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DISTRIBUTED GENERATION PLANNING USING TEACHING LEARNING BASED OPTIMIZATION WITH VOLTAGE STABILITY CONSIDERATION

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ABSTRACT

This paper presents an algorithm for selection of optimal location of DG and minimizing losses based on voltage stability using Teaching Learning Based Optimization (TLBO). The optimal location of distributed generator's is obtained such that its mitigating power losses and voltage deviation of radial distribution test system simultaneously. The proposed algorithm has been implemented on IEEE 33 bus and IEEE 69 bus radial distribution test systems. The performance of the TLBO has been compared with Genetic Algorithm (GA). The obtained result indicate that the proposed TLBO algorithm provides better optimized solution than Genetic Algorithm (GA).The results shows the significant reduction in power loss and improvement in voltage profile.

***Keywords**: Distributed Generation, Teaching Learning Based Optimization (TLBO), Power Losses, Voltage Stability, Voltage Deviation.*

I. INTRODUCTION

Distributed Generation (DG) can be defined as the power generation at the customer side of system. Distributed generation offers various technical and economical benefits like power loss reduction, voltage profile improvement, decreased conductor loading, reduced Right of Way (ROW), reduced cost of generation etc. During recent years, several factors have been responsible for the appearance of DG in electric distributions systems. Among them are environmental concerns to reduce emissions of greenhouse gases, depletion of fossil fuels, advances in generation technologies, as well as the current global trend of deregulation of the electricity market which implies the need for more flexible electric systems.

Research has shown that installation of DG sources in the power distribution system could lead to achieve many benefits, some of which are voltage profile improvement, reduced lines losses, increased security for critical loads, grid reinforcement, reduction in the on-peak operation cost, etc. In order to optimize these benefits, it is essential to determine the optimal sizes of DG units and their best locations in distribution systems.

Many methods have been reported to solve this problem. In summary, existing approaches could be grouped into three different categories: classical optimization [1-3], analytical approaches [4-6] and the meta-heuristics [7-9]. Since then (year 2010), a large number of articles have been published on this subject and examples of this are Refs. [10-12]. This fact indicates that this topic remains an interesting line of research. In Ref [12] Differential Evolution is used for selection of buses in a sub transmission system for location of DG and determination of their optimum capacities by minimizing transmission losses.

In the classical optimization approaches, among others, are included techniques such as the Optimal Power Flow (OPF), which is able to optimize highly complex problems with many variables, although limited by the high dimensionality of power systems [1]; linear programming, whose methodology is easy to implement, but is usually very difficult to reduce the models into a set of linear equations [2]; or the Lagrange multipliers, which also becomes less efficient when the number of elements increases [3].

In relation to analytical approaches, Wang and Nehrir [4] were primarily concerned with finding the optimal locations of DG but failed to optimize size. Acharya et al. [5]proposed an analytical expression to calculate the optimal size, and an effective methodology to identify the corresponding optimal location for DG placement based on an approximate loss formula. In addition, this methodology is compared with the loss sensitivity factor method. The analytical procedure used by Gozel and Hocaoglu [6]is faster and more accurate than previous analytical methods, since the former does not make use of admittance, impedance or Jacobian matrices; however, it is only suitable for radial systems.

Due to the high dimension of the possible solutions and the nonlinear nature of this problem, meta-heuristic techniques have come to be the most widely used way to solve it. Among these techniques there are many

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optimization algorithms inspired by nature. To mention but a few: In [7]a methodology based on Tabu Search (TS) is presented for finding the optimal location of DG units so as to minimize power losses. Ref. [8]adopts the Genetic Algorithm (GA) approach for optimal DG allocation and sizing in distribution systems. On the other hand, many researchers have considered the combination of two optimization techniques together for obtaining a better solution. So, a new hybrid algorithm of GA and TS is proposed in [9] to avoid the major drawbacks of the classical simple GA.

