Dual techniques of load shedding and capacitor placement considering load models for optimal distribution system

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Article Info	ABSTRACT
	Voltage stability represents one of the main issues in electrical power system. Under voltage load shedding (UVLS) has long been regarded as one of the most successful techniques to prevent the voltage collapse. However, the ordinary load shedding schemes do not consider the different load models and decreasing in the economic cost that resulted from load disconnection, so the dual techniques of load shedding with reactive compensation are needed. Usually loads being modeled as constant power, while in fact of load flow the various load models are utilized. An investigation of optimal dual load shedding with reactive compensation for distribution system based on direct backward forward sweep method (DBFSM) load flow along with a comparison among the other load models are presented in this paper. The teaching learning-based optimization (TLBO) algorithm is executed in order to reduce power losses and enhance the voltage profile. This algorithm is tested and applied to IEEE-16 bus distribution test system to find the optimal superior capacitor size and placement while minimizing load shading for the network. Five different load shedding sequences are considered and the optimization performance of load models demonstrated the comparison through MATLAB program.

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1. INTRODUCTION

The electrical power system is frequently used within its safety limits. The unequipoise of reactive and active power enables the concurrent instability of voltage system and if the contrast between the active and reactive power expanded the whole system will be block out at the end [1]. The undervoltage scheme is outlined since appears the conclusive protective line in opposition to voltage instability that established on the decision of load shedding according to the voltage measure data. Under voltage load shedding approach is presented and settled with the help of particle swarm optimization (PSO) algorithm [2]. The voltage stability criterion represents the objective purpose of problem in order to orientate the evolution process of algorithms for measuring the sum of loads that to be shed and offer the improvement in losses reduction and voltage values of buses (voltage profile) for electrical power system. This ultimately results in a decrease in the amount of non-supplied energy and in the cost of load disconnection. The failure of a highly loaded transmission line or outage of considerable generating unit can cause the collapse of power system. With such a state of affairs, technique of load shedding is undertaken in an effort to stay away from the situation of voltage failure after consuming all other countermeasures. The optimal power flow (OPF) method for power system is applied to determine the lowest value of load shedding. The main goal is to eliminate the

interruption costs, while the voltage stability indicates the voltage and transfer limits. The sensitivity of voltage stability margin is specified based on the shedding of load using P-V curves for various system buses. A well planning of load shedding based on the intelligent algorithm to deal with the stability of voltage has been proposed by using the genetic algorithm (GA). The GA optimization method is applied for solving a nonlinear problem in the OPF structure and the sum of load shedding is decided at each system bus [3].

The advanced under voltage load shedding (UVLS) method has been offered that deals with the power system constraints at emergency conditions without broken its limits. This method used the pressure-volume (P-V) curves and UVLS logical relay that designed using (MATLAB/Simulink) environment. UVLS logical relay method is mainly applied for an emergency condition without broken the limits of power system constraints. The time delay for the activation of load drop should be applied within the period (3-10) seconds. Typical steps for decentralized relays are implemented by triggering 5% of load shedding in each step during a certain time based on the monitoring values of system bus voltages [4].

The voltage stability index (VSI) dependent on UVLS scheme for distribution network is suggested. The energization of distribution network is employed using two DGs that performed in PSCAD software for testing UVLS level. The location selection of load shedding is investigated using a novel fast voltage stability index (FVSI) and these loads are classified into three kinds, nonvital, semi vita and vital loads. Two case studies were performed to test the proposed islanding method and power change in P-V based DG [5].

UVLS scheme is offered, taking into account the unsatisfactory of line and load parameters. This given plane investigates the ideal load shedding modality that is exposed to practical constraints. To find the powerful and cost-efficient pattern of load shedding, the info-gap decision theory uncertainty modelling method is applied. This proposed method is conceived as a problem of nonlinear programming, which is settled using the technique of sequential quadratic programming. Utilizing the lower limit load shedding manner outcomes based on the putted technique within the operative constraints, the predefined voltage stability margin is calculated [6]. Hybrid optimization is introduced as a new load-shedding strategy based on the use identification of weak system buses based on the FVSI that used to recognize the sensitive regions in a large power system, which deducing the point of voltage failure, the top admissible load, and the interlinked structure of the optimal line. Enhancing the system voltage profile and optimal load shed using a hybrid optimization algorithm based on (GA) and (PSO) that leads to a stabilization of FVSI values. The GAPSO algorithm is used to diminish the overall account of shedded load on weakened buses based on the minimum system voltage profile preservation requirement. With a view to achieve the voltage stability for all system buses by stabilizing the increasing FVSI values, the proposed technique transforms UVLS into a multi-objective optimization problem function that involves the shedding of minimum load for the selecting of weak buses with minimum voltage drop [7].

A modern centralized and adaptive UVLS to lessen the short-term voltage instability while the inspecting of UVLS core oppositions has been offered and the aggregate of load shedding is evaluated based on the topical computations that required for such method. The selection of suitable location for implementing the load shedding within seconds after activating UVLS is accomplished using the proposed technique. The changing of impedance ratio for any bus depends on threshold value (TV). This value be dependent on the configuration of power system. This value and the operating point must be chosen far enough from the highest impedance ratio. If the value is not carefully chosen, UVLS may not be activated [8].

The UVLS method employing ant lion optimizer (ALO) is offered. The placement of shedded load bus is nominated based on the VSI. The ALO algorithm is utilized for the purpose of superior load amount to be shed in order to voltage profile enhancement and power loss minimization. Three cases of disturbances for overloading conditions were considered which P increase alone, Q increase alone, and both P and Q increase. For implementation of UVLS technique, the minimum voltage obtained with different load factor of three cases and the load factor of 1.8 p.u is chosen [9].

In this study, a dual mode of UVLS strategy and capacitor placement technique was used based on TLBO algorithm to solve all of these problems utilizing direct backward forward sweep method (DBFSM) for radial distribution system (RDS) with multi-objective functions. Different load models were considered and ZIP type represent the best model and that OCP then DLS give the best results increasing annual cost savings, lowering active power losses, and voltage profile optimization. All while retaining within the limits of RDS.

2.   DISTRIBUTION SYSTEM OPTIMAL LOAD SHEDDING

UVLS assesses itself to be method for instability of voltage and system breakdown because it is very saving and uncomplicated to carry out. The values of voltages on the busses that are the most sensitive decrease when the system is heavily load which consequences to sparsity of reserves of reactive power and

this can also happen as a result of reactive power service that is disorganized. UVLS is implemented after several control operations flopped to respond with the necessary operating mode, so the corrective factor is applied [10]. The utilization of appropriate load shedding can reduce the investment losses while also improving the profile of voltage for economic reasons. An optimal load shedding is offered for reducing the effects of voltage instability and system blackouts. The optimal load shedding based on the convenient optimization algorithm anticipates the subsequent advantages [11]: i) optimum and accurate calculation for the amount of load shedding, ii) powerful and reliable performance, and iii) the facility to implement in the complex and modern system.

