Al-Azhar Engineering 16th International Conference

Vol. 19, No. 72, July 2024, 298 - 315

DANDELION OPTIMIZER FOR SIZING AND PLACEMENT OF ENERGY STORAGE SYSTEMS TO IMPROVE VOLTAGE STABILITY AND REDUCE TOTAL COST

Ramy M. Hany[1*], Tarek Mahmoud[2], El Said A. Osman[2], Abo El Fotouh Abd El Rehim[1]

[1] Department of Electrical power and Machines Engineering, The Higher Institute of Engineering, Elshorouk City, Elshorouk Academy, Cairo, Egypt

[2]Electrical Engineering Department, Faculty of Engineering, Al-Azhar University, Nasr City, Cairo, Egypt

***Correspondence:** r.hany@sha.edu.eg

Citation:

R.M. Hany, T. Mahmoud, E.A. Osman and A. Abd El Rehim, “Dandelion optimizer for sizing and placement of energy storage systems to improve voltage stability and reduce total cost” Journal of Al-Azhar University Engineering Sector, vol. 19, pp. 298 - 315, 2024.

Received: 02 February 2024

Revised: 13 May 2024

Accepted: 27 May 2024

DoI:10.21608/auej.2024.267263.1611

ABSTRACT

By incorporating energy storage systems (ESSs), a distribution network's energy efficiency can be increased. These technologies can considerably improve the network's overall performance if they are placed and sized properly. A well-sized and well-positioned energy storage system can help manage power quality, optimize the choice of distributed and renewable energy sources, efficiently handle peak energy demand, and lower the costs related to growing distribution networks. In order to find out the ideal location and size of ESSs in a distribution network, this paper suggests a practical method that makes use of the Dandelion Optimizer (DO). Reducing the system's total yearly cost—which accounts for costs connected to power outages, voltage variations, and peak load—is the aim. The IEEE 33 bus radial system is used to implement the study's methods. The results from the original system and the suggested DO are compared to show how the position of the ESS affects the voltage profile and total cost. In addition, a comparison is presented between the results of the Ant Lion Optimizer (ALO), the Whale Optimization Algorithm (WOA) and the planned Design of Dandelion Optimizer (DO), indicating that the DO has achieved more savings than the other Algorithms. Findings indicate that the (DO) method delivers a net cost reduction of 7% and 1.7% compared to the WOA and ALO methods respectively, while also improving the voltage profile. The minimum bus voltage increased by 0.277% in the case of WOA and by 4.27% in the case of ALO while applying the DO increased this voltage by 6.6% with respect to the original system. The locations and sizes of the acquired ESSs are advantageous for system implementation due to the ease of use and effectiveness of the recommended methodology in resolving the optimization problem that was explored.

KEYWORDS: Energy Storage Systems, Dandelion Optimizer, Distribution System, Optimal Sizing

تحديد المكان والحجم الأمثل لأنظمة تخزين الطاقة باستخدام خوارزمية الداندليون (الهندباء) لتحسين استقرار الجهد وتقليل التكلفة

رامي محمد هاني[1*]، طارق محمود [2]، السعيد عبد العزيز عثمان[2]، ابو الفتوح عبد الرحيم محمد[1]

[1]قسم هندسة القوى والالات الكهربية، المعهد العالي للهندسة، مدينة الشروق، أكاديمية الشروق، القاهرة، مصر.

[2]قسم الهندسة الكهربية، كلية الهندسة، جامعة الأزهر، مدينة نصر، القاهرة، مصر.

***البريد الاليكتروني للباحث الرئيسي :** r.hany@sha.edu.eg

الملخص

باضافة أنظمة تخزين الطاقة (ESSs) ، يمكن زيادة كفاءة الطاقة في شبكة التوزيع. يمكن أن تحسن هذه التقنيات بشكل كبير أداء الشبكة بشكل عام إذا تم وضعها وتحديدها بشكل صحيح. يمكن لنظام تخزين الطاقة الذي يكون بحجم مناسب وموقع مناسب أن يساعد في إدارة جودة الطاقة ، وتحسين إضافة مصادر الطاقة الموزعة والمتجددة بشكل فعال ، والتعامل بكفاءة مع الطلب الأقصى على الطاقة ، وتقليل التكاليف المتعلقة بتوسيع شبكات التوزيع. من أجل تحديد الموقع والحجم المثاليين لأنظمة تخزين الطاقة ESSs في شبكة التوزيع ، يقترح هذا البحث طريقة عملية تستخدم محسن الهندباء (DO). الهدف هو تقليل الكلفة السنوية الإجمالية للنظام - التي تشمل تكاليف انقطاع التيار وتغييرات الجهد وأقصى حمل - وذلك عبر هذه الطريقة. يُستخدم نظام التوزيع bus IEEE 33 لتنفيذ طرق الدراسة. يتم مقارنة النتائج من النظام الأصلي قبل اضافة أنظمة تخزين الطاقة و DO المقترح لإظهار كيف يؤثر موقع ESS على الجهد والتكلفة الإجمالية. بالإضافة إلى ذلك ، يتم تقديم مقارنة بين نتائج محسن Ant Lion (ALO) وخوارزمية تحسين الحوت (WOA) وتصميم محسن الهندباء المخطط له (DO) ، مشيرة إلى أن DO قد حقق مزيدًا من التوفير من الخوارزميات الأخرى. تشير النتائج إلى أن طريقة (DO) تحقق تخفيضًا صافياً في التكلفة بنسبة 7% و1.7% مقارنة بطرق WOA و ALO على التوالي، بينما تحسن أيضًا ملف الجهد الكهربائي. ارتفع أدنى جهد للناقل بنسبة 0.277% في حالة WOA وبنسبة 4.27% في حالة ALO بينما عند تطبيق DO زاد هذا الجهد بنسبة 6.6% بالنسبة للنظام الأصلي. تعتبر مواقع وأحجام ESSs المكتسبة مفيدة لتنفيذ النظام نظرًا لسهولة الاستخدام وفعالية المنهجية الموصى بها في حل مشكلة التحسين التي تم استكشافها.

الكلمات المفتاحية : أنظمة تخزين الطاقة، محسن الهندباء، شبكة التوزيع، الحجم الأمثل.

1. INTRODUCTION

Existing distribution networks are undergoing significant changes for a variety of reasons, including demand management, renewable energy integration, compliance with power quality standards, greenhouse gas emission reduction objectives, network expansion, and dependability[1-6]. A scientific forecast expected that challenges associated with the distribution system will incur annual expenses of approximately 100 billion USD [7]. It is anticipated that ESSs will efficiently address issues arising from power oscillations, disruptions in the transmission and distribution networks, and abrupt fluctuations in demand [8, 9]. The integration of ESSs into distribution networks is being pursued with the aim of improving power quality, increasing network capacity, decreasing expenses, guaranteeing operational reserves, and mitigating greenhouse gas emissions.

As referenced in [10-18], ESSs provide a number of additional benefits, such as load shifting, load trimming, load normalization, and voltage deviation reduction. While there are environmental benefits to generating electricity from renewable sources, an overreliance on such sources may jeopardize the dependability of the distribution networks. The implementation of ESSs can efficiently mitigate output fluctuations, synchronize generated power and demand, and stabilize power transmission. In light of this, the implementation of ESS holds considerable promise for both utilities and customers. ESS that are improperly positioned or sized in distribution networks may have detrimental effects on power quality, load management, voltage and frequency regulation, and overall dependability [19-25].

