An Efficient and reliable method for optimal allocating of the distributed generation based on optimal teaching learning algorithm

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Abstract: - This paper presents an improved methodology based on Teaching Learning Based Optimization (TLBO) algorithm which applied for determining the optimal number, allocation and size of distributed generation (DG) to reduce the active power loss and improve the voltage profile of the network. The improved TLBO algorithm is based on the updating process in the learner phase based on the interaction between the learners and the teacher by adding a weighting factor represents the importance of the obtained solution. A constrained objective function presents the system power loss and voltage profile of the network has been suggested. The results obtained from TLBO algorithm is compared to three different intelligent optimization algorithms, genetic algorithm (GA), particle swarm optimization (PSO) and cuckoo search (CS). The analysis has been applied on two different systems, 9-bus system and IEEE 57-bus system. The results showed that the proposed TLBO algorithm is efficient and reliable method in solving the problem compared to other algorithms.

Keywords: - Distributed Generation, TLBO algorithm, Objective function.

1. Introduction

The demand of power is mounting, raising a need of more power generation, and so the need of distributed generation (DG) which can be located close to load centers to help meet the demand of electric power [1]. In the last decade, the penetration of DG is increasing in order to reduce the greenhouse gas emission and global warming. The DG penetration in the grid poses new challenges and problems to the network operators as theses can have a significant impact on the system and equipment in terms of steady-state operation, dynamic operation, reliability, power quality, stability and safety of both customers and electricity suppliers. DG poses less harm to environment as it reduces green-house gas emissions, reduces the line losses, improve the voltage profile and improve reliability and security of distribution network [2]. The optimal location and sizing of the DG in the distribution network play a pivotal role in the distribution network operation as the well DG sitting and sizing improve the performance of the network. In the last years, several works have been presented in determining the optimal allocation and sizing of DG. In [3, 4] an analytical method is used to minimize the power loss of the system by allocating the DG. In [5] the equivalent load centroid and a performance index combine the real power loss and average node voltage are presented to determine the size and location of the DG in the distribution system. In [6] a cuckoo search is harnessed to determine the optimal allocation of DG to improve the voltage profile and reduce the power loss of distribution network. In [7] a combined loss sensitivity index vector and voltage sensitivity index methods are presented to obtain the optimal location and size of DG; additionally the cost of losses and the cost of power obtained from DG are presented. A comprehensive multi-objective optimization approach to localize the DG optimally in a distribution system has been introduced in [8, 9]. In [8] the main objectives are total imposed cost, total network loss and the customer outage costs while in [9] the main objectives are the cost of active and reactive losses, voltage profile and distribution system reliability with variable load models. In [10] a method determines the DG allocation associated with the optimal reconfiguration of distribution network to minimize the energy loss based on sensitivity indices is presented. A Fuzzy logic to determine the optimal DG allocation to improve voltage profile and reduce the network losses has been presented in [11-13]. The voltage sensitiveness of the loads has been given in [14]. A Fuzzy interactive method based on hybrid modified shuffled frog leaping algorithm to solve the problem of multi-objective optimal placement and sizing of DG has been presented in [15]. A dynamic programming to solve a multi-objective function to determine the optimal location of the DG to minimize the power loss, enhance the reliability and improve the voltage profile with time varying load has been presented in [16].

The energy storage system has been optimally allocated in the distribution network with high penetration of wind energy to minimize the annual electricity cost [17]. An overview of the state of the art models and methods applied to the optimal DG placement has been presented in [18]. The general limitations of the previous works are, in general, 1- limited number of DGs are used that provide a sub-optimal solution because of limited input data, 2- the transmission lines capacities were not taken in consideration and 3- the used meta-heuristic technique in some previous work failed in providing an optimal solution due to the controlling parameter of the algorithm. Since the optimal DG number, allocation and sizing problem is complicated optimization process, the application of heuristic algorithms and Artificial Intelligence in solving it is necessary, so in this paper a proposed efficient, reliable optimization algorithm has been proposed which is Teaching Learning Based Optimization (TLBO) algorithm as its less controlling parameter compared to other algorithms. The proposed improvement action in TLBO is based on weighting inertia updating in the learner phase based on the interaction between the teacher and learners. A constrained objective function presents the system power loss and voltage profile of the network has been suggested. The results obtained from TLBO algorithm are compared with the results of three different intelligent optimization algorithms, genetic algorithm (GA), particle swarm optimization (PSO) and cuckoo search (CS). The analysis has been applied on two different systems, 9-bus system and IEEE 57-bus system. The results show that the proposed TLBO algorithm is the best one to solve the optimization problem (minimize the system losses and improve the system voltage profile).

2. Mathematical Model Formulation

In this section a mathematical model of the proposed objective function and constraints is described.

