Optimized Capacitor Allocation in Radial Distribution Network Using Teaching Learning Based Optimization

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Abstract: *This work proposes to reduce power loss and improve voltage profile at buses in distribution networks where optimized static capacitors are allocated using Teaching-learning-based optimization (TLBO) algorithm. This algorithm identifies optimal sizing and placement of capacitors and takes the final decision for optimum location within the number of buses nominated. The result is enhancement of the overall system voltage profile. The proposed method is applied on standard 33 bus radial distribution system. Simulations carried out using MATLAB environment to validate the effectiveness of the proposed optimization technique.*

Keywords: **Radial distribution system, teaching learning based optimization (TLBO), Loss reduction, voltage profile**

1. Introduction

The Analysis of power distribution system is an interface between the bulk power system and the consumers. The radial distribution systems are common due to its low cost and simple design. The reactive power flows in distribution network cause high power loss and decrease in voltage. In order to improve the overall efficiency of power delivery, power utilities are being forced to reduce the losses at the distribution level. This is achieved by installing shunt capacitors in the distribution network which help in reducing power loss, minimising peak demand loss, improvement in the voltage profile at buses and ensuring system stability. Installing capacitors fulfil the reactive power demand of the system; however capacitor allocation is useful only when it is optimally placed in the system.

Classical optimization techniques though useful suffer from many disadvantages like being highly sensitive to initial conditions problem, limited in handling algebraic functions and unable to consider the dynamic characteristics. They may either converge to local optimum solutions instead of global solutions or, under some situations may diverge. Owing to the complexities arising out of computational difficulties, degree of freedom in choice of objective functions and the types of constraints are limited. The classical optimization methods are time consuming and therefore not only unsuitable for automated computation but also may compromise the optimality.

Recent developments of deregulation in power utility sector have given rise to new electricity market. The new restructured power system introduced competition in generation, transmission and distribution. This competitive market along with increasing electricity demand necessitated power systems to seek more advanced techniques for optimized operation. These drawbacks of classical optimization techniques are overcome by modern heuristic optimization techniques such as evolutionary algorithms (EAs).

This work proposes to reduce the power loss in the system and improve the voltage profile of the system buses using capacitor allocation at selected buses in distribution system. Optimal capacitor placement was attempted using tabu search (TS) combined with other combinatorial approaches such as genetic algorithms and simulated annealing [3].Capacitor placement & sizing has been computed by loss sensitivity factors which uses particle swarm optimization (PSO) technique to improve the voltage profile of the system and reduce active power loss [4]. Ant colony search algorithm (ACSA) is implemented to reduce power loss and improve voltage profile using distribution network reconfiguration and optimal capacitor placement [5]. Simulated annealing (SA) technique was proposed to search an acceptable non-inferior solution however the algorithm is time consuming [6]. Genetic algorithm has been used which improves the voltage profile and reduces losses in the power distribution system simultaneously. An attempt has been made to use large number of variables (capacitor sizes) and constraints without affecting the accuracy of the results [7]. In the capacitor placement problem, investment and energy loss are minimized by Immune Algorithm while considering practical capacitor operating constraints, load profiles, feeder capacities and allowable voltage limits at different load levels [8]. The relationship between voltage stability and loss minimization is established where it can be shown that voltage stability is maximized if power losses are minimized. A fast branch exchange algorithm has been used to investigate the effect of network reconfiguration on voltage stability and load balancing [9].The maximum loading margin (MLM) approach is proposed in finding generation directions to maximize the static voltage stability margin [11].

2. Problem Formulation

In the radial distribution system, optimal capacitor placement leads to optimization of certain objective functions such as cost of operation, minimisation of power loss, improvement in voltage profile etc. In this work, reduction of real power loss has been considered as objective function.