3. OPTIMUM CAPACITOR POSITIONING

RDS represents the link between customers and most power systems. The shunt connected capacitors furnish the lack of reactive power induced by the dropping of voltage and high losses of power. Therefore, the optimum capacitor banks are integrated into RDS to increase the rate of power factor, improve the voltage profile and minimize losses. Previous access to this issue requires the inclusion of [12]: i) demonstrated procedures, ii) numerical methods of programming with iterative techniques to lessen or optimize an objective function, iii) heuristics mechanisms, and iv) artificial intelligent processes.

The comparison between the cost of capacitors and their advantages has been implemented in the issue of optimal capacitor placement. These costs include the overall expense of the installation and maintenance for capacitor placement technique. A step-like function is used to express the cost function because capacitors are pulled in typical discrete capacity banks with equivalent prices of non-linear capacitor bank size [13].

4. TYPES AND LOAD MODELLING

The outcomes of researches for load flow and stability are highlighted options that required to improve the whole power system effectiveness. As a result, to represent the entire power system, all of the component mathematical patterns need to be merged into a unique pattern. The representations of models for power system demands can have a significant impact on the study conclusions. It provides several advantages such as reduction of losses, voltage profile improvement, and voltage regulation (over/under) of the specific value and actual calculation of (P&Q) that requested at specific buses. Two types of load models static and dynamic are represented, and this research discusses the type of static load model. Polynomial and exponential load models are two different forms of static load models that are commonly used to solve the problems of load flow [14].

4.1. Exponential load

This pattern calculates reactive and active power as a function of the bus (voltage and frequency). Load architecture is depicted as a voltage (V) function that is exponential:

$$P_d = P_0 (V/V_0)^{np} \tag{1}$$

$$Q_d = Q_0 (V/V_0)^{nq} \tag{2}$$

where (P_d, Q_d) are represent the demanded of power for both (P, Q), (P_0, Q_0) are represent the expending power for both (P, Q), (n_p, n_q) are indicate the exponent of power for both (P, Q) and (V, V_0) are represent the voltage for both (supply and rated voltage). Table 1 lists different load values of n_p and n_q. These values are determined based on the measurement area of assessment system parameters.

Table 1. Common rates for distinct exponents of loads [15]

Type of Load	n_p	n_q
Flourcent lamps	2.07	3.21
Air conditioning	0.5	2.5
Coolers and pumps	0.08	1.6
Incandescent lamps	1.54	0
Light bulbs	1	0.35
Small motors	0.1	0.6
Large motors	0.05	0.5
Const.P	0	0
Const.I	1	1
Const.Z	2	2

4.2. Polynomial load

Electrical power systems use a variety of loads, and every bus possesses a fixed proportion of these types of loads and such loads change over time. ZIP model is the generality vastly utilized model and ZIP represents an incorporation of (P-$model$), (I-$model$), and (Z-$model$) [16]. It is represented:

$$P = \alpha P_0 V^2 + \beta P_0 V + \gamma P_0 \tag{3}$$

$$Q = \alpha Q_0 V^2 + \beta Q_0 V + \gamma Q_0 \tag{4}$$

$$Q_d = Q_0 (V/V_0)^{nq} \tag{5}$$

Percentage offerings in each node are shown to be constant (Z), (I), and (P) by (α, β and γ). Reactive and active power are just investigated depends on voltage changes. (α=0.6, β=0.2 and γ=0.2) have been choosing to give superior consequences of improving voltage level and lowering system losses.

5. OBJECTIVE FUNCTIONS

It is beneficial to employ multi-objective functions. It will improve the system bus voltage values and decrease power loss using optimization approaches. The following are examples of objective functions ($ob.fun.$):

5.1. Lowering of (P_{loss}) ($ob.fun.1$)

Reducing of real power losses ($ob.fun.1$).

$$(ob.fun.1) = P_{loss} \tag{6}$$

$$P_{loss} = \sum_{l=1}^{N_{br}} P_{lossl} \ kW \tag{7}$$

$$P_{lossl} = I_l^2 * R_l \ kW \tag{8}$$

where:
P_{loss}: represent the total amount of losses.
N_{br}: represent the number of system branches.
R_l: represent the branch l resistance.
I_l: represent the branch l current sweep.

5.2. Voltage profile enhancement ($ob.fun.2$)

Bus voltages must stay within a specified range (limits).

$$(ob.fun.2) = V_C * Re_v + C_C * Re_i \tag{9}$$

where:
V_C: limits for bus voltages.
C_C: limits of branch currents.
Re_v: the penalty variable of bus voltage. When the value of voltage at each bus is within permissible limits then this variable equal zero.
Re_i: the penalty variable of branch currents. When the value of thermal limit is not reached by the branch current, this variable is set to zero. Voltages must be within a certain range on buses.

5.3. Increment of annual saving cost ($ob.fun.3$)

Limiting losses is intended to magnify the value of saving related with capacitor investment costs and power loss. Capacitor acquisition, installation, and maintenance costs are all comprised in the expense of capacitor investment. The difference between the cost of losses in the base case and the cost of losses incurred as a result of executing the solutions proposed, plus the cost of capacitors investment as detailed below, represent the anniversary savings [17]:

$$C_P = \sum_{c=1}^{Nc} Q_c * C_{Pc} \ \$ \tag{10}$$

$$C_I = C_P + \sum_{c=1}^{Nc}(C_{Ic} + C_{Oc}) \ \ \$ \tag{11}$$

$$C_A = C_{En} * Time * P_{loss} + C_I \ \ \$ \tag{12}$$

$$C_A{}^B = C_{En} * Time * P_{loss}{}^B \ \ \$ \tag{13}$$

$$C_A{}^A = C_{En} * Time * P_{loss}{}^A + C_I \ \ \$ \tag{14}$$

$$ob.fun.3 = max(C_{sav}) = C_A{}^B - C_A{}^A \ \ \$ \tag{15}$$

where:
C_P: the cost of purchasing a capacitor in (\$).
C_{Pc}: the cost of purchasing a capacitor in (\$/kVAr).
C_I: the investment cost of capacitor in (\$).
C_{Ic}: the total expense of capacitor investment in (\$/Loc_c).
C_{Oc}: cost location for annual capacitor activity in (\$/ Loc_c/Year).
$C_A{}^B$: the cost of annual losses before implementing any approach in (\$).
$C_A{}^A$: the cost of annual losses after applying the techniques in (\$).
C_{sav}: represent the annual saving cost in (\$).
C_{En}: represent the cost of energy losses in (\$/kWh).
$Time$: represent the time per year of operation in (h).
$P_{loss}{}^B$: P_{loss} in (kW) before implementing any strategy.
$P_{loss}{}^A$: P_{loss} in (kW) after implementation the techniques.
N_c: number of capacitors under injection.
Q_c: capacitor sizes inserted in (kVAr).