2.1 The proposed Objective Function

When DG is imposed in the distribution network, the voltage profile is improved while the system power losses are increased [6]. For any secured system it is required to minimize the losses so the paper aims to evaluate a certain objective function that improves the voltage profile and in the same time minimizes the total losses in the system. The decision variables which are required to be obtained from optimization problem are the size and location of DG inserted, $x= [P_{DG}, N_{DG}]$ where P_{DG} is the DG generated active power and N_{DG} is the DG location. The active power losses, P_L, in any system are equal to the total load power subtracted from the total generated power and can be expressed by eqn. 1, as

$$P_L = \left(\sum_{i=1}^{N_G} P_{Gi} + \sum_{j=1}^{N_{DG}} P_{DGj} - \sum_{l=1}^{N_L} P_{Dl}\right) \quad (1)$$

Where P_{Gi} is the generated active power from i^{th} generator, P_{DGj} is the generated active power from j^{th} DG and P_{Dl} is the load active power at bus l. N_G, N_{DG} and N_L are the no. of generators, DG and load buses respectively. The bus voltage profile plays an important role in the selection of the maximum allowable capacity of the DG along the distribution feeder and the optimal location of DG unit. The bus voltage deviation is the summing of the difference between nominal voltage and the calculated voltage at all buses and given as follows:

$$VD = \sum_{i=1}^{N_{bus}} \left|\frac{V_{ni} - V_i}{V_{ni}}\right| \quad (2)$$

Where, V_{ni} and V_i are the nominal and the real value of the bus voltages and N_{bus} is the number of network buses. The proposed combined objective function containing the network active loss and the bus voltage profile can be written as follows:

$$Minimize\ f(N_{DG}, P_{DGj}, V_i) = \left(\frac{1}{W_L} * \left(\sum_{i=1}^{N_G} P_{Gi} + \sum_{j=1}^{N_{DG}} P_{DGj} - \sum_{l=1}^{N_L} P_{Dl}\right) + * \sum_{i=1}^{N_{bus}} W_{Vi} * \left|\frac{V_{ni} - V_i}{V_{ni}}\right| \right) \quad (3)$$

Where W_L is the summing of all generation power (from the system generator and from DG) and W_{Vi} is the weighting factor of the voltage of bus number i.

2.2 The system Constraints

Generally constraints can be classified into equality and inequality parametric or functional constraints.

- Bus voltage limits (parametric inequality)

$$V_i^{min} \le V_i \le V_i^{max} \qquad \forall_i \in N_{Bus} \quad (4.a)$$

Where V_i^{min} and V_i^{max} are the minimum and maximum voltage and V_i is the real voltage at bus i.

- Line flow security constraints(parametric inequality)

$$S_{li} \le S_{li}^{max} \quad (4.b)$$

- Power balance constraints (equality)

$$\sum_{i=1}^{N_G} P_{Gi} + \sum_{j=1}^{N_{DG}} P_{DGj} = P_{DT} + P_L \quad (4.c)$$

$$\sum_{i=1}^{N_G} Q_{Gi} + \sum_{j=1}^{N_{DG}} Q_{DGj} = Q_{DT} + Q_L \quad (4.d)$$

Where P_L and Q_L are the system active and reactive power losses

3. 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 in [19]. 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 [20]. 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.

3.1 Teacher Phase

The teaching phase represents the process of student learning through the teacher. The teacher is the most experienced and knowledge person in a subject, so the best learner in the population, including learners and teacher, is the teacher. The difference between the result of the teacher and the mean result of the learners in each subject can be calculated as follows [20]:

$$\mathrm{D}_{\mathrm{mean\ j,i}} = \mathrm{rand} * \left(x_{(teach)}{}^{g} - \mathrm{T_F M_{j,i}}\right) \qquad (5)$$

Where $x_{(teach)}{}^{g}$ is the result of the teacher in subject at iteration g, T_F is the teaching factor, *rand* is the random value in the range [0, 1] and $M_{j,i}$ is the mean results of the learners i in subject j. The value of TF is calculated randomly as follows [21]:

$$\mathrm{T_F} = 0.5 * \left[1 + \mathrm{rand}(0,1)\right] \qquad (6)$$

The obtained solution is updated in the teacher phase based on the value of $D_{mean\,j,k,i}$ as follows:

$$x^{new}{}_{(teach)}{}^{g} = x_{(teach)}{}^{g} + \mathrm{D}_{\mathrm{mean\ j,i}} \qquad (7)$$

Where $x^{new}{}_{(teach)}{}^{g}$ is the updated value of $x_{(teach)}{}^{g}$. The updated solution is accepted if it gives better function value. The accepted function values are the input to the learner phase.

