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A teaching learning based optimization technique for optimal location and size of DG in distribution network

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Abstract

DGs are placed for the purpose of real power loss minimization and voltage improvement in distribution network system. This paper presents a recent optimization technique, i.e. teaching learning based optimization (TLBO) technique for finding the optimal size and location of Distributed generation (DG) in radial distribution system (RDS). The optimal location and size of DG is analyzed considering voltage stability index as an objective function. The superiority of the proposed approach has been shown by comparing the results with GA and PSO methods in RDS. The comparison is done using system performances such as the real power loss and voltage profile of RDS. In this paper, performance analysis is carried out considering IEEE 33 bus and 69 buses as the test system.

Keywords: Distributed generation (DG); Teaching Learning based optimization technique (TLBO); Radial distribution network (RDS)

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1. Introduction

Due to competition and restructuring in power systems and also changes in management and ownership of electricity industry, the role of distributed generation (DG) units are expected to increase dramatically in the future. Also, factors such as environmental pollution, problems establishment of new transmission lines and technology development of DG unit increase the use of these resources. The use of DGs can lead to the distribution network to lower loss, higher reliability, improvement of voltage profile, etc. All these advantages will be achieved only on the condition that the DGs are placed in proper buses. Any improper placing or having improper size may adverse system condition in distribution network. Radial distribution systems (RDS) are usually taken in distribution system due to its simple operational nature. As this system is fed only at substation and this is passive in nature, therefore 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

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of voltage stability index at most of its nodes. In power system, operator is obligated to maintain voltage level of each customer bus within the required limit. Hence, DGs are placed in the distribution network to reduce above all these difficulties.

Several definitions and advantages of DG and different technologies used in DG have been described (Ackermann et al., 2001; Khattam and Salama, 2004). In order to achieve the benefits of DG, the size and location of DGs are optimized using a multi-objective evolutionary algorithm developed by Celli et al. (2005). Iyer et al. (2006) used the primal-dual IP method to find optimal DG location through combined line loss reduction and voltage profile improvement indices. However, the proposed method was based on initial location of DGs at all of the buses in order to determine DGs proper placements. This method may not be realistic for large scale systems. Acharya et al. (2006) used the incremental change of the system power losses as compared to the change of injected real power sensitivity factor, that developed by Ol Elgerd (1971). 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.

Carmen et al. described a methodology for optimal DG 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 genetic algorithms (GA) techniques, with methods to evaluate DG impacts in system reliability, losses and voltage profile. Haesen et al. 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. (2005) hybridized algorithm to solve DG sizing problem. They combined GA and simulated annealing methods to solve optimal DG power output. In Ghosh et al. (2010), optimal sizing and placement of DG is found considering a simple conventional iterative search technique along with Newton Raphson method for load flow study, on modified IEEE 6 bus, IEEE 14 bus and IEEE 30 bus systems. Moradi et al. (2010) programmed the optimization of both location and capacity of DG sources by employing only the GA method. Moradi et al. (2010) utilized the hybrid technique in solving multiple DG sizing and location, to find optimal DG location through combined losses reduction, voltage profile improvement and increasing the voltage stability within the frame-work of system and security constraints in network systems. They used the GA for finding location of DGs and particle swarm optimization (PSO) for sizing the DGs. Falaghi and Haghifam (2007) presented a procedure using Ant Colony Optimization (ACO) for DG sources allocation and sizing in distribution systems, etc. Nowadays, these techniques are still used for trying to enhance the solutions of this problem. Singh and Goswami (2010) used a nodal pricing method for optimal placement of DG to achieve profit, reduction of loss and improvement of voltage. Gomez-Gonzalez et al. (2012) employed discrete PSO and OPF method to overcome the optimal DG placement and sizing in distribution systems. López-Lezama et al. (2012) presented an approach based on a specialized GA to determine the location and contract pricing of dispatchable DG units in distribution systems.

For proper operation of GA, proper selection of specific algorithm parameters are required which affects the optimal solution. Any change in the parameter changes the effectiveness of the algorithm. Some disadvantages associated with it: (1) unless the fitness function is defined properly, GA may have a tendency to converge towards local optima rather than the global optimum of the problem; (2) operating on dynamic data sets is difficult; and (3) for specific optimization problems, and given the same amount of computation time, simpler optimization algorithms may find better solutions than GAs. PSO has also specific algorithm parameters, i.e. inertia weight and c_1 and c_2, which affects the convergence of optimal solution. It has been found that a large inertia weight facilitates global exploration (searching new areas), while a small one tends to facilitate local exploration, i.e. fine-tuning the current search area, when no better global best is found by any other particle for some time, all particles converge about the existing global best, potentially eliminating even the nearest local minimize. The disadvantages of PSO algorithm are that it is easy to fall into local optimum in high-dimensional space and has a low convergence rate in the iterative process.

