Optimal Location for types of capacitor to maximize the net saving in RDS using MTLBO algorithm

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ABSTRACT *The capacitor connected in the radial distribution system (RDS) is capable of providing reactive power and which impacts of increasing power utilization and voltage profile of the system. This paper presents a net saving maximization based optimal location and sizing of fixed and switched capacitor in radial distribution system. The net saving maximization is considered as a cost of energy loss, installation, purchase and operating costs of capacitors. It is formed as an objective function and which is solved by using a modified teaching learning based optimization (MTLBO) algorithm. In this algorithm basically consider as three phases, namely teaching phase, learning phase and mutation phase. The MTLBO algorithm is to employ in this problem in order to exploit the objective function. The efficiency of the MTLBO algorithm is validated by testing it on 34-node and 69-node systems. The simulation results of this proposed approach are compared within the existing report.*

KEY WORDS: *modified teaching learning based optimization, capacitor, cost, radial distribution system.*

1. Introduction

The authors presented a TLBO based optimal placement of capacitors to minimize the power loss and energy cost of radial distribution system in [1]. The artificial bee colony (ABC) based optimization approach to work out the problem with capacitor placement (sizing and location) in order to maximize the net saving and to improve system static voltage stability has been depicted and investigated in [2 - 4]. The loss sensitivity factors are used to identify the buses for compensation and then a discrete particle swarm optimization (PSO) and Plant Growth Simulation algorithms (PGSA) are used to determine the optimal size of the capacitors in [5 - 6].

The authors proposed a mixed integer nonlinear programming approach for capacitor placement in radial/mesh distribution systems that determine the optimal location and sizing of capacitors in [7]. Heuristic search strategies are applied to determine the capacitor location and rating for the distribution systems. The solution to the capacitor problem using heuristic rules involves searching through a set of potential solutions discussed in [8]. Genetic algorithm (GA) based fuzzy multi-objective approach for optimal capacitor placement while getting a better voltage profile and maximizing net savings in a radial distribution system. The objectives considered attempt to maximize the fuzzy satisfaction of maximization of net savings and minimization of nodes voltage deviations in [9]. In [10], discuss with the optimal location and sizing of static and switched shunt capacitors in radial distribution systems. The problem has been formulated as the maximization of the net present value of a cash flow of the compensation project.

The authors developed for optimizing the net monetary savings associated with the reduction of power and energy losses through placement of fixed and switched shunt capacitors on primary distribution feeders [11]. The distribution system is normally in unbalanced loading condition and has very high R/X ratio. The forward and backward propagation based efficient power flow solution technique has been executed in the radial distribution system [12].

The authors proposed an optimization method called 'Teaching–Learning-Based Optimization (TLBO) algorithm for large scale nonlinear optimization problems for finding the global solutions in [13]. The authors concluded in [14], by identifying the true exploration and exploitation powers of TLBO, more insights about the algorithm's inner workings and a better explanation of the presented results. TLBO uses the mean value of the population to update the solution. In teacher and learner phases of TLBO, the update of a solution from an old solution is considered as the exploration and the greedy selection which follows it is considered as the exploitation [15]. A Modified Teaching–Learning Based Optimization (MTLBO) algorithm is proposed to determine the optimal placement and size of Distributed Generation (DG) units in distribution systems in [16]. The mutation operator of the differential evolution (DE) is clearly described in

reference [17]. In this approach, optimal location and sizing of fixed and switched capacitors in the radial distribution system using MTLBO in order to maximize net saving and voltage profile of the system. The entire procedure for MTLBO algorithm has been followed by reference [16].

2. Problem Formulation

The net saving maximization is considered as an objective of optimal location and sizing of types of capacitor in radial distribution system is to minimize power loss and cost of capacitor with specified operating constraints. The modified teaching learning based optimization algorithm based net saving maximization is mathematically formulated as,

$$\max f = C_E\left(P_{LB} - P_{LA}\right)T - \beta\left(C_I N_B + C_P \sum_{i=1}^{N_B} Q_{ci}\right) - C_o N_B \quad (1)$$

where,

C_E	=	cost of energy is \$0.06/KWh
C_I	=	cost of installation is \$1600/location
C_P	=	capacitor purchase cost is \$25/KVAr
C_o	=	capacitor operating cost is \$300/year/location
β	=	Depreciation factor is 20%
N_B	=	number of candidate location for capacitor placement
P_{LB}	=	total active power loss before compensation
P_{LA}	=	total active power loss after compensation
Q_{ci}	=	size of the capacitor at node *i*
T	=	time period 8760 hours/year.

The different operating constraints are taken into account and which signifies a limit in the search is capable of learners can move over the feasible region. These constraints are discussed as follows.

