Application of hybrid TLBO-PSO algorithm for allocation of distributed generation and STATCOM

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Article Info	ABSTRACT
	This paper proposes a hybrid teaching learning-based optimization- particle swarm optimization (TLBO-PSO) Algorithm for optimal distributed generation (DG) and STATCOM placement. A multi-objective formulation is developed that optimizes the DG and STATCOM placement in IEEE 33 and real-time 52 bus distribution system. The objective function formulated involves maximizing cost-benefit and voltage stability factors while minimizing network security index and power losses. Simulation is carried out in MATLAB/Simulink for different systems and different cases. The results for single and multiple STATCOM and DG are compared with TLBO and PSO algorithm and the results exhibit better convergence performance with the hybrid optimization algorithm.

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1. INTRODUCTION

Increased utilization of renewable energy sources (RES), including Photovoltaic and Wind turbine generators, has sparked a movement toward energy-efficient gadgets and conservation strategies to reduce energy consumption. Distribution networks suffer higher losses (about 13 percent) in the overall power system, and RES integration in distribution networks introduces voltage stability issues. Radial distribution systems (RDS) should have their voltage stability issues solved quickly to avoid the catastrophic effect. Introducing STATCOMs and distributed generations (DGs) in the system ensures voltage stability and healthy power delivery. Although power loss is compensated by integrating new DGs into the system, placement and sizing of DGs are challenging. In places where reactive power compensation is required, the installation of D-STATCOM improves the voltage profile of the buses [1]. Consumer side load variations increase the need for voltage regulation in the distribution network. Thus, the network is not a static entity [2]. Expansion of the network with the predicted load pattern may not be a balanced power system at any point [3]. Placement of DGs and sizing are relevant to research topics on the dynamics involved in the power system loads [4]. An analytical method is employed to obtain the optimal location of D-STATCOM and DGs in an RDS [5]. Load demand unpredictability is considered while sizing the D-STATCOM in RDSs [6]. Feeder reconfiguration using a Fuzzy controller and placement using an evolutionary algorithm for D-STATCOM in RDSs are developed [7], [8]. Monte Carlo simulation-based DG scaling in RDS is developed [9]. DG and STATCOM sizing methods that reduce power loss, costs, and voltage profile enhancement are discussed [10]. Evolutionary approaches are already being employed in a variety of distribution system applications (DSS). Optimal location and sizing of DSTATCOM and DG to minimize system power losses using harmony search algorithm (HAS)

[11], the Cuckoo search algorithm (CSA) [12], the invasive weed optimization technique [13], the Stud Krill herd technique [14], the backtracking search optimization (BSO) technique [15], and ant lion optimization (ALO) algorithm [16] is developed. Implemented the enhanced differential search method [17], used the whale optimization algorithm (WOA) [18], [19], and implemented the particle swarm optimization (PSO) [20]. TLBO optimization algorithm [21], genetic algorithm (GA) [22], Cuckoo search algorithm [23], fuzzy lighting search algorithm [24], and artificial fish swarm optimization algorithm [25] are used to solve optimal placement problems. The evolutionary-based Bat algorithm is incorporated to place DG and STATCOM in the distributed system [26]. Placement of distributed STATCOM (D-STATCOM) is developed as a solution to the multi-objective problem. The TLBO method is a new efficient optimization technique that was inspired by a student learning process [27], [28].

This paper uses the superior qualities of TLBO and PSO, presenting a novel algorithm that incorporates the evolutionary natures of both algorithms (denoted as TLBO-PSO). Placement of DGs and STATCOM in an RDS is implemented using the hybrid algorithm proposed. Section 2 defines the problem formulation of the multi-objective implementation. Section 3 details the hybrid PSO-TLBO algorithm implemented on the multi-objective problem defined in section 2. Results and discussion are detailed in section 4, followed by conclusion and references.

2. MULTI-OBJECTIVE PROBLEM FORMULATION FOR DG/STATCOM PLACEMENT

The cost function generated for optimizing the placement involves voltage stability factor (VSF) and network security index, investment cost (IC), operation and maintenance cost (OMC) of DG, and benefit to cost ratio (BCR). A similar formulation is defined by the author in [21], which is explained in detail in [10]. Formulation starts with the total cost of renewable energy DG installation operation and maintenance as given in (1).

$$Cost_{DG\ renw} = \sum_{i=2}^{N} IC_i * n_i * l_i + \left(\sum_{i=2}^{N} OMC_i * P_{DG\ renw} * n_i * l_i\right) * CPV \qquad (1)$$

where
$IC_i -$ Inverstment cost of renewable DG at bus'i'
$OMC_i -$ Operation and maintenance cost of renewable DGat bus'i' $n_i -$
number of DG unit connected at bus 'i'
$l_i -$ location variable at bus'i' (0 or 1)
$P_{DG\ ren\ i} -$ Power generated by DG at bus 'i'
$N -$ number of buses in the network

With the variation in inflation, interest rate of the capital cost and number of years from the planning horizon the cost value will vary with different factors like cumulative present value (CPV in (2)) and cost of electricity.