To find the best ideal ESSs for the distribution networks, an optimization problem (multi-objective) combining technological and economic goals was presented in a prior study [26]. In their study, the authors have introduced a multi-objective function that takes into account energy cost, bus voltage, and network losses [27, 28]. Prior research utilized a particle swarm optimization (PSO) technique [29, 30]. Previous studies have demonstrated the use of genetic algorithms (GAs) [31, 32]. In the study conducted by [33], a Grey Wolf Optimizer (GWO) was used to optimize the target function, which takes into account the entire annual cost. The price in question consists of three parts: the price of energy that isn't delivered, the price of buying ESSs, and the price of keeping the ESSs running.

Present study showcases the utilization of the Dandelion Optimizer (DO) methodology in order to ascertain the most advantageous placement and scalability of ESS within the distribution network. The rationale behind choosing DO was to ensure straightforward implementation, prompt response, and minimal control variables. A constrained objective function, which considers the expenses related to voltage variation, power loss, and highest demand, has been devised with the aim of minimizing the annual cost. The methodology that was proposed is executed on the 33-bus system. An evaluation is made between the results obtained using the DO and those attained using both the WOA and the ALO [34]. The method that has been proposed results in a decrease in the overall cost with an increase in voltage stability.

This research demonstrates the application of the DO based approach to determine the optimal location and scaling of ESS in the distribution network. DO was selected due to the need for simple deployment, rapid response, and reduced controlling elements. A restricted optimization function has been formulated with the purpose of reducing the annual cost. This cost includes the expenses associated with voltage variation, power loss, and maximum demand. The suggested methodology is implemented on the 33-bus system. The study compares the outcomes obtained using the DO method with those obtained using the ALO and the WOA methods [35, 36]. The proposed technique yields a reduced overall cost and better voltage profile.

In this paper a load flow analysis was made by MATLAB on the IEEE 33 bus system to obtain the bus voltage at each bus and the power loss. Then a multi objective optimization function was introduced to attain minimum system cost. This function is applied to the system utilizing three different optimization techniques considering the different system constraints. ALO, WOA and the proposed DO algorithms were applied with a comparison of the system outcomes indicating a great advantage of employing the anticipated DO.

1. THE MODELLING OF ESS IN RADIAL NETWORKS

Both charging and discharging are influenced by the burden level. The operational condition of ESSs is determined by their daily energy consumption. As a result, ESSs function as generators to rebalance the burden among themselves in times of inadequate energy supply, specifically when demand is increasing significantly. Conversely, electric self-suspending batteries (ESSs) are currently undergoing charging to store surplus energy, specifically during periods of low demand. Load management pertains to the observation that ESSs are effectively disconnected from the network when the load levels fall within the designated range.

In accordance with the ESS performance specifications outlined in reference [30], the minimum and maximum load levels depicted in Figure 1 were established at 50% and 75% correspondingly. Assuming the entire installed capacity for a given day, the producing units of the network can only provide 75% of the reference load, as stated in the hypothesis. Positive active power is identified throughout the discharging process, while negative active power is detected throughout the charging process of the ESS, denoted as the PQ bus in the system. In all the above circumstances, the reactive power can have either a positive or negative value.

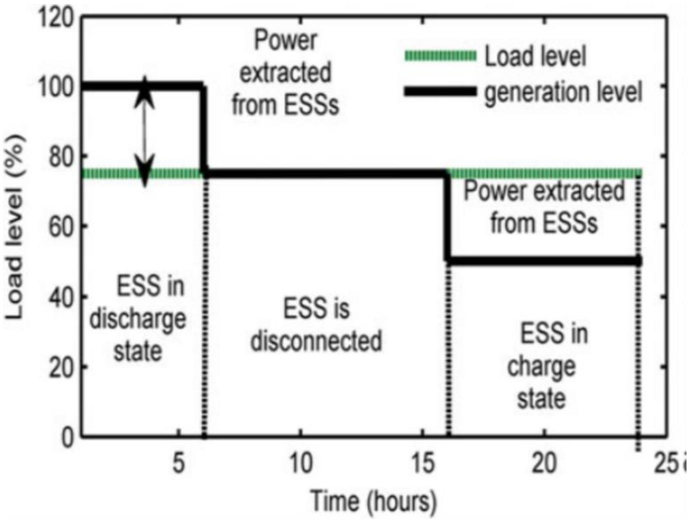

Fig. 1. The performance of ESS dependent on load level [30].

The rates at which ESSs are charged and discharged are determined by [37]:

$$\delta E_B = E_B(t) - E_B(t-1) \quad \text{Eq. (1)}$$

$$P_{ch}(t) = \delta E_B(t)/(\delta t \times \eta\text{ch}) \quad \text{Eq. (2)}$$

$$P_{disch}(t) = \delta E_B(t)/(\delta t \times \eta\text{disch}) \quad \text{Eq. (3)}$$

EB represents the stored energy in the battery, while δEB is the variation in the energy of the battery. Charging efficiency is assumed to be ηch is the same as the efficiency of the discharging process ηdisch. The charged power, denoted as Pch, is typically positive, whereas the discharged power, denoted as Pdisch, is frequently negative. The symbol δt denotes the duration between successive samples. The effectiveness of the ESSs in this research is 85%.

ESS size that maximizes efficiency is indicated as:

$$ESS\ size = \frac{E_{Bmax} - E_{Bmin}}{DoD_{max}} \quad \text{Eq. (4)}$$

DoDmax represents the assumed maximum depth of discharge, which is set at 80%, EBmax denotes the maximum value of energy while and EBmin is the minimum value.

2. DANDELION OPTIMIZER (DO)

DO is a method influenced by natural means, was first proposed in [38] [48]. The dandelion, which belongs to the Asteraceae family, is a perennial herb technically known as Herba taraxaci (refer to Figure 2). The aforementioned herbs reach a height above 20 cm during their peak growing period. Seed scattering with wind enables the colonization of new organisms once they have reached their full developmental stage.

Fig.2. The floating Dandelions in nature.

The three stages of development that dandelion seeds undergo are as follows:

1. A vortex is created over the dandelion seed as it ascends, pushed greater by wind and sunshine. There are no swirling currents of water over the seeds on a day with rainfall. Only local searches are available in this case.
2. Once seeds reach a specific altitude, they start to gently fall during the descent phase.
3. During the landing phase, dandelions disperse erratically to the ground, where, contingent on external factors such as wind and weather, they germinate into new plants.

To advance their population, dandelion individuals progress through a series of developmental stages, primarily through the process of seed dispersal.

Step I: Initializing.

Every individual seed in the DO algorithm symbolizes a prospective result. The size of a population in a DO issue is determined by the problem's dimension and the number of individuals generated, taking into account both dimension of the variables and the population size. Randomly generated potential solutions are considered inside the specified issue's upper limit and lower limit, taking into account the problem's dimension [38].

As per the DO algorithm, the initial elite member is determined as the individual with the highest fitness estimate, which signifies the ideal condition for the growing of a seed.

Step II: Growing.

