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Optimal Allocation of Different Types of Distributed Generators in Distribution System

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Abstract

In this paper, an effective methodology is proposed for the optimal allocation of conventional (Gas turbines) and renewable based distributed generators (solar, wind) in the distribution system (DS) are presented. The objectives are to minimize real, reactive power losses and emission produced by the sources. Initially, the best locations for placement of DGs are identified by voltage stability factor (VSF) concept. The number and size of solar, wind based DGs and gas turbines corresponding to these locations are determined by applying search-based dragonfly algorithm (DFA). The generation uncertainties associated with wind and solar based DGs is effectively modeled by Weibull and beta probability distribution functions (PDF) to determine the exact output power. Two different scenarios, i.e. optimal allocation and the combination of different types DERs in the distribution system is considered in this analysis. The developed method is tested on IEEE 33 and 69 bus distribution systems. The results show its effectiveness in terms of solving respective objective function.

1. INTRODUCTION

Electricity demand around the world is increasing by 28 percent during the years 2011- 2040 [1], so there is a need to escalate the power generation capacity during this period. Also, rapid exhaustion of fossil fuels, difficulties in network upgradation and environmental issues raised by conventional power plants, utilities are interested to generate electric power through distributed generation (DG) sources. DGs are small scale generators which are connected near the load centers [2]. DGs are categorized into two different types, conventional (Gas turbine, diesel generator and micro turbine) output power is controllable and renewable (solar, wind and etc..) output is uncontrollable. Optimal integration of these generation sources to the existing distribution network improves the performance of the distribution system in terms of peak demand shaving, postponement of network upgradation, power loss reduction, enhancement of voltage profile and reliability [3]. In order to accomplish above mentioned advantages, it is indispensable to determine best locations and sizes of DGs. In recent years, several analytical, numerical and meta heuristic techniques are effectively applied and solve the DG allocation problem in the DS.

Analytical methods are used for solving DG allocation problem in the DS with an objective of power loss minimization has been presented in [4,5]. Analytical and improved analytical methods for determining best locations, sizes and optimal power factors of different types of DGs placed in the DS with an objective of loss minimization is proposed by Hung D.Q. et al. [6,7]. Analytical methods give optimal solutions, but it is difficult for solving complex problems. Next numerical methods like mixed integer nonlinear programming (MINLP) are applied to solve DG allocation problem with an objective of improving voltage stability and energy loss minimization is presented in [8,9]. However, it is difficult to understand and implementation of MINLP technique. Finally, meta heuristic techniques are effectively applied for solving

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DG allocation problem in the DS. Optimal allocation of solar and wind-based generation sources in the DS with an objective of energy loss minimization using evolutionary programming technique is presented in [10]. Multi objective particle swarm optimization (MOPSO) technique is used for wind and PV array placement in the DS with an objective of voltage stability enhancement and power loss reduction has been presented in [11]. Safaei et. al. [12] proposed a two-step PSO algorithm for placement of wind-based generation sources in the DS. The objective is to minimize power loss with satisfying different constraints of the DS. In this paper authors consider various ratings of wind turbine generating units and placed in the DS, but did not consider the generation uncertainties associated with these sources. Sultana et al. [13] proposed a krill herd algorithm for placement of different types of renewable based generation sources in the DS with an objective of improving energy loss reduction. Different types of DGs allocation problem in the DS with an objective of power loss minimization are discussed in [14]. Attia El-Fergany used a backtracking search algorithm [15] for the placement of multi-type DGs in the DS with an objective power loss reduction and the voltage profile enhancement. A combined method loss sensitivity factor (LSF) and simulated annealing technique [16] are effectively applied for solving DG allocation problem in the DS. The objectives are to improve power loss and voltage stability of the system. A combined approach of LSF and bacterial foraging optimization algorithm for optimal allocation of multiple DGs in DS has been presented in [17]. The objective is to reduce operating cost, power loss and improving voltage deviation index. Multiple DGs placement with considering different load models in the DS using shuffled bat algorithm is presented in [18]. Hybrid methods like integration of analytical and meta heuristic [19,20] or combination of two meta heuristic methods [21,22] are effectively used for solving DG allocation problem in DS. It is very difficult for hybridization of two algorithms and coding is relatively not easy [23].

Most of the literature, it is noticed that different types of DGs are considered and placed in the DS. But they did not consider the generation uncertainties associated with renewable based generation sources. Next in view of the objective function, most of the literature shows real power loss reduction or energy loss reduction is a primary objective followed by voltage profile enhancement. Suppose, Type-C DGs (wind based) [19] are considered that injecting both active and reactive power into the system. So, DG placement influences the reactive power of the system, but in most of the literature this objective is not considered. Also, placement of RDGs in the DS shows positive impact on emission reduction, but this objective is also not considered in most of the literature. In the entire literature, the authors consider either conventional (Gas turbines, diesel, etc..) or non-conventional based DGs (solar, wind and biomass etc..) and placed in the DS. However, the combination of conventional and renewable based DG allocation in the DS shows positive impact on the system in terms of reducing uncertainties associated with the RDGs and emissions produced by the conventional based DGs.

In this paper an effective methodology is proposed for optimal combination of conventional (Gas turbines) and renewable based DGs (solar, wind) allocation in the DS is presented. The objective is to minimize real, reactive power loss and emissions produced by the conventional generation sources. First, the uncertainties associated with the wind speed and solar irradiance is effectively modeled by using Weibull and beta probability distribution functions (PDF) and determine the exact output power of these renewable energy sources. In this work, best locations for placement of DGs is found out by using voltage stability factor (VSF). Next, the optimal sizes of gas turbines and exact number of wind turbines and PV arrays placed at these locations are determined by using recently developed search-based technique dragonfly algorithm (DFA). Even though meta heuristic algorithms produce promising results in solving nonlinear optimization problems, but the difficulty associated with these algorithms is how effectively tunes its control parameters and balance between exploration and exploitation during the optimization process. In case of the DFA, good balance between exploration and exploitation abilities is achieved by considering proper cohesion and alignment weights. Different scenarios are considered for the analysis and it is tested on IEEE 33 and 69 bus test systems.

The remaining sections of the paper are organized as follows: DERs modelling is explained in section 2. Problem formulation with different constraints is explained in section 3. The best nodes for placement of DERs in the DS using VSF concept is explained in section 4. The optimal of sizes of DERs using dragonfly algorithm concept is explained in section 5. Simulated results and discussion followed by the conclusion of the article is explained in sections 6 and 7.

