the position of neighboring DFs, and N is the total number of neighboring DFs.

Alignment: It indicates the matching of the velocity of individuals with that of other individuals in their neighbourhood. This can be modelled as in (4).

$$A_i = \frac{\sum_{K=1}^{N} V_k}{N} \tag{4}$$

V_k is the velocity of the k^{th} neighbouring individuals, A_i represents the alignment of the i^{th} individual.

Cohesion: All DFs in the area will move towards the center of mass. This can be represented using (5).

$$C_i = \frac{\sum_{K=1}^{N} V_k}{N} - X \tag{5}$$

Food: DFs will move toward survival food. Their attraction to food can be modelled using the (6).

$$F_i = X_F - X \tag{6}$$

X_F: is the sitting of the food location.

Enemy: All DFs move away from enemies, which can be modelled as in (7) by moving away from an enemy located at a specific position X_E.

$$E_i = X_E + X \tag{7}$$

All five motions affect DFs swarm behaviour. To obtain a new position update with step function ΔX_{i+1} as in (8).

$$\Delta X_{i+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + w\Delta X_i \tag{8}$$

Separation weight (s), alignment weight (a), cohesion weight (c), food factor (f), enemy factor (e), inertia weight (w), and iteration counter (i).

The position vectors are calculated as in (9).

$$X_{i+1} = X_i + \Delta X_{i+1} \tag{9}$$

3. Methodology

The methodology includes the following:

Optimal BESS placement and sizing to reduce total system losses.

The BESS placement and sizing were optimized simultaneously to reduce total system losses and enhance voltage stability. The objective function (OF) as in (10) and is constrained by (11) and (12).

$$OF = \sum_{i}^{Nbranch} |I_i|^2 \times R_i \tag{10}$$

$$P_{BESS,min} \leq P_{BESS} \leq P_{BESS,max} \tag{11}$$

$$V_{min} \leq V_k \leq V_{max} \tag{12}$$

N_{branch}: Number of branches, V_k is the bus voltage at bus k, I_i is the current magnitude of the i branch, R_i is the resistance of the i branch, P_{BESS} is BESS power at bus k, $P_{BESS,min}$ is the minimum BESS power, V_{min} is the minimum voltage in the system equals 0.95 PU, and V_{max} is the maximum voltage in the system equals 1.05 PU, $P_{BESS,max}$ is the maximum BESS power.

Distribution Network Scenarios: This paper includes data on two cases, Case 1 includes a system with 33 buses, a total active load of 3.715 MW and a total reactive load of 2.3 MVAR. Bus and branch data for this case can be found in Tables A1 and A2, respectively in Appendix A, and the single line diagram is shown in Fig. 1. Case 2 involves a system with 85 buses, a total active load of 2.51428 MW and a total reactive load of 2.5650783 MVAR. Bus and branch data for this case can be found in Tables A3 and A4, respectively in Appendix A, and the single line diagram is shown in **Error! Reference source not found.**. The electricity distribution system was modeled, and load flow calculations were performed using the MATPOWER software in MATLAB (2022b). The analysis revealed that the total system losses were 0.211 MW for Case 1 without BESS and 0.2993 MW for Case 2 without BESS.

MATPOWER is a collection of MATLAB M-files designed to solve power flow and optimal power flow problems. The purpose of this program is to serve as a simulation tool for researchers and educators, with a focus on ease of use and flexibility for modification. MATPOWER is optimized to achieve optimal speed while maintaining a straightforward and modifiable code structure. This paper utilizes the Newton-Raphson method to solve power flow equations. The calculations are performed using MATPOWER 7.1, running on MATLAB (2022b).

A method for implementing PSO and DA can be used to reduce power losses and enhance voltage in power systems.

- Open MATPOWER in MATLAB, select the distribution grid of Case 1 or Case 2, and connect with PSO or DA.
- Set the number of population search agents and iterations to 100, and specify lower and upper bounds for buses and BESS sizing.
- Commence the power flow analysis by initiating the DA or PSO algorithms using the MATPOWER software.

- Evaluate the objective function.
- update the location and size of the search agents.
- repeat the steps until the maximum iteration is reached.
- Save the data, location, size, and voltage magnitude of each bus.

The flowcharts illustrate the procedures for optimizing BESS placement and sizing using PSO, as shown in Fig. 3, and DA, as shown in Fig. 4.