Very recently, Rao et al. (2011) developed a new optimization technique called Teaching–Learning Optimization (TLBO) algorithm. It is based on the effect of the influence of a teacher on the output of learners in a class. TLBO method has the major advantage of not requiring any parameter of the algorithm for its operation with the exception of the population size and maximum number of iterations. Furthermore the algorithm is easily implemented and requires less computational memory when compared with all the above mentioned algorithms like GA, PSO, ACO, etc. Nayak et al. (2012) applied multi-objective TLBO technique for optimal power flow problem. Rao presented TLBO technique for solving different types of optimization problems in Rao et al. (2012) and Rao and Patel (2012, 2013). Sneha in Ref.

Sultana and Roy (2014) implemented TLBO technique for the optimal placement of capacitor in radial distribution systems.

In this paper, the proposed TLBO algorithm is implemented to determine the optimal location and size of DG in distribution systems. Considering voltage stability index as objective function, optimal position and size of DG is found. The performances of system such as reduction of real power loss, improvement of voltage profile and improvement of voltage stability index are calculated after placing the DG of optimal size in optimal location. After the calculation, the results obtained from TLBO algorithm are compared with the results of GA and PSO techniques, considering two test systems, i.e. 33-bus and 69-bus radial distribution system.

This paper is organized as: Problem formulation comes in Section 2, Methodological framework comes in Section 3, TLBO algorithm is described in Section 4, Numerical results and discussion comes under Section 5 and at last the conclusion part comes under in Section 6.

2. Problem formulation

The objective of optimal DG placement problem in radial distribution system is to optimize a certain performances of the system such as real power loss, voltage profile, and voltage stability index while satisfying all operational constraints. Considering voltage stability index as objective function, optimal size and location of the DG is found out. By placing the DG in optimal position with optimal size, the performances of the system are calculated. Mathematical expressions for different performances are given below.

2.1. Real power loss

One important benefit of optimal placement of DG in distribution network is to minimize real power losses of the system (Moradi and Abedini, 2012). Mathematically it can be written as:

$$P_{RPL} = f_1 = \sum_{i=2}^{n_n} \left(P_{gni} - P_{dni} - V_{mi} V_{ni} Y_{mni} \cos(\delta_{mi} - \delta_{ni} + \theta_{ni}) \right) \tag{1}$$

where P_{RPL} is the real power loss; P_{gni} is the active power output of the generator at bus n_i; P_{dni} is the active power demand at bus n_i; V_{mi} is the voltage of bus m_i; V_{ni} is the voltage of bus n_i; Y_{mni} is the admittance between bus m_i and bus n_i; δ_{mi} is the phase angle of voltage at bus m_i; δ_{ni} is the phase angle of voltage at bus n_i; θ_{ni} is the admittance angle of $Y_i = Y_{ni} \angle \theta_{ni}$. n_n is total number of buses in the given radial distribution system. n_i is receiving bus number ($n_i = 2, 3, \ldots, n_n$) and m_i is the bus number that sending power to bus $n_i (m_2 = n_1 = 1)$ and i is the branch number that fed bus n_i.

2.2. Voltage profile of the system

Mathematically, voltage profile of the system is calculated as given in Moradi and Abedini (2012):

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

where V_{rated} is the rated voltage (1 pu).

2.3. Improving voltage stability index

A branch of radial system is shown in Fig. 1. The voltage stability index is improved, when the DG is placed in a distribution network. This index that can be calculated at all buses in radial distribution systems is presented in (Moradi and Abedini, 2012).

The voltage stability index of the system as given in (Moradi and Abedini, 2012) is:

$$SI(n_i) = |V_{mi}|^4 - 4[P_{ni}(ni)R_{ni} + Q_{ni}(ni)X_{ni}]|V_{mi}|^2 - 4[P_{ni}(ni)R_{ni} + Q_{ni}(ni)X_{ni}]^2 \tag{3}$$

where $P_{ni}(ni)$ is the total real power fed through bus n_i, $Q_{ni}(ni)$ is the total reactive power load through bus n_i, R_{ni} is the resistance of branch i, X_{ni} is the reactance of branch i and $SI(n_i)$ is the voltage stability index of node.