Mathematically, the real power loss minimization is given by,

$$minimise(P_{RPL}) = \sum_{i=2}^{n_n}(P_{gni} - P_{dni} - V_{mi}V_{ni}Y_{mni}\cos(\partial_{mi} - \partial_{ni} + \theta_{ni})) \qquad (1)$$

where P_{RPL} is the real power loss, P_{gni} is the active power output of the generator at bus ni, P_{dni} is the active power demand at bus ni, V_{mi} is the voltage of bus mi, V_{ni} is the voltage of bus ni, Y_{mni} is the admittance between bus ni and mi, ∂_{mi} is the phase angle of voltage at bus mi, ∂_{ni} is the phase angle of voltage at bus ni and θ_{ni} is the admittance angle.

In distribution network optimal capacitor placement is subjected to following constraints:

1) The voltage must be kept within the specified limits at each bus.

$$V_{min} \leq V \leq V_{max} \qquad (2)$$

2) The apparent power flow in each branch must be less than the maximum power admissible for the line

$$S_{min} \leq S \leq S_{max} \qquad (3)$$

3) Capacitors are available in discrete sizes. So, shunt capacitors to be used are in multiple integers of the smallest capacitor size available

$$Q_c \leq LQ_s \qquad L = 1,2,3 \ldots\ldots nc \qquad (4)$$

3. Teaching-Learning Based Optimization

Teaching-learning-based optimization (TLBO) is an algorithm centred around teaching learning process which assesses impact of a teacher on the result of learners in a class. This algorithm attempts to define the teaching learning capability of the teacher-learners in a classroom. This algorithm is grouping of two basic approaches of the learning, namely teacher phase and learner phase [17]. In teacher phase, teacher is generally considered as a highly knowledgeable person who motivates learners so that they can have better results. In learner phase, learners learn from the group discussions and interactions among peers which also help in refining their results.

TLBO is a population based optimization technique where number of learners is similar to a population and different courses or subjects available to the learners are considered as variables of the problem to be optimized. The learner's performance is analogous to the fitness of problem to be optimized. The best value in the whole population is comparable to the teacher as teacher is considered as highly learned person.

Teacher phase

It is the primary phase of the algorithm where learning is done through the teacher. A teacher attempts to increase mean result of the class in subject or course taught by him to his best ability. At any given iteration i, let number of subjects are m, variables of objective function, number of learners or population size be n and $M_{j,i}$ be the mean result of the learners in a specific subject j. Considering all the subjects together in the whole population of learners, best result $X_{total} - k_{best,i}$ is the result of best learner k_{best}. But since a teacher is regarded as highly knowledgeable and learned, the best learner k_{best} is considered as the teacher. The difference of the current mean result of each course and the result of teacher for every subject can be stated as,

$$\text{Difference\_Mean}_{j,k,i} = r_i(X_{j,kbest,i} - T_F \mathrm{M}_{\mathrm{j,i}}) \qquad (5)$$

Where, $X_{j,kbest,i}$ is the result for the best learner in the course j. T_F is defined as the teaching factor used to alter the value of mean and r_i is any random number which exist in the range of [0, 1]. T_F is recommended to be either 1 or 2 and based on experimentation on number of standard functions and given by,

$$\mathrm{T}_F = \text{round}[1 + \text{rand}(0,1)\{2 - 1\}] \qquad (6)$$

On the basis of $\text{Difference\_Mean}_{j,k,i}$, the current solution is updated in the first part i.e., teacher phase according to the following expression.

$$X'_{j,k,i} = X_{j,k,i} + \text{Difference\_Mean}_{j,k,i} \qquad (7)$$

Where, $X'_{j,k,i}$ is the new and final solution if it gives best fitness value compared to $X_{j,k,i}$. At the end of teacher phase, all the best function values are now input to the learner phase.