2.1 Power - Conservation Limits

The algebraic sum of all receiving and sending powers including line losses over the complete distribution network and reactive power inject from capacitor unit should be equal to zero.

$$P_{SS} = \sum_{i=2}^{NB} P_D(i) + \sum_{j=1}^{NL} P_{loss}(j) \quad (2)$$

$$Q_{SS} = \sum_{i=2}^{NB} Q_D(i) + \sum_{j=1}^{NL} Q_{loss}(j) - \sum_{k=1}^{NC} Q_C(k) \quad (3)$$

where,

P_{SS}	- Real power conservation of the system (MW)
P_D	- Total system real power demand (MW)
P_{loss}	- Total system real power loss (MW)
Q_{SS}	- Reactive power conservation of the system (MVAr)
Q_D	- Total system reactive power demand (MVAr)
Q_{loss}	- Total system reactive power loss (MVAr)
Q_C	- Total reactive power injects by capacitor (MVAr)
NL	- Number of lines
NC	- Number of capacitor.

2.2 Reactive Power Compensation Limits

The reactive power delivered by each capacitor is limited by its lower and upper limits as,

Q_C = 600 KVAr (Fixed type capacitor)

$$0 \le Q_{Ci} \le Q_{Ci}^{\max} \quad \text{(Switched type capacitor)} \quad (4)$$

Permissible capacitor range 0 to 1500 KVAr with step of 50 KVAr.

2.3 Voltage Profile Limits

The voltage magnitude at each node of the radial distribution system is strictly maintained as,

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

(5) $0.95 \le V_i \le 1.05$ (34-node system)

$0.90 \le V_i \le 1.00$ (69-node system)

2.4. Line capacity Limits

The distribution of power is done through the feeder in the radial distribution system, and in this feeder should not go beyond the thermal capacity of the line.

$$S_{(i,j)} \le S_{(i,j)}^{\max} \quad (6)$$

3. Modified Teaching Learning Based Optimization algorithm

The TLBO algorithm is divided into two parts such as 'Teacher Phase' and 'Learner Phase'. The 'Teacher Phase' means learning from the teacher and the 'Learner Phase' means learning through the interaction between learners.

Teacher Phase:

In this phase, first of all the teaching role is assigned to the best individual ($X_{teacher}$). To improve the other individuals of this algorithm by moving their position according to the position of the $X_{teacher}$ by taking into account the current mean value of the individuals (X_{mean}). T_F is a teaching factor, which can be either 1 or 2, thus highlights the significance of student quality.

$$X_{new} = X_i + rand[0,1] * (X_{teacher} - (T_F * X_{mean})) \quad (7)$$

Learner Phase:

During the Learner Phase, students try to improve his/her knowledge with the help of group discussions, presentations, creation, etc. A best learner learns something new when compared to other learner has more knowledge than him or her. Learner phase can be expressed as,

$$X_{new} = X_i + rand[0,1] * (X_{ii} - X_i) \quad (8)$$

$$X_{new} = X_i + rand[0,1] * (X_i - X_{ii}) \quad (9)$$

where, $i \neq ii$

Mutation Phase:

The mutation operator is combined with TLBO called MTLBO and which improves the local search ability of the algorithm. This phase can be done for modification and update of the population for after completion of the Learner Phase. This phase can be expressed as,

$$X_{mut} = X_{rand1} + F * (X_{rand2} - X_{rand3}) \quad (10)$$

where,

X_{rand1}, X_{rand2} and X_{rand3} are three students randomly selected for the i^{th} learner,
X_i, from the population, such that rand1 ≠ rand2 ≠ rand3 ≠ i
F is a number between 0.4 and 1.0.

After completing the mutation process, to update the population as follows,

$$X_{new} = \begin{cases} X_{mut} & if\ rand(0,1) \ge 0.5 \\ X_i & otherwise \end{cases} \quad (11)$$

Finally, to apply the greedy selection and updates the best population of the algorithm.

3.1. MTLBO Algorithm Implementation of Objective Function

The MTLBO algorithm is to calculate the optimal location and size of fixed and switched capacitors as follows:

1) Initialization: Set the population size (PS), D-dimensional parameter vectors, number of generation (NG) and number of iteration (NI) in the MTLBO algorithm. Maximum number iteration is considered as the convergence criteria of an optimization problem.
2) Generate randomly the initial population vector of problem using equation and maintain the limit as,
$$x_i = lb_i + rand[0,1] * (ub_i - lb_i) \quad (12)$$
For the location and sizing of the capacitors are considered as the integer and real variable of the Learner respectively. In this approach, the integer variables of the MTLBO algorithm can be reformulated by rounding off the Learner position to the nearest integer.
3) Teacher phase: To generate new solutions x_{new} of the teacher phase by using (7) and determined them. Further, evaluates the fitness value and to apply the greedy selection between $\vec{x}_{new}$ and $\vec{x}_i$.

