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Optimal allocation of DSTATCOM and PV array in distribution system employing fuzzy-lightning search algorithm

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ABSTRACT

Increased electric energy demand is the major factor that cracks the researchers to focus on electrical energy demand to meet the challenge. Accordingly, the power loss should be minimized. Due to this, Distribution Flexible Alternating Current Transmission System (DFACTS) and Distributed Generation (DG) must be placed in an appropriate way in distribution systems. Fuzzy-Lightning Search Algorithm (FLSA) has been proposed to minimize the power loss in the radial distribution network by solving the optimal placement problem of Distribution STATic COMpensator (DSTATCOM) as DFACTS device and photo voltaic (PV) array unit as DG. The improved voltage profile values, less power loss and reduced stability problems have been attained by using FLSA. The proposed FLSA technique is evaluated through IEEE 30-bus system with MATLAB software. The power flow investigation has been done by Newton Raphson method. Optimum siting of DSTATCOM and PV array induced outstandingly decreased the losses to 7.0073 kW. The accomplished objectives and results have validated the FLSA is more advantageous than other optimization techniques.

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KEYWORDS
Distribution systems; DSTATCOM; FLSA; load flow control; optimization; PV array

1. Introduction

Nowadays, the generation of electrical energy is inadequate to the customers, and it should be resolved. Because of this, renewable energy sources are used because of its abundancy and pollution-free nature. The sustainable sources of energy such as wind power, solar energy, etc., are used as DG. Optimal placement of DG is very important to reduce losses and solve power quality problems. Inappropriate DG placement will cause voltage stability problems and it leads to high power losses [1]. On the contrary, proper placement of DG can improve voltage profile value, increased percentage of loss reduction and less operating cost [2]. By the consideration of environmental and economic aspects, optimal allocation of renewable-based DG and the location of energy pack up devices in distribution network have been proposed to reduce the operating cost and to reduce the environmental pollution [3]. Generally, operating cost can be calculated by sampling methods by solving optimal power flow to place DG in a proper way [4].

However, the sampling methods take a large computational time to determine DG placement. Robust optimization technique has been employed in recent times to decrease the computational cost [5]. Although, in real-time optimal siting calculations, robust optimization provides unfeasible solutions. Hence, an analytical method has been employed for locating DG in the distribution network [6]. An analytical method provides an exact solution nevertheless, it takes high computation time. To improve the voltage profile value, multiple DG units have been optimally located by loss sensitivity factor [7]. Jumping Frog Particle Swarm Optimization (JFPSO) technique has been used in DG to improve the performance of the system [8].

In photo voltaic (PV)-based DG, it demands reactive power because it delivers real power only [9]. For reimbursing the reactive power, DFACTS devices have been utilized. Consequently, it enhances the system's stability [10,11]. Using DFACTS devices increase the system load ability and it should be placed optimally to improve the voltage profile value by using a generic graphical user interface-based genetic algorithm (GA) optimization process [12]. Most of DFACTS devices, DSTATCOM is mainly employed due to its portable size and low cost. Usage of DSTATCOM decreases the power loss, reduces the fluctuations in voltage and it reduces the stability problems [13–15]. In the distribution system, the optimal allocation of energy storage devices decreases the power loss [16]. In the power system, the reactive power compensation using fuzzy gain scheduling controlled STATCOM for grid-connected PV system has been developed to improve the voltage stability by reduced voltage fluctuations [17]. To optimally allocate the capacitors in distribution system, an approximate reasoning method has been used. In this technique, fuzzy membership functions have been used to reduce losses [18]. The effect of high penetration of

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PV in the distribution network has been analysed with the help of optimal allocation of DSTATCOM by which the total voltage deviation has been reduced [19]. The optimal location and parameter setting of STATCOM has been analysed using Multi-Objective Differential Evolution Harmony Search Algorithm (MODEHS) to reduce the power loss of the system [20].

However, 13% of power generation is depleted as losses in the distribution sides. Hence, the voltage profile value gets down from its allowable value. Thus, several optimization approaches have been projected to optimally allocate DGs and DFACTS to obtain the most excellent outcomes. Currently, particle-based meta-heuristic algorithms are exploited to acquire the optimal solutions. GA [21] has an advantage of less computation time, but an optimal solution is not guaranteed. Particle swarm optimization (PSO) [22] offers robust control; however, there are some challenges to design optimal parameters. Improved harmony search algorithms (IHSA) [23] have an impressive advantage of easy implementation, thus it never finds a fulfilled result. Multi-objective grey wolf optimizer algorithm (GWO) [24,25] has a notable quality of easy implementation, though it has many disadvantages like slow convergence, low-solving precision, etc. Analytical crow search optimization (CSO) algorithm [26] can easily solve the complex engineering problems but the search speed is very slow, so the computation takes more time. Whale optimization algorithm (WOA) [27] can solve complex optimization problems easily, yet it is not good for searching optimal solutions. Bat algorithm [28] is simple and flexible to implement but the convergence rate is slow, and it has less accuracy. The characteristics of Improved Moth Flame Optimization (IMFO) Algorithm [29] are flexibility, robustness and higher exploration of the search space. Lightning search algorithm (LSA) [30] has a high convergence rate, but computational accuracy is low. LSA has been compared with other optimization algorithms and this survey shows that the LSA can produce better results than other optimization techniques [31].

Based upon the thorough literature review, to overcome all the above disadvantages and add the advantages of existing optimization algorithms, FLSA is proposed here to reach excellent convergence rate, robustness, high computational accuracy and obtain the best optimal solutions. The proposed FLSA has been used to calculate the optimal bus value of DSTATCOM and PV array in an IEEE 30-bus system. By optimally placing the DSTATCOM and PV array in the distribution system, the objectives can be attained. To determine the voltage profile values and the power losses presented in the system, the power flow analysis has been conducted using Newton Raphson method [32]. The proposed network which has been implemented is validated via IEEE 30-bus network. To evaluate the efficacy of the proposed system, the outputs found are compared to the existing algorithms performed for the optimum location of DSTATCOM and PV array. The obtained results of the proposed system compared to the results of the existing systems show that the loss of power presented in the proposed system is very less. This reduced power loss extremely satisfies the customer load demands.

The problem formulation including load flow analysis, DSTATCOM, PV array and fuzzy multi-objective functions are briefly resumed in Section 2. Proposed methodology is described in Section 3. Discussion on the results is demonstrated in Section 4 and conclusions are given in Section 5.

2. Problem formulation

The challenges that were found in the distribution systems are high power loss, poor voltage profile values and low voltage stability. Hence, these all should be minimized to reach the customer satisfaction. Because of this, FLSA optimization technique has been proposed. As LSA is an efficient optimization technique compared to other optimization techniques [31], it has been used to obtain the benefits of the distribution system. LSA has the capability to solve the real-world problems. Also, it has the advantages of high searching capacity, fast convergence rate and take less time for the iteration process. Hence, this effective LSA has been merged with fuzzy to obtain extremely effective outputs in distribution systems. To obtain the continuous power supply from the distribution system, DSTATCOM and PV array have been installed in the distribution system. For this, the optimal location of DSTATCOM and PV array must be necessary to reduce the power loss in the distribution systems. Hence, FLSA has been used to find the optimal solutions. Here, Newton Raphson method has been used for load flow analysis [32]. Also, the brief about DSTATCOM, PV array and fuzzy technique have been explained below.

2.1. DSTATCOM

DSTATCOM is a type of DFACTS device that has many advantages compared to other DFACTS devices such as Thyristor Controlled Series Compensator (TCSC), Static VAR Compensator (SVC) and Unified power flow controller (UPFC). Some advantages of DSTATCOM are high-speed response, portable in size, reduce power loss and voltage transients as well as the capacity to produce or absorb the reactive power when the distribution system voltage drops. Hence, the stability and reliability of the distribution system have been maintained excellently. So, the power supply never fails, and the customers will get a good quality power supply with the placement of DSTATCOM. Hence, the optimal allocation of DSTATCOM with FLSA is necessary to highly reduce the power loss in the distribution system.

