Optimal Placement of Multiple DG Units With Energy Storage in Radial Distribution System by Hybrid Techniques

Munisekhar P., Jawaharlal Nehru Technological University, India*

G. Jayakrishna, St. Peter's Engineering College, India

N. Visali, Jawaharlal Nehru Technological University, India

ABSTRACT

In recent years, distributed generations (DGs) are extremely fast in detecting their location, which helps to satisfy the ever-increasing power demands. The placement of energy storage systems (ESSs) could be a substantial opportunity to enhance the presentation of radial distribution system (RDS). The major part of DG units in RDS deals with the detection of ideal placement and size of the DGs, which efficiently balance the power loss and voltage stability. The ideal location and size of ESSs are examined in standard IEEE-33 and 69 bus systems, which is important to reduce power losses. Nowadays, several algorithms or techniques are modified for the development of hybrid algorithms to improve the quality of DG allocation. In this research, a hybrid shuffled frog leap algorithm (SFLA) with ant lion optimizer (SFLA-ALO) is proposed for the optimal placement and size of the DG and ESS in the RDS to reduce power losses and maintain the stability of voltage. The performance of the proposed SFLA-ALO technique is compared with the implemented BPSO-SFLA technique.

KEYWORDS

Ant Lion Optimizer, Distributed Generation, Energy Storage Systems, Radial Distribution System, Shuffled Frog Leap Algorithm

INTRODUCTION

Network reconfiguration is widely used to determine the radial operating structure that is obtained by modifying the network topology. The change in the status of open/closed switches is used to modify the topology. Hence, the radial operating structure is used to reduce the losses and improve the voltage stability to satisfy the operating controls (Oliveira et al. 2016). The tap switches considered in the system reconfiguration to overcome the problems related to load balancing, loss minimization, etc. (Rao et al. 2013). Additionally, this system reconfiguration is considered an issue in multi-target integer collecting optimization. Generally, the reconfiguration helps to minimize the power losses (Murty &

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*Corresponding Author

Kumar 2015) and to avoid overload of voltage profile (López et al. 2016) in the network. The changes in the feeder load and an adequate number of open/close status of the switches are used to obtain the aforementioned features (Liu et al. 2015). The distribution networks are organized radially and the switches are either in open mode or closed modes operation which are deliberated as premeditated facts for network reconfiguration (Das et al.2017). The DG allocation is one of the most important factors due to its substantial part in radial network (Sannigrahi & Acharjee 2018). The magnitude of RDS bus voltage is increased by incorporating the DG that helps to reduce the total power loss over the most ideal topology (i.e., reconfiguration with DGs) (Imran et al. 2014).

Renewable DGs such as wind and solar based structures are extensively utilized as substitute resources to resolve the issues in various environmental disturbs (Kaveh 2018). To minimize the fossil fuel consumption in electrical energy creation, DGs based on the usage of renewable are established (Ramaswamy et al. 2015) that support to reduce the power loss (Kianmehr et al. 2019). DG helps to attain and support the real power along with reactive power compensation and is responsible for producing efficient reliability of power and energy (Raut & Mishra 2019). The voltage deviation and the control of the generation system are openly subject to the proper size/location of DG units (Aman et al. 2012). The passive network is converted into an active network using a distribution system when the DG is incorporated with the distribution system (Kansal et al. 2013). However, the voltage profile gets minimized and power loss occurs in the system due to the random/unfair location of the DG units which increases the cost (Hamida et al. 2018). Shuffled Frog Leaping Algorithm (SFLA) is suitable for solving various combinatorial optimization problems. However, the algorithm has the disadvantages of slow convergence, easy to fall into the local optimal solution and premature convergence. So, here, the combination of SFLA-ALO is chosen as a proposed method, because, it effectively improves the search accuracy, accelerates the convergence speed and can avoid the algorithm from premature convergence to some extent. The simulation results show that the proposed method effectively improves the search accuracy and convergence speed. Hence in this paper, a Novel Optimization algorithm based on optimal allocation and sizing of DG and ESS in the RDS has been proposed to decrease the losses, cost and to enhance the stability of voltage magnitude.

PROBLEM STATEMENT

The chief intention of this research is to ensure the estimation of the best position/size of DG and ESS, along with an increment in voltage stability and reduction the total power loss.

- The inappropriate placement and size of fuel cell DG resources lead to major losses in the distribution systems and various methods were exploited in many types of research to resolve the DG placement issue.
- Conversely, the main necessities of real-time presentation and the resolving of nonlinear complications, have not been studied in the previous work.
- Some of the optimization techniques deliver the assignment of DGs and ESS completely but the experiment results are not sufficient enough to prove the system efficiency.
- The cost function is one of the problems in DG and ESS allocation, and the total loss in the network is dependent upon nonlinear equality controls.

From the above-mentioned points, the main problem is the optimization issue of DGs and ESS placement. To allocate the most suitable size, it must be positioned in an ideal location to obtain the steadiness and the load response of RDS. Therefore, a supplementary and simple optimization procedure is crucial to control differentiated problematic parameters.

CONTRIBUTION

A hybrid SFLA-ALO method is suggested to control the optimum reconfiguration and ideal sizing of DG and ESS to decrease the power loss and enhance the voltage profile. Initially, the procedure is executed to identify the ideal allocations for the connection of DG and ESS for implementing the reconfiguration, transiently.

The simulated outcomes of the SFLA-ALO method are related through the outcomes of existing methods to evaluate the behaviors of SFLA-ALO method.

Case I: The network operates with reconfiguration process;
Case II: The network operates with DG alone;
Case III: Network reconfiguration and placement of single DG;
Case IV: Network reconfiguration and placement of multiple DGs;
Case V: Network reconfiguration and placement of ESS.

LITERATURE SURVEY

Researchers have recommended numerous approaches or procedures for DG and ESS distribution. This section presents a brief evaluation of some of the significant existing researches towards DG placements in RDS.

Literature Based on Optimization Methods

Sanjay et al. 2017 developed an optimal allocation of the DG using a combined Grey Wolf Optimizer (GWO). This procedure was utilized to resolve discrete, non-convex and DG-related problems on 33-bus, 69-bus and 85-bus RDS. The proposed method reduced the power loss and enhanced the voltage magnitude of the buses across the system. The main drawback of GWO was the low capacity to handle difficulties involved in a multi-modal search landscape.

Prakash and Lakshminarayana 2016 presented Multiple DG Placements in the radial network for enhancing the voltage magnitude and minimizing the loss with the help of the Particle Swarm Optimization (PSO) Algorithm. Appropriate size and optimal placement of the DGs in the system, by using the PSO algorithm, had considerably minimized the power loss in the system. This method only focuses on power loss and voltage profile and does not deliberate about cost-related and load restoration problems. However, the results obtained from the PSO trapped into the local exploration in high dimensional space and it occurred with a less convergence percentage.

Nguyen et al. 2016 presented the Adaptive Cuckoo Search process to identify the ideal location and magnitudes of the DG. The exploration space of every single tie-line was predisposed by the cuckoo search process to find out the weakest area. This method has improved the divergence speed and resolution accuracy of the 33 and 69 bus systems. A large quantity of tie-line combinations interrupts the radial boundary and the reconfiguration procedure of the radial system was not considered in this research.

Singh and Gyanish 2018 demonstrated a control valuation of DG in disseminated structures to decrease the total real power loss by using optimal power flow procedures. In this research, the real power and reactive power loss are reduced similarly, through an increment in power factor values. Meanwhile, the cost of real/reactive power decreases by increasing the DG size. But, after a certain point in time, the loss starts to increase with respect to size.

