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Intelligent Management of Distributed Generators for Loss Minimization Using Teaching Learning Based Optimization

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Abstract: *Distributed Generation (DG) has been utilized in electric power distribution networks. Network loss reduction, voltage profile improvement and increase in the system reliability are some advantages of DG application. Determination of suitable size and location of DG is essential and the task can be mathematically formulated as an optimization problem. Various analytical and soft computing methods have been reported and improvements in the solution quality are still required. The modern meta-heuristic algorithm known as Teaching Learning Based Optimization (TLBO) has been chosen as the main tool to address the DG application problem. The intended algorithm is implemented for solving three different test cases and the standard radial distribution system is used for demonstration. The simulation results are compared with earlier reports and the comparison reveals that the TLBO is a promising tool for solving DG application problems.*

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I. Introduction

The modern power distribution network is constantly being faced with an ever growing load demand resulting into increased burden and reduced voltage. The distribution network also has a typical feature that the voltage at nodes reduces if moved away from substation. This decrease in voltage is mainly due to insufficient amount of reactive power. Thus to improve the voltage profile and to avoid voltage collapse reactive compensation is required. The X/R ratio for distribution levels is low compared to transmission levels, causing high power losses and a drop in voltage magnitude along radial distribution lines. It is well known that loss in a distribution networks are significantly high compared to that in a transmission networks. Such non-negligible losses have a direct impact on the financial issues and overall efficiency of distribution utilities. The need of improving the overall efficiency of power delivery has forced the power utilities to reduce the losses at distribution level. Many arrangements can be worked out to reduce these losses like network reconfiguration, shunt capacitor placement, distributed generator placement etc. The distributed generators supply part of active power demand, thereby reducing the current and MVA in lines. Installation of distributed generators on distribution network will help in reducing energy losses, peak demand losses and improvement in the networks voltage profile, networks stability and power factor of the networks.

Distributed generation (DG) technologies under smart grid concept forms the backbone of our world Electric distribution networks. Renewable energy source (RES) based DGs are wind turbines, photovoltaic, biomass, geothermal, small hydro, etc. Fossil fuel based DGs are the internal combustion engines (IC), combustion turbines and fuel cells. Environmental, economic and technical factors have a huge role in DG development. In accord with the Kyoto agreement on climate change, many efforts to reduce carbon emissions have been taken, and as a result of which, the penetration of DGs in distribution systems rises. Presence of Distributed generation in distribution networks is a momentous challenge in terms of technical and safety issue. Thus, it is critical to evaluate the technical impacts of DG in power networks. Thus, the generators are needed to be connected in distributed systems in such a manner that it avoids degradation of power quality and reliability. Evaluation of the technical impacts of DG in the power networks is very critical and laborious. Inadequate allocation of DG in terms of its location and capacity may lead to increase in fault currents, causes voltage variations, interfere in voltage-control processes, diminish or increase losses, increase system capital and operating costs, etc. Moreover, installing DG units is not straight forward, and thus the placement and sizing of DG units should be carefully addressed. Investigating this optimization problem is the major motivation of the present thesis research.

In most of the planning models, the optimal distribution network is determined based on a deterministic load demand which is usually obtained from a load forecast. The optimal DG power generation of a distribution network is determined based on the DG generation (i.e., electric utilities and customers) and weather forecast in the form of wind or solar power generation. However, such a forecast is always subject to some error. Since the operating conditions (e.g. node voltage, branch current, illumination of sun, wind speed, etc.) of any distribution network depend on the load, a network operating with loads that differ from the nominal ones may be subject to violations of the acceptable operating conditions. Also the placement of the DG units is affected by several factors such as environmental factors, geographical topography, etc.

DG allocation is formulated mathematically as a complex combinatorial optimization issue which requires concurrent optimization of objective. The optimization is carried out under the constraints of DG size, thermal limit of network branches and voltage limit of the nodes. There are numerous optimization techniques used in the literature.