Seeds must attain a specific altitude during their ascent to disperse from their parent plants. The growth of the seeds can vary in height due to reasons such as wind speed and humidity of air. There are two meteorological conditions in this scenario, namely:

Case1:

Wind speeds on a sunny day can be considered to follow a lognormal distribution. The elevation of a seed is influenced by the velocity of the air. Increased wind strength enhances the dandelion's ability to ascend to greater heights and facilitates the wider dispersal of its seeds.

$$X_{t+1} = X_t + \propto \times \frac{1}{e^{\Theta}} \cos \Theta \times \frac{1}{e^{\Theta}} \sin \Theta \times \ln Y \times (X_s - X_t) \qquad \text{Eq. (5)}$$

The variable Xs represents the position randomly selected at iteration t inside the upper and lower limits UB and LB. Xt represents the seed location at iteration t, and ϴ is an arbitrary value that ranges from -π to π. The equation representing the randomly generated position is as follows:

$$X_s = rand(1, \mathrm{dim}) \times (UB - LB) + LB \qquad \text{Eq. (6)}$$

lnY is a lognormal distribution subject to mean value μ = 0 and variance σ2 = 1.

$$ln\,Y = \begin{cases} \frac{1}{y\sqrt{2\pi}} \exp\,[-\frac{1}{2\sigma^2}(\ln y)\text{^}2\,] & y \geq 0 \\ 0 & y < 0 \end{cases} \qquad \text{Eq. (7)}$$

y is the standard normal distribution [0, 1].

$$\alpha = rand(\,) \times (\tfrac{1}{T^2}t^2 - \tfrac{2}{T}t + 1) \qquad \text{Eq. (8)}$$

The dandelion's lift component is represented by the coefficients v_x and v_y, whereas α characterizes an arbitrary perturbation ranging from 0 to 1.

Case2:

The presence of humidity and the air's resistance make it challenging to properly uproot dandelions when there is a damp breeze.

$$X_{t+1} = X_t \times (1 - rand(\,) * q) \qquad \text{Eq. (9)}$$

The domain (q) can be obtained as:

$$q = \frac{1}{T^2-2T+1}t^2 - \frac{1}{T^2-2T+1}t + 1 + \frac{1}{T^2-2T+1} \qquad \text{Eq. (10)}$$

The exact equation for the growing stage of the seed is as follows:

$$X_{t+1} = \begin{cases} X_t + \propto \times\, v_x \times v_y \times \ln Y \times (X_s - X_t) & randn < 1.5 \\ X_t \times k & else \end{cases} \qquad \text{Eq. (11)}$$

The arbitrary number produced by function randn() has a normal distribution.

Step III: Descending.

During this stage, seeds undergo growth until they reach a specific height, at which point they gradually start to descend (exploration phase). Brownian motion is working to repeat the path followed by a mobile dandelion.

$$X_{t+1} = X_t - \alpha \times \beta_t \times (\frac{1}{pop}\sum_{i=1}^{pop} X_i - \propto \times\, \beta_t \times X_t) \qquad \text{Eq. (12)}$$

where β_t is the Brownian motion, pop is the population size.

step IV: Landing.

During this last stage, based on the results of the preceding two stages, the dandelion seed selects a random location to land. As the number of iterations grows, the algorithm should approach the optimal conclusion more closely.

Ultimately, the population evolution yields the optimal reaction on a global scale:

$$X_{t+1} = X_{elite} + s \times \frac{w \times \sigma}{|t|^{(\frac{1}{\beta})}} \times \propto \times (X_{elite} - X_t \times \delta) \qquad \text{Eq. (13)}$$

where X_{elite} represents the optimal position of the seed. S has a constant value of 0.01, while b is an arbitrary value that can range from 0 to 2. Both w and t are random values between 0 and 1. S is accurately depicted as:

$$\boldsymbol{\sigma} = \frac{\boldsymbol{\Gamma}(\mathbf{1}+\boldsymbol{\beta})\times\mathbf{sin}\,(\frac{\boldsymbol{\pi\beta}}{\mathbf{2}})}{\boldsymbol{\Gamma}(\frac{\mathbf{1}+\boldsymbol{\beta}}{\mathbf{2}})\times\mathbf{sin}\,(\frac{\boldsymbol{\beta}-\mathbf{1}}{\mathbf{2}})} \qquad \text{Eq. (14)}$$

β equals 1.5, and δ is calculated as:

$$\delta = \frac{2t}{T} \qquad \text{Eq. (15)}$$

The flow chart of the dandelion optimizer is depicted in Figure 3.