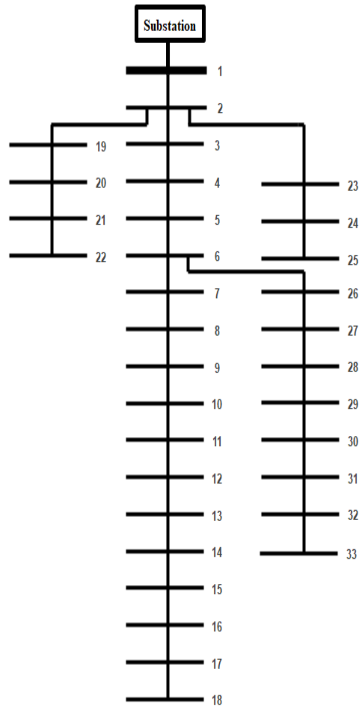

Fig. 1. The single-line diagram for Case 1

Fig. 2. The single-line diagrams for Case 2

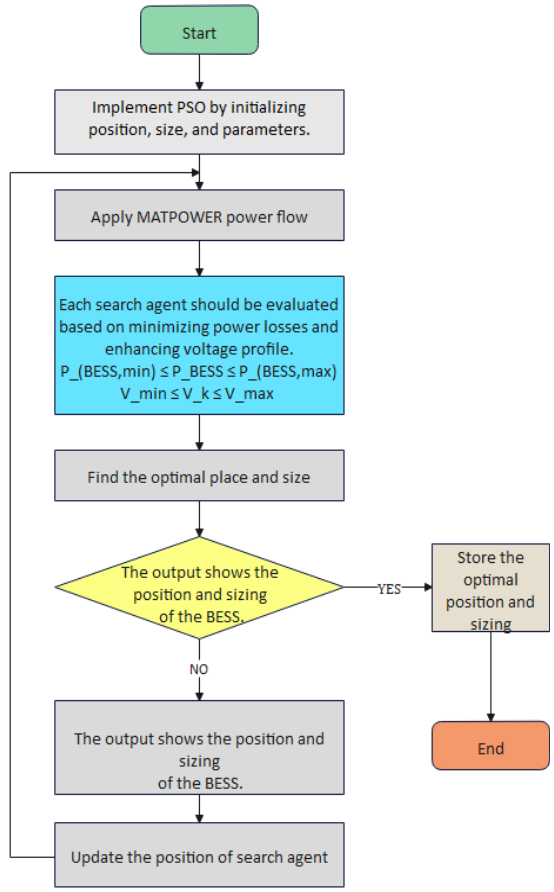

Fig. 3. Procedures for optimizing BESS placement and sizing using PSO

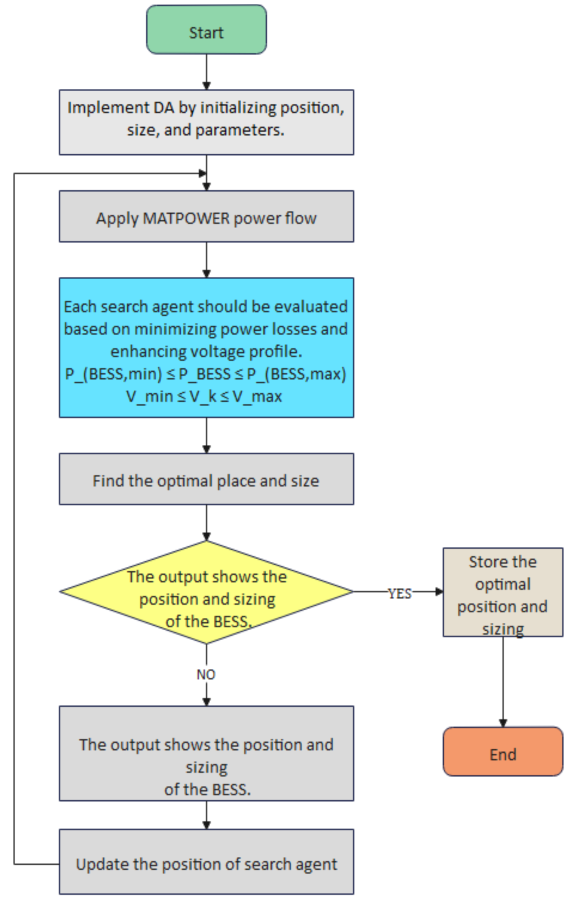

Fig. 4. The process of optimizing the placement and size of BESS using DA

4. Results and Discussion

In this section, the results of two algorithms are applied for optimal BESS placement and sizing for two different cases. DA algorithm was compared with PSO to find out the best locations and sizes of BESS that can reduce loss and improve voltage profile. All the optimization algorithms utilized in the study had the same problem parameters, including a population size and maximum number of iterations set to 100. The PSO parameters were also consistent, with cognitive and social coefficients values of 1.5, and an inertia weight value of 0.5. Additionally, the DA parameter had an inertia weight of 0.9. In Case 1, the first algorithm which is DA has found bus 7 to be the optimal location for placing the BESS. Optimal sizing is 2.887 MW and a total system loss of 0.1148 MW after putting in place the BESS at optimal locations compared to 0.211 MW in the base case. The second algorithm, which is the PSO method, has also identified bus 7 as the optimal location for placing the BESS in Case 1. After placing the BESS at the optimal locations, the optimal capacity is found to be 2.887 MW with a total real power loss in the system is 0.1148 MW. The original loss for Case 1 is 0.211 MW. Both algorithms resulted in a loss reduction of 45.59%. In Case 2, both DA and PSO identified that bus 26 is the optimal location for placing the BESS. The optimal sizing found was 2.5273 MW, resulting in a total system loss of 0.1793 MW. The original loss for Case 2 is 0.2993 MW. Both algorithms resulted in a loss reduction of 40.09%, as shown in Table 1. The percentage loss reduction for PSO and DA algorithms is compared with the base case, as shown in Figs. 5-8. In Case 1 (Fig. 5) of the distribution system, the voltage range was between 0.904 to 1 PU, and in Case 2, it was between 0.874 to 1 PU. Both cases had a wide range of voltage deviations. However, after using BESS through PSO and DA algorithms, the voltage profile improved significantly by reducing the loss and voltage deviation. Consequently, the voltage range for Case 1 increased to 0.95 to 1 PU, as shown in Fig. 7. The voltage range for Case 2 also improved, reducing the voltage deviation and resulting in a range of voltage from 0.95 to 1 PU, as shown in Fig. 8. Fig. 6, displays a comparison of the minimum voltage in the buses before and after integrating BESS using two algorithms. In Case 1, the minimum voltage in the system was 0.904 PU. However, in Case 2, the minimum voltage dropped further to 0.874 PU. But, after integrating BESS, the voltage range of both systems became 0.95 to 1 PU, which is considered safe and within the acceptable range.

Table 1. Loss results for Case1 and Case2

	Optimal Location of BESS		**Optimal size of BESS (MW)**		**Real power Loss (MW)**			
	DA	**PSO**	**DA**	**PSO**	**DA**	**PSO**	**Percentage reduction**	**Base case**
Case 1,33 Bus	7	7	2.887	2.887	0.1148	0.1148	45.59%	0.211
Case 2,85 Bus	26	26	2.5273	2.5273	0.1793	0.1793	40.09%	0.2993