Learner phase

This is the second and final part of the algorithm which models the learning of the learners through interaction among peers i.e., the students improves their understanding by interaction with their classmates. Every learner acquires new information from other randomly chosen learner if it has better knowledge. For a population size of n, learners phase can be explained as below. Randomly choose two learners P and Q such that,

$$\mathrm{X'}_{\mathrm{total-P,i}} \neq \mathrm{X'}_{\mathrm{total-Q,i}} \qquad (8)$$

where, $X'_{total-P,i}$ and $X'_{total-Q,i}$ are the new updated values of $X_{total-P,i}$ and $X_{total-Q,i}$ of P and Q respectively at the end of first or teacher phase.

$$X''_{j,P,i} = X'_{j,P,i} + r_i (X'_{j,P,i} - X'_{j,Q,i}) \quad \text{if } X'_{total-P,i} < X'_{total-Q,i} \tag{9}$$

$$X''_{j,P,i} = X'_{j,P,i} + r_i (X'_{j,Q,i} - X'_{j,P,i}) \quad \text{if } X'_{total-Q,i} < X'_{total-P,i} \tag{10}$$

$X''_{j,P,i}$ is accepted as a new solution if it gives a better function value

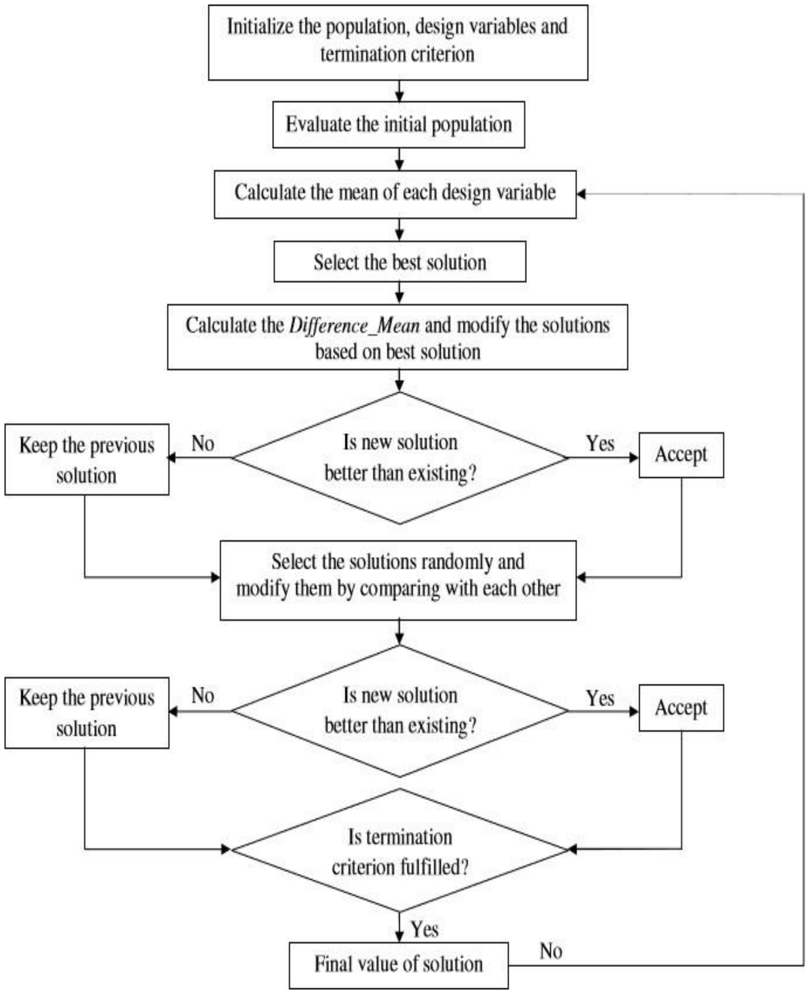

Fig 1. Flow chart of TLBO

4. TLBO Algorithm Applied to Optimal Capacitor Placement

The objective of optimal placement of capacitor in distribution system considers the size of capacitors and their locations as the decision variables. The steps to implement TLBO algorithm to decide optimal placement of capacitors are given as following.