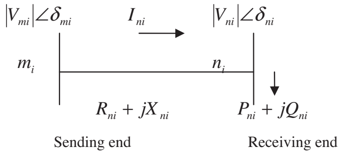

Fig. 1. A representative branch of a radial distribution system.

In this paper the objective function considered is given by

$$Minimize(f_3) = \left(\frac{1}{(SI(n_i))}\right) \quad n_i = 1, 2, 3, \ldots, n_n \tag{4}$$

For stable operation of the radial distribution systems, $SI(n_i) > 0$ and the maximum value of $SI(n_i)$ for $n_i = 2, 3, \ldots, n_n$ causing minimum value of f_3. The buses which have minimum value of voltage stability index are considered as weak buses of the system. To minimize the proposed objective function, $SI(n_i)$ must be maximized for improving voltage stability.

2.4. Constraints

2.4.1. Load balancing constraints

These constraints expressed as follows for each bus:

$$P_{gni} - P_{dni} - V_{ni}\sum_{j=1}^{N} V_{nj}Y_{nj}\cos(\delta_{ni} - \delta_{nj} - \theta_{nj}) = 0 \tag{5}$$

$$Q_{gni} - Q_{dni} - V_{ni}\sum_{j=1}^{N} V_{nj}Y_{nj}\sin(\delta_{ni} - \delta_{nj} - \theta_{nj}) = 0 \tag{6}$$

where $n_i = 1, 2, 3, \ldots, n_n$.

2.4.2. Voltage constraints

The following range for voltage of the buses is considered:

$$V_{\min} \le V_{ni} \le V_{\max} \tag{7}$$

where $V_{\min}$ is the minimum voltage at bus n_i, $V_{\max}$ is the maximum voltage at bus n_i.

2.4.3. DG constraints

The used DG source must have the allowable size and power factor as the following range:

$$S_{\min}^{DG} \le S_{ni}^{DG} \le S_{\max}^{DG} \tag{8}$$

where $S_{\min}^{DG}$ is minimum apparent power at bus n_i, $S_{\max}^{DG}$ is maximum apparent power at bus n_i and S_{ni}^{DG} is the apparent power at bus n_i.

3. Teaching learning based optimization algorithm

Teaching–Learning-Based Optimization (TLBO) is a newly introduced metaheuristic algorithm developed by Rao et al. (2011). It works on the basis of teaching and learning mechanism in a class between the teacher and the students. This method is based on the effect of the influence of a teacher in the results of students in a class. The teacher is generally considered as most respected and highly learned person in society who imparts quality education to their students in the class. The result of a student is improved not only the quality of teaching delivered by the teacher but also the collective knowledge of his/her own and the sharing knowledge of his/her classmates. The result of the students is finally evaluated on the basis of their outcomes/grades in the class. TLBO is a nature inspired, parameter free algorithm which uses a population of solutions to proceed to the optimal solution. For TLBO, the population is considered as students in a class and the control variables are the subjects offered to them. This algorithm working process is divided into two parts, namely teaching phase and learning phase are described below.

3.1. Teacher phase

This phase of algorithm simulates the learning of the students through the teacher. During this phase the teacher conveys knowledge among the learners to improve the mean result of the class. Suppose there are ‘*m*’ no. of subjects (i.e. design problems) offered to ‘*n*’ no. of learners (i.e. population size $k = 1, 2, 3, \ldots, n$) and in sequential teaching–learning process *i*, M_{ji} be the mean results of the learners of a particular subject ($j = 1, 2, \ldots, m$). Since the teacher is a highly educated and most experienced person on that subject, so in the entire population the teacher is considered to be the best learner in the class. Let $X_{total-kbest,i}$ is the result of the best learner considering all the subjects in the whole class, who is identified as the teacher of the class. Teacher will put maximum effort to enhance the knowledge level of the entire class, but learners will gain the knowledge according to the quality of teaching delivered by the teacher and quality of learners present in the class. Considering this fact the difference between the result of the teacher and mean result of the learners in each subject is expressed as:

$$Difference\_mean_{jki} = r_i(X_{jkbesti} - T_F M_{ji}) \tag{9}$$

where $X_{jkbesti}$ is the result of the best learner (i.e. the teacher) in the subject *j*. T_F is the teaching factor which decides the value of mean to be changed and r_i is the random number in the range [0,1]. T_F is not a parameter in this TLBO algorithm and its value can be either 1 or 2. The value of T_F is randomly decided as:

$$T_F = round[1 + rand(0, 1)\{2 - 1\}] \tag{10}$$

Based on, the existing solution is updated according to the following equation:

$$X'_{jki} = X_{jki} + Difference\_mean_{jki} \tag{11}$$

where X_{jki} is the result of the learners in the class considering all the subjects. X'_{jki} is the updated value of learners. This is accepted if it gives the better value.