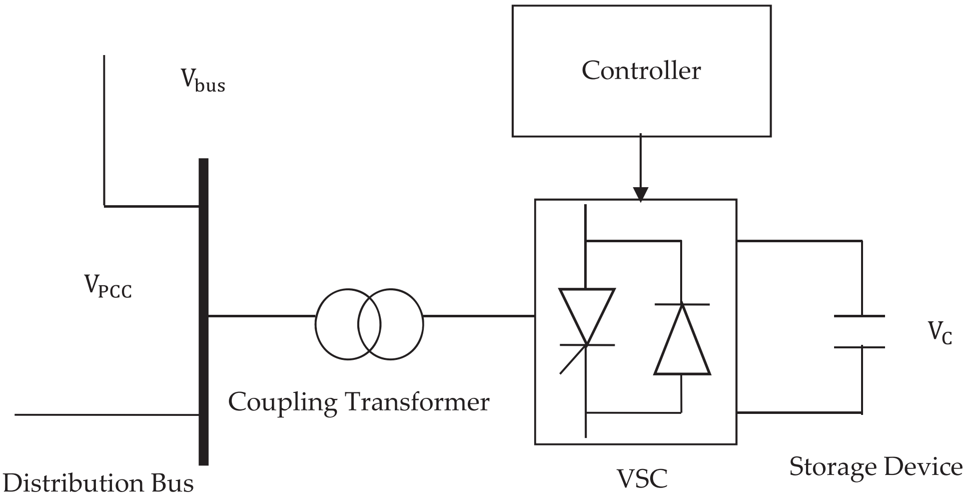

Figure 1. DSTATCOM block diagram.

Also, DSTATCOM is a shunt device in which the active and reactive power at bus can either be inserted or absorbed. However, DSTATCOM is an energy storage device because it provides constant DC link voltage. Furthermore, DSTATCOM behaves as synchronous voltage source which can control the bus voltage and power factor. The controller of DSTATCOM uninterruptedly checks the line waveform with reference signal to reduce voltage fluctuations. DSTATCOM contains voltage source inverter (VSC), controller and a set of coupling transformers which are shown in Figure 1.

VSC is connected to the energy storage device. In VSC, the DSTATCOM produces an alternating current (AC) voltage. The coupling transformer has the leakage reactance, and its value appears behind the AC voltage. Because of this, there is a true and reactive power transfer among DSTATCOM and the power network. The connecting point between power system and DSTATCOM is named as Point of common coupling (PCC). Voltages and current fed to the controller are compared to the base values. After that, the controller sends the feedback signals to the power system converter. At PCC, if the output voltage is more than the input voltage, then the DSTATCOM takes the additional reactive power and if the output voltage is less than the input voltage, then the DSTATCOM injects the reactive power by acting as a variable capacitor.

2.2. DSTATCOM modelling

The mathematical model of the DSTATCOM is represented in Figure 2. Consider the radial distribution system in which the electrical energy is provided from the single side. The DSTATCOM installed in bus m+1 is shown below. In this, the line resistance is represented as "r_m" and the line reactance is represented as "X_m". At bus "m", $p_m + jq_m$ load is connected and in bus "m + 1", $p_{m+1} + jq_{m+1}$ load is present. The voltage at buses "m" and "m + 1" are represented as "V'_m" and

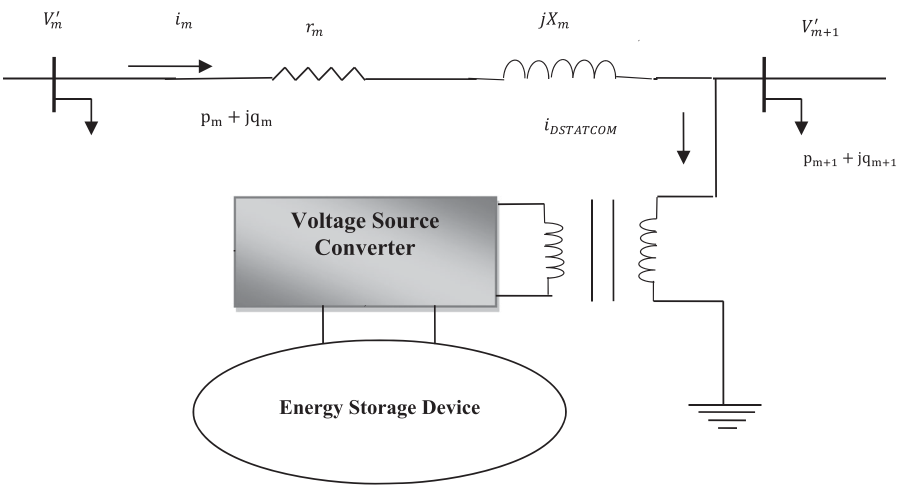

Figure 2. Modelling of DSTATCOM.

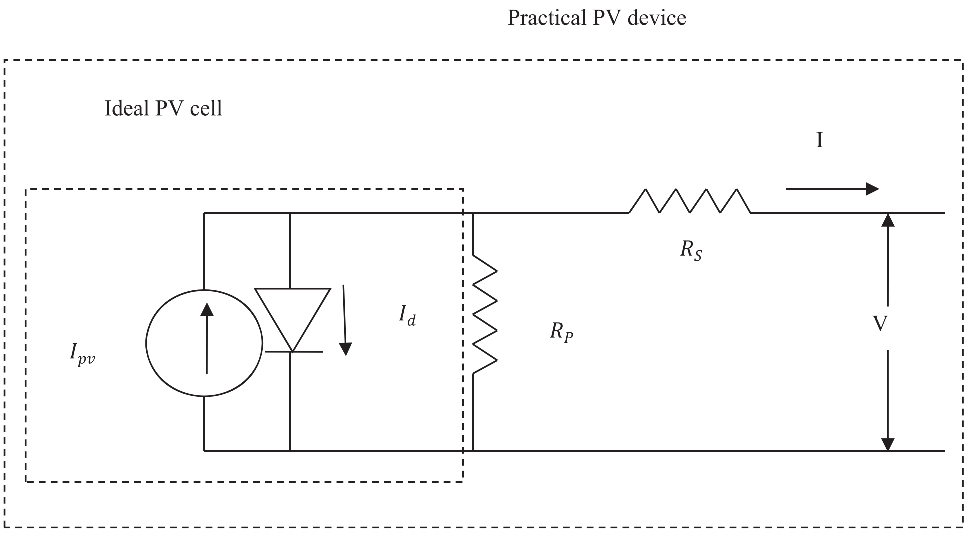

Figure 3. Equivalent circuit of PV cell.

"V'_{m+1}," respectively. The voltages at the bus in the conventional radial system and are always less than 1.5 pu and the maximum capacity of DSTATCOM is 3MW. To enhance the voltage profile value, the optimal bus value should be found to place the DSTATCOM in it.

At bus "m", the voltage is represented as $v_m\angle\theta_m$, the line current is $i_m\angle\alpha$. At bus m + 1, the injected voltage is,

$$v'_{m+1} = v'_{m+1}\angle\theta'_{m+1} \tag{1}$$

The injected current will be,

$$i_{DSTATCOM} = i_{DSTATCOM}\angle(\theta'_{m+1} + \pi/2) \tag{2}$$

The reactive power will be,

$$jq_{DSTATCOM} = i^*_{DSTATCOM}v'_{m+1} \tag{3}$$

Here, $*$ denotes conjugate of complex variable.

Thus, the injected voltage, injected current and the reactive power can be found by the above equations.

2.3. PV array

In PV array, PV cell is the fundamental device. The PV array uses sunlight as a source to produce electricity. To generate large amount of electricity, the area of PV cells should be enlarged. PV cells connected in parallel is called as PV panel. The series or parallel combination of PV panels are called as PV array. The maximum rating of PV array is 10 MW. The reasons for using PV array are providing clean energy, less maintenance cost and abundantly present in nature. Hence, the placement of PV array delivers continuous power supply to the customers. The optimal placement of PV array has reduced the power loss of the distribution system excellently with the help of FLSA technique.

