Electrical Power and Energy Systems 34 (2012) 66–74

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems

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ARTICLE INFO

Article history:
Received 31 October 2010
Received in revised form 20 August 2011
Accepted 20 August 2011
Available online 29 October 2011

Keywords:
Distributed generation
Genetic algorithm
Placement
Particle swarm optimization
Losses

ABSTRACT

Distributed generation (DG) sources are becoming more prominent in distribution systems due to the incremental demands for electrical energy. Locations and capacities of DG sources have profoundly impacted on the system losses in a distribution network. In this paper, a novel combined genetic algorithm (GA)/particle swarm optimization (PSO) is presented for optimal location and sizing of DG on distribution systems. The objective is to minimize network power losses, better voltage regulation and improve the voltage stability within the frame-work of system operation and security constraints in radial distribution systems. A detailed performance analysis is carried out on 33 and 69 bus systems to demonstrate the effectiveness of the proposed methodology.

1. Introduction

Distribution systems are usually radial in nature for the operational simplicity. Radial distribution systems (RDSs) are fed at only one point which is the substation. The substation receives power from centralized generating stations through the interconnected transmission network. The end users of electricity receive electrical power from the substation through RDS which is a passive network. Hence, the power flow in RDS is unidirectional. High R/X ratios in distribution lines result in large voltage drops, low voltage stabilities and high power losses. Under critical loading conditions in certain industrial areas, the RDS experiences sudden voltage collapse due to the low value of voltage stability index at most of its nodes.

Recently, several solutions have been suggested for complementing the passiveness of RDS by embedding electrical sources with small capacities to improve system reliability and voltage regulation [1,2].

Such embedded generations in a distribution system are called dispersed generations or distributed generations (DG).

Distributed generation is expected to play an increasing role in emerging electrical power systems. Studies have predicted that DG will be a significant percentage of all new generations going on lines. It is predicted that they are about 20% of the new generations being installed [3].

Main reasons for the increasingly widespread usage of distributed generation can be summed up as follows [4]:

- It is easier to find sites for small generators.
- Latest technology has made available plants ranging in capacities from 10 KW to 15 MW.
- Some technology have been perfected and are widely practiced (gas turbines, internal combustion engines), others are finding wider applications in recent years (wind, solar energy) and some particularly promising technologies are currently being experimented or even launched (fuel cell, solar panels integrated into buildings).
- DG units are closer to customers so that Transmission and Distribution (T&D) costs are ignored or reduced.
- Combined Heat and Power (CHP) groups do not require large and expensive heat networks.
- Natural gas, often used as fuel in DG stations is distributed almost everywhere and stable prices are expected for it.
- Usually DG plants require shorter installation times and the investment risks are not so high.
- DG offers great values as it provides a flexible way to choose wide ranges of combining cost and reliability.

In order to achieve the aforementioned benefits, DG size has to be optimized. Researchers have developed many interesting algorithms and solutions. The differences are about the problem which is formulated, methodology and assumptions being made. Some of the methods are mentioned in [5] as analytical approaches [6] numerical programming, heuristic [7,8]. All methods own their

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doi:10.1016/j.ijepes.2011.08.023

Nomenclature

n_n	total number of buses in the given RDS
n_i	receiving bus number ($n_i = 2,3,\ldots,n$)
m_i	bus number that sending power to bus n_i ($m_2 = n_1 = 1$)
i	branch number that fed bus n_i
$N = n_n - 1$	total number of branches in the given RDS
N_{DG}	total number of DG
C_{DG}	capacity of DG
n_{DG}	bus number of DG installation
P_{gni}	active power output of the generator at bus n_i
Q_{gni}	reactive power output of the generator at bus n_i
P_{dni}	active power demand at bus n_i
Q_{dni}	reactive power demand at bus n_i
$P_{ni}(n_i)$	total real power load fed through bus n_i
$Q_{ni}(n_i)$	total reactive power load through bus n_i
$P_{gni}^{\min}$	minimum active power of DG at bus n_i
$P_{gni}^{\max}$	maximum active power of DG at bus n_i
P_{RPL}	real power losses of n_n-bus distribution system
V_{ni}	voltage of bus n_i
V_{mi}	voltage of bus m_i
$V_{ni}^{\min}$	minimum voltage at bus n_i
$V_{ni}^{\max}$	maximum voltage at bus n_i
V_{rated}	rated voltage (1 p.u.)
$\lvert S_{ni}^{\max}\rvert$	maximum apparent power at bus n_i
Y_{ni}	admittance between bus n_i and bus m_i
θ_{ni}	phase angle of $Y_i = Y_{ni}\angle\theta_{ni}$
δ_{ni}	phase angle of voltage at bus n_i ($V_{ni} = V_{ni}\angle\delta_{ni}$)
δ_{mi}	phase angle of voltage at bus m_i
I_{ni}	current of branch i
R_{ni}	resistance of branch i
X_{ni}	reactance of branch i
$SI(n_i)$	voltage stability index of node $n_{i.}$ ($n_i = 2,3,\ldots,n$)
β_1	penalty coefficient, 0.32
β_2	penalty coefficient, 0.3
K_1	penalty coefficient ($k_1 = 0.6$)
K_2	penalty coefficient ($k_2 = 0.35$)
C_1, C_2	constants
r_1, r_2	random numbers in [0,1]
J_{best}	global best position associated with the whole neighborhood experience
W	weight inertia
f_1	network real power losses (pu)
f_2	network voltage profile (pu)
f_3	network voltage stability index (pu)

advantages and disadvantages which rely on data and system under consideration. Generally the allocation problem formulation of distributed generation is non linear, stochastic or even a fuzzy function as either an objective function or constraints. Generally, in all formulations the objective function is to minimize the real power losses and improve voltage; while abiding into all physical constraints equations in terms of voltage and power. The variable limits in the optimization procedure must also be obeyed.