All the accepted function values at the end of teacher phase are maintained and these values become input to the learner phase. The flowchart for the TLBO process is shown below in Fig. 2.

3.2. Learner phase

This phase of the algorithm simulates the learning of the students through mutual interaction among themselves. The students can also enhance their knowledge by discussing or interacting with other students. This learning phenomenon can be expressed as follows.

Randomly two different learners, i.e. *P* and *Q* are selected such that

$$X'_{total-Pj} \neq X'_{total-Qj}$$

where $X'_{total-Pj}$ and $X'_{total-Qj}$ are updated values of $X_{total-Pj}$ and $X_{total-Qj}$ respectively at the end of teacher phase.

If $X'_{total-Pj} < X'_{total-Qj}$

$$X''_{jpi} = X'_{jpi} + r_i(X'_{jQi} - X'_{jPi}) \tag{12}$$

If $X'_{total-Qj} < X'_{total-Pj}$

$$X''_{jpi} = X'_{jpi} + r_i(X'_{jpi} - X'_{jQi}) \tag{13}$$

X''_{jpi} is accepted if it gives a better function value.

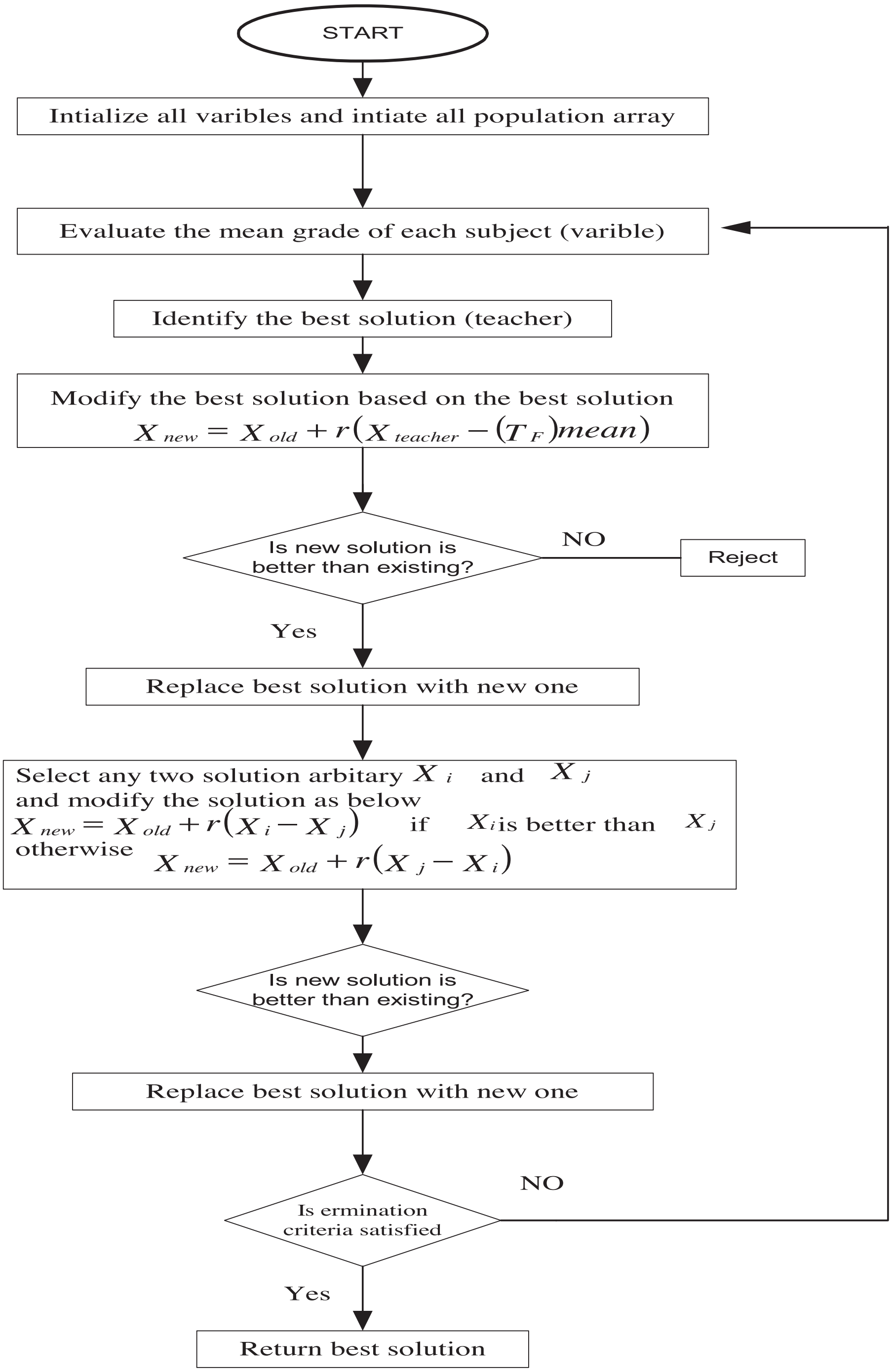

Fig. 2. Flowchart for TLBO algorithm.

4. Implementation of TLBO technique for optimal DG placement problem

The stepwise procedure for the implementation of TLBO algorithm in solving the optimal placement of DG is given by following steps.

Step 1. Initialize the following optimization parameters: population size (N_P), maximum number of iterations, number of design variables (N_D) (i.e. DG) and limits of design variables to be installed in the distribution network.

Step 2. Randomly generate different locations for the placement of DG depending upon number of DG.

Step 3. Randomly generate different size of the DGs within their operating limits which are installed in the distribution network. The operating KW of all the installed DGs comprise a vector which represents the grade of different subjects of a particular student and it also represents a candidate solution for the optimal DG placement problems. Each set of the feasible solution of matrix P_i represents a potential solution and is given by,

$$P_i = [loc_{i,1}, loc_{i,2}, \ldots, loc_{i,N_D}, PG_{i,1}, PG_{i,2}, \ldots, PG_{i,N_D}] \quad (14)$$

where PG_i is the initial size of installed DGs. i represents the students and j represents the subjects.

Depending upon the population size, initial solution P is created which is given by:

$$P = [P_1, P_2, \ldots, P_i, \ldots, P_{N_P}] \quad (15)$$