Power loss in distribution networks have become the most concerned issue in power losses analysis in any power networks. In the effort of reducing power losses within distribution networks, reactive power compensation has become increasingly important as it affects the operational, economical and quality of service for electric power networks[1]. The sequential quadratic programming has been applied to determine the suitable size and location of DG-unit treating the cost of DG units as the main objective. Further, the voltage stability based method has been reported to identify the DG location[2]. A sensitivity analysis relating the power loss with respect to DG-unit current injection has been used to identify the DG-unit size and its operation point[3].

The well known meta-heuristic algorithms such as genetic algorithm and evolutionary programming have been used as optimization tools to address DG application problems[4,5]. An analytical method utilizing exact transmission loss formula is reported for selecting DG location[6]. The artificial bee colony (ABC) algorithm has been applied to determine the size, power factor and location of DG units in order to reduce network loss[7].

The analytical methods can provide the feasible solution but their application is limited only for small size systems. The computational burden is increases while including the nonlinear operational constraints and if the system size increases. The soft computing are good in handling the non linear constraints and their search mechanism can work even for the large scale systems but it requires proper selection of parameters in the algorithm domain. The improper selection of these parameters may trap the solution to local optima. The improvements in the solution procedure are still an interesting research task. Inspiring the teaching learning process in the class room, a modern meta-heuristic algorithm known as Teaching Learning Based Optimization (TLBO) is developed[8]. This algorithm does not require tuning of algorithmic parameters and it performs well for various optimization problems[8,9]. This motivates the authors to choose as the main optimization tool for the DG application problem.

The remainder of the article is arranged as follows: the mathematical formulation of DG application problem is detailed in Section 2. The implementation of TLBO for solving the chosen problem is detailed in Section 3. The simulation results and discussion are presented in Section 4. The concluding remarks of the article are presented in Section 5.

II. Problem Formulation

Selecting the feasible location of DG in electric power distribution system is formulated to reduce the network loss. This process is formulated mathematically as an optimization problem which is a complex, non-linear and mixed integer in nature. The formulation of the sizing and location of DG in radial distribution system to minimize the real power loss is detailed below.

Objective Function: The total real power loss can be written as

$$F = \min \sum_{i=0}^{n} \left(\frac{P_i^2 + Q_i^2}{V_i^2} \right) \times r_{i+1} \quad (1)$$

System and Operational Constraints: Real and reactive power balance

The following non-linear recursive power flow equations are treated as equality constraints.

$$P_i - \frac{r_{i+1}(P_i^2 + Q_i^2)}{V_i^2} - P_{L_{i+1}} + \mu_P AP_{i+1} - P_{i+1} = 0 \quad (2)$$

$$Q_i - \frac{x_{i+1}(P_i^2 + Q_i^2)}{V_i^2} - Q_{L_{i+1}} + \mu_Q RP_{i+1} - Q_{i+1} = 0 \quad (3)$$

$$V_{i+1}^2 = V_i^2 - 2(r_{i+1}P_i + x_{i+1}Q_i) + \left(\frac{(r_{i+1}^2 + x_{i+1}^2)(P_i^2 + Q_i^2)}{V_i^2} \right) \quad (4)$$

Bus voltage limits: The bus voltage must be maintained within the prescribed limits. voltage limits and is usually±5% of the nominal voltage.

$$\left|V_{min}^{spec}\right| \le \left|V_i^{sys}\right| \le \left|V_{max}^{spec}\right| \quad (5)$$

Complex power transfer limits: The thermal capacity of feeder lines should be within their transfer limits.

$$S_{i,i+1}^{sys} \le S_{i,i+1}^{rated} \ge S_{i+1,i}^{sys} \quad (6)$$

Size and power factor of DG

$$S_{max}^{DG} \ge S_i^{DG} \ge S_{min}^{DG} \quad (7)$$

$p.f._{max}^{DG} \geq p.f._{i}^{DG} \geq p.f._{min}^{DG}$ (8)

Practical concerns in terms of DG-unit sizes and power factors are considered in the proposed method. Since the rounded-off issues of the DG-unit's sizes or power factors are treated initially in the proposed method, the accuracy of the results is guaranteed. The preselected (discretized) DG-unit sizes are from 10% – 80% of the total system demands (i.e., (|∑SL,i+1|)), approximated to integer values with a 100-step interval between sizes.