Step 1: Initialize the number of iterations (generations), the size of population and number of capacitors to be installed in the distribution system

Step 2: Capacitor locations are randomly generated based on capacitor number

Step 3: Initialize at random the size of capacitors subject to operating limits

Let Q_{s1}, Q_{s2}, ... Q_{sn} be the sizes of capacitors at disposal. The Kvar of installed capacitors are elements of a vector which represents the grade point of different subjects of a particular learner. This vector represents a feasible candidate solution for optimal capacitor placement problem. A potential solution may be given by,

$$P_i = [\, loc_{i,1}, loc_{i,2}, \ldots \, loc_{i,nc}, Q_{i,1}, Q_{i,2}, \ldots \, Q_{i,nc} \,]$$ where nc is number of capacitors.

Now initial solution *P* is formed, size of which depend upon the number of population considered.

$$P = [\, P_1, P_2, .. P_i \ldots P_{NP} \,]$$ where NP is population size

Step 4: Power loss of distribution network is estimated using Newton Raphson load flow method. Based on fitness value of objective function, learners are sorted form best to worst and the best solution obtained is regarded as teacher of the class

Step 5: Grade point of every subject or Kvar of installed capacitors are modified for each learner using the concept of teaching phase

Step 6: The grade points are now updated of each subject of all learners using the learning phase

Step 7: Using the concept of Step 3, change the continuous rating of capacitors to discrete rating

Step 8: Examine if Kvar of the any installed capacitor violate the operating constraints

$$\text{if} \quad Kvar \geq Kvar_{max} \quad \text{then} \quad Kvar = Kvar_{max}$$

$$\text{if} \quad Kvar \leq Kvar_{min} \quad \text{then} \quad Kvar = Kvar_{min}$$

Step 9: Iteration process is stopped if predetermined number of iterations are over. The best solution comprising optimal location and size of capacitors is now printed. If stopping criterion is not satisfied, go to Step 4

Initial parameters of TLBO

To get optimal solution using TLBO algorithm, optimum values of the parameters like population size, mutation probability, number of iterations etc are taken from the studies already conducted in literature [12], [13] and shown in Table I.

Table I - Optimization Parameters of TLBO

Population size	50
Maximum number of iteration	50
Capacitors sizes	200 Kvar to1200 Kvar in step of 2 Kvar

5. Simulation Results and Discussion

The test system considered for study is radial distribution system of 33 buses, 5 tie-lines shown in figure 2. The loads connected to this system are 3.715 MW and 2.3 Mvar. The line and load data of test system is from [14]. The proposed scheme for reduction in loss by capacitor placement is implemented on test system using MATLAB programming environment. The base values of system voltage and generator rating are 12.66 kV and 100 MVA respectively. The capacitor size ranges from 200 Kvar to 1200 Kvar with step size of 2 Kvar. The simulation performed on base case gives power loss of 202.49 kW. The power loss reduces to 143.75 kW after compensation i.e., when capacitors are placed at optimized locations as shown in Table II.