2.4. PV array modelling

From the equivalent circuit of PV cell shown in Figure 3, the mathematical equations that represents the V-I characteristics of the PV cell can be formulated as,

$$I = I_{pv,cell} - I_{0,cell}\left[exp\left(\frac{qV}{aKT}\right) - 1\right] \tag{4}$$

Here, the current generated from the source is denoted as "$I_{pv,cell}$" and "$I_{0,cell}$" is the diode's reverse saturation current. Also, "q" is the Electric charge, "K" is the Boltzmann constant, and the temperature of the junction is "T".

The above equation represents the ideal PV array equation, but this case is not same for the practical PV array. Thus, for the practical PV array, the I-V characteristic equation includes additional parameters such as thermal voltage, series and parallel resistance, etc.

$$I = I_{pv} - I_0\left[exp\left(\frac{V + R_sI}{V_ta}\right) - 1\right] - \frac{V + R_sI}{R_p} \tag{5}$$

where I_{pv} is the photovoltaic current and I_0 is the saturation current.

2.5. Fuzzy multi-objective function

Figure 4 shows the triangular fuzzy membership function for the objective functions. The multi-objective function has been declared here to find an optimal allocation of DSTATCOM and PV array. Here, the three objective functions considered are: (1) reducing the power loss, (2) enhancing the voltage profile values and (3) improving the voltage stability of the system. Voltage and power loss reduction indices of distribution system is modelled by fuzzy membership functions. Here, triangular membership function is used as fuzzy

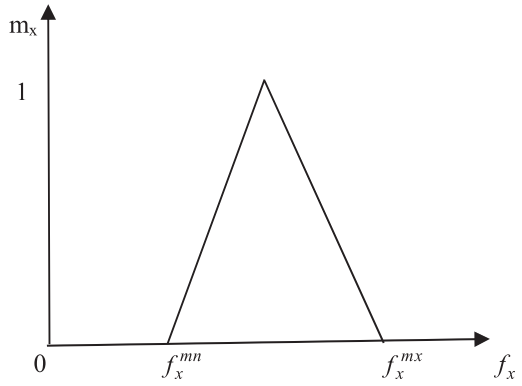

Figure 4. Triangular fuzzy membership function for objective functions.

membership function (m_x) and is expressed as follows:

$$m_x = \begin{cases} 1, f_x \le f_x^{mn} \\ \frac{f_x^{mx} - f_x}{f_x^{mx} - f_x^{mn}} & , f_x^{mn} \le f_x \le f_x^{mx} \\ 0, f_x^{mx} \le f_x \end{cases} \quad (6)$$

where f_x^{mn} and f_x^{mx} represents the best and worst solutions for objective function "x" respectively and f_x is the objective function and it can be written as follows:

$$f_x = \frac{t_x}{t_0} \quad (7)$$

where "t_x" is the attained value for xth term of the objective function and "t_0" is the base value of objective function.

Power balance constraint:

The total power injected into the PV array must be equal to the total power in the DSTATCOM and the total power loss as exemplified in the following equation.

$$\sum_{i=1}^{N} P_{PV,i} = \sum_{i=1}^{N} P_{D,j} + P_{loss} \quad (8)$$

Voltage limits:

Voltage value for each bus in the system must be within the range of the permissible bound value as shown in the following equation:

$$0.95pu \le |V_i| \le 1.10pu \quad (9)$$

Voltage stability index (VSI):

VSI between sending end and receiving end is given by the following equation:

$$VSI = \frac{4Z_{ij}^2 Q_i}{V_i^2 X_{ij}} \quad (10)$$

where "Z_{ij}" is the line impedance magnitude, "Q_i" is the receiving point reactive power, "V_i" is the sending point voltage and "X_{ij}" is line reactance. The bus that affords the maximum value of VSI will be chosen as the optimal bus for DSTATCOM and PV placement.

Total voltage deviation (TVD):

TVD is given as follows:

$$TVD = \sum_{m=1}^{k} |V_{mref} - V_m| \quad (11)$$

where "V_m" is the bus voltage magnitude value and "V_{mref}" is the reference voltage.

Power loss:

By reducing the power loss in the system, the efficiency can be enhanced in the radial distribution systems. The power loss can be determined by the difference between generated power and power demand. The power loss can be estimated by the following equation:

$$P_{loss} = \sum_{k=1}^{N_x} Loss_k \quad (12)$$

Net power calculation of bus "i" can be determined by the following equation:

$$P_i = P_{PV,j} - P_{D,i} \quad (13)$$

By the proposed approach, the optimal location of DSTATCOM and PV system can be determined.

3. Proposed methodology

LSA is an optimization algorithm that follows the phenomenon of natural lightning. The lightning discharge in a thunderstorm is being inspired for this lightning search algorithm. The fast particles used in this optimization algorithm are known as projectiles. Initial population size used in LSA is called the projectiles. The solution of this algorithm depends on step leader's energy.

In LSA, projectiles are classified into three types, named as, transition projectile, space projectile and lead projectile. The population of first step leader has been formed by the transition projectiles for solutions, the second projectile is the space projectiles which engage in exploration, and it aimed to be the leader, and the third type of projectile is the lead projectiles that try to discover and exploit the optimum result.

Transition Projectile:

Here, a leader tip is formed at the initial step then the transition makes an ejected projectile in a random direction from the thunder cell. Since the transition projectiles are formed randomly. The probability density function $f(x^p)$ is given as follows:

$$f(x^p) = \begin{cases} \frac{1}{n-m} for \,\&\, m \le x^p \le n \\ 0 \, for \,\&\, x < m \, or \, x^p > n \end{cases} \quad (14)$$

where "m" and "n" are the lower and upper limits and "x^p" is a random number used to find the solution. For population of "N_p", step leaders, $SLR = [slr_1, slr_2, slr_{3,....,}slr_{N_p}]$ and $P^t = [P_1^t, P_2^t, P_3^t, \ldots.., P_{N_p}^t]$ be the "N_p" random projectiles.

Space projectile:

The space projectile for a population can be described as, $P^s = [P_1^s, P_2^s, P_3^s, \ldots, P_{N_p}^s]$. The exponential distribution probability density function $f(x^d)$ along with shaping parameter "β" is represented as below.

$$f(x^d) = \begin{cases} \frac{1}{\beta} e^{-x^d/\beta}, & x^d \geq 0 \\ 0, & x^d \leq 0 \end{cases} \tag{15}$$

For a specific space projectile "β_i" the distance between the lead projectiles is taken as "P_i^s". Then, "P_i^s" can be obtained by the following equation:

$$P_{i\_new}^s = P_i^s \pm exprand(\beta_i) \tag{16}$$

where *exprand* is an exponential random number. If "P_i^s" is negative, then the generated random number should be subtracted since Equation (16) can produce only positive numbers.

Lead projectile:

The normal probability density function $f(x^k)$ can be represented as follows:

$$f(x^k) = \frac{1}{\alpha\sqrt{2\pi}} e^{-(x^k-\beta)^2/2\alpha^2} \tag{17}$$

where "β" is the shape parameter and "α" is the scale parameter.

Also, the position of "P^k" at step + 1 can be derived as follows:

$$P_{i\_new}^k = P_i^k \pm normrand(\beta_L, \alpha_k) \tag{18}$$

where *normrand* is a random number for the normal distribution function. If "P_{new}^k" delivers a better result at step + 1, then "P^k" is updated to "$P_{i\_new}^k$" and step leader "sl_r" is extended to a new position "$sl_{r_{new}}$". Else, they continue unchanged until the next step.

To advance the search capability of LSA by solving the premature convergence problem, FLSA is proposed here. In FLSA, fuzzy membership functions are hybridized with LSA parameters to obtain high accuracy and efficient optimal solutions. Also, the fuzzy numbers used in a distribution system is one of the most effective methods to get an accurate solution. Hence, the combination of fuzzy and LSA provides improved searching capability to solve the optimization problems, and it has a high convergence rate. Here, FLSA is used to optimally allocate DSTATCOM and PV array in a distribution network to attain the goals, which is summarized in the following steps.

Step 1 : Load the bus data and line data values to obtain the base case active and reactive power losses and voltage profile values at each bus by Newton Raphson's load flow analysis.

Step 2 : Set the values of LSA control parameters that are iteration numbers, channel time and upper and lower limits for the constraints.