The main limitation of these meta-heuristic techniques is the difficulty in determining the optimal controlling parameters. Thus, they generally provide a near optimal solution for a problem with a large number of variables, and change in the selection of the algorithm parameters changes the effectiveness of it. This difficulty for the selection of parameters can increase if hybridization or modifications are carried out.

In this paper a proposed efficient, reliable optimization algorithm has been proposed which is Teaching Learning Based Optimization (TLBO) algorithm [13] as its less controlling parameter compared to other algorithms. A multi-objective function is used which simultaneously minimizes the power loss, improves voltage profile and maximizes voltage stability index. The results obtained from TLBO algorithm are compared with the results of Genetic algorithm (GA). The analysis has been implemented on IEEE 33-bus and IEEE 69-bus distribution test system. The results show that the proposed TLBO algorithm is the best one to solve the optimization problem.

The rest of the paper is organized as follows. Voltage stability describes in section 2. In Section 3, problem formulation with constraints of optimal DG allocation problem is discussed. The TLBO method is briefly described in Section 4. The algorithm steps of TLBO applied to optimal DG placement problem of radial distribution system are explained in Section 5. Results and Discussion are reported in Section 6. Finally, conclusions are drawn in Section 7.

II. VOLTAGE STABILITY

Voltage Stability is defined as the ability of a power system to maintain steady-state voltage at all buses in the system after being subjected to a disturbance from a given initial operating condition [14].

Voltage stability is usually represented by P-V curve. In Fig. 1 the noise point is called the point of voltage collapse (PoVC) or equilibrium point. At this point, voltage drops rapidly with an increase of the power load and consequently, the power flow Jacobian matrix becomes singular. Classical power-flow methodologies fail to converge beyond this limit, which indicates voltage instability and can be associated with a saddle-node bifurcation point. Although voltage instability is a local phenomenon, the problem of voltage stability concerns the whole power system, and it is essential for its operation and control. This aspect is more critical in power networks, which are heavily loaded, faulted, or with insufficient reactive power supply.

Voltage Collapse is the process by which the sequence of events accompanying voltage instability leads to a blackout or abnormally low voltages in a significant part of the power system [14].

DG units can offer the ability of providing a very fast dynamic Var injection, so their optimal allocation in the power network could alleviate the voltage instability or even prevent the voltage collapse.

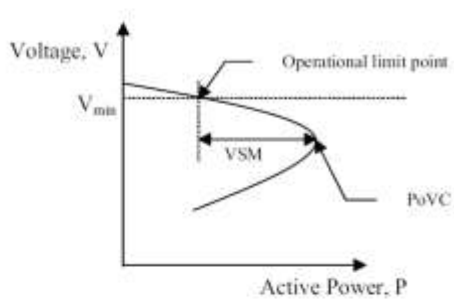

Fig.1: P-V curve

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III. PROBLEM FORMULATION

Objective function

Single objective function

Real Power loss minimization: The real power loss minimization function may be defined as:

$$F_1 = Minimize\ (P_L) \tag{1}$$

Where P_L is real power loss of the distribution network.

Voltage profile improvement: Voltage profile improvement function may be defined as:

$$F_2 = \sum_{i=1}^{n_b} (V_i - V_{rated})^2 \tag{2}$$

Maximize voltage stability index: Voltage stability index of radial distribution system is given by:

$$F_3 = VSI_i = |V_j|^4 - 4[P_i r_{ij} + Q_i x_{ij}]|V_j|^2 - 4[P_i x_{ij} - Q_i r_{ij}]^2 \qquad i = 2,3,4,\ldots\ldots\ldots n_b \tag{3}$$

Where VSI_i is the voltage stability index of the i_{th} bus. P_i, Q_i are respectively total real and reactive power of i_{th} bus; r_{ij}, x_{ij} are resistance and reactance of line connecting i_{th} and j_{th} bus respectively; V_i, V_j are Voltages at bus *i and j* respectively.