3.2 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. Two learners *i*, *r* is selected randomly such that $x_{(i)}{}^{g} \neq x_{(r)}{}^{g}$ (Where, $x_{(i)}{}^{g}$ and $x_{(i)}{}^{g}$ are the solutions at the end of teacher phase). The logic path of the learning process in TLBO algorithm is from the teacher to learners but in sometimes if the other learner has more knowledge than the teacher, he/she gained more knowledge; therefore a modified TLBO is obtained by adding extra term in learner phase to interact this action [21]. In modified TLBO the learner phase is represented as follows:

$$x_{new\,(i)}{}^{g} = \omega * x_{(i)}{}^{g} + rand * \left(x_{(i)}{}^{g} - x_{(r)}{}^{g}\right) + \mathrm{T_F} * \left(x_{(teach)}{}^{g} - x_{(i)}{}^{g}\right) \quad if \;\; f\left(x_{(i)}{}^{g}\right) < f\left(x_{(r)}{}^{g}\right) \qquad (8.a)$$

$$x_{new\,(i)}{}^{g} = \omega * x_{(i)}{}^{g} + rand * \left(x_{(r)}{}^{g} - x_{(i)}{}^{g}\right) + \mathrm{T_F} * \left(x_{(teach)}{}^{g} - x_{(i)}{}^{g}\right) \quad otherwise \qquad (8.b)$$

Where, $x_{new\,(i)}{}^{g}$ is the updated value of $x_{(i)}{}^{g}$ at iteration g, ω is the weighting factor which is assumed to be 0.4. The updated solution gives the best function value is accepted.

4. Proposed Algorithm

In order to identify the optimal allocation and size of DG to reduce the active power loss and the voltage violation, the main proposed procedures that are used are described as follows:

Step 1: Run a base case optimal power flow of the network without DG and store the obtained voltage as base case as vector V^0, set iteration count k=0.

Step 2: Calculate the value of objective function ($f^{b}(V_i^0)$) based on the base case quantities from eqn. 3 and store it.

Step 3: Identify the design variables of the optimization problem $x = \left[N_{DG1}, .., N_{DGN_{DG}}, P_{DG1}, .., P_{DGN_{DG}}, V_i\right]$.

Step 4: Run the TLBO algorithm described in Fig. 1and determine the optimal allocation and size of DG.

Step 5: Run optimal power flow in the network with DG and calculate the value of objective function $f^{k}(N_{DG}{}^{k}, P_{DGj}{}^{k}, V_i{}^{k})$ as k is the no. of iteration.

Step 6: If $f^{k}(N_{DG}{}^{k}, P_{DGj}{}^{k}, V_i{}^{k}) < f^{b}(V_i{}^{0})$ then update the value of fitness function and repeat steps (4-6)

Step 7: If $f^{k}(N_{DG}{}^{k}, P_{DGj}{}^{k}, V_i{}^{k}) > f^{b}(V_i{}^{0})$ set $k=k+1$ and repeat steps (3-6).

The proposed flow chart used in this work is shown in Fig. 1.

5. Numerical Analysis

The proposed methodology has been applied on two different test systems. The first is a simple 9-bus network while the other is IEEE 57 bus network. The configuration and data of the two systems are given in [22]. The DGs have been assumed as a constant active power which means unity power factor. It is known that all the load buses have been considered as candidate for installing DG. In this work, four different optimization methods have been investigated (GA, Cuckoo search, PSO and proposed TLBO algorithm). The results of the four methods are compared.

5.1 The analysis of 9-bus network

The configuration of 9-bus network is given in Fig. 2. In order to show the effect of installing the DG on the