$$CPV = \frac{(1 - PV^{N_y})}{(1 - PV)} \qquad (2)$$

According to (2) PV is the present value of the cost as defined in (3).

$$PV = \frac{1 + \frac{IF}{100}}{1 + \frac{IR}{100}} \qquad (3)$$

Present value depends on the, $IR -$ interest rate and $N_y -$ Number of year in planning horizon and $IF -$ Inflation rate. Considering all the cost factors total benefit is calculated. As shown in (4) defines the totalbenefit that is obtained for placement of DG and STATCOM during any iterative point in the algorithm.

$$Benefit_{DG_{DStatcom\ ren}} = \{(\sum_{i=2}^{N}(P_{DG\ ren\ i} + Q_{DStatcom\ ren\ i}) * n_i * l_i) + \Delta Ploss_{DG\ ren}\} * C_{hr} * 8760 * CPV \qquad (4)$$

$\Delta Ploss_{DG\ ren}$ is the Power loss due to allocation of renewable DGs and C_{hr} is Cost of electricity.
STATCOM Cost is dependent on the reactive power injection rating denoted as Qst (MVAR) in (5). The cost of STATCOM is calculated in terms of dollar per hour.

$$C2(Q_{ST}) = \frac{1000 x Q_{ST}}{8760 x 15}(0.0002466Q_{ST}^2 - 0.2243Q_{ST} + 150.527) in\ \$/h \qquad (5)$$

Whether spending on installation and other costs is beneficial is determined using the factor Benefit to cost ratio $BCR_{DG\ ren}$ as defined in (6).

$$BCR_{DG\ ren} = \frac{Benefit_{DG\_STATCOM\ ren}}{Cost_{DG\ ren}} \tag{6}$$

One of the factors that affects the objective function of the proposed implementation is VSF. Voltage profile disturbance needs to be assessed to obtain the stability of voltage. VSF for any bus i+1 in the distribution network is as given in (7).

$$VSF_{i+1} = (2V_{i+1} - V_i) \tag{7}$$

$V_i - voltage\ magnitude\ at\ bus\ i$
$V_{i+1} - voltage\ magnitude\ at\ bus\ i+1$

Average of all the VSF obtained from different buses is given as the total VSF of the network chosen as given in (8).

$$VSF = \frac{\sum_{i=1}^{N-1} VSF_{i+1}}{(N-1)} \tag{8}$$

Line limit of the ith bus LL_i is as defined in (9) which is the ratio of actual MVA $L_{MVA,i}$ and the maximum MVA $L_{MVA_{max,i}}$.

$$LL_i = \frac{L_{MVA,i}}{L_{MVA_{max,i}}} \tag{9}$$

Average of the line limit for all the lines is defined as the network security index as defined in (10).

$$NSI = \frac{\sum_{i=1}^{N-1} LL_i}{(N-1)} \tag{10}$$

Network security index in (10) needs to be minimized while BCR, VSF are to be maximized while DG and STATCOM placement. Thus, the objective function is defined as a minimization function with NSI in the numerator, while BCR and VSF as the denominator as defined in (11).

$$minimize\ f\left(P_{DG\ ren\ ij}, n_i, l_i\right) = \left(1 + \left(\frac{1}{BCR}\right)\right) + \left(1 + \frac{1}{VSF}\right) + NSI + \frac{P_{loss_{without}}}{P_{loss_{with}}} \tag{11}$$

As shown in (11) is used as the objective function for placement of STATCOM and DG in the distribution system. With (11) as the objective function the PSO -TLBO algorithm defined in the next section is used as the optimization algorithm to optimize DG and STATCOM placement.

3. PROPOSED PSO-TLBO ALGORITHM

The TLBO algorithm emulates the behavior of the teacher teaching the student and the student learning from the teacher. The PSO algorithm emulates the food-searching behavior algorithm for birds. The proposed method combines these two algorithms to obtain improved convergence performance.

The fitness function defined in (11) is subjected to convergence by using the hybrid algorithm of TLBO-PSO that helps in better convergence in the defined problem. The fitness function is minimized for the best placement of DG and STATCOM in the distribution system. PSO particles make up half of the particles, whereas TLBO learners make up the other half. PSO's parameters (C1 and C2) are essential to the algorithm's convergence feature. A chaos idea is to tune the inertia weight to avoid these problems and boost the efficiency of the PSO algorithm. CPSO determines the state of the switches (open or closed) and the number of sectionalizing switches in this paper.

The flow chart of the proposed hybrid algorithm is depicted in Figure 1. Load flow solution for the distribution system is developed for each iteration of the new population generated from the hybrid algorithm. Line flow values are obtained from the load flow solution. As shown in (11) is solved while varying the placement and sizing of the DG and STATCOM. Both PSO and TLBO are run in parallel to obtain the best solutions for each iteration. The results from both algorithms are obtained. The best among the algorithms in each iteration stage decides the new population that is optimized. This process is continued till the minimized

in (11) is obtained and is not changed for a few iterations. Optimized location and sizing of STATCOM and DG at this stage is the best placement solution in the distribution system.