Step 3 : To estimate the amount of KVAR's to be injected within the lower and upper constraints, initialize the random LSA population.

Step 4 : Create initial step leaders called transition projectiles.

Step 5 : Check whether the obtained value reaches the maximum population. If it satisfies the condition, it proceeds the next step otherwise, estimate the fuzzy membership value (m_j) and compute the fitness value. Save the result as the best result and then increment the value of "j".

Step 6 : Check whether the obtained value reaches the maximum iteration. If it satisfies the condition, it saves as the final optimal solution otherwise, follow the next step.

Step 7 : The projectiles (E_p) and step leader energies (E_{SLR}) are updated.

Step 8 : The ideal and nadir step leaders are updated for further projectile functions. Calculate the step leader's objective function f(SLR)).

Step 9 : Check whether the obtained value reaches the maximum channel time. If it satisfies the condition, update the direction and the kinetic energy otherwise, reject the bad channel and then reset the channel time to get the objective function value.

Step 10 : Remove the space and lead projectiles. Calculate the performance of the projectile's energies.

Step 11 : Repeat the same condition of Step 5, i.e. Check whether the obtained value reaches the maximum population. If the condition is not satisfied, update the LSA projectile value using fuzzy. By updating LSA, a new result is generated, and the fitness value of new result is compared with the fitness value of the best result of Step 5. If the fitness value of the newly created result has been better than the best result fitness value, then the newly created result is stored as best result.

Step 12 : If the condition is satisfied, check $E_p > E_{SLR}$.

Step 13 : If $E_p > E_{SLR}$, check the forking incident possibility. If yes, the fork forms two symmetrical buses and it reject the low energy channel to get new location after that the Step, i.e. increase the iteration and the channel time has been processed otherwise keep the SLR in same positions, and increase the iteration and the channel time.

Step 14 : Then go to Step 6. Check whether the maximum iteration is reached. If it satisfies, save

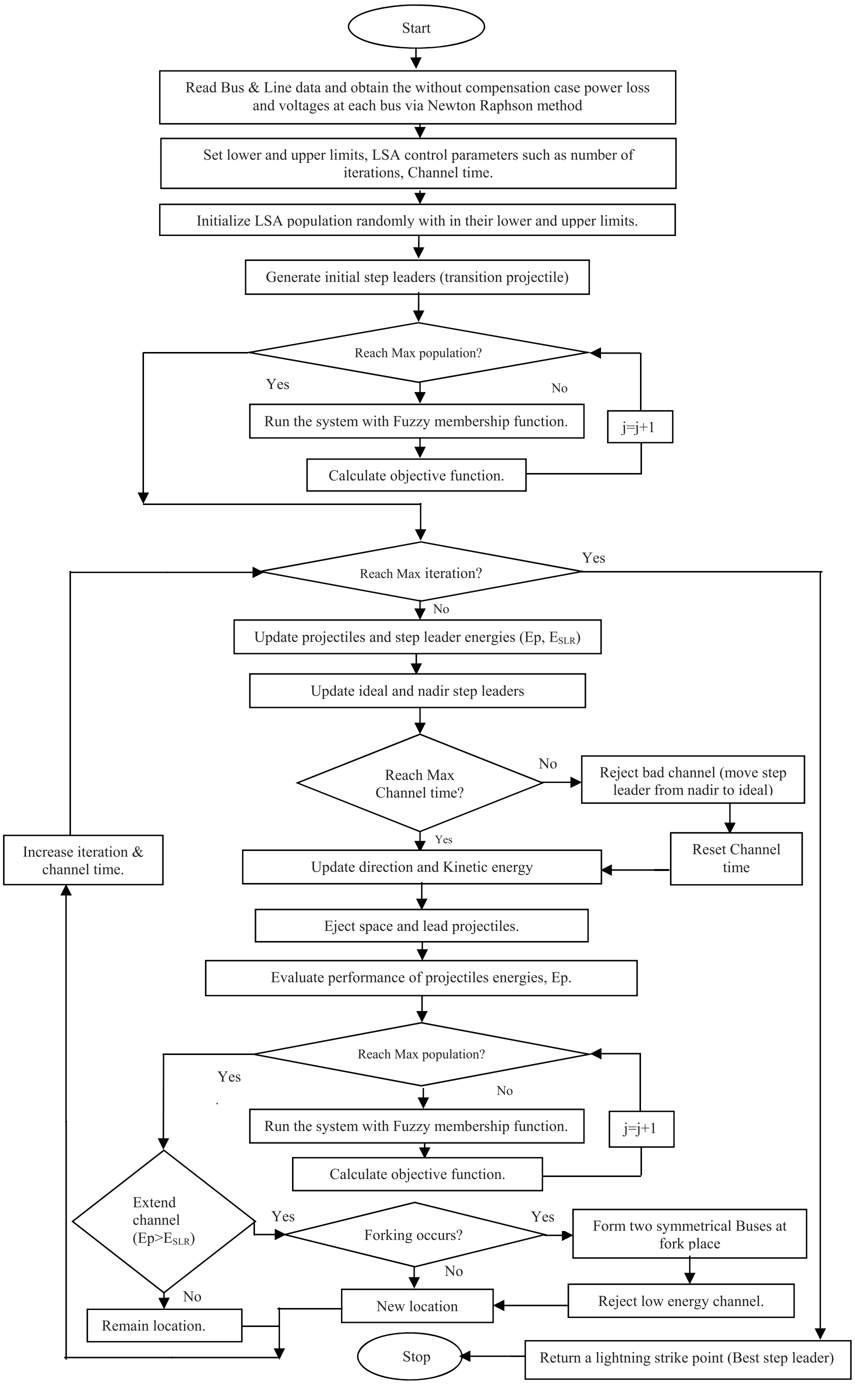

Figure 5. Flow chart of proposed method.

as the best solution, otherwise repeat the Step 7 to Step 13.

Step 15 : Display the optimal solution.

Figure 5 shows the flow chart of the proposed FLSA method. From this, the process of FLSA can be understood easily also it shows how the membership function is combined with LSA in a pictorial manner.

4. Results and discussion

In distribution systems, the load flow analysis has been used to calculate the voltage profile and the power loss of the system. Here, Newton Raphson method is used to accomplish the power flow analysis.

In this, assume that all the loads are constant. MATLAB software has been considered for modelling the power flow analysis by means of the Newton Raphson method. From this method, the base case active and reactive power values and the bus voltage values of the radial distribution network can be calculated. Also, the optimal location of DSTATCOM and PV array can be attained by the hybrid optimization algorithm called as FLSA approach. To estimate the effectiveness and performance of the proposed technique, a standard IEEE 30-bus system has been considered.

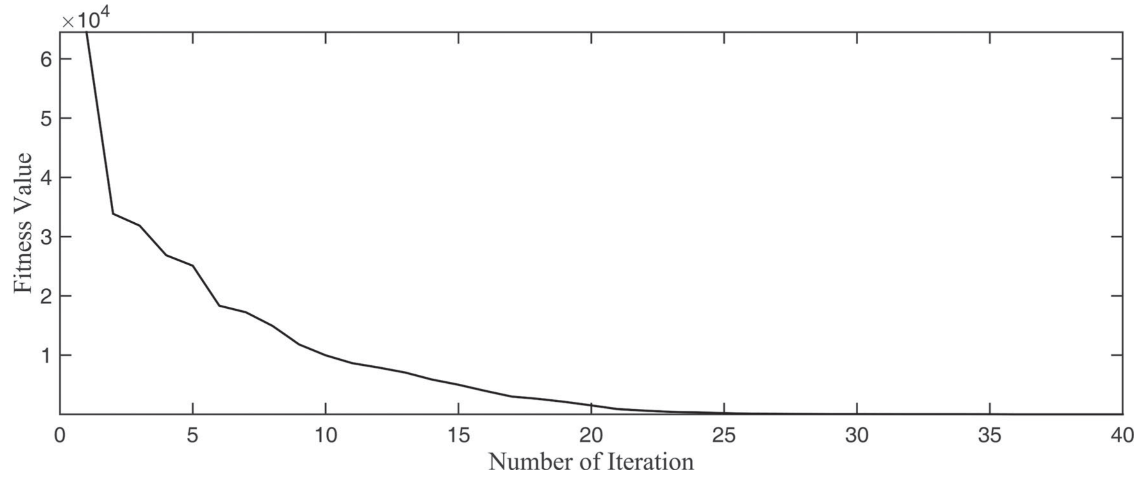

Figure 6. Fitness value for number of iterations.