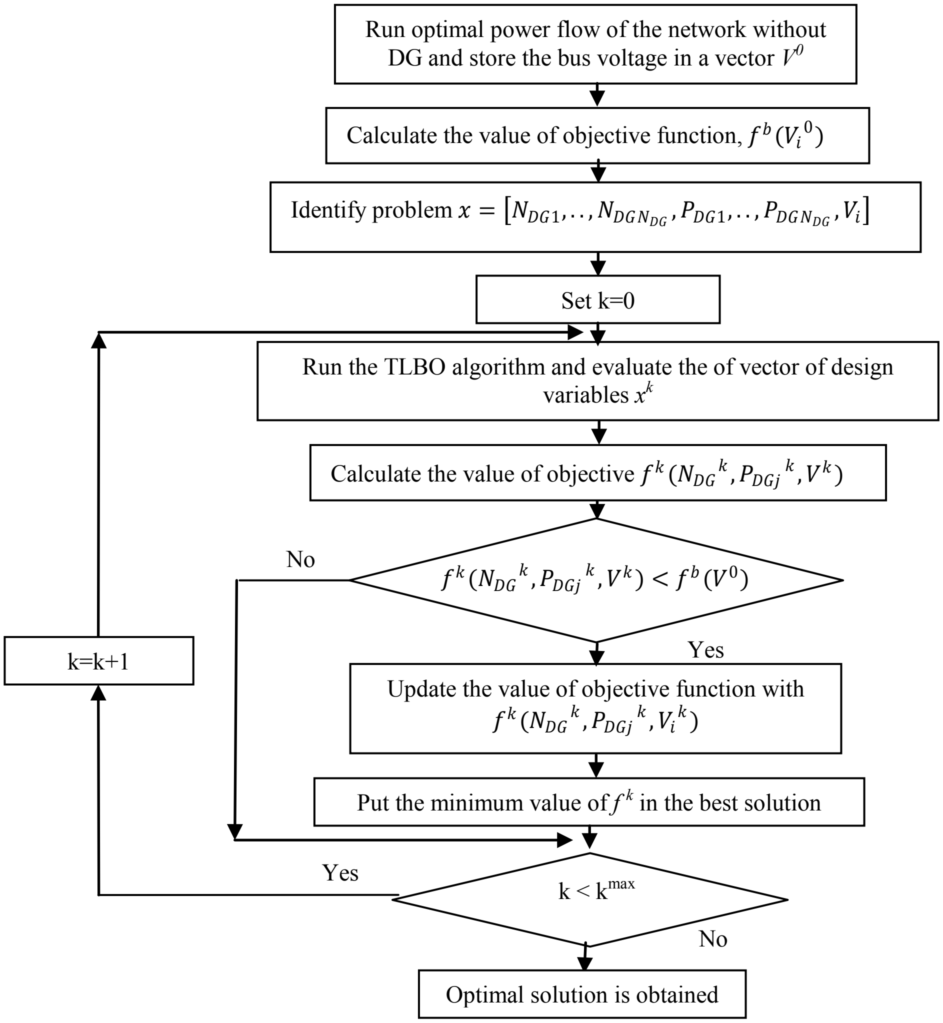

Fig. 1 The proposed algorithm of solution

network performance, the scenario of the analysis applied on 9-Bus systems is described as follows:
Assuming that the available numbers of DGs are four, each one has a generated active power $2\ MW \leq P_{DG} \leq 50\ MW$, the four DGs are installed gradually and the proposed analysis is performed for each DG installation. The voltage limits are $0.95 \leq V_i \leq 1.05$. The GA optimal solutions for four cases are given in Table 1. The total generated power required in the base case is 319.955 MW with cost 5666.144 \$/hr, the base case total active loss of the network is 4.95500000 MW. A comparison between the GA, CS, PSO and TLBO algorithms at the same DG optimal number, allocation and sizing obtained from GA algorithm is given in Table 2. It is clear that the less power loss and less total generation cost are obtained by TLBO algorithm. According to results of table 2, the optimal solution is obtained by installing 3.002387 MW at bus 6, 7.003244 MW at bus 5, 10.001671 at bus 7 and 13.00348 MW at bus 4 using four DGs. Based on TLBO results this installation reduces the total active loss by 33.8113% compared with the base case results and 23.4% compared with the results of GA and reduces the total generation cost to 3169.536 \$/hr with 5.7% compared with GA.

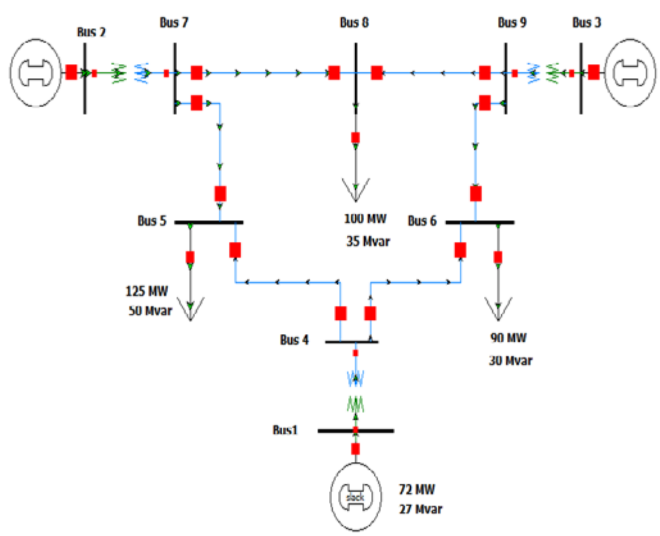

Fig. 2 Topology of 9-bus Network

The statistics of each algorithm (best minimum, best mean, and best standard deviation) for case (3) and case (4) are calculated and given in Table 3.