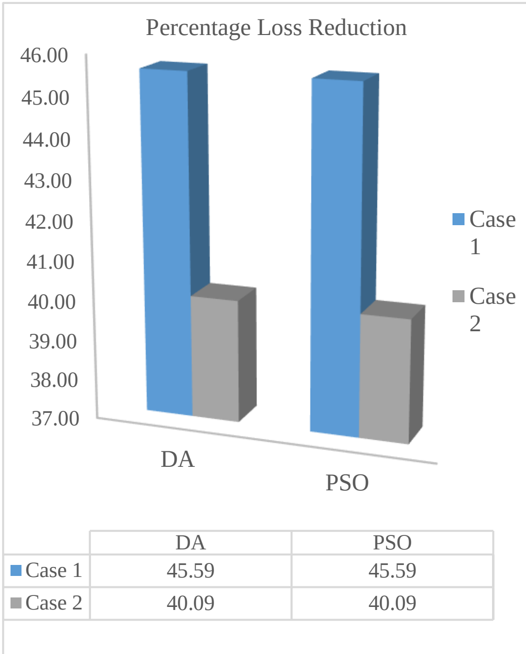

Fig. 5. Percentage Loss Reduction for PSO and DA algorithms

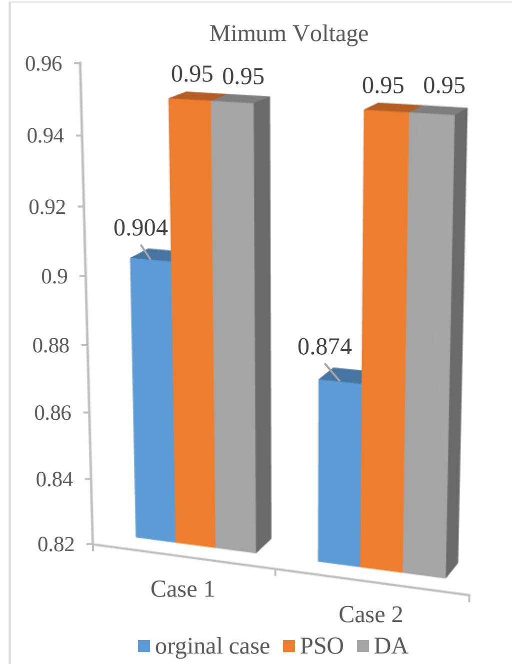

Fig. 6. Minimum voltage in the buses before and after integrating BESS

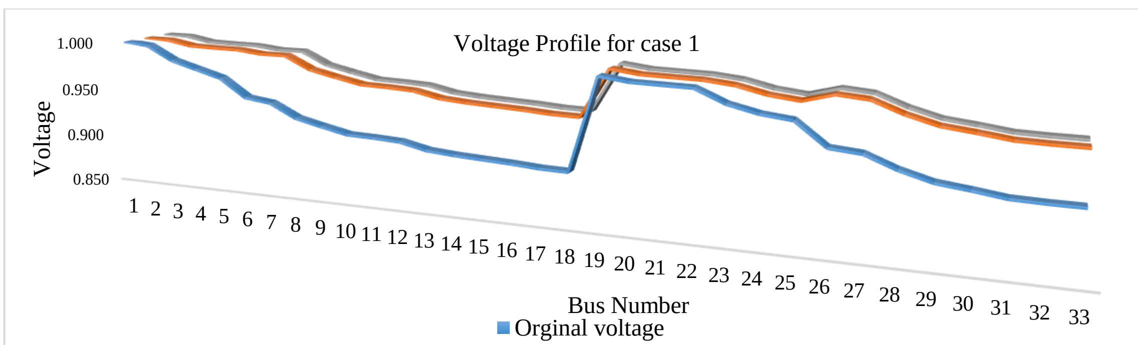

Fig. 7. Voltage values for all buses in the base case and after adding BESS using two algorithms

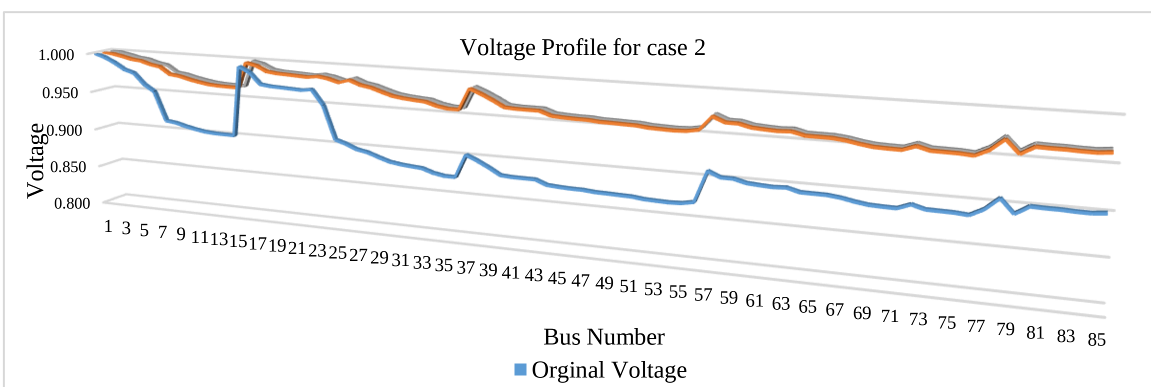

Fig. 8. Voltage values for all buses in the base case and after adding BESS using two algorithms

5. Conclusion

This study aimed to optimize the placement and size of BESS in electric power distribution systems. PSO and DA were used as optimization algorithms to minimize power losses and improve voltage profiles. Testing of the proposed approach was carried out on two different cases in the electricity grid. In the first case, both algorithms identified the same optimal location and size BESS, which reduced power loss by 45.59% and improved voltage profiles. Similarly, in the second case, which involved a BESS of similar size and location, the outcome was also a reduction in losses by 40.09% and improved voltage profiles. Ultimately, the optimal placement and sizing of BESS in electricity distribution systems can effectively reduce power losses and improve voltage profiles. Future studies could investigate multiple BESS units installed at different positions and sizes in a network utilizing solar energy sources. Thereby appreciating their implications on losses.