The problem of optimal DG location and sizing is divided into two sub problems, where the optimal location for DG placement is the one and how to select the most suitable size is the second. Many researches proposed different methods such as analytic procedures as well as deterministic and heuristic methods to solve the problem. Kean and Omalley [9] solved for the optimal DG sizing in the Irish system by using a constrained linear programming (LP) approach. The objective of their proposed method was to maximize the DG generation. The nonlinear constraints were liberalized with the goal of utilizing them in the LP method. A DG unit was installed at all the system buses and the candidate buses were ranked according to their optimal objective function values. Kashem et al [10] developed an analytical approach to determine the optimal DG sizing based on power loss sensitivity analysis. Their approach was based on minimizing the distribution system power losses. The proposed method was tested using a practical distribution system in Tasmania, Australia. Griffin et al. [11] analyzed the DG optimal location analytically for two continuous load distributions types, uniformly distributed and uniformly increasing loads. The goal of their studies was to minimize line losses. One of the conclusions of their research was that the optimal location of DG which is highly dependent on the load distribution along the feeder; significant losses reduction would take place when DG is located toward the end of a uniformly increasing load and in the middle of uniformly distributed load feeder.

Acharya et al. [12] used the incremental change of the system power losses with respect to the change of injected real power sensitivity factor developed by Elgerd [13]. This factor was used to determine the bus and causing the losses to be optimal when hosting a DG. They proposed an exhaustive search by applying the sensitivity factor on all the buses and ranked them accordingly. The drawback of their work is the lengthy process of finding candidate locations and the fact that they sought to optimize only the DG real power output. Rosehart and Nowicki [14] dealt with only the optimal location portion of the DG integration problem. They developed two formulations to assess the best location for hosting the DG sources. The first is a market based constrained optimal power flow that minimizes the cost of the generation DG power, and the second is voltage stability constrained optimal power that maximizes the loading factor, distance to collapse. Both formulations were solved by utilizing the interior point (IP) method. Outcomes of the two formulations were used in ranking the buses for DG installations. The optimal DG size problem was not considered in their paper.

Carmen et al. [15] describes a methodology for optimal distributed generation allocation and sizing in distribution systems, in order to minimize the electrical network losses and to guarantee acceptable reliability level and voltage profile. The optimization process is solved by the combination of genetic algorithms (GA) techniques with other methods to evaluate DG impacts in system reliability, losses and voltage profile.

Haesen and Espinoza [16] considered optimal DG problem for single and multiple DG sizing. They used GA method to minimize the distribution systems active power flow. Gandomkar et al. [17] hybridized two methods to solve DG sizing problem. They combined GA and simulated annealing meta-heuristic methods to solve optimal DG power output. Nara et al. [18] assumed that the candidate bus locations for DG unit to be installed were pre-assigned by the distribution planner. Then they used the tabo search (TS) method for solving the optimal DG size. The objective of their formulation was to minimize system losses. Golshan and Arefifar [19] applied the TS method to size the DG optimally, as well as the reactive sources within the distribution system. He formulated the constrained nonlinear optimization problem by minimizing an objective function that sums the total cost of active power losses, line loading and the cost of adding reactive sources. Falaghi and Haghifam [20] proposed the ant colony optimization method as an optimization tool for solving the DG sizing and location problems. Minimized objective function for used method was the global network cost. Khalesi et al. [21] considered multi-objective function to determine the optimal locations to place DGs in distribution system to minimize power loss of the system and enhance reliability improvement and voltage profile. Time varying load is applied in this optimization to reach pragmatic results meanwhile all of the study and their requirements are based on cost/benefit forms. Finally to solve this multi-objective problem a novel approach based on dynamic programming is used. Naresh et al. [22] considered an analytical expression to calculate the optimal size and an effective methodology to identify the corresponding optimum location for DG placement for minimizing the total power losses in primary distribution systems. Sudipta et al. [23] considered a simple method for optimal sizing and optimal placement of generators. A simple conventional iterative search technique along with Newton Raphson method of load flow study is implemented on modified IEEE 6 bus, IEEE 14 bus and IEEE 30 bus systems.

In our latest published papers, the optimization of both location and capacity of Distributed Generation sources was programmed by employing only the GA method [28,29].

