AMSE JOURNALS –2015-Series: Advances C; Vol. 70; N° 1; pp 46-70
Submitted March 2015; Revised Sept. 24, 2015; Accepted Oct.15, 2015

Solution of Multi-Objective Optimal DG Placement Problems using Swine Influenza Model Based Optimization (SIMBO)

S. Sharma, S. Bhattacharjee, A. Bhattacharya

Department of Electrical Engineering, National Institute of Technology,
Agartala, Tripura, 799046 India
(sharmistha.sharma34@yahoo.com, subhadeep_bhattacharjee@yahoo.co.in,
bhatta.aniruddha@gmail.com)

Abstract

Distributed Generation (DG) sources are becoming more and more prominent in distribution networks due to the incremental demands for electrical energy. Determination of optimal locations and capacities of Distributed Generation (DG) sources has become one of the major problems of distribution utilities. In this paper Swine Influenza Model Based Optimization with Quarantine (SIMBO-Q) has been applied to determine optimal location and size of DGs in distribution systems to minimize network power losses, achieve better voltage regulation and improve the voltage stability. SIMBO-Q performs the optimization through quarantine and treatment based on probability. SIMBO-Q provides optimization of complex multi-modal functions with improved convergence and accuracy. The proposed algorithm is applied to 33-bus and 69-bus radial distribution systems and results are compared with other evolutionary techniques like Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and combined GA/PSO. Numerical studies represent the effectiveness and out-performance of the proposed algorithm.

Key words

Distributed Generations, power losses, Swine Influenza Model Based Optimization with Quarantine (SIMBO-Q), voltage profile, voltage stability

1. Introduction

Electric utilities are continuously planning the expansion of their existing electrical networks to meet increasing the load growth. An alternative way to satisfy the increasing demand is to use Distributed Generation (DG) system. Distributed Generation can be defined as small scale generation which is located onsite or close to the load centre and is interconnected to the distribution network [1]. Some advantages of DG are grid reinforcement, power loss reduction, increasing efficiency, eliminating the upgrades of power system, reliability, improving voltage profile and load factors and hence power quality, reducing transmission and distribution costs, saving the fossil fuel, decreasing in electricity price, reduction in emissions of green-house gases and also sound pollutions [2]. Different DG technologies available in the market are reciprocating engines, combustion gas turbines, micro turbines, fuel cells, photovoltaic system, wind turbines, small hydro- electric plant etc.

Interconnection of renewable energy sources to power system networks have profoundly impacted on many factors of power system networks like system loss, voltage profile, voltage stability, thermal loadings etc. In [3], R. Mohapatra and A. Kalam analyzed the impact of renewable energy sources in power system GE wind turbine with Zero Power Mode (ZPM) characteristics connected to a weak power system of Australian Grid, on network voltage profiles, thermal loadings and settling times for voltage disturbances under various demand conditions. In [4], R. Mohapatra et al. analyzed the variation in voltage of the power system network in terms of its stability, when renewable energy sources are interconnected to the network. In view of these, determination of optimal location and size of Distributed Generation sources (DGs) in distribution network is considered as one of the major problems of distribution utilities.

Many researchers proposed different methods such as analytical methods as well as deterministic and heuristic methods to solve optimal DG placement and sizing problem. Authors Frauk Ugranli and Engin Karatepe [5] proposed a power flow algorithm based on Newton-Raphson method to consider the impact of multiple DG units on power losses and voltage profile in respect of point of common coupling (PCC), DG size and power factor of DG. Mohab M. Elnashar et al.[6] presented a visual optimization approach for determining the optimal placement and sizing of the DG through the choice of the appropriate weight factors of the parameters like losses, voltage profile and short circuit level. Sudipta Ghosh et al.[7] suggested a simple conventional iterative search technique based on Newton-Raphson load flow method study for optimal sizing and placement of DG by optimizing both cost and loss simultaneously. R.K.Singh and S.K.Goswami [8] presented a new methodology based on nodal pricing for optimally allocating DG for profit maximization, loss reduction and voltage improvement including voltage rise phenomenon. In [9-11], authors proposed analytical methods to determine optimal size and location of DG in radial systems to minimize the loss of the systems. A. Kazemi and M. Sadeghi [12] presented a load flow based algorithm for DG allocation in radial systems for voltage profile improvement and loss minimization. M.H.Moradi et al. [13] presented a Genetic Algorithm (GA) based evolutionary technique for optimum placement and sizing of four different types of DG and the objective was to minimize real power loss within security and operational constraints. M.H.Aliabadi et al. [14] proposed a combination of GA and optimum power flow (OPF) technique for optimum placement and sizing of DG units in a given distribution system to minimize the cost of active and reactive power generation. M.Gomez-Gonzalez et al. [15] applied a new discrete Particle Swarm Optimization (PSO) and OPF technique to achieve optimal location and size of DG system in a distribution system. M.H.Moradi and M.Abedini [16] proposed a combined GA/PSO technique for finding optimal location and sizing of DG to minimize the losses, to increase the voltage stability and to improve the voltage regulation index in radial distribution systems. In [17-18] authors proposed ant colony optimization technique and dynamic programming approach for solving DG sizing and placement problems.

Recently, Swine Influenza Model based Optimization (SIMBO) has been developed by S.S. Pattnaik et al.[19] and it is mimicked from Susceptible-Infectious-Recovered (SIR) models of swine flu. The developments of SIMBO follow through treatment (SIMBO-T), vaccination (SIMBO-V) and quarantine (SIMBO-Q) based on probability. The SIMBO variants are used to solve complex multimodal problems with fast convergence and also delivering good quality of optima. The algorithm converges rapidly due to the presence of vaccination/quarantine and treatment loops. The major advantages of SIMBO variants are their easy implementation and better accuracy to reach to the optimum solution. Exploration and exploitation ability of SIMBO is much improved compared to many previously developed optimization techniques. The improved performance of SIMBO-Q to solve different benchmark functions has motivated the present authors to apply the SIMBO-Q algorithm to evaluate the optimum DG location and size in radial distribution networks. In [20] authors have already applied SIMBO-Q algorithm to minimize active power loss of 33-bus radial distribution system. In the present work, authors have applied both single-objective and multi-objective optimizations to minimize power loss, improve voltage profile and voltage stability of 33-bus and 69-bus radial distribution systems. To show the effectiveness and superiority of SIMBO-Q algorithm in solving optimal DG placement problem, the results obtained in this paper have been compared to other optimization techniques like GA, PSO and combined GA/PSO.

The paper is structured as follows: Section 2 of the paper provides a brief description and mathematical formulation of power loss minimization, voltage profile improvement and voltage stability improvement problems for optimal placement and sizing of DG. Section 3 describes the SIMBO-Q algorithm shortly and the application of SIMBO-Q algorithm to determine optimal placement and sizing of DG. Simulation results and discussion are presented in Section 4. The conclusion is drawn in Section 5.

2. Problem Formulation

Proposed methodology in this paper aims to find optimum placement and size of DGs in a given radial distribution system by minimizing the power losses, maximizing the voltage stability and improving voltage profile in a radial distribution network. The full formulation of the DG optimization problem is organized in the following sections.

2.1. Case 1: Active Power loss minimization

The objective function to minimize real power loss of the distribution system is given by:

$$f_1 = Min\,(P_{RPL}) \tag{1}$$

where P_{RPL} is the real power loss of n_n-bus distribution system and is expressed as:

$$P_{RPL} = \sum_{i=1}^{N} I_{ni}^2 R_{ni} \tag{2}$$

where f_1 is the objective function value for active power loss minimization in p.u.; i is the branch number that fed bus n_i; n_i is the receiving bus number; m_i is the bus number that sending power to bus n_i; N is the total number of branches in the given radial distribution system ($N = n_n - 1$); I_{ni} is the branch current of the radial system shown in Fig.1 and is obtained from:

$$I_{ni} = \frac{V_{mi} - V_{ni}}{R_{ni} + jX_{ni}} \tag{3}$$

where V_{mi} is the voltage of bus m_i; V_{ni} is the voltage of bus n_i; R_{ni} is the resistance of branch i; X_{ni} is the reactance of branch i.