Ghatak et al. 2018 proposed a PSO process with adaptive inertia mass to identify the ideal allocation of the distribution static compensator (DSTATCOM) and DG, by considering security limits. The DSTATCOM has various benefits, for example, less noise, size and harmonic content when compared with the conventional reactive power recompensation devices. The proposed technique was not appropriate for bulky dispersal systems that consumed several sectionalized switches and more determination is required for generating circles. While an arbitrary initialization of sectionalizing switches results in less rate of convergence.

Chithra et al. 2017 demonstrated the Stud Krill Herd Algorithm (SKHA) for the result of ideal sizing/allocation of DG in RDS. SKHA was exploited to solve the ideal DG placement issue in the radial system. The proposed method prominently progresses the accuracy of the overall ideality and supremacy of the solution. The implemented SKHA can be executed to some extent of DG count, but while considering the consistency, DG count is restricted to 3.

Literature Based on Analytical Methods

Mahmoud et al. 2016 proposed an Efficient Analytical (EA) method for optimum installation of multiple DG technologies to decrease power loss in the system. The suggested EA technique was incorporated with the Power Flow process to produce a novel technique. This EA technique was evaluated in the standard IEEE 33 and 69 RDS bus systems. The proposed method could precisely deliver the optimum result with quick computational speed, but could not deliver the optimal result for assigning a combination of DGs that belonged to dissimilar categories.

Gholamreza Memarzadeh, Farshid Keynia 2020 presented an analytical index for determining the optimal size and location of distribution gateways in a network. This article purpose is to present a new DG placement index for the small and big distribution network. In contrast to current methods in this sector that require complex optimization algorithms, the suggested method may solve the optimal DG siting problem very simply and quickly, especially for large networks. The simulation approach has been implemented on the IEEE 33 and 69 bus distribution systems to evaluate the efficiency of the proposed method in the preceding section. However, this strategy outperforms all others in terms of lowering power losses, with the exception of ALO.

From the analyzed works, both optimization and analytical procedures does not sensibly demonstrate the formula for compensating every optimization issue. However, ALO demonstrates that it could be employed for resolving optimization issues. While SFLA has high proficiency, fast computing speed, better premature convergence and local optimum for complex optimization issues. The SFLA-ALO method has not been exploited in DG assignment literature.

PROBLEM FORMULATION

The influence of DGs is appropriately evaluated through voltage magnitude, losses and stability of the system. In this research, the proposed SFLA-ALO is targeted at minimization of an objective function (1) combined as power losses (2) deviation of voltage. The DG connection at ideal allocations eventually leads to positive impacts such as line loss minimization, enhancement of the voltage magnitude, security, and reliability. The optimal sizing and position of DGs are the final multi-objective optimization issues with a nonlinear process that has equivalent parameters such as DG constraints, voltage constraints, power balance constraints, etc. The objective function of the system problem is to decrease total power loss and voltage deviation subject to the system constraints. According to (Imran & Kowsalya 2014), the two objectives are instantaneously considered by combining them into one objective as shown in equation (1).

$$Minimize\ F = \min\left(f1 + f2\right) \tag{1}$$

where the system loss and voltage magnitude are specified as $f1$ and $f2$ respectively. The calculated equivalence of the objective function is designated as the following constraints:

Power Loss ($f1$)

The radial benchmark network creates uncertainty during the period of peak loading circumstances that damages the control parameters. The attained DG position and its size should minimalize the loss and realize the boundaries of the following parameters. The precise requirement of the radial network is designed by using the next equation (2).

$$f1 = P_L = \sum_{i=1}^{n} I_i^2 R \tag{2}$$

where the line current is designated as I_i the exact loss of RDS is specified as P_L and its resistance is characterized as R that lies amongst nodes i and j. The magnitude of voltage is briefly explained in the next subdivision.

Voltage Deviation ($f2$)

The essential calculation for deviation of voltage is presented in the subsequent equation (3).

$$f2 = \sum_{i=1}^{N} \left(V_i - V_{rated}\right)^2 \tag{3}$$

where V_i represents the voltage at a bus i, V_{rated} is designated as rated voltage; and the number of buses is denoted as N. Voltage deviation is caused due to the load or condition changes which easily affect the transmission capability of the network and voltage control limits. DG is used as a Reactive power compensation to improve both power transfer capability and voltage stability of the system. Voltage deviation is one of the power quality indices. To maintain the system as radial, bus voltage deviation should be minimized. The objective function of the proposed method is completely based on the following constraints, for example, power balance, DG capacity, and bus voltage that are explained in the next section.

Constraints

Power Balance Constraint

The constraints of power balance mostly designate the produced power from DG used to fulfill the request at various circumstances. The prerequisite calculation of the power balance is designated in the subsequent equations (4) and (5).

$$P_{Di}^{D} = P_{Gi}^{D} - Y_{ij} \sum_{i=j=1}^{N} V_i V_j cos\left(\delta_i - \delta_j - \theta_i\right) \tag{4}$$

$$Q_{Di}^{D} = Q_{Gi}^{D} - Y_{ij} \sum_{i=j=1}^{N} V_i V_j sin\left(\delta_i - \delta_j - \theta_i\right) \tag{5}$$

where the power generations of DG are specified as P_{Gi}^{D} and Q_{Gi}^{D} at a bus i, the phase angle is expressed as θ_i for a bus i, the admittance is designated as Y_{ij} which lies in the mid of the line i and j, load demands are stated as P_{Di}^{D} and Q_{Di}^{D} at the bus j which stays in the boundaries $P_{Di}^{D(\min)} \le P_{Di}^{D} \le P_{Di}^{D(\max)}$, $Q_{Di}^{D(\min)} \le Q_{Di}^{D} \le Q_{Di}^{D(\max)}$ and $\delta_{i,j}$ represents the angle at bus i and j.

Bus Voltage Constraint

The boundaries for every bus voltage stay within specified ranges which are quantified in equation (6).

$$V^{min} \leq V_i \leq V^{max} \tag{6}$$

where the minimum and maximum standards of voltage are designated as V^{min} and V^{max} at the bus i; usually the voltage of every bus should lie in the middle of the definite ranges ($0.95 \leq V_i \leq 1.05\, pu$).

Constraint of DG

The parameters of DG generally comprise the permissible dimensions for the nodes and their equivalent power-factor of DG. The DG capacity is designated in the subsequent equation (7).

$$P_{Dgi}^{min} \leq P_{DGi} \leq P_{Dgi}^{max} \tag{7}$$

where, P_{DGi} refers to the Real power supplied by the DG. P_{Dgi}^{min} and P_{Dgi}^{max} are represented as the minimum and maximum power delivered by the DG.

The proposed technique exploits the parameters to discover the node that achieves the least loss for the duration of the faulted situation, which is recognized as the ideal position. The detailed procedure for DG/ESS positioning and sizing using the proposed technique is defined in the next section.