A new combined algorithm is proposed to evaluate the DG site and size in Distribution network. In this method, site of DG is searched by GA and its size is optimized by PSO. First the initial population for DG size and site are produced by random, then the load flow was run. Using the given cost function was implemented to optimize the size of DG which was calculated by PSO for the known site. In the next step the new site of DG was calculated by GA to optimize the cost function. The GA is run by the predetermined iteration and in each iteration for a candidate site, the size of DG was re-optimized by PSO which this reduces the search area for the GA and gives better optimization in each iteration.

The results showed that the proposed combined GA/PSO method is better than the GA and PSO in terms of solution quality and number of iterations.

This paper is organized as follow; Problem formulation in Section 2, optimal sitting and sizing of DG in Section 3, application study and numerical results in Section 4, discussions in Section 5 and the conclusion in Section 6.

2. Problem formulation

Proposed methodology presented in this paper is aimed to optimized technique functionality of distribution system by minimizing the power losses, maximize the voltage stability and improve voltage profiling in a given radial distribution network. The goal is to converge these three objective functions into one, using the penalty coefficients. The objective functions have no units and they are going to be qualified as ratios. For example the amount of first objective function (f_1) is just a ratio in comparison with the basic loss of 210.99 (kW). Therefore we are dealing with a one dimensional problem.

2.1. The objective function

Mathematically, the objective function is formulated as:

$$f = Min\left((f_1 + k_1 f_2 + k_2 f_3) + \beta_1 \sum_{i \in N_{DG}} \left[\max\left(V_{ni} - V_{ni}^{\max}, 0\right) + \max\left(V_{ni}^{\min} - V_{ni}, 0\right)\right] + \beta_2 \sum_{i \in N} \max(|S_{ni}| - |S_{ni}^{\max}|, 0)\right) \quad (1)$$

Subjected to: C_{DG} and n_{DG}

2.2. Power losses

The real power losses in the system is given by (2).

$$f_1 = P_{RPL} \quad (2)$$

P_{RPL} is the real power losses of n_n-bus distribution system, and is expressed in components as:

$$P_{RPL} = \sum_{i=2}^{n_n} (P_{gni} - P_{dni} - V_{mi} V_{ni} Y_{ni} \cos(\delta_{mi} - \delta_{ni} + \theta_{ni})) \quad (3)$$

2.3. Improve voltage profile

The objective function to improve voltage profile is,

$$f_2 = \sum_{ni=1}^{n_n} (V_{ni} - V_{rated})^2 \quad (4)$$

2.4. Voltage stability index

Fig. 1 shows a branch of radial system. In radial distribution system each receiving node is fed by only one sending node,

From Fig. 1

$$I_i = \frac{V_{mi} - V_{ni}}{R_{ni} + jX_{ni}} \quad (5)$$

$$P_{ni}(ni) - jQ_{ni}(ni) = V_{ni}^* I_{ni} \quad (6)$$

When distributed generation is connected to distribution network, the index of voltage stability for distribution network will be changed. This index, which can be evaluated at all nodes in radial distribution systems, was presented by Charkravorty and Das [24]. Equations used to formulate this index are presented in [25], to solve the load flow for radial distribution systems. Eq. (7) represents the voltage stability index. Using (5) and (6):

$$SI(n_2) = |V_{mi}|^4 - 4[P_{ni}(ni)R_{ni} + Q_{ni}(ni)X_{ni}]|V_{mi}|^2 - 4[P_{ni}(ni)R_{ni} + Q_{ni}(ni)X_{ni}]^2 \quad (7)$$

Objective function for improving voltage stability index is,

$$f_3 = \left(\frac{1}{(SI(ni))}\right) \quad n_i = 2, 3, \ldots, n_n \quad (8)$$

For stable operation of the radial distribution systems, $SI(n_i) > 0$ for $i = 2,3\ldots,n_n$, so that; there exists a feasible solution. It is very important to identify weak buses for nodes with minimum voltage stability index that are prone to voltage instability. Investigating the voltage stability index behavior demonstrate that the buses which experiencing large voltage drops are weak and within the context of remedial actions. So, it makes sense to act on controls that will improve the voltage magnitudes at weak buses.

2.5. Constraints

2.5.1. Load balance constraint

For each bus, the following equations should be satisfied:

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

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

where $n_i = 1, 2, \ldots, n_n$.

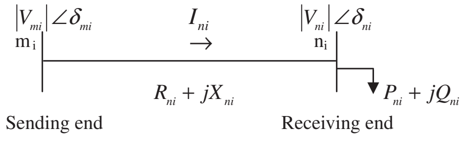

Fig. 1. A representative branch of a radial distribution system.

2.5.2. Voltage limits

The generator voltage will be the load/bus voltage plus some values related to impedance of the line and the power flows along that line. It is evident that the larger the impedance and power flow, the larger the voltage rises. The increased active power flows on distribution network have a large impact on the voltage level because resistive elements of the lines on distribution networks are higher than other lines. This leads to an X/R ratio of approximately 1 rather than a more typical value of 5 on transmission networks. The voltage must be kept within standard limits at each bus [24,26]:

$$V_{ni}^{\min} < \quad V_{ni} < V_{ni}^{\max} \tag{11}$$

2.5.3. DG technical constraints

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

$$P_{gni}^{\min} \leqslant \quad P_{gni} \leqslant P_{gni}^{\max} \tag{12}$$

2.5.4. Thermal limit

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

$$|S_{ni}| \leqslant \quad |S_{ni}^{\max}| \quad i = 1, \ldots, N \tag{13}$$

3. Optimal siting and sizing of distributed generation

The optimal sitting and sizing problems of distributed generation are formulated as a multi-objective constrained optimization problem. This paper uses novel combined GA/PSO for solving the problems of optimal sitting and sizing DG .The results were compared to PSO and GA.