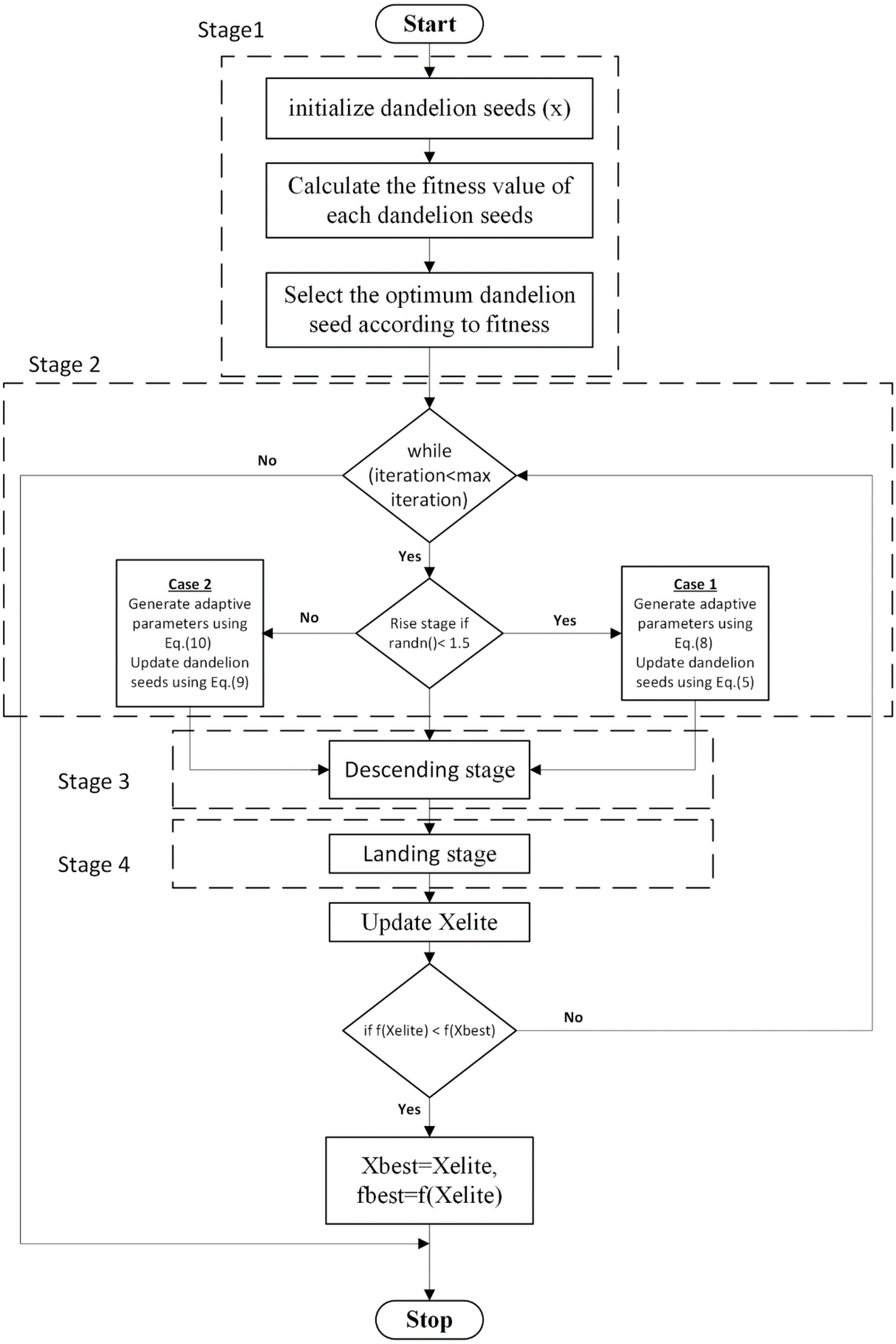

Fig. 3. Dandelion Optimizer Flow Chart

3. THE PROPOSED OPTIMIZATION

3.1 Objective Function

In light of the extraordinary progress in technology, it is imperative to ensure the optimal operation of distribution systems. The significance of energy storage devices is rising in tandem with the expansion of renewable energy utilization in power networks.

The appropriate location and size of ESSs are the variables required to solve a multi-objective optimization obstacle that involves several cost objectives [35, 39]. The target of this optimization problem is to decrease the overall system cost, which includes costs correlated with power losses, voltage variations, and maximum load [40].

$$F = \left(\sum_{K=1}^{Nl} G_K\left[V_i^2 + V_j^2 - 2|V_i||V_j|cos\left(\delta_i - \delta_j\right)\right] \times C_{loss}\right) + \left(\sum_{i=1}^{Nl}(1 - V_i) \times C_{Dev}\right) + \left(P_{max} \times \delta t \times C_{peak}\right) \quad \text{Eq. (16)}$$

The variable Nl represents the upper limit on the number of lines that can be interconnected within the system, whereas GK denotes the conductance value of transmission line k. The voltage at the sending end of the line is denoted as Vi, while the voltage at the receiving end is denoted as Vj. Similarly, the voltage angle at the sending end is represented as δi, while the voltage angle at the receiving end is represented as δj. Pmax represents the maximum rate of the real power supplied to the reference bus for a specified time period.

Variables Closs, CDev, and Cpeak reflect the costs related to line losses, voltage variation, and highest demand, respectively. The anticipated cost rates are as follows: Closs = \$284 per MWh, CDev = \$142 per MWh, and Cpeak = \$200,000 per MWh per year [35, 37].

3.2 The Proposed Constraints

The optimization technique merely considers the capacity of ESS and their locations as variables to be optimized. The limitations delineated in this problem can be classified into four discrete categories: limitations on load flow, limitations bus voltage, limitations on transmission lines, and limitations on ESS. The following subsections provide a comprehensive illustration of each of these elements.

4.2.1. limitations on energy storage

$$\mathrm{P}_{\mathrm{ch}}^{\mathrm{t}} \geq \mathrm{P}_{\mathrm{Bmin}} \quad \text{Eq. (17)}$$

$$P_{disch}^{t} \leq P_{Bmax} \quad \text{Eq. (18)}$$

$$E_{Bmin} \leq E_B^t \leq E_{Bmax} \quad \text{Eq. (19)}$$

The ESS limitations specified in equations (17) and (18) are intended to ensure that the charging power $\boldsymbol{P_{ch}^{t}}$ remains above the minimum ESS capacity $\boldsymbol{P_{Bmin}}$, and the discharging power

$\boldsymbol{P_{disch}^{t}}$ does not exceed the greatest power capacity of the ESS $\boldsymbol{P_{Bmax}}$. The selection of values for the lower and upper limits should be based on the ESS capacity, as specified in equation (19).

4.2.2. Limitations on bus voltage.

$$0.95\ PU \le V_i^t \le 1.05\ PU \qquad \text{Eq. (20)}$$

The bus voltage should remain within the range of 95% to 105% of its rated value throughout time.

4.2.3. Limitations on transmission lines.

$$S_l^t \le S_{lmax} \qquad \text{Eq. (21)}$$

The largest permissible load for any line, denoted as Slmax, must not be surpassed over a given period of time.

4.2.4. Limitations on power flow.

$$P_{Gmin} \le P_G^t \le P_{Gmax} \qquad \text{Eq. (22)}$$

$$Q_{Gmin} \le Q_G^t \le Q_{Gmax} \qquad \text{Eq. (23)}$$

As per the capacity restrictions, for each power plant the active and reactive power must vary within the authorized upper and lower limits.

4. RESULTS AND DISCUSSION

This section examines the impacts of the projected deployment of ESS on the voltage profile, performance, and cost containment of the system. The performance analysis focuses on four distinct case studies. Case 1 represents the fundamental situation without ESSs. situations 2 and 3 involves the positioning of ESSs using the ALO and the WOA optimization methods. Case 4 involves the positioning of ESSs using the suggested DO optimizer. The IEEE 33 bus radial system is employed in this simulation [31]. The organizational configuration of the bus system consists of 33 bus radials and 32 lines. Additionally, there is one slack bus with a base voltage of 12.66 kV and a base power of 100 MVA. The total real power is 3.71 MW, whereas the reactive power is 2.31 MVAr. Figure 4 illustrates a single line representation of the IEEE 33 bus under study.

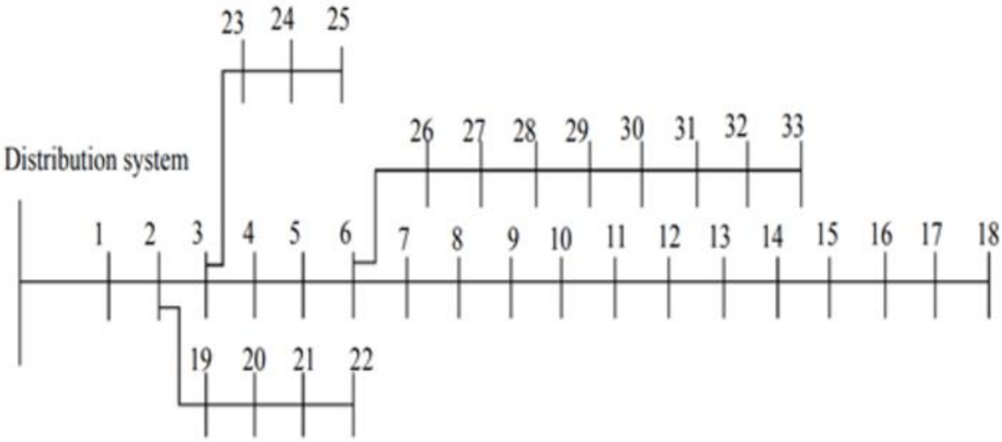

Fig. 4. IEEE 33 Bus Distribution System.

Figure 5 displays the bus voltage for four scenarios: the first one with no ESSs installed, the second and the third following the installation of ESSs using the WOA and the ALO optimization algorithms, and the fourth one representing the voltage profile obtained using the employed (DO) algorithm. Figure 5 study demonstrates that the application of the Energy Storage Systems has a beneficial impact on the voltage profile of the system. Figure 6 demonstrates the voltage variation in the buses caused by the four situations, whereas Figures 7, 8, 9 and 10 display the specific bus voltages for each corresponding scenario.