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References

[1] Z. Yuan, W. Wang, H. Wang, and A. Yildizbasi, "A new methodology for optimal location and sizing of battery energy storage system in distribution networks for loss reduction," Journal of Energy Storage, vol. 29, p. 101368, 2020, doi: https://doi.org/10.1016/j.est.2020.101368.
[2] R. Johnson, M. Mayfield, and S. Beck, "Optimal placement, sizing, and dispatch of multiple BES systems on UK low voltage residential networks," Journal of Energy Storage, vol. 17, pp. 272-286, 2018, doi: https://doi.org/10.1016/j.est.2018.03.005.
[3] S. Salee and P. Wirasanti, "Optimal siting and sizing of battery energy storage systems for grid-supporting in electrical distribution network," in 2018 International ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering (ECTI-NCON), 2018: IEEE, pp. 100-105, doi: https://doi.org/10.1109/ECTI-NCON.2018.8378290.
[4] C. Chen, S. Duan, T. Cai, B. Liu, and G. Hu, "Optimal allocation and economic analysis of energy storage system in microgrids," IEEE Transactions on Power Electronics, vol. 26, no. 10, pp. 2762-2773, 2011, doi: https://doi.org/10.1109/TPEL.2011.2116808.
[5] T. A. Abdul-jabbar, A. A. Obed, and A. J. Abid, "An Approach for an Intelligent Lithium-Ion Battery Management System with Active Balancing," in Electronic Systems and Intelligent Computing: Proceedings of ESIC 2021: Springer, 2022, pp. 751-764, doi: https://doi.org/10.1007/978-981-16-9488-2_71.
[6] K. Bai and A. Yildizbasi, "Optimal siting and sizing of battery energy storage system for distribution loss reduction based on meta-heuristics," Journal of Control, Automation and Electrical Systems, vol. 31, pp. 1469-1480, 2020, doi: https://doi.org/10.1007/s40313-020-00616-6.
[7] L. A. Wong, H. Shareef, A. Mohamed, and A. A. Ibrahim, "Optimal battery sizing in photovoltaic based distributed generation using enhanced opposition-based firefly algorithm for voltage rise mitigation," The Scientific World Journal, vol. 2014, 2014, doi: https://doi.org/10.1155/2014/752096.
[8] L. Chang, W. Zhang, S. Xu, and K. Spence, "Review on distributed energy storage systems for utility applications," CPSS Transactions on Power Electronics and Applications, vol. 2, no. 4, pp. 267-276, 2017, doi: https://doi.org/10.24295/CPSSTPEA.2017.00025.
[9] S. B. Maddina, R. Thirunavukkarasu, and N. Karthik, "Optimization of Energy Storage Unit Size and Location in a Radial Distribution Network to Minimize Power Loss Using Firefly Algorithm," Journal of Advanced Research in Applied Sciences and Engineering Technology, vol. 31, no. 3, pp. 25-42, 2023, doi: https://doi.org/10.37934/araset.31.3.2542.
[10] M. Sagara, M. Furukakoi, T. Senjyu, M. S. S. Danish, and T. Funabashi, "Voltage stability improvement to power systems with energy storage systems," in 2016 17th International Conference on Harmonics and Quality of Power (ICHQP), 2016: IEEE, pp. 7-10, doi: https://doi.org/10.1109/ICHQP.2016.7783463.
[11] H. Fedayi, M. Ahmadi, A. B. Faiq, N. Urasaki, and T. Senjyu, "BESS based voltage stability improvement enhancing the optimal control of real and reactive power compensation," AIMS Energy, vol. 10, no. 3, 2022, doi: https://doi.org/10.3934/energy.2022027.