Table 1 The optimal solution for 9-bus network Based on GA

Case No.		P_{DG1} (MW)	P_{DG2} (MW)	P_{DG3} (MW)	P_{DG4} (MW)	N_{DG1}	N_{DG2}	N_{DG3}	N_{DG4}	Total active losses (MW)	% loss reduction
Case (0)	Base Case	Without DG								4.955000	0
Case (1)	One DG	20	--	--	--	9	--	--	--	4.796000	3.2088
Case (2)	Two DG	10	30	--	--	5	9	--	--	4.461000	9.9697
Case (3)	Three DG	4	12.018	20		4	8	5	--	4.366000	11.8869
Case (4)	Four DG	3.002387	7.003244	10.001671	13.00348	6	5	7	4	4.281654	13.5892

Table 2 Comparison between the GA, CS, PSO and TLBO solutions for 9-bus network

Algorithm	One DG		Two DG		Three DG		Four DG	
	P_{loss} (MW)	Total generation cost ($/hr)	P_{loss} (MW)	Total generation cost ($/hr)	P_{loss} (MW)	Total generation cost ($/hr)	P_{loss} (MW)	Total generation cost ($/hr)
GA	4.796000	5666.144	4.461000	4381.948	4.366000	3811.031	4.281654	3360.829
Cuckoo	4.539647	5661.299	4.339647	3221.474	4.059647	3827.478	3.979600	3381.061
PSO	4.677889	5697.946	4.483934	3283.936	4.047723	3804.161	3.895543	3359.273
TLBO	4.279647	5480.328	3.439647	3081.043	3.359647	3603.001	3.279647	3169.536

The best statistics are obtained by TLBO algorithm. A comparison between the responses of GA, CS, PSO and TLBO algorithms has been given in Fig. 3.

Table 3 Comparison between the GA, CS, PSO and TLBO statistics for 9-bus network

Case No.	Statistics parameters	GA	Cuckoo	PSO	TLBO
Case (3)	Best min.	4.366	4.0600	4.0477	3.3600
	Best mean	4.789	4.1650	4.73016145	3.4060
	Best std.	0.8247	0.4321	0.8807	0.3211
Case (4)	Best min.	4.282	3.9800	3.8955	3.2800
	Best mean	4.413	4.36100	4.194	3.3190
	Best std.	0.1583	0.9355	1.4000	0.3195

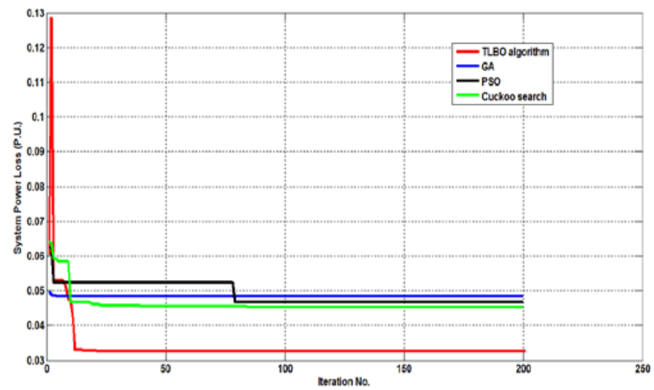

Fig. 3 A comparison between the four algorithms responses for 9-bus system

On the other hand it is important to check the effect of DG installation on the network voltage. Table 4 shows network average voltage obtained from each optimization algorithm in the four cases. It is clear that the base case average voltage of the network is 1.016122 P.U., by using TLBO algorithm this value is increased to 1.039889 P.U. due to installing four DGs. A comparison between the bus voltages obtained from the four algorithms has been given in Fig. 4. The resulting values of the bus voltage weighting values in case of GA and TLBO algorithms are given in Table 5. One can derive that the average value of the weighting factor of bus voltage produced by TLBO algorithm is greater than that obtained by GA. In order to check the reliability of the proposed algorithm in solving the proposed optimization problem; another case has been studied for 9-Bus system in which the bus voltage limits are assumed $0.98 \leq V_i \leq 1.02$. Table 6 shows the comparison between the four algorithms results for permissible bus voltage violation ±2%. The main derivation from the new case is that by reducing the bus voltage constraints the total network active loss obtained by TLBO algorithm is reduced by 2.2% compared to results of Table 2 (with voltage limits ±5%), while the total generation cost is increased by 0.82%. The average voltages of the 9-bus network obtained by four algorithms with voltage limits ±2% are given in Table 7.

5.2 The analysis of IEEE 57-bus Network

The configuration of IEEE 57-bus network is shown in Fig. 5. The scenario of the analysis used in this network is generalized, unlike the previous used in the 9-bus system, to obtain not only the optimal location and size of DG but also the optimal number of DGs. At the beginning the analysis is performed on constrained number of DG which is assumed to be 10. The optimal solution obtained from each algorithm and the statistics of each intelligent algorithm are given in Table 8. Referring to Table 8, one can get that the optimal solution is obtained by TLBO algorithm as the total active loss of the base case 27.86400 MW has been minimized to 24.20638 MW by inserting 9 DGs as it given in Table 5 with percentage reduction 13.13% the power cost generated by TLBO is decreased by 5.91% compared to GA. The power loss by TLBO is decreased by 6.5% compared to GA.