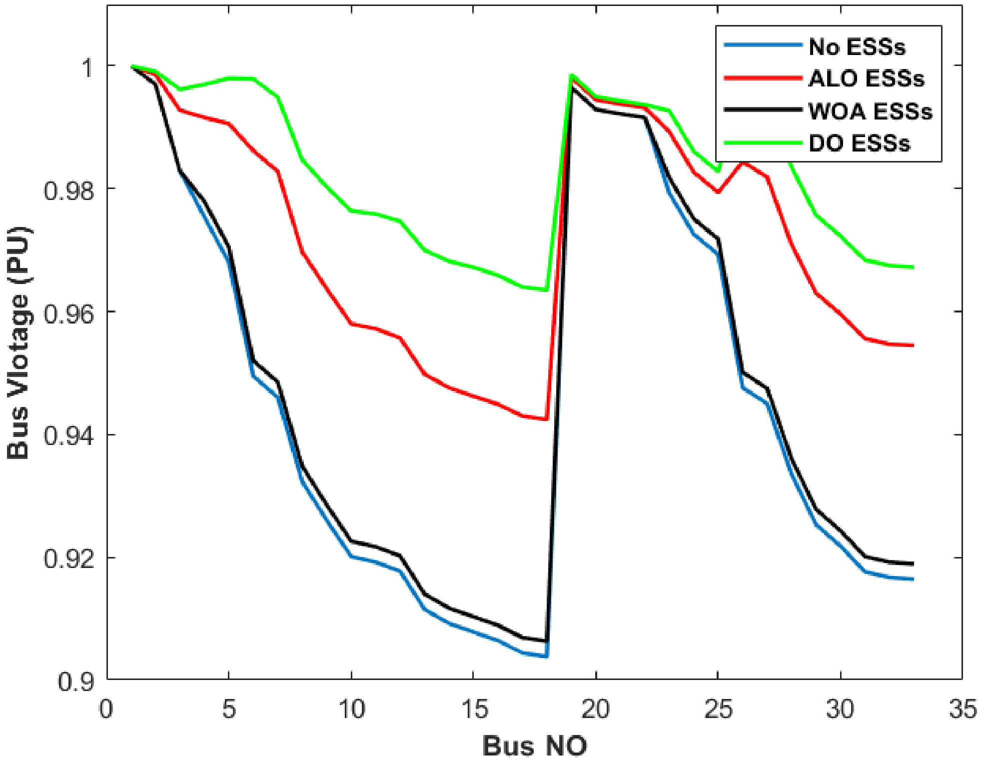

Fig. 5. IEEE 33 Bus voltages with a) No ESSs installed b) WOA optimized ESSs c) ALO optimized ESSs d) proposed DO optimized ESSs.

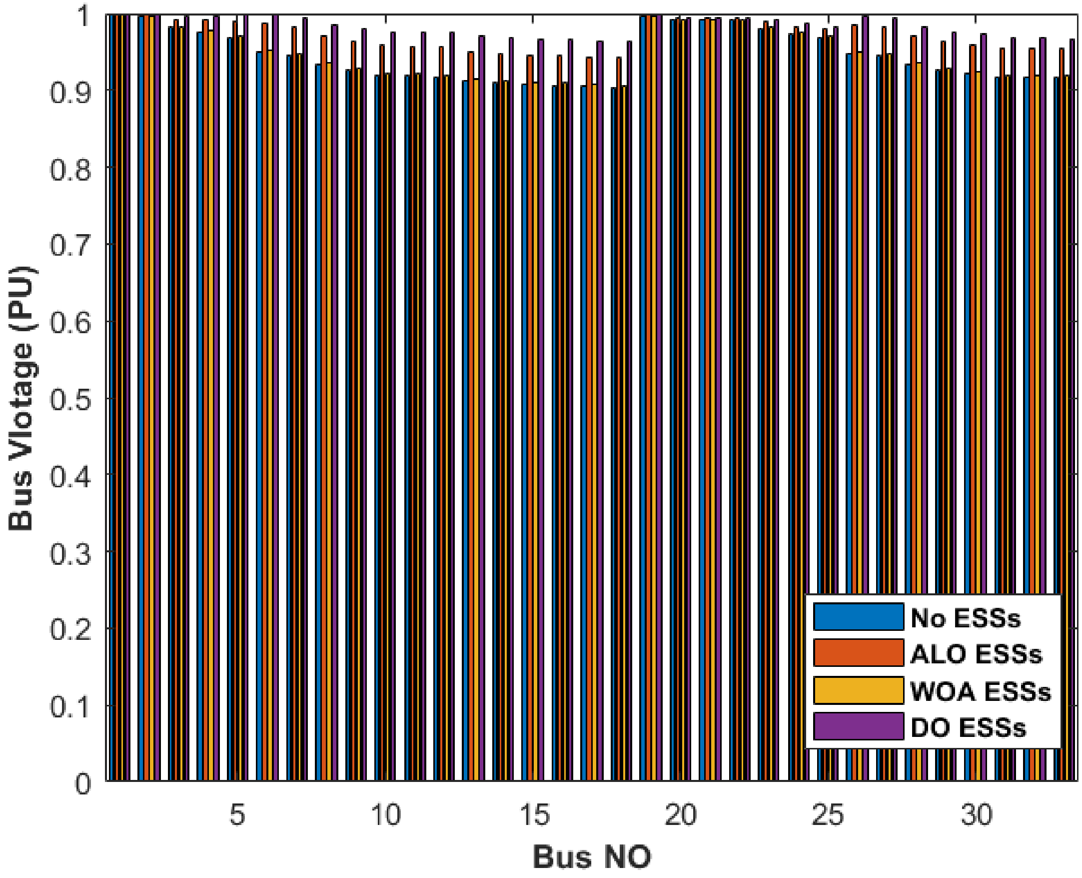

Fig.6. Variation of voltage profile without ESSs and with ESSs using WOA, ALO and DO optimization for the IEEE 33 bus system.

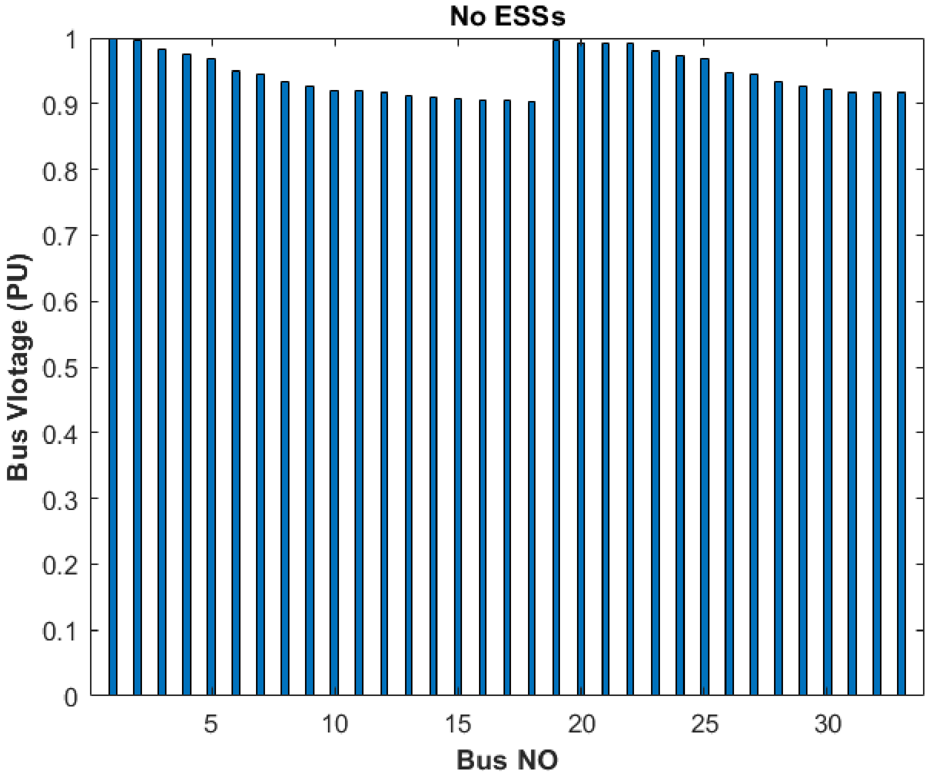

Fig. 7. Various bus voltage for IEEE 33 bus with no ESSs installed.

