Simultaneous Allocation of Distributed Generators and Shunt Capacitors in a Distribution System

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ABSTRACT

Performance of a distribution system is negatively affected with the usage of non linear loads and rapid growth in electricity demand. It is possible to improve the voltage profile and reduce the power loss in a distribution system, by integrating distributed generators (DGs) and shunt capacitors (SCs). Identifying the optimal location and capacity of DGs and SCs are the crucial factors affecting the DS performance. This paper aims to reduce the power losses in the DS and facilitates an improvement in voltage profile with optimal allocation of DGs and SCs. First, the vulnerable nodes for placement of DGs and SCs are identified by loss sensitivity factor (LSF) technique. Next, the sizes of SCs and DGs at these corresponding locations are determined using a recently developed swarm intelligent technique dragonfly algorithm (DFA). Various constraints of the DS are included to estimate the objective function. To analyze the performance of the proposed method it is investigated on IEEE 69 bus radial distribution systems (RDS) considering constant power load at different load levels. Several case studies are conducted to analyze the performance of the DS. Three different load levels at different power factors are considered in the study. Initially few case studies are performed by considering single DG and single SC. Further the analyses are extended with multiple DGs and SCs. Finally, the proposed method is compared with other prominent methods accessible in the literature. It can be inferred from the analyses that simultaneous allocation of DGs and SCs in DS improves the overall performance of the system.

Keywords: Distributed Generators, Shunt Capacitors, Loss Sensitivity Factor, Dragonfly Algorithm, Power Loss Minimization, Voltage Stability Index, Distribution System

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Nomenclature

P_{m+1}	Real power flows out of bus m+1
Q_{m+1}	Reactive power flows out of bus m+1
$P_{m,m+1}$	Real power flows out of buses m and m+1
$Q_{m,m+1}$	Reactive power flows out of buses m and m+1
$R_{m,m+1}$	Resistance of line between buses m and m+1
P^{L}_{m+1}	Active power load demand at bus m+1
Q^{L}_{m+1}	Reactive power load demand at bus m+1
P^{DG}_{m+1}	Injected real power by the DG unit at bus m+1
Q^{DG}_{m+1}	Injected reactive power by the DG unit at bus m+1
Q^{C}_{m+1}	Injected reactive power by the shunt capacitor at bus m+1
β_{PDG}	Real power multiplier that value is set to one, if injected active power source (DG unit) is present otherwise the value is set to zero
β_{qDG}	Reactive power multiplier that value is set to one, if injected reactive power source (Type-C DG unit) is present otherwise the value is set to zero
β_{qcp}	Reactive power multiplier that value is set to one, if injected reactive power source (by the shunt capacitor) is present otherwise the value is set to zero
n	Total number of buses
n_b	Total number of branches
n_c	Total number of capacitors
$I_{m,m+1}$	Maximum permissible branch current limit of the buses m and m+1
V_m	Voltage magnitude at bus m
$P_{Totalloss}$	Total power loss in the system without DGs and SCs
$P^{DGSC}_{Totalloss(m,m+1)}$	Total power loss of the system with placement of DGs and SCs
V^{min}_{m}	Minimum voltage limit of the bus m
V^{max}_{m}	Maximum voltage limit of the bus m
P^{DG}_{min}	Minimum power generation limit of the system in kWs
P^{DG}_{max}	Maximum power generation limit of

	the system in kWs
pf_m^{DG}	Operating power factor of mth DG unit
P_m^{DG}	Size of mth DG unit in kW
Q_m^{DG}	Size of mth DG unit in kVAr
Q_C^L	Sum of total kVAr demand of the RDS

1. INTRODUCTION

In modern power systems there is a rapid growth in electricity demand, which in turn requires expansion of generation facilities. Existing generating stations are located far away from the consumer loads resulting in increased power loss in the system. Further voltage profile of the system is badly affected for the end consumers. This can be overcome by connecting distributed energy resources (DERs) i.e. DGs and Shunt Capacitors (SCs) in a distribution system (DS) at suitable locations. Renewable based generation is environment friendly and can be generated close to the load centers. Utilities show interest on promoting these non conventional energy resources due to the concern on environmental issues, decline of fossil fuels and liberalization of electricity markets. Optimal allocation of these sources in DS plays a vital role in reducing power loss and voltage profile enhancement. Inappropriate placement and sizing of these sources in the distribution network show a negative impact on the system performance. Optimal allocation of DGs in DS has become a challenging issue for researchers and planners working in this field.

DG and SC allocation problems are solved independently using several analytical, heuristic and search based optimization techniques. Researchers considered power loss minimization, voltage stability improvement and voltage profile enhancement as objective functions in solving DG and SC allocation problems. A few works attempted in recent years are discussed here. Attia et al. [1] developed a cuckoo search based optimization technique for allocating shunt capacitors in the DS to reduce operating cost and improve the voltage profile of the system. A bacterial foraging optimization technique along with LSF and VSI concepts used for optimal allocation of capacitors in the DS for minimizing power loss has been addressed in [2]. In [3] the gravitational search algorithm for optimal allocation of capacitors in the DS for minimizing real power losses was utilized. An improved harmony algorithm (IHA) for optimal allocation of capacitors for reducing power losses and total cost of the system is discussed in [4]. A combination of fuzzy and genetic algorithm (GA) based method proposed for identifying the optimal location of capacitor to reduce power loss, improve the voltage profile and power factor of the system has been addressed in [5]. Two bio inspired algorithms named Bat and Cuckoo Search (CS) used to find out the optimal location of a capacitor with minimizing real power loss and maximizing network savings are presented in [6]. Analytical and improved analytical expressions for finding out the best size and power factor of different types of DGs with minimizing real power loss of the system is discussed in [7,8]. A combination of GA and PSO techniques used to find out the best location and sizes of DGs for minimizing power losses, improving the voltage profile and VSI of the system is studied in [9]. A flower pollination algorithm (FPA) used to solve a DER allocation problem in DS with an aim of reducing system losses is discussed in [10]. A combination of simulated annealing technique and LSF approach for finding out the best locations and sizes of DGs with minimizing power loss and improving voltage stability of the system is presented in [11]. LSF technique and bacterial foraging optimization algorithm for finding out the optimal allocation of DGs for improving voltage stability, minimizing power loss and operational costs of the system is presented in [12]. A backtracking search algorithm used for identifying best locations and sizes of DGs with improving power loss reduction, voltage profile and network performance are discussed in [13]. A solar based DG allocation problem in DS using FPA is presented in [14]. The main aim of this approach is loss reduction of the system. An oppositional krill herd algorithm used for optimal allocation of DGs in RDS for minimizing energy losses has been discussed in [15]. A PSO technique used for optimal allocating of different types of DGs in the DS for minimizing power losses is presented in [16].