Multi-objective function

A multi-objective function which simultaneously minimizes the power loss, improves voltage profile and maximizes voltage stability index.

$$F = \min\,(F_1 + C_1 F_2 + C_2 F_3) \tag{4}$$

where C_1 is the penalty coefficient 0.59; C_2 is the penalty coefficient 0.34; F_1 is the power loss minimization function; F_2 is the voltage profile improvement function; F^3 is the voltage stability function.

System constraints

- Power balance constraint

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{N} V_j Y_{ij} \cos(\phi_i - \phi_j - \theta_{ij}) = 0 \tag{5}$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{N} V_j Y_{ij} \sin(\phi_i - \phi_j - \theta_{ij}) = 0 \tag{6}$$

Where i, j are the receiving end and sending end bus; P_{Gi} and Q_{Gi} are active and reactive power output of generator at bus *i*; P_{Di} and Q_{Di} are active and reactive power demand at bus *i*; V_i; V_j are the voltages at bus *i* and *j*, respectively; $Y_{ij}; \theta_{ij}$ are the magnitude and angle of admittance, respectively of the distribution line connected between bus *i* and *j*. $\phi_i; \phi_j$ are the phase angles of voltage at bus *i* and *j* respectively.

- Voltage limit

$$V_i^{min} \le V_i \le V_i^{max} \tag{7}$$

Where V_i^{min} and V_i^{max} are the lower and upper limit of bus voltage respectively.

- Thermal limit

$$I_{ij} \le I_{ij}^{max} \tag{8}$$

where I_{ij}^{max} is the maximum loading of the distribution line connected between the i^{th} and the j^{th}bus.

- Real power limit

$$P_{DGi}^{min} \leq P_{DGi} \leq P_{DGi}^{max} \tag{9}$$

where $P_{DGi}^{min}, P_{DGi}^{max}$ are the lower and upper limits, respectively, of real power of the i^{th} DG.

- Reactive power limit

$$Q_{DGi}^{min} \leq Q_{DGi} \leq Q_{DGi}^{max} \tag{10}$$

where $Q_{DGi}^{min}, Q_{DGi}^{max}$ are the lower and upper limits, respectively, of reactive power of the i^{th} DG.

IV. TEACHING LEARNING BASED OPTIMIZATION (TLBO)

In order to solve a nonlinear optimization problem, meta-heuristic optimization techniques must be taken place. Among these techniques there are many algorithms inspired by nature. The main disadvantage of these heuristic techniques is the adjusting process of the controlling parameter of the optimization algorithm is difficult. Therefore, the provided solution is a sub-optimal solution with large number of controlling variables. Additionally, the improper tuning of algorithm-specific parameters either increases the computational effort or yields the local optimal solution. A new evolutionary method called Teaching-Learning Based Optimization (TLBO) algorithm has been presented. It does not require any algorithm-specific control parameters and requires only common controlling parameters like population size and number of generators therefore; TLBO can be considered as an algorithm-specific parameter-less algorithm. The algorithm is easily implemented and required less computational time when compared to the other heuristic techniques. TLBO is a teaching-learning process inspired algorithm based on the effect of influence of a teacher on the output of learners in a class room. There are two basic modes of the learning process, teacher phase and learner phase. The output of the algorithm is considered in terms of results are grades of the learners depends on the quality of teacher.

In this algorithm an initial set of solutions are generated randomly called as learners. The knowledge possessed by each learner is judged by the value of objective function. The learner who possesses most knowledge (best objective function value) is treated as teacher and rest of the solutions as students. It consists of two phases.

1. Teacher phase

The teaching phase represents the process of student learning through the teacher. The teacher is the most experienced and knowledgeable person in a subject, so the best learner in the population, including learners and teacher, is the teacher. In teacher phase knowledge is passed from teacher (best solution) to learners.

$$\text{Diff}_{\text{mean}} = \text{rand}\ (X_{tj} - (T_f * M_j)). \tag{11}$$

$$X_{i,j}^{new} = X_{i,j}^{old} + \text{Diff}_{\text{mean}} \tag{12}$$

where M_j is the mean of j^{th} variable considering all learners; $X_{i,j}$ is i^{th} learner's j^{th} variable; $X_{t,j}$ is Teacher's j^{th} variable.