Table 4 The average voltage of the network obtained from four algorithms for 9-bus system

	Case	Average voltage of the network (P.U.)		Average voltage of the network (P.U.)
GA Solution	One DG	1.023233	PSO Solution	1.014678
	Two DG	1.024667		1.022444
	Three DG	1.030189		1.023611
	Four DG	1.030867		1.024422
Cuckoo Solution	Case	Average voltage of the network	TLBO Algorithm	Average voltage of the network
	One DG	1.023233		1.023233
	Two DG	1.028322		1.030022
	Three DG	1.029086		1.031500
	Four DG	1.029356		1.039889
Base Case	Without DG	1.016122		

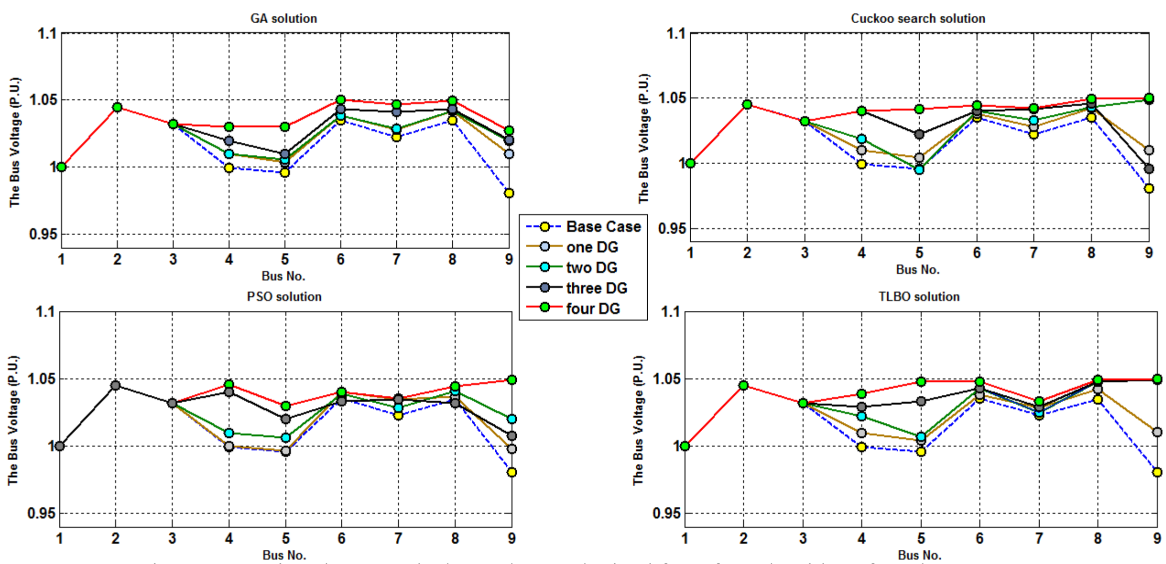

Fig. 4 Comparison between the bus voltages obtained from four algorithms for 9-bus system

Table 5 the values of the bus voltage weighting factor in case of GA and TLBO

Bus No.	1	2	3	4	5	6	7	8	9
GA solution	0.9956	0.9962	0.9953	0.9835	0.9723	1.0000	0.9819	0.9936	0.9547
TLBO solution	1.0000	0.9999	0.9904	0.9917	0.98102	0.9999	0.98818	0.9991	0.9680

Table 6 Comparison between the GA, CS, PSO and TLBO solutions for 9-bus network with voltage limits ±2%

Algorithm	One DG		Two DG		Three DG		Four DG	
	P_{loss} (MW)	Total generation cost ($/hr)	P_{loss} (MW)	Total generation cost ($/hr)	P_{loss} (MW)	Total generation cost ($/hr)	P_{loss} (MW)	Total generation cost ($/hr)
GA	4.685824	5688.037	4.35852	4397.103	4.2625218	3809.881	4.166521	3359.595
Cuckoo	4.454781	5687.652	4.25852	4332.569	3.9625214	3846.196	3.866520	3391.293
PSO	4.570463	5685.337	4.37990	4397.44	3.9538158	3805.729	3.805166	3472.753
TLBO	4.210095	5679.008	3.383719	4081.76	3.303719	3731.485	3.207719	3195.739

The proposed TLBO decreases also the cost by 5.9% compared with GA. Additionally the total generation cost obtained by TLBO is the less one compared to other algorithms. A comparison between GA, PSO, CS and TLBO response is given in Fig. 6. The average voltage of total network obtained from each algorithm is given in Table 9 which proved that the maximum average voltage is obtained from TLBO algorithm. A comparison

Table 7 The average voltage of the network obtained by four algorithms for 9-bus system with voltage limits ±2%

	Case	Average voltage of the network (P.U.)		Average voltage of the network (P.U.)
GA Solution	One DG	0.9859784	PSO Solution	0.9777373
	Two DG	0.9917738		0.9852206
	Three DG	0.9935346		0.9863451
	Four DG	0.9968859		0.9871265
Cuckoo Solution	Case	Average voltage of the network	TLBO Algorithm	Average voltage of the network
	One DG	0.98666666		0.98238917
	Two DG	0.988544033		0.98270965
	Three DG	0.99363475		0.98974322
	Four DG	1.00661606		0.98421710
Base Case	Without DG	0.989478403		

between the bus voltages obtained from four algorithms for IEEE 57-bus system is shown in Fig. 7.