The DG-unit's power factor is set to operate at practical values, that is, unity, 0.95, 0.90, and 0.85 leading towards the optimal result. Moreover, the operating DG-unit's power factor (i.e., lagging or leading) must be dissimilar to the bus's load power factor at which the DG-unit is placed. Consequently, the net total of both active and reactive powers of that bus (where the DG-unit is placed) will decrease

III. TLBO for DG Sizing and Placement

Teaching Learning Based Optimization: By inspiring a teaching-learning process, Rao et al. proposed relatively a new population based meta-heuristic optimization algorithm called, Teaching Learning Based Optimization (TLBO). It works on the effect of influence of a teacher on the output of learners in a class. The key advantage of this algorithm is that it has no user-defined parameter which makes it better than other optimization algorithms. The TLBO method works on the philosophy of teaching and learning. Teacher and learners are the two vital components of the algorithm. The working of TLBO is divided into two parts, "teacher phase" and "learner phase". In this algorithm, a group of learners is considered as population and design variables are considered as different subjects offered to the learners and the learner's result is analogous to the "fitness" value of the optimization problem. In the entire population, the best solution is considered as the teacher. The implementation steps of TLBO for DG Location and Placement are shown below.

Step 1: Read the system data including number of buses, voltage limits, etc.,

Step 2: Initialize population size (Ps), number of design variables (Nd), limits of design variables and stopping criteria (maximum number of iterations).

Step 3: Generate the initial population within the limits of decision variables according to Ps.

Step 4: Compute the objective function detailed in (1) and evaluate the fitness of the candidate subject to constraints detailed in (2) – (8).

Step 5: Teacher phase:

i. The candidate having the minimum fitness function is mimicked as teacher ($x_{teacher}$).
ii. Compute the mean of the learners (Mi) in the class column-wise and identify the best solution.
iii. Shift Mi towards xteacher which acts as the new mean (M_{new}).
iv. Calculate the difference mean and evaluate xnew.
v. Compare fitness values and keep the best.

Step 6: Learner phase:

i. Obtain the xnew.
ii. Compute and compare the fitness function values.
iii. Retain the candidate having the minimum fitness value.

Step 7: Termination criteria: Repeat the procedure from Step 5 till the maximum number of iterations is reached

IV. Simulation Results and Discussions

The TLBO is chosen as the main optimization tool to address the DG placement application problem in electric power distribution system. The optimization procedure is coded in Matlab 7 and is executed in the personal computer with the hardware configuration of Intel Core i3 2.4 GHz processor and 4 GB RAM. The algorithm is implemented on the standard 69 node radial distribution system. The following cases have been performed to validate the potential of the method.

Test Case 1: Single DG unit application

Test Case 2: Multiple DG unit application and

Test Case 3: Single DG unit and a capacitor application

Furthermore, two load scenarios, scenario I and scenario II are considered. For the first scenario, the total demands are 3802.19kW and 2694.60kVar. Scenario II, on the other hand, represents the situation where the loads of the feeder system increased by 50%. The single-line diagram of the 69-bus feeder system is shown in Figure 1. The base case study is conducted and the attained results are presented in Table 1. The source or substation voltage is assumed to be 1.0 pu and lagging power factor is considered for bus loads at both scenarios.