[12] M. Nick, R. Cherkaoui, and M. Paolone, "Optimal allocation of dispersed energy storage systems in active distribution networks for energy balance and grid support," IEEE Transactions on Power Systems, vol. 29, no. 5, pp. 2300-2310, 2014, doi: https://doi.org/10.1109/TPWRS.2014.2302020.
[13] S. Peng, L. Zhu, Z. Dou, D. Liu, R. Yang, and M. Pecht, "Method of site selection and capacity setting for battery energy storage system in distribution networks with renewable energy sources," Energies, vol. 16, no. 9, p. 3899, 2023, doi: https://doi.org/10.3390/en16093899.
[14] T. T. Nguyen, T. T. Nguyen, and T. D. Nguyen, "Minimizing electricity cost by optimal location and power of battery energy storage system using wild geese algorithm," Bulletin of Electrical Engineering and Informatics, vol. 12, no. 3, pp. 1276-1284, 2023, doi: https://doi.org/10.11591/eei.v12i3.4779.
[15] A. Giannitrapani, S. Paoletti, A. Vicino, and D. Zarrilli, "Optimal allocation of energy storage systems for voltage control in LV distribution networks," IEEE Transactions on Smart Grid, vol. 8, no. 6, pp. 2859-2870, 2016, doi: https://doi.org/10.1109/TSG.2016.2602480.
[16] H. Zhao, Q. Wu, S. Huang, Q. Guo, H. Sun, and Y. Xue, "Optimal siting and sizing of Energy Storage System for power systems with large-scale wind power integration," in 2015 IEEE Eindhoven PowerTech, 2015: IEEE, pp. 1-6, doi: https://doi.org/10.1109/PTC.2015.7232615.
[17] P. Fortenbacher, A. Ulbig, and G. Andersson, "Optimal placement and sizing of distributed battery storage in low voltage grids using receding horizon control strategies," IEEE Transactions on Power Systems, vol. 33, no. 3, pp. 2383-2394, 2017, doi: https://doi.org/10.1109/TPWRS.2017.2746261.
[18] T. Kerdphol, R. N. Tripathi, T. Hanamoto, Y. Qudaih, and Y. Mitani, "ANN based optimized battery energy storage system size and loss analysis for distributed energy storage location in PV-microgrid," in 2015 IEEE Innovative Smart Grid Technologies-Asia (ISGT ASIA), 2015: IEEE, pp. 1-6, doi: https://doi.org/10.1109/ISGT-Asia.2015.7387074.
[19] S. B. Karanki and D. Xu, "Optimal capacity and placement of battery energy storage systems for integrating renewable energy sources in distribution system," in 2016 National Power Systems Conference (NPSC), 2016: IEEE, pp. 1-6, doi: https://doi.org/10.1109/NPSC.2016.7858983.
[20] P. Lata and S. Vadhera, "Optimal placement and sizing of energy storage systems to improve the reliability of hybrid power distribution network with renewable energy sources," Journal of Statistics and Management Systems, vol. 23, no. 1, pp. 17-31, 2020, doi: https://doi.org/10.1080/09720510.2020.1714147.
[21] N. Krstić, "Reduction of Energy and Power Losses in Distribution Network Using Energy Storage Systems," in 2020 55th International Scientific Conference on Information, Communication and Energy Systems and Technologies (ICEST), 2020: IEEE, pp. 127-130, doi: https://doi.org/10.1109/ICEST49890.2020.9232913.
[22] R. Djidimbélé, B.-P. Ngoussandou, D. K. Kidmo, M. Bajaj, and D. Raidandi, "Optimal sizing of hybrid systems for power loss reduction and voltage improvement using PSO algorithm: case study of Guissia rural grid," Energy Reports, vol. 8, pp. 86-95, 2022, doi: https://doi.org/10.1016/j.egyr.2022.06.093.