2. DISTRIBUTED ENERGY RESOURCES (DER) MODELING

In this paper three different types of DERs (Gas turbines, solar and wind) are adopted and placed in the DS. First, gas turbines based DGs are considered for the analysis that injecting both active and reactive power into the system. Next, renewable energy resources, i.e. solar based DGs that injecting only real power and operating at unity power factor and wind based DGs injecting both active and reactive power into the system operating at 0.85 power factor lagging is considered. Before placement of these sources in the DS, first model the generation uncertainties associated with solar and wind-based DG sources and determine exact output power.

2.1. Solar PV Modeling and Output Power Calculation

The output power of solar PV is intermittent because of its random nature of solar irradiance. So, determine the exact output power from these sources and model the solar irradiance effectively. For these different probability distribution functions (PDF) are used, but the beta PDF is appropriate for modeling the solar irradiance [9,24]. Beta PDF for solar irradiance s is given by

$$f_b(s) = \frac{\Gamma(\alpha_a + \beta_a)}{\Gamma(\alpha_a)\Gamma(\beta_a)} s^{\alpha_a - 1}(1-s)^{(\beta_a - 1)} \quad for\ \alpha_a > 0; \beta_a > 0 \tag{1}$$

where α_a and β_a are the shape parameters and Γ is the gamma function. Shape parameters of $f_b(s)$ can be calculated using mean (μ) and standard deviation (σ) of s.

$$\alpha_a = \frac{\mu\beta_a}{1-\mu} \tag{2}$$

$$\beta_a = (1-\mu)\left(\frac{\mu(1+\mu)}{\sigma^2} - 1\right) \tag{3}$$

Next output power of photo voltaic array (PVA) at corresponding solar irradiance (s) is calculated as follows [25].

$$P_{PVA}(s) = N_{PVM} * FF * V_y * I_y \tag{4}$$

where

$$FF = \frac{V_{MPP} * I_{MPP}}{V_{oc} * I_{sc}} \tag{5}$$

$$V_y = V_{oc} - K_v T_{cy} \tag{6}$$

$$I_y = s[I_{sc} + K_i(T_{cy} - 25)] \tag{7}$$

$$T_{cy} = T_A + s\left(\frac{N_{OT} - 20}{0.8}\right) \tag{8}$$

Here, FF is the fill factor and N_{PVM} is the total number of PV modules used. V_{oc}, I_{sc} and N_{OT} are open circuit voltage, short circuit current and nominal operating temperature of PV module respectively. T_{cy} and T_A are cell and ambient temperature. Finally, K_v and K_i are voltage and current temperature coefficients respectively.

The mean (μ =0.7305) and standard deviation (σ =0.1510) of the spring season for 12th hour (peak load) is taken from [26] . Next it is assumed that one hour is divided into 20 possible states for solar irradiance within a step of 0.05 kW/m^2. The PDF for each state is calculated and then determine the output power of a PV module for that 1 hour. The PV module specifications are taken from [27].

The expected output power of PV module at corresponding solar irradiance (s) can be written as

$$Ep(s) = P_{PVM}(s) * f_b(s) \tag{9}$$

Finally, the total expected output power corresponding to a specific time segment is determined as follows.

$$TEP = \int_0^1 P_{PVM}(s) * f_b(s) ds \tag{10}$$

The total expected output power of 1 PV module is the sum of all powers that is shown in Fig.1. is 134.21 W. The number of PV modules considered here is 1000 to form a PV array. So output power of 1 PV array is 134.21 kW.

2.2. Wind Speed Modelling and Output Power Calculation

The output power of wind based DGs is extremely influenced by wind speed. So before placement of these sources in DS the uncertainty associated with wind speed is effectively modeled. For these Weibull PDF has been used [26].

The Weibull PDF for the wind speed is given as follows

$$f_v(v) = \frac{k}{c}\left(\frac{v}{c}\right) \exp\left(-\left(\frac{v}{c}\right)^{k-1}\right) \quad for \quad c > 1; \quad k > 0 \tag{11}$$

Where k , c are shape and scale factors and these are calculated using Eqs. (12) and (13).

$$k = \left(\frac{\sigma}{\mu}\right)^{-1.086} \tag{12}$$

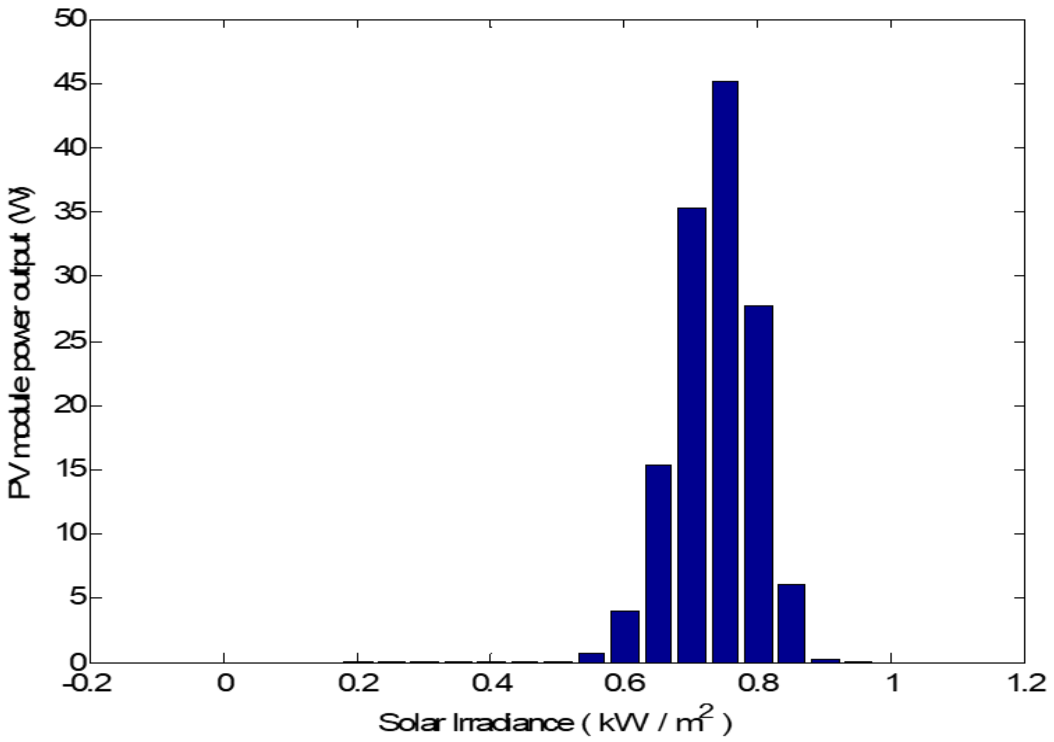

Figure 1. *PV module expected power output*

$$c = \frac{\mu}{\Gamma\left(1+\frac{1}{k}\right)} \tag{13}$$

Here μ and σ are the mean and standard deviation of wind speed.