3.1. Genetic algorithms (GA)

In GA algorithm, the population has n chromosomes that represent candidate solution; each chromosome is an m dimensional real value vector where m is the number of optimized parameters. Therefore each optimized parameter represents a dimension of the problem space.

Step 1 (initialization): set the time counter $t = 0$ and generates randomly n chromosomes. $[X_j\ (0),\ j = 1,\ldots,n]$, where $x_j(0) = [x_{j,1}(0), x_{j,2}(0), \ldots, x_{j,m}(0)]$. $x_{j,k}(0)$ is generated in search space $[x_k^{\min}, x_k^{\max}]$ randomly.
Step 2 (fitness): evaluate each chromosome in the initial population using the objective function, J. search for the best value of the objective function J_{best}. Set the chromosome associated with J_{best} as the global best.
Step 3 (time updating): update the time counter $t = t + 1$.
Step 4 (new population): create a new population by repeating the following steps until the new population is completed:

- *Selection*: select two parent chromosomes from a population according to their fitness.
- *Crossover*: with a crossover probability, cross over the parents to form a new child.
- *Mutation*: with a mutation probability method mutates new child at each chromosome.
- *Acceptance*: place new child in a new population

Step 5 (replacement): use new generated population for a further run of algorithm.
Step 6: if one of the stopping criteria is satisfied then stop, else go to step 2.

Fig. 2 shows the flow chart of optimal sitting and sizing of distributed generation.

3.2. Particle swarm optimization (PSO)

In PSO algorithm, the population has n particles that represent candidate solutions. Each particle is an m dimensional real valued vector where m is the number of optimized parameters. Therefore each optimized parameter represents a dimension of the problem space. The PSO technique can be described in the following steps in Fig. 3:

Step1 (initialization): set the time counter $t = 0$ and randomly generate n chromosomes, $[x_j(0), j = 1, \ldots, n]$, where $x_j(0) = [x_{j,1}(0), x_{j,2}(0), \ldots, x_{j,m}(0)]$. $x_{j,k}(0)$ is randomly generated in search space. $[x_k^{\min}, x_k^{\max}]$. $V_j(0)$ is randomly generated for evaluation of the objective function. For each particle, set $x_j^*(0) = x_j(0)$ and $j^*j = j_j$, $j = 1,\ldots,n$. Search for the best value of the objective function J_{best}. Set the particle associated with J_{best} as the global best, x^{**} (0) with an objective function of j^{**}. Set the initial value of the w (0) = 0.98.
Step 2 (time updating): update the time counter $t = t + 1$.
Step 3 (weight updating): update the inertia weight.
Step4(velocityupdating): using the global best and the individual best to change the particle velocity in the following equation:

$$\begin{aligned} v_{j,k}(t) = \omega(t) v_{j,k}(t-1) + c_1 r_1 (x_{j,k}^*(t-1) - x_{j,k}(t-1) \\ + c_2 r_2 (x_{best}^{**} - x_{j,k}(t-1))) \end{aligned} \tag{14}$$

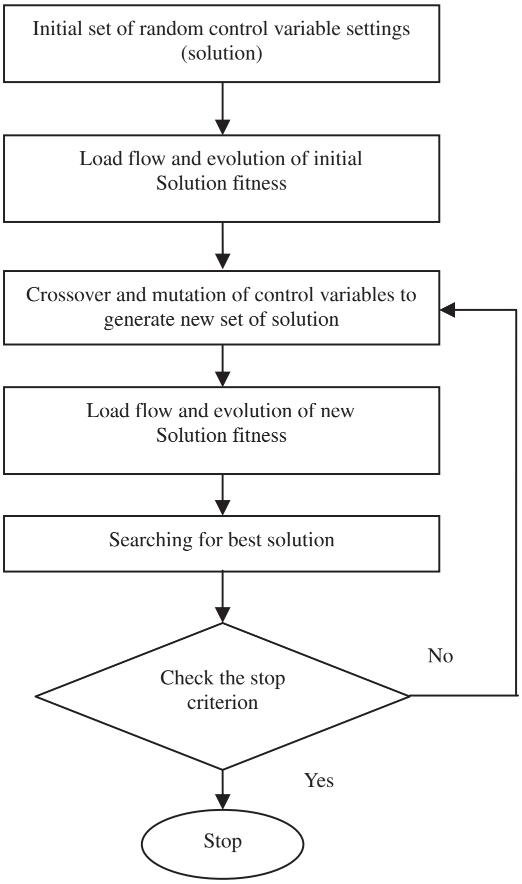

Fig. 2. The GA method for optimal sitting and sizing of DG.