Finally; the generalized optimal number, size and location of the DG installed in 57-bus IEEE system are calculated based on four algorithms and given in Table 10. The final optimal number of DGs is 20. TLBO algorithm reduces the total active loss by 34.3% compared with the base case and minimizes the total generation cost by 22.25% compared with the base case cost. On the other hand the active loss is decreased by 6.57% compared to GA using N_{DG}=20, while the cost is decreased by 0.13% compared also GA.

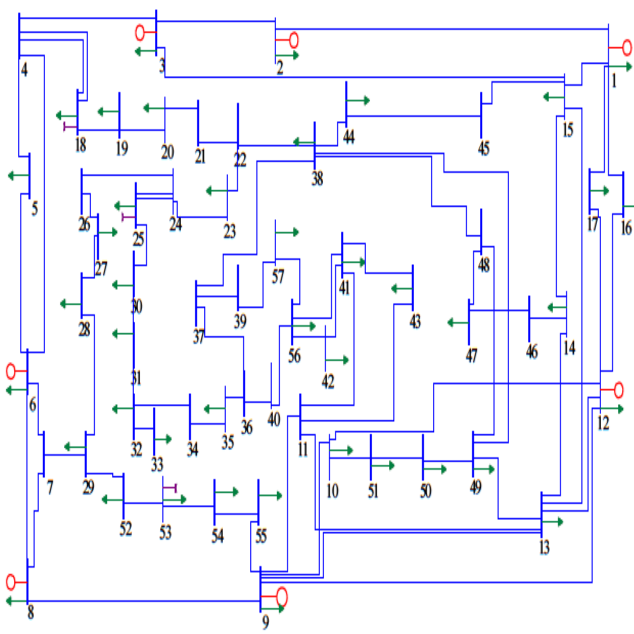

Fig. 5 Configuration of IEEE 57-bus system

5. Conclusion

The DGs are used with the power system to improve the system performance and the results were obtained by the optimal power flow. A reliable and efficient method based on optimal teaching learning algorithm (TLBO) using inertia weighting update process based on the

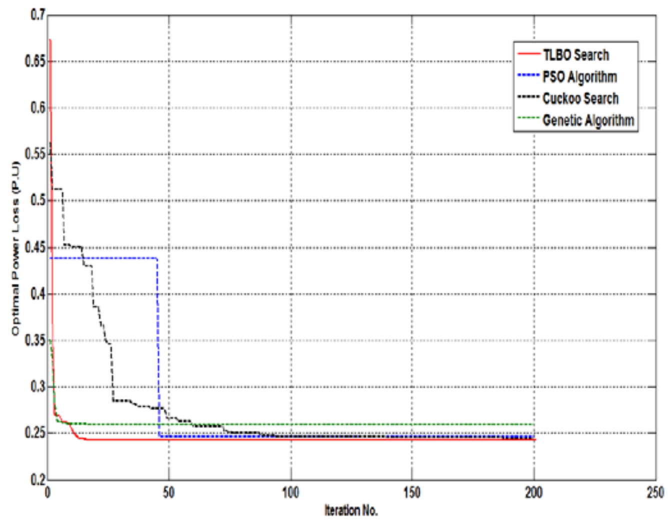

Fig. 6 Comparison between GA, PSO, Cuckoo and TLBO responses for 57-bus IEEE system

interaction between the teacher and learners is proposed in this paper. The main objective is to minimize the system loss obtained from the OPF and improve the system voltage profile. The optimal number, allocation and size of distributed generation (DG) are determined using the proposed algorithm. The results obtained from TLBO algorithm is compared with three different intelligent optimization algorithms, genetic algorithm (GA), particle swarm optimization (PSO) and cuckoo search (CS). The analysis has been applied on two different systems, 9-bus system and IEEE 57-bus system. For 9-bus system, the results showed that the proposed TLBO algorithm is the best one in solving the optimization problem as it minimizes the system power loss with 33.8113% compared with the base case results and 23.4% compared with the results of GA. Also the proposed TLBO reduce the total generation cost to 3169.536 \$/hr with 5.7% compared with GA. Additionally by reducing the bus voltage limits to ±2%, the total network active loss obtained by TLBO algorithm is reduced by 2.2% compared to the case of voltage limit ±5%.