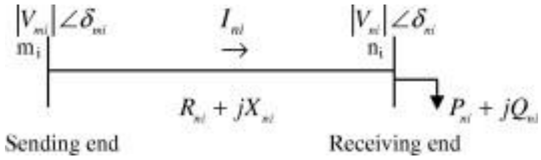

Fig. 1. A representative branch of a radial distribution system

2.2. Case 2: Voltage profile improvement

The objective function to improve voltage profile is expressed as:

$$f_2 = Min\,(\sum_{n=1}^{n_n}(V_n - V_{rated})^2) \tag{4}$$

where V_n is the voltage of bus n; V_{rated} is the rated voltage (1 p.u.).

2.3. Case 3: Voltage stability index improvement

Objective function for improving voltage stability index is,

$$f_3 = Min\left(\frac{1}{(SI(n_i))}\right), n_i = 2, 3, ..., n_n \tag{5}$$

where the voltage stability index of node n_i is given by:

$$SI(n_i) = |V_{mi}|^4 - 4\left[P_{ni}(n_i)R_{ni} + Q_{ni}(n_i)X_{ni}\right]|V_{mi}|^2 - 4\left[P_{ni}(n_i)X_{ni} - Q_{ni}(n_i)R_{ni}\right]^2 \tag{6}$$

where V_{mi} is the voltage of bus m_i; $P_{ni}(n_i)$ is total real power load fed through bus n_i; $Q_{ni}(n_i)$ is total reactive power load fed through bus n_i; R_{ni} is the resistance of branch i; X_{ni} is the reactance of branch i; P_{ni} and Q_{ni} of any bus n_i are obtained from:

$$P_{ni}(n_i) - jQ_{ni}(n_i) = V_{ni}^{*} I_{ni} \tag{7}$$

where I_{ni} is the branch current of the radial system shown in Fig. 1 and is obtained from Eq.(3); V_{ni} is the voltage of bus n_i;

The stability index which can be evaluated at all nodes of a radial distribution system was presented by Chakravorty and Das [21] and the equations used to formulate this index are presented in [22], to solve the load flow for radial distribution systems. For stable operation of radial distribution systems, $SI(n_i) > 0$ for $n_i = 2, 3, ..., n_n$, there exists a feasible solution. In [23], S. Banerjee determined voltage stability margin (VSM) of 33 bus and 69 bus radial distribution systems heuristically by considering reactive loading index of each branch.

2.4. Case 4: Active power loss minimization, voltage profile and voltage stability index improvement

Objective function for simultaneous minimization of active power loss, improvement of voltage profile and voltage stability index is given by:

$$f = Min(w_1 \times f_1 + w_2 \times f_2 + w_3 \times f_3) \tag{8}$$

where f_1 is the objective function for active power loss minimization; f_2 is the objective function for voltage profile improvement; f_3 is the objective function for voltage stability index improvement; w_1, w_2, w_3 are the weighting factors whose value varies uniformly between (0,1) such that $w_1 + w_2 + w_3 = 1$.

2.5. Constraints

The constraints used for solving optimum placement and sizing problem of DG in radial distribution network, are:

2.5.1. Load balance constraint

For each bus, the following equations should be satisfied:

$$P_{gni} - P_{dni} - V_{ni} \sum_{j=1}^{N} V_{nj} Y_{nj} \cos(\delta_{ni} - \delta_{nj} - \theta_{nj}) = 0 \tag{9}$$

$$Q_{gni} - Q_{dni} - V_{ni} \sum_{j=1}^{N} V_{nj} Y_{nj} \sin(\delta_{ni} - \delta_{nj} - \theta_{nj}) = 0 \tag{10}$$

where $n_i = 1, 2, ..., n_n$; P_{gni} is active power output of the generator at bus n_i ; Q_{gni} is reactive power output of the generator at bus n_i ; P_{dni} is active power demand at bus n_i ; Q_{dni} is reactive power demand at bus n_i ; V_{ni} is voltage of bus n_i ; δ_{ni} is phase angle of voltage at bus n_i ; $N = (n_n - 1)$ is total number of branches in the given radial distribution system (RDS); n_n is total number of buses in the given RDS; Y_{nj} is the admittance magnitude of branch *j*; θ_{nj} is the admittance angle of branch *j*.

2.5.2. Voltage limits

Voltage at each bus must be kept within its maximum and minimum standard values i.e.

$$V_{ni}^{\min} \le V_{ni} \le V_{ni}^{\max} \tag{11}$$

where V_{ni} is the voltage of bus n_i ; $V_{ni}^{\min}$ is the minimum voltage at bus n_i ; $V_{ni}^{\max}$ is the maximum voltage at bus n_i ;

2.5.3. DG technical constraints

As DG capacity is inherently limited by the energy resources at any given location, it is necessary to maintain capacity between the maximum and the minimum levels.

$$P_{gni}^{\min} \le P_{gni} \le P_{gni}^{\max} \tag{12}$$

where P_{gni} is active power output of the generator at bus n_i ; $P_{gni}^{\min}$ is minimum active power of DG at bus n_i ; $P_{gni}^{\max}$ is maximum active power of DG at bus n_i ;

2.5.4. Thermal limit

Final thermal limit of distribution lines for the network must not be exceeded:

$$|S_{ni}| \le |S_{ni}^{\max}|, i = 1, ..., N \tag{13}$$

where S_{ni} is the apparent power at bus n_i ; $S_{ni}^{\max}$ is maximum apparent power at bus n_i (Here, $S_{ni}^{\max}$ = 5 MVA); *i* is the branch number that fed bus n_i ; *N* is the total number of branches in the given RDS;

3. Optimal placement and sizing of DG using SIMBO-Q algorithm

The optimal placement and sizing problems of DG are formulated as a multi-objective constrained optimization problem. This paper uses Swine Influenza Model Based Optimization with Quarantine (SIMBO-Q) for solving optimal placement and sizing problem DG in radial distribution systems.

3.1. Swine Influenza Model Based Optimization with Quarantine (SIMBO-Q)

SIMBO-Q performs the optimization through quarantine and treatment loop [19]. Basic steps of SIMBO-Q algorithm are given below and these steps continue until all generations are over.

3.1.1. Step 1: Evaluate health [19]

In this step, initially the health of all individuals is evaluated which depends upon the given fitness function. Then the suspected patients of swine flu are sampled for confirmation of the diagnosis.

3.1.2. Step 2: Swine flu test [19]

This test is done to confirm the suspected patients with swine flu virus. If current health of individual is greater than dynamic threshold (*D_Threshold*) then it is suspected, otherwise it is recovered case. *D_Threshold* depends on the health of best 50% population (*Sr*), *μ*, *rand* and primary symptoms as given in Eq.(15). Before calculation of *D_Threshold* value, all the individuals are sorted in order of ascending current health [19].

$$D\_Threshold = [Sum(Current\_health(1:Sr))/Sr) * \mu * rand * \mathrm{Pr}imary(Day)] \tag{14}$$

where μ is the probability of vaccination; $\mathrm{Pr}imary(Day)$ is the primary symptoms of swine flu caused due to fever, cough, fatigue and headache, nausea and vomiting and diarrhea during each day. It is expressed as:

$$\text{Primary}(Day) = (Fe * Co * fathead * NV * Dai) * \exp\left(-\frac{TD}{Day}\right) \tag{15}$$

where Fe, fever; Co, cough; $fathead$, fatigue and headache; NV, nausea and vomiting; Dai, diarrhea; TD, total number of days or generations; Day, current generation or iteration;

3.1.3. Step 3: Quarantine [19]

Quarantine is enforced isolation or restriction of free movement imposed to prevent the spread of contagious disease. The confirmed cases of swine flu are isolated or quarantined from the population so that they would not affect the health of other individual in population [19]. The quarantined individual is swapped with best individual in population. The *rand* is multiplied with best individual population i.e. Pandemic State (*PS*) to achieve diversity in the population. If probability of quarantined (β) is less than *rand* and current health of individual is greater than *D_Threshold*, then individual is quarantined otherwise it is part of population [19]. In order to isolate less number of individual from the population, the probability of quarantine (β) is kept high. The steps are:

```
for k= 1:TI
    if  rand > β
        if  current_health(k) > D_Threshold
            S(k) = PS * rand
        end
    end
end
```

where TI is total number of individuals in population; S is the state or position of individual; PS is pandemic (global) best state amongst all individuals.