Many researchers inferred that DGs help in power loss minimization and voltage profile enhancement. But their continuous operation is limited by many factors. To overcome this problem, another better solution is to incorporate parallel capacitors simultaneously with DGs. This technique further minimizes the power loss and enhances the voltage profile of the system. So it is very important to consider both the capacitor and DGs simultaneously in the optimization problem for achieving better results. Very few researchers addressed this problem and analyzed the performance of the DS. An analytical approach to solve simultaneous allocation of DGs and capacitors for minimizing power loss is discussed in [17]. Simultaneous placement of DGs and capacitors considering different load models for improving voltage profile, minimizing real, reactive power loss of the system is presented in [18]. Simultaneous allocation of DGs and capacitors using a hybrid ICA and GA method for minimizing real power losses and improving the voltage profile and VSI of the system is discussed in [19]. A PSO technique for simultaneous placement of DGs and SCs for improving power loss reduction and voltage regulation of the system is presented in [20]. An improved variant teaching learning based optimization (ITLBO) technique for simultaneous allocation of DERs in the RDN for minimizing annual energy loss and improving the voltage profile of the system is discussed in [21].

$$P_{m+1} = P_{m,m+1} - \left(R_{m,m+1} \frac{P_{m,m+1}^2 + Q_{m,m+1}^2}{|V_m|^2} \right) - P_{m+1}^L + \beta_{PDG} P_{m+1}^{DG} \tag{1}$$

$$Q_{m+1} = Q_{m,m+1} - \left(X_{m,m+1} \frac{P_{m,m+1}^2 + Q_{m,m+1}^2}{|V_m|^2} \right) - Q_{m+1}^L + \beta_{qDG} Q_{m+1}^{DG} + \beta_{qcp} Q_{m+1}^C \tag{2}$$

$$|V_{m+1}|^2 = |V_m^2| + \frac{R_{m,m+1}^2 + X_{m,m+1}^2}{|V_m|^2} \left(P_{m,m+1}^2 + Q_{m,m+1}^2 \right) - 2 \left(P_{m,m+1} R_{m,m+1} + Q_{m,m+1} X_{m,m+1} \right) \tag{3}$$

From the literature, it is observed that different optimization techniques are used for solving DG, capacitor allocation problem separately. Very few authors consider the simultaneous allocation of these sources in the system and analyze the performance of the distribution network. Even though search based algorithms solved the complex optimization problems effectively, the actual challenge of using these techniques lies on how effectively the control parameters are tuned and balance between exploration and exploitation abilities during the optimization process. In most cases the analysis is performed for nominal load conditions. Since the load is variable in real time it is necessary to perform the study for variable load conditions to avoid negative impact on the system at other load levels. In this work an effective method based on combined approach of LSF and recently developed search technique DFA is implemented to solve the DG and capacitor allocation problem in the DS. Various loading conditions are considered and determine the exact dispatches of DGs and SCs at these load levels. The objective is to minimize power loss and facilitate an improvement in the voltage profile of the DS. In the case of DFA the balance between exploration and exploitation abilities are achieved by considering proper alignment and cohesion weights. The advantage of the proposed method is DFA determines only the sizes of DGs and SCs not the locations. So the computational time to reach optimal solution and convergence characteristics are improved. A detailed analysis explaining the benefits with the optimal allocation of DG units of different types i.e (Type-A i.e. injecting only real power), (Type-C i.e. injecting both active and reactive power) and shunt capacitors in the distribution system for different test cases are presented. Simulations are performed on IEEE 69 bus RDS. The efficacy of the proposed method is tested and validated by comparing with other existing methods available in the literature.

The remaining sections of the article are formulated as follows: Problem formulation considering different constraints are discussed in Section 2. A loss sensitivity factor technique for vulnerable node identification for placement of DGs and SCs is discussed in Section 3. Application of Dragonfly algorithm for determining optimal sizes of DGs and SCs is discussed in Section 4. Results and discussion followed by the conclusion is discussed in Section 5 and 6.

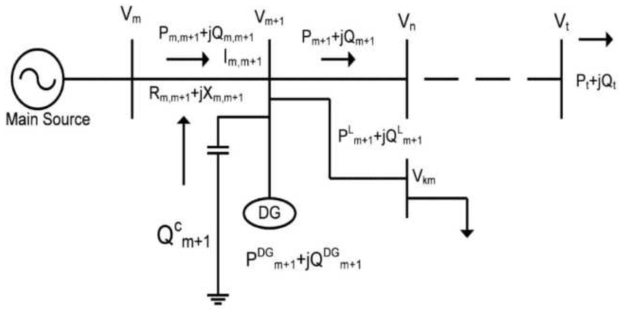

Fig.1: *Single line diagram of RDS with placement of DGs and SCs at random location.*

2. PROBLEM FORMULATION

Simultaneous allocation of DGs and SCs with appropriate sizes in the DS is a very significant issue. Improper location and sizing of these sources in DS reduces the system efficiency, and increases the power loss and operating cost. The objective of the proposed method is to place the DGs and SCs optimally in the DS for minimizing power loss. Analysis is performed at three different load levels, considering various operating constraints of the RDS.

The single line diagram of RDS with the placement of DGs and SCs at random locations is shown in Fig. 1. The load flow equations are calculated by backward/forward distribution load flow [22]. The real, reactive power flows and voltage magnitude at the buses m and m+1 can be mathematically stated as in Eq. (1)–(3) where $m = 1, 2 \ldots n$.

The equivalent current flows through the branch between the buses m and m+1 can be calculated as

$$I_{m,m+1} = \sqrt{\frac{P_{m+m+1}^2 + Q_{m+m+1}^2}{|V_{m+1}|^2}} \tag{4}$$

The real power loss associated with the branch between the buses m and m+1 may be computed as

$$P_{loss} = (m, m+1) = |I_{m,m+1}|^2 R_{m,m+1} \tag{5}$$

The total system loss is the summation of power losses in all the line sections, which is given as

$$P_{Total\ loss} = \sum_{m=1}^{nb} P_{loss}(m, m+1) \quad (6)$$

$$obj function = \min(P_{Totalloss}) \quad (7)$$

The power loss after placement of DGs and SCs optimally in the distribution system is computed as

$$P^{DGSC}_{loss(m,m+1)} = R_{m,m+1}\left[\frac{(P_{m,m+1} - \beta_{pDG} P_{DGm+1})^2}{|V_m|^2} + \frac{(Q_{m,m+1} - \beta_{qDG} Q_{DGm+1} - \beta_{qcp} Q^C_{m+1})^2}{|V_m|^2}\right] \quad (8)$$

The total power loss after placement of DGs and SCs in the RDS can be computed as

$$P^{DGSC}_{Total\ loss(m,m+1)} = \sum_{m=1}^{nb} P^{DGSC}_{loss(m,m+1)} \quad (9)$$

The objective function should satisfy different equality and inequality constraints of RDS that is given below.

2.1 Equality Constraints

Power balance constraints: The active and reactive power flow through all branches of RDS is to satisfy Eqs. (1) and (2) respectively.

2.2 Inequality Constraints

Bus voltage magnitude limits: The bus voltages must be within prescribed limits that are represented in Eq. (10).

$$V^{\min}_m \le V_m \le V^{\max}_m \quad (10)$$

where the minimum and maximum values of bus voltages at corresponding bus m is 0.9 and 1.1 p.u respectively.