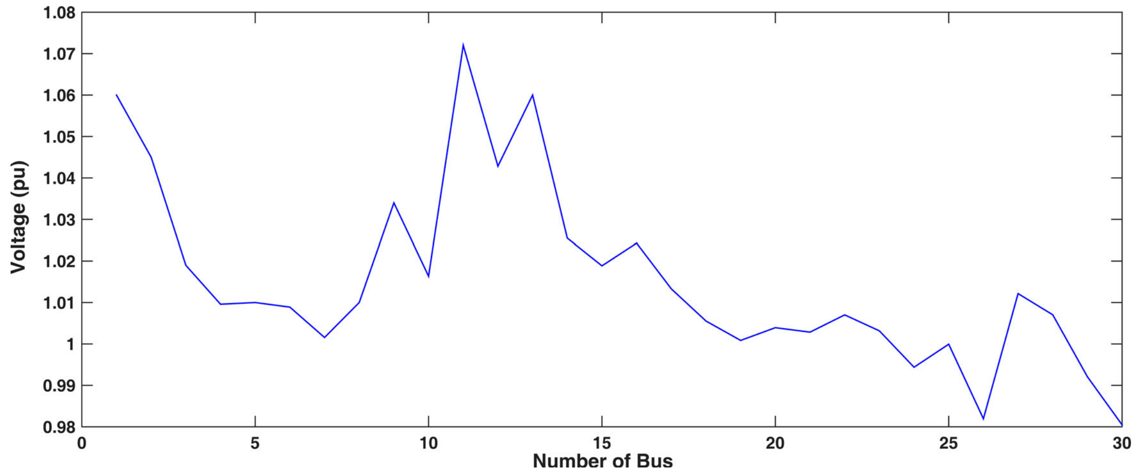

Figure 7. Voltage profile for network without DSTATCOM and PV.

IEEE 30-bus test system is a radial distribution system containing 30 buses and 29 branches. The line data and load data are used to execute the load flow analysis in MATLAB toolbox. The base network voltage is 11 kV and the base apparent power is 100 MVA.

Four different cases have been considered for analysing the efficiency of the FLSA method in IEEE 30-bus test system.

Case (1) : Base system without DSTATCOM and PV array
Case (2) : Base system with DSTATCOM
Case (3) : Base system with PV array
Case (4) : Base system with DSTATCOM and PV array

1. Base system without DSTATCOM and PV array. Using Newton Raphson technique, the power flow investigation has been done for an uncompensated IEEE 30-bus test system. From Figure 7, the minimum voltage is 0.9805 pu. The power loss of the system without compensation is 118.0815 kW and the VSI value is 0.8426 from Table 4. The base network voltage is 11 kV and the base apparent power is 100MVA. The optimal location can be found by using FLSA algorithm.

Figure 6 demonstrates the fitness value for number of iterations. The graph is plotted against the number of iterations of the process and fitness values. The fuzzy rules are combined with LSA to acquire the optimum

Table 1. DSTATCOM values in 14th bus.

DSTATCOM Optimal location	V_{sh} (pu)	Th_{st} (θ_{st}) (degree)	Q_{sh}(pu)
14	1.0500	−15.3785	−0.0519

Table 2. PV array values in 25th bus.

PV array Optimal location	V_{PV} (pu)	Th_{PV} (θ_{PV}) (degree)	Q_{PV} (pu)
25	0.9967	−15.8228	0.0099

Table 3. DSTATCOM & PV values in 14th and 25th bus.

DSTATCOM & PV array optimal location	V (pu)	Th (θ) (degree)	Q (pu)
14	1.0468	−−15.0653	−0.0188
25	1.1044	−16.4354	−0.2421

Table 4. Results of IEEE 30-bus system for four cases.

Case	Total power loss (kW)	% P_{loss} reduction	V_{min}	VSI	TVD	Optimal location (Bus No.)
1	118.0815	–	0.9805	0.8426	3.8007	–
2	21.0780	82.14	0.9911	0.9795	0.1926	14
3	12.6512	89.28	0.9806	0.9855	0.7215	25
4	7.0073	94.06	1.0100	0.9924	0.0094	14, 25

location of DSTATCOM and PV array in IEEE-30 bus system. The load flow analysis calculates the voltage of every bus in the IEEE-30 bus system.

Figure 7 illustrates the voltage profile graph for network without compensation. Here, the graph is plotted for voltage values versus number of bus.

2. Base system without DSTATCOM and PV array. By the proposed method, the optimal placement required for the DSTATCOM is calculated from voltage and power values assessed over the Newton Raphson power flow method. From the proposed algorithm, the optimal location of DSTATCOM is selected as 14th bus in the IEEE 30-bus system. In this case, the power loss has been reduced from 118.0815 to 21.0780 kW after the placement of DSTATCOM in the optimal place and the VSI value is 0.9795 from Table 4. It is detected from Figure 8 that at the 14th bus, the voltage profile before the installation of DSTATCOM is 1.0255 pu. After the optimal placement of DSTATCOM using FLSA at 14th bus, the voltage profile has been from 1.0255 to 1.0450 pu.

Figure 8 shows the voltage profile graph for network with compensation using DSTATCOM. The DSTATCOM values at 14th bus is calculated which is given in Table 1.

3. Base system with PV array. In this case, the PV array has been optimally located at the 25th bus with the help of FLSA algorithm. The power loss has been reduced from 118.0815 to 12.6512 kW after placing the PV array in the 25th bus and the voltage stability index (VSI) value is 0.9855 which are shown in Table 4. After the placement of PV array at bus 25, the voltage profile value has become 1.0000 pu from 0.9999 pu, as displayed in Figure 9.

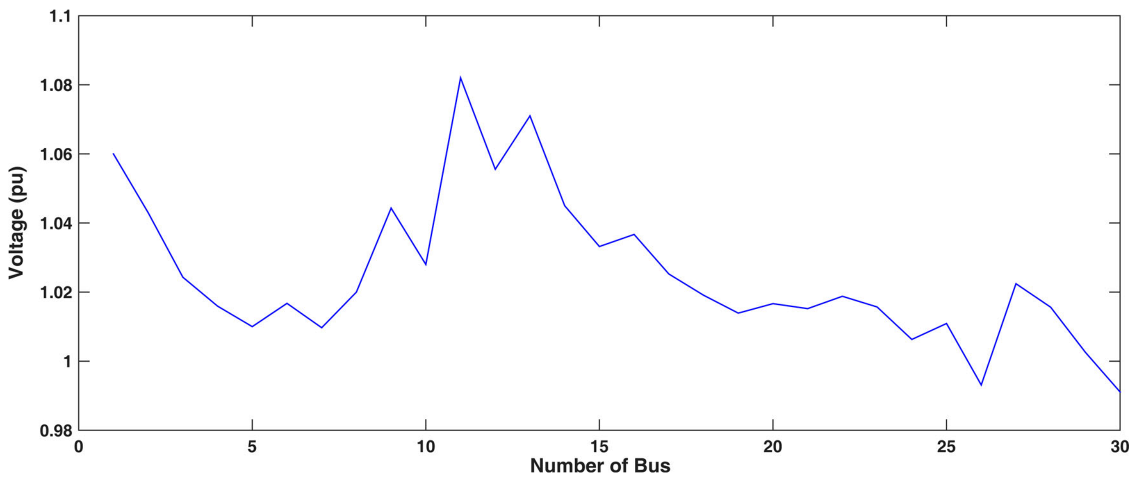

Figure 8. Voltage profile for network with DSTATCOM.