3.1.4. Step 4: Treatment [19]

In SIMBO-Q the percentage of antiviral drugs depend on primary and secondary symptom as well as current health and pandemic health [19]. The dose given to the individual and the corresponding change in individual state are given by Eq.(16) and Eq.(17).

$$\begin{aligned} Dose(m+1) &= Dose(m) * Md + \text{Primary}(Day) * rand * (1 - Current\_health(m) / rand * PH) \\ &\quad + R0(Day) * rand * (Current\_health(m) - PH) \end{aligned} \tag{16}$$

$$S(m+1) = S(m) * Ms + Dose(m+1) \tag{17}$$

where $Dose$ is the anti-viral drugs given to swine flu patient as a curative strategy; $\Pr imary(Day)$ is the primary symptom of swine flu per day which is calculated by using Eq. (15); $R0(Day)$ is the secondary symptom caused per day is given by:

$$R0(Day) = 1 - \exp(-\Pr imary(Day)) \tag{18}$$

S is the state or position of individual; PH is the fitness value corresponding to pandemic (global) best state amongst all individuals; Md is momentum factor of dose and is used to restrict the dose of individual; Ms is the momentum factor of state and is used to restrict the state of individual;

The treatment given to individuals in the population depends upon the probability of recovery (α), which is kept very low to recover most of the individuals.

3.2. SIMBO-Q algorithm for optimum placement and sizing of DG

Different steps for applying this algorithm for optimum placement and sizing of DG in 33 bus radial distribution system are given below:

Step 1) Initialize the SIMBO-Q parameters i.e. Fe, Co, $fathead$, NV, Dai, α, β, μ.

Step 2) Generate an initial population matrix of NP individual populations with random location and size of DG.

Step 3) Run the load flow and check the constraints limits used in the problem.

Step 4) If constraints limits are satisfied, then go to the next step, otherwise again generate the initial population matrix and repeat the step 3.

Step 5) Set the initial "dose" given to individual randomly between 0 to 1.

Step 6) Evaluate the fitness function of each individual in terms of objective function values.

Step 7) Calculate the initial value of minimum fitness function value i.e. pandemic_health (*PH*) and the corresponding state i.e. pandemic_state (*PS*).

Step 8) Evaluate the current health of each individual which is equal to fitness function of each individual.

Step 9) Sort individual in order of ascending health and determine the dynamic threshold value, primary and secondary symptom values of swine flu using Eqs. (14), (15) and (18).

Step 10) Update the dose given to individual and state of individual depending on the values of probability of recovery, α and probability of quarantined, β.

Step 11) Check the limits of position and size of DG and run the load flow and check the constraints limits.

Step 12) If constraints limits are satisfied, then go to the next step, otherwise go to step 10 again and update the dose and state values of individual using its old value.

Step 13) Evaluate the fitness function of each individual and update the values of *PS* and *PH* and also calculate the best solution corresponding to the minimum fitness function value.

Step 14) For single objective optimization, if the maximum number of iterations is reached, terminate the iterative process, else repeat steps 8 to 13. For multi-objective optimization problems, if the current iteration is greater than or equal to the maximum iteration, keep the result in an array (known as the Pareto-optimal set) and stop; otherwise, repeat steps 8 to 13.

Step 15) In case of the tri-objective optimization problem using three weighting factors w_1, w_2, w_3 (as per Eq.(8)), increment the value of the weighting factors in steps of 0.1 starting from 0 to 1 so that sum of w_1, w_2, w_3 is 1 and each time repeat the steps starting from step 2 to step 14.

Step 16) Best compromise solution— the algorithm described above generates the non-dominated set of solutions known as the Pareto-optimal solutions. In the proposed method, for solving multi-objective optimization problems, fuzzy based mechanism and fitness sharing are employed to choose the best compromise solution from the pareto-front. For selecting an operating point from the obtained set of Pareto-optimal solutions, the fuzzy logic theory is applied to each objective function to obtain a fuzzy membership function μ_{fi} as follows:

$$\mu_i = \frac{f_i^{\max} - f_i}{f_i^{\max} - f_i^{\min}} \tag{19}$$

$$\mu_{fi} = \begin{cases} 0 & \mu_i \le 0 \\ \mu_i & 0 \angle \mu_i \angle 1 \\ 1 & \mu_i \ge 1 \end{cases} \tag{20}$$

where $f_i^{\max}$ and $f_i^{\min}$ are the maximum and minimum values of the *i*th objective function respectively. For each non-dominated solution *k*, the normalized membership function FDM^k is calculated as:

$$FDM^k = \left[\frac{\sum_{i=1}^{N_{obj}} \mu_{fi}^k}{\sum_{k=1}^{M} \sum_{i=1}^{N_{obj}} \mu_{fi}^k} \right] \tag{21}$$

where M is the number of non-dominated solutions, and N_{obj} is the number of objective functions. The best non-dominated solution can be found when Eq. (21) is maximum, where the normalized sum of membership function values for all objectives is highest. After completing the process, the best solution of the optimization problem is found.

4. Simulation Results and Discussion

The proposed SIMBO-Q algorithm for optimum placement and sizing of DG has been implemented using MATLAB 7.8 software and executed on a personal computer with Intel (R) Core i7, 3.40 GHz processor with 2 GB RAM. The proposed algorithm has been tested on 33-bus and 69-bus radial distribution systems. Test results of the 33-bus and 69-bus radial distribution systems are presented and discussed in this section. The rating of maximum active power generation of distributed generation sources and the power factor are taken as 1.5 MW and unity respectively. The optimization has been performed using Swine Influenza Model Based Optimization with Quarantine (SIMBO-Q) algorithm. During simulation, the values of parameters used in SIMBO-Q are $Fe = 0.4$, $Co = 0.4$, $fathead = 0.2$, $NV = 0.2$, $Dai = 0.2$, $\alpha = 0.2$, $\beta = 0.5$, $\mu = 0.8$, Md = rand and Ms = rand.

4.1. Simulation results and convergence characteristics

In this paper performance analysis of different single and tri-objective optimization case studies has been made on the basis of the DG location and size. The aim is to minimize active power loss, improve voltage profile and increase voltage stability. In 'Case 1' DG locations and sizes have been found to minimize active power loss of the system. In 'Case 2', aim is to improve voltage profile of the system. In 'Case 3' improvement of voltage stability index has been considered. In 'Case 4' a tri-objective optimization has been performed to minimize active power loss, to improve voltage profile and voltage stability index. Details of the results for different case studies are presented below.

4.1.1. Test system 1: 33-bus radial distribution system

In this case study a 33-bus radial distribution system with the total load of 3.72 MW, 2.3 MVAR has been used. Fig. 2 shows the single line diagram of the test system and the line data and load data are taken from [24]. The real power loss in the system is 210.98 kW and the reactive power loss is 143 kVAR when calculated using the Backward-Forward Sweep method of load flow [25]. Table 1 shows the objective function values of 33-bus distribution system before installation of DG. The optimum size and location of DGs for both single objective and multi objective optimization cases are also shown in table 1. Table 2 represents the comparative study for tri-objective optimization obtained using SIMBO-Q, GA [16], PSO [16] and GA/PSO [16].

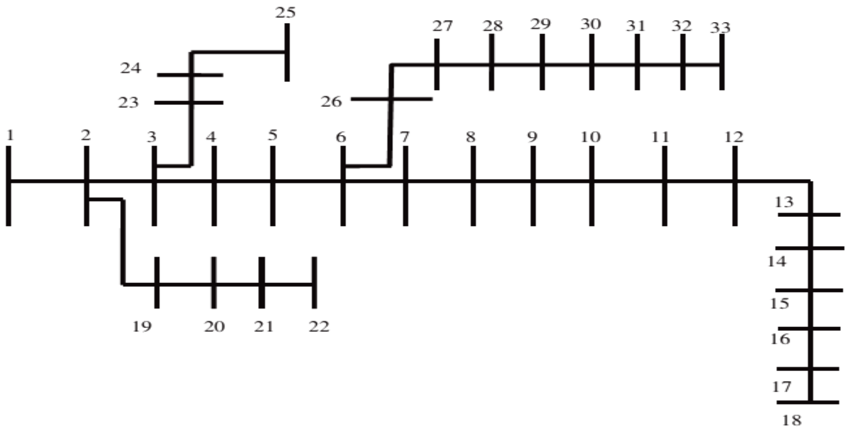

Fig.2. Single line diagram of 33 bus radial distribution system

Table 1. Performance analysis of SIMBO-Q algorithm for the 33-bus system for single objective and multi-objective cases