Thermal limits: Branch current should not exceed its thermal limits

$$|I_{m,m+1}| \le |I_{m,m+1\ rated}| \quad (11)$$

DG capacity limits: In this study, two different types of DGs are considered that is Type-A DG units injecting only real power operating at unity power factor, Type-C DG units injecting both real and reactive power factor operating at optimal power factor [7]. Also, the capacity of DG units consider in the range of 10-80% of the system active power demand.

$$P^{DG}_{\min} \le P^{DG}_m \le P^{DG}_{\max} \quad (12)$$

where $P^{DG}_{\min} = 0.1\sum_{m=2}^{n} P^{DG}_m$ and $P^{DG}_{\max} = 0.8\sum_{m=2}^{n} P^{DG}_m$.

$$pf^{DG}_{\min} \le pf^{DG}_m \le pf^{DG}_{\max} \quad (13)$$

$$Q^{DG}_m = P^{DG}_m \tan(\cos^{-1}(pf)) \quad (14)$$

The power factor limits in case of Type-A DG units are $pf^{DG}_{\max} = pf^{DG}_{\min} = 1$.

2.3 Capacitor Constraints

The injected reactive power into the system using SCs and Type-C DG units are not exceeding the total reactive power demand of RDN.

$$\sum_{l=1}^{n_c} Q_{cl} \le 1.0 \sum_{l=1}^{n_l} Q^L_c \quad (15)$$

SCs available in industry are represented in Eq. (16)

$$Q_{cl} = KQ_0 \quad K = 1, 2, \ldots n_c \quad (16)$$

where K is an integer number and Q_0 is the minimum capacity of capacitance bank.

2.4 Computation of voltage stability index

Under the heavy load condition, it is necessary to improve the voltage profile of the DS. For maintaining the system stability, VSI value at each bus should be maintained near to unity [23]. For that, the VSI value at each node is determined and weak buses which are prone to voltage collapse are identified.

The VSI is improved with the optimal installation of DGs and SCs in the RDS. The voltage stability at the corresponding node of RDS is determined and it is given by [23, 24].

$$VSI(s) = \Big[|V_t|^4 - 4\{P_s r_{st} + Q_s x_{st}\}|V_t|^2 - 4\{P_s x_{st} - Q_s r_{st}\}^2\Big] \quad (17)$$

where $VSI(s)$ is the voltage stability index of the sth bus; r_{st} and xst are the resistance and reactance of the distribution line connected between the sth and tth bus.

3. LSF TECHNIQUE FOR IDENTIFYING WEAK NODES FOR SC AND DG PLACEMENT

LSF technique is utilized to identify the weak nodes, which are prone to high loss reduction when real and reactive power injected by SCs and DGs is put in place [25]. The initial identification of these candidate buses minimizes the problem search space for optimization procedure.

In Fig. 1, the power loss at the buses m and m+1 can be determined with the help of the following equation that is

$$P_{line\ loss} = \left(\frac{P_{m+1,eff}^2 + Q_{m+1,eff}^2}{|V_{m+1}|^2}\right) R_{m,m+1} \quad (18)$$

The real and reactive power loss sensitivity factors (RPLSF and RAPLSF) are calculated by taking the partial derivative of the power loss with respect to (w.r.t.) active and reactive power injection. They are given in Eq. (19) and Eq. (20).

$$\begin{aligned} RPLSF(m, m+1) &= \frac{\partial P_{line\ loss}}{\partial P_{m+1,eff}} \\ &= \left(\frac{2P_{m+1,eff}R_{m,m+1}}{|V_{m+1}|^2}\right) \end{aligned} \quad (19)$$

$$\begin{aligned} RAPLSF(m, m+1) &= \frac{\partial P_{line\ loss}}{\partial Q_{m+1,eff}} \\ &= \left(\frac{2Q_{m+1,eff}R_{m,m+1}}{|V_{m+1}|^2}\right) \end{aligned} \quad (20)$$

The RPLSF and RAPLSF are computed at each bus using distribution load flow and obtained values are arranged in descending order of their loss sensitivities. The buses which have highest real and reactive power loss sensitivities with respect to real and reactive power injections are taken as candidate buses for DG and capacitor installation. In Fig. 2, RPLSF and RAPLSF at all the buses in a 69 bus RDS are shown. The top 15 buses with highest RPLSF and RAPLSF are considered for placement of DGs and SCs.

In 69 bus RDS, the optimal buses considered for DG and capacitor placement are 61, 64, 49, 12, 65, 21, 11, 17, 50, 59, 59, 68, 34, 10, 7 and 33.

4. DRAGONFLY ALGORITHM

Dragonfly Algorithm (DFA) is proposed by Seyedali Mirjalili in the year 2015 [26]. The inspiration to develop this algorithm is based on swarming behaviours of dragonflies. Dragonflies are predatory insects that predate small insects in nature. The life cycle of dragonflies includes two different stages that are nymph and metamorphism. The greater period of life span is spent in the nymph stage. The nymph dragonflies eat marine insects and also small fishes by utilizing exclusive swarming behaviour. The two important swarming behaviours of dragonflies in nature are static and dynamic nature. In a static swarm, they form a very small group and fly in a smaller area and hunt small insects like mosquitoes and butterflies. Next, in case of dynamic swarm dragonflies form a large group and travel in one particular direction for long distances. The static and dynamic swarming behaviours correlate to the two very important phases of optimization that is an exploration and exploitation.

The main goals of dragonflies are attraction towards the food sources and distraction outwards from enemies. The two very important phases of DFA are mathematically implemented as follows [28].

1. Separation: The main aim of this stage is to avoid collisions among themselves in the neighbourhood. Separation is given as follows.

$$S_i = -\sum_{j=1}^{N} X - X_j \quad (21)$$

where X, X_j are the position of current and j^{th} neighbouring individual. Also, N is the number of neighbouring individuals.

2. Alignment: In this stage velocity matching of an individual to that of another individual is given by

$$A_i = \frac{\sum_{j=1}^{N} V_j}{N} - X \quad (22)$$

where V_j is the velocity of j^{th} neighbouring individual.

3. Cohesion: This refers to the attraction of the swarm towards the centre of the group of swarms.

$$C_i = \frac{\sum_{j=1}^{N} X_j}{N} - X \quad (23)$$

where X_j is the position of the j^{th} neighbouring individual and X is the position of the current individual respectively.

4. Attraction towards the food (F) source is mathematically represented by

$$F^i = X^+ - X \quad (24)$$

where X^+ is the food source position and X is the position of the current individual.

5. Distraction outwards from the enemy (E) is calculated by

$$E^i = X^- + X \quad (25)$$

where X^- is the enemy position and X is the current individual's position.

Finally, the overall behaviour of dragonflies depends upon the combination of the five Eqs. (21-25). In a search space the position and the movements of dragonflies are updated by considering two vectors that are step vector (ΔX) and position vector (X).