   The capacitor costs and sizes are given in [18]. After the load shedding procedure has been implemented, the optimizing of economizing saving problem be dependent on the difference between the cost of base power losses and the expense of power loss. Table 2, which provided the values of cost parameters for the capacitors that used for cost calculations [19].

Table 2. Cost parameter standard values

Parameter	Value
C_{Ic} (\$/Loc_c)	1,600
C_{Oc} (\$/Loc_c/year)	300
C_{En} (\$/kWh)	0.06
$Time$ (h)	8,760

The three objective functions $(ob.fun.1)$, $(ob.fun.2)$ and $(ob.fun.3)$ are incorporated to create the composed objective function $(ob.fun.f)$.

$$ob.fun.f = ob.fun.1 + ob.fun.2 + ob.fun.3 \tag{16}$$

6.   GENERAL CONSTRAINTS
   The following are clarified as general restrictions in terms of technical and operational constraints, including advanced RDS performance. These include the power balance equations for system buses, limits of lower and upper voltage and reactive power for generation units. The main goals of power system constraints to prevent the quality standards violations (safety, reliable and economic).

6.1. Technical limitations
   Technical limits are the name given to these types of limitations, which are divided into three categories:
a. System bus voltage limitations
   To save energy, each of the system buses should have a voltage value that is within the acceptable range.

$$|V_{jmin.}| \leq |V_j| \leq |V_{jmax.}| \ \ j \in N_{bus} \tag{17}$$

where: (N_{bus}) is the number of buses. Normal voltage bus boundaries are ($0.95 - 1.05$) $p.u$ [20].

b. Current restrictions for system branches

From a safety standpoint, the current in the branch must not surpass a predetermined superior aggregate while also asserting load power transmission [21].

$$|I_l| \leq |I_{lmax.}| l \in N_{br.} \tag{18}$$

The maximum current value for each branch has been stated in [22].

c. Constraints for total sizing of capacitors

In the RDS, the entire size of capacitors (Q_{CT}) should not overtake than the actual total reactive power of load (Q_{load}) [23].

$$Q_{CT} \leq Q_{load} \tag{19}$$

6.2. Equality limitations

Equality limitations are a form of constraints that are split into two types:

a. Radial limitations for affecting of entire loads

RDS arrangement condition has been confirmed by looking at the determinant for [A] bus incidence matrix, which has columns equal to the number of buses and rows equal to the number of branches [24]:

$$[A] = \begin{cases} 1 \ \ If\ the\ branch\ \ i\ is\ out\ from\ bus\ j \\ -1\ if\ the\ branch\ i\ is\ inside\ into\ bus\ j \\ 0\ if\ the\ branch\ i\ is\ not\ linked\ to\ bus\ j \end{cases} \tag{20}$$

b. Limitation of balancing real power

$$P_{Sup} = P_{Dem} + P_{loss} \tag{21}$$

where P_{sub} is substation power, P_d is demand power.

7. TEACHING LEARNING BASED OPTIMIZATION (TLBO) ALGORITHM

Teaching learning based optimization (TLBO) algorithm is a universal optimization method primarily sophisticated by Rao *et al*. in 2011 [25]. It is an inhabitance based iterative learning algorithm that shows some common data characteristics with other evolutionary computation (EC) algorithms (Fogel 1995). However, TLBO investigates for an optimum through each learner trying to attain the experience of the teacher, which is considered as the most learned person in the society, obtaining optimum results, rather than through learners undergoing genetic operations like selection, crossover, and mutation. TLBO has been successfully utilized to many real-world problems due to its simple concept and high efficiency. The premier population is created having population size (NP) and the number of design variable (D), from regular distribution between the lower and upper limits of resolve variables [26]. There are two basic modes of the learning process, teacher phase and learner phase. The output of the algorithm is assessed in terms of results where the degrees of the learners depends on the quality of teacher [27].

7.1. Teacher phase

The teaching phase represents the process of student learning through the teacher. The superior learner in a subject in the population is the teacher due to his experience and knowledge. The distinction between the outcome of the teacher and the mean outcome of the learners in each topic can be calculated [28].

For any iteration *i* assume that there are m number of subjects (i.e. design variables), *n* number of learners (i.e. population size, k=1, 2, ..., n) and M (j, i) are the mean outcome of the learners in the same subject j (j=1, 2, ..., m). The superior gross results $X_{total-kbest,i}$ assessing all the topics together gained in the whole population of learners can be assessed as the result of best learner *kbest*. The distinction between the current average outcome of each subject and the coinciding outcome of each subject's teacher is given by:

$$Differene\_Mean_{j,k,i} = r_i(X_{j,kbest,i} - T_F\ M_{j,i}) \tag{22}$$

where $X_{j,kbest,i}$: is the outcome of best learner in subject j. T_F : is the teaching factor which determines the mean worth to be modified. r_i: is the random number in the range (0, 1).

The worth of T_F can be either 1 or 2. The worth of T_F with equal probability, it is decided randomly as (23):

$$T_F = \text{round } [1 + \text{rand } (0, 1) \{2 - 1\}] \tag{23}$$

T_F is not a parameter of TLBO algorithm and its worth is randomly settled by the algorithm using (23). The algorithm executes better if the worth of T_F is either 1 or 2. Based on the $Difference\_Mean_{j,k,i}$, the current solution is updated in the teacher phase according to the expression (24):

$$X'_{j,k,i} = X_{j,k,i} + Differene\_Mean_{j,k,i} \tag{24}$$

where $X'_{j,k,i}$ is the updated value of $X_{j,k,i}$ and accept $X'_{j,k,i}$ if it gives the better function value. All the accepted function values are maintained at the end of the teacher phase and these values represents the input to the learner phase. The learner phase depends on the teacher phase.

7.2. Learner phase

A learner interacts with other learners at random in order to improve her or his understanding. The learning phenomenon of this phase can be seen below, taking into account the population size of (n): Choose two learners at random, P and Q, so that:

$$X'_{total-P,i} \neq X'_{total-Q,i} \tag{25}$$

where:
$X'_{total-P,i}$ is the most recent value of $X_{total-P,i}$ at the ending of teacher stage.
$X'_{total-Q,i}$ is the most recent value of $X_{total-Q,i}$ at the ending of teacher stage.

$$X''_{j,P,i} = X_{j,P,i} + r_i (X_{j,P,i} - X_{j,Q,i}), if \ X'_{total-P,i} < X'_{total-Q,i} \tag{26}$$

$$X''_{j,P,i} = X_{j,P,i} + r_i(X_{j,Q,i} - X_{j,P,i}), if \ X'_{total-Q,i} < X'_{total-P,i} \tag{27}$$

Agree $X''_{j,P,i}$ if it results in a higher function value. Table 3 shows the most optimal TLBO parameters.