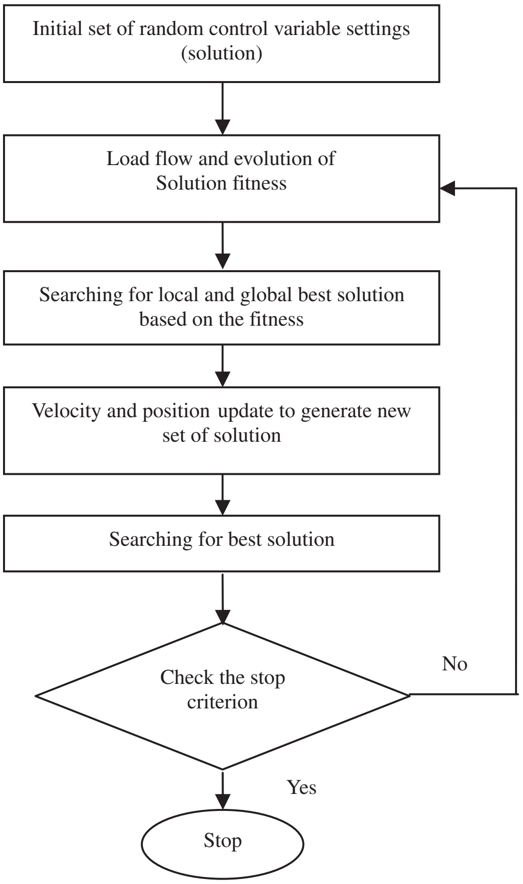

Fig. 3. The PSO method for optimal sitting and sizing of DG.

Step 5 (position updating): based on the updated velocity, each particle changes its position according to the following equation:

$$X_{j,k}(t) = X_{j,k}(t-1) + V_{j,k}(t) \tag{15}$$

If a particle violates is position limits in any dimension set its position at the proper limit.
Step 6: each particle is evaluated according t the updated position. If $j_{\min} < j^*$ then updates individual best as

$$x_j^*(t) = x_j(t) \quad ,j_i = j_i^*$$

Step 7: now search for the minimum value, if $j_{\min} < j^{**}$ then updates global best as $j^{**} = j_{\min}$ and $x^{**} = x_{\min}(t)$.
Step 8: if one of the stopping criteria is satisfied then stop, else go to step 2.

3.3. Proposed methodology

This is a searching technique developed for optimal sitting and sizing of DG. The problem consists of two parts. The first is the optimal location of DG and the second is the optimal sizing. Result for the first part is an integer which is either a bus number where DGs are suggested to be installed. This needs an integer-based optimization algorithm. GA has been chosen to play this role because of its attractive quality. The answer obtained from GA solution is used in PSO algorithm to optimize the sizing for DG. PSO has the fast convergence ability which is a great attractive property for a large iterative and time consuming problem. Interaction between the two algorithms as shown in Fig. 4 goes as follows.

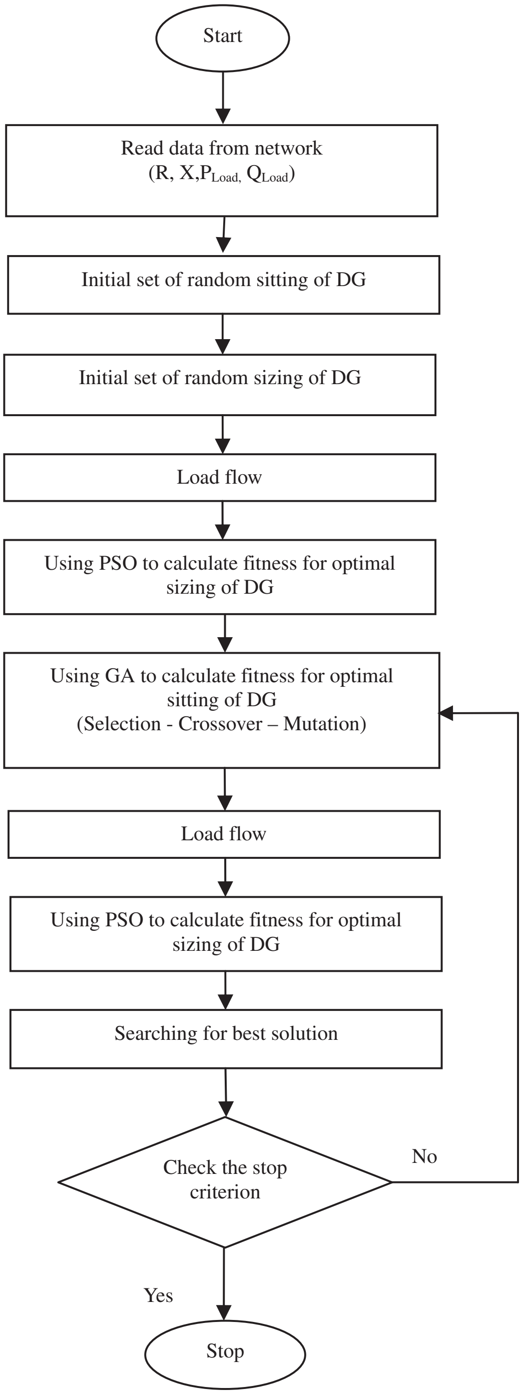

Fig. 4. The GA/PSO method for optimal sitting and sizing of DG.