The step vector is calculated by using Eq. (26)

$$\Delta X_{t+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + w\Delta X_t \quad (26)$$

where S_i, A_i, C_i, F_i, and w refer to separation, alignment, cohesion, attraction towards the food source

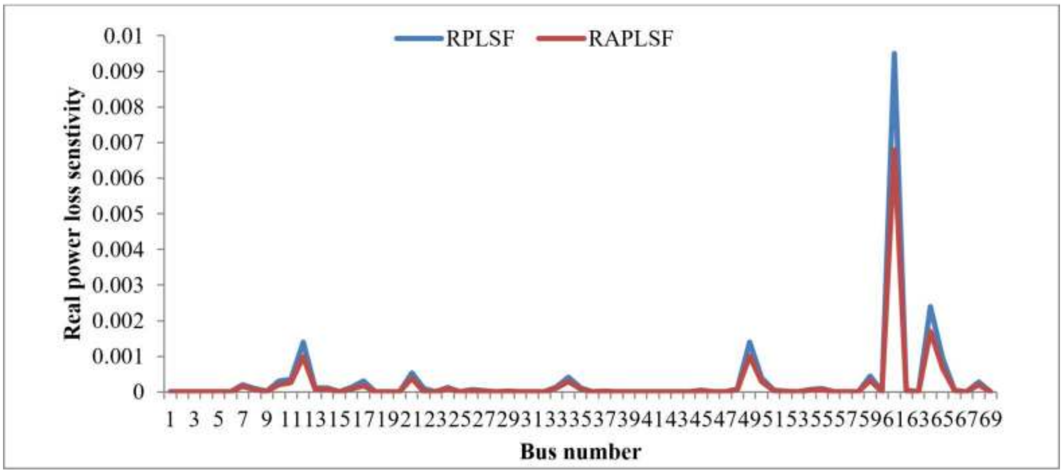

Fig.2: *Active and Reactive power loss sensitivities at different buses in 69 bus RDS.*

and distraction outwards from the enemy of i$^{\text{th}}$ individual. Also, s, a, c, f, e, and w are the weighting factors corresponding to each parameter and t is the iteration counter.

Once step vector is calculated, one can update the position vectors by using Eq. (27).

$$X_{t+1} = X_t + \Delta X_{t+1} \tag{27}$$

Even though search based optimization techniques give better results, they suffer from convergence and optimality issues. The convergence of dragonflies is assured because they change their weights flexibly for passage from exploration to the exploitation of the search space. Also, neighbourhood area is increased with increasing radii as the swarm turned into one group and the solution converges to the global optimum.

The searching ability, stochastic behaviour and randomness can be improved in a search space by introducing random walk (Levy flight). If there is no further improvement in solutions dragonflies update their positions using the Eq. (28).

$$X_{t+1} = X_t + Levy(d) \times X_t \tag{28}$$

Where d is the dimension of position vectors and t is the current iteration. Levy flight is determined as follows.

$$Levy(d) = 0.01 \times \frac{r1 \times \sigma}{|r_2|^{\frac{1}{\beta}}} \tag{29}$$

where β is constant, r_1, $r2$ are two random numbers in [0, 1] and σ is determined as follows.

$$\sigma = \left(\frac{\Gamma(1+\beta) \times \sin(\frac{\pi\beta}{2})}{\Gamma(\frac{1+\beta}{2}) \times \beta \times 2^{(\frac{\beta-1}{2})}} \right)^{\frac{1}{\beta}} \tag{30}$$

The concept of Dragonfly algorithm is represented in Pseudo code that is shown in Fig. 3.

```
Initialize the dragonflies population Xi (i=1, 2...n)
Initialize step vectors
While the end condition not satisfied
        Calculate the objective function values of all dragonflies
        Update the food source and enemy
        Update w, s, a, c, f and e
        Calculate s, a, c, f and e using Eqs. (21) to (25)
        Update neighbouring radius
        If a dragonfly has at least one neighbouring dragonfly
                Update velocity vector using Eq. (26)
                Update position vector using Eq. (27)
        else
                Update position vector using Eq. (28)
        end if
Check and correct the new positions based on the boundaries of variables
        end while
```

Fig.3: *Pseudo code of dragonfly algorithm.*

4.1 Application of DFA to Solve Optimal DG and Capacitor Sizes

The important steps for reducing the objective function are as follows (Fig. 4):

Step 1: Read the system data which include bus and line data

Step 2: Run the base case load flow

Step 3: Identify the best locations for DGs and SCs using LSF technique

Step 4: Input identified locations to DFA

Step 5: Initialize the parameters of DFA i.e. No of search agents (15) dimension of the search space (9), w, s, a, c, f and e.

Step 6: Generate an initial population of dragonflies

Step 7: Initialize the step vectors

Step 8: While the specified number of evaluations is not reached that is end condition is not satisfied

Step 9: Dragonfly Algorithm determines the best sizes of DGs and SCs at the specified locations

Step 10: Attraction towards food source is proportional to the optimal sizes of DGs and SCs that is calculated by using Eq. (24) and also evaluate the power loss of the system using distribution load flow

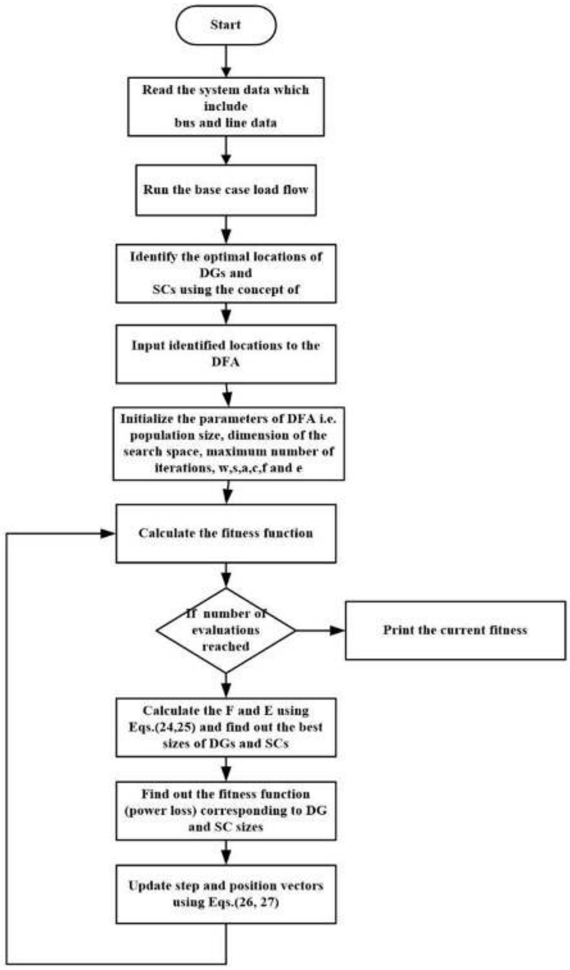

Fig.4: *Flowchart of proposed DFA.*

Step 11: Distraction outwards from enemy is proportional to the worst values of DGs and SCs that is calculated by using Eq. (25) and also evaluate the power loss of the system using distribution load flow

Step 12: Update velocity and position vectors using Eqs. (26–27)

Step 13: end while

Step 14: Store the results that are optimal DG, capacitor sizes and corresponding objective function values

5. RESULTS AND DISCUSSION

The application of the DFA along with LSF is not analyzed in the previous literature for optimal allocation of DGs and SCs in the distribution network. This motivates the author to use search based technique DFA along with LSF for solving the DG and capacitor allocation problem simultaneously in the DS with minimizing power loss of DS. To check the efficacy of the proposed method, it is tested on IEEE 69 bus RDS while considering constant power load at different load levels. To examine the predominance of the proposed method the following different cases are considered.