Table 3. Optimal parameters of TLBO algorithm

Setting Parameter	Value
Population No.	30
Max.loop (No. of iteration)	80

8. SIMULATION AND COMPARISON RESULTS

The TLBO algorithm is executed for minimization the search space for optimal applying of load shedding and capacitor placement technique for standard IEEE RDS 16 bus. This power system composed of 3 feeders, 16 buses, 16 branches, 28.7 MW and 14.9 MVAR loads based on the rating values of 23 kV and 100 MVA. The system data is provided in the reference [29] and see Figure 1.

The network is tested according to various models of load. Two dual techniques are implemented, dual distribution load shedding then capacitor placement DLS-OCP and dual capacitor placement then distribution load shedding OCP-DLS. The network is studied in the healthy case and for the faulty case after isolating one of the lines and the network is reconnected using a different tie-line.

8.1. IEEE 16 bus (health system case)

Table 4 demonstrates the results that obtained from comparing the various models of loads without and with (DLS-OCP) technique using three installed capacitors based on the optimum location by applying TLBO algorithm for healthy network case. The table findings demonstrate that the ZIP is the superior model for DLS-OCP approach among the other models. These results are enhanced by OCP-DLS technique using three capacitors based on the optimum placement by TLBO algorithm as demonstrated in the Table 5.
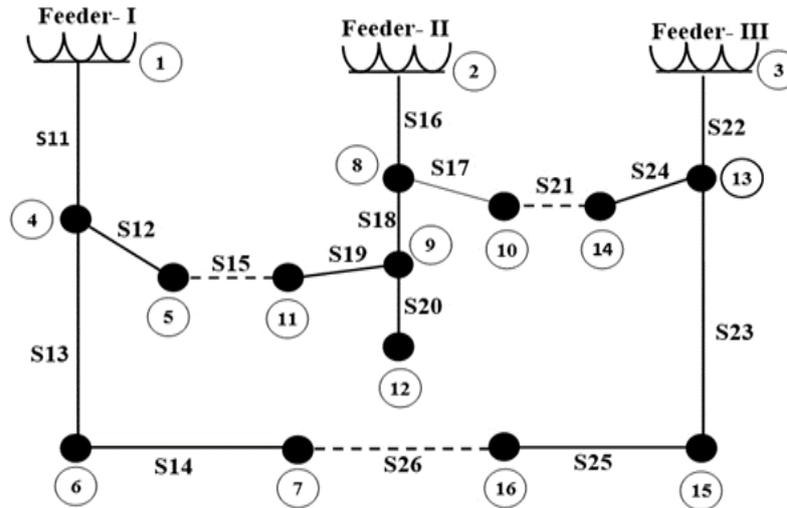
Figure 1. The IEEE-16 bus RDS single line diagram [29]

Table 4. Results of 16 bus network with and without dual (DLS-OCP) technique at healthy system

Item	Normal ($C.P$) model		($C.I$) model		($C.Z$) model		ZIP model	
	without	with	without	with	without	with	without	with
P. loss (kW)	511.003	266.83	483.63	225.37	459.329	200.25	426.470	161.1
Q. loss (kVAr)	577.99	317.88	547.62	267.58	520.615	237.81	483.106	191.87
Location	-	7, 13, 9	-	7, 13, 9	-	7, 13, 9	-	7, 13, 9
Shedding amount	-	0.256, 0.362, 0.168	-	0.195, 0.391, 0.123	-	0.306, 0.157, 0.159	-	0.142, 0.273, 0.143
Shedding percentage	-	26.2%	-	23.63%	-	20.73%	-	18.6%
Losses reduction%	-	47.78%	-	53.4%	-	56.4%	-	62.22%
Capacitor size (kVAr)	-	1500, 600, 900	-	1500, 900, 600	-	1500, 900, 600	-	1500, 900, 600
C_P ($)	-	598.2	-	598.2	-	598.2	-	598.2
C_A^B ($)	-	268538.229	-	254199.65	-	241418.59	-	224152.84
C_A^A ($)	-	146544.04	-	124752.67	-	111549.6	-	90972.36
Saving %	-	45.42%	-	50.92%	-	53.79%	-	59.41%
Vol.min. ($p.u.$)	0.9617	0.984	0.96301	0.986	0.96418	0.9868	0.96537	0.987
Vol.max. ($p.u.$)	Unity (1)	1	1	1	1	1	1	1

Table 5. Results of 16 bus network with and without dual (OCP-DLS) technique a healthy system

Item	Normal ($C.P$) model		($C.I$) model		($C.Z$) model		ZIP model	
	without	with	without	with	without	with	without	with
P.loss (kW)	511.003	253.38	483.63	217.43	459.329	198.62	426.470	152.97
Q.loss (kVAr)	577.99	250.82	547.62	259.07	520.615	235.95	483.106	151.43
Location	-	7, 13, 9	-	7, 13, 9	-	7, 13, 9	-	7, 13, 9
Shedding amount	-	0.184, 0.25, 0.114	-	0.128, 0.171, 0.184	-	0.155, 0.196, 0.121	-	0.17, 0.115, 0.125
Shedding percentage	-	18.26%	-	16.1%	-	15.73%	-	13.66%
Losses reduction%	-	50.41%	-	55.04%	-	56.75%	-	64.13%
Capacitor size (kVAr)	-	900, 600, 1500	-	900, 450, 1650	-	900, 450, 1650	-	900, 450, 1650
C_P ($)	-	598.2	-	597	-	597	-	597
C_A^B ($)	-	268538.229	-	254199.65	-	241418.59	-	224152.84
C_A^A ($)	-	139474.72	-	120578.2	-	110691.67	-	86698.03
Saving %	-	48.06%	-	52.56%	-	54.14%	-	61.32%
Vol. min. ($p.u.$)	0.9617	0.984	0.96301	0.986	0.96418	0.9866	0.96537	0.988
Vol. max. ($p.u.$)	Unity (1)	1	1	1	1	1	1	1

The table findings also show that employing the dual (OCP-DLS) technique, the voltage profile is improved and losses are reduced. In addition, the quantity of shed load in each bus is lowered. Figures 2 to 7 demonstrate the voltage profiles and power losses of branches for two dual techniques and indicate the dual (OCP-DLS) technique is superior than the dual (DLS-OCP) technique.
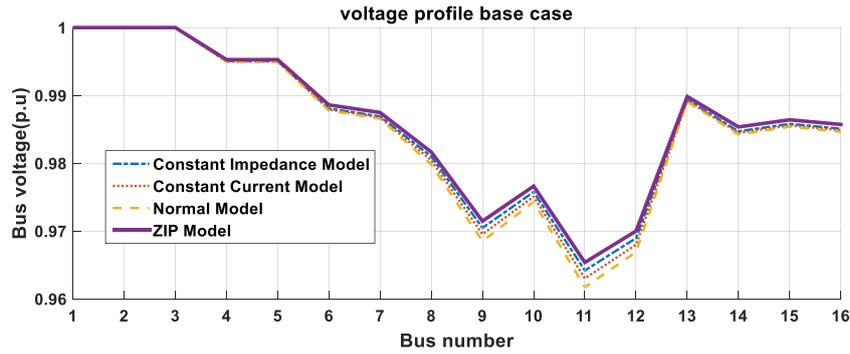
Figure 2. The values of voltage profile for 16 bus networks without any technique (base case) at the health system
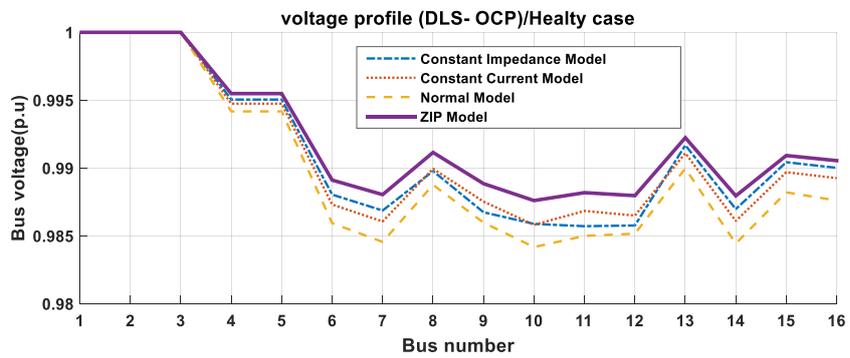