[23] Q. H. Mirdas, N. M. Yasin, and N. K. Alshamaa, "PSO Algorithm for Three Phase Induction Motor with V/F Speed Control," in 2022 4th International Conference on Advanced Science and Engineering (ICOASE), 21-22 Sept. 2022 2022, pp. 166-171, doi: 10.1109/ICOASE56293.2022.10075610.
[24] A. A. R. Mohamed, D. J. Morrow, R. J. Best, I. Bailie, A. Cupples, and J. Pollock, "Battery energy storage systems allocation considering distribution network congestion," in 2020 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), 2020: IEEE, pp. 1015-1019, doi: https://doi.org/10.1109/ISGT-Europe47291.2020.9248982.
[25] M. C. Barla and D. Sarkar, "Optimal placement and sizing of BESS in RES integrated distribution systems," International Journal of System Assurance Engineering and Management, vol. 14, no. 5, pp. 1866-1876, 2023, doi: https://doi.org/10.1007/s13198-023-02016-w.
[26] N.-C. Yang, Y.-C. Zhang, and E. W. Adinda, "Sizing and Sitting of Battery Energy Storage Systems in Distribution Networks with Transient Stability Consideration," Mathematics, vol. 10, no. 19, p. 3420, 2022, doi: https://doi.org/10.3390/math10193420.
[27] A. Ahlawat and D. Das, "Optimal sizing and scheduling of battery energy storage system with solar and wind DG under seasonal load variations considering uncertainties," Journal of Energy Storage, vol. 74, p. 109377, 2023, doi: https://doi.org/10.1016/j.est.2023.109377.
[28] P. Boonluk, A. Siritaratiwat, P. Fuangfoo, and S. Khunkitti, "Optimal siting and sizing of battery energy storage systems for distribution network of distribution system operators," Batteries, vol. 6, no. 4, p. 56, 2020, doi: https://doi.org/10.3390/batteries6040056.
[29] B. Bahmani-Firouzi and R. Azizipanah-Abarghooee, "Optimal sizing of battery energy storage for micro-grid operation management using a new improved bat algorithm," International Journal of Electrical Power & Energy Systems, vol. 56, pp. 42-54, 2014, doi: https://doi.org/10.1016/j.ijepes.2013.10.019.
[30] S. Mirjalili, "Dragonfly algorithm: a new meta-heuristic optimization technique for solving single-objective, discrete, and multi-objective problems," Neural computing and applications, vol. 27, pp. 1053-1073, 2016, doi: https://doi.org/10.1007/s00521-015-1920-1.
[31] J. Kennedy and R. Eberhart, "Particle swarm optimization," in Proceedings of ICNN'95-international conference on neural networks, 1995, vol. 4: IEEE, pp. 1942-1948, doi: https://doi.org/10.1109/ICNN.1995.488968.
[32] Y. Fukuyama and H. Yoshida, "A particle swarm optimization for reactive power and voltage control in electric power systems," in Proceedings of the 2001 Congress on Evolutionary Computation (IEEE Cat. No. 01TH8546), 2001, vol. 1: IEEE, pp. 87-93, doi: https://doi.org/10.1109/CEC.2001.934375.
[33] B. Mahdad, T. Bouktir, and K. Srairi, "Strategy based PSO for dynamic control of UPFC to enhance power system security," Journal of Electrical Engineering & Technology, vol. 4, no. 3, pp. 315-322, 2009, doi: https://doi.org/10.5370/JEET.2009.4.3.315.