Objective	**Objective function value**				**Bus No.**	**DG size (MW)**
	Active power loss in MW	***Voltage deviation in p.u.***	***Voltage stability index^{-1}***	***Voltage stability index***		
Without DG	0.2109	0.1338	1.4988	0.6672	--------	-------
Case 1: Active power loss minimization	**0.0736**	0.0156	1.1343	0.8816	**14 25 30**	**0.7613 0.8657 1.1070**
Case 2: Voltage profile improvement	0.1265	**0.00085**	1.0716	0.9332	**13 29 28**	**1.0998 1.1702 1.2743**
Case 3: Voltage stability index improvement	0.1460	0.0036	**1.0346**	**0.9666**	**18 24 32**	**1.4270 1.0761 1.4623**
Case 4 : Loss minimization, voltage profile and voltage stability index improvement	**0.0982**	**0.00081**	**1.0370**	**0.9643**	**30 12 24**	**1.5000 1.3482 1.3805**

Table 2. Performance analysis of SIMBO-Q algorithm for the 33-bus system, after DG installation, with tri-objective optimization (Case 4)

Method	Objective function value				Bus No.	DG size (MW)
	Active power loss in MW	*Voltage deviation in p.u.*	*Voltage stability index^{-1}*	*Voltage stability index*		
GA/PSO [16]	0.1034	0.0124	1.0517	0.9508	32 16 11	1.2 0.863 0.925
GA [16]	0.1063	0.0407	1.0537	0.9490	11 29 30	1.5 0.4228 1.0714
PSO [16]	0.1053	0.0335	1.0804	0.9256	13 32 8	0.9816 0.8297 1.1768
SIMBO-Q	**0.0982**	**0.00081**	**1.0370**	**0.9643**	**30** **12** **24**	**1.5000** **1.3482** **1.3805**

Case 1: Active power loss minimization:

Optimum placement and sizing of DG for minimization of active power loss of 33-bus system reduces objective function value by 65.10% (compared to base case), while voltage profile and voltage stability index are improved by 88.34% and 32.13% respectively.

Case 2: Voltage profile improvement:

Optimum placement and sizing of DG for voltage profile improvement of 33-bus system reduces objective function value by 99.37% (compared to base case), while system active power loss is reduced by 40.02% and voltage stability index is improved by 39.87%.

Case 3: Voltage stability index improvement:

In this case, voltage stability index improvement of 33-bus system reduces objective function value by 30.97% (compared to base case), while system loss is reduced by 30.77% and voltage profile is improved by 97.31%.

Case 4: Loss minimization, voltage profile and voltage stability index improvement:

In this case study, a tri-objective optimization has been performed to simultaneously minimize loss, to improve voltage profile and voltage stability index. The pareto-optimal front for Case 4 is shown in Fig. 3. The best compromise solution obtained for loss minimization, voltage profile and voltage stability index improvement are 0.0982 MW, 0.00081 p.u. and 1.0370 respectively. It is observed that with simultaneous minimization of all the three objectives, the objective function values are improved by 53.44%, 99.39% and 30.81% respectively compared to base case values.

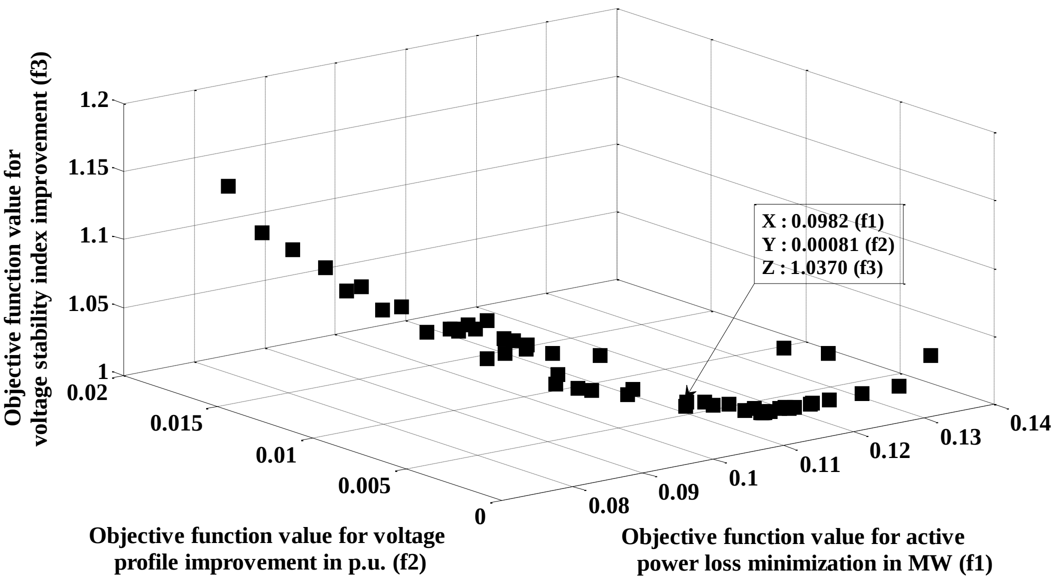

Fig.3. Pareto-optimal front of three objective minimization using SIMBO-Q algorithm for 33-bus distribution system

Table 2 shows the objective function values obtained for Case 4 for 33-bus system using GA [16], PSO [16], GA/PSO [16] and SIMBO-Q algorithms. It is found that active power loss obtained without DG is 0.2109 MW. However, considering multi-objective formulation (Case 4), after DG installation, the active power loss obtained using GA/PSO [16], GA [16], PSO [16] and SIMBO-Q algorithms are found to be 0.1034 MW, 0.1063 MW, 0.1053 MW and 0.0982 MW respectively. The reduction of loss using GA/PSO, GA, PSO and SIMBO-Q algorithms are 50.97%, 49.6% 50.07% and 53.44% respectively compared to the base case (without DG).

Similarly, voltage deviation achieved by GA/PSO, GA, PSO and SIMBO-Q algorithms are 0.0124 p.u., 0.0407 p.u., 0.0335 p.u. and 0.00081 p.u. respectively. The value of voltage stability index attained by GA/PSO, GA, PSO and SIMBO-Q algorithms are 0.9508 p.u., 0.9490 p.u., 0.9256 p.u. and 0.9643 p.u. respectively. From the results, it is observed that for Case 4, overall performance improvement of the system is better with SIMBO-Q algorithm compared to other techniques. Therefore, it may be concluded that the proposed SIMBO-Q algorithm is more efficient compared to GA/PSO, GA and PSO algorithms for minimization of active power loss, maximization of the voltage stability index and improvement of voltage profile of 33-bus radial distribution network by optimal placement and sizing of DG.

4.1.2. Test system 2: 69-bus radial distribution system

In this case study a 69-bus radial distribution system with the total load of 3.80 MW, 2.69 MVAR has been used to show the performance of SIMBO-Q algorithm in large scale distribution system. Fig. 4 shows the single line diagram of the test system and the line data and load data are taken from [21]. Before installation of DG, the real and reactive power losses in the system are found to be 224.7 kW and 102.13 kVAR, when calculated using the Backward-Forward Sweep method of load flow [25]. Table 3 shows the objective function values of 69-bus distribution system before installation of DG. The results for objective function values and corresponding size and location of DGs in the 69-bus distribution system for single objective and tri-objective optimization cases are also shown in table 3. Table 4 represents the comparative study for optimal locations and sizes of DGs, based on objective function values for tri-objective optimization, obtained by applying SIMBO-Q, GA [16], PSO [16] and GA/PSO [16] algorithms in the 69-bus distribution system.