Figure 3. The values of voltage profile for 16 bus networks with dual (DLS-OCP) technique at health system
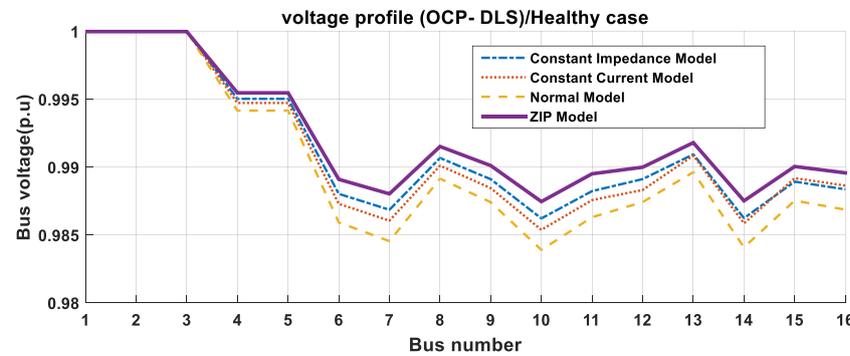

Figure 4. The values of voltage profile for 16 bus networks with dual (OCP-DLS) technique at health system
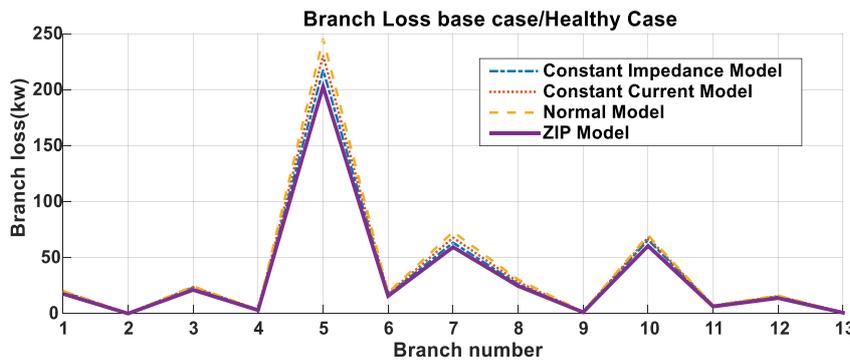

Figure 5. Losses of branches for 16 bus networks without any technique (base case) at health system
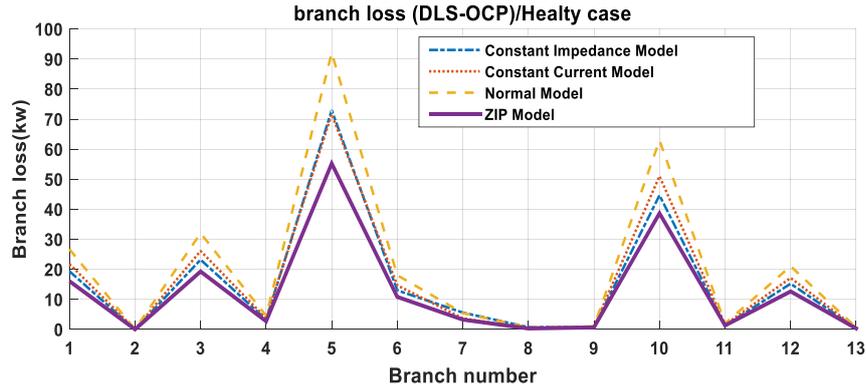
Figure 6. Losses of branches for 16 bus networks with dual (DLS-OCP) technique at health system case
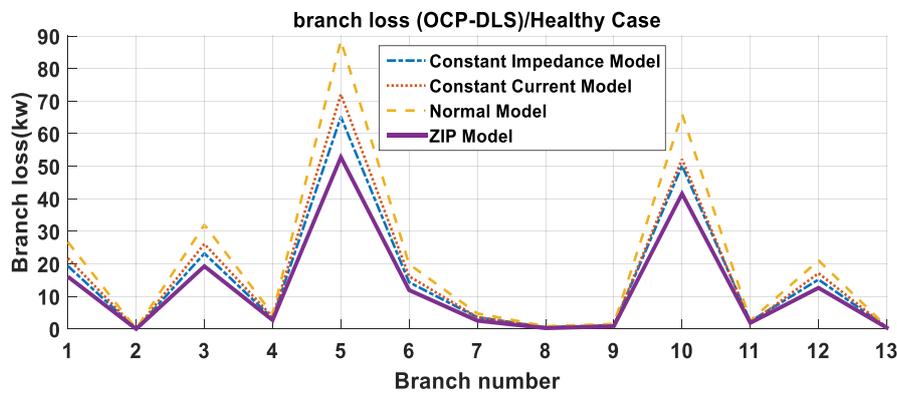

Figure 7. Losses of branches for 16 bus networks with dual (OCP-DLS) technique at health system case

8.2. IEEE 16 bus (fault system case)

Table 6 shows the outcomes and comparison among the various models of loads without and with dual (DLS-OCP) technique using installation three capacitors based on the optimum position by applying TLBO algorithm at fault system case. Line (13-14) is disconnected, and the network is then reconnected through tie-line (10-14) via tie switch, the information data of fault system is given in the reference [30]. The table findings demonstrate that the ZIP is the superior model for the DLS-OCP approach among the other models. The OCP-DLS technique, which uses three capacitors and is based on the TLBO algorithm optimal position, improves these findings, as shown in Table 7.