Constraints of ESS

The objective function is dependent on the following equations which are organized through equivalences of ESS modeling constraints which are specified below.

$$P_i^g + \sum_{j \in J+} \left(P_{j \to i}^d \right) = P_i^c + \sum_{k \in J-} P_{k \to d}^i \tag{8}$$

$$Q_i^g + \sum_{j \in J+} \left(Q_{j \to i}^d \right) = Q_i^c + \sum_{k \in J-} Q_{k \to d}^i \tag{9}$$

Equation 8 and 9 denotes that the real power (P_i^g) and reactive power (Q_i^g) distributed to bus i need to be composed. $Q_{k \to d}^i$ refers that reactive power delivered from k to d. $P_{k \to d}^i$ refers that active power delivered from k to d. Real power and reactive power consumed at bus i is referred as P_i^c and Q_i^c. The suboptimal ESS location and sizing can cause under or over-voltages in the distribution network.

$$P_{ESS-min < P_{ESS} < P_{ESS-max}} \tag{10}$$

$$P_{ESS,c}^t \leq P_{ESS}^t \leq P_{ESS,d}^t \tag{11}$$

$$E_{ESS-min < E_{ESS} < E_{ESS-max}} \tag{12}$$

$P_{ESS-min < P_{ESS} < P_{ESS-max}}$ is represented as power obtained from the ESS with respect to minimum and maximum ranges. $P_{ESS,d}^t$ specified the ESS discharging power at t, $P_{ESS,c}^t$ specified the ESS charging power at t. The outcomes of optimization during various cases in radial networks are accomplished to validate its efficiency which is tabulated in the result section. Equations 10 – 12 confirms that the energy of the ESSs will not surpass the borderline restrictions for the duration of the charging and discharging period. Additionally, it ensures the operation of ESS must stay inside the State of Charge (SOC) boundary.

However, the situation has changed with the emergence of generating sources, with power output which is not dispatchable. Sometimes, higher efficiency is restricted by depth of discharge effects. Nevertheless, the losses become the main concern, because of the external forces of battery.

Equation (13) describes the battery efficiency. The loss in charging and discharging process of batteries are calculated based on the efficiency. The efficiency of a battery η_{bat} is calculated by subtracting the battery loss η_{loss} from the initial battery efficiency. The efficiency gets increase when there is a decrement in η_{loss} which is shown in Equation (14). I_{bat}. is the charge-discharge current, R is the battery's internal resistance, and V_{bat} is the battery voltage.

$$\eta_{bat} = 100 - \eta_{loss} \tag{13}$$

$$\eta_{loss} = \frac{I^2 bat \times R}{V_{bat} \times I_{bat}} \tag{14}$$

The electric charge equation is used in Equation (15). The battery loss equation and battery efficiency can be determined using Equation (16). The internal resistance of the battery is given by equation (17).

$$I_{bat} = \frac{Q_{bat}}{t} \tag{15}$$

$$\eta_{loss} = \frac{\frac{Q_{bat}}{t} \times R}{V_{bat}} \tag{16}$$

$$R = \frac{\eta_{loss} \times V_{bat} \times t}{Q_{bat}} \tag{17}$$

Cost of Energy Losses

DG power calculation completely depends upon the calculated model which is characterized as the cost of energy loss as specified in equation (18).

$$CL = \left(TRPL\right)*\left(K_p + K_e*LSF*8760\right) \tag{18}$$

where Total Real Power Losses is represented as TRPL, cost of energy loss is defined as K_e; demand price of energy loss is specified as K_p; CL denotes the cost of energy losses

Loss Sensitivity Factor (LSF) is conveyed using Load Factor (Lf) which is given in equation (19)

$$LSF = k*Lf + \left(1 - k\right)*Lf^2 \tag{19}$$

The standards occupied for the quantities in the LF design are:

$k = 1.3$, $Lf = 0.46$, $K_p = 61.4832$ \$/kW, $K_e = 0.0019362$ \$/kW h.

Cost of DG

The cost calculation of DG for real/reactive power is expressed in equation (20)

$$C\left(P_{dg}\right) = a^{*}P_{dg}^{\ 2} + b^{*}P_{dg} + c \tag{20}$$

The coefficients of Cost are taken as:

$a = 1,\ b = 19,\ c = 0.19$

These aforementioned features minimize the exploration space by discovering the ideal positions that protect the DG cost in controlling the losses. The reactive power cost delivered by DG is premeditated and completely depends upon the determined composite energy delivered, which are explained in equations (21) & (22).

$$C\left(Q_{dg}\right) = \left[Cost\left(S_{gmax}\right) - Cost\sqrt{S_{gmax}^{\ 2} - Q_{g}^{\ 2}}\right) \right]^{*}k \tag{21}$$

$$S_{gmax} = \frac{P_{gmax}}{\cos\phi} \tag{22}$$

where, k =0.03-0.09; P_{dg} and Q_{g} are described as real power and reactive power produced by DG. S_{gmax} specifies the maximum apparent power delivered by the generator. $P_{gmax} = 1.1^{*}P_{g}$, $\cos\phi$ is considered as 1 at unity PF and lagging PF is considered as 0.9 for the analysis purpose.

The output value of DG should stay in the assortment of active/reactive power as specified in Eq. (23) and (24).

$$P^{min}{}_{DG,i} \le P_{Dg,i} \le P^{max}{}_{DG,i} \tag{23}$$

$$Q_{G,min} \le Q_{G} \le Q_{G,max} \tag{24}$$

where, $P_{Dg,i}$ and Q_{G} denotes the DG size with reference to real power and reactive power respectively. $P^{min}{}_{DG,i}$ represents the real power DG with the minimum value, $P^{max}{}_{DG,i}$ specifies the real power DG with the maximum value, $Q_{G,min}$ designates the minimum value of reactive power DG, $Q_{G,max}$ describes the maximum value of reactive power.

The optimal placement of DG units using SFLA-ALO in a mesh network causes the following problems.

- It's costly as compared to the opposite network topologies.
- Installation is extremely difficult in the mesh.
- Power requirement is higher as all the nodes will need to remain active all the time and share the load.

So, proposed method is applied to radial network; it produces power generations with less cost & easy to install at the center of consumers. Also provide simplicity and low first cost, so, different feeders radiate from a substation and feed the distributors at one end. While in the further process, this test system will be designed for non-radial topology to handle the problems similar to a severely interlocked network by numerous transformers and feeder lines. This topology is typically utilized in communications planning and energy resource analysis.

PROPOSED METHOD

From the reliability aspect, considering load shedding results in more realistic optimization method. It is assumed that if the total DGs rating in an island are less than the total loads located in that island, then no loads can be served and all those loads are shed until the feeder under fault is repaired. Because allocation and sizing of distributed generation units have a discrete nature. SFLA in this paper is used to achieve an optimal response. To accelerate the algorithm convergence and to prevent the algorithm from converging it to a wrong answer, a new algorithm name called ALO is added to the original formulation to create a SFLA-ALO algorithm.

The major intention of this new proposed model is to discover the ideal size and assignment of the DG units, for voltage development, reduction of power loss, and maintaining steadiness in the power system. The proposed SFLA-ALO is tested on the IEEE distribution network and its outcomes indicate that there are a substantial reduction and enhancement in the power loss and voltage stability, respectively. The block diagram of the hybrid SFLA-ALO is demonstrated in figure 1.

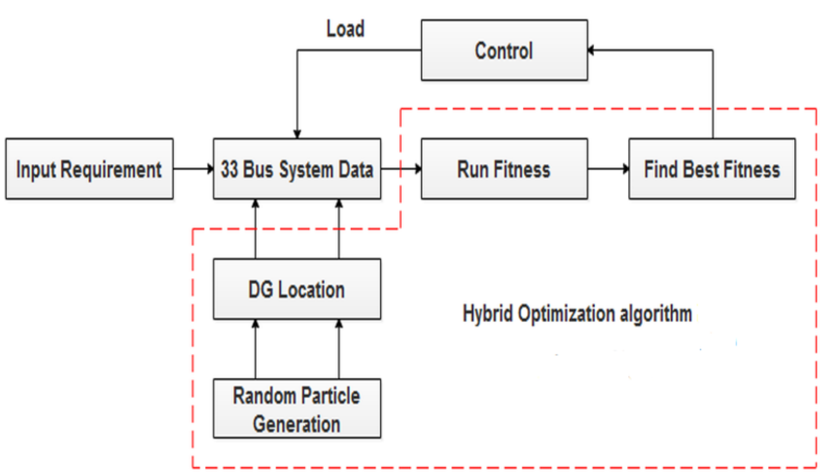
SFLA Based Optimal Location

SFLA is a populace-based search similarity that was impelled by memetic features. The calculation contains components of nearby search and worldwide data trade. Multi-dimensional complications for i^{th} frog is characterized as the equation (25).

$$X_i = X_{i1}, X_{i2}, \ldots X_{in} \tag{25}$$

In the interior of every single memeplex, the finest and poorest fitness of the frog is recognized as X_g. At that moment, a procedure comparable to PSO is exploited to increase the poorest fitness of the frog in the respective sequence. Consequently, the poorest fitness value of the frog's location is used and given in equations (26) & (27).