This algorithm is preferable to previous ones because it does not have user-defined parameters. Furthermore, TLBO can do global and local searches, divided into two parts: instructor and learner, respectively.
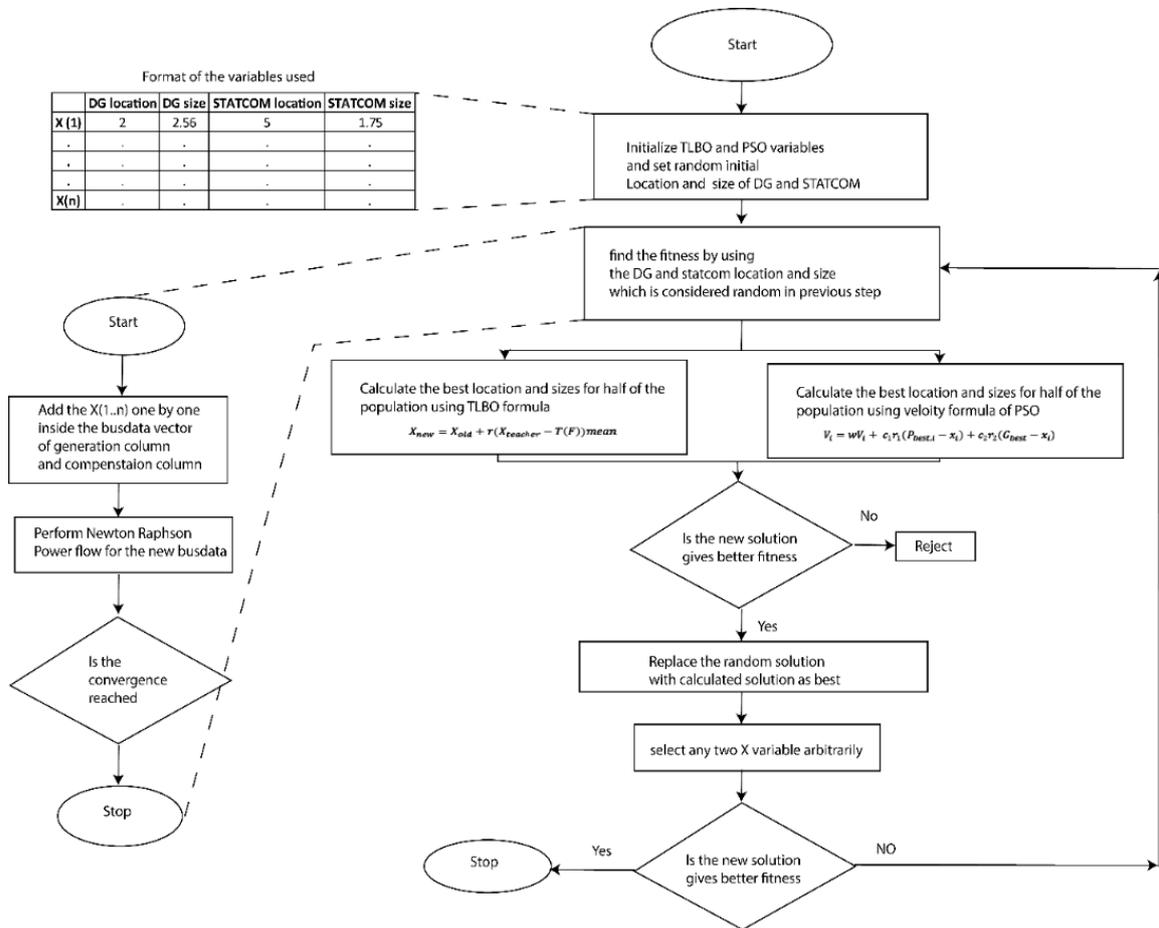
Figure 1 Flow chart of proposed new hybrid TLBO-PSO algorithm

4. RESULTS AND DISCUSSION

For this analysis, the IEEE 33 bus system is used. The losses, VSI, BCR, and NSI, are evaluated in the multi-objective optimization, and the DG considered is the doubly fed induction generator (DFIG). There are five cases for multiple DG and multiple STATCOM taken. The proposed hybrid algorithm is implemented in two scenarios: the IEEE 33 bus system and a real-time 52 bus system. Different cases used are Case 1: Single DG and single STATCOM (1DG1Stat), Case 2: Two DG and single STATCOM(2DG1Stat), Case 3: Two DG and Two STATCOM(2DG2Stat), Case 4: Three DG and Two STATCOM(3DG2Stat), Case 5: Three DG and Three STATCOM(3DG3Stat). Common terminology of the cost function is assigned in (11), although it contains different terms. A convergence graph is obtained from the implementation that defines the cost function output with the iteration. This algorithm is preferable to previous ones because it does not have user-defined parameters. Furthermore, TLBO can do global and local searches, divided into two parts: instructor and learner, respectively.