Table 6. Results of 16 bus network with and without dual (DLS-OCP) technique at fault system

Item	Normal $(C.P)$ model		$(C.I)$ model		$(C.Z)$ model		ZIP model	
	without	with	without	with	without	with	without	with
P.loss (kW)	729.75	317.68	675.71	248.65	629.52	231.03	590.72	180.87
Q.loss (kVAr)	789.43	315.32	732.25	246.67	683.32	230.59	640.62	179.47
Location	-	9, 13, 8	-	9, 13, 8	-	9, 13, 8	-	9, 13, 8
Shedding amount	-	0.113, 0.275, 0.252	-	0.17, 0.318, 0.11	-	0.113, 0.275, 0.15	-	0.158, 0.239, 0.101
Shedding percentage	-	21.3%	-	19.93%	-	17.93%	-	16.6%
Losses reduction %	-	56.46%	-	63.2%	-	63.3%	-	69.38%
Capacitor size (kVAr)	-	1650, 600, 750	-	900, 450 1650	-	900,450 1650	-	1200,150, 1650
C_P ($)	-	657.45	-	651	-	651	-	597.45
C_A^B ($)	-	383556.6	-	355153.17	-	330875.71	-	310482.43
C_A^A ($)	-	173330.05	-	137041.44	-	127780.36	-	101362.72
Saving %	-	54.8%	-	61.41%	-	61.38%	-	67.35%
Vol. min. $(p.u.)$	0.955	0.973	0.957	0.9766	0.9586	0.9768	0.9598	0.98
Vol. max. $(p.u.)$	Unity (1)	1	1	1	1	1	1	1

Table 7. Results of 16 bus network with and without dual (OCP-DLS) technique at fault system

Item	$Normal(C.P)$ model		$(C.I)$ model		$(C.Z)$ model		ZIP model	
	without	with	without	with	without	with	without	with
P.loss (kW)	729.75	282.34	675.71	240.24	629.52	220.27	590.72	170.93
Q.loss (kVAr)	789.43	280.04	732.25	233.11	683.32	218.59	640.62	169.54
Location	-	9, 13, 8	-	9, 13, 8	-	9, 13, 8	-	9, 13, 8
Shedding amount	-	0.121, 0.207, 0.17	-	0.142, 0.19, 0.165	-	0.157, 0.188, 0.115	-	0.104, 0.16, 0.192
Shedding percentage	-	16.6%	-	16.56%	-	15.33%	-	15.2%
Losses reduction%	-	61.31%	-	64.44%	-	65%	-	71.06%
Capacitor size (kVAr)	-	1350, 150, 1500	-	1350, 600 1050	-	1350, 600 1050	-	1650,450, 900
C_P ($)	-	655.95	-	650.85	-	650.85	-	597
C_A^B ($)	-	383556.6	-	355153.17	-	330875.71	-	310482.43
C_A^A ($)	-	154753.85	-	132620.99	-	122124.76	-	96137.8
Saving %	-	59.65%	-	62.65%	-	63.09%	-	69.03%
Vol. min. ($p.u.$)	0.955	0.973	0.957	0.9766	0.958	0.978	0.96537	0.9801
Vol. max. ($p.u.$)	1	1	1	1	1	1	1	1

The table findings also demonstrate that employing the dual OCP-DLS technique, the voltage profile was improved and losses were reduced. Furthermore, the shed load amount is reduced in each bus. Figures 8 to 13 demonstrate the voltage profiles of system buses and branch power losses for two dual approaches, indicating that the dual OCP-DLS technique is superior to the dual DLS-OCP technique.

It is clear from the results that the optimized dual (DLS-OCP) and (OCP-DLS) techniques are effective for achieving the lower (active and reactive) losses, preferable voltage profile, and maximize the frugality charge under the health and fault matters of power system. In addition, the results confirmed the optimized dual (OCP-DLS) technique has a superiority performance when compared to the dual (DLS-OCP) technique. Finally, the ZIP load model represent the best load model for distribution networks. Table 8 shows the comparison among the proposed TLBO algorithm and various procedures in the literature for reactive power compensation using capacitors without dual load shedding techniques, like improved binary particle swarm optimization algorithm (IBPSO) [31] and ant colony search algorithm (ACSA) [32].
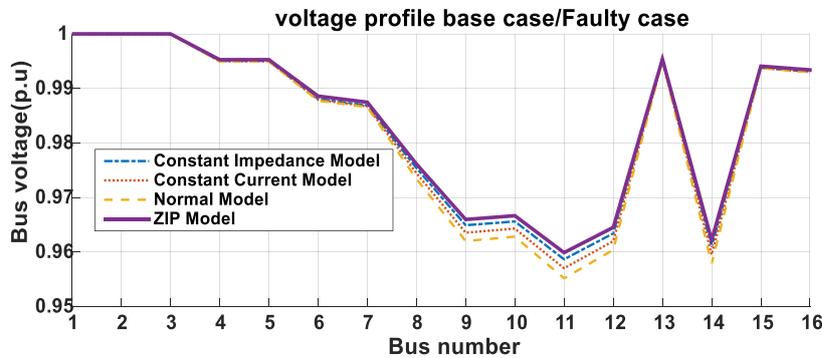

Figure 8. Values of voltage profile for 16 bus networks without any technique (base case) at fault system
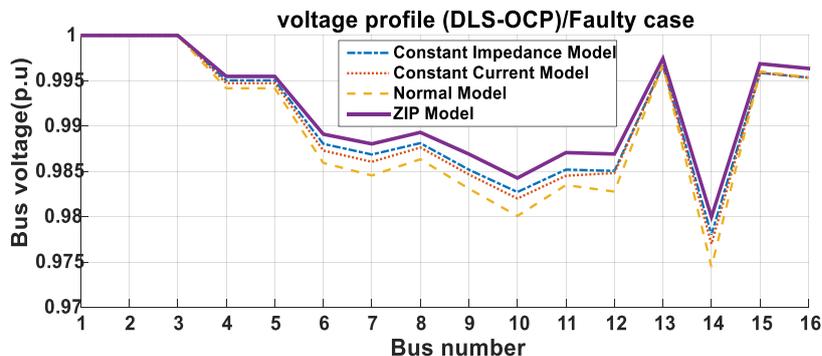