The mean (μ =11.2333) and standard deviation (σ =2.5891) are taken from [26]. Next it is assumed that one hour is divided into 20 possible states for wind speed within a step of 1 m/s. The Weibull distribution function for each state is calculated and then determine the output power of a wind turbine (WT) for that 1 hour. The specifications of WT are taken from [9].

$$PG_{WT}(v) = \begin{cases} 0, & for \;\; 0 \le v < V_{cut-in} \;\; and \;\; v > V_{cut-out} \\ \left(a.v^3 + b.P_r\right), & for\, V_{cut-in} \le v \le V_r \\ P_r & for\, V_r \le v \le V_{cut-out} \end{cases} \tag{14}$$

where

$$a = \frac{P_r}{(V_r^3 - V_{cut-in}^3)} \tag{15}$$

$$b = \frac{V_{cut-in}^3}{(V_r^3 - V_{cut-in}^3)} \tag{16}$$

The expected power output of the WT at corresponding wind speed is calculated as follows.

$$EP_{WT} = PG_{WT} * f_v(v) \tag{17}$$

Finally, the total expected output power of WT at a specific time period is determined as follows.

$$TEP_{WT} = \int_0^1 PG_{WT} * f_v(v)\, dv \tag{18}$$

The total expected output power of a wind turbine is a summation of powers that is shown in Fig.2. is 355.94 kW.

3. PROBLEM FORMULATION

The main aim of the placement of different types of DERs in the DS is to minimize the different objective functions. The problem is solved at full load condition and respective objective functions are described as follows.

3.1.1. Active power loss minimization

The power loss of DS is majorly depending upon exact location and size of DERs. The real power loss is defined as [28].

$$f_1 = \sum_{k=1}^{nb} |I_k|^2 \, R_k \tag{19}$$

where I_k and R_k are the current magnitude and resistance corresponding to k^{th} branch. nb is the number of branches.

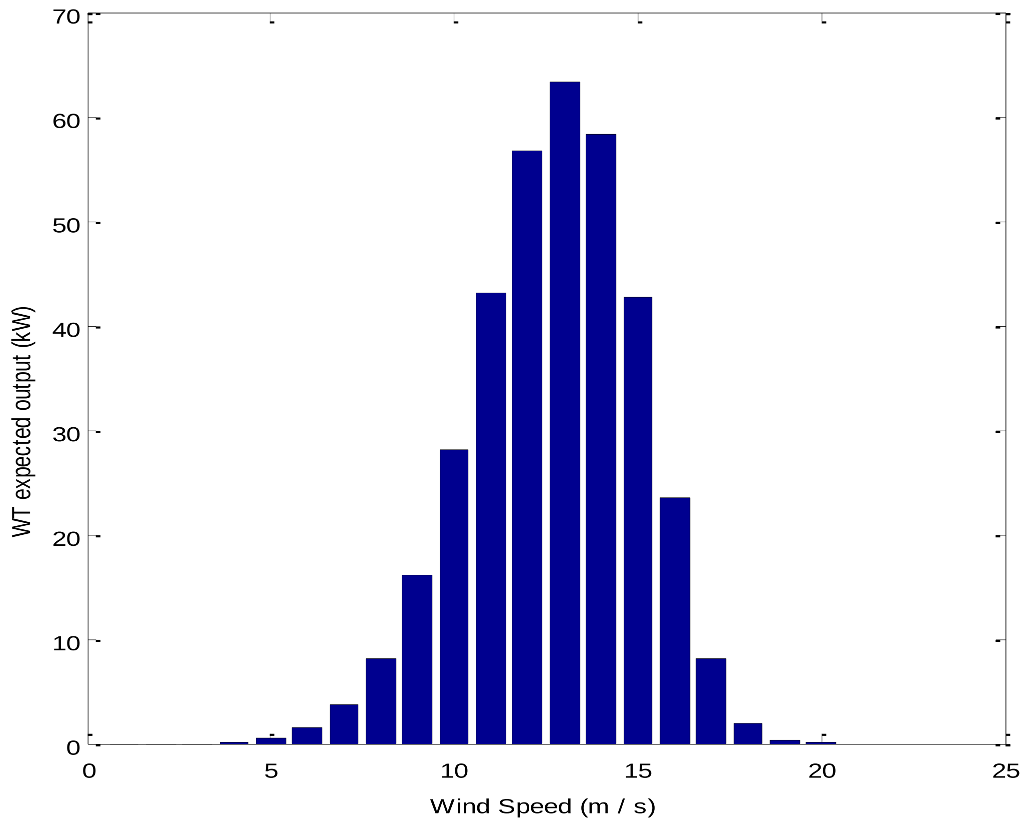

Figure 2. *Wind turbine expected power output*

3.1.2. Reactive power loss minimization

DERs injecting both and active and reactive power into the system shows positive impact of reactive power loss minimization of the system. So, the reactive power loss is calculated as [28].

$$f_2 = \sum_{k=1}^{nb} |I_k|^2 X_k \tag{20}$$

3.1.3. Minimization of emission

Another most important advantage of the DERs placement in the DS is generating electrical power with minimum gas emissions compared to conventional power plants. The important pollutants are examined, i.e. sulfur dioxide, carbon dioxide and nitrogen oxides. The emission factors of grid and different types of DERs are taken from [29]. Finally, emission objective is given as follows [29].

$$f_3 = \sum_{i=1}^{N_{GAST}} E_{GAST_i} + \sum_{i=1}^{N_{PVA}} E_{PVA_i} + \sum_{i=1}^{N_{WindT_i}} E_{WindT_i} + E_{Grid} \tag{21}$$

$$E_{Grid} = \left(CO_2^{Grid} + NO_x^{Grid} + SO_2^{Grid} \right) * P_{Grid} \tag{22}$$

$$E_{GAST_i} = \left(CO_2^{GAST} + NO_x^{GAST} + SO_2^{GAST} \right) * P_{GAST_i} \tag{23}$$

$$E_{WindT_i} = \left(CO_2^{WindT} + NO_x^{WindT} + SO_2^{WindT} \right) * P_{WindT_i} \tag{24}$$

$$E_{PVA_i} = \left(CO_2^{PVA} + NO_x^{PVA} + SO_2^{PVA}\right) * P_{PVA_i} \tag{25}$$

Where E_{Grid}, E_{GAST_i}, E_{WindT_i}, E_{PVA_i} are emissions produced and P_{Grid}, P_{GAST_i}, P_{WindT_i}, P_{PVA_i} are the power generated by the ith energy sources consisting of grid, GTs, WTs and PVA units respectively.