Step 4. Run the load flow to find the power losses of the distribution network. In this paper, forward–backward sweep algorithm is used for the load flow of the given distribution network (Bompard et al., 2000). Afterward, the objective functions are evaluated. Based on the objective value, sort the students from best to worst and the best solution obtained so far is assigned as the teacher of the class.

Step 5. Modify the grade point of each subject (i.e. KW of installed DGs) using the concept of teaching phase as discussed in Section 3.

Step 6. Update the grade point (KW of installed DGs) of each subject of all students using the concept of learning phase as explained in Section 3.

Step 7. Check whether the updated KW of the any installed DG violates the operating limits or not. If any value is less than the minimum value it is made equal to minimum limit and if it is greater than the maximum value it is made equal to the maximum limit.

Step 8. Check for the stopping criteria. If it is satisfied, then stop the iteration process and print the best solution else go to step no. 4 and repeat the whole process.

5. Numerical results and discussion

IEEE 33 bus and 69 bus radial distribution systems are considered as test system. To evaluate the effectiveness of the proposed TLBO algorithm, the performances of the systems are analyzed and compared with PSO and GA methods. The proposed TLBO algorithm is implemented for optimal size and location of DG in distribution network using MATLAB software.

The parameters of the TLBO algorithm for these systems are: the population size (N_P) and the maximum iteration number ($N_{\max}$) are taken as 50 and 100, respectively. In the test system, TLBO algorithm is run for 50 times with the different randomly generated initial solutions and the best results are listed in the corresponding tables. Similarly, the parameters for GA method are 100, 50, 0.85 and 0.01 for population size, number of generations, crossover probability and mutation probability respectively. The parameters for PSO method are 40, 100, [0,2], [0,1] and [0.4,0.9] for population size, maximum iteration, accelerating factors c_1 and c_2, two random numbers r_1 and r_2 and updating factor w respectively.

5.1. 33-Bus radial distribution system

The first test system, i.e. 33 bus radial distribution system is taken as the test system with total load of 3.7 MW, 2.3 Mvar, 12.66 kV, 33 bus and 32 branches which is demonstrated in Fig. 3 and the data is given in Hamouda and Zehar (2006). The real power loss in the system is 213 (kW) while the reactive power loss is at 143 (kVar) when calculated using the load flow method reported in Bompard et al. (2000).