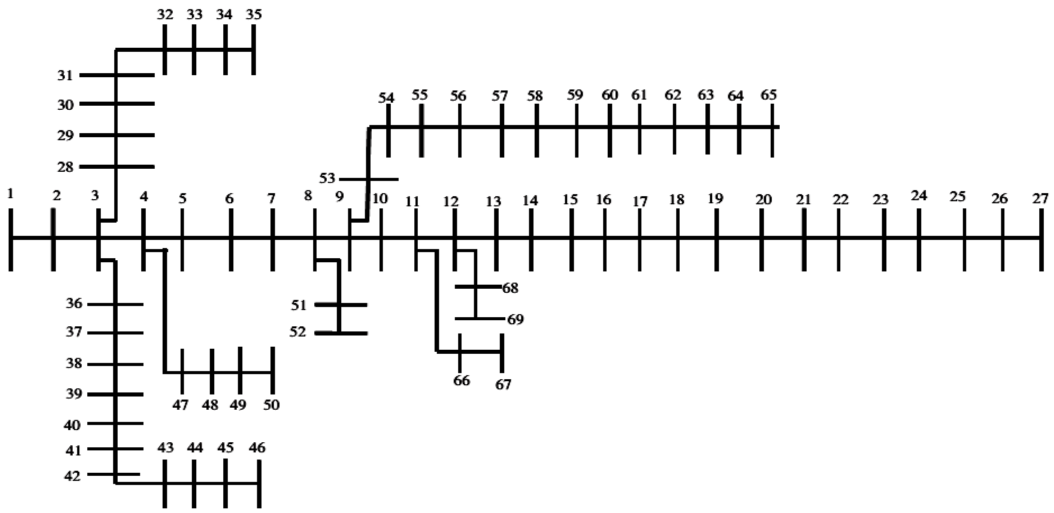

Fig.4. Single line diagram of 69 bus radial distribution system

Table 3. Performance analysis of SIMBO-Q algorithm for the 69-bus system for single objective and multi-objective cases

Objective	**Objective function value**				**Bus No.**	**DG size (MW)**
	Active power loss in MW	***Voltage deviation in p.u.***	***Voltage stability index^{-1}***	***Voltage stability index***		
Without DG	0.2249	0.0993	1.4635	0.6833	--------	-------
Case 1: Active power loss minimization	**0.0714**	0.0082	1.1231	0.8904	**61** **17** **67**	**1.5000** **0.4285** **0.4863**
Case 2: Voltage profile improvement	0.0908	**0.000208**	1.0235	0.9770	**63** **59** **13**	**1.5000** **0.8224** **1.1716**
Case 3: Voltage stability index improvement	0.1420	0.0147	**1.0235**	0.9770	**21** **63** **64**	**1.3841** **1.5000** **1.0555**
Case 4: Loss minimization, voltage profile and voltage stability index improvement	**0.0800**	**0.0007**	**1.0235**	**0.9770**	**15** **62** **61**	**0.7722** **0.8232** **1.3526**

Table 4. Performance analysis of SIMBO-Q algorithm for the 69-bus system, after DG installation, with tri-objective optimization (Case 4)

Method	Objective function value				Bus No.	DG size (MW)
	Active power loss in MW	*Voltage deviation in p.u.*	*Voltage stability index^{-1}*	*Voltage stability index*		
GA/PSO [16]	0.0811	0.0031	1.0237	0.9768	21 61 63	0.9105 1.1926 0.8849
GA [16]	0.0890	0.0012	1.0303	0.9705	21 62 64	0.9297 1.0752 0.9848
PSO [16]	0.0832	0.0049	1.0335	0.9676	17 61 63	0.9925 1.1998 0.7956
SIMBO-Q	0.0800	0.0007	1.0235	0.9770	15 62 61	0.7722 0.8232 1.3526

Case 1: Active power loss minimization:

Optimum placement and sizing of DG for minimization of active power loss of 69-bus system reduces objective function value by 68.25% (compared to base case), while voltage profile and voltage stability index are improved by 91.74% and 30.31% respectively.

Case 2: Voltage profile improvement:

Optimum placement and sizing of DG for voltage profile improvement of 69-bus system reduces objective function value by 99.79% (compared to base case), while system active power loss is reduced by 59.63% and voltage stability index is improved by 42.99%.

Case 3: Voltage stability index improvement:

In this case, voltage stability index improvement of 69-bus system reduces objective function value by 30.07% (compared to base case), while system loss is reduced by 36.86% and voltage profile is improved by 85.2%.

Case 4: Loss minimization, voltage profile and voltage stability index improvement

A tri-objective optimization has been performed here to simultaneously minimize loss, to improve voltage profile and voltage stability index of 69-bus system. The pareto-optimal front for Case 4 is shown in Fig. 5. The best compromise solution obtained for loss minimization, voltage profile and voltage stability index improvement are 0.0800 MW, 0.0007 p.u. and 1.0235 respectively. It is observed that with simultaneous minimization of all the three objectives, the objective function values are improved by 64.43%, 99.30% and 30.07% respectively compared to base case values.

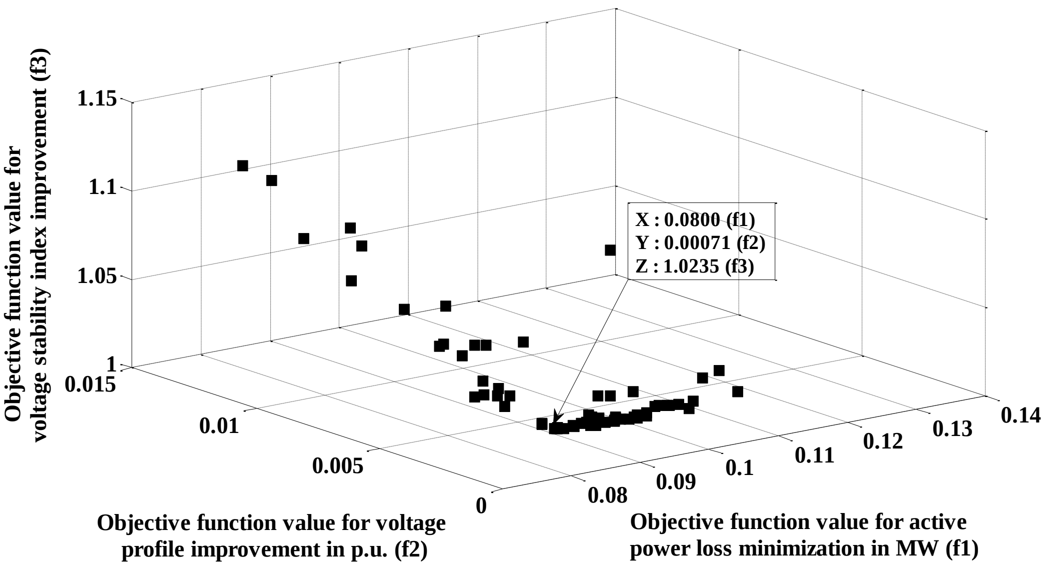

Fig.5. Pareto-optimal front of three objective minimization using SIMBO-Q algorithm for 69-bus distribution system

The objective function values obtained for Case 4 for 69-bus system using GA [16], PSO [16], GA/PSO [16] and SIMBO-Q algorithms are depicted in table 4. It is found that active power loss obtained without DG is 0.2249 MW. However, considering multi-objective formulation (Case 4), after DG installation, the active power loss obtained using SIMBO-Q algorithm is 0.0800 MW which is better than the loss of 0.0811 MW, 0.0890 MW and 0.0832 MW respectively obtained with GA/PSO, GA and PSO algorithms. The reduction of loss using SIMBO-Q algorithm is 64.43% whereas with GA/PSO, GA and PSO algorithms, the loss reduction obtained are 63.94%, 60.43% and 63% respectively compared to the base case (without DG).

Similarly, voltage deviation achieved by SIMBO-Q algorithm is 0.0007 p.u. which is better than 0.0031 p.u., 0.0012 p.u. and 0.0049 p.u. obtained by GA/PSO, GA and PSO algorithms. The value of voltage stability index attained by SIMBO-Q algorithm is 0.9770 p.u. whereas with GA/PSO, GA and PSO algorithms, the values of voltage stability index obtained are 0.9768 p.u., 0.9705 p.u. and 0.9676 p.u. respectively. So, overall performance improvement of the system is better with SIMBO-Q algorithm compared to other techniques. Therefore, it may be concluded that the proposed SIMBO-Q algorithm is more efficient compared to GA/PSO, GA and PSO algorithms for minimization of active power loss, maximization of the voltage stability index and improvement of voltage profile of 69-bus radial distribution system by optimal placement and sizing of DG.

4.2. Comparative Study

Figures 6-7 show the active power loss profiles of the 33-bus and 69-bus radial distribution systems for both single objective and multi objective optimization cases. In both cases the results show a considerable reduction of active power loss compared to the case where no DG is installed in the system.

The voltage profiles of each bus of the 33-bus and 69-bus radial distribution systems for both single objective and multi-objective optimization cases are shown in figures 8-9. The results show different voltage levels during pre and post installation of DG. From the figures it is observed that, after DG installation voltage levels at all buses of the system have been improved compared to the base case (before installation of DG).

Figures 10-11 depict the voltage stability index of the 33-bus and 69-bus radial distribution systems. It is clear from the figures that voltage stability indexes at all nodes of both the systems were very poor before installation of DG. Results show that after installation of DG, voltage stability indexes at all nodes of the radial distribution systems have been considerably improved.