Table 8 The optimal solution for IEEE 57-bus network based on four algorithms

Base Case	Without DG									Total active losses (MW)	Total generation cost ($/hr)
										27.86400	26709.17
GA Optimal solution											
N_{DG}	22	37	14	21	47	19	42	50	57	Total active losses (MW)	Total generation cost ($/hr)
P_{DG} (MW)	5.0000	10.0000	13.0000	15.0000	18.0000	26.0000	28.0000	30.0000	35.0000	25.907991	24736.19
GA statistics	Best min.				Best mean					Best std	
	25.91				26.33					1.448	
PSO Optimal solution											
N_{DG}	22	37	14	21	47	19	42	50	57	Total active losses (MW)	Total generation cost ($/hr)
P_{DG} (MW)	5.0000	10.0000	13.0000	15.0000	18.0000	26.0000	28.0000	30.0000	35.0000	24.6556992	23698.7
PSO statistics	Best min.				Best mean					Best std	
	24.656				28.9486					7.9866	
CS Optimal solution											
N_{DG}	22	37	14	21	47	19	42	50	57	Total active losses (MW)	Total generation cost ($/hr)
P_{DG} (MW)	5.0000	10.0000	13.0000	15.0000	18.0000	26.0000	28.0000	30.0000	35.0000	24.4552508	23537.63
Cuckoo statistics	Best min.				Best mean					Best std	
	24.4552508				27.6698					6.6809	
TLBO search Optimal solution											
N_{DG}	22	37	14	21	47	19	42	50	57	Total active losses (MW)	Total generation cost ($/hr)
P_{DG} (MW)	5.0000	10.0000	13.0000	15.0000	18.0000	26.0000	28.0000	30.0000	35.0000	24.20638	23273.33
TLBO statistics	Best min.				Best mean					Best std	
	24.21				24.65					3.422	

Table 9 The average voltage of the network obtained from four algorithms for IEEE 57-bus system

GA Solution	Average voltage of the network (P.U.)	**PSO Solution**	Average voltage of the network (P.U.)
	1.012216		1.01373
Cuckoo Solution	Average voltage of the network (P.U.)	**TLBO solution**	Average voltage of the network (P.U.)
	1.017461		1.035888
Base Case	Average voltage of the network (P.U.)		
	0.992533		

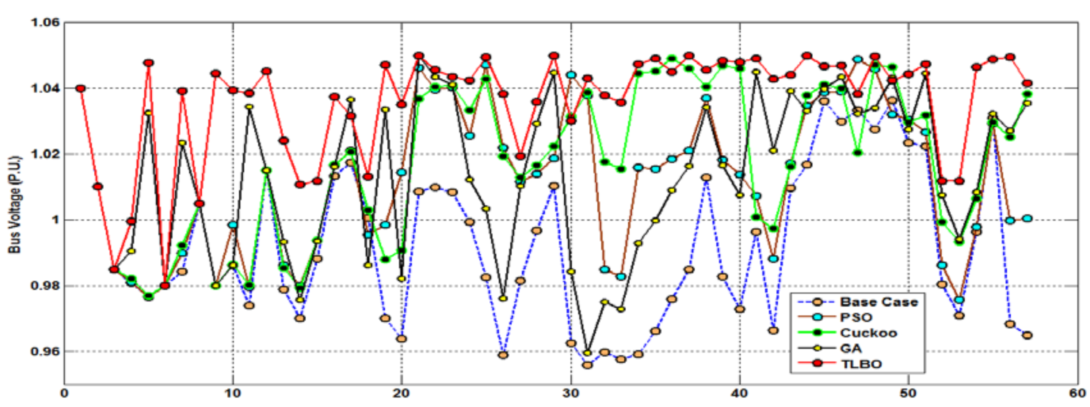

Fig. 7 Comparison between the bus voltages obtained from four algorithms for IEEE 57-bus system

Table 10 The final optimal DG size and location for IEEE 57

GA solution												
N_{DG}	26	25	37	40	41	47	51	11	44	29	Total active losses (MW)	Total generation cost ($/hr)
P_{DG} (MW)	4	8	11	15	17	25	9	24	15	21	19.5788977	20793.84
N_{DG}	52	4	13	43	38	21	28	39	54	23		
P_{DG} (MW)	30	28	23	21	10	3	13	5	2	6		
CS solution											18.4810043	20770.55
PSO solution											18.6319948	20773.75
TLBO solution											18.2929688	20766.56

In case of IEEE 57-Bus system TLBO algorithm reduced the network active loss by 34.3% compared with the base case and minimized the total generation cost by 22.25% compared with the base case cost but, the proposed TLBO is decreased the system losses by 6.5% and the generation cost by 5.91% compared to GA. Finally the proposed TLBO algorithm is simple, efficient, less controlling parameters and reliable in solving the proposed objective function and determining the optimal number, allocation and size of DGs which are used to minimize the system losses and improve the voltage profile.

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