T_f is Teaching factor either 1 or 2.

$$T_f = 0.5 * [1 + \text{rand}\ (0,1)] \tag{13}$$

Replace $X_{i,j}^{old}$ with $X_{i,j}^{new}$ only if $X_{i,j}^{new}$ gives better solution than $X_{i,j}^{new}$.

2. Learner phase

It simulates the learning of the students through interaction among themselves as the knowledge can be gained by interaction between students by discussion. In this phase each learner tries to improve his knowledge by learning from other learners having better knowledge than him. For each learner 'i' a partner is selected randomly say 'q'

If $F(X_{ij}) < F(X_{qj})$

Then $$X_{i,j}^{new} = X_{i,j}^{old} + \text{rand} * (X_{i,j}^{old} - X_{qj}) \tag{14}$$

If $F(X_{ij}) > F(X_{qj})$

Then $X_{i,j}^{new} = X_{i,j}^{old} - \text{rand}*(X_{i,j}^{old} - X_{qj})$ (15)

Where X_{qj} is q^{th} learner's j^{th} variable; $F(X_{ij})$ is Objective function value for variables X_{ij}.

$X_{i,j}^{new}$ is accepted only if $F(X_{i,j}^{new}) < F(X_{i,j}^{old})$

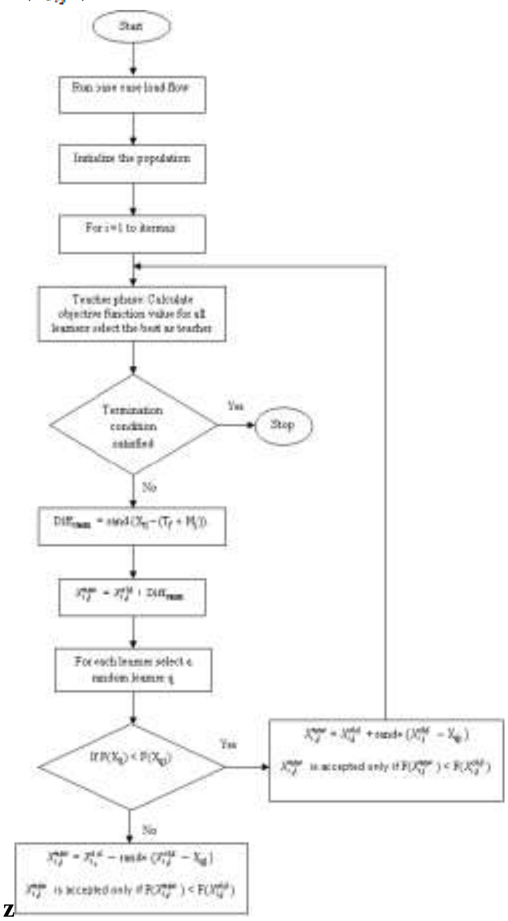

Fig 2: Flow chart for TLBO

V. PROPOSED ALGORITHM

Algorithm of TLBO applied to optimal DG allocation problem

Step 1: Read the system data, constraints, the population size (), the maximum number of iterations and the number of DGs to be installed in the distribution network.

Step 2: The size of the DGs are randomly generated and normalized between the maximum and the minimum operating limits. The rating of DG is normalized to *P* as given below:

$$P = P^{min} + r * (P^{max} - P^{min}) \quad (16)$$

Number of the buses is selected randomly in the range of [1,]. Here is the number of buses in the network where the DGs are installed in these selected buses. The rating of all the installed DGs, comprise a vector which represents the grade of different subjects of a particular student Each set of the feasible solution of matrix represents a solution which is given by:

$$U_i = [P_{i1}, P_{i2} \dots \dots P_{ij}, \dots \dots, P_{in_D}] \quad (17)$$

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

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$$U = [U_1, U_2 \dots \dots U_j, \dots \dots, U_{P_{size}}] \quad (18)$$

Step 3: To obtain the power losses, voltage deviation and voltage stability index of the distribution network, run a direct load flow based on the bus-injection to branch-current (BIBC) matrix and the branch-current to bus-voltage (BCBV) matrix [15] .