Figure 1. Block diagram of the proposed methodology



Alteration in a position of the frog is:

$$D_i = rand*\left(X_b - X_w\right) \tag{26}$$

Newly obtained location is

$$X_w = \ present\ location\ X_w + D_i \tag{27}$$
$$D_{max} > D_i > -D_{max}$$

where, rand is defined as a random number generated between 0 and 1 and the determined acceptable modification in the frog's location is specified as D_{max} .

But this procedure delivers an improved outcome which substitutes the frog with the worst value. Else the intentions in (9) and (10) are repetitive but then again with reference to finest frog (X_g substitutes X_b), p is specified as a number of frogs/memeplexes. The flowchart for SFLA with optimal DG placement is illustrated in figure 2.

DG and ESS Placement Using SFLA and ALO

STEP 1: Set line data/ bus data, frogs count, the total quantity of memeplexes, and frog amount in a memeplex; define shuffling count and the overall count of evolutions. Initially produce a random number of frogs/population.
STEP 2: Evaluate the analysis of load flow and calculate power losses once employing every frog inappropriate position. Recognize lowest loss-producing frogs by consolidating all the frogs in a downward manner based on fitness. Similarly, this frog is choosen as best frog.
STEP 3: Categorize both the best frog (Xb) and worst frog (Xw). Local/global search processes can be exploited for DG/ESS assignment. Substitute the poorest frog to the novel worst frog which is attained by local search.
STEP 4: Keep on updating the new count of population. Rearange the frogs and increase the shuffle computation, then move into STEP 2.
STEP 5: Once the shuffling count extended the limit, calculate the best value.
STEP 6: End.

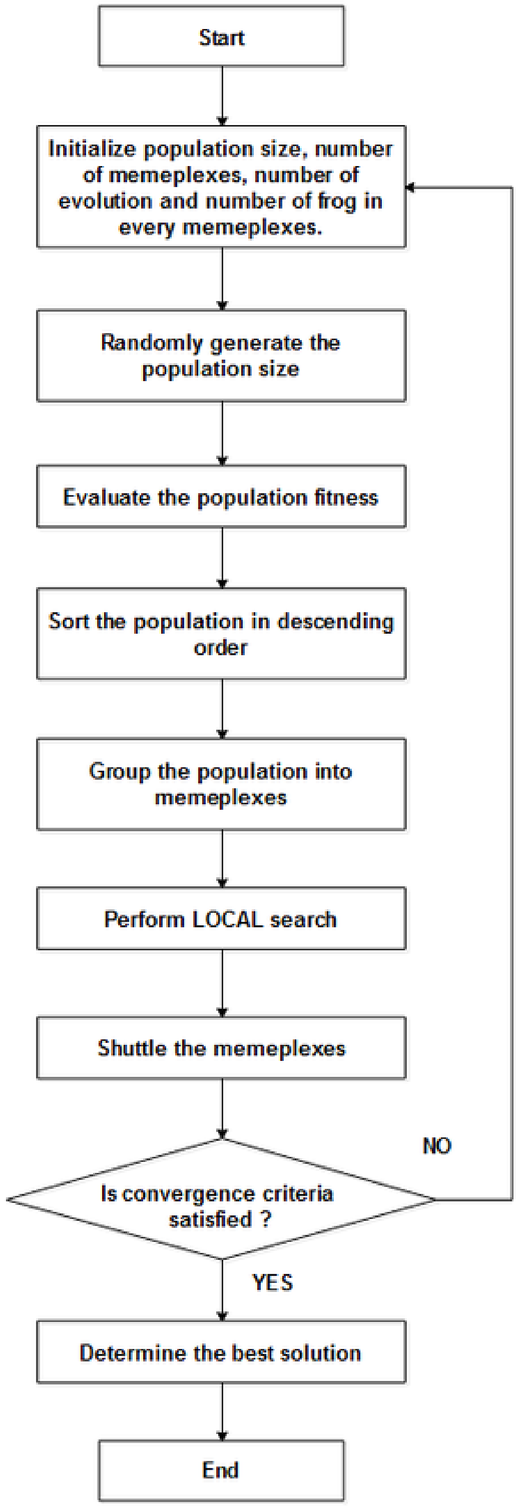
The Proposed SFLA-ALO is employed for below mentioned three scenarios, which are,

1 Single DG/ESS (one frog in one DG/ESS location)
2 Two DG/ESS (one frog in two DG/ESS location)
3 Three DG/ESS (one frog is placed in three DG/ESS locations). The location of DG gives minimum loss with reference to ideal location and size in the case of instantaneous assignment of two DG and ESS which injects reactive power.

ALO Based Optimal Sizing of DG and ESS

ALO emulates the hunting behavior of ant-lions in nature. ALO has primarily five processes and those are called random movement, the building of trap, trapping, preys catching, and re-building of traps. The location of ants are kept randomly in M_{ant} a matrix that is specified in equation (28):

Figure 2. Flowchart of SFLA for optimal DG and ESS



$$M_{ant} = \begin{bmatrix} Ant_{1,1} & Ant_{1,2} & \cdots & Ant_{1,n} \\ Ant_{2,1} & Ant_{2,2} & \cdots & Ant_{1,1} \\ \vdots & \vdots & \cdots & \vdots \\ Ant_{n,1} & Ant_{n,1} & \cdots & Ant_{n,d} \end{bmatrix} \tag{28}$$

Here $A_{n,d}$ designates the n^{th} assessment of a d^{th} variable; the number of ants is specified as n. The fitness of ant would be retained inside the M_{OA} matrix by using the objective function f that is assumed in equation (29):

$$M_{OA} = \begin{bmatrix} f[Ant_{1,1} & Ant_{1,2} & \cdots & Ant_{1,n}] \\ f[Ant_{2,1} & Ant_{2,2} & \cdots & Ant_{1,1}] \\ \vdots & \vdots & \cdots & \vdots \\ f[Ant_{n,1} & Ant_{n,1} & \cdots & Ant_{n,d}] \end{bmatrix} \tag{29}$$

$M_{antlion}$ and M_{OAL} are represented as location and fitness of ant-lions that is assumed in equation (30):

$$M_{antlion} = M_{OAL} = \begin{bmatrix} f([Ant_{1,1} & Ant_{1,2} & \cdots & Ant_{1,n}]) \\ f([Ant_{2,1} & Ant_{2,2} & \cdots & Ant_{1,1}]) \\ \vdots & \vdots & \cdots & \vdots \\ f([Ant_{n,1} & Ant_{n,1} & \cdots & Ant_{n,d}]) \end{bmatrix} \tag{30}$$

RESULTS AND DISCUSSION

The proposed SFLA-ALO is executed on both IEEE-33 and 69-bus RDS. Initially, the DGs are placed only in few locations and its solution set is obtained from each candidate location. But, some of the solutions cause restrictions in the distribution system. To overcome the aforementioned issues, the hybrid SFLA-ALO method is used, because, SFLA is mainly preferred due to the efficiency of its searching mechanism, and it removes the damages early for the duration of examining progression. In the hybrid SFLA-ALO, two main parameters of DG which are size and location, are calculated using the ALO method. The ALO is used to identify the test system over the DG rating, load flow and optimal DG placement. Hybrid SFLA-ALO outcomes show that DGs inclusion will results in lesser network loss and maintain the voltage of the system.