3.2. Objective Function Formulation

The developed multi objective function (MOF) is formulated to reduce active and reactive power loss and emission produced by the DERs.

$$Min\ OF = \min\left(\beta_1 f_1 + \beta_2 f_2 + \beta_3 f_3\right) \tag{26}$$

where

$$\sum_{j=1}^{3} \beta_j = 1.0 \wedge \beta_j \in [0,1] \tag{27}$$

The weights of the OF are considered as follows β_1=0.5, β_2=0.4, and β_3=0.1. These give respective importance of each objective function. Choosing better weights depends upon the experience of the planners [30].

The formulated OF, satisfy various operating constraints of the DS these are discussed as follows.

3.3. Constraints

The proposed objective function satisfies the various equality and inequality constraints of the DS which is given as follows.

Voltage magnitude limits:

The minimum (0.95 p.u.) and maximum (1.05 p.u.) voltage magnitude of each bus should be within the specified limits, i.e.

$$V_{\min} \leq V \leq V_{\max} \tag{28}$$

Power flow constraints:

$$P_{sub} + \sum_{DER=1}^{k} P_{DER} = P_L + P_{loss} \tag{29}$$

$$Q_{sub} + \sum_{DER=1}^{k} Q_{DER} = Q_L + Q_{loss} \tag{30}$$

Thermal constraint:

$$|I_{line}| \leq |I_{\max}| \tag{31}$$

DG penetration limit

$$P_{DER} \leq P_D \tag{32}$$

where P_{DER} is the power generated by the distributed energy resource and P_D is the total load demand of the system.

All the above constraints of DS are satisfied, then the obtained solution is considered, otherwise it is rejected.

4. VOLTAGE STABILITY FACTOR (VSF) TECHNIQUE FOR DERS PLACEMENT

The best locations for placement of different types of DERs in the DS are identified by using VSF method [31]. The VSF of bus n+1 can be calculated as follows.

$$VSF_{n+1} = 2V_{n+1} - V_n \tag{33}$$

From the above equation, determine the VSF for all buses and place the DERs in which buses having less value of VSF. VSF values for 33 and 69 bus system are shown in Figs. 3 and 4.

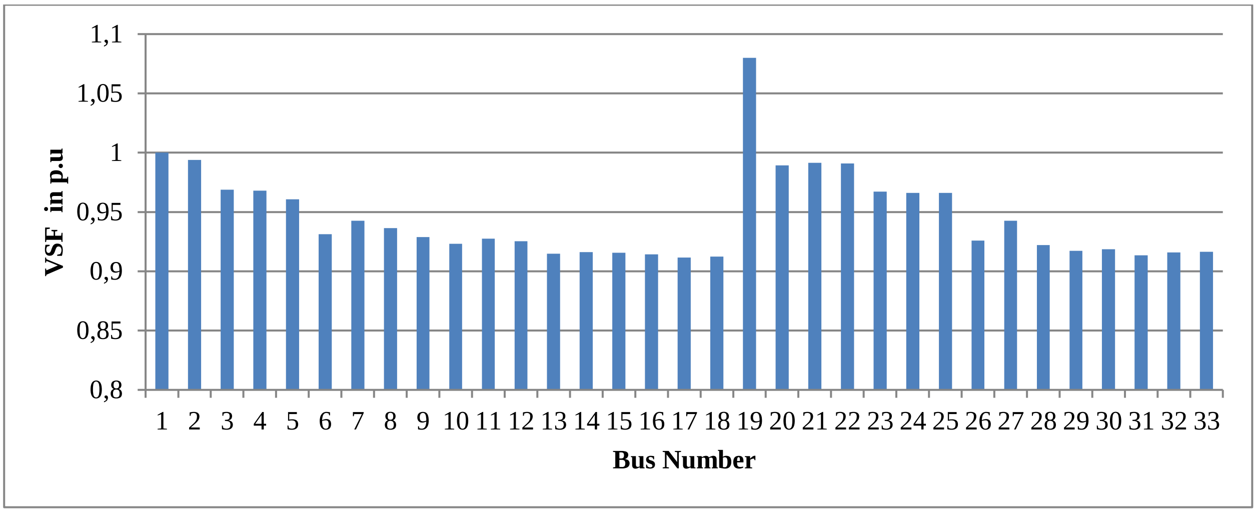

Figure 3. *Voltage Stability Factor values for 33 bus RDS*

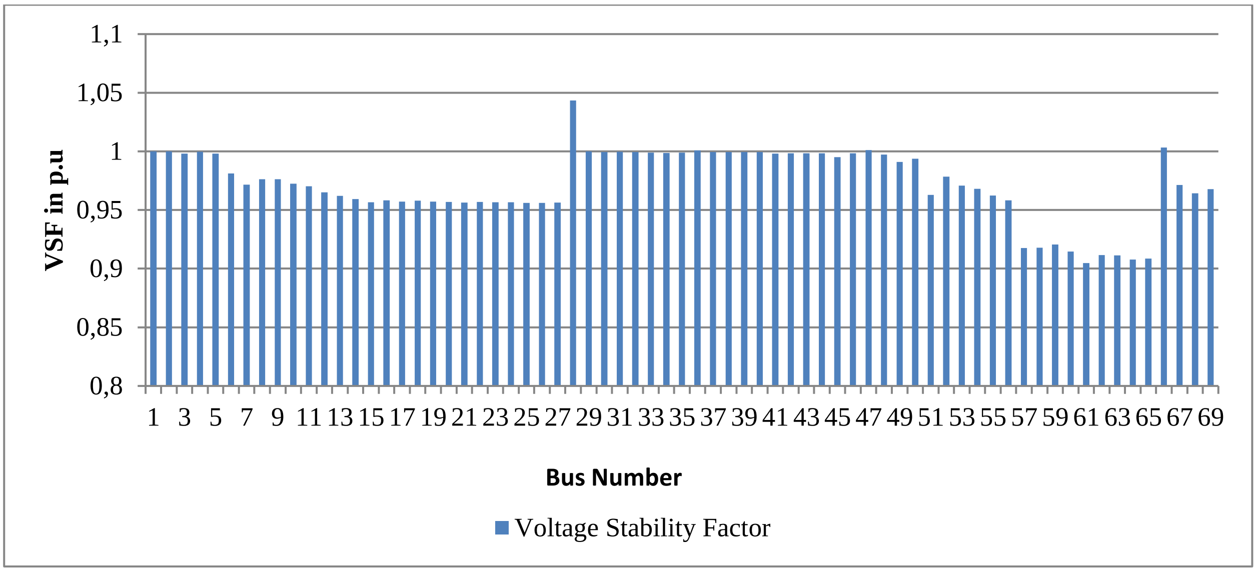

Figure 4. *Voltage Stability Factor values for 69 bus RDS*

5. OVERVIEW OF DRAGONFLY ALGORITHM (DFA)

Dragonfly algorithm (DFA) is developed by Seyedali Mirjalili in the year 2015 [32]. This algorithm is developed based on static and dynamic swarming behaviours of dragonflies. In case of static swarm, dragonflies create sub swarms and moves different areas in the search space for searching food. In case of dynamic swarm, group of dragonflies moves in a particular direction over long distances. Finally, these two swarming behaviours correlate two very important phases of optimization that is an exploration and exploitation. These two phases are mathematically explained by using the following equations.