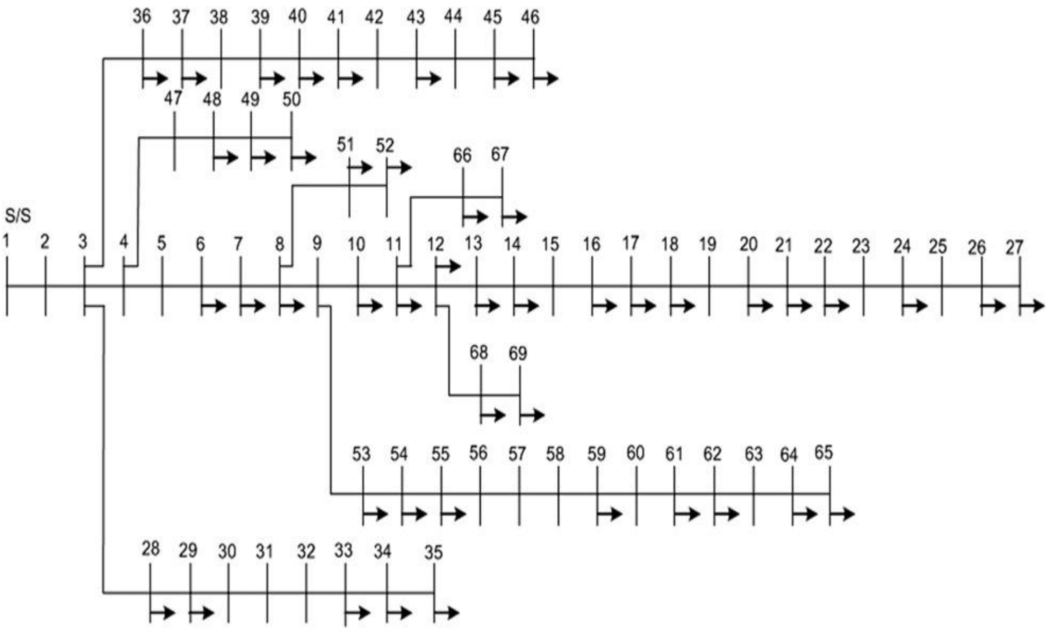

Fig 1: Single-line diagram of the 69-bus feeder system

Table 1: Optimal result of base case

Load Scenario	I	II
kW loss	224.8	560.34
kVar loss	102.157	252.98
|Vmin|, p.u	0.90919	0.85603
Ploss (KW)	1.0000	1.0000

Initially, parameter sensitivity analysis is performed and the optimal algorithmic parameters are identified. As the TLBO is randomised procedure, in order to prove its consistency in getting the optimal solutions, 30 independent runs have been conducted. The obtained numerical results are compared against earlier reports in terms of solution quality.

Table 2: Optimal result of test case I

Load Scenario	I Base Load		II 50% increased load	
	TLBO	ABC[7]	TLBO	ABC[7]
Power Factor	0.85 lead	0.85 lead	0.85 lead	0.85 lead
DG-unit (KVA)	2000	2200	2000	3400
DG Location	Node 65	Node 61	Node 65	Node 61
Real Power Loss (KW)	19.8267	23.92	48.354	54.73
Voltage Profile improvement %or P.U	1.623	-	1.578	-