Base Case: System without placement of DGs and shunt capacitors

Case-1: System with placement of single DG operating at unity power factor

Case-2: System with placement of single DG operating at unity power factor plus capacitor

Case-3: System with placement of multiple DGs operating at unity power factor

Case-4: System with placement of multiple DGs operating at unity power factor plus capacitors

Case-5: System with placement of single DG operating at optimal power factor

Case-6: System with placement of single DG operating at optimal power factor plus capacitor

Case-7: System with placement of multiple DGs operating at optimal power factor

Case-8: System with placement of multiple DGs operating at optimal power factor plus capacitors.

5.1 69 Bus Radial Distribution System

IEEE 69 bus test system consisting of 69 buses and 68 branches operating at a voltage of 12.66 kV. The active and reactive power demands of this test system are 3800 kW and 2690 kVAr respectively. The data related to the test system are taken from [27]. The active and reactive power losses before placement of DGs and SCs at three different load levels, i.e. half, full and heavy loads are respectively as follows (51.59 kW, 23.55 kVAr), (224.98 kW, 102.19 kVAr) and (652.42 kW, 294.32 kVAr). First, the best locations of DGs and SCs are identified by LSF technique. Different cases are studied for evaluating the performance of the DS.

Base case: In this case, system without placement of DGs and SCs is considered. The real and reactive power losses at different load levels, i.e. half, full and heavy loads are respectively as follows (51.60 kW, 23.55 kVAr), (224.99 kW, 102.19 kVAr) and (652.49 kW, 294.32 kVAr).The minimum node voltages at different load levels (half, full and heavy) are 0.9567, 0.9092 and 0.8445 in p.u. Also, the minimum VSI values are 0.8372, 0.6822 and 0.5066 in p.u.

Case-1: In this case, the placement of the single DG unit (Type-A) capable of injecting real power only is placed at optimal bus that is at bus number 61. Simulated results at different load levels are presented in Tables 1-3. The loss reduction percentages at different load levels are reduced uniformly. Also, voltage profile and VSI values are improved adequately.

Case-2: In this case, the single DG unit (Type-A) is placed along with a capacitor at optimal buses. The optimal bus for placement of both DG and the SC is 61. The results of power loss reduction, minimum voltage profile and VSI values at all load levels are represented in Tables 1-3. The results clearly show that the placement of single DG along with SC

Table 1: *Simulated results of 69 bus test system for different cases at half load level.*

Different cases/items	DG size in kW (bus)	Capacitor size in kVAr (bus)	P_{loss} in kW	% red of P_{loss}	V_{min} in p.u.	VSI_{min} in p.u.
Base case	NA	NA	51.59	NA	0.9567	0.8372
Case 1 Single DG (Type-A)	863.37(61)	NA	20.42	60.41	0.9840	0.9375
Case 2 Single DG (Type-A) + Capacitor	892(61)	650(61)	5.70	88.95	0.9863	0.9562
Case 3 Multiple DGs (Type A)	251.08(11) 162.89(17) 882.04(61)	NA	17.10	66.85	0.9904	0.9462
Case 4 Multiple DGs (Type-A) + (Type-A)	254.22(11) 177.96(17) 863.48(61)	150(11) 150(17) 600(61)	1.08	97.90	0.9971	0.9794
Case 5 Single DG (Type -C)	911.97/0.82(61)	NA	5.68	88.52	0.9864	0.9466
Case 6 Single DG (Type-C)+ Capacitor	911.58/0.83(61)	150(21)	4.51	91.25	0.9887	0.9556
Case 7 Multiple DGs (Type -C)	232.25/0.83(11) 197.21/0.84(17) 844.32/0.82(61)	NA	1.07	97.93	0.9971	0.9793
Case 8 Multiple DGs (Type-C)+ Capacitors	268.99/0.96(11) 190.73/0.84(17) 825.73/0.99(61)	100(12) 250(49) 500(61)	0.88	98.29	0.9985	0.9877

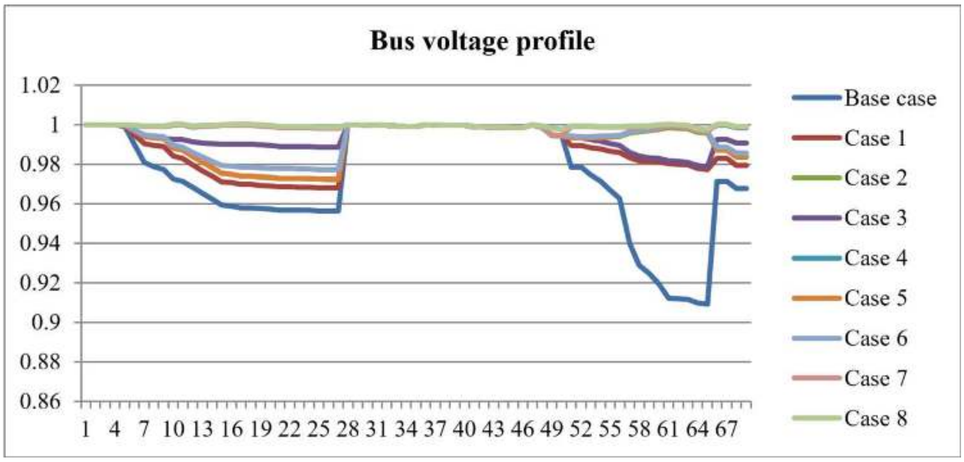

Fig.5: *Bus voltage profile of 69 bus test system with different cases at full load.*

improves the power loss reduction with good enhancement in voltage profile and VSI values. Also, it is observed that power loss reduction, voltage profile and VSI are improved to maximum extent as compared to Case-1. In this case placement of a DG injects real power to the system and placement of a SC injects reactive power into the system. So, combined allocation of these sources improves the system performance to greater extent.

Case-3: In this case, multiple DGs of Type-A operating at unity power factor are placed at optimal buses i.e. 11, 17 and 61. The simulated results after placement of DGs at different load levels are presented in Tables 1-3. From the results, it is observed that power losses are reduced effectively with good enhancement in voltage profile and VSI at all load levels. Further, it is verified that placement of DGs in multiple locations improves the system performance

Table 2: *Simulated results of 69 bus test system for different cases at full load level.*

Different cases/items	DG size in kW (bus)	Capacitor size in kVAr (bus)	P_{loss} (kW)	% red of P_{loss}	V_{min} (p.u.)	VSI_{min} (p.u.)
Base case	NA	NA	224.99	NA	0.9092	0.6822
Case 1 Single DG (Type A)	1823.80(61)	NA	83.30	62.97	0.9680	0.8777
Case 2 Single DG (Type A) + Capacitor	1793.6(61)	1300(61)	23.20	89.68	0.9722	0.8935
Case 3 Multiple DGs (Type-A)	457.91(11) 379.76(17) 1720.63(61)	NA	69.48	69.11	0.9722	0.9128
Case 4 Multiple DGs (Type A) + Capacitors	481.49(11) 381.79(17) 1677.13(61)	350(11) 250(17) 1200(61)	4.27	98.10	0.9943	0.9588
Case 5 Single DG (Type C)	1828.5/0.82(61)	NA	23.17	89.70	0.9724	0.8943
Case 6 Single DG (Type C) + Capacitor	1819.8/0.83(61)	300(21)	18.32	91.85	0.9722	0.9117
Case 7 Multiple DGs (Type C)	522.07/0.84(11) 369.43/0.82(17) 1668.48/0.82(61)	NA	4.28	98.09	0.9943	0.9587
Case 8 Multiple DGs (Type C) + Capacitors	510.95/0.83(11)) 375.59/0.83(17) 1676.9/0.86(61)	50(12) 550(49) 200(61)	3.47	98.46	0.9975	0.9771