Step 4: Select the best solution and assign that solution as the teacher of the class. Update the grade of each subject of each student based on the teacher knowledge.

Step 5: Update grade of each subject of each student based on the teaching and learning phase.

Step 6: Check the independent variables are within their operating limits or not. If any independent variable is less than the minimum level, it is made equal to minimum value and if it is greater than the maximum level it is made equal to maximum level.

Step 7: Until the current iteration number reaches the pre specified maximum number of iteration, go to Step 3; otherwise stop.

VI. RESULTS AND DISCUSSION

To verify the effectiveness of proposed TLBO method, it is applied on standard IEEE 33-bus and IEEE 69-bus radial distribution systems to determine the optimal location and size of multiple DGs. The proposed TLBO algorithm is run for 45 population size and 150 iterations for each case.

6.1 For 33-bus radial distribution system

The single line diagram of 33-bus radial distribution system is shown in Fig. 3 and the line data and load data are given in [16]with rated voltage of 12.66 kV. The system has total active and reactive power loads of 3.72MW and 2.3 MVar respectively. Without installation of DG the total real and reactive power losses are 210.998 KW and 143 KVar [17]respectively.

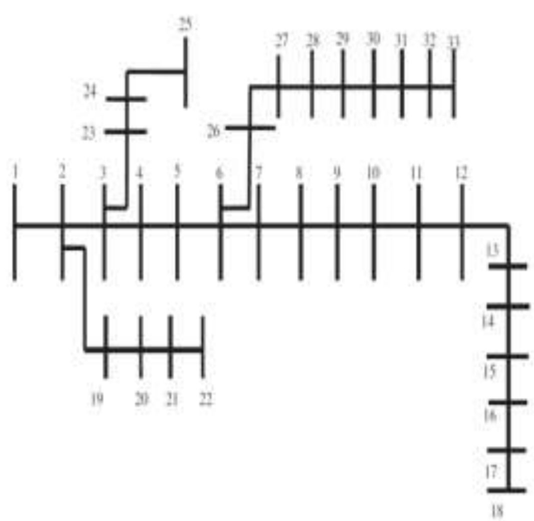

Fig 3: Single line diagram of 33-bus radial distribution system.

TABLE I: Results using TLBO algorithm of 33-bus system for optimize Single Objective Function.

Objective Functions	**Loss minimization**		**Voltage Deviation minimization**		**Voltage Stability maximization**	
	Optimal DG location	Optimal DG size (MW)	Optimal DG location	Optimal DG size (MW)	Optimal DG location	Optimal DG size (MW)
	10	0.8236	14	1.1307	8	1.1979
	24	1.0299	29	1.1967	12	1.1983
	31	0.8852	30	1.0069	31	1.1979
Objective functions	**Loss minimization**		**Voltage Deviation minimization**		**Voltage Stability maximization**	
Power loss(KW)	75.615		126.622		132.823	
Voltage Deviation	0.0221		0.0011		0.0024	
Voltage Stability Index^{-1}	1.1967		1.0741		1.0423	
Voltage Stability Index	0.8355		0.9309		0.9593	

Single objective

The results obtained by TLBO including optimal sitting and sizing of DG for three individual objective functions are listed in Table 1, respectively. The proposed TLBO algorithm attains a power loss of 75.615 KW. Similarly for voltage deviation minimization and voltage stability index maximization, proposed TLBO attains value of 0.0011p.u and 1.0423p.u. The convergence characteristics of power loss and obtained by TLBO is shown in Figs. 4 and 5.

Multi objective

The proposed method is applied on the same test system for simultaneous minimization of real power loss, improvement of voltage deviation and voltage stability index and the results are compared with Genetic Algorithm and are listed in Table 2. The proposed TLBO algorithm produces real power loss of 124.819 KW. It may further be noted from Table2that voltage deviation and voltage stability index obtained by TLBO (0.0012p.u. and 0.9492p.u.) is better than those obtained by GA (0.0408p.u. and 0.9479p.u.).