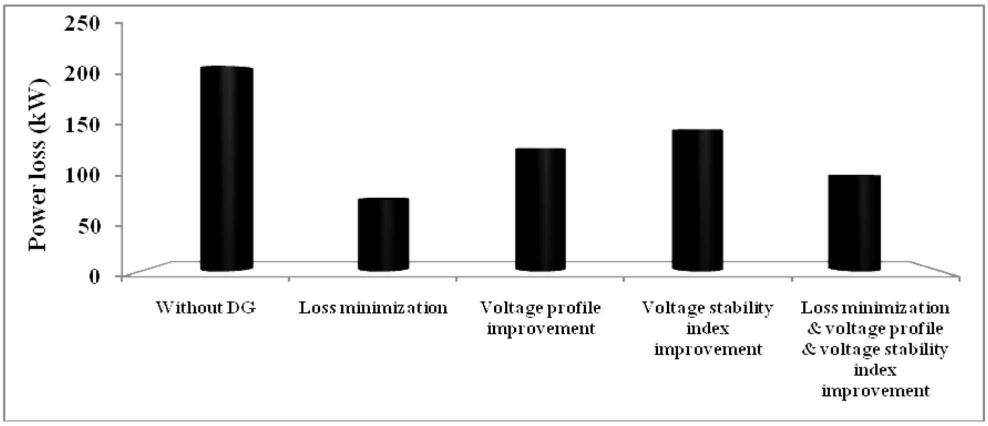

Fig.6. Loss profile of 33-bus radial distribution system pre and post installation of DG for both single objective and multi-objective optimizations

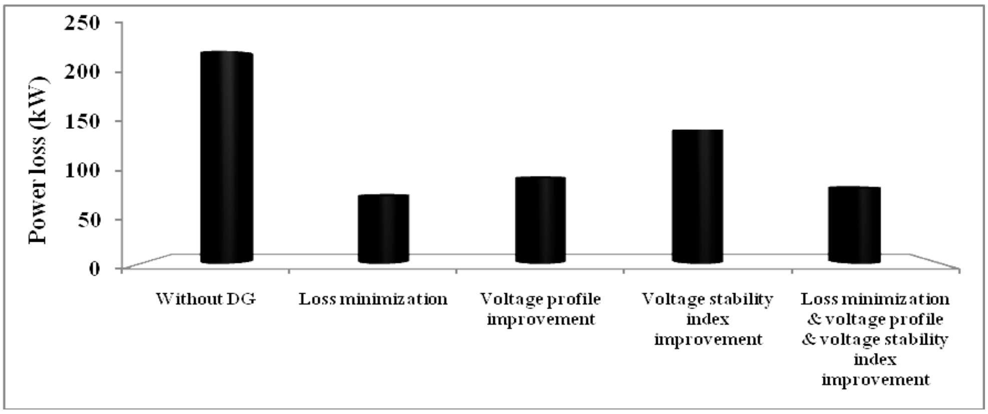

Fig.7. Loss profile of 69-bus radial distribution system pre and post installation of DG for both single objective and multi-objective optimizations

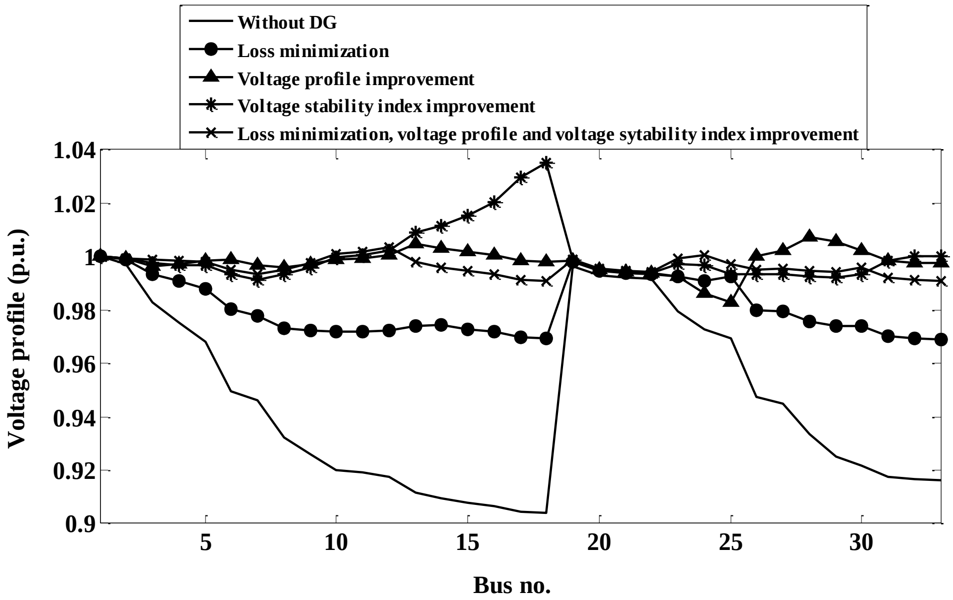

Fig.8. Voltage profile of each bus of 33-bus radial distribution system pre and post installation of DG for both single objective and multi-objective optimizations

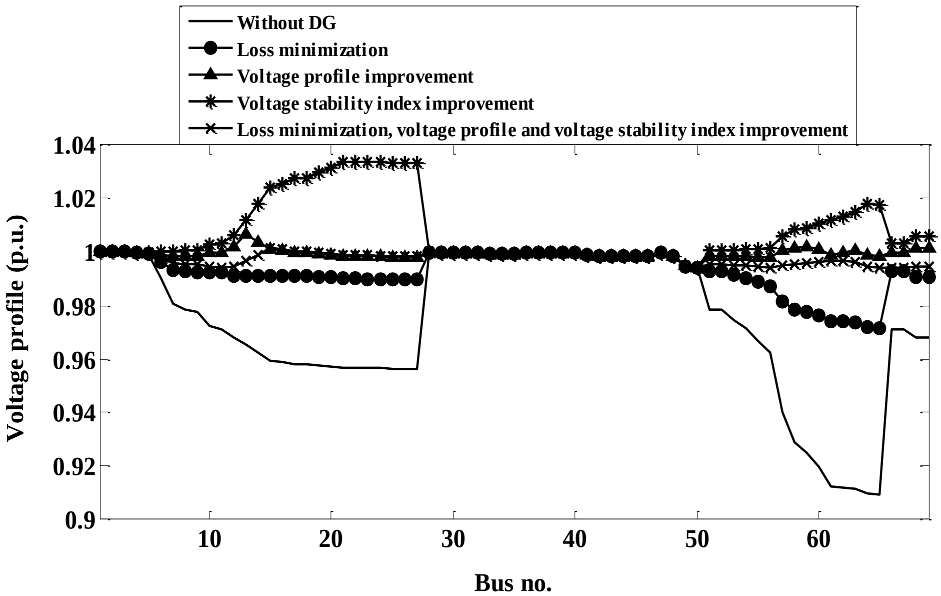

Fig.9. Voltage profile of each bus of 69-bus radial distribution system pre and post installation of DG for both single objective and multi-objective optimizations

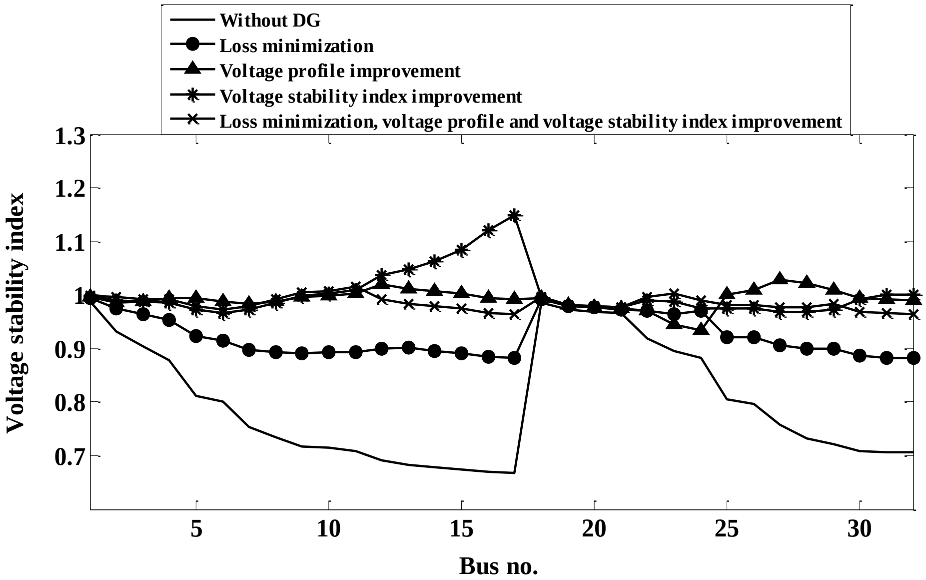

Fig.10. Voltage stability index with and without DG in each branch of 33-bus radial distribution system for both single objective and multi-objective optimizations