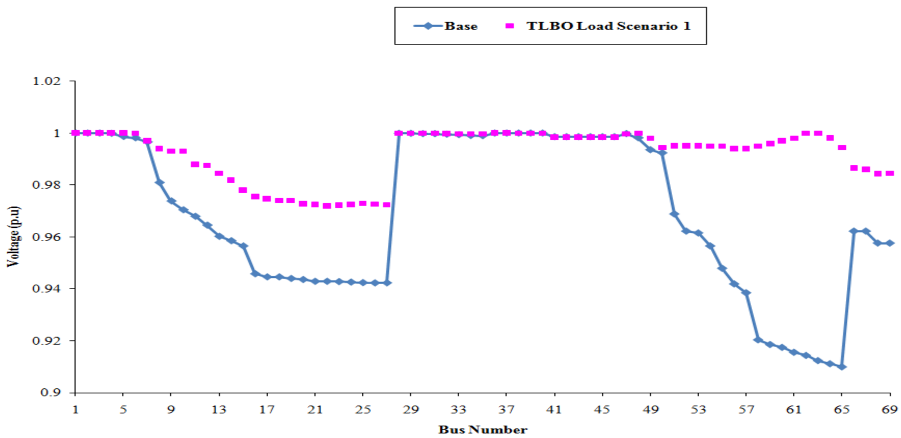

Fig 2(a): Voltage profile of test case I at load scenario 1

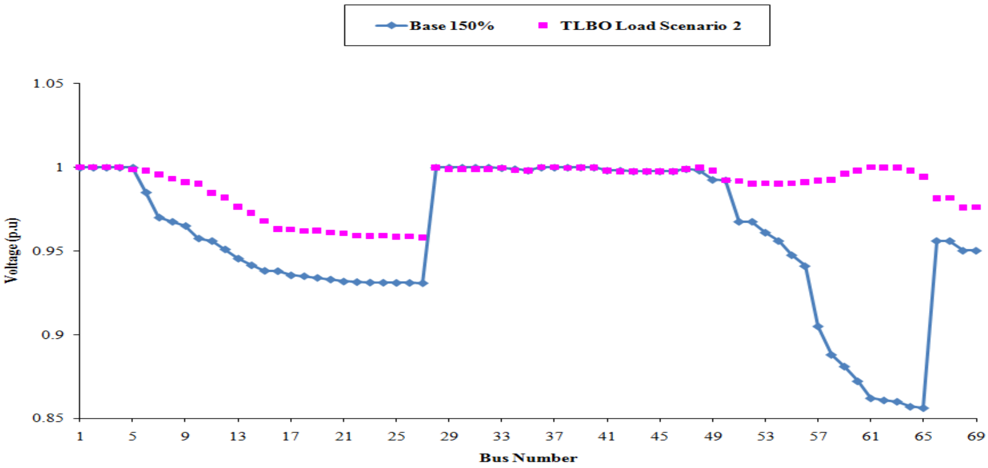

Fig 2(b): Voltage profile of test case I at load scenario 2

Test Case I - Single DG unit: The TLBO algorithm is applied to identify the best feasible location in the chosen 69 node radial distribution system to reduce the network loss. The attained numerical results for both scenarios are presented in Table 2. The best feasible location to place DG unit is identified as node 65 for both scenarios. The DG unit with a capacity of 2000 kVA with 0.85 leading power factor is placed on the node 65. Due to presence of DG unit, the real power loss of the network is reduced to 19.8267 kW and 48.354 kW for scenarios 1 and 2 respectively. Moreover, Table 2 details the improvement of the voltage profile. The enhancement results in terms of voltage profiles are also illustrated in Figure 2 (a) and 2(b) for scenarios 1 and 2 respectively.

Test Case II – Multiple DG unit: Further, the TLBO is applied for solving the multiple DG unit application problem. The algorithm is implemented on the 69 node radial distribution system and the attained results are presented in Table 3. The nodes 64 and 65 are the best feasible locations to reduce the network loss. The DG units with the ratings of 1400 kVA and 1500 kVA injecting 0.85 leading power factor at nodes 65 and 64 respectively for scenario 1. Further, the DGs with the capacity of 1500 kVA and 2000 kVA with 0.85 leading power factor is placed at nodes 65 and 64 respectively. Due the presence of multiple DG units in the network, the transmission loss is reduced to 7.7372 kW and 11.5611 kW for scenarios 1 and 2 respectively. Further, the improvements in the voltage profile are illustrated in Figure 3(a) and 3(b) for scenarios 1 and 2 respectively.

Table 3: Optimal result of test case II

Load Scenario	I Base load	II 50% increased load
	TLBO	TLBO
Power Factor	0.85 lead	0.85 lead
DG-unit 1 (KVA)	1400	1500
DG-unit 2 (KVA)	1500	2000
DG Location 1	Bus 65	Bus 65
DG Location 2	Bus 64	Bus 64
Real Power Loss (Kw)	7.7372	11.5611
Voltage profile improvement %or P.U	1.697	1.712