Figure 9. Values of voltage profile for 16 bus networks with dual (DLS-OCP) technique at fault system case
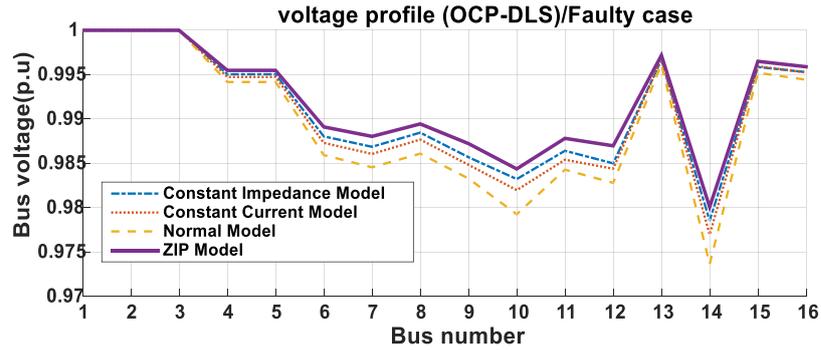
Figure 10. Values of voltage profile for 16 bus networks with dual (OCP-DLS) technique at fault system case
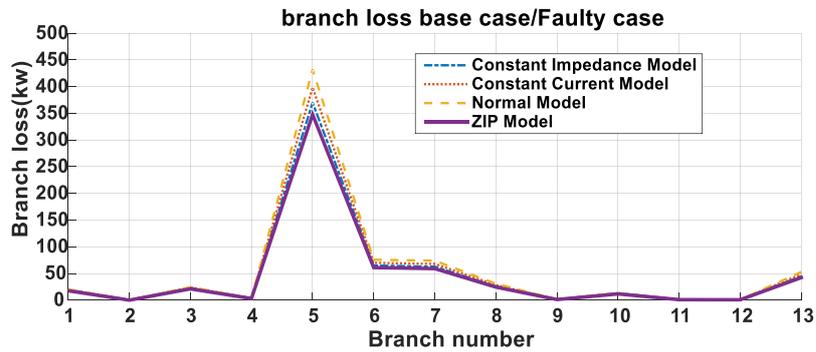

Figure 11. Losses of branches for standard 16 bus networks without any technique (base case) at fault system
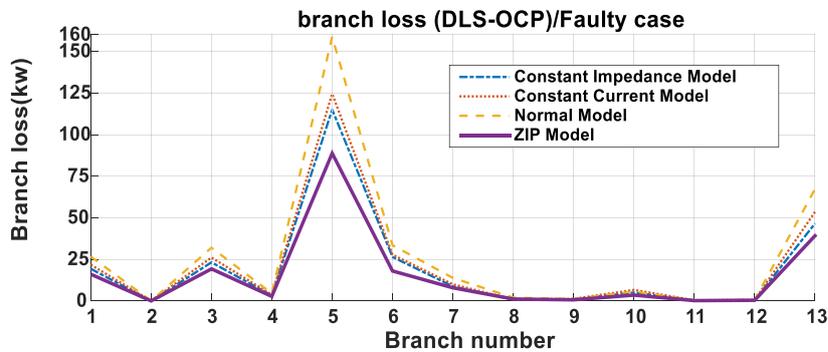

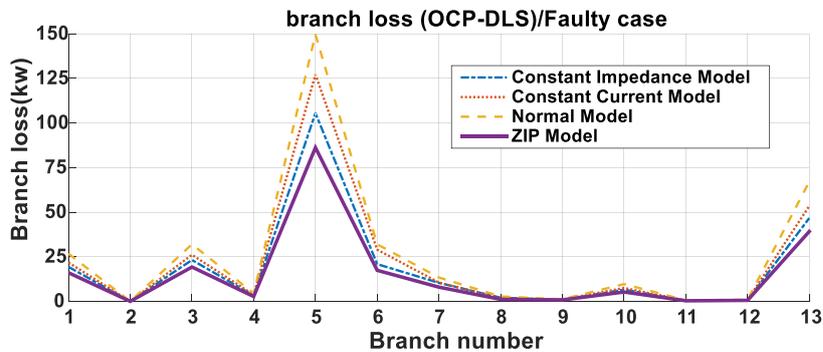Figure 12. Losses of branches for 16 bus networks with dual (DLS-OCP) technique at fault system case

Figure 13. Losses of branches for 16 bus networks with dual (OCP-DLS) technique at fault system case

Table 8. Comparison of various algorithms in the 16-Bus for optimal OCP-DLS

Parameters	Base Case	IBPSO (OCP) [31]	ACSA (OCP) [32]	TLBO, Healthy (ZIP Model)	TLBO, Faulty (ZIP Model)
Power losses (kW)	511.003	448.07	448.1	152.97	180.87
Location of buses	-	4, 7, 8, 9, 13	15, 21, 26	7, 13, 9	9, 13, 8
Capacitor sizes (kVAr)	-	1500, 900, 1800, 900, 900	NR*	900, 450, 1650	1650, 450, 900

NR*: Not Reported

9. CONCLUSION

In this paper, based on the dual (DLS-OCP) and (OCP-DLS) techniques, improving the voltage profile, achieving further reduction of power loss and minimizing the overall cost of the radial distribution system were presented with taking into consideration the distinct of load models. Because of the existence of diverse loads, inaccurate detail for load modeling leading to improper outputs with dispersion of exploitations and expenses. For both approaches, the TLBO optimization approach is implemented using search space minimization to determine the superior capacitor size and placement while minimizing shading. The findings illustrated the efficacy of the proposed methods for achieving optimum capacitor positions and minimum shedding quantity in the radial distribution system and their ability to dissolve multi-objective issues. The outcomes of contrast among the various models of loads indicated that the ZIP as the superior option for the positioning of shaded buses and sizing of capacitors for the two techniques. The comparison with previous researches, the TLBO offers the greatest potential for achieving the best settlement enabling significant loss reduction, cost savings, and enhancement of the voltage profile.

REFERENCES

[1] K. R. Gayathri and and G.V Maruteswar, "Frequency and voltage stability assessment applied to load shedding," *International Journal of Engineering Trends and Technology*, vol. 19, no. 2, pp. 106–115, Jan. 2015, doi: 10.14445/22315381/ijett-v19p219.

[2] S. Pérez, K. López, and L. Rodríguez, "Optimal under voltage load shedding based on voltage stability index," *Ingeniería e Investigación*, vol. 36, no. 2, Aug. 2016, doi: 10.15446/ing.investig.v36n2.53773.

[3] P. Chawla and V. Kumar, "Optimal load shedding for voltage stability enhancement by genetic algorithm," *International Journal of Applied Engineering Research*, vol. 7, no. 11, pp. 2066–2070, 2012.

[4] R. M. Larik, M. W. Mustafa, S. Qazi, and N. H. Mirjat, "Under voltage load shedding scheme to provide voltage stability," *Energy, Environment and Sustainable Development (EESD)*, 2016

[5] H. Mokhlis, J. A. Laghari, N. A. Yusof, M. Karimi, H. A. Illias, and N. M. Sapari, "Under-voltage load shedding scheme based on voltage stability index for distribution network," in *3rd IET International Conference on Clean Energy and Technology (CEAT)*, 2014, vol. 2014, doi: 10.1049/cp.2014.1470.

[6] I. Kaffashan, S. M. T. M. Mortezaee, and T. Amraee, "A robust undervoltage load shedding scheme against voltage instability," *Turkish Journal of Electrical Engineering and Computer Sciences*, vol. 24, no. 4, pp. 3309–3320, 2016, doi: 10.3906/elk-1411-182.

[7] R. M. Larik, M. W. Mustafa, and A. O. Otuoze, "A new technique of load shedding to stabilize voltage magnitude and fast voltage stability index by using hybrid optimization," *ARPN Journal of Engineering and Applied Sciences*, vol. 13, no. 8, pp. 2734–2745, 2018

[8] J. Modarresi, E. Gholipour, and A. Khodabakhshian, "New adaptive and centralised under-voltage load shedding to prevent short-term voltage instability," *IET Generation, Transmission and Distribution*, vol. 12, no. 11, pp. 2530–2538, Jun. 2018, doi: 10.1049/iet-gtd.2017.0783.