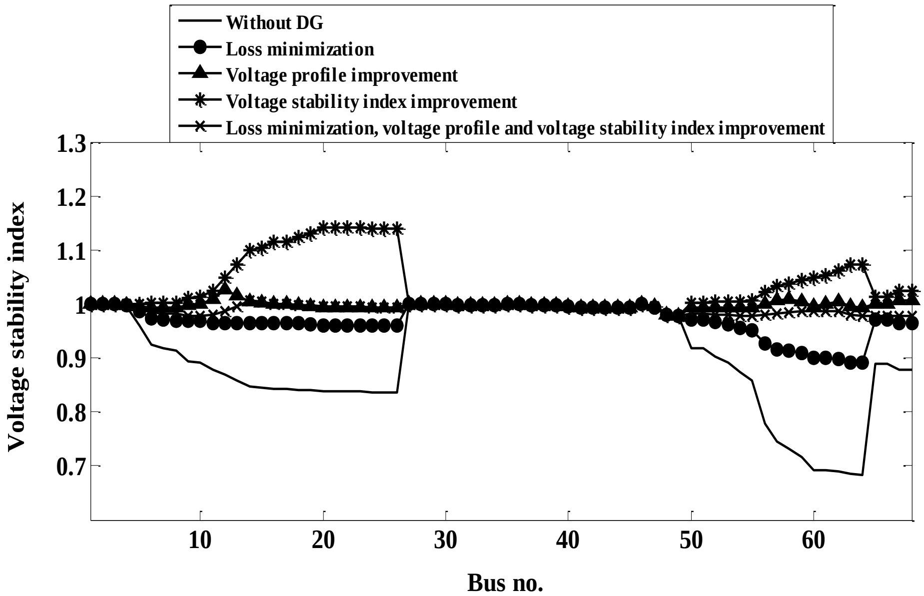

Fig.11. Voltage stability index with and without DG in each branch of 69-bus radial distribution system for both single objective and multi-objective optimizations

4.3. Determination of parameters for SIMBO-Q algorithm

The following procedure has been adopted to calculate optimum values of probability of recovery (α), probability of quarantine (β) and probability of vaccination (μ) used in SIMBO-Q algorithm. The value of α is kept too small to recover most of the individuals while β is kept high so that less number of individual are isolated from the population. Similarly μ is kept high so that less number of individual will change their state directly. For different population sizes, the value of α is increased from 0.1 to 0.5 in steps of 0.1, while the values of β and μ are increased from 0.5 to 0.9 in steps of 0.1 as shown in table 5. Performance of SIMBO-Q algorithm to determine optimum placement and size of DG for minimizing the active power loss of 33-bus radial distribution system is evaluated for all the above mentioned combinations. 50 independent trials have been made with 1000 iterations per trail and the minimum objective function value of 50 trails for different values of parameters, are shown in table 5. Results show that population size of 100, probability of recovery (α) 0.2, probability of quarantine (β) 0.5 and probability of vaccination (μ) 0.8 give the minimum active power loss of 0.0736 MW. So these parameter values have been used for all case studies reported in this paper.

Table 5. Influence of SIMBO-Q parameters on objective function value for loss minimization of 33-bus system (after 50 trails)

Population size	**Probability of Vaccination (μ)**	**Probability of Quarantine (β)**	**Probability of Recovery (α)**				
			0.1	**0.2**	0.3	0.4	0.5
20	μ=0.5	0.5	0.0836	0.0865	0.0855	0.0867	0.0868
		0.6	0.0828	0.0826	0.0843	0.0863	0.0859
		0.8	0.0832	0.0817	0.0856	0.0872	0.0841
		0.9	0.0845	0.0834	0.0853	0.0841	0.0848
	μ=0.6	0.5	0.0816	0.0812	0.0832	0.0842	0.0836
		0.6	0.0822	0.0809	0.0827	0.0833	0.0829
		0.8	0.0827	0.0823	0.0837	0.0832	0.0831
		0.9	0.0835	0.0826	0.0848	0.0828	0.0826
	μ=0.8	0.5	0.0794	0.0792	0.0795	0.0801	0.0814
		0.6	0.0797	0.0794	0.0799	0.0805	0.0805
		0.8	0.0798	0.0798	0.0797	0.0793	0.0801
		0.9	0.0805	0.0801	0.0808	0.0810	0.0806
	μ=0.9	0.5	0.0797	0.0796	0.0799	0.0804	0.0805
		0.6	0.0795	0.0799	0.0805	0.0803	0.0809
		0.8	0.0794	0.0805	0.0798	0.0807	0.0817
		0.9	0.0799	0.0810	0.0806	0.0811	0.0814
50	μ=0.5	0.5	0.0755	0.0752	0.0757	0.0756	0.0763
		0.6	0.0750	0.0748	0.0752	0.0762	0.0758
		0.8	0.0747	0.0753	0.0756	0.0760	0.0765
		0.9	0.0749	0.0751	0.0752	0.0773	0.0754
	μ=0.6	0.5	0.0749	0.0743	0.0745	0.0752	0.0757
		0.6	0.0755	0.0749	0.0755	0.0760	0.0767
		0.8	0.0748	0.0757	0.0752	0.0756	0.0775
		0.9	0.0745	0.0759	0.0762	0.0767	0.0764
	μ=0.8	0.5	0.0743	0.0740	0.0742	0.0740	0.0747
		0.6	0.0745	0.0741	0.0752	0.0753	0.0755
		0.8	0.0755	0.0745	0.0749	0.0758	0.0757
		0.9	0.0753	0.0749	0.0754	0.0755	0.0754
	μ=0.9	0.5	0.0743	0.0740	0.0742	0.0740	0.0747
		0.6	0.0745	0.0741	0.0752	0.0753	0.0755
		0.8	0.0755	0.0745	0.0749	0.0758	0.0757
		0.9	0.0753	0.0749	0.0754	0.0755	0.0754
100	μ=0.5	0.5	0.0739	0.0738	0.0741	0.0739	0.0738
		0.6	0.0742	0.0740	0.0739	0.0741	0.0742
		0.8	0.0740	0.0739	0.0742	0.0745	0.0740

		0.9	0.0745	0.0743	0.0746	0.0747	0.0744
	μ=0.6	0.5	0.0738	0.0739	0.0739	0.0740	0.0739
		0.6	0.0740	0.0740	0.0740	0.0741	0.0740
		0.8	0.0741	0.0741	0.0742	0.0740	0.0742
		0.9	0.0744	0.0739	0.0744	0.0743	0.0744
	μ=0.8	**0.5**	0.0738	**0.0736**	0.0738	0.0739	0.0740
		0.6	0.0739	0.0738	0.0739	0.0740	0.0741
		0.8	0.0741	0.0739	0.0740	0.0742	0.0743
		0.9	0.0742	0.0741	0.0743	0.0744	0.0745
	μ=0.9	0.5	0.0738	0.0739	0.0740	0.0742	0.0739
		0.6	0.0740	0.0742	0.0742	0.0744	0.0741
		0.8	0.0739	0.0745	0.0744	0.0742	0.0745
		0.9	0.0744	0.0747	0.0748	0.0746	0.0747
150	μ=0.5	0.5	0.0739	0.0738	0.0740	0.0739	0.0740
		0.6	0.0740	0.0739	0.0743	0.0740	0.0742
		0.8	0.0742	0.0741	0.0741	0.0743	0.0743
		0.9	0.0746	0.0749	0.0746	0.0745	0.0747
	μ=0.6	0.5	0.0740	0.0739	0.0741	0.0742	0.0743
		0.6	0.0742	0.0740	0.0744	0.0740	0.0744
		0.8	0.0745	0.0742	0.0746	0.0745	0.0747
		0.9	0.0748	0.0747	0.0749	0.0748	0.0750
	μ=0.8	0.5	0.0739	0.0738	0.0739	0.0740	0.0739
		0.6	0.0740	0.0740	0.0742	0.0742	0.0742
		0.8	0.0741	0.0742	0.0743	0.0743	0.0745
		0.9	0.0743	0.0745	0.0745	0.0746	0.0749
	μ=0.9	0.5	0.0739	0.0740	0.0741	0.0739	0.0741
		0.6	0.0742	0.0743	0.0742	0.0741	0.0743
		0.8	0.0744	0.0744	0.0743	0.0745	0.0746
		0.9	0.0748	0.0747	0.0746	0.0748	0.0747

4.4. Effect of population size on SIMBO-Q algorithm

Table 6 shows the performance of SIMBO-Q algorithm for different population sizes for optimal placement and sizing of DG for minimizing the active power loss in 33-bus radial distribution network. From the results it is clear that change in population size affects the performance of the SIMBO-Q algorithm. Tests are carried out 50 times for each case with 1000 iteration numbers. It is observed from the results that for population size 20, 50 and 150, number of hits to optimum solution is zero whereas for population size 100, number of hits to optimum solution is 50. Also the simulation time for population size 100 is much less (48.7 sec.). By considering all these factors, a population size of 100 is considered as the best population size in achieving best optimum solution with less computational time for both single objective and multi-objective optimization case studies of the test systems.