So, it can be concluded that proposed TLBO algorithm is more efficient than GA for simultaneous optimization of power loss, voltage profile and voltage stability index for 33-bus radial distribution system.

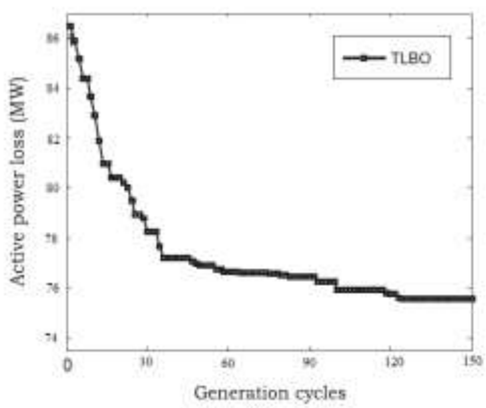

Fig 4: Loss convergence characteristics using TLBO algorithm of 33-bus system.

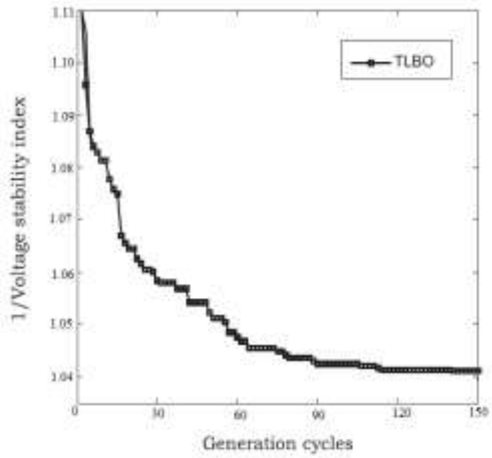

Fig5:Voltage stability convergence characteristics using TLBO algorithm of 33-bus system.

TABLE II: Comparison of TLBO algorithm with Genetic algorithm of IEEE 33-bus system for loss minimization, voltage profile and voltage stability index.

TLBO		**GA**	
Optimal DG location	**Optimal DG size (MW)**	**Optimal DG location**	**Optimal DG size (MW)**
12	1.1813	11	1.4983
28	1.1899	29	0.4223
30	1.1849	30	1.0702
Power loss(KW)	124.819	**Power loss(KW)**	126.067
Voltage Deviation	0.0012	**Voltage Deviation**	0.0408
Voltage Stability Index^{-1}	1.0523	**Voltage Stability Index^{-1}**	1.0549
Voltage Stability Index	0.9492	**Voltage Stability Index**	0.9479

6.2 For 69-bus radial distribution system

To show the performance for large scale distribution network, TLBO is implemented on 69-bus test system. The single line diagram of this test system is shown in Fig. 6and the line data and load data are given in [18]with rated voltage of 12.66 kV. The system has total load of 3.80MW and 2.69 MVar. The real and reactive power losses without installation of DG are found to be 224.7 KW and 102.13 KVar [19].

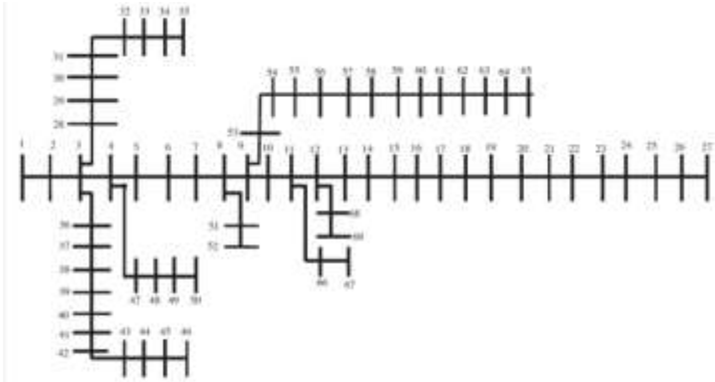

Fig 6: Single line diagram of IEEE 69-bus radial distribution system.