4.1. Scenario 1: IEEE 33 bus

Convergence graph of all the three considered optimization algorithm is shown in Figures 2 to 6 for all the 5 cases. Convergence performance is the ability to provide a minimal cost than the other algorithms used. The hybrid algorithm exhibited a better convergence performance than the other two algorithms, while

the TLBO algorithm performed while individual meta-heuristic methods were used. The voltage profile graph versus the bus number for PSO, TLBO, and TLBO-PSO algorithms are shown in Figures 7-9, respectively.
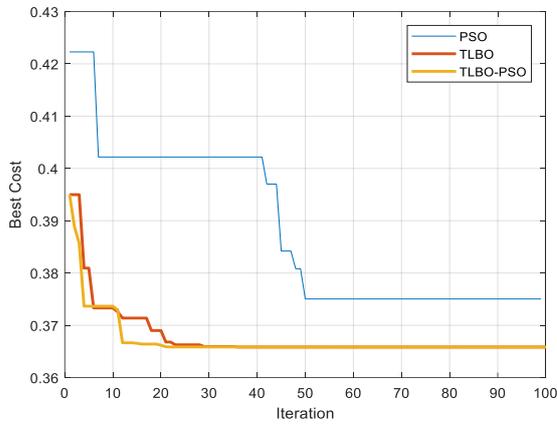