Table 6. Effect of population size on minimum objective function value for optimum sitting and sizing of DG for loss minimization using SIMBO-Q algorithm (for 1000 iterations)

Population size	No. of hits to optimum solution	Simulation Time (s)	Objective function value for loss minimization in MW		
			Minimum	Maximum	Average
20	0	15.3	0.0792	0.0792	0.0792
50	0	30.1	0.0740	0.0740	0.0740
100	**50**	**48.7**	**0.0736**	**0.0736**	**0.0736**
150	0	67	0.0738	0.0738	0.0738

5. Conclusion

In this paper SIMBO-Q algorithm has been applied to determine optimum location and size of DG in 33-bus and 69-bus radial distribution networks to minimize the active power loss, increase the voltage stability and improve the voltage regulation index of the networks. Results obtained from the SIMBO-Q algorithm have been compared with the results obtained from other evolutionary techniques such as GA, PSO and combined GA/PSO. Analysis shows that SIMBO-Q algorithm is able to find the improved quality solutions for the test systems, with superior computational efficiency. Considering the performance of SIMBO-Q algorithm, it may be concluded that the algorithm exhibits a higher capability in finding optimum size and location of DG in distribution system.

References

1. T. Ackermann, G. Andersson, L. So"der, "Distributed generation: a definition", *International Journal of Electric Power System Research*, vol. 57, no. 3, pp. 195-204, 2001.
2. K. Abookazemi, M.Y. Hassan, M.S. Majid, "A review on optimal placement of distribution generation sources", *2010 IEEE International Conference on Power and Energy (PECon)*, Kuala Lumpur, November-December 2010, pp. 712 – 716.
3. R. Mohapatra, A. Kalam, "Impact of renewable energy sources interconnected to the power systems and compliances to the Australian grid", AMSE journals, Modelling A, vol. 85, no. 2, pp. 47-70, 2012.
4. R. Mohapatra, A. Kalam, B. Coulter, A. Zayegh, "Voltage Stability Analysis of Renewable Energy Sources interconnected to the power systems", AMSE journals, Modelling A, vol. 71, no. 1, pp. 16-22, 1998.
5. F. Ugranli, E. Karatepe, "Convergence of rule of thumb sizing and allocating rules of distributed generation in meshed power networks", *International Journal of Renewable and Sustainable*

Energy Reviews, vol. 16, no. 1, pp. 582-590, 2012.

6. Mohab M. Elnashar, Ramadan El Shatshat, Magdy M.A. Salama, "Optimum siting and sizing of a large distributed generator in a mesh connected system", *International Journal of Electric Power Systems Research*, vol. 80, no. 6, pp. 690-697, 2010.
7. S. Ghosh, S.P. Ghosal, S. Ghosh, "Optimum sizing and placement of distributed generation in a network system", *International Journal of Electrical Power and Energy Systems*, vol. 32, no. 8, pp. 849-856, 2010.
8. R.K. Singh, S.K. Goswami, "Optimum allocation of distributed generations based on nodal pricing for profit, loss reduction and voltage improvement including voltage rise issue", *International Journal of Electric Power and Energy Systems*, vol. 32, no. 6, pp. 637-644, 2010.
9. T. Gozel, M.H. Hocaoglu, "An analytical method for the sizing and placement of distributed generators in radial systems", *International Journal of Electric Power Systems Research*, vol. 79, no. 6, pp. 912-918, 2009.
10. N. Acharya, P. Mahat, N. Mithulananthan, "An analytical approach for DG allocation in primary distribution network", *International Journal of Electrical Power and Energy Systems*, vol. 28, no. 10, pp. 669-678, 2006.
11. R.K. Hosseini, R. Kazemzadeh, "Optimal DG allocation by extending an analytical method to minimize losses in radial distribution systems", *2011 19th Iranian Conference on Electrical Engineering (ICEE)*, Tehran, May 2011, pp. 1-6.
12. A. Kazemi, M. Sadeghi, "Distributed generation allocation for loss reduction and voltage improvement", *IEEE Power and Energy Engineering Conference, 2009, APPEEC 2009*, Asia-Pacific, Wuhan, March 2009, pp. 1-6.
13. M.H. Moradi, M. Abedinie, H.B. Tolabi, "Optimal multi-distributed generation location and capacity by Genetic algorithm", *4th International Power Engineering and Optimization Conference (PEOCO2010), IEEE*, Shah Alam, Selangor, Malaysia, June 2010, pp. 440-444.
14. M.H. Aliabadi, B. Behbahani, A. Jalilvand, "Combination of GA and OPF for allocation and active and reactive power optimization in distributed generation units", *2nd IEEE International Conference on Power and Energy (PECon08)*, Johor Bahru, December 2008, pp. 1541-1544.
15. M. Gomez-Gonzalez, A. Lopez, F. Jurado, "Optimization of Distributed generation systems using a new discrete PSO and OPF", *International Journal of Electric Power Systems Research* vol. 84, no. 1, pp. 174-180, 2012.

16. M.H. Moradi, M. Abedini, “A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems”, *International Journal of Electrical Power and Energy Systems*, vol. 34, no. 1, pp. 66-74, 2012.
17. H. Falaghi, M.R. Haghifam, “ACO based algorithm for distributed generation sources allocation and sizing in distribution networks”, *2007 IEEE Lausanne Power Tech*, Lausanne, July 2007, pp. 555-560.
18. N. Khalesi, N. Rezaei, M.R. Haghifam, “DG allocation with application of dynamic programming for loss reduction and reliability improvement”, *International Journal of Electrical Power and Energy Systems*, vol. 33, no. 2, pp. 288-295, 2011.
19. S.S. Pattnaik, K.M. Bakwad, B.S. Sohi, R.K. Ratho, S. Devi, “Swine Influenza Models Based Optimization (SIMBO)”, *Applied Soft Computing*, vol. 13, no. 1, pp. 628-653, 2013.
20. S. Sharma, S. Bhattacharjee, A. Bhattacharya, “Optimal Location and Sizing of DG to Minimize Loss of Distribution System Using SIMBO-Q Method”, *2014 International Conference on Control, Instrumentation, Energy & Communication (CIEC), IEEE*, Calcutta, India, January - February 2014, pp. 340 – 344.
21. M. Chakravorty, D. Das, “Voltage stability analysis of radial distribution networks”, *International Journal of Electrical Power and Energy Systems*, vol. 23, no. 2, pp. 129–135, 2001.
22. P.N. Vovos, J.W. Bialek, “Direct incorporation of fault level constraints in optimal power flow as a tool for network capacity analysis”, *IEEE Transactions on Power System*, vol. 20, no. 4, pp. 2125-2134, 2005.
23. S. Banerjee, “Voltage stability margin of radial distribution systems considering reactive loading index”, AMSE Journals, Advances C, vol. 66, no. 2, pp. 42-55, 2011.
24. M.A. Kashem, V. Ganapathy, G.B. Jasmon, M.I. Buhari, “A Novel Method for Loss Minimization in Distribution Networks”, *in: Proceedings of International Conference on Electric Utility Deregulation and Restructuring and Power Technologies,2000*, City University, London, April 2000, Proc. pp. 251 – 256.
25. K.K. Murthy, S.V. Jaya Ram Kumar, “Three-phase unbalanced radial distribution load flow method”, *International Referred Journal of Engineering and Science*, vol. 1, no. 1, pp. 039-042, 2012.