Appendix A

Table A1. Bus data of Case 1

Buses#	P_L (kW)	Q_L (kVAR)	Buses#	P_L (kW)	Q_L (kVAR)	Buses#	P_L (kW)	Q_L (kVAR)
1	0	0	12	60	35	23	90	50
2	100	60	13	60	35	24	420	200
3	90	40	14	120	80	25	420	200
4	120	80	15	60	10	26	60	25
5	60	30	16	60	20	27	60	25
6	60	20	17	60	20	28	60	20
7	200	100	18	90	40	29	120	70
8	200	100	19	90	40	30	200	600
9	60	20	20	90	40	31	150	70
10	60	20	21	90	40	32	210	100
11	45	30	22	90	40	33	60	40

Table A2. Branch data for Case 1

From Bus	To Bus	R	X	From Bus	To Bus	R	X	From Bus	To Bus	R	X
1	2	0.0922	0.047	14	15	0.591	0.526	27	28	1.059	0.9337
2	3	0.493	0.2511	15	16	0.7463	0.545	28	29	0.8042	0.7006
3	4	0.366	0.1864	16	17	1.289	1.721	29	30	0.5075	0.2585
4	5	0.3811	0.1941	17	18	0.732	0.574	30	31	0.9744	0.963
5	6	0.819	0.707	2	19	0.164	0.1565	31	32	0.3105	0.3619
6	7	0.1872	0.6188	19	20	1.5042	1.3554	32	33	0.341	0.5302
7	8	1.7114	1.2351	20	21	0.4095	0.4784	21	8	2	2
8	9	1.03	0.74	21	22	0.7089	0.9373	9	15	2	2
9	10	1.044	0.74	3	23	0.4512	0.3083	12	22	2	2
10	11	0.1966	0.065	23	24	0.898	0.7091	18	33	0.5	0.5
11	12	0.3744	0.1238	24	25	0.896	0.7011	25	29	0.5	0.5
12	13	1.468	1.155	6	26	0.203	0.1034	-	-	-	-
13	14	0.5416	0.7129	26	27	0.2842	0.1447	-	-	-	-