In this paper, the number of DGs is considered as 3 and the maximum and minimum limits of DG are taken as 0.1 MW to 1.48 MW respectively. Performance analysis of both the test systems is presented in Table 1 before the installation of DG.

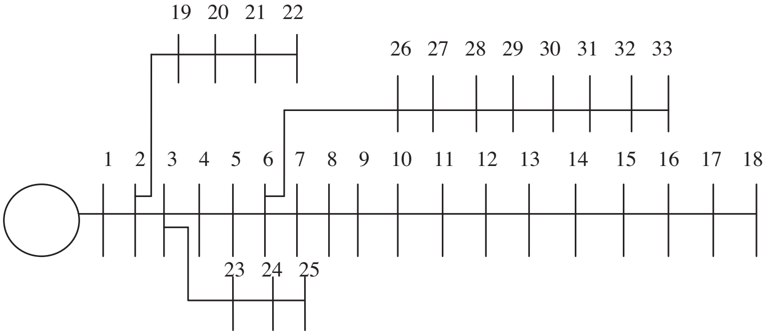

Fig. 3. Single line diagram of the 33 bus distribution test system.

Table 1
Performance analysis of both the systems before DG installation.

System	f_1 (pu)	f_2 (pu)	f_3 (pu)
33-Bus	0.213	0.3140	1.4233
69-Bus	0.224	0.2198	1.4045

The results for optimal sitting and sizing problems of DG for the 33-bus system are described in Table 2. The results obtained from TLBO algorithm are compared with the results obtained using PSO and GA techniques separately; for the location of DG, DG sizes, the real power losses, voltage profile and the voltage stability index.

From the results shown in Table 2, it can be observed that with TLBO algorithm real power loss is improved by 2% and 2.5% compared to PSO and GA techniques respectively. Similarly, voltage deviation is improved by 3.5% and 1.5% with TLBO algorithm compared to PSO and GA techniques respectively, as in Moradi and Abedini (2012), with optimal sizing and sitting of DG.

Fig. 4 depicts voltage profile of each bus in 33 bus distribution system. The results show different voltage levels during the pre and post installation of DG. It is found that before installation of DG, voltage level of bus no. 18 is low. After installation of DG with optimal sitting and sizing, the voltage level of the weak bus is improved. Furthermore, the voltage levels at all nodes for RDS have also improved with all the three methods. But, significant improvement can be seen with TLBO algorithm compared to GA and PSO algorithms.

Fig. 5 shows the voltage stability indices at all nodes of 33-bus RDS. As seen from the figure, voltage stability indices have reduced value for all nodes before installation of DG. After installation of DG voltage stability indices have improved for all nodes with TLBO, PSO and GA methods. But, with TLBO algorithm voltage stability indices for all nodes are improved significantly compared to GA and PSO techniques as given in Moradi and Abedini (2012).

Convergence characteristics of power loss, of the proposed TLBO algorithm, GA and PSO for the 33-bus system are shown in Fig. 6. From the convergence graph, it may be observed that the objective function value converges smoothly

Table 2
Performance analysis of the 33-bus test system after DG installation.

Methods	f_1(pu)	f_2(pu)	f_3(pu)	Bus no.	DG size (MW)
TLBO	0.1040	0.0295	1.0474	18	0.8953
				9	0.8847
				31	1.1958
PSO (Moradi and Abedini, 2012)	0.1053	0.0335	1.0804	13	0.9816
				32	0.8297
				8	1.1768
GA (Moradi and Abedini, 2012)	0.1063	0.0407	1.0537	11	1.5
				29	0.4228
				30	1.0714

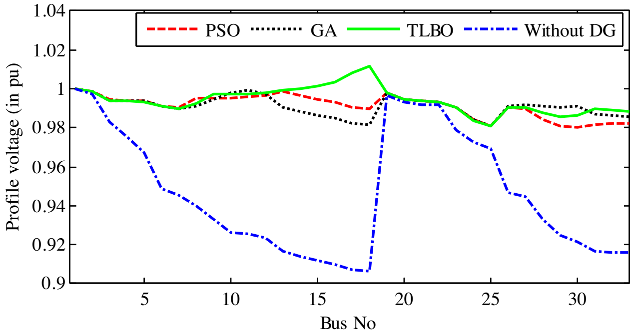

Fig. 4. Voltage profile of the 33-bus radial distribution system.