4) Learner phase: To modify the population by using the learner phase equations (8) & (9) and evaluates them. If any one of the modified parameter is violating the limit, it is shifted to the permissible limit of the optimization problem. Further, evaluates the fitness value and to apply the greedy selection.
5) Mutation phase: In this phase, the mutation operator is to implement by using the equation (10) & (11) for the modification of the population. After that, evaluates the fitness value and to apply the greedy selection between current and previous solution.
6) If the number of iteration is equal to maximum number of generations, go to step 7. Otherwise go to step 3.
7) STOP and print the result.

The proposed approach has been implemented in the test systems using MATLAB 2009 running on a core i3 processor based computer.

4. Simulation Results

The 34-node and 69-node radial distribution systems are used in order to evaluate the performance of the proposed approach. In this test system, the base values used are 100 MVA for both test systems and 11 KV for 34-node and 12.66 KV for 69-node. The system and load data on the 34-node radial distribution system is taken from reference [8] and 69-node is taken from [9]. The problem formulation of this approach is to reduce the power loss and exploit the net saving per year of the test system with satisfied constraints. In this approach, the simulation results are presented for simultaneously located in fixed and switched type capacitor in the test systems. To express the benefit of MTLBO approach has a simulation results have been compared with various algorithm results in the report, such as GA, PSO, ABC, Fuzzy GA, Direct Search algorithm (DSA) and TLBO algorithm.

4.1. 34-node system

The table 1 shows the result of real power loss, minimum voltage stability index, minimum voltage, optimal location and sizing of the fixed and switched capacitors of the 34-node system are determined by different methods. From the table, it is clearly indicates the MTLBO result of real power loss is major reduction when compared to existing methods. The real and reactive power loss of the test system by using MTLBO is 161.17 KW and 47.21 KVAR respectively. Consequently, the real power loss of the system is reduced to 27.31% with compared to the base case. The minimum value of VSI is 0.8147 and the voltage is 0.9499 (p.u.) of this approach greatly improved when compared to different methods in the system (except TLBO).

Table 1

The performance analysis of 34-node radial distribution system with capacitors

Method	P_{loss} (KW)	VSI_{min}	V_{min} (p.u.)	Node no.	Capacitor size (KVAr)	Net saving/year
Base case	221.72	0.7864	0.9416	-	-	-
GA [2]	164.96	0.8071	0.9478	5 9 12 22 26	300 300 300 600 300	$15093.00
PSO [2]	169.36	0.8097	0.9486	19 22 20	781 803 479	$15570.00
ABC [2]	167.99	0.8129	0.9496	19 24	950 900	$17756.00
TLBO	161.68	0.8150	0.9500	26 21 10 (fixed)	500 1050 600	$18947.00
MTLBO (Proposed)	**161.17**	**0.8147**	**0.9499**	**10** **25** **19 (fixed)**	**750** **850** **600**	**$18964.00**

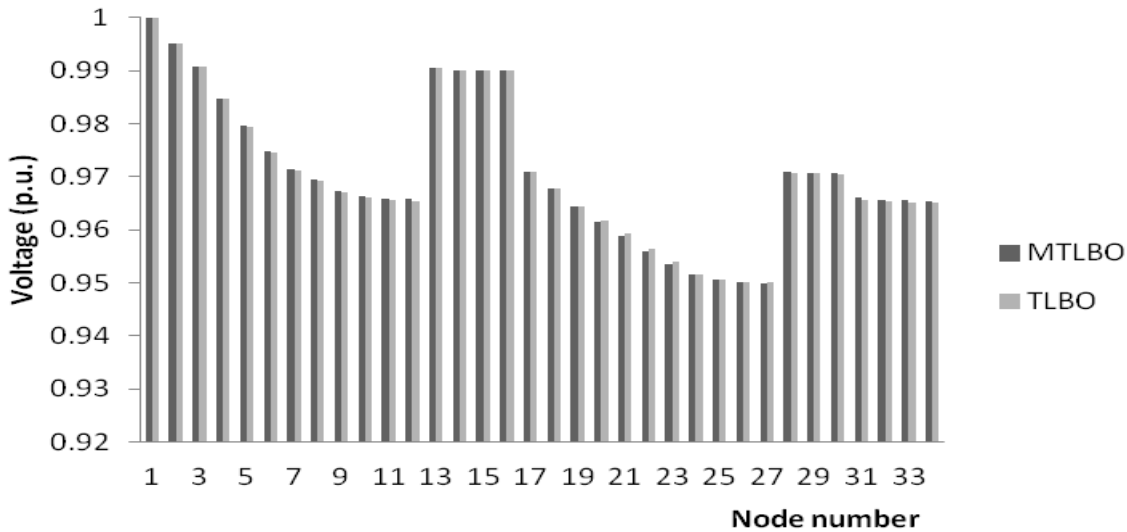

Figure 1. Comparison of Voltage profile between MTLBO and TLBO of 34-node system

The MTLBO algorithm based result of net saving/year is better objective is listed in table 1. The voltage profile of the system is greatly improved with the presence of capacitors and voltage at each node of the system is compared with TLBO result shown in figure 1.