Table A3. Bus data for Case 2

Buses#	P_L(kW)	Q_L(kVAR)	Buses#	P_L(kW)	Q_L(kVAR)	Buses#	P_L(kW)	Q_L(kVAR)
1	0	0	30	35.28	35.9928	59	56	57.1314
2	0	0	31	35.28	35.9928	60	0	0
3	0	0	32	0	0	61	56	57.1314
4	56	57.1314	33	14	14.2829	62	56	57.1314
5	0	0	34	0	0	63	14	14.2829
6	35.28	35.9928	35	0	0	64	0	0
7	0	0	36	35.28	35.9928	65	0	0
8	35.28	35.9928	37	56	57.1314	66	56	57.1314
9	0	0	38	56	57.1314	67	0	0
10	0	0	39	56	57.1314	68	0	0
11	56	57.1314	40	35.28	35.9928	69	56	57.1314
12	0	0	41	0	0	70	0	0
13	0	0	42	35.28	35.9928	71	35.28	35.9928
14	35.28	35.9928	43	35.28	35.9928	72	56	57.1314
15	35.28	35.9928	44	35.28	35.9928	73	0	0
16	35.28	35.9928	45	35.28	35.9928	74	56	57.1314
17	112	114.2629	46	35.28	35.9928	75	35.28	35.9928
18	56	57.1314	47	14	14.2829	76	56	57.1314
19	56	57.1314	48	0	0	77	14	14.2829
20	35.28	35.9928	49	0	0	78	56	57.1314
21	35.28	35.9928	50	36.28	37.013	79	35.28	35.9928
22	35.28	35.9928	51	56	57.1314	80	56	57.1314
23	56	57.1314	52	0	0	81	0	0
24	35.28	35.9928	53	35.28	35.9928	82	56	57.1314
25	35.28	35.9928	54	56	57.1314	83	35.28	35.9928
26	56	57.1314	55	56	57.1314	84	14	14.2829
27	0	0	56	14	14.2829	85	35.28	35.9928
28	56	57.1314	57	56	57.1314	-	-	-
29	0	0	58	0	0	-	-	-

Table A1. Branch data for Case 2

From Bus	To Bus	R	X	From Bus	To Bus	R	X	From Bus	To Bus	R	X
1	2	0.108	0.075	29	30	0.546	0.226	57	58	0.819	0.34
2	3	0.163	0.112	30	31	0.273	0.113	58	59	0.182	0.075
3	4	0.217	0.149	31	32	0.182	0.075	58	60	0.546	0.226
4	5	0.108	0.074	32	33	0.182	0.075	60	61	0.728	0.302
5	6	0.435	0.298	33	34	0.819	0.34	61	62	1.002	0.415
6	7	0.272	0.186	34	35	0.637	0.264	60	63	0.182	0.075
7	8	1.197	0.82	35	36	0.182	0.075	63	64	0.728	0.302
8	9	0.108	0.074	26	37	0.364	0.151	64	65	0.182	0.075
9	10	0.598	0.41	27	38	1.002	0.416	65	66	0.182	0.075
10	11	0.544	0.373	29	39	0.546	0.226	64	67	0.455	0.189
11	12	0.544	0.373	32	40	0.455	0.189	67	68	0.91	0.378
12	13	0.598	0.41	40	41	1.002	0.416	68	69	1.092	0.453
13	14	0.272	0.186	41	42	0.273	0.113	69	70	0.455	0.189
14	15	0.326	0.223	41	43	0.455	0.189	70	71	0.546	0.226
2	16	0.728	0.302	34	44	1.002	0.416	67	72	0.182	0.075
3	17	0.455	0.189	44	45	0.911	0.378	68	73	1.184	0.491
5	18	0.82	0.34	45	46	0.911	0.378	73	74	0.273	0.113
18	19	0.637	0.264	46	47	0.546	0.226	73	75	1.002	0.416
19	20	0.455	0.189	35	48	0.637	0.264	70	76	0.546	0.226
20	21	0.819	0.34	48	49	0.182	0.075	65	77	0.091	0.037
21	22	1.548	0.642	49	50	0.364	0.151	10	78	0.637	0.264
19	23	0.182	0.075	50	51	0.455	0.189	67	79	0.546	0.226
7	24	0.91	0.378	48	52	1.366	0.567	12	80	0.728	0.302
8	25	0.455	0.189	52	53	0.455	0.189	80	81	0.364	0.151
25	26	0.364	0.151	53	54	0.546	0.226	81	82	0.091	0.037
26	27	0.546	0.226	52	55	0.546	0.226	81	83	1.092	0.453
27	28	0.273	0.113	49	56	0.546	0.226	83	84	1.002	0.416
28	29	0.546	0.226	9	57	0.273	0.113	13	85	0.819	0.34