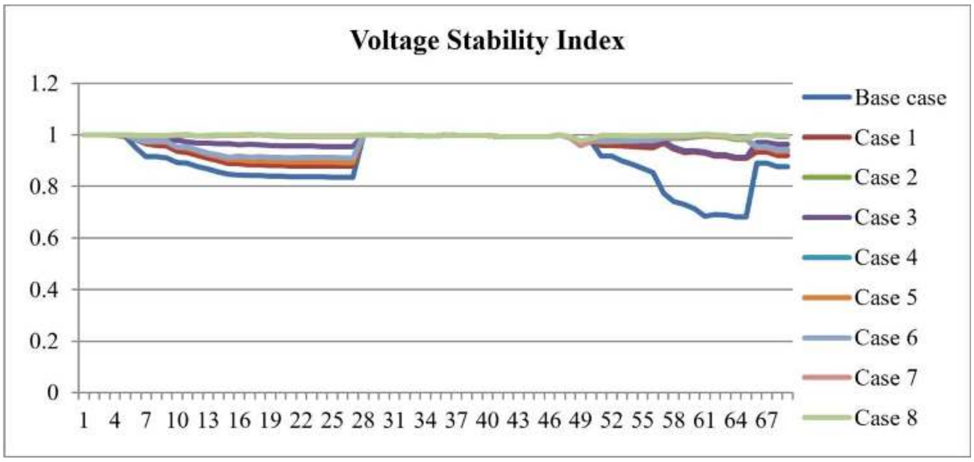

Fig.6: *Voltage stability index of 69 bus test system with different cases at full load.*

effectively as compared placement of a single DG with higher ratings.

Case-4: In this case, multiple DGs of Type-A along with multiple SCs are placed at optimal buses i.e. 11, 17 and 61. The results obtained after placement of DGs and SCs at different load levels are tabulated in Tables 1-3. From the results, it is clear that maximum percentage loss reduction is obtained with good improvement in voltage profile and VSI at all load levels. Further, it is verified that power loss

Table 3: *Simulated results of 69 bus test system for different cases at heavy load level.*

Different cases/items	DG size in kW (bus)	Capacitor size in kVAr (bus)	P_{loss} (kW)	% red of P_{loss}	V_{min} (p.u.)	VSI_{min} (p.u.)
Base case	NA	NA	652.49	NA	0.8445	0.5066
Case 1 Single DG (Type A)	3071(61)	NA	219.71	66.32	0.9485	0.8085
Case 2 Single DG (Type A) + Capacitor	2972.9(61)	2100(61)	60.73	90.69	0.9556	0.8338
Case 3 Multiple DGs (Type-A)	1284.01(11) 606.50(17) 2000(61)	NA	204.21	68.70	0.9405	0.7747
Case 4 Multiple DGs (Type A) + Capacitors	1150.41(11) 601.22(17) 2000(61)	600(11) 400(17) 1900(61)	26.02	96.01	0.9736	0.8974
Case 5 Single DG (Type C)	2934/0.82(61)	NA	60.68	90.70	0.9553	0.8328
Case 6 Single DG (Type C) + Capacitor	3040/0.85(61)	200(21)	53.86	91.75	0.9588	0.8452
Case 7 Multiple DGs (Type C)	1102.09/0.89(11) 627.59/0.85(17) 2000/0.8(61)	NA	32.28	95.05	0.9675	0.8752
Case 8 Multiple DGs (Type C) + Capacitors	1166.3/0.92(11)) 587.18/0.85(17) 2000/0.89(61)	150(12) 1150(49) 900(61)	23.99	96.32	0.9739	0.8982

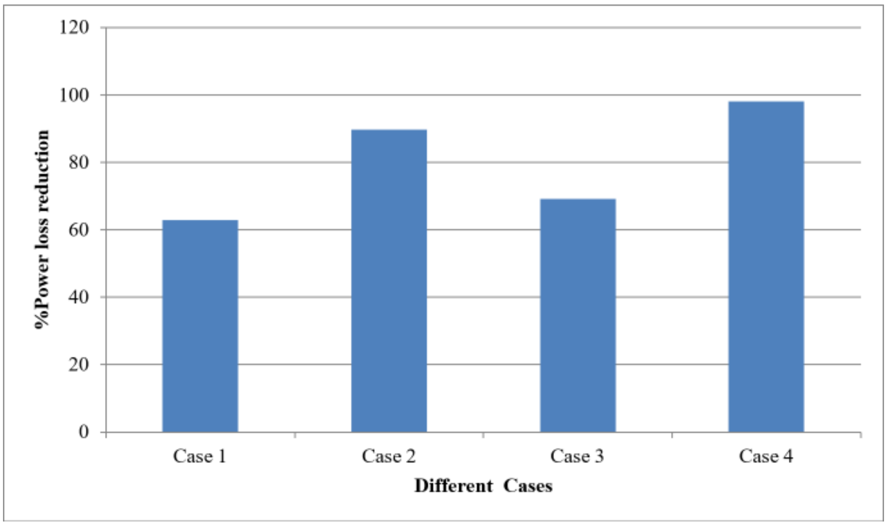

Fig.7: *Percentage power loss reduction for cases 1-4.*

is reduced to maximum extent along with good improvement of voltage profile and VSI as compared to cases 1, 2 and 3. In this case DGs and SCs placed at multiple locations inject both real and reactive power into the system.

Case-5: In this case, a single DG of Type-C that

Table 4: *Comparison of proposed method for Case-1(single DG (Type-A) placement) at full load.*

Method	LSF [8]	IA [8]	PSO [16]	**Proposed DFA**
Optimal size of DG in kW (location)	1520(65)	1900(61)	1807.8(61)	**1823.80(61)**
Base Case P_{loss} in kW	219.28	219.28	225	**225**
P_{loss} with DG and capacitor in kW	109.77	81.33	83.37	**83.30**
% reduction of P_{loss}	49.94	62.91	62.94	**62.97**
V_{min} in p.u	NA	NA	NA	**0.9680**

Table 5: *Comparison of proposed method for Case-2 (single DG (Type-A) placement with capacitor) at full load.*

Method	PSO [20]	PSO [16]	**Proposed DFA**
Optimal size of DG in kW (location)	1566.0(61)	1828.5(61)	**1793.6(61)**
Optimal size of capacitor in kVAr (location)	1401.3(61)	1300.6(61)	**1300(61)**
Base Case P_{loss} in kW	225	225	**225**
P_{loss} after placement of DG and capacitor in kW	25.90	23.17	**23.20**
% red of P_{loss}	88.48	89.70	**89.68**
V_{min} in p.u	NA	NA	**0.9722**