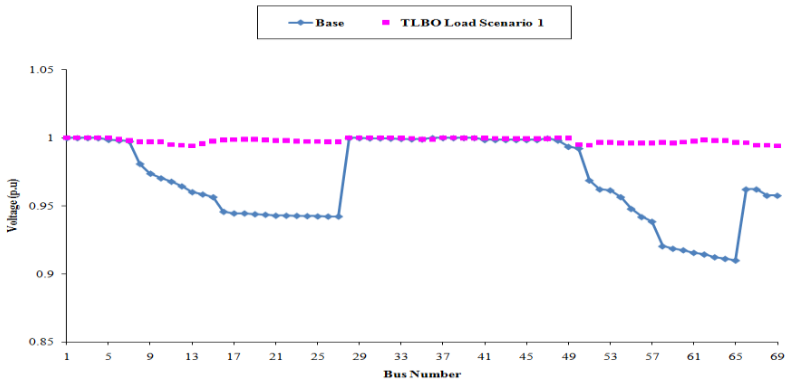

Fig 3(a): Voltage profile of test case II at load scenario 1

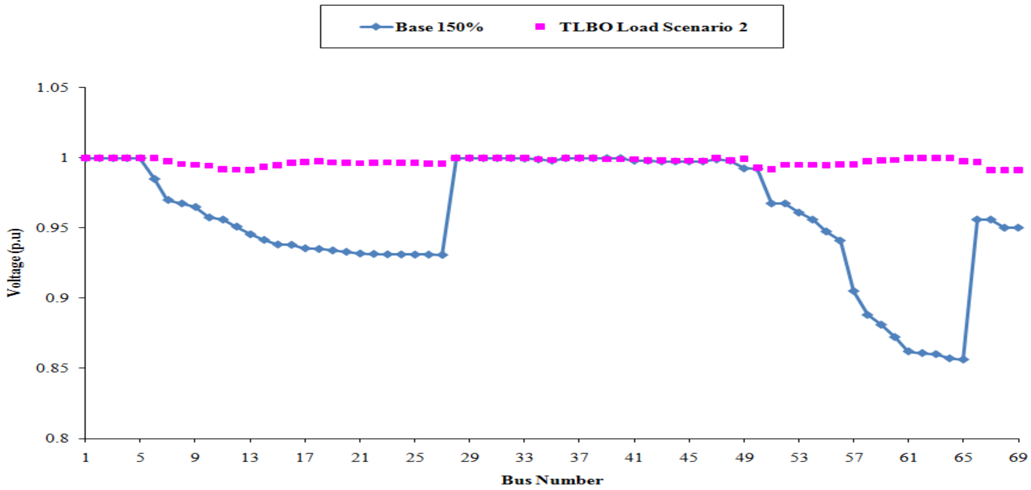

Fig 3(b): Voltage profile of test case II at load scenario 1

In this test case, the capacitor placement problem is combined with DG application problem. This case study also details the effect of installing an optimal reactive power source as well as a DG unit simultaneously in order to minimize the network loss subject to variety of equality and inequality constraints. Thus, inclusion of capacitor placement problem increases further complexity in the DG application. The TLBO algorithm is applied to determine the feasible location for capacitor and DG unit.

Test Case III – Single DG unit and a Capacitor: The attained numerical results for both scenarios are presented in Table 4. The feasible locations of capacitor and DG unit are nodes 61 and 65 respectively. For scenario 1, the presence of 1500 kvAr capacitor and the DG unit having the rating of 1000 kVA with 0.85 power factor lead provides the network loss of 16.253 kW. Further, the reactive power source 1500 kVar and DG unit with the rating of 200 kVA are placed in the network that reduces the real power loss of the network to 38.9214kW. The improvements in the voltage profiles are detailed in Table 4 and are also depicted in Figures 4 (a) and 4(b) respectively.

Table 4: Optimal result of test case III

Load Scenario	I Base load	II 50% increased load
	TLBO	TLBO
Power Factor	0.85 lead	0.85 lead
DG-unit (KVA)	1000	2000
Capacitor (kVar)	1500	1500
DG Location	Bus 65	Bus 65
Capacitor Location	Bus 61	Bus 61
Real Power Loss (Kw)	16.253	38.9214
Voltage profile improvement %or P.U	1.624	1.688