Figure 2. Convergence graph for case 1
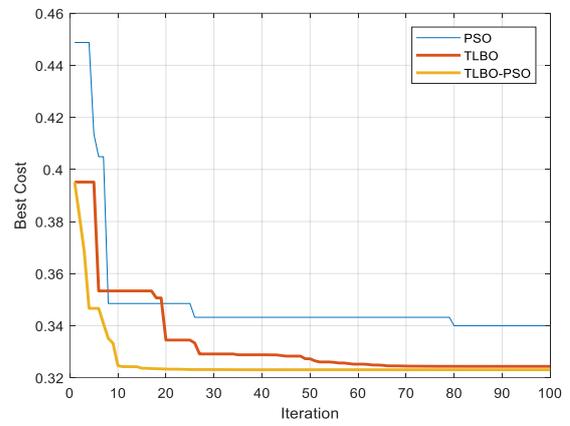
Figure 3. Convergence graph for case 2
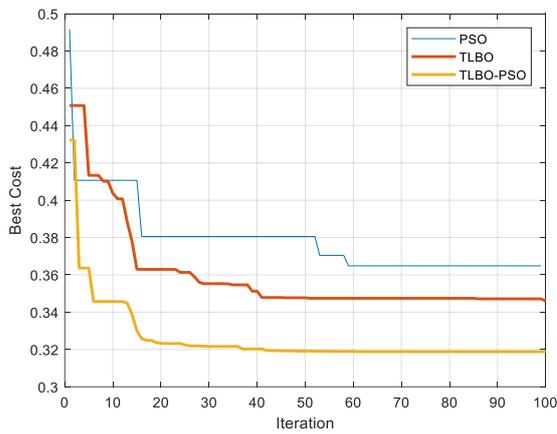
Figure 4. Convergence graph for case 3
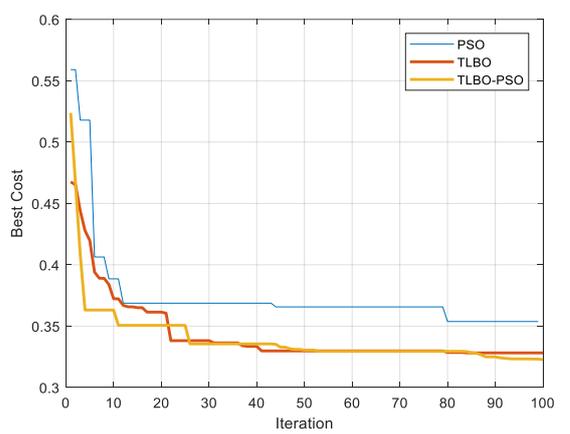
Figure 5. Convergence graph for case 4
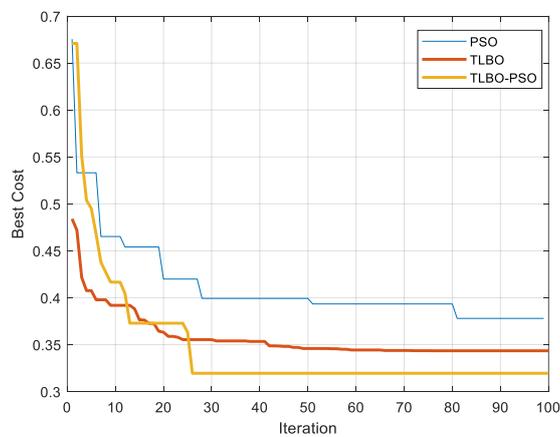
Figure 6. Convergence graph for case 5
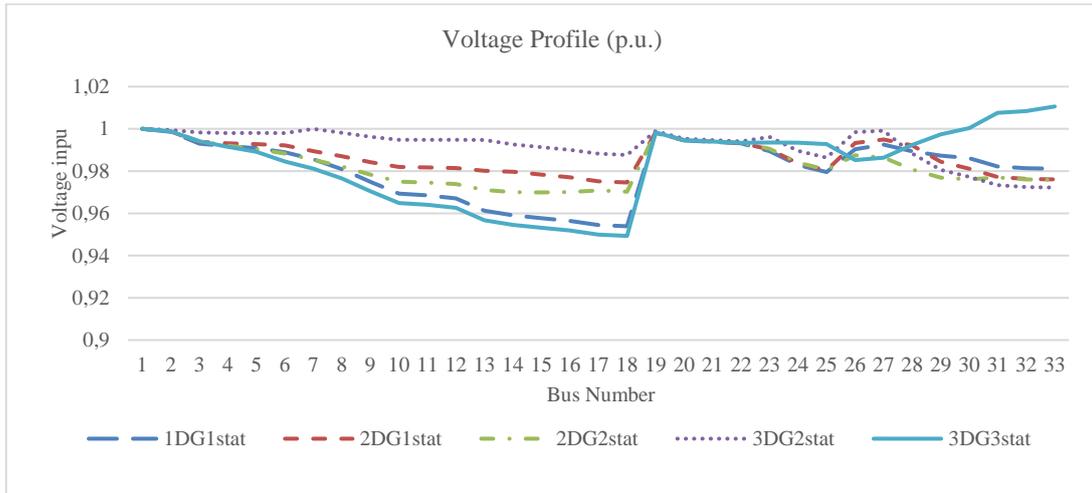
Figure 7. Voltage profile using PSO algorithm
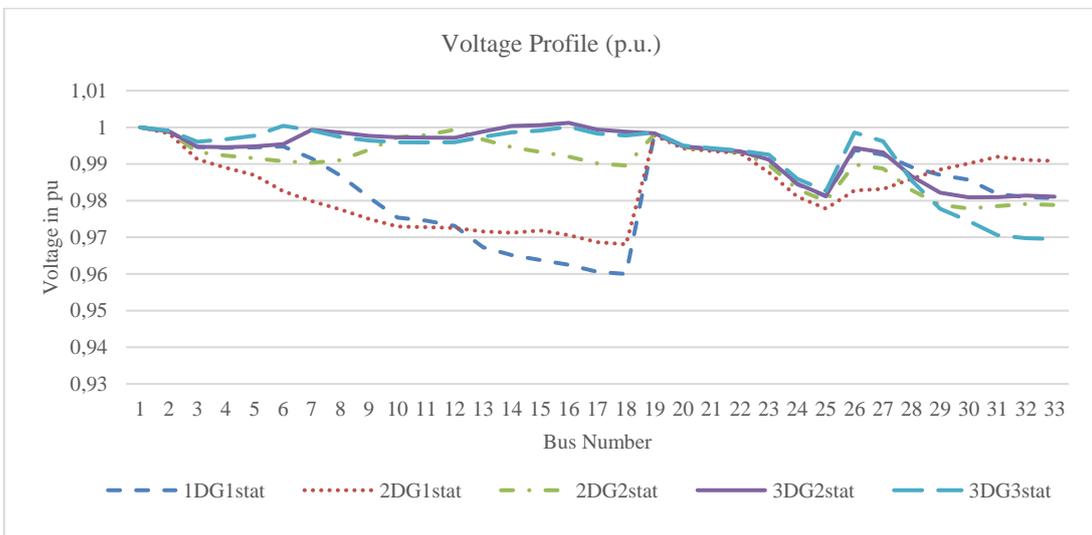
Figure 8. Voltage profile using TLBO algorithm
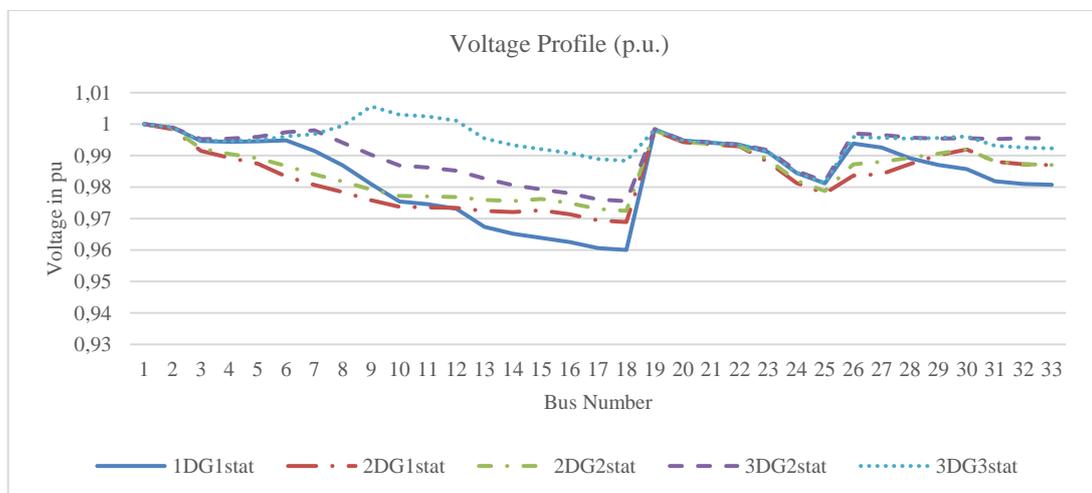
Figure 9. Voltage profile using TLBO-PSO algorithm