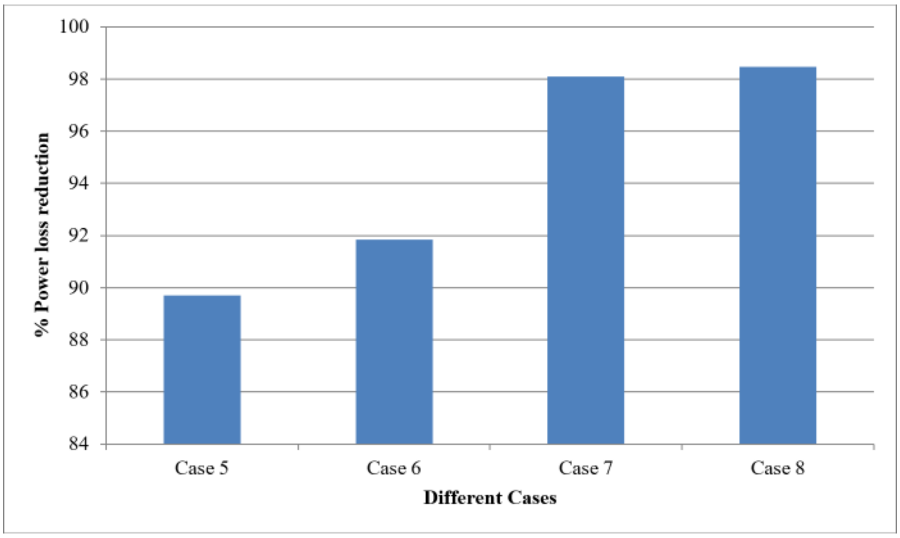

Fig.8: *Percentage power loss reduction for cases 5-8.*

injects both active and reactive power into the system is placed at the bus number 61 and the obtained results are presented in Tables 1-3. From the simulated results, it is clear that power loss reduction, voltage profile and VSI values at all load levels are improved effectively compared to the base case. Also, it is observed that placement of a single DG unit of Type-C gives a better loss reduction and good enhancement of the voltage profile compared to the placement of Type -A DG unit.

Case-6: In this case, a Type-C DG unit operating at optimal power factor along with the SC is placed at optimal buses i.e. 61 and 21 and the obtained results are presented in Tables 1-3. After placement of these sources in the DS, power loss is reduced effectively at all load levels with simultaneous improvement in voltage profile and VSI values. Further, it is verified that power loss reduction is improved to maximum extent as compared to cases 1-5. This is because, in this case the DG placed in the system is injecting both active and reactive power into the system considered along with capacitors.

Case-7: In this case multiple DGs operating at optimal power factor are placed in optimal buses and the simulated results are tabulated in Tables 1-3. From the obtained results, it is clear that power losses are reduced uniformly at all load levels. Also, minimum voltage magnitude and VSI values are improved effectively. It is also clear that placement of multiple DGs of Type-C achieves better loss reduction and

Table 6: *Comparison of proposed method for Case-3(Multiple DGs (Type-A) placement) at full load.*

Method	GA [9]	PSO [9]	GA/PSO [9]	SA [11]	BFOA [12]	**Proposed DFA**
Optimal size of DG in kW (location)	984.8(64) 1075.2(62) 929.7(21)	795.6(63) 1199.8(61) 992.5(17)	884.9(63) 1192.6(61) 910.5(21)	429.8(65) 1331.1(60) 420.4(18)	447.6(65) 1345.1(61) 295.4(27)	**457.91(11)** **379.96(17)** **1720.63(61)**
Base Case P_{loss} (kW)	224.7	224.7	224.7	224.7	224.9	**224.99**
Ploss after placement of multiple DGs (kW)	89.0	83.20	81.10	77.10	75.23	**69.48**
% reduction of P_{loss}	60.39	62.97	63.90	65.68	66.54	**69.11**
V_{min} in p.u	0.9936	0.9901	0.9925	0.9811	0.9808	**0.9786**

Table 7: *Comparison of proposed method for Case-4 (Multiple DGs (Type-A) with capacitors) at full load.*

Method	ITLBO [21]	**Proposed DFA**
Optimal size of DG in kW (location)	485(11) 382(18) 1675(61	**481.49(11)** **381.79(17)** **1677.13(61)**
Optimal size of capacitor in kVAr (location)	300(11) 300(18) 1200(61)	**350(11)** **250(17)** **1200(61)**
Base Case P_{loss} (kW)	225	**224.99**
P_{loss} after placement of multiple DGs with multiple capacitors (kW)	4.33	**4.27**
% reduction of P_{loss}	98.07	**98.10**
V_{min} in p.u	0.9943	**0.9943**

good enhancement of voltage profile and VSI values compared to the placement of multiple DGs of Type A in the DS due to their ability in delivering active and reactive powers.

Case-8: In this case, multiple DGs of Type-C with multiple SCs are placed at optimal buses. Three different load levels considered and the simulated results are tabulated in Tables 1-3. From the simulated results, it is very clear that maximum power loss reduction is achieved in this case at all load levels. Also, voltage profile and VSI values are improved to the maximum extent in this case compared all the above cases.

From different cases, it is observed that the maximum percentage of power loss reduction with good enhancement in the voltage profile obtained is in Case-8. In this case the optimal placement of DGs that injects both real and reactive power into the system is placed along with SCs.

Bus voltage profile and VSI values of 69 bus test system considering different cases at full load are shown in Figs. 5 and 6. From the figures, it is clear that voltage profiles and VSI values of all buses are improved significantly with optimal placement of DGs and SCs.

The power loss reduction considering various cases at full load is statistically compared and it is shown in Fig. 7 and 8. From the statistical results, it is very clear that placement of DGs along with SCs gives highest loss reduction as compared to placement of DGs alone. Further, DG type plays a significant role in loss reduction because Type-C DGs inject both real and reactive power system. Finally, compared to all cases the loss reduction is high in Case-8 because DGs of Type-C placed along with SCs in the system.

5.2 Comparative Study of Proposed Method with Other Methods

First the simulated results of the proposed method considering full load condition for different cases (Cases-1, 2, 3 and 4) is compared with other available methods in the literature and the results are tabulated in Tables 4-7.

In the above cases DGs of Type-A is considered for placement. In Case-1, a single DG is placed in the system and the results obtained by DFA method are compared with IA, LSF and PSO methods. The power loss reduction of proposed DFA method is high compared to all other methods. In Case-2, placement of a single DG of Type-A is placed along with SCs and the obtained results of DFA method is compared with PSO method. The power loss reduction of both methods is almost same. Further, in Case-3, multiple DGs of Type-A is considered and placed in the DS. The

Table 8: *Comparison of proposed method for Case-5 (single DG (Type-C) placement) at full load.*

Method	IA [8]	PSO [16]	**Proposed DFA**
Optimal size of DG in kVA (location)	2242.89(61)	2243(61)	**2229.87(61)**
Optimal power factor of DG	0.82	0.82	**0.83**
Base Case P_{loss} in kW	219.28	225	**225**
P_{loss} after placement of DG in kW	22.62	23.18	**23.17**
% reduction of P_{loss}	89.68	89.69	**89.70**
V_{min} in p.u	NA	NA	**0.9724**

Table 9: *Comparison of proposed method for Case-6 (single DG (Type-C) placement with capacitor) at full load.*

Method	PSO [16]	**Proposed DFA**
Optimal size of DG in kVA (location)	2224(61)	**2192.53(61)**
Optimal size of capacitor in kVAr (location)	1292(61)	**300(21)**
Optimal power factor of DG	0.81	**0.83**
Base Case P_{loss} (kW)	225	**225**
P_{loss} after placement of DG and Capacitor (kW)	23.19	**18.32**
% reduction of P_{loss}	89.69	**91.85**
V_{min} in p.u	NA	**0.9772**