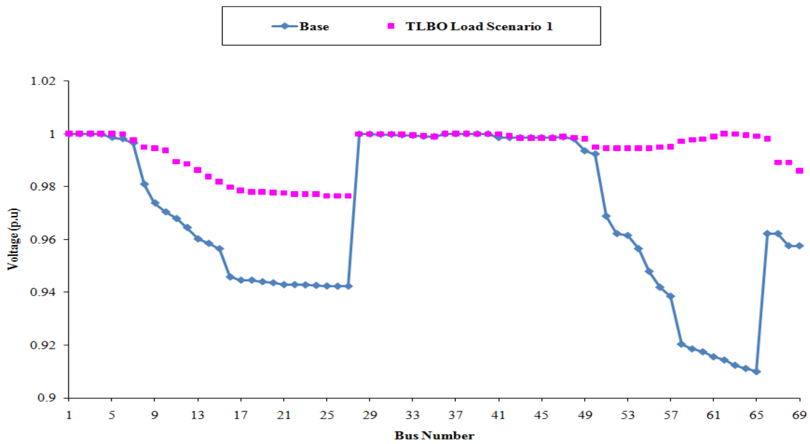

Fig 4(a): Voltage profile of test case III at load scenario 1

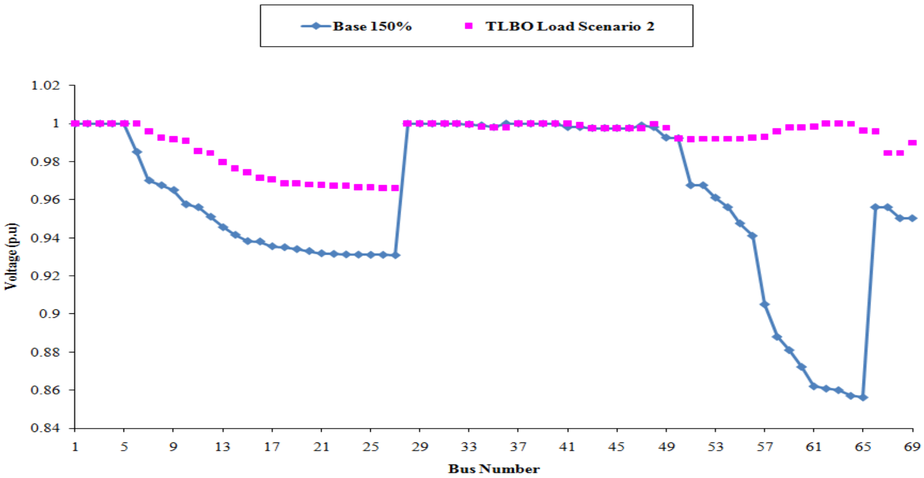

Fig 4(b): Voltage profile of test case III at load scenario 2

Comparison of all the Test Cases: Table 5 presents the Summarized Optimal result of all the test cases at load scenario I and II respectively. Different cases were tested for the single DG, multiple DG and single DG with a capacitor and the results of these analyses are compared in the same Table 5. The first column indicates the load scenario, the second column furnishes the base load and third column displays the 50% increased base load. It is observed that real power loss is reduced which obtained using the proposed TLBO and presents good accuracy is compared to the ABC with less computation time.

Table 5: Summarized Optimal result of test case at load scenario I and II

Load Scenario	I Baae load			II 50% increased load		
Test cases	Single DG unit	Multiple DG unit	Single DG unit &Capacitor	Single DG unit	Multiple DG unit	Single DG unit &Capacitor
Power Factor	0.85 lead	0.85 lead	0.85 lead	0.85 lead	0.85 lead	0.85 lead
DG-unit 1 (KVA)	2000	1400	1000	2000	1500	2000
DG-unit 2 (KVA)	-	1500	-	-	2000	-
Capacitor (kVar)	-	-	1500	-	-	1500
DG Location 1	Bus 65	Bus 65	Bus 65	Bus 65	Bus 65	Bus 65
DG Location 2	-	Bus 64	-	-	-	Bus 61
Real Power Loss (Kw)	19.8267	7.7372	16.253	48.354	11.5611	38.9214
Voltage profile improvement %or P.U	1.623	1.697	1.624	1.578	1.712	1.688

V. Conclusion

In this work, the modern soft computing technique known as TLBO based DG unit application is proposed. This work deals with the optimal selection of nodes for the placement and size of the DG and capacitor. The effectiveness of the approach is demonstrated on the standard 69-node radial distribution system. Three different test cases are conducted in order to verify the applicability of the intended algorithm. The attained numerical results are compared with base studies that clearly indicate the reduction in network loss and improvement in the voltage profile. The intended algorithm is parameter free, easy to implement and capable to determine the best feasible solution for highly constrained non-linear optimization problems. The performance of the TLBO shows it is a promising alternative for solving DG unit application problem.