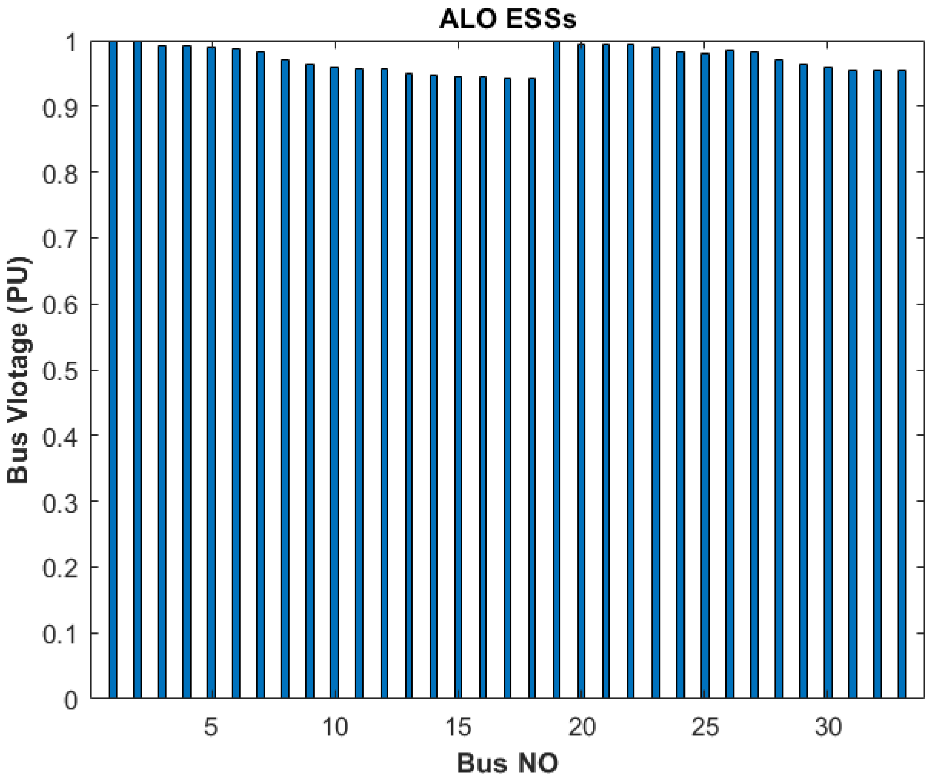

Fig. 8. Various bus voltage for IEEE 33 bus with ESSs applying ALO algorithm.

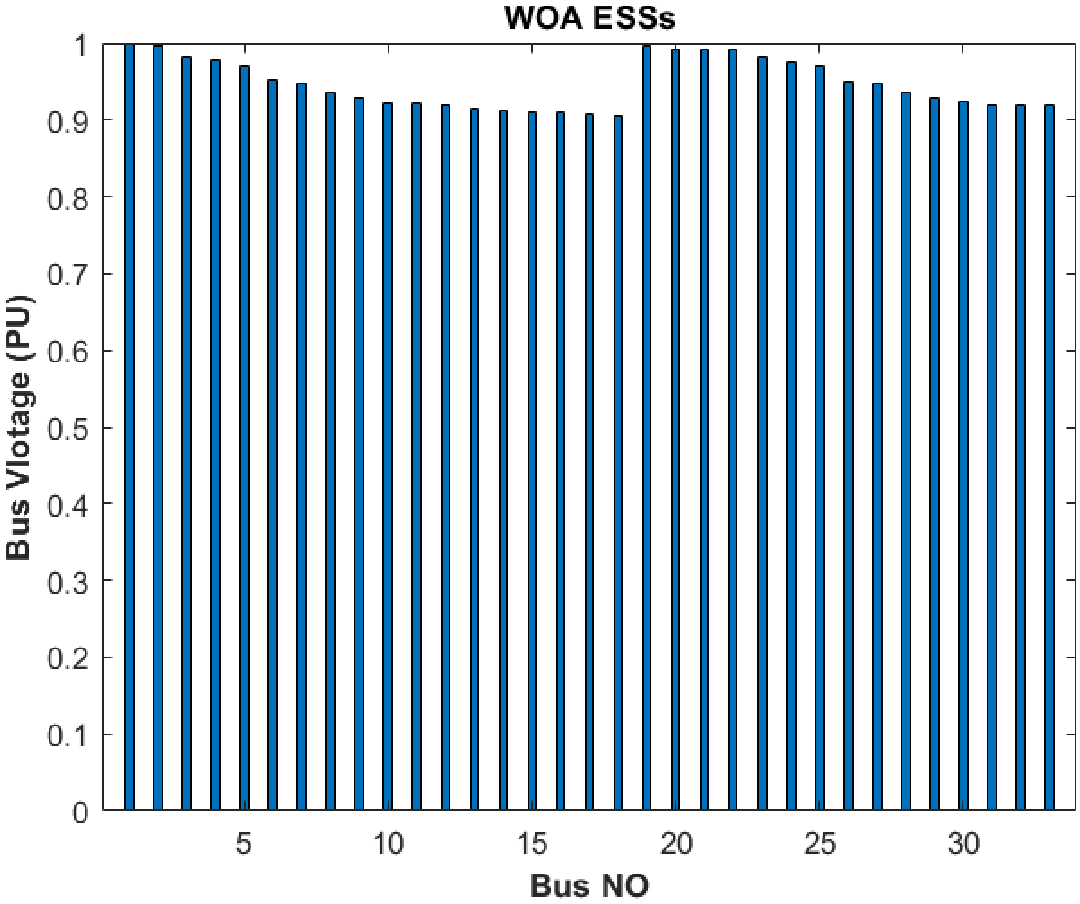

Fig. 9. Various bus voltage for IEEE 33 bus with ESSs applying WOA algorithm.