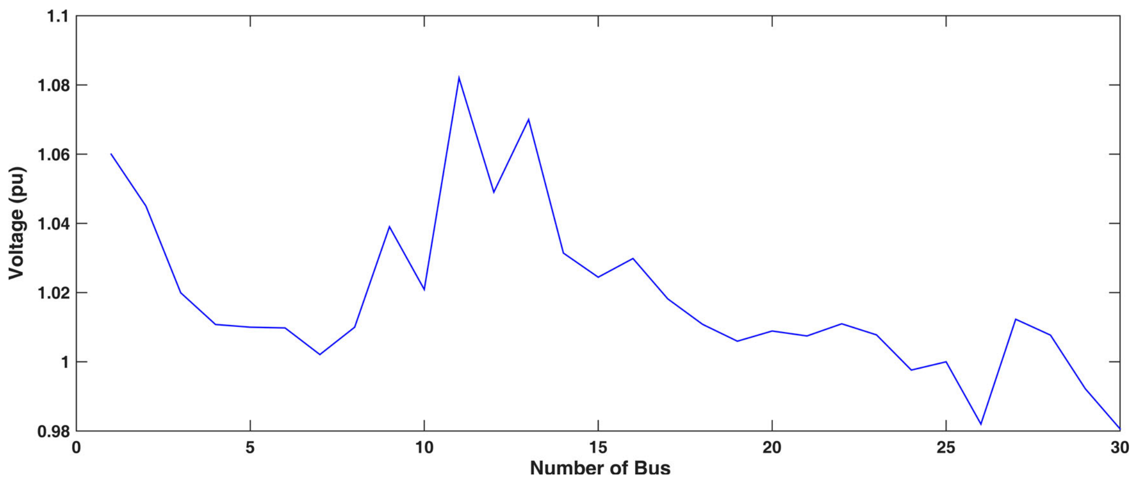

Figure 9. Voltage profile for network with PV array.

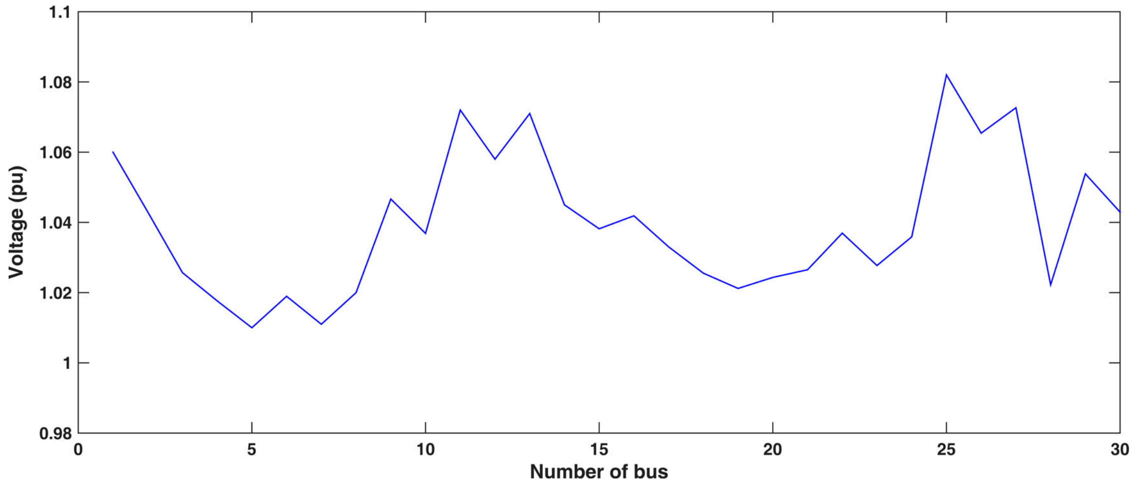

Figure 10. Voltage profile for network with DSTATCOM and PV.

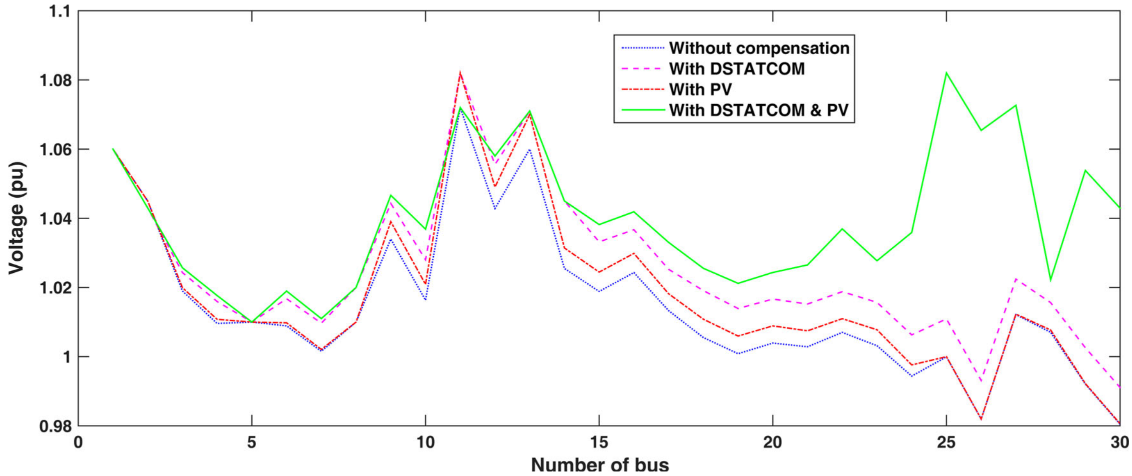

Figure 11. Comparison plot of four cases.

Figure 9 depicts the voltage profile graph for the network with compensation using PV array. The PV array values at 25th bus are calculated which are given in Table 2.

4. Base system with DSTATCOM and PV array. In this case, DSTATCOM and PV array have been optimally located at 14th and 25th bus with the help of FLSA algorithm. The power loss has been reduced from 118.0815 to 7.0073 kW after placing the DSTATCOM and PV array in the 14th and 25th bus and the VSI value is 0.9924 as shown in Table 4. The voltage profile values have become 1.0450 pu from 1.0255 and 1.0820 pu from 0.9999 pu, respectively, after the optimal placement of DSTATCOM and PV array using FLSA at 14th and 25th bus as represented in Figure 10.

Figure 10 displays the voltage profile graph for the network with a compensation using the DSTATCOM and PV array. Here, the graph will be plotted against the voltage and the number of bus. The DSTATCOM and PV array values at 14th and 25th bus are calculated, which are given in Table 3.

Figure 11 shows the comparison plot of the four cases. This expressed the voltage profile improvement in each case clearly. By this voltage profile improvement, the power loss has been reduced. The power loss values are separately plotted as chart in Figure 12 and it exhibits that the Case 4 (proposed case) has very low power loss.

Table 4 depicts the total power loss, power loss reduction in percentage, the value of minimum bus voltages, VSI, TVD and optimal locations for four cases correspondingly. The less power loss and the improved minimum bus voltage of Case (4) shows the efficiency of FLSA method. Also, in Case (4), the TVD value has been reduced nearly to zero. This indicates the proposed Case (4) has better voltage stability. Figure 13 represents the performance parameters of the four cases, and it displays that Case 4 gives an improved voltage value, enhanced voltage stability and less deviation in voltage to improve the power loss reduction.

Figure 14 depicts the voltage value for different load conditions. Here, the rated power of the load is taken and is compared with its corresponding voltage values. It is plotted against the "P_r" and voltage. It gives the comparison graph for the two cases that

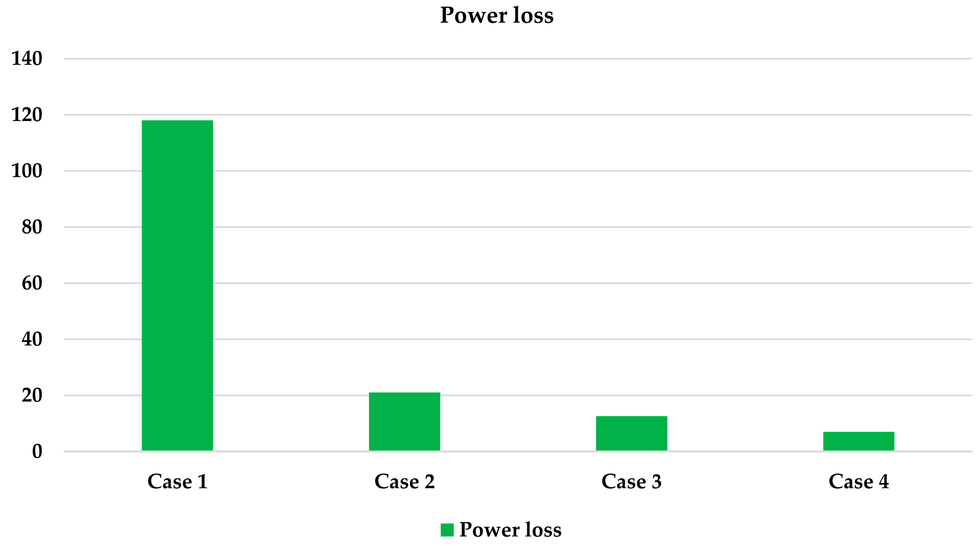

Figure 12. Power loss comparison of four cases.