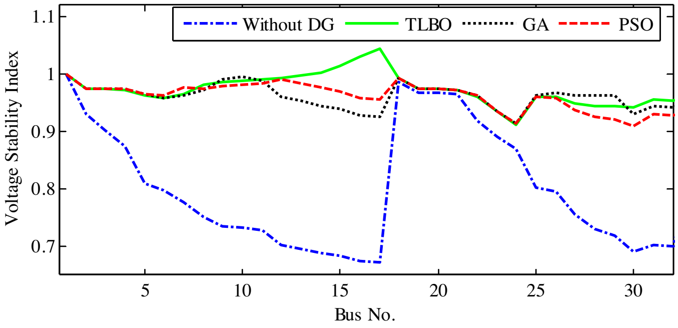

Fig. 5. Voltage stability indices at all nodes of the 33-bus system.

to the optimum value without any abrupt oscillations. This confirms the convergence reliability of the proposed TLBO algorithm. The real power loss is better in case of TLBO compared to GA and PSO techniques.

5.2. 69-Bus radial distribution system

The second test system is 69-bus radial distribution system which has the total load of 3.80 MW and 2.69 MVar and it is demonstrated in Fig. 7. The real power loss and the reactive power loss are 2.24 kW and 1.10 MVar for this test system respectively when calculated using the power flow described in Bompard et al. (2000) and the data of 69-bus is given in Hamouda and Zehar (2006).

Performance analysis of 69-bus test system of pre-installation of DG is presented in Table 1. The performance analysis for optimal sitting and sizing of DG for the second test system are given in Table 3. The performances of 69-bus test system obtained with TLBO algorithm are compared with the results using PSO and GA techniques separately; for the location of DG, DG size, the real power losses, profile voltage and the voltage stability similarly as the case of 33 bus test system.

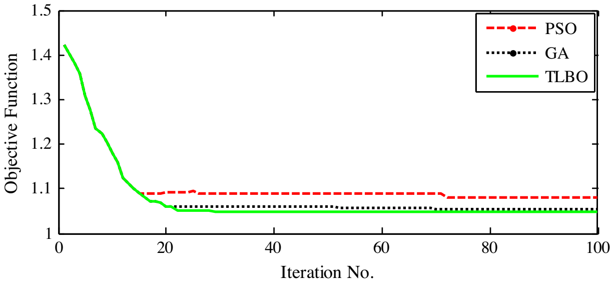

Fig. 6. Convergence graph of power loss for 33-bus using TLBO.

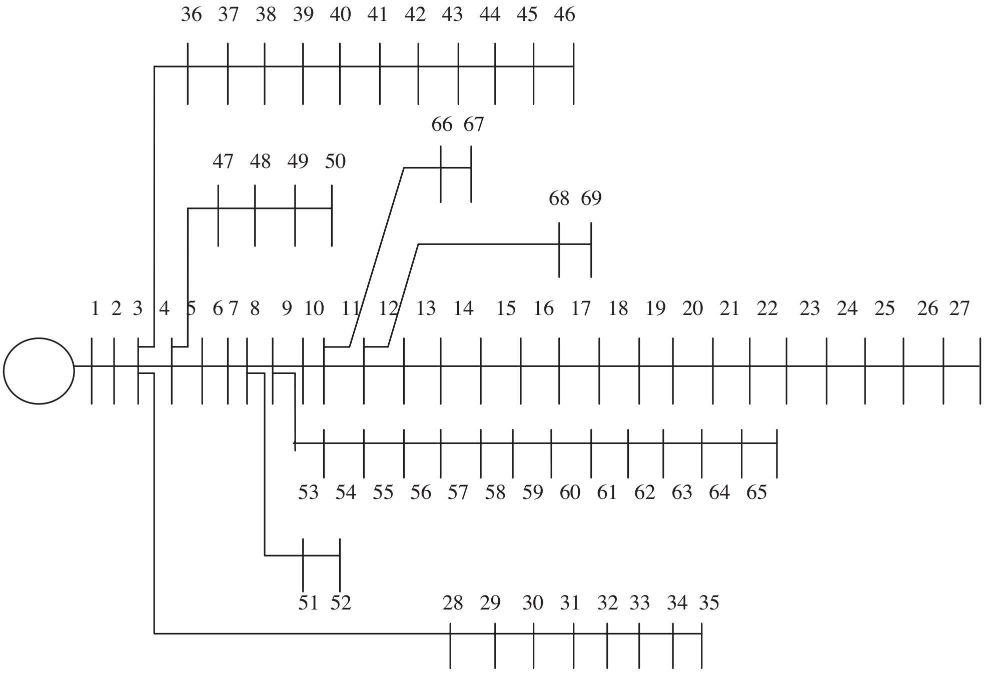

Fig. 7. Single line diagram of the 69 bus distribution test system.