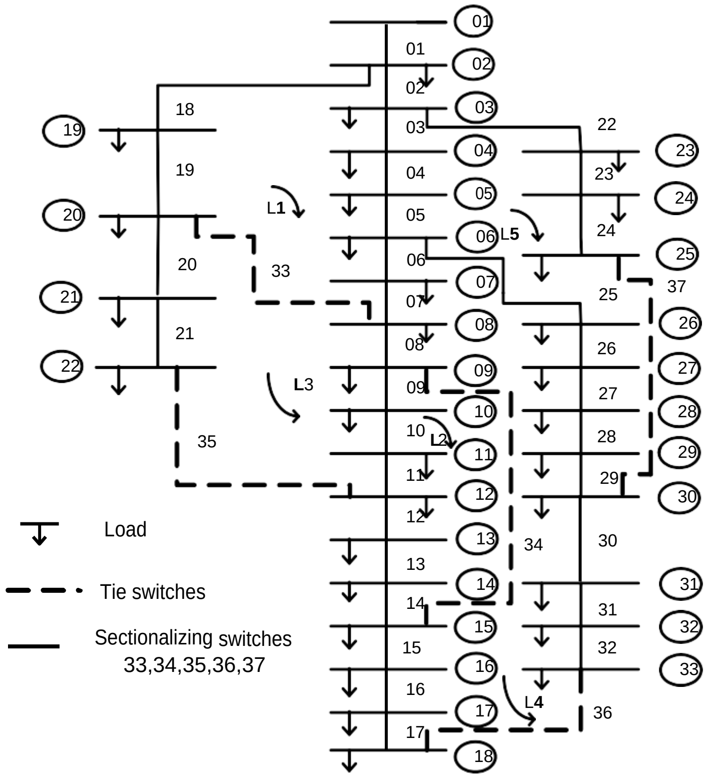

Fig 2. Test system of 33 bus radial distribution system

Table II – Compensation using capacitor placement

Before compensation		After compensation	
Power Loss (kW)	Min voltage (p.u)	Power Loss (kW)	Min voltage (p.u)
202.4957	0.9131	143.7549	0.9255

The minimum voltage of the test system is 0.913 pu and it occurs at bus number 18 when base case is simulated. This minimum voltage improves to 0.925 pu after capacitor placement. The optimal capacitor placement is found to be at bus number 6, 28 and 29. The voltage profile is shown in Figure 3.

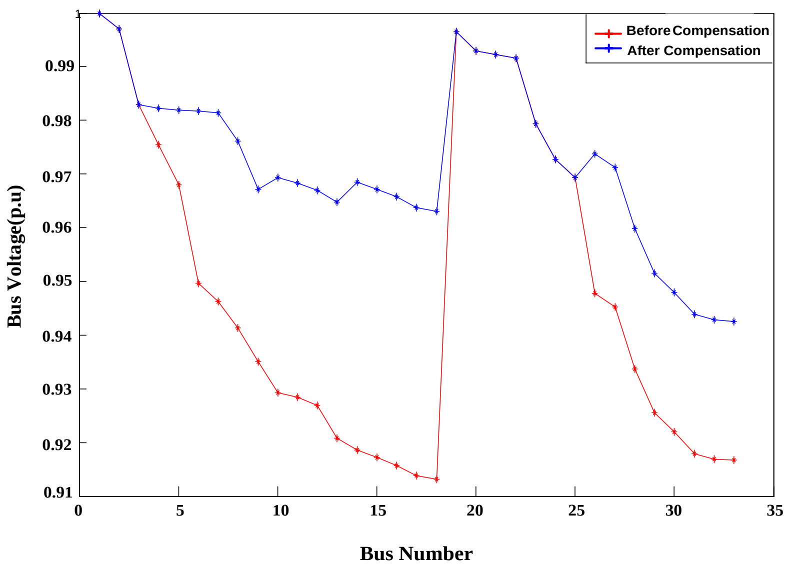

Fig. 3. Voltage profile of test system after capacitor placement

The results of the proposed scheme have been compared with that of result obtained using Genetic Algorithm (GA) method [12]. The proposed method using TLBO though reduces power loss to the same extent as GA does but with fewer capacitors and optimal locations as shown in Table III. The CPU time required by the proposed scheme is 5.13 sec.

Table III – Comparison of TLBO with GA

Parameters	GA	Proposed
Power loss (KW)	143.83	143.7549
Optimal location (bus no) and sizes (Kvar)	300 at {8,15,20,21, 24,26,28} 600 at 27	6 -1200 28 -760 29 -200
Total Kvar	2700	2160

6. Conclusion

The teaching-learning based optimization (TLBO) technique has been implemented using a test case of 33 bus radial distribution system to reduce the power loss and to improve voltage profile at the buses. The simulations carried out demonstrate the effectiveness of the proposed technique to identify the optimal capacitor placement locations. The proposed approach of TLBO when compared with GA, it is found that Kvar requirement decreases to get same power loss reduction and number locations also reduces where capacitors are different sizes are connected.

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