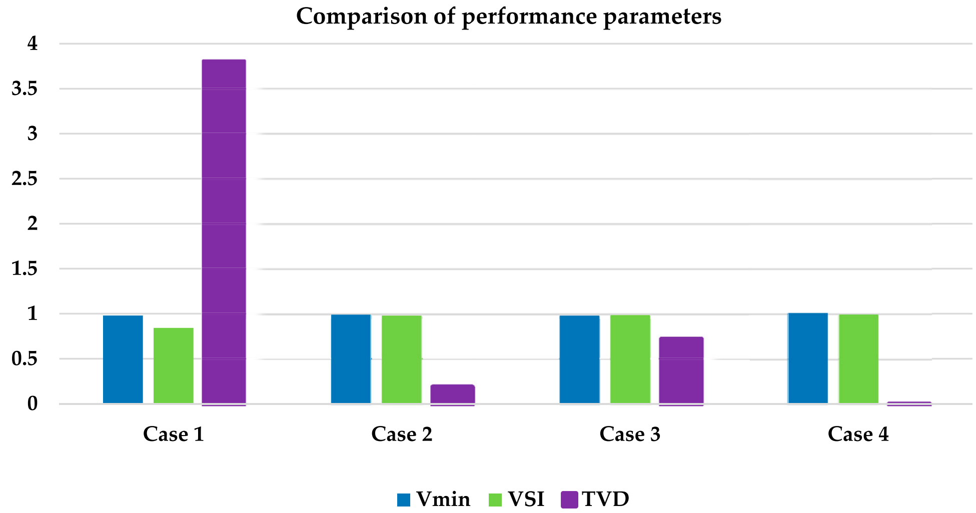

Figure 13. Comparison of performance parameters for four cases.

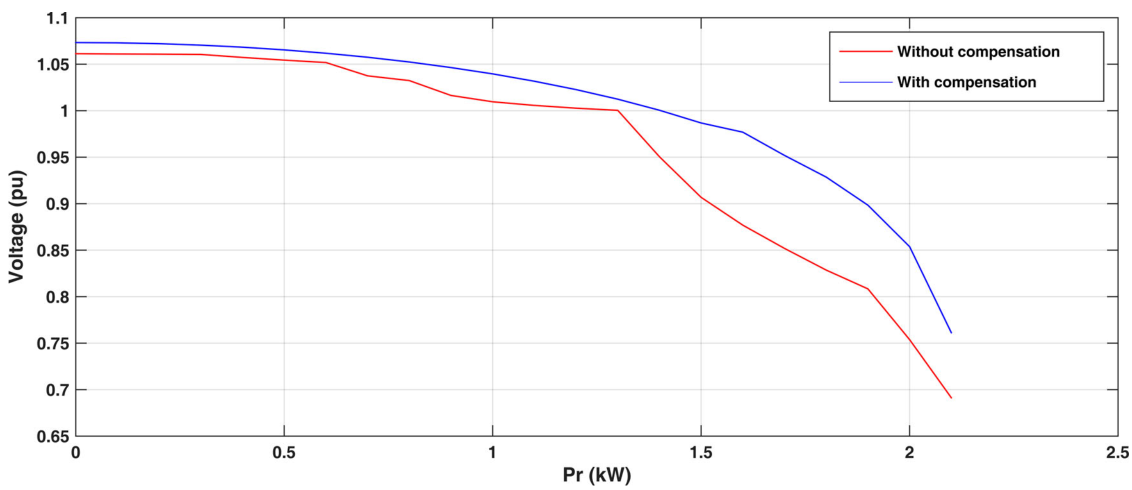

Figure 14. Voltage for various loads.

are without compensation and with compensation. It shows that the proposed system (with compensation) gives an improved voltage profile values for different load conditions compared with the base case (without compensation) values. Because DSTATCOM and PV array have been installed in the optimal place in the proposed case that is in the with compensation case by using the proposed optimization algorithm FLSA.

But in the base case or without compensation case, no DSTATCOM and no PV array have been installed.

Without DSTATCOM and PV array, the voltage profile ranges from 0.9805 to 1.0720 pu. Thus, the minimum voltage in the base case is 0.9805 pu. After the installation of DSTATCOM and PV array, the voltage profile in most of the buses has been improved significantly. Most of the bus voltages after the DSTATCOM and PV array placement are improved and are within the range, which can be seen in Figure 11. Table 4 shows the performance parameters of all the four cases. From this, the voltage profile value of proposed Case (4) has been improved compared to other three cases that can be realized. Also, it shows the improved voltage stability index value in Case (4) by comparing other three cases. Hence, the TVD and power loss values have been reduced in Case (4).

The optimal location of only DSTATCOM (Case 2), only PV (Case 3) and DSTATCOM with PV (Case 4) has been shown in Table 4. These optimal bus values of Case 2, Case 3 and Case 4 have been obtained by the proposed optimization algorithm FLSA using MATLAB software.

The parameters of proposed technique have been compared with the existing algorithms in Table 5 and it shows the effectiveness of the proposed FLSA.The maximum number of iterations are 40 and accuracy is 94.06% for proposed FLSA.

Table 5. Parameters of proposed method with existing methods.

	Technique			
Parameter	IMFO	MODEHS	JFPSO	Proposed FLSA
Maximum number of iterations	500	250	60	40
Accuracy (%)	–	–	90	94.06

Table 6 demonstrates the performance analysis of the IEEE 30-bus system with other approaches like analytical approach, PSO, etc. To validate the performance of the proposed FLSA, power loss, $\%P_{loss}$ reduction and optimal location of the proposed system are compared with other algorithms. The comparison table shows that FLSA algorithm has attained the objective conditions.

In Figure 15, % power loss reduction in the proposed FLSA is very high compared to the other optimization techniques, which has been shown. The voltage stability has been reached by improving the voltage profile values. Improvement in voltage profile proves that the power loss has been reduced. Finally, the proposed optimization technique FLSA has the super capability to reduce the power loss, improving the voltage profile value and enhance the voltage stability value compared with the existing methods can be seen clearly with the help of Table 6.

5. Conclusion

The proposed FLSA has been presented for the optimum allocation of DSTATCOM and PV array to reduce the power loss, improve the voltage profile value and increase the voltage stability value in the radial distribution system. Standard IEEE-30 bus test system has been employed to verify the efficiency of the proposed method and Newton Raphson power flow analysis has been performed for obtaining the voltage and power losses in the distribution system. The usefulness of the

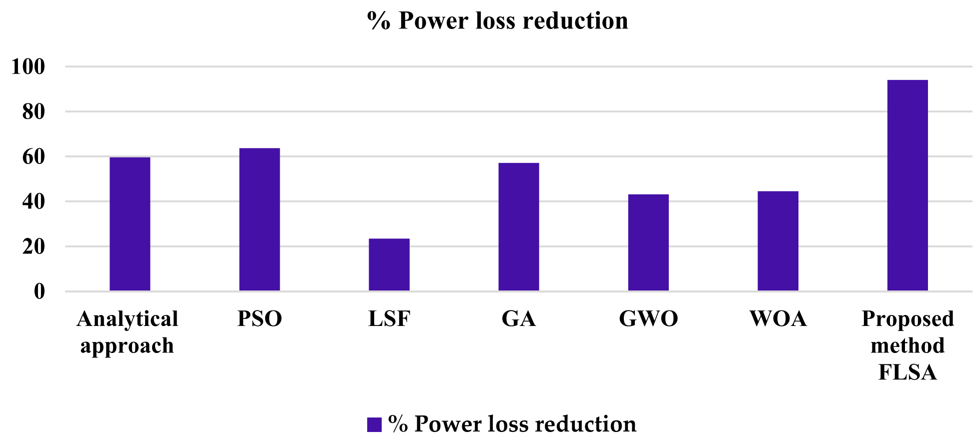

Figure 15. % Power loss reduction comparison for different optimization techniques.