1. Separation (S_i): During the search process, dragonflies avoid collision among themselves in the neighborhood that is determined as follows.

$$S_i = -\sum_{j=1}^{N} X - X_j \tag{34}$$

where X, X_j is the position of current and j[th] neighbouring individual. Also N is the number of neighbouring individuals.

2. Alignment (A_i): Velocity matching between individuals is very important during the search process, i.e. given by

$$A_i = \frac{\sum_{j=1}^{N} V_j}{N} - X \tag{35}$$

where V_j is the velocity of j[th] neighbouring individual.

3. Cohesion (C_i): This refers to the attraction of the swarm towards the center of the group of swarms.

$$C_i = \frac{\sum_{j=1}^{N} X_j}{N} - X \tag{36}$$

whereas X_j is the position of the j[th] neighbouring individual and X is the position of current individual respectively.

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

$$F^i = X^+ - X \tag{37}$$

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

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

$$E^i = X^- + X \tag{38}$$

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

Finally, the behaviour of dragonflies during search process is effectively modelled by using these five Eqs (34-37). In the search space, the position and movements of dragonflies are updated by using two vectors that are step vector (ΔX) and position vector (X).

The step vector is calculated by using Eq. (39)

$$\Delta X_{t+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + w\Delta X_t \tag{39}$$

where S_i, A_i, C_i, F_i , and E_i are separation, alignment, cohesion, attraction towards food source and distraction outwards enemy of i[th] individual. Also $s, a, c, f, e,$ and w are the weighting factors corresponding to each parameter and t is the iteration counter.

Update the position vectors by using Eq. (39).

$$X_{t+1} = X_t + \Delta X_{t+1} \tag{40}$$

where t is the current iteration.

If any search based technique gives better results it is important to maintain balance between exploration and exploitation abilities during the search process. In case of DFA, balance between exploration and exploitation is achieved by assigning exact alignment and cohesion weights. Also, convergence characteristics plays an vital role discuss the ability the search algorithm. In case DFA, convergence is assured, because dragonflies change their weights adaptively during optimization and maintain good balance between exploration and exploitation.

Exploration capability, randomness and stochastic behaviour of dragonflies are improved in a search space using random walk (Levy flight) , if there is no improvement in the neighbouing solutions. In this situation , the position of dragonflies is updated by using Eq.(40).

$$X_{t+1} = X_t + Levy(d) \times X_t \tag{41}$$

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

The Levy flight is determined as follows.

$$Levy(d) = 0.01 \times \frac{r1 \times \sigma}{|r_2|^{\frac{1}{\beta}}} \tag{42}$$

where β is constant, r_1, r_2 are two random numbers in [0, 1] and σ is calculated as follows.

$$\sigma = \left(\frac{\Gamma(1+\beta) \times \sin(\frac{\pi\beta}{2})}{\Gamma(\frac{1+\beta}{2}) \times \beta \times 2^{\left(\frac{\beta-1}{2}\right)}} \right)^{\frac{1}{\beta}} \tag{43}$$

5.1. Application of DFA for Determining Optimal Sizes of DERs

DFA has been a recently developed search based technique and it is effectively applied for solving DG allocation problem in the DS. The pseudo code and steps for solving DG allocation problem is illustrated in Figures. 5 and 6.

```
Initialize the dragonflies population X_i (i=1,2…..n)
Initialize step vectors ΔX_i (i = 1, 2,....n)
While the end condition is 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.(34) to (38)
        Update neighbouring radius
        if a dragonfly has at least one neighbouring dragonfly
                Update velocity vector using Eq. (39)
                Update position vector using Eq. (40)
        else
                Update  position vector using Eq.(41)
        end if
        Check and correct the new positions based on the boundaries of variables
end while
```