Analysis of SFLA-ALO in 33-Bus

The losses attained are lesser if the DG is used at lagging PF when compared to the DG used at unity PF, because the reactive power is obtainable at lagging PF. The outcomes attained are specified in Tables 1 and 2. Figure 3 indicates the Voltage profile at a unity power factor.

Table 1, describes the performance of DG placement with unity PF. Here, the real power loss before allocating the DG is mentioned as 211 kW, and the total reactive power loss previously assigning the DG units (base case) is stated at 143 kVAR. Finally, the proposed SFLA is used to attain the optimal size and location of DG, which is represented as 'DG size (placement)' which is = 1542.7 (30). Therefore the real power loss reduces to 125.1650, reactive power loss to 89.2868, achieves minimum bus voltage of 0.9412 with a cost of 31.104. From this table 2, it can be concluded that the proposed SFLA-ALO attains better performance and results when compared to existing methods.

Figure 4 indicates the voltage profile at the lagging power factor. Table 2 describes the data of 33 bus radial systems for optimal DG placement with a 0.9 power factor. Finally, the proposed SFLA is used to attain the optimal size and location of DG, which is represented as 'DG size (placement)'

Table 1. Performance of DG at unity PF

Parameters	Exclusion of DG	Proposed SFLA-ALO
Cost of real power dg	--	31.104
DG location	--	30
DG size (kW)	--	1542.7
Minimum bus voltage (p.u.)	0.9040	0.9553
Real power loss (kW)	211	125.1650

Figure 3. Voltage profile at a unity power factor

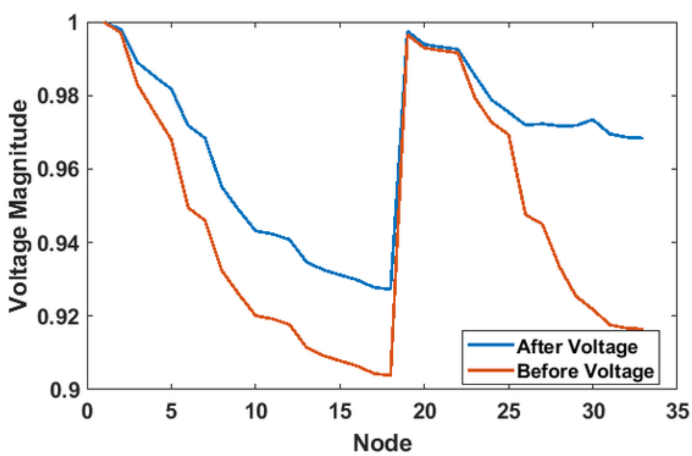
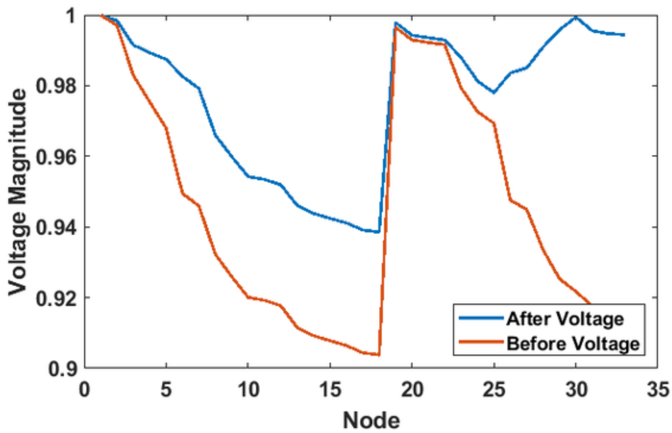


Table 2. DG at 0.9 power factor

Parameters	Proposed SFLA-ALO
Total reactive power loss (kVAR)	57.7324
Minimum bus voltage (p.u.)	0.9566
Cost of Energy losses ($)	6308.935
Cost of real power dg ($/MW h)	35.172
Cost of reactive power dg ($/MVAR h)	3.886

Figure 4. Voltage profile at 0.9 lagging power factor



which is = 1940.4 (6). Therefore the real power loss reduces with a minimum bus voltage of 0.9566 with a cost of 35.172. From this table, it determined that SFLA-ALO achieves better results when compared to existing methods.

Analysis of SFLA-ALO for 69 Bus

The outcomes attained from the proposed SFLA-ALO are specified in Tables 3 and 4. By implementing the reactive power of DG at unity pf, improved outcomes are attained.

Figure 5 indicates the voltage magnitude at 0.9 power factor. Table 3, indicates the data of 69 bus radial systems for optimal DG placement with unity power factor. Here, total real power loss before assigning the DG is mentioned as 225 kW, total reactive power loss before placing the DG units is mentioned as 102.109 kVAR. Finally, the proposed SFLA is used for optimal DG placement and size of 61 & 1872.7 kW, respectively, which reduces the real power loss to 83.2261, reactive power loss to 41.3486, achieves a minimum bus voltage of 0.9599. From this table, it can be concluded that the SFLA-ALO technique attains improved outcomes when compared to existing methods.

Table 4, clearly indicates 69 bus radial systems for optimal DG placement with a 0.9 power factor. Finally, the proposed SFLA is used for optimal DG placement as 61 with a size of 2217.3 which reduces the real power loss to 27.9636, reactive power loss to 16.4979, achieves a minimum bus voltage of 0.9728 with a cost of 40.16. From this table, it can be concluded that SFLA-ALO accomplishes improved outcomes while compared to existing methods.

The execution of the SFLA-ALO contains four dissimilar test cases which are used to examine the advantages of the proposed method.

Table 3. Performance of DG at unity PF

Parameters	Before DG	SFLA-ALO
DG location	--	61
Minimum bus voltage (p.u.)	0.9092	0.9599
DG size (kW)	--	1872.7
Total real power loss (kW)	225	83.2261
Total reactive power loss (kVAR)	102.109	41.3486

Figure 5. Voltage profile at 0.9 lagging power factor

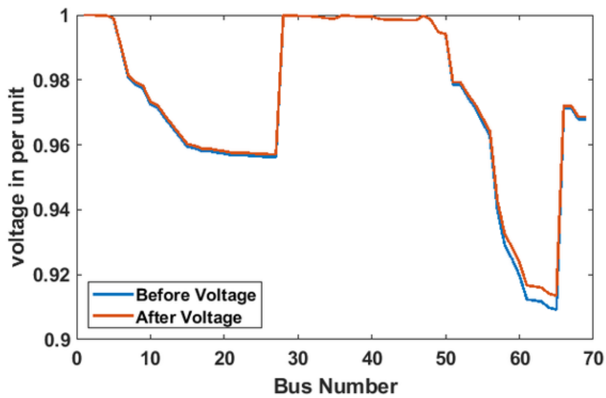


Table 4. Performance of DG at 0.9 PF

Parameters	Proposed SFLA-ALO
DG location	61
DG size (kVA)	2217.3
Total real power loss (kW)	27.9636
Total reactive power loss (kVAR)	16.4979
Bus voltage (p.u.)	0.9728
Cost of PDG ($/MWh)	40.16
Cost of QDG ($/MVARh)	4

Test case I: The process of Reconfiguration alone;
Test case II: The placement of DG installation alone;
Test case III: The process of Reconfiguration with single DG/ESS;
Test case IV: The process of Reconfiguration with multi DG/ESS;

33-Bus System

For executing Test case 1, the process of reconfiguration alone is included in the considered RDS without the addition of DG. The resultant voltage stability of the test case 1 is demonstrated in subsequent Fig. 6 and it's correspondent ideal values are attained and given in table 5.