When implemented individually, voltage profile improvement for the TLBO-PSO algorithm is better than the PSO and TLBO algorithm. Fitness values of PSO, TLBO, and proposed TLBO-PSO algorithms are tabulated in Table 1. The fitness value of the proposed algorithm (highlighted) is found to be competitive with the other two algorithms. The fitness Output comparison of the IEEE 33 bus system, which is scenario 1 is given in Table 1. Table 1 shows that the fitness value is better in TLBO-PSO implementation with the lowest cost value. The contribution of DG and STATCOM for different cases of cost of DG and STATCOM power usage in terms of $/kW is given in Table 2.

Table 1. Fitness output comparison Scenario1

	1DG 1Stat	2DG 1Stat	2DG 2Stat	3DG 2Stat	3DG 3Stat
PSO	0.3750	0.3399	0.3648	0.3537	0.3779
TLBO [21]	0.3658	0.3244	0.3459	0.3282	0.3194
Proposed TLBO-PSO	0.3658	0.3231	0.3188	0.3227	0.3194

Table 2. Cost of DG (C_DG) per unit power, cost of STATCOM (C_STAT) per unit power and loss

Units		1DG 1Stat	2DG 1Stat	2DG 2Stat	3DG 2Stat	3DG 3Stat
C_DG ($/kW)	PSO	1.4675	1.5477	4.0381	2.5171	2.7006
	TLBO [21]	1.4311	1.4200	1.8946	1.5327	1.9498
	TLBO-PSO	1.4310	1.4224	1.7796	1.6438	1.9498
C_STAT ($/kW)	PSO	388.7711	427.0511	224.9921	585.4747	338.8437
	TLBO [21]	481.0093	294.1574	365.2181	475.8128	434.9284
	TLBO-PSO	481.4424	305.3935	314.004	491.0967	434.9284
LOSS in MW	PSO	0.0574	0.0446	0.0765	0.0440	0.0597
	TLBO [21]	0.0521	0.0431	0.0456	0.0429	0.0322
	TLBO-PSO	0.0521	0.0415	0.0369	0.0334	0.0322

Cost analysis in the IEEE 33 bus system is computed and tabulated. Loss is minimum in the multi-DG and STATCOM cases for the proposed algorithm. TLBO algorithm is optimized with a lesser cost for locating two units of DG and a STATCOM. However, there is a tradeoff between the cost per unit of the three algorithms. TLBO-PSO algorithm outperforms all the algorithms while the convergence of the overall objective is considered. The second scenario used is for the cost optimization of a 52 bus system for real-time is considered from [29]-[30].

4.2. Scenario 2: 52 bus system results

Convergence graph of all the three considered optimization algorithm is shown in Figures 9 to 13 for all the 5 cases. The convergence graphs show that the hybrid algorithm performs better in each case. The TLBO is better than the PSO, and TLBO-PSO is better than the TLBO. The voltage profile graph versus the bus number for PSO, TLBO, and TLBO-PSO algorithms are shown in Figures 14-16, respectively.
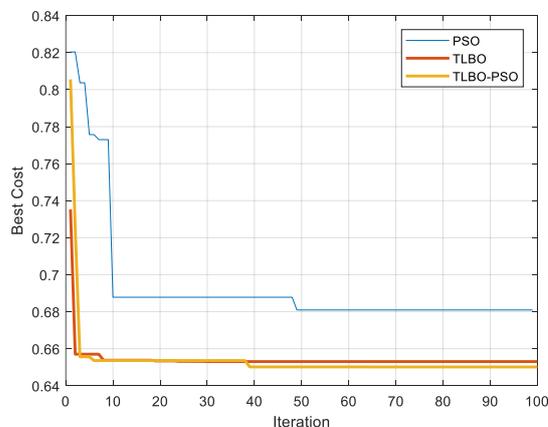
Figure 9. Convergence graph for case 1
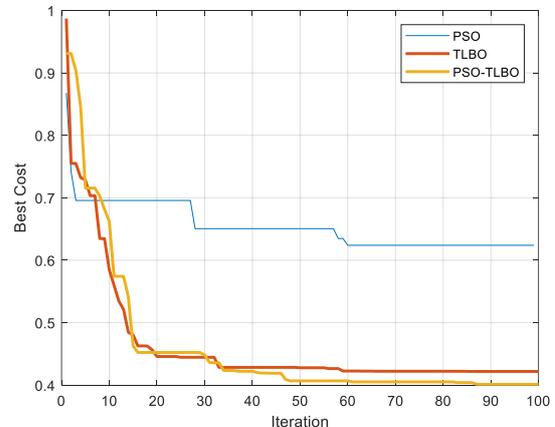
Figure 10. Convergence graph for case 2

When implemented individually, voltage profile improvement for the TLBO-PSO algorithm is better than the PSO and TLBO algorithm. Fitness values of PSO, TLBO, and proposed TLBO-PSO algorithms of the real-time 52 bus system are tabulated in Table 3. The fitness value of the proposed algorithm(highlighted) is found to be competitive with the other two algorithms.