Table 3
Performance analysis of the 69-bus test system after DG installation.

Methods	f_1 (pu)	f_2 (pu)	f_3 (pu)	Bus no.	DG size (MW)
TLBO	0.0810	0.0018	1.0219	63	1.1784
				25	0.7574
				60	1.0188
PSO (Moradi and Abedini, 2012)	0.0832	0.0049	1.0335	61	1.1998
				63	0.7956
				17	0.9925
GA (Moradi and Abedini, 2012)	0.089	0.0031	1.0303	21	0.7297
				52	1.0752
				54	0.9858

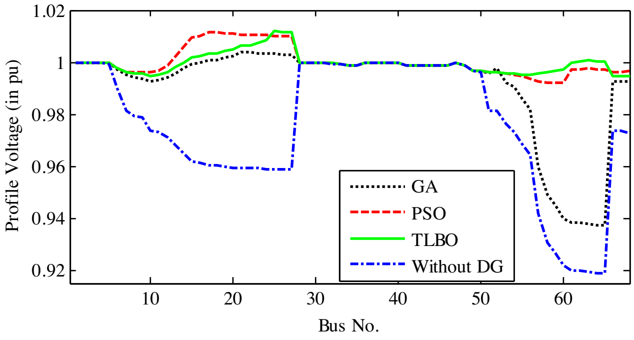

Fig. 8. Voltage profile of the 69-bus radial distribution system.

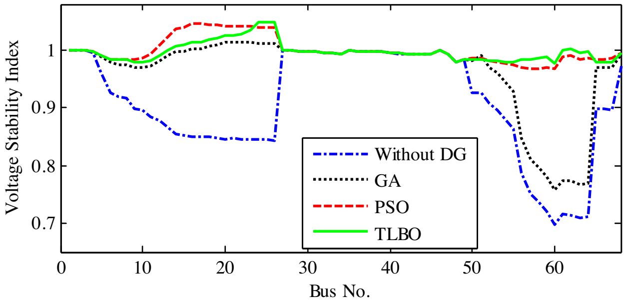

Fig. 9. Voltage stability indices at all nodes of the 69-bus system.

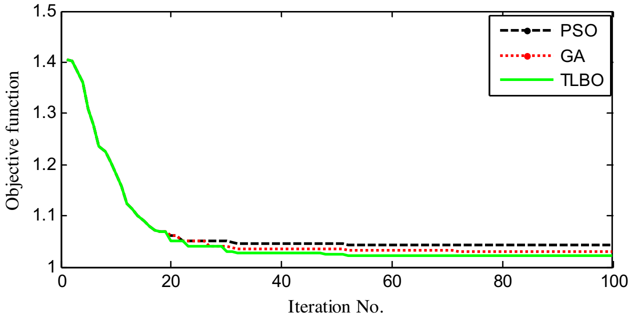

Fig. 10. Convergence graph of power loss for 69-bus using TLBO.

Figs. 8 and 9 shows the voltage profile and voltage stability indices of 69-bus test system. It is seen from Fig. 8, the voltage level bus no. 61 is low before installation of DG. After installing DG, the voltage profile of each bus number is improved with all the three methods. But, significant improvement is visible with TLBO algorithm compared to GA and PSO methods as in Moradi and Abedini (2012). Similarly, before installation of DG voltage stability indices have poor values. After installation of DG, significant improvement is seen with TLBO algorithm compared to GA and PSO methods. Convergence characteristics of power loss, of the proposed TLBO algorithm, GA and PSO for the 69-bus system are shown in Fig. 10.

6. Conclusion

In this paper, optimal placement and optimal sizing of DG for radial distribution network is carried out. Performances like real power loss, voltage profile and voltage stability index for two test systems are analyzed with before and after installation of DG. As seen from analysis, system performances are improved with placement of DG is the system. A new optimization technique, i.e. the teaching–learning based optimization (TLBO) technique which is one of the recently developed population based optimization technique is implemented and successfully applied on radial distribution network. The proposed method is implemented to improve the voltage profile, to reduce the real power loss and to improve the voltage stability index at each bus in two test systems, i.e. 33-bus and 69-bus radial distribution system. The simulation results have shown good performances and effectiveness of the proposed method compared to PSO and GA method for the same test system. Further work can be explored considering different types of DG. Along with DGs, fixed capacitors can be used for obtaining more effective results.

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