Table 5. Performance analysis of test case 1

Test case 1	BEFORE Reconfiguration	SFLA-ALO
Minimum voltage:	0.91075pu	0.91525 pu
Power loss	202.68 kW	96.1831 KW
Loss Reduction	-------------	52.5443%
Tie switches	33 34 35 36 37	17 19 14 22 27

In test case 1, the switches are used in each bus of the IEEE 33 bus RDS. The voltage steadiness for test case 1 is shown in Fig. 6. This test case 1 is used to handle on/off modes of the switches. The operating modes of switches are controlled by the hybrid SFLA-ALO. The switch is in active mode (on) when the respective bus is corrupted by any of the faults. By disabling the respective bus, the other buses which are near to the affected bus are safe from the fault. From Table 5, it can be concluded that the power loss after reconfiguration, without DG unit, is lesser compared to the power loss before reconfiguration.

In test case 2, the 33-bus structure is used with a single DG. The test case 2 performance is shown in Table 6 and the stability of the voltage diagram is shown in figure 7.

In test case 2, the DG units are randomly placed in the IEEE 33 RDS. Here DGs are placed inappropriately because there is no way to determine the proper location and size for the respective DGs. From Table 6, it determined that power loss after reconfiguration, with only DG placements, is lesser when related to power loss before reconfiguration with only DG placements.

In test case 3, RDS is implemented by reconfiguration with single DG units. The test case 3 performance is illustrated in Table 7 and voltage stability analysis is shown in Figure 8. From table 7, the proposed SFLA-ALO achieves the minimum voltage of 0.91981 pu, reduced the power losses up to 67.426 kW with a reduction of 66.7328%.

Figure 6. Voltage stability for test case 1

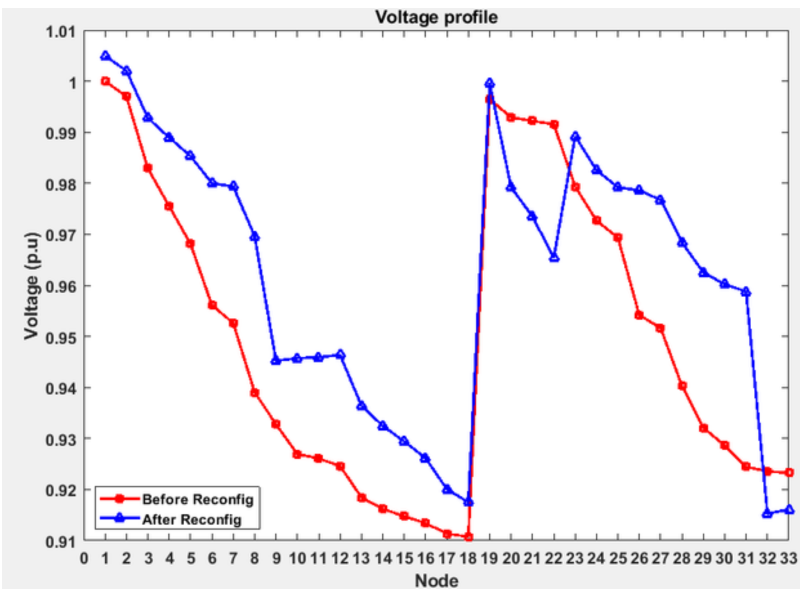


Table 6. Performance of test case 2

Test case 2	BEFORE DG	AFTER DG
Location of DG	-------------	33
Power loss	202.68 KW	145.9591kW
Loss reduction	-------------	27.9855%
Size of DG	-------------	0.15 MW

Figure 7. Voltage stability for test case 2

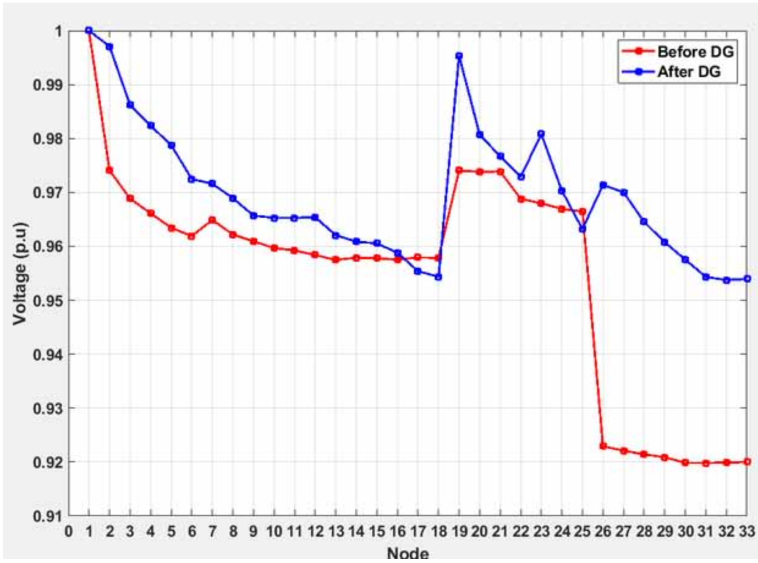
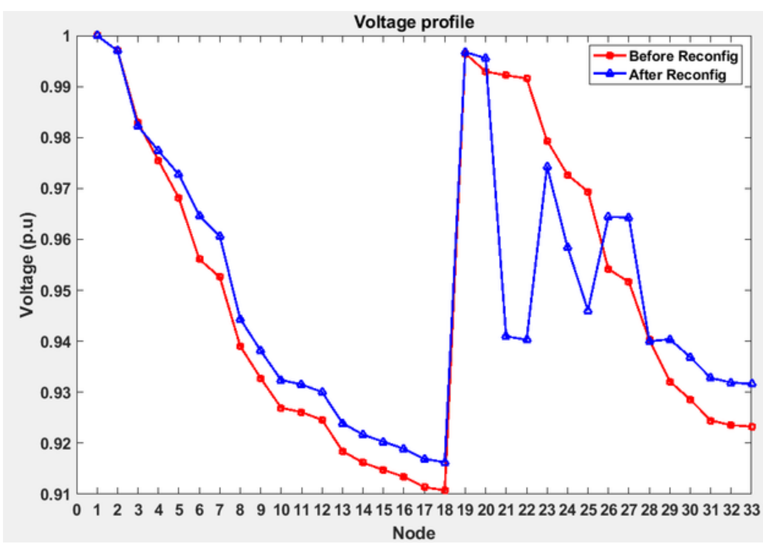


Table 7. Performance analysis of test case 3

Test case 3	BEFORE DG	SFLA-ALO
Minimum voltage:	0.91075pu	0.91981pu
Power loss	202.68 kW	67.426 kW
Loss reduction	-------------	66.7328%
Size (location of DG)	-------------	1.13 MW (25)
Tie switches	33 34 35 36 37	7 10 14 37 36

Figure 8. Voltage stability for test case 3



In test case 4, the ideal location and magnitude of the DG were carried out by the hybrid SFLA-ALO which is described in table 8. The locations of the multi DG unit obtained from hybrid SFLA-ALO are used to inject the real and reactive power in the IEEE 33 bus network. The power loss of the bus system with three DG units, after reconfiguration, is lesser, when compared to the power loss before reconfiguration.