Table 6. Comparative analysis of proposed method with existing methods.

References	Algorithm	Power loss (kW)	$\% P_{loss}$ reduction	Optimal location (Bus No.)
Acharya et al. [6]	Analytical approach	154.87	59.62	12
Varesi [22]	PSO	49.7	63.7	4
Ramamoorthy and Ramachandran [7]	LSF	2234	23.44	30, 24, 19
Mosbah et al. [9]	GA	4038	57.14	6
Ansari et al. [25]	GWO	118.452	43.17	27
Adetunji et al. [27]	WOA	7543	44.50	2, 6, 7
Proposed method	FLSA	7.0073	94.06	14, 25

proposed method has been analysed with four different cases in IEEE 30-bus system. Among four cases, the proposed case (4) which is the allocation of DSTATCOM and PV array in a network is found to be better compared to others. For the proposed system, the power loss is 7.0073 kW and $\%P_{loss}$ reduction is 94.06% by the improvement in voltage profile. This increases the system stability. The results obtained have been compared with the existing optimization techniques and found to be better than other algorithms. Hence, the proposed FLSA algorithm used in the distribution networks for optimal placement of DSTATCOM and PV array is more advantageous than other existing algorithms to meet customer load demands.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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References

[1] Keane A, Ochoa LF, Borges CL, et al. State of-the-art techniques and challenges ahead for distributed generation planning and optimization. IEEE Trans Power Syst. 2013;28(2):1493–1502.
[2] Haider W, Jarjees S, Mehdi A, et al. Voltage profile Enhancement and loss Minimization using optimal placement and sizing of distributed generation in reconfigured network. Machines. 2021;9:20.
[3] Home-Ortiz JM, Pourakbari-Kasmaei M, Lehtonen M. José roberto sanches mantovani. optimal location-allocation of storage devices and renewable-based DG in distribution systems. Electr Power Syst Res. 2019;172:11–21.
[4] Sheng W, Liu KY, Liu Y, et al. Optimal placement and sizing of distributed generation via an improved non dominated sorting genetic algorithm II. IEEE Trans Power Deliv. 2015;30(2):569–578.
[5] Wang Z, Chen B, Wang J, et al. Robust optimization based optimal DG placement in micro grids. IEEE Trans Smart Grid. 2014;5(5):2173–2182.
[6] Acharya N, Mahat P, Mithulananthan N. An analytical approach for DG allocation in primary distribution network. Elsevier Trans Electr Power Energy Syst. 2006;28:669–678.
[7] Ramamoorthy A, Ramachandran R. Optimal siting and sizing of multiple dg units for the enhancement of voltage profile and loss minimization in transmission systems using nature inspired algorithms. Sci World J; 2016:1–16.
[8] Gomez-Gonzalez M, López A, Jurado F. Optimization of distributed generation systems using a new discrete PSO and OPF. Electric Power Syst Res. 2012;84:174–180.
[9] Mosbah M, Arif S, Zine R, et al. Optimal size and location of PV based DG-unit in transmission system using GA method for loss reduction. J Electr Eng. 2017;17:10, Edition 4.
[10] Sunitha D, Senthilkumar V, Subramani C. Optimal placement and parameter setting of FACTS device using particle swarm technique for power system stability problems. J Electr Eng. 2017;17:1–4, Edition 4.
[11] Khan AN, Imran K, Nadeem M, et al. Ensuring reliable operation of electricity grid by placement of FACTS devices for developing countries. Energies, MDPI. 2021;14:1–21.
[12] Ghahremani E, Kamwa I. Optimal placement of multiple-type FACTs devices to maximize power system loadability using a generic graphical user interface. IEEE Trans Power Syst. 2013;28(2):764–778.
[13] Merini K, Rami A. Optimal allocation and voltage stability in electrical network by using STATCOM. J Electr Eng. 2016;16:1–9.
[14] Sanam J. Optimization of planning cost of radial distribution networks at different loads with the optimal placement of distribution STATCOM using differential evolution algorithm. Soft comput. 2020;24(17):13269–13284.
[15] Kumar N, Ramraj M. Combined reconfiguration and capacitor placement for distribution system volt/Var control through opposition based differential evolution algorithm. Autom J Control Meas Electron Comput Commun. 2015;56(2):140–148.
[16] Tang Y, Low SH. Optimal placement of energy storage in distribution networks. IEEE Trans Smart Grid. 2017;8(6):3094–3103.
[17] Ganesh R, Senthil Kumar V. Reactive power compensation using fuzzy gain scheduling controlled STATCOM for grid connected PV system. J Electr Eng. 2016;16:787–802. Edition 4.
[18] Ng HN, Salama MMA, Chikhani AY. Capacitor allocation by approximate reasoning: fuzzy Capacitor placement. IEEE Trans Power Deliv. 2000;15:393–398.
[19] Zhang T, Yu L. Optimal allocation of DSTATCOM considering the uncertainty of photovoltaic systems. IEEJ Trans Electr Electron Eng. 2020;15:355–363.
[20] Zhang T, Xu X, Li Z, et al. Optimum location and parameter setting of STATCOM based on improved Differential Evolution Harmony search algorithm. IEEE Access. 2020;8:87810–87819.
[21] Vatankhah M, Hosseini SM. Determination of optimum size and location of DG for loss reduction using genetic algorithm. J Electr Eng. 2012;6:1–9.
[22] Varesi K. Optimal allocation of DG units for power loss reduction and voltage profile improvement of distribution networks using PSO algorithm. World Acad Sci Eng Technol. 2011;5(12):1847–1851.
[23] Sri Kumar K, Ranadev K. Optimal allocation and sizing of multiple distributed generation units using improved HSA. J Electr Eng. 2018;18, Edition1.
[24] Selvaraj G, Rajangam K. Multi-objective grey wolf optimizer algorithm for combination of network reconfiguration and D-STATCOM allocation in distribution system. Int Trans Electr Energy Syst. 2019;29(11):e12100.
[25] Ansari MM, Guo C, Shaikh MS. Nitish chopra inzamamul Haq and lingbing shen. planning for distribution system with grey wolf optimization method. J Electr Eng Technol. 2020;15:1485–1499. https://doi.org/10.1007/s42835-020-00419-4.
[26] Pandey AK, Kirmani S. Optimal location and sizing of hybrid system by analytical crow search optimization algorithm. Int Trans Electr Energy Syst. 2020;30(5):e12327.
[27] Adetunji KE, Hofsajer I, Cheng L. Optimal DG allocation and sizing in power system networks using Swarm-Based Algorithms. A PREPRINT. 2020.

[28] Yang X-S, Gandomi AH. Bat algorithm: a novel approach for global engineering optimization. Eng Comput (Swansea). 2012;29(5):464–483.

[29] Sayed F, Kamel S, Taher MA, et al. Enhancing power system loadability and optimal load shedding based on TCSC allocation using improved moth fame optimization algorithm. Electr Eng. 2020;103(1):205–222.

[30] Hussain Shareef Q, Ibrahim AA, Mutlag AH. Lightning search algorithm. Appl Soft Comput. 2015;36:315–333.

[31] Abualigah L, Elaziz MA, Hussien AG, et al. Lightning search algorithm: a comprehensive survey. Appl Intell. 2021;51:2353–2376.

[32] Sharma P, Batish N, Khan S, et al. Power flow analysis for IEEE 30 Bus distribution system. WSEAS Trans Power Syst. 2018;13:48–59.