Single objective

The results of three individual objective functions are listed in Table 3. The proposed TLBO algorithm attains a power loss of 72.478KW. Similarly for voltage deviation minimization and voltage stability index maximization, proposed TLBO attains value of 0.0004p.u and 0.9751p.u. The voltage deviation convergence characteristics obtained by TLBO is shown in Fig. 7.

Multi objective

The proposed method is applied on the same test system for simultaneous minimization of real power loss, improvement of voltage deviation and voltage stability index and the results are compared with Genetic Algorithm and are listed in Table 4. From results it is also clear that the real power loss achieved by TLBO (82.254 KW) is better than GA (89.089 KW). Moreover, voltage profile and voltage stability index achieved by TLBO (0.0009 p.u. and 0.9734) are superior to GA (0.0013 p.u. and 0.9694).

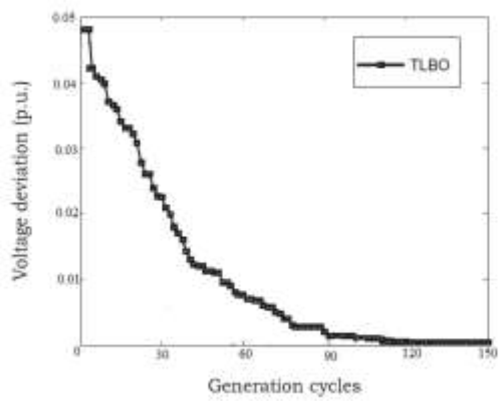

Fig 7:Voltage deviation convergence characteristics using TLBO algorithm of 69 bus system.

TABLE III: Results using TLBO algorithm of IEEE 69-bus system for optimize Individual Objective Function.

Single Objective Functions	**Loss minimization**		**Voltage Deviation minimization**		**Voltage Stability maximization**	
	Optimal DG location	Optimal DG size (MW)	Optimal DG location	Optimal DG size (MW)	Optimal DG location	Optimal DG size (MW)
	15	0.5912	14	0.9751	27	0.7018
	61	0.8178	59	1.1375	60	1.1703
	63	0.8993	64	1.1622	61	1.1617
Single Objective functions	**Loss minimization**		**Voltage Deviation minimization**		**Voltage Stability maximization**	
Power loss(KW)	72.478		90.192		88.979	
Voltage Deviation	0.0064		0.0004		0.0010	
Voltage Stability Index^{-1}	1.0920		1.0247		1.0255	
Voltage Stability Index	0.9157		0.9759		0.9751	

TABLE IV: Comparison of TLBO algorithm with Genetic algorithm of IEEE 69-bus system for loss minimization, voltage profile and voltage stability index

TLBO		**GA**	
Optimal DG location	**Optimal DG size (MW)**	**Optimal DG location**	**Optimal DG size (MW)**
13	1.01228	21	0.9286
61	0.9890	62	1.0740
62	1.1588	64	0.9837
Power loss(KW)	82.254	**Power loss(KW)**	89.089
Voltage Deviation	0.0009	**Voltage Deviation**	0.0013
Voltage Stability Index^{-1}	1.0273	**Voltage Stability Index^{-1}**	1.0315
Voltage Stability Index	0.9734	**Voltage Stability Index**	0.9694

VII.CONCLUSION

The proposed algorithm for optimal DG allocation has been implemented on IEEE 33bus and IEEE 69 bus radial distribution systems. The optimal number, allocation and size of distributed generation (DG) are determined using the proposed algorithm. The main objectives (power loss minimization, voltage profile improvement and voltage stability index maximization) are optimized. In order to prove the superiority of proposed TLBO algorithm, the numerical results of the proposed method are compared with those obtained by GA. The comparative simulation results show that TLBO approach is capable of obtaining better optimized solutions than GA technique.

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