4.2. 69-node system

The table 2 shows the results of real power loss, minimum voltage stability index, minimum voltage, optimal location and sizing of the fixed and switched capacitors of the 69-node system are obtained by using MTLBO and existing methods. The real power loss of the system by using MTLBO is 146.71 KW which is reduced to 34.79 % with compared to base case method. The reactive power loss of the system by proposed algorithm is 68.25 KVAR. From this approach, the total size of the capacitor is 1550 KVAR less when compared to other methods listed in table 2. The better result of real power loss in MTLBO algorithm listed in table 2. The voltage profile of the system is greatly improved when the presence of the capacitor. The figure 2 graphical representation of voltage profiles at each node of the test system in MTLBO and compared with TLBO algorithm.

Table 2

The performance analysis of 69-node radial distribution system with capacitors

Method	P_{loss} (KW)	VSI_{min}	V_{min} (p.u.)	Node no.	Capacitor size (KVAr)	Net saving/year
Base case	224.97	0.6833	0.9416	-	-	-
Fuzzy GA [1]	156.52	0.7706	0.9369	59 61 64	100 700 800	-
DSA [1]	146.99	0.7537	0.9318	15 60 61	450 450 900	-
TLBO [1]	146.80	0.7550	0.9321	22 61 62	500 1050 600	-
MTLBO (Proposed)	**146.71**	**0.7514**	**0.9307**	**22** **61** **61 (fixed)**	**300** **650** **600**	**$31504.00**

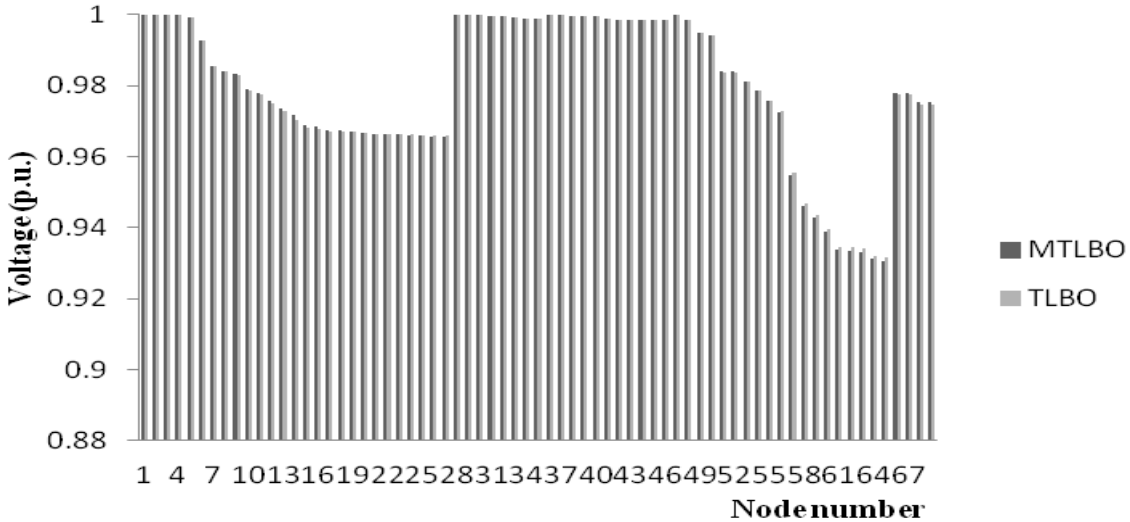

Figure 2. Comparison of Voltage profile between MTLBO and TLBO of 69-node system

Maximize the value of net saving/year is significantly impacting the cost of the capacitor. During the solution in the feasible region of this algorithm is related to maintaining the cost of energy reduction is always greater than the remaining cost of the capacitor of the proposed problem. If it is not maintained results for infeasible solution and skip the population in the next iteration. This process till continues until the number of iterations is lesser than the maximum number of generations.

5. Conclusion

The MTLBO algorithm has been successfully applied to the objective of maximizing of net saving per year with constraints. The proposed algorithm has effectively determined the optimal value of placement and sizing of fixed and switched capacitors in the test systems. The capacitors are located in the test systems which results are significant impacts of voltage profiles and power loss are proved. The comparison of simulation results with existing methods obviously the MTLBO algorithm better achievement of real power loss minimization.

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