Figure 5. *Pseudo code of DFA (adapted from [32])*

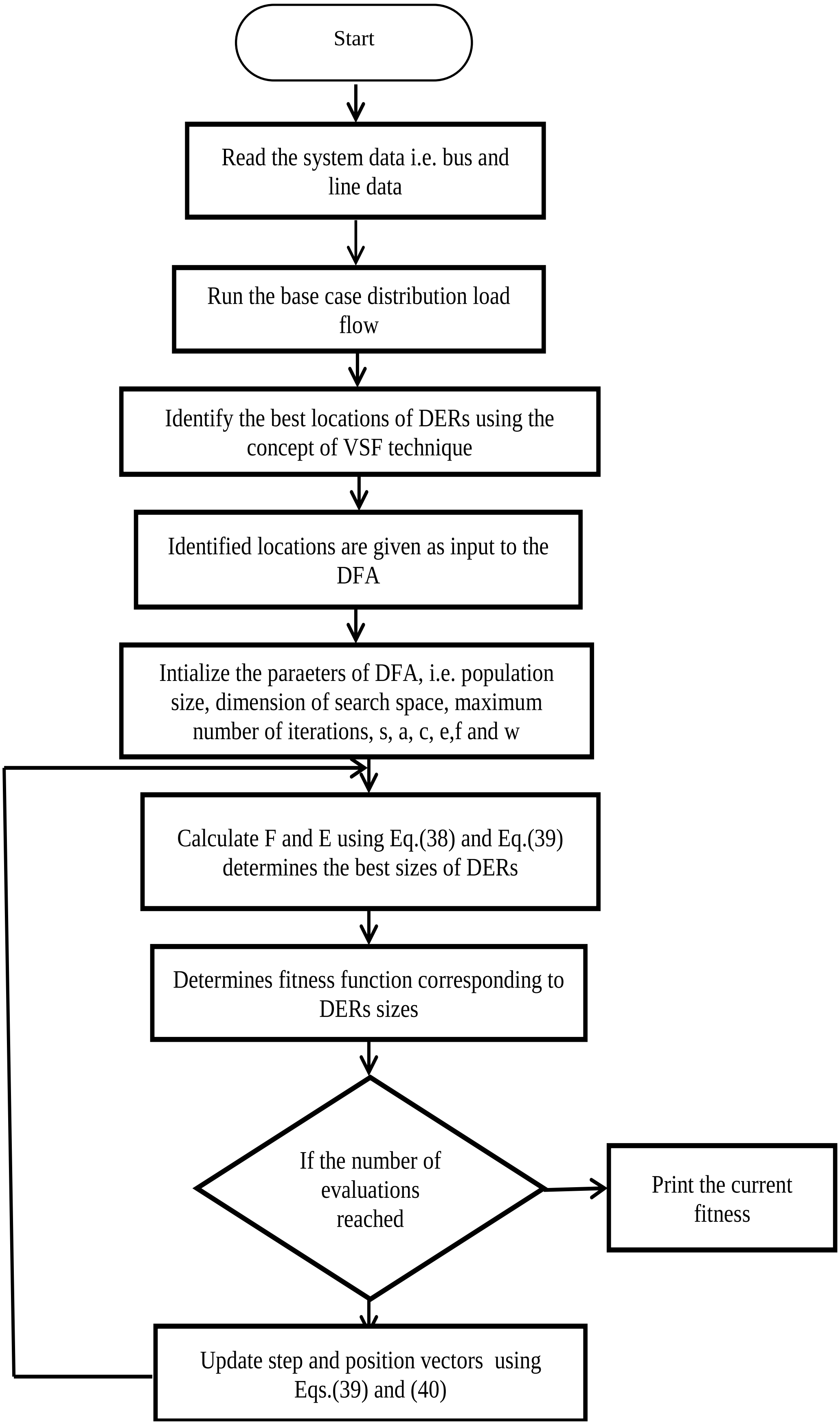

Figure 6. *Flowchart for solving DER allocation problem using DFA*

6. RESULTS AND DISCUSSION

In this section optimal allocation of different types of DERs in the DS is presented. The objectives of the proposed method are to minimize real, reactive power losses and emissions produced by the conventional based generation sources. The developed method is implemented on IEEE 33 and 69 bus test systems. A forward-backward distribution load flow is used for power flow calculations [33]. The parameters considered for DFA for both the test systems are number of search agents=20, dimension of search space (d=6), separation weight(s=0.1), alignment weight(a=0.1), cohesion weight (c=0.7), food attraction weight (f=1), enemy distraction weight (e=1) and inertia weight (w=0.8) and maximum number of iterations=100. The developed method is implemented in MATLAB environment.

6.1. 33-Bus Test System

The data related to the test system is taken from [34]. The active and reactive power losses without placement of DERs in the DS is 211 kW and 143.03 kVAr respectively. First, the best locations for placement of DERs are found out using VSF concept. The buses which have less value of VSF are considered as optimal buses for DER placement. After identifying the best locations, the sizes of GTs, the exact number of PVAs and WTs placed in the identified locations are determined by using search-based technique DFA. The output power of wind and solar based generation sources are highly influenced by meteorological conditions like wind speed and solar irradiance. So, before placement, stochastic behavior of these sources (solar irradiance and wind speed) is effectively modeled using suitable PDFs and determine the exact output. The output power of 1 PV array is 134.21 kW and WT are 355.94 kW.

Two different scenarios are considered in the analysis. In the first scenario, optimal allocation of different types of DERs i.e. GTs, WTs that are operating at 0.85 power factor and solar based DGs operating at unity power factor are considered and placed in the DS. Obtain the results are tabulated in Table 1. From Table 1, it is observed that active and reactive power losses are reduced effectively with the optimal allocation of different types of DERs. In case of placement of GTs, the real and reactive power losses are reduced to the maximum extent, but emissions produced by the sources are high. Next, in case of placement of wind based DGs on the DS, the active and reactive power losses are minimized effectively. The emissions produced by WTs are negligible, because there are no direct emissions produced by these sources. Finally, placement of solar based DGs in the DS. The power losses are reduced to some extent, but this is not much less compared to the placement of GTs and WTs. Because, placement of solar based DGs operating at unity power factor injects only real power into the system. Renewable based generation sources (wind, solar) placement in the DS shows the positive impact in view of emission reduction. But, intermittent and uncertainty in their output power show a negative impact on the system. So, it is better using these sources in combination with conventional based generation sources (GTs).

In the second scenario optimal combinations of different types of DERs in the DS are considered and the obtained results are tabulated in Table 2. From Table 2, it is clear that real and reactive power losses are reduced effectively with optimal combinations of different types of DERs placed in the DS. Different combinations of these sources show clear impact in the emission reduction. The emissions produced by the GTs are high compared to the placement of WTs and solar based DGs in the DS. So it is very clear from the results, a combination of GTs with WTs reduces the emissions compared to placement of only GTs. Next, combinations of GTs with solar based sources reduce the emission value compared to placement of only GTs. But, the overall active and reactive power loss, the emission reduction value is less compared to the placement of GTs and WTs. Because, solar based DGs injects only active power into the system. Also, the injected active power from solar based DGs is less compared to GTs. Finally, optimal combination of GT, WTs and solar based DGs is considered and placed in the DS. In this case power losses are reduced to maximum value. Also, emission value is less because GTs is in combination is with both WTs and solar based DGs. So, optimal combination of different types of DERs is placed in the DS improves the distribution network performance in terms of both technical as well as environmental aspects. The voltage profile of the DS before and after placement of different types and combination of DERs placed in the DS is shown in Figs.7 and 8. From the figures, it is clear that the voltage profile enhanced effectively in both the cases.

Table 1. *Optimal allocation of different types of DERs in 33 bus distribution system*

DER Type	DG location (bus)	DG size in kW/kVAr	P_{loss} (kW)	Q_{loss} (kVAr)	Emission (Ib/h)	V_{min} in p.u
Base case	NA	NA	211	143.03	NA	0.9037
GTs	13 18 31	670.58/415.58 142.83/88.51 1040/644.53	35.06	24.49	2771.14	0.9793
WTs	13 29 32	711.88/441.18 355.94/220.59 1067.82/661.77	34.45	26.80	NA	0.9806
Solar	14 28 31	671.05/0.0 536.84/0.0 805.26/0.0	85.02	58.59	NA	0.9637