[9] Z. Mat Yasin, "Optimal undervoltage load shedding using ant lion optimizer," *International Journal of Simulation: Systems, Science & Technology*, vol. 17, no. 41, Jan. 2016, doi: 10.5013/IJSSST.a.17.41.47.

[10] M. Klaric, I. Kuzle, and S. Tesnjak, "Example of undervoltage load shedding implementation," in *AFRICON 2007*, Sep. 2007, pp. 1–6, doi: 10.1109/AFRCON.2007.4401446.

[11] N. M. Sapari, H. Mokhlis, J. A. Laghari, A. H. A. Bakar, and M. R. M. Dahalan, "Application of load shedding schemes for distribution network connected with distributed generation: a review," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 858–867, Feb. 2018, doi: 10.1016/j.rser.2017.09.090.

[12] S. Nawaz and A. Tando, "A solution to capacitor placement problem for the minimization of power loss in distribution system," *Skite Research Journal*, vol. 4, no. 2, pp. 38–42, 2014

[13] H. Zayandehroodi, M. Amirinejad, H. Afzalynia, and A. Noori, "Particle swarm optimization algorithm for optimal capacitor placement on electric power distribution networks," *International Journal of Scientific and Engineering Research*, vol. 5, no. 8, pp. 381–386, 2014

[14] N. Rostami and M. O. Sadegh, "The effect of load modeling on load flow results in distribution systems," *American Journal of Electrical and Electronic Engineering*, vol. 6, no. 1, pp. 16–27, 2018

[15] U. Eminoglu and M. H. Hocaoglu, "A new power flow method for radial distribution systems including voltage dependent load models," *Electric Power Systems Research*, vol. 76, no. 1–3, pp. 106–114, Sep. 2005, doi: 10.1016/j.epsr.2005.05.008.

[16] S. Mok, S. Elangovan, C. Longjian, and M. Salma, "A new approach for power flow analysis of balanced radial distribution systems," *Electric Machines & Power Systems*, vol. 28, no. 4, pp. 325–340, Apr. 2000, doi: 10.1080/073135600268298.

[17] D. Das, "Optimal placement of capacitors in radial distribution system using a fuzzy-GA method," *International Journal of Electrical Power and Energy Systems*, vol. 30, no. 6–7, pp. 361–367, Jul. 2008, doi: 10.1016/j.ijepes.2007.08.004.

[18] A. Elsheikh, Y. Helmy, Y. Abouelseoud, and A. Elsherif, "Optimal capacitor placement and sizing in radial electric power systems," *Alexandria Engineering Journal*, vol. 53, no. 4, pp. 809–816, Dec. 2014, doi: 10.1016/j.aej.2014.09.012.

[19] A. A. El-Fergany and A. Y. Abdelaziz, "Artificial bee colony algorithm to allocate fixed and switched static shunt capacitors in radial distribution networks," *Electric Power Components and Systems*, vol. 42, no. 5, pp. 427–438, Apr. 2014, doi: 10.1080/15325008.2013.856965.

[20] M.-R. Haghifam and O. P. Malik, "Genetic algorithm-based approach for fixed and switchable capacitors placement in distribution systems with uncertainty and time varying loads," *IET Generation, Transmission and Distribution*, vol. 1, no. 2, 2007, doi: 10.1049/iet-gtd:20045267.

[21] R. S. Rao, S. V. L. Narasimham, M. R. Raju, and A. S. Rao, "Optimal network reconfiguration of large-scale distribution system using harmony search algorithm," *IEEE Transactions on Power Systems*, vol. 26, no. 3, pp. 1080–1088, Aug. 2011, doi: 10.1109/tpwrs.2010.2076839.

[22] M. Sedighizadeh, M. Ghalambor, and A. Rezazadeh, "Reconfiguration of radial distribution systems with fuzzy multi-objective approach using modified big bang-big crunch algorithm," *Arabian Journal for Science and Engineering*, vol. 39, no. 8, pp. 6287–6296, Aug. 2014, doi: 10.1007/s13369-014-1249-6.

[23] V. Tamilselvan, T. Jayabarathi, T. Raghunathan, and X.-S. Yang, "Optimal capacitor placement in radial distribution systems using flower pollination algorithm," *Alexandria Engineering Journal*, vol. 57, no. 4, pp. 2775–2786, Dec. 2018, doi: 10.1016/j.aej.2018.01.004.

[24] P. S. R. Murty, *Power system analysis*. BS Publications, 2007.

[25] S. C. Satapathy, A. Naik, and K. Parvathi, "A teaching learning based optimization based on orthogonal design for solving global optimization problems," *SpringerPlus*, vol. 2, no. 1, Dec. 2013, doi: 10.1186/2193-1801-2-130.

[26] A. Tiwary, "Reliability enhancement of distribution system using teaching learning based optimization considering customer and energy based indices," *International Journal on Future Revolution in Computer Science and Communication Engineering*, vol. 3, no. 10, pp. 58–62, 2017.

[27] M. El-Arini and A. Fathy, "An efficient and reliable method for optimal allocating of the distributed generation based on optimal teaching learning algorithm," *WSEAS Transcations on Power Systems*, vol. 10, pp. 188–197, 2015.

[28] P. J. Pawar and R. V. Rao, "Parameter optimization of machining processes using teaching–learning-based optimization algorithm," *The International Journal of Advanced Manufacturing Technology*, vol. 67, no. 5–8, pp. 995–1006, Jul. 2013, doi: 10.1007/s00170-012-4524-2.

[29] M. F. Sulaima, M. S. Shidan, W. M. Dahalan, H. Mokhlis, M. F. Baharom, and H. I. Jaafar, "A 16kV distribution network reconfiguration by using evolutionaring programming for loss minimizing," *International Journal of Applied Engineering Research*, vol. 9, no. 10, pp. 1223–1238, 2014.

[30] Z. Chen, "A study of power distribution system reconfiguration based on reliability indices," Faculty of the Graduate School, University of Missouri-Columbia, 2016.

[31] M. Sedighizadeh, M. Dakhem, M. Sarvi, and H. H. Kordkheili, "Optimal reconfiguration and capacitor placement for power loss reduction of distribution system using improved binary particle swarm optimization," *International Journal of Energy and Environmental Engineering*, vol. 5, no. 1, pp. 1–11, Mar. 2014, doi: 10.1007/s40095-014-0073-9.

[32] C. F. Chang, "Reconfiguration and capacitor placement for loss reduction of distribution systems by ant colony search algorithm," *IEEE Transactions on Power Systems*, vol. 23, no. 4, pp. 1747–1755, Nov. 2008, doi: 10.1109/TPWRS.2008.2002169.

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