Table 8. Performance analysis of test case 4

Test case 4	BEFORE DGs	SFLA-ALO
Minimum bus voltage	0.91075 pu	0.9547pu
Power loss	202.68 kW	45.71 kW
Loss reduction	-------------	77.4472%
Size (location of DG)	-------------	1.1368 (21), 1.4647 (33), 0.8199 (29)
Tie switches	33 34 35 36 37	7 8 27 14 36

ESS for 33 System

BPSO-SFLA

Table 9. Comparative table for ESS

Test case	BEFORE ESS	AFTER ESS
Power loss	202.68 kW	101.04354 kW
Power loss reduction	-------------	50.4357%
Size (location of ESS)	-------------	1.1506 kW, 1.8165 kW, 1.4285 kW (31 15 22)

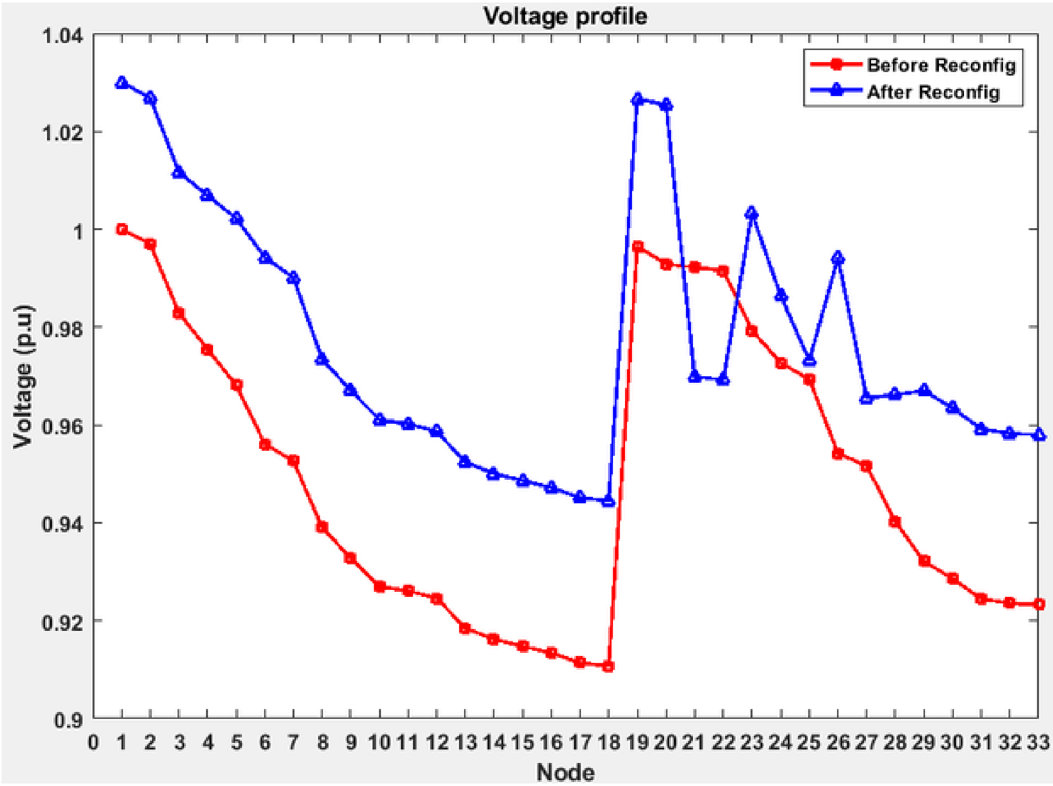
SFLA-ALO

Table 10. Comparative table for ESS

Test case	BEFORE ESS	AFTER ESS
Power loss	202.68 kW	81.9396 kW
Power loss reduction	-------------	59.5738%
Size (location of ESS)	-------------	1.1548, 0.5738, 0.5744 (18 32 30)

From this table 9 & 10, it can be determined that the proposed SFLA-ALO reduces the total loss from 202.68 kW to 81.9396 kW which indicates a 59.5738% of overall loss decrease. Figure 9 illustrates the voltage stability for test case 4.

Figure 9. Voltage stability for test case 4



ESS for 69-bus System

The stability of voltage for multiple ESS is presented in figure 10. From table 11, it is determined that the proposed SFLA-ALO method minimizes the total power loss from 224.9804 kW to 28.2072 kW which indicates an 87.2973% decrease of overall loss.

BPSO-SFLA

Table 11. Assessment for the test case 4

Scenario 4	BEFORE ESS	SFLA-ALO bases ESS
Minimum voltage:	0.90919 pu	0.96286 pu
Power loss reduction	-------------	87.2973%
Power loss	224.9804 kW	28.2072 kW
Size (location of DG)	0.4 MW	0.2, 0.172,0.824 (23, 53, 61)
Tie switches	69 70 71 72 73	3 36 63 11 38

Figure 10. Voltage stability of ESS

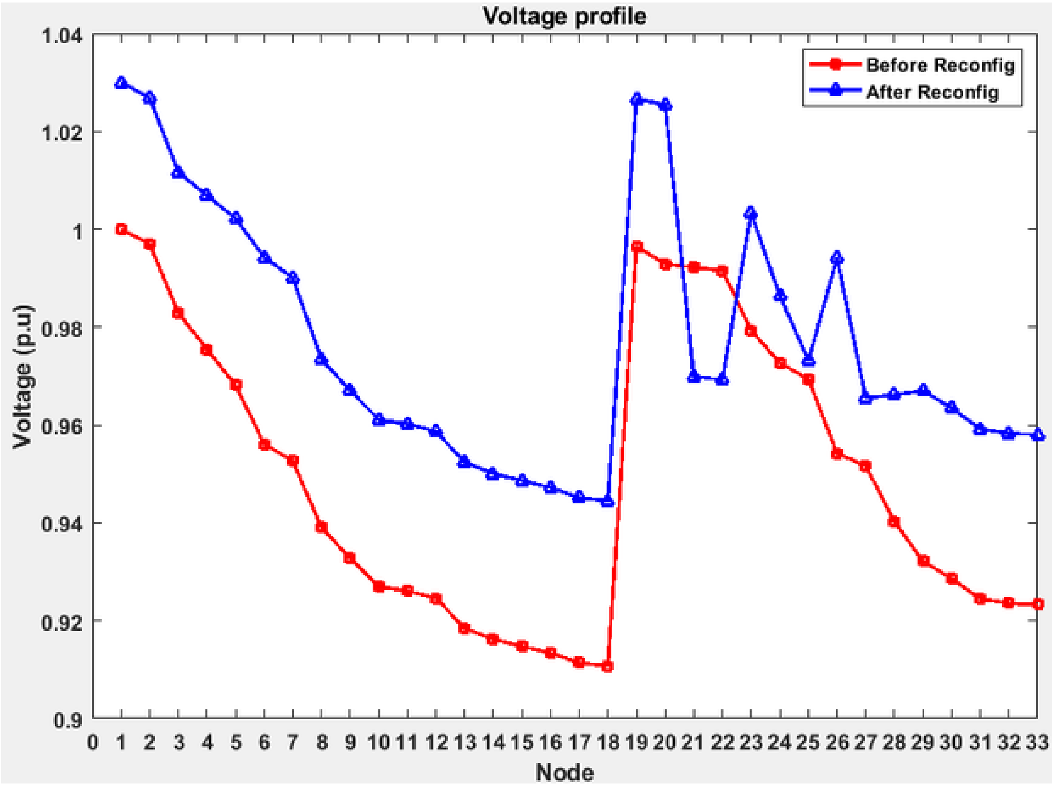


Table 12. Comparative table for ESS

Scenario	BEFORE ESS	AFTER ESS
Tie switches	69 70 71 72 73	23 36 32 54 69
Power loss	224.9804 kW	84.0275 kW
Location and size	-------------	1.0688, 1.3196, 1.5309 (48 44 3)
Power loss reduction	-------------	62.6369%

SFLA-ALO

The statistical study of the subsequent voltage is characterized in Tables 12 & 13. From these tables, it is determined that the proposed SFLA-ALO method reduces the power loss from 224.9804 kW to 80.0722 kW that designates 64.3956% of complete loss reduction. Table 14 illustrates the proportional investigation of the proposed SFLA-ALO methodology with SPEA (Hamida et 2018) and ACSA (Mahmoud et al. 2016).