- *Initialization*: Set the time counter $t = 0$ and generate randomly n chromosomes, this represent n initial candidates sitting of DG.
- *Fitness using PSO:* Evaluate each chromosome and optimal sizing of DG
  - Initialize particle population, modified matrix and contain size of DG.
  - Calculate the objective values which are the total real power losses and the voltage profile improvement.
  - Record objective function as the best candidate of particle and the minimum value as the current overall global best of the group.
  - Update the velocity (v) and position.
  - Check the stop criterion if it is satisfied then stop.

Table 1
GA/PSO, GA and PSO parameters.

Method	Pop. size	Selection method	Cross over	Mutation		Algorithm termination
GA/PSO	GA = 30 PSO = 20	Normalized geometric selection	Simple Xover	Binary mutation		Maximum number of generation (30)
GA	50	Normalized geometric selection	Simple Xover	Binary mutation		Maximum number of generation (60)
Parameters PSO		c_1	c_2	r_1	r_2	–
PSO	40	2	2	1	1	Maximum number of generation (40)

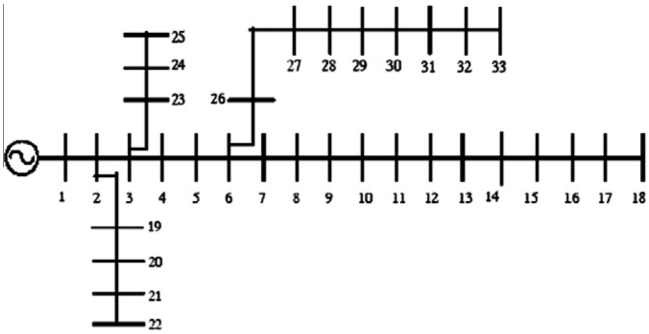

Fig. 5. Single line diagram of a 33-bus system.

Table 2
Objective function value of the systems before DG installation.

System	Objective function value		
	f_1	f_2	f_3
33-Bus	0.2109	0.3141	1.4907
69-Bus	0.2217	0.2197	1.4509

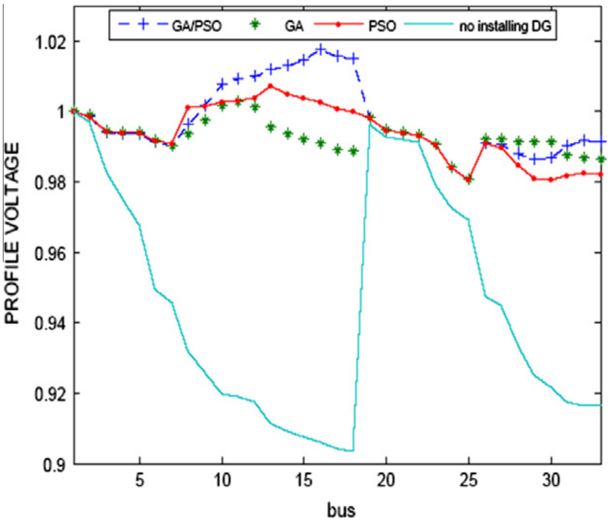

Fig. 6. Voltage levels of 33-bus radial distribution system.

- *Time updating:* Update the time counter $t = t + 1$.
- *New population:* Create a new population of sitting of DG by repeating the following steps until the new population is completed:

-Selection -Crossover -Mutation

- Fitness using PSO and time updating.
- Check the stop criterion, if it is satisfied then stop, else go to time updating.

4. Application study and numerical results

The proposed method for optimal sitting and sizing of DG has been implemented in the MATLAB and tested for several power systems. In this section, the test results for two different distribution systems are presented and discussed. The rating active power of distributed generation and the power factor are 1.2 MW and 1, respectively. The optimization was performed using GA/PSO software package which is written for the simulation of optimal sitting and sizing of DG in any radial distribution systems. The parameters of GA/PSO method used for solving the problems presented in this paper are furnished in Table 1.

4.1. 33 Bus radial distribution systems

The first system is a radial system with the total load of 3.72 MW, 2.3 MVar, 33 bus and 32 branches as it is shown in Fig. 5. The real power losses in the system is 210.998 (kW) while the reactive power losses is at 143 (kVar) when calculated using the load flow method reported in [26].

The results for optimal sitting and sizing problems of distributed generation are described in Table 3. The GA/PSO combined results are compared with the results using PSO and GA separately; the location, DG size, the real power losses, profile voltage and the voltage stability. For example, in the first column, the objective

Table 3
Performance analysis of the 33-bus system after DG installation.