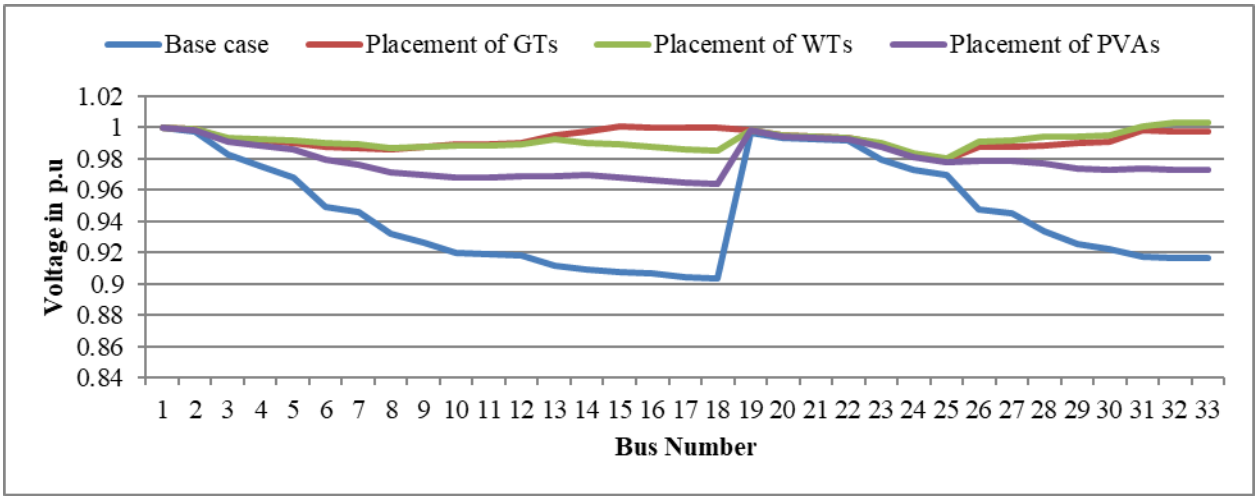

Figure 7. *Voltage profile of 33 bus test system with optimal allocation of GTs, WTs and PVAs placed in DS*

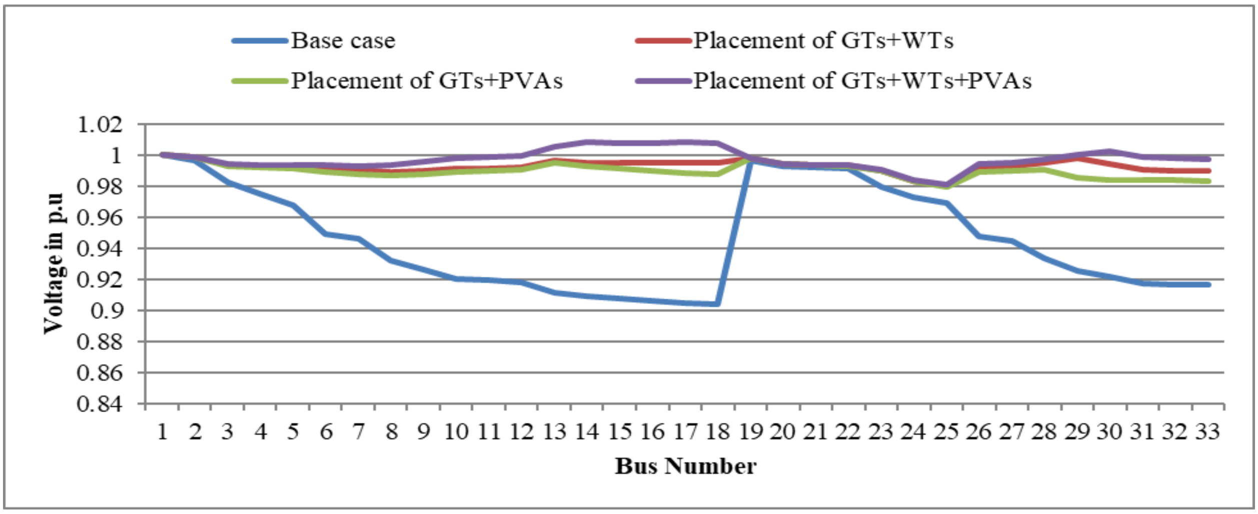

Figure 8. *Voltage profile of 33 bus test system with optimal combination of different types of DERs placed in DS*

Table 2. *Optimal combination of different types of DERs in 33 bus distribution system*

DER Type	DG location (bus)	DG size in kW/kVAr	P_{loss} (kW)	Q_{loss} (kVAr)	Emission (Ib/h)	V_{min} in p.u
Base case	NA	NA	210.99	143.03	NA	0.9037
GT GT WT	13 18 29	610.50/378.25 171.40/106.22 1067.82/661.72	35.24	23.52	1169.06	0.9792
GT GT Solar	13 28 32	796.10/493.37 778.61/482.53 536.84/0.0	40.33	28.51	2353.37	0.9798
GT Solar WT	14 17 30	651.07/403.49 268.42/0.0 1067.82/661.72	33.91	23.76	973.45	0.9796

6.2. 69-Bus Test System

The test system data are taken from [34]. The active and reactive power loss before allocation of DERs in the DS is 225 kW and 102.2 kVAr respectively. The best locations for placement of DERs in the DS is found out by using the concept of VSF. The buses which have less value of VSF is considered as candidate buses for DERs placement. Two different scenarios are considered. In the first scenario, optimal allocation of different types of DERs is placed in the DS and the obtained results are tabulated in Table 3. From the Table 3, it is observed that placement of GTs and WTs in optimal locations reduces the active and reactive power loss effectively compared to placement of solar based DGs. In case of placement of GTs and WTs in the DS, injects both active and reactive power into the system. But, in case of solar based DGs placed in the DS, injects only active power. So, active and reactive power loss reduction is less compared to the placement of GTs and WTs. Finally, in view of emission reduction, emissions produced by the gas turbines are more compared to the placement of WTs and solar based DGs. Because, there are no direct emissions produced by the WTs and PVAs. Even though the placement of solar based DGs and WTs in the DS shows positive impact on emission reduction. But the uncertainties associated with these sources shows a negative impact on the system. So, it is better to use renewable based generation sources in combination with conventional based sources.

In the second scenario, optimal combination of different types of DERs is considered and placed in the DS. The obtained results with different combinations of DERs placed in the DS are tabulated in Table 4. From the obtained results, it is clear that placement of GTs in combination with WTs and solar based DGs improves the distribution network performance in terms of both technical as well as environmental aspects.Voltage profile at all buses are improved effectively after placement DERs of different types in the DS that is illustrated in Figs.9 and 10.

Table 3. *Optimal allocation of different types of DERs in 69 bus distribution system*

DER Type	DG location	DG size in kW/kVAr	P_{loss} (kW)	Q_{loss} (kVAr)	Emission (Ib/h)	V_{min} in p.u.
Base case	NA	NA	225	102.19	NA	0.9090
GTs	61 64 21	1346.2/834.35 400.15/247.99 420.55/260.63	8.44	8.70	3238.51	0.9916
WTs	61 64 21	1423.7/882.36 355.94/220.59 355.94/220.59	9.06	8.97	NA	0.9905
Solar	61 64 24	805.26/0.0 671.05/0.0 536.84/0.0	76.73	38.19	NA	0.9704

Table 4. *Optimal combination of different types of DERs in 69 bus distribution system*