The power loss of the hybrid SFLA-ALO is very less when compared to the Strength Pareto Evolutionary Algorithm [15] and ACSA [22]. The above comparison, clearly confirms that the proposed method achieved better performance in all the scenarios. Because the combination of SFLA-ALO gives an optimized location and size for the DG. Based on this optimal placement with effective size, the power loss and reliability are improved in the radial distribution network.

Table 13. Comparative table for ESS

Scenario	BEFORE ESS	AFTER ESS
Tie switches	69 70 71 72 73	61 7 4 38 53
Power loss	224.9804 kW	80.0722 kW
Location and size	-------------	0.413, 0.307, 0.934 (44 38 15)
Power loss reduction	-------------	64.3956%

Table 14. Comparative investigation of SFLA-ALO with Existing System

Scenarios	Methods	Minimum Voltage (p.u.)	Tie Switches	Power Loss (kW)	Power Loss Reduction (%)	DG Size (MW) [Location]
Scenario 1	SPEA (Hamida et 2018)	-	33 34 35 36 37	202.68	-	-
	ACSA (Mahmoud et al. 2016)	0.9413	7 14 9 32 28	139.98	30.93	--
	Hybrid SFLA-ALO	0.92564	9 21 15 3 19	91.1831	53.253	
Scenario 2	SPEA (Hamida et 2018)	-	33 34 35 36 37	105.63	47.88	2.22 [6]
	ACSA (Mahmoud et al. 2016)	-	33 34 35 36 37	74.26	63.26	0.7798 [14]
	Hybrid SFLA-ALO	-	33 34 35 36 37	69.284	65.81	0.1 [17], 0.42 [12], 0.61 [30]
Scenario 3	SPEA (Hamida et 2018)	-	9 14 27 33 34	80.59	60.23	1.93 [29]
	ACSA (Mahmoud et al. 2016)	-	-	-	-	-
	Hybrid SFLA-ALO	0.9366	4 14 28 11 9	64.1247	70.19	1.04 [18]
Scenario 4	SPEA (Hamida et 2018)	-	11 27 30 33 34	58.55	71.11	0.6910 [18] 0.7334 [29] 0.7429 [8]
	ACSA (Mahmoud et al. 2016)	0.9806	33 34 11 31 28	53.21	73.75	0.8968 [18], 1.4381 [25], 0.9646 [7]
	Hybrid SFLA-ALO	0.9798	14 17 25 31 33	39.15	86.1465	0.95 [28] 1.06 [32] 0.45 [18]

The simulation results of SFLA-ALO are compared to existing methods named SKHA (Chithra et al. 2017) and BPSO-SFLA which are depicted in table 15. Table 15 indicates that the proposed SFLA-ALO overcomes all the existing methods in all scenarios. The comparison, clearly shows that the proposed SFLA-ALO is higher in all the scenarios. Especially in placing multiple DG/ESS, the proposed SFLA-ALO effectively performs 86.1465% of power loss reduction by allocating multiple DGs in a specific location (18 28 32) which is much better when compared with the existing methods.

CONCLUSION

In this research, an ideal distribution and sizing of DG in RDS is presented using Shuffled Frog Leap Algorithm with Ant Lion Optimization (SFLA-ALO) to solve the multi-objective optimization problem. A Newton-Raphson based power flow method for RDS is utilized for function evaluation to analyze optimal power flow. Various case studies like the incorporation of two types of DGs, implementing single and multi-objective cases, placement of single and several DGs with variable and fixed PF, and combinations thereof are implemented. In this research, SFLA has been exploited for optimal DG locations and the suitable sizing is attained from the PLI technique to enhance the voltage

Table 15. Comparison table for all scenarios

Scenarios	Methods	Minimum Voltage (p.u.)	Tie Switches	Power Loss (kW)	Power Loss Reduction (%)	DG Size (MW) [Location]
Scenario 1	SKHA (Chithra et al. 2017)	0.9428	69 18 13 56 61	99.35	50.98	-
	BPSO-SFLA	0.94947	69 18 13 56 61	97.2984	51.99	-
	Hybrid SFLA-ALO	0.92564	14 56 61 69 70	91.1831	55.01	-
Scenario 2	SKHA (Chithra et al. 2017)	0.9697	69 70 71 72 72	86.77	57.18%	0.34 [54]
	BPSO-SFLA	0.9494	69 70 71 72 73	82.1119	63.488%	0.73 [45]
	Hybrid SFLA-ALO	0.9728	69 70 71 72 73	69.284	65.81%	0.1 [17], 0.42 [12], 0.61 [30]
Scenario 3	SKHA (Chithra et al. 2017)	0.9619	69 18 13 56 61	51.30	74.75	0.52 [24]
	BPSO-SFLA	0.94693	40 60 5 30 6	46.9193	77.11	0.952 [43]
	Hybrid SFLA-ALO	0.9737	4 14 28 11 9	43.1247	78.72	1.04 [18]
Scenario 4	SKHA (Chithra et al. 2017)	0.9736	69 17 13 58 61	40.30	82.08	1.0666 [61], 0.3525 [60], 0.4527 [62]
	BPSO-SFLA	0.9590	17 14 48 13 36	35.92	84.026	0.4 [21] 0.4 [32] 0.4 [63]
	Hybrid SFLA-ALO	0.9798	14 17 25 31 33	31.15	86.1665	0.45 [18] 0.95 [28] 1.06 [32]

stability, decrease real power losses, increase the reliability of the system, and gain commercial profit. The proposed method in this research achieves improved results, i.e., real power loss minimization and voltage stability enhancement with DG at 0.9 pf lag since DG functioning at 0.9 pf produces reactive power source to the network. Moreover, the DG working at 0.9 pf provides a better improvement in the results. In this paper, the problem of optimal placement and sizing of energy storage in RDS is studied and analyzed using the SFLA-ALO method. The results indicate that the proposed SFLA-ALO achieves better performances in terms of power loss reduction as 59.5738% and 64.5936% for 33 bus and 69 bus systems, respectively.

DECLARATIONS

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Conflict of Interest

The authors declare that they have no conflict of interest.

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G. Jayakrishna received B.Tech, M.Tech, and Ph.D degrees in Electrical Engineering from Jawaharlal Nehru Technological University, India in 1993, 2004, and 2013, respectively. Currently he is working as Professor in the department of Electrical and Electronics Engineering, St. Peter's Engineering College, India. His research interests include power quality, electrical drives, and power systems. He is life member of ISTE & IAENG.

N. Visali received the B.Tech degree from the JNTU College of Engineering, Ananthapuram, M.Tech from Karnataka Regional Engineering College in the year 1998, PhD Degree from JNTU A, Anantapur, in 2013. She is currently working as Professor in Department of Electrical and Electronics Engineering in JNTUA, Anantapur. Her research area is electrical distribution systems, Energy systems. She has published more than 20 technical papers in various international and national journals & presented many papers in national and international conferences in India and abroad.