Method	Objective function value				
	f_1	f_2	f_3	Bus no.	DG size (MW)
GA/PSO	0.1034	0.0124	1.0517	32 16 11	1.2 0.863 0.925
GA	0.1063	0.0407	1.0537	11 29 30	1.5 0.4228 1.0714
PSO	0.1053	0.0335	1.0804	13 32 8	0.9816 0.8297 1.1768

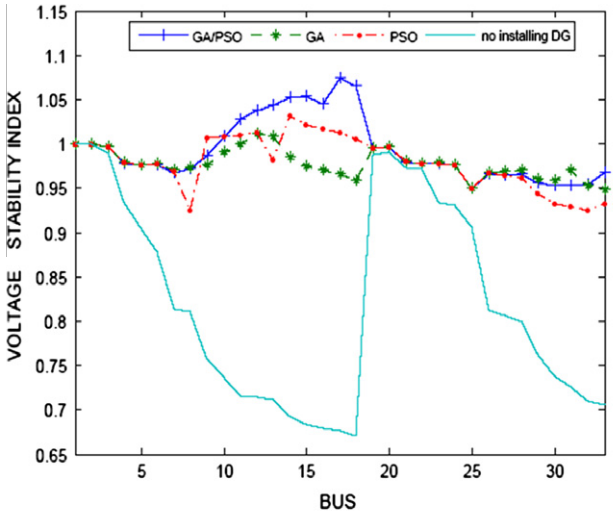

Fig. 7. Voltage stability index of 33-bus radial distribution system.

function is P_{loss} which has been minimized to find out the best results.

Table 2 shows the pre installation values of the objective functions for DG. From the results presented in Table 3, it can be observed that GA/PSO is effective for optimal sitting and sizing of DG.

Fig. 6 depicts voltage profile of each bus in 33 bus distribution. The results show different voltage levels during the pre and post installation of DG. Before installation of DG, voltage level of bus 18 was low. After installation; the voltage was improved. Furthermore, the voltage levels at all nodes for RDS have improved. The voltage stability index is given in Fig. 7. It is also clear that voltage stability indexes for all nodes in the radial distribution system were very poor before installing the DG. Results show that stability indexes at the nodes for RDS were improved after installing the DG.

4.2. 69 Bus radial distribution systems

The second is a 69 bus radial distribution system that has the total load of 3.80 MW and 2.69 MVar and it is demonstrated in Fig. 8. Data for this system are given in [27] which have seven lateral lines. Results are furnished in Table 4 and also in Figs. 9 and 10. In Table 2, objective functions values of pre installation for DG are demonstrated.

Results of the detailed performance analysis are illustrated in Figs. 9 and 10. In these networks; the R/X ratio is approximately equal to 3. This means that the network is highly resistive in nature and needs to supply by a distributed real power source.

Results confirmed that by applying the proposed method, the voltage level and voltage stability index were improved.

5. Discussion

The proposed method involves a search technique developed for optimal sitting and sizing of the DG. In particular, in this method reduces the search space is reduced and a tight distribution for the search results is obtained. Since the location is represented by a discrete variable (the bus number indicated by an integer ranging from 1 to 69), the search is performed by the GA method, which is an integer-based optimization algorithm. The solution obtained based on the GA method is, then, used in the PSO algorithm to optimize the sizing for the DG. The major disadvantage of this method, however, is the fact that it more time consuming as compared to the case where either method is applied alone. However, given the fact that the combined method is implemented on an offline basis, this issue is not of major concern. The following provides a discussion of the performance of the various methods outlined with regards to specific aspects.

5.1. Simulation results

The worst, the best and the average of the objective functions to improve loss in system 33 bus for all three methods are illustrated and compared in Fig. 11. The best and the worst are from the combined method and the GA, respectively. Looking at the worst objective functions results reveal that the value for combined method is at 14% compared to 37% and 24% for the GA and the PSO respectively. By considering the best and average objective functions, similar trends were observed.

5.2. Number of iterations and running time

The Combined method is converted to solution in minimum number of iterations and the PSO is the least. But the running time for the PSO was faster in comparison with the other two and the least is for GA.

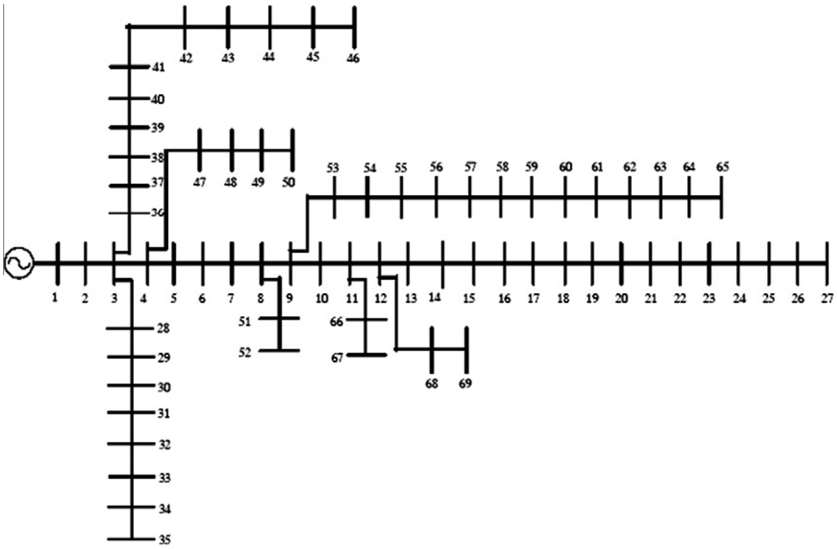

Fig. 8. Single line diagram of a 69-bus system.