DER Type	DG location	DG size in kW/kVAr	P_{loss} (kW)	Q_{loss} (kVAr)	Emission (Ib/h)	V_{min} in p.u
Base case	NA	NA	225	102.19	NA	0.9090
GT GT WT	61 64 26	1428.30/885.18 322.50/199.86 355.94/220.59	10.61	9.57	2617.27	0.9902
GT GT Solar	61 65 24	1525.5/945.41 213.60/132.37 402.43/0.0	14.34	11.16	2599.48	0.9892
GT WT Solar	61 64 21	1411/874.45 355.94/220.59 402.63/0.0	13.48	10.77	2109.66	0.9894

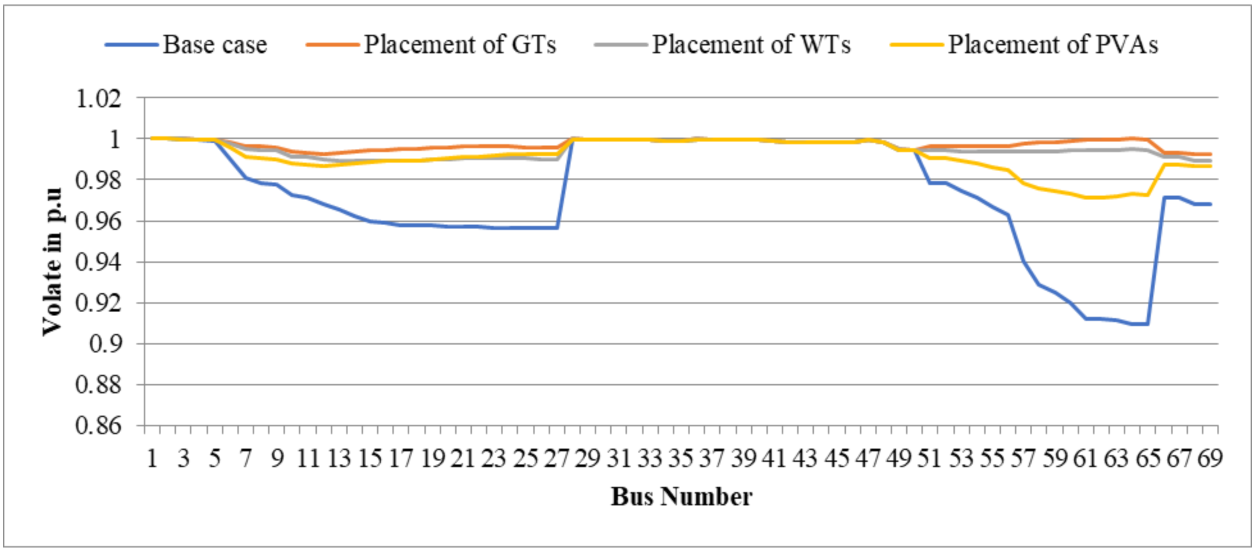

Figure 9. Voltage profile of 69 bus test system with optimal allocation of GTs, WTs and PVAs placed in DS

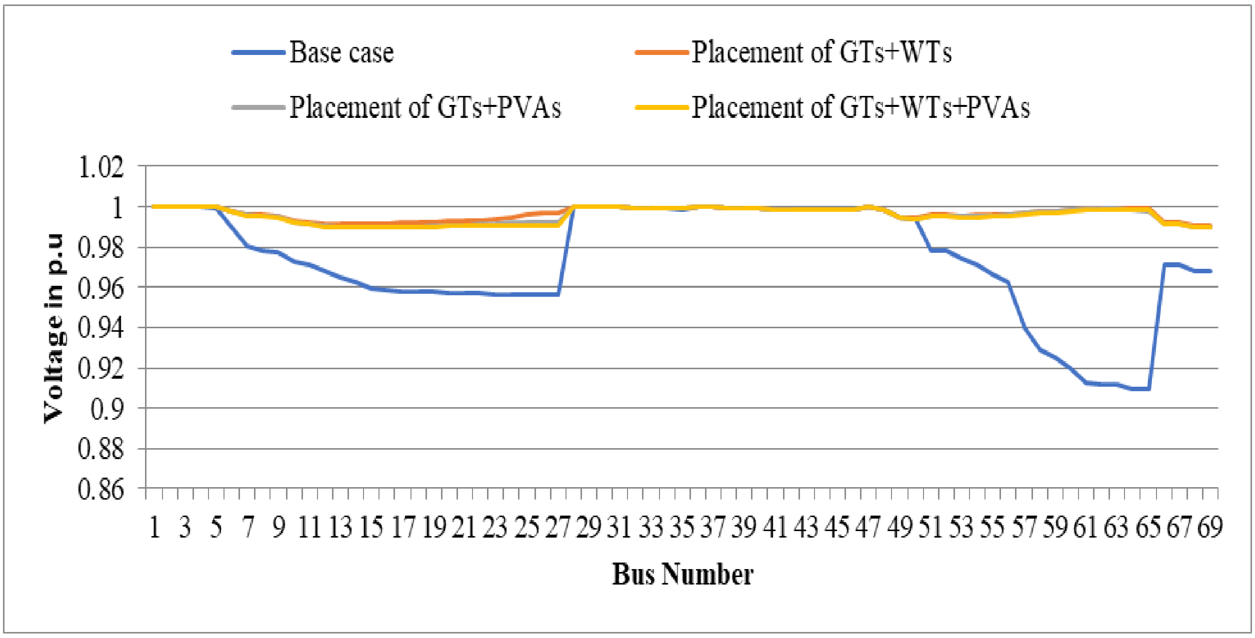

Figure 10. Voltage profile of 69 bus test system with optimal combination of different types of DERs placed in DS

7. CONCLUSION

In this paper, an effective methodology has proposed for optimal allocation of different types of DERs in the DS was presented. An integrated approach of VSF and search based technique DFA is effectively applied for determining the best location and sizes of these sources. Weibull and beta probability distribution functions (PDF) are effectively applied for modelling the generation uncertainties associated with wind and solar based generation sources. The developed method is implemented on IEEE 33 and 69 bus test systems. Two different scenarios are considered in the analysis. In the first scenario, optimal allocation of GTs, WTs and solar based DGs in the DS is presented. From the obtained results, it is observed that placement of GTs and WTs with suitable sizes minimizes the active and reactive power losses effectively compared to placement of solar based DGs. Optimal placement of GTs with suitable sizes minimizes the losses effectively, but the emissions produced by the sources are high compared to placement WTs and solar based DGs. Even though the optimal placement of WTs minimizes the losses and emissions, but the generation uncertainties associated with these sources show a negative impact on the system. In the second scenario, optimal combinations of different types of DERs are considered and placed in the DS. From the simulated results, it is observed that optimal placement of GTs, WTs and solar based DGs on the DS minimizes the power losses and emission produced by the sources. Finally, it can be concluded that optimal combination of different types of DERS placed in the distribution system improves performance of the system in terms of both of technical as well as environmental aspects

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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