Nomenclature

n Number of buses.
P_i Real power flows frombus i to bus $i+1$
Q_i Reactive power flows from bus i to bus $i+1$
$P_{L_{i+1}}$ Real power load at bus $i+1$.
$Q_{L_{i+1}}$ Reactive power load at bus $i+1$.
V_i Bus voltage at bus i .

r_{i+1} Resistance of line connecting buses i and $i+1$
x_{i+1} Reactance of line connecting buses i and $i+1$
$P_{Lossi+1}$ Real power loss between buses i and $i+1$
AP_{i+1} Active power magnitude injected a bus $i+1$
RP_{i+1} Reactive power magnitude injected at bus $i+1$.
μ_P Real power multiplier set to zero when there is no active power source or set to 1 when there is an active power source.
μ_Q Reactive power multiplier set to zero when there is no reactive power source or set to when there is a reactive power source.
V_i^{sys} System voltage at bus i.
V^{spec} Specified allowable voltage value.
$S_{i,i+1}^{sys}$ System apparent power flows from bus i to bus $i+1$
$S_{i+1,i}^{sys}$ System apparent power flows from bus $i+1$. to busi.
$S_{i,i+1}^{rated}$ System rated apparent power flows from bus to i bus $i+1$or vice versa.
S_{min}^{DG} Minimum distributed generation (DG)-unit size in kilovolt amperes.
S_{max}^{DG} Maximum DG-unit size in kilovolt amperes.
$p.f._{min}^{DG}$ Minimum DG-unit's operating power factor
$p.f._{max}^{DG}$ Maximum DG-unit's operating power factor
$S_{L,i+1}$ Apparent power load at bus $i+1$.

References

[1]. Wanik MZ, Erlich I, Mohamed A. Intelligent management of distributed generators reactive power for loss minimization and voltage control. InMELECON 2010-2010 15th IEEE Mediterranean Electrotechnical Conference 2010 Apr 26 (pp. 685-690). IEEE.

[2]. Le AD, Kashem MA, Negnevitsky M, Ledwich G. Maximising voltage support in distribution systems by distributed generation. InTENCON 2005 2005 IEEE Region 10 2005 Nov 21 (pp. 1-6). IEEE.

[3]. Kashem MA, Le AD, Negnevitsky M, Ledwich G. Distributed generation for minimization of power losses in distribution systems. InPower Engineering Society General Meeting, 2006. IEEE 2006 Jun (pp. 8-pp). IEEE.

[4]. Mardaneh M, Gharehpetian GB. Siting and sizing of DG units using GA and OPF based technique. InTENCON 2004. 2004 IEEE Region 10 Conference 2004 Nov 21 (Vol. 100, pp. 331-334). IEEE.

[5]. De Souza BA, De Albuquerque JM. Optimal placement of distributed generators networks using evolutionary programming. InTransmission & Distribution Conference and Exposition: Latin America, 2006. TDC'06. IEEE/PES 2006 Aug 15 (pp. 1-6). IEEE.

[6]. Acharya N, Mahat P, Mithulananthan N. An analytical approach for DG allocation in primary distribution network. International Journal of Electrical Power & Energy Systems. 2006 Dec 1;28(10):669-78.

[7]. Abu-Mouti FS, El-Hawary ME. Optimal distributed generation allocation and sizing in distribution systems via artificial bee colony algorithm. IEEE transactions on power delivery. 2011 Oct;26(4):2090-101.

[8]. Rao RV, Savsani VJ, Vakharia DP. Teaching–learning-based optimization: a novel method for constrained mechanical design optimization problems. Computer-Aided Design. 2011 Mar 1;43(3):303-15.

[9]. Rao RV, Savsani VJ, Vakharia DP. Teaching–learning-based optimization: an optimization method for continuous non-linear large scale problems. Information sciences. 2012 Jan 15;183(1):1-5.

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