Table 10: *Comparison of proposed method for Case-7 (Multiple DGs (Type-C) placement) at full load.*

Method	SA [11]	BFOA [12]	**Proposed DFA**
Optimal size of DG in kVA (location)	360.50(65) 1380.36(60) 634.84(18)	436.54(27) 379.28(65) 1542.74(61)	**621.56(11)** **450.52(17)** **2034.67(61)**
Optimal power factor of DG	0.866 0.866 0.866	0.866 0.866 0.866	**0.83** **0.83** **0.86**
Base Case Ploss (kW)	224.7	224.99	**225**
P_{loss} after placement of multiple DGs (kW)	16.26	12.90	**4.28**
% reduction of P_{loss}	92.77	94.26	**98.09**
V_{min} in p.u	0.9885	0.9896	**0.9943**

Table 11: *Comparison of proposed method for Case-8 (Multiple DGs (Type-C) with capacitors) at full load.*

Method	GA/PSO [19]	**Proposed DFA**
Optimal size of DG in kVA (location)	496.46(18) 1345.45(61) 367.46(64)	**612.19(11)** **455.87(17)** **2041.62(61)**
Optimal power factor of DG	0.85 0.88 0.83	**0.83** **0.83** **0.86**
Optimal size of capacitor in kVAr (location)	150(11) 150(49) 600(61)	**50(12)** **550(49)** **200(61)**
Base Case P_{loss}in kW	224.99	**225**
P_{loss} after placement of multiple DGs with multiple capacitors (kW)	8.02	**3.47**
% reduction of P_{loss}	96.39	**98.46**
V_{min} in p.u	NA	**0.9975**

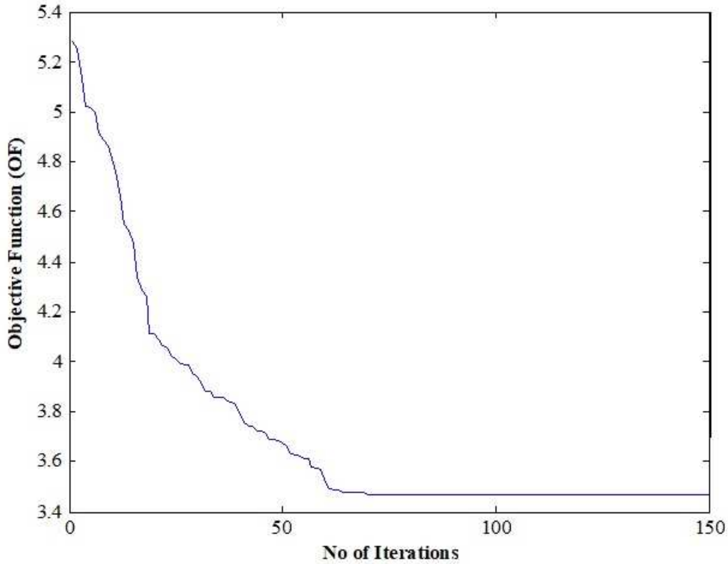

Fig.9: *Convergence characteristics of DFA for Case-8(Multiple DGs of Type-C with capacitors) at full load.*

Table 12: *Comparison of solution quality in minimizing a fitness function with different cases.*

Test system	Different cases	Best fitness P_{loss} (kW)	Worst fitness Ploss (kW)	Mean fitness Ploss (kW)	Standard deviation	Time (Sec)
69 bus RDS	Case-3: Multiple DGs of Type-A	69.48	70.10	69.58	0.136	1.01
	Case-6: Single DG of Type-C with capacitor	18.32	18.67	18.40	0.081	1.095
	Case-8: Multiple DGs of Type-C with multiple capacitors	3.47	4.55	3.74	0.214	9.841

results obtained by DFA method is compared with GA, PSO, GA/PSO, BFOA and SA. The loss reduction attained by the proposed method is highest as compared to all other methods. Finally, in Case-4 multiple DGs of Type-C is placed along with multiple SCs and the obtained results are compared with ITLBO, the result obtained by DFA method is almost the same as compared to ITLBO method. Further comparison of the proposed method at full load condition is discussed in Cases-5, 6, 7 and 8. The results are tabulated in Tables 8-11. In these cases, DGs of Type-C is considered for placement. In Case-5, single DG of Type-C is considered and placed in the system. The results obtained by DFA method is compared with IA and PSO method. The power loss reduction of the proposed DFA method is less as compared to IA method and almost same with less injecting size of DG into the system. In Case-6, a single DG (Type-C) of Type-C placed along with SC in the system. The result obtained by DFA method is compared with PSO method. The loss reduction of the developed method is good as compared to PSO method. Further, in Case-7, multiple DGs of Type-C are considered for placement and the performance studied. The obtained results are compared with SA and BFOA. The results clearly show that power loss reduction of DFA method is very high as compared to SA and BFOA. Finally in Case-8, multiple DGs of Type-C are placed along with multiple SCs. The results obtained by the proposed DFA method are compared with GA/PSO method. It is clear that the power loss reduction of DFA method is very high as compared to GA/PSO method. Finally, in the overall comparative analysis the optimal allocation of multiple DGs with multiple SCs give the highest amount of power loss reduction with good improvement in the voltage profile at all buses. The convergence characteristics of DFA with Case-8 (multiple DGs of Type-C with multiple capacitors) at full load are depicted in Fig. 9. From the convergence curve, it is observed that DFA reduces the objective function effectively with lower number of iterations.

The parameters of DFA are: No of search agents=15, dimension (d=9), max iterations=150, separation (s=0.1), alignment (a=0.1), cohesion (c=0.7), food attraction (f=1), enemy distraction (e=1) and inertia (w=0.8).

Finally the computational performance and solution quality of any search based optimization technique is evaluated after the specified number of independent trials. The solution quality of DFA after 50 independent trials is presented in Table 12. The table shows statistical values of best, worst, mean fitness, standard deviations and average simulation times. From the statistical values, it is proved that the DFA achieves better performance in terms of solution accuracy.

6. CONCLUSIONS

This paper presented a new approach for improving the voltage profile and reducing power loss in a Distribution System. DGs and SCs are simultaneously placed at optimal locations with appropriate sizes to attain the objectives. The best locations of DGs and SCs are identified using LSF technique. Further optimal sizes corresponding to these locations are determined by using the Dragonfly Algorithm. The developed method is demonstrated on IEEE 69 bus radial, a distribution network considering various load levels at different power factors. The results obtained using this method is compared with recent methods to show the potency of this method. From the results, it is observed that power loss is reduced in all the cases at all load levels. Further, the voltage profile and VSI of the system are improved significantly at all load levels. Maximum loss reduction with good improvement in voltage profile and VSI values are attained with simultaneous placement of multiple DGs (Type-C) with multiple SCs in the system. So it can be concluded that simultaneous allocation of DGs and SCs using Dragonfly Algorithm enhances the efficiency of the distribution system. The generation uncertainties associated with renewable power generation would be analyzed considering the installation and maintenance costs. Also, incorporating energy storage would be beneficial for future extension of this work.

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