From the article [21], it is clear that the fitness is slightly less than TLBO and PSO, which shows proof that TLBO-PSO is performing better. Parameter-wise comparison is given in Figures 14-16.
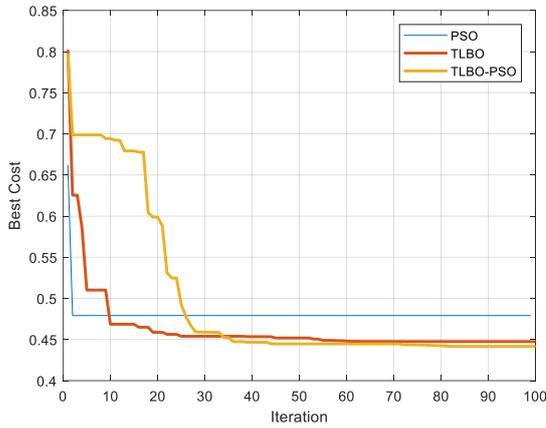
Figure 11. Convergence graph for case 3
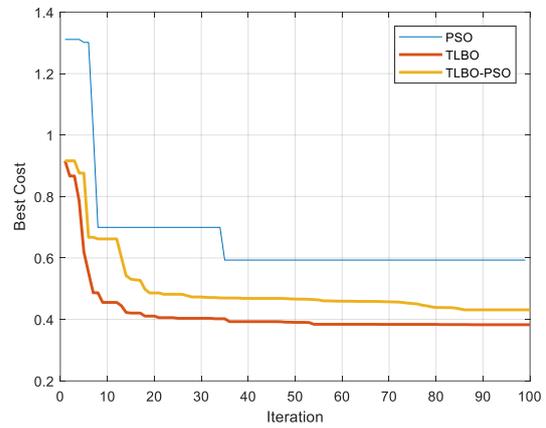
Figure 12. Convergence graph for case 4
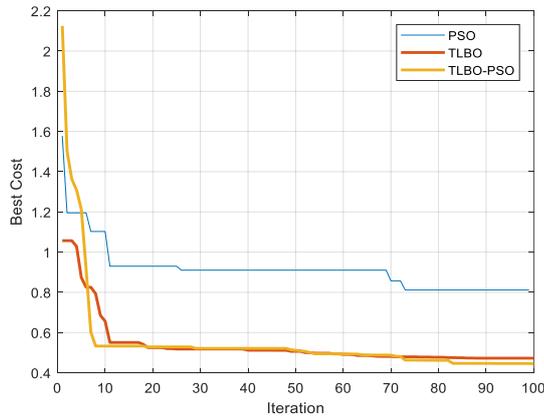
Figure 13. Convergence graph for case
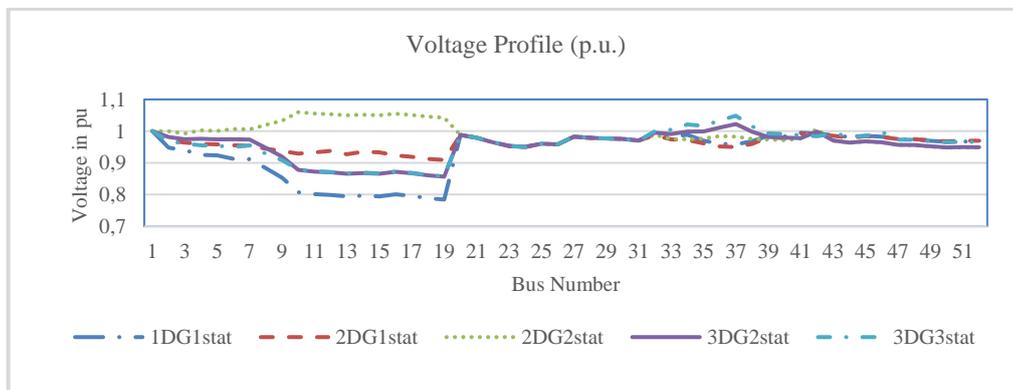
Figure 14. Voltage profile for PSO