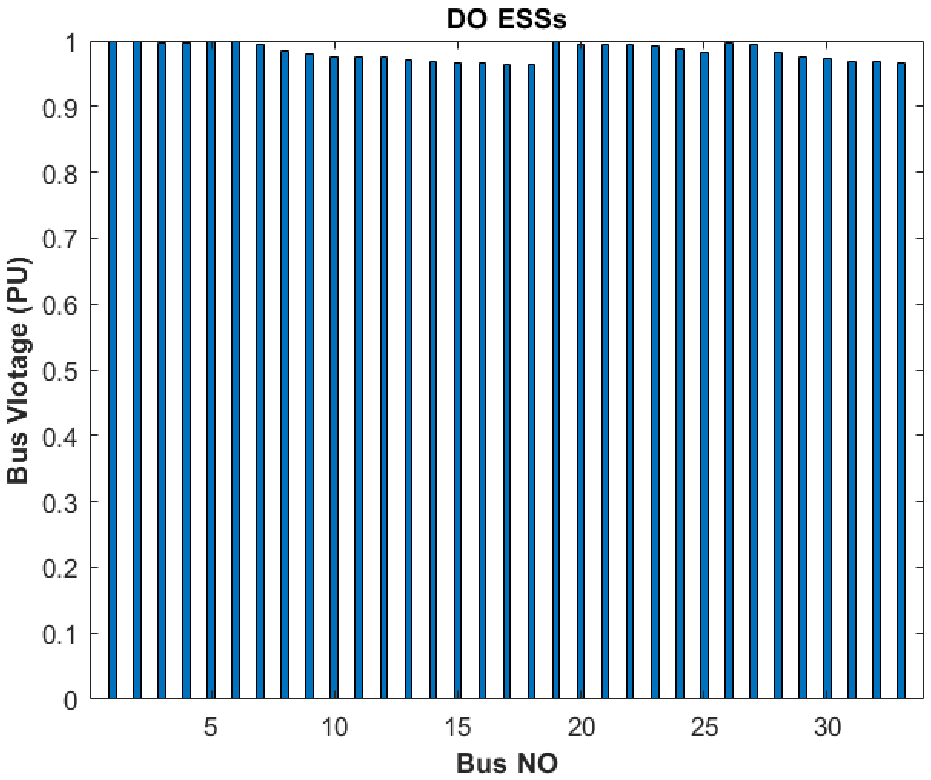

Fig. 10. Various bus voltage for IEEE 33 bus with ESSs applying DO algorithm.

The efficacy of the proposed technique is highlighted by contrasting the system outcomes with those derived from an alternate approach, such as the ALO and the WOA methods. Table 1 presents a thorough analysis of the outcomes obtained from the initial system and the subsequent incorporation of ESSs using WOA, ALO and the proposed approach for evaluating minimum voltage, power loss and operational costs of the system. Findings indicate that the (DO) method delivers a net cost reduction of 7% and 1.7% compared to the WOA and ALO methods respectively, while also improving the voltage profile, The minimum bus voltage increased by 0.277% in the case of WOA and by 4.27% in the case of ALO while applying the DO increased this voltage by 6.6% with respect to the original system.

Table 1. Optimal size & location of installed ESS for IEEE 33 bus systems.

Algorithms	Without ESS	WOA	ALO	DO
Bus Number	----	27	26	6
ESS Size in MWh	----	1.7961	2.4507	2.5902
Minimum Bus Voltage in pu	0.9038	0.9063	0.9424	0.9635
Power Loss in KW	211	180.56	111.0320	111.0320
Annual Operating Cost in USD	----	53056.3	50167.5	49320.1

Table 2 shows the effect of increasing the amount of ESS on the 33-bus system.

Table 2. Effect of increasing the amount of ESS on the 33-bus system.

The quantity of energy storage systems (ESSs) that can be supplied		1	5				
WOA based optimal allocation of ESSs	Bus no.	27	6	10	3	14	8
	Size MWh	1.7961	2.59021	3.07004	1.67196	1.55569	3.41607
Overall Operating Cost $/year		53056.3	53924.3				
Algorithmic time for finding the optimal solution measured in seconds		27.94725	38.21296				
ALO based optimal allocation of ESSs	Bus no.	26	6	5	14	7	33
	Size MWh	2.4507	2.59023	3.63091	0.820672	2.34196	0.948381
Overall Operating Cost $/year		50167.5	49320.1				
Algorithmic time for finding the optimal solution measured in seconds		23.818414	24.711285				
DO based optimal allocation of ESSs	Bus no.	6	6	4	11	15	26
	Size MWh	2.5902	2.59023	0.100124	0.135889	0.10601	0.566627
Overall Operating Cost $/year		49320.1	49320.1				
Algorithmic time for finding the optimal solution measured in seconds		16.695445	17.278905				

5. CONCLUSION

Integrating ESSs into a distribution network has the capacity to significantly optimize the network's energy efficiency as a whole. Wisely sizing and strategically installing these ESSs in appropriate locations can optimize the network's overall performance. Attaining this outcome is feasible by adhering to the procedures specified in this document. The effectiveness of these ESSs in meeting high energy request, utilizing renewable energy sources, maintaining electricity reliability, and reducing costs related to distribution network installation depends on their appropriate sizing and strategic placement. The Dandelion Optimizer (DO) is employed in the proposed approach outlined in this article to achieve this goal as its final outcome. The method was evaluated using an IEEE 33 bus distribution system. The results showed that the technique outperformed the initial system in terms of cost, voltage profile, and even surpassed the performance of both the WOA and the ALO Algorithms. Due to its simplicity of implementation and effectiveness in addressing optimization challenges, the chosen ESS sites and sizes have promise for practical deployment in distribution networks. The employed DO can achieve a great reduction in the overall system cost, minimize the power losses and improve the voltage stability of the system with remarkable effect to avoid or reduce the overloading of transformers, reduce over- and under-voltages and augment the short circuit capability of the distribution line by supporting in clearing faults, improving safety on the network.

References

[1] L. Taylor and T. A. Short, Distribution reliability and power quality. Crc Press, 2018.

[2] K. Kumar and B. J. E. G. M. Jaipal, "The role of energy storage with renewable electricity generation," 2022.

[3] T. J. J. I. J. o. E. P. Hammons and E. Systems, "Integrating renewable energy sources into European grids," vol. 30, no. 8, pp. 462-475, 2008.

[4] M. Sedghi, M. Aliakbar-Golkar, M.-R. J. I. J. o. E. P. Haghifam, and E. Systems, "Distribution network expansion considering distributed generation and storage units using modified PSO algorithm," vol. 52, pp. 221-230, 2013.

[5] R. H. Zubo et al., "Operation and planning of distribution networks with integration of renewable distributed generators considering uncertainties: A review," vol. 72, pp. 1177-1198, 2017.

[6] C. K. Das, O. Bass, G. Kothapalli, T. S. Mahmoud, D. J. R. Habibi, and S. E. Reviews, "Overview of energy storage systems in distribution networks: Placement, sizing, operation, and power quality," vol. 91, pp. 1205-1230, 2018.

[7] S. M. Amin and C. W. J. E. Gellings, "The North American power delivery system: balancing market restructuring and environmental economics with infrastructure security," vol. 31, no. 6-7, pp. 967-999, 2006.

[8] A. K. Srivastava, A. A. Kumar, and N. N. J. I. S. J. Schulz, "Impact of distributed generations with energy storage devices on the electric grid," vol. 6, no. 1, pp. 110-117, 2012.

[9] N. S. Wade, P. Taylor, P. Lang, and P. J. E. p. Jones, "Evaluating the benefits of an electrical energy storage system in a future smart grid," vol. 38, no. 11, pp. 7180-7188, 2010.