Table 4
Performance analysis of the 69-bus system after DG installation.

Method	Objective function value				
	f_1	f_2	f_3	Bus no.	DG size (MW)
GA/PSO	0.0811	0.0031	1.0237	63	0.8849
				61	1.1926
				21	0.9105
GA	0.089	0.0012	1.0303	21	0.9297
				62	1.0752
				64	0.9848
PSO	0.0832	0.0049	1.0335	61	1.1998
				63	0.7956
				17	0.9925

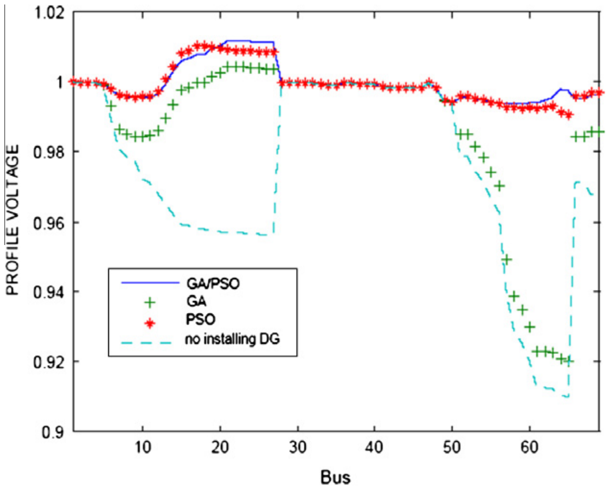

Fig. 9. Voltage levels for a 69-bus radial distribution system.

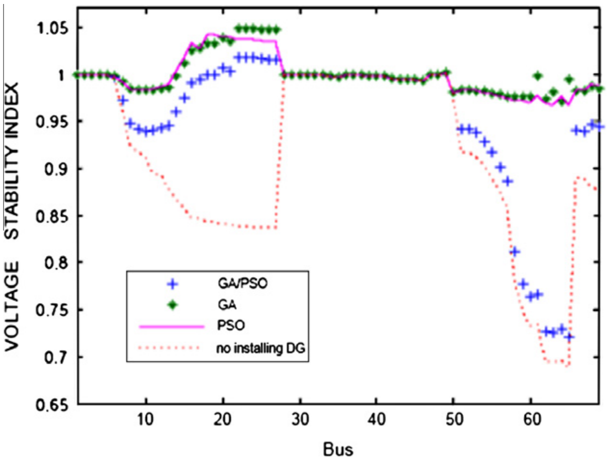

Fig. 10. The voltage stability index of 69-bus radial distribution system.

5.3. Output variance

In Fig. 12, variance for the objective functions is illustrated. The variance is calculated for the fifty initial populations. The output variances for GA and PSO are at 0.0986 and 0.02134 respectively, but it has found to be almost at zero for the combined method. This is an indication of output uniformity for the combined method and non-uniformity for the others. Having zero variance is demonstrating that the combined method is preferred in comparison with the other two.

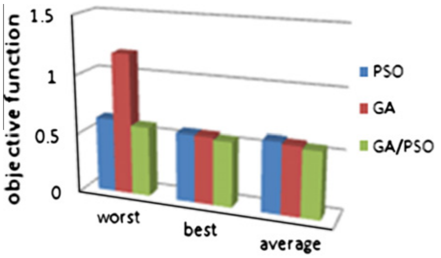

Fig. 11. The worst, the best and the average of objective function.

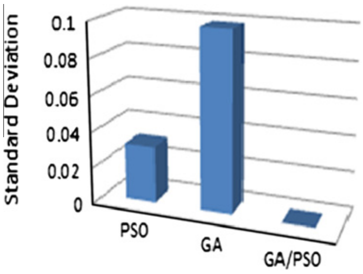

Fig. 12. Variances of objective function.

As shown in Fig. 12, this implies that the combined method is providing high quality solutions.

5.4. Objective function values

Amongst the three, the combined method showed less objective function value in comparing with GA and PSO, Tables 3 and 4.

5.5. Stability and voltage regulation

Voltage stability index in bus 18 from the first system and bus 61 from the second were low before DG installation. This could cause instability in the networks in the presence of disturbances. After DG installation, the three methods showed major improvements, Figs. 7 and 10. Besides, the Figs. 6 and 9 are demonstrating that the voltage regulation index is at highest for GA/PSO and for the GA is the lowest.

6. Conclusion

In the paper combined method was proposed to solve location and capacity problems for DG. In this method, GA and PSO methods were used to determine the location and to calculate the capacity of DG respectively. Combined method was implemented for the

33 and 69 bus systems to minimize the losses, to increase the voltage stability and to improve the voltage regulation index. Results from combined method were compared to the results from the other two and advantages and disadvantages were discussed. Results showed that the proposed method is better; one of its advantages is the uniform answers with negligible value for the variances. At the same time, it was able to find the best optimized solution for the system. Considering active power losses, reactive power and the value for objective function, it can be concluded that the combined method exhibited a higher capability in finding optimum solutions.

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