The fitness function in TLBO-PSO is better, as seen in Table 4. Though the overall fitness function improves, the BCR is reduced in multiple DG and STATCOM cases. The VSF is better in multiple DG and STATCOM cases. And NSI also reduces in multiple DG and multi STATCOM cases.
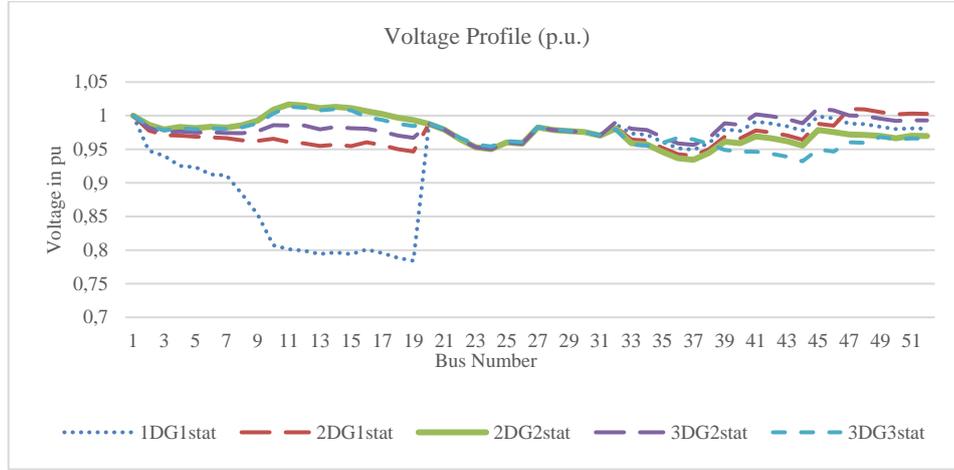
Figure 15. Voltage profile for TLBO
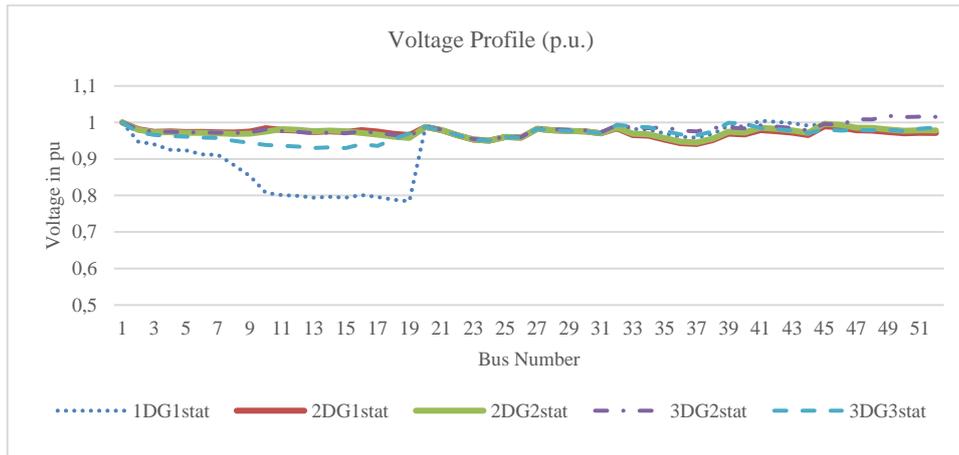
Figure 16. Voltage profile for TLBO-PSO

Table 3. Fitness output comparison scenario2

	1DG 1Stat	2DG 1Stat	2DG 2Stat	3DG 2Stat	3DG 3Stat
PSO	0.6809	0.4416	0.4013	0.4312	0.4447
TLBO [21]	0.6530	0.4475	0.4219	0.3827	0.4725
PSO-TLBO	0.6501	0.4416	0.4013	0.4312	0.4447

Table 4. Cost of DG (C_DG) per unit power, cost of STATCOM (C_STAT) per unit power and loss

		1DG 1Stat	2DG 1Stat	2DG 2Stat	3DG 2Stat	3DG 3Stat
C_DG ($/kW)	PSO	0.6447	0.2163	2.0179	0.8903	3.3395
	TLBO [21]	0.7935	0.6932	1.1469	1.1901	0.7992
	TLBO-PSO	0.8383	0.6886	1.0903	1.0413	2.2372
C_STAT ($/kW)	PSO	308.7599	458.9876	575.5966	552.2832	323.8146
	TLBO [21]	269.8115	448.8931	460.2749	473.8769	506.024
	TLBO-PSO	288.8140	475.5330	439.8650	523.9570	449.295
LOSS in MW	PSO	0.3527	0.1771	0.2717	0.2362	0.4343
	TLBO [21]	0.3311	0.1467	0.1145	0.0981	0.1548
	TLBO-PSO	0.3283	0.1325	0.1101	0.1233	0.1443

Cost analysis in the real-time bus system is calculated and tabulated in Table 4. Loss is minimum in the multi-DG and STATCOM cases for the proposed algorithm. TLBO algorithm is better optimized with the lesser cost where 2 DG and a STATCOM are placed. Table 5 tabulates the percentage improvement of the convergence performance between the algorithms. It can be observed from Table 5 (highlighted) that the TLBO-PSO algorithm has a dominant performance of convergence among the PSO, TLBO, and TLBO-PSO algorithms. TLBO-PSO algorithm outperforms all the algorithms. At the same time, the convergence of the overall objective is considered.

Table 5. Percentage improvement between convergence performance

	1DG 1Stat	2DG 1Stat	2DG 2Stat	3DG 2Stat	3DG 3Stat
TLBO over PSO	2.453	14.9055	-5.1639	7.2292	15.4763
PSO-TLBO over TLBO	2.4e-5	0.3989	7.8594	1.6629	0

5. CONCLUSION

MATLAB simulation of the proposed algorithm for DG and STATCOM placement is developed. The multi-objective function is formulated, which includes maximizing cost-benefit and voltage stability while minimizing network security index and power losses. The proposed strategy is used on IEEE 33bus and real-time 52 bus distribution systems, and the results are compared with existing methods. Although voltage stability is evident in both PSO and TLBO algorithms individually, the hybrid TLBO-PSO algorithm exhibited better convergence both in terms of improved performance indexes and also the cost minimization. Results of hybrid TLBO-PSO indicate better convergence compared to TLBO and PSO methods.

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