[10] Y. Ghiassi-Farrokhfal, C. Rosenberg, S. Keshav, and M.-B. J. I. J. o. S. A. i. C. Adjaho, "Joint optimal design and operation of hybrid energy storage systems," vol. 34, no. 3, pp. 639-650, 2016.

[11] S. Koohi-Kamali, V. Tyagi, N. Rahim, N. Panwar, H. J. R. Mokhlis, and S. E. Reviews, "Emergence of energy storage technologies as the solution for reliable operation of smart power systems: A review," vol. 25, pp. 135-165, 2013.

[12] T. Mahlia, T. Saktisahdan, A. Jannifar, M. Hasan, H. J. R. Matseelar, and s. e. reviews, "A review of available methods and development on energy storage; technology update," vol. 33, pp. 532-545, 2014.

[13] T. Kousksou, P. Bruel, A. Jamil, T. El Rhafiki, Y. J. S. E. M. Zeraouli, and S. Cells, "Energy storage: Applications and challenges," vol. 120, pp. 59-80, 2014.

[14] M. Farhadi and O. J. I. T. o. I. A. Mohammed, "Energy storage technologies for high-power applications," vol. 52, no. 3, pp. 1953-1961, 2015.

[15] K. K. Zame, C. A. Brehm, A. T. Nitica, C. L. Richard, G. D. J. R. Schweitzer III, and S. E. Reviews, "Smart grid and energy storage: Policy recommendations," vol. 82, pp. 1646-1654, 2018.

[16] A. Chauhan, R. J. R. Saini, and S. E. Reviews, "A review on Integrated Renewable Energy System based power generation for stand-alone applications: Configurations, storage options, sizing methodologies and control," vol. 38, pp. 99-120, 2014.

[17] S. M. Said et al., "Optimal design and cost of superconducting magnetic energy storage for voltage sag mitigation in a real distribution network," vol. 73, p. 108864, 2023.

[18] M. Hashem, M. Abdel-Salam, M. T. El-Mohandes, M. Nayel, and M. J. J. o. E. S. Ebeed, "Optimal placement and sizing of wind turbine generators and superconducting magnetic energy storages in a distribution system," vol. 38, p. 102497, 2021.

[19] A. Evans, V. Strezov, T. J. J. R. Evans, and s. e. reviews, "Assessment of utility energy storage options for increased renewable energy penetration," vol. 16, no. 6, pp. 4141-4147, 2012.

[20] N. S. Hasan, M. Y. Hassan, M. S. Majid, H. A. J. R. Rahman, and S. E. Reviews, "Review of storage schemes for wind energy systems," vol. 21, pp. 237-247, 2013.

[21] W. S. Ho et al., "Optimal scheduling of energy storage for renewable energy distributed energy generation system," vol. 58, pp. 1100-1107, 2016.

[22] F. Díaz-González, A. Sumper, O. Gomis-Bellmunt, R. J. R. Villafáfila-Robles, and s. e. reviews, "A review of energy storage technologies for wind power applications," vol. 16, no. 4, pp. 2154-2171, 2012.

[23] M. Beaudin, H. Zareipour, A. Schellenberglabe, and W. J. E. f. s. d. Rosehart, "Energy storage for mitigating the variability of renewable electricity sources: An updated review," vol. 14, no. 4, pp. 302-314, 2010.

[24] M. Y. Suberu, M. W. Mustafa, N. J. R. Bashir, and S. E. Reviews, "Energy storage systems for renewable energy power sector integration and mitigation of intermittency," vol. 35, pp. 499-514, 2014.

[25] A. Castillo, D. F. J. E. C. Gayme, and Management, "Grid-scale energy storage applications in renewable energy integration: A survey," vol. 87, pp. 885-894, 2014.

[26] M. Nick, R. Cherkaoui, and M. J. I. T. o. P. S. Paolone, "Optimal allocation of dispersed energy storage systems in active distribution networks for energy balance and grid support," vol. 29, no. 5, pp. 2300-2310, 2014.

[27] M. Nick, R. Cherkaoui, M. J. I. J. o. E. P. Paolone, and E. Systems, "Optimal siting and sizing of distributed energy storage systems via alternating direction method of multipliers," vol. 72, pp. 33-39, 2015.

[28] M. Nick, M. Hohmann, R. Cherkaoui, and M. Paolone, "Optimal location and sizing of distributed storage systems in active distribution networks," in 2013 IEEE grenoble conference, 2013, pp. 1-6: IEEE.

[29] S. Joseph et al., "PSO based controller algorithm for optimal allocation & setting of fuel cell in a wind—PV integrated power system for maximizing loadability," in 2014 International Conference on Advances in Green Energy (ICAGE), 2014, pp. 1-6: IEEE.

[30] H. Saboori, R. Hemmati, and M. A. J. E. Jirdehi, "Reliability improvement in radial electrical distribution network by optimal planning of energy storage systems," vol. 93, pp. 2299-2312, 2015.

[31] A. S. Awad, T. H. El-Fouly, and M. M. J. I. T. o. P. s. Salama, "Optimal ESS allocation for load management application," vol. 30, no. 1, pp. 327-336, 2014.

[32] L. Grisales-Noreña, O. D. Montoya, and W. J. J. o. E. S. Gil-Gonzalez, "Integration of energy storage systems in AC distribution networks: Optimal location, selecting, and operation approach based on genetic algorithms," vol. 25, p. 100891, 2019.

[33] A. Fathy, A. Y. J. E. P. C. Abdelaziz, and Systems, "Grey wolf optimizer for optimal sizing and siting of energy storage system in electric distribution network," vol. 45, no. 6, pp. 601-614, 2017.

[34] S. Mirjalili, "The Ant Lion Optimizer," Advances in Engineering Software, vol. 83, no. 0, pp. 80-98, 5// 2015.

[35] R. M. Hany, T. Mahmoud, E. S. A. E. A. Osman, A. E. F. A. El Rehim, and H. M. J. P. o. Seoudy, "Optimal allocation of distributed energy storage systems to enhance voltage stability and minimize total cost," vol. 19, no. 1, p. e0296988, 2024.

[36] L. A. Wong, V. K. J. I. J. o. E. Ramachandaramurthy, E. Engineering, and Telecommunications, "Optimal battery energy storage system placement using Whale optimization algorithm," vol. 9, no. 4, pp. 268-272, 2020.

[37] P. Boonluk, A. Siritaratiwat, P. Fuangfoo, and S. J. B. Khunkitti, "Optimal siting and sizing of battery energy storage systems for distribution network of distribution system operators," vol. 6, no. 4, p. 56, 2020.

[38] S. Zhao, T. Zhang, S. Ma, and M. J. E. A. o. A. I. Chen, "Dandelion Optimizer: A nature-inspired metaheuristic algorithm for engineering applications," vol. 114, p. 105075, 2022.

[39] T. Ali, S. A. Malik, A. Daraz, S. Aslam, and T. J. E. Alkhalifah, "Dandelion optimizer-based combined automatic voltage regulation and load frequency control in a multi-area, multi-source interconnected power system with nonlinearities," vol. 15, no. 22, p. 8499, 2022.

[40] H. H. Fayek, F. H. Fayek, and E. J. A. S. Rusu, "Pharmacophore-Modeling-Based Optimal Placement and Sizing of Large-Scale Energy Storage Stations in a Power System including Wind Farms," vol. 13, no. 10, p. 6175, 2023.