

Optimum reactive power compensation for distribution system using dolphin algorithm considering different load models

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ABSTRACT

The distribution system represents the connection between the consumers and entire power network. The radial structure is preferred for distribution system due to its simple design and low cost. It suffers from problems of rising power losses higher than the transmission system and voltage drop. One of the important solutions to evolve the system voltage profile and to lower system losses is the reactive power compensation which is based on the optimum choice of position and capacitor size in the network. Different models of loads such as constant power (P), constant current (I), constant impedance (Z), and composite (ZIP) are implemented with comparisons among them in order to identify the most effective load type that produces the optimal settlement for minimization loss reduction, voltage profile enhancement and cost savings. Dolphin Optimization Algorithm (DOA) is applied for selecting the sizes and locations of capacitors. Two case studies (IEEE 16-bus and 33-bus) are employed to evaluate the different load models with optimal reactive power compensation. The results show that ZIP model is the best to produce the optimal solution for capacitors position and sizes. Comparison of results with literature works shows that DOA is the most robust among the other algorithms.

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1. INTRODUCTION

Design of structure radial distribution system (RDS) is preferred because of simple, low cost, more effective for protective devices and guaranteed the minimum value of fault currents. The RDS is suffering from many issues, including high real losses, voltage perversion of system buses, lopsided load and overload and these RDS issues can be resolved by employing many different methods [1]. These methods used to solve the RDS problems are Replacement of Conductors (RC) in RDS, voltage regulator (VR) for voltage control of generation unit, Distributed Generation (DG), techniques for reconfiguring distribution system (DSR) and optimizing capacitor positioning (OCP) [2, 3]. The methods of RC and DG are used in the special cases due to a huge cost for purchase and installation though receiving the benefit income from provision do not covered of these expenses [4]. The most effective and economical technique is the OCP where the cost of saving is exceeds the total investment cost.

OCP technique handled the reactive power that represented the most challenging mission in the electrical power system operation and control. The OCP is a process of reactive power control (injection or absorption) in the RDS that lead to voltage improvement and losses minimization [5]. In addition,

the reactive power compensation enhances system stability with power factor improvement; therefore the optimum picking of worth and location of capacitors is needful to achieve the objectives of RDS by minimizing overall cost [6]. The implementation of OCP technique includes the calculation of numbers, positions and values of capacitors needed to be positioned at the network nodes. Therefore, the installation of capacitors in the inappropriate locations causes many problems in the system such as an increasing the real losses and voltage drop of buses [7]. The minimization of the cost function while choosing the OCP for improving the network voltage profile with a minimization of active real losses and increasing of the power factor is provided in reference [8]. Optimal capacitor positioning and problem sizing solution is implemented using genetic algorithm. Electrical transient analyzer program (ETAP) is used for the assessment and resolving the network and genetic algorithm (GA) is utilized as a strategy for reducing the objective function to a minimum.

Many optimization methods have been applied for OCP technique such as the voltage stability index (VSI) providing optimum system buses for installation the capacitors whilst the cuckoo search (CS) optimization algorithm used to select the optimum capacitor size on two IEEE standard networks (34 and 69 bus) [9]. In a subsequent study, index of loss sensitivity (LSI) with VSI are utilized to provide optimal positions of capacitors whilst the optimum size in the IEEE-33 bus network was determined by bacterial foraging algorithm (BFA) [10]. The improving of VSI and maximizing of the total saving cost have been done based on artificial bee colony (ABC) algorithm, then LSI and VSI used to determine the location of capacitors [11]. Several researchers used LSI to determine the candidates of buses for capacitors and particle swarm optimization (PSO) optimization algorithm was applied to get optimum capacitor extent based on objective reduction of losses with voltage enhancement function for 10, 34 and 85-bus RDS [12]. Literature works dealt with OCP technique have some drawbacks such as break the constraint limits for buses voltage and total size of capacitors. In addition, the objective functions (voltage profile enhancement and losses reduction) that used in these works as an individual not group together.

In this paper, OCP technique was implemented using DOA algorithm to solve multi-objective functions problems such as a reduce actual active real power losses, raise the cost savings annually, and voltage profile enhancement while retaining the (RDS) qualifications. The DOA algorithm used searching for optimum positions and sizes of capacitors on system buses without considering the VSI and LSI indices that specified in the former studies. The offered technique has been implemented on 16 and 33 bus standard IEEE RDSs with four models of loads which are constant power model (P), constant current model (I), constant impedance model (Z), and ZIP model for the purpose of identification the most effective load which produces optimal solution for historic reduction of losses and improvement of voltage profile.

2. OPTIMAL CAPACITOR PLACEMENT FOR DISTRIBUTION SYSTEM

An electrical distribution power system is a connection between the consumers and the majority of power system. The shunt capacitors provide the deficient amount of reactive power that rises the voltage reduction and high power losses. Therefore, the optimal capacitor banks are incorporated into the radial distribution system (RDS) for rising the power factor, enhancement of voltage profile, and loss reduction. The previous access to this issue involves [13]:

- Analytical methods
- Numerical programming methods to minimize or maximize an objective function using iterative techniques
- Heuristics techniques
- Artificial intelligent methods.

The optimal problem of capacitor placement investigates the best adjustment between capacitors cost and their system benefits. Total cost of capacitor placement technique include purchase costs, fixed installation costs, and operating costs. The cost function is represented as a step-like function instead of a continuously differentiable function as virtually capacitors are assimilated in banks of standard discrete capacity with non-linear capacitor bank size related costs [14].

3. MODELING OF LOADS IN A POWER FLOW ANALYSIS

The results of power flow and stability researches represent the choices needed for enhancement of the system performance. So, all models of components must be incorporated in a one mathematical model to represent the complete power system. Modeling of loads can has a considerable impact on the analysis results. It gives many advantages like reducing losses, improving in the voltage profile, regulating the voltage (under/over) the specified value and actual calculation of active and reactive power demand at individual nodes. There are two types of models for load representation, the static and dynamic load model and this

article concerns with static load model. The static load model is a most basic is the one used for power flow solutions and has two types: exponential and polynomial load models [15].

3.1. Exponential load model

This model extracts the active and reactive power as a function for the voltage and frequency of the bus bar. The design model of static load is given as function of exponential voltage (V)

$$P_d = P_0 (V/V_0)^{n_p} \quad (1)$$

$$Q_d = Q_0 (V/V_0)^{n_q} \quad (2)$$

where (P_d, Q_d) represents the desire of actual real active and reactive power of load, (P_0, Q_0) represent active and reactive power consumption of load, (n_p, n_q) represent active and reactive power exponent, V is the supply voltage and V_0 is the rated voltage. The customary values of n_p and n_q are listed in Table 1. These values are calculated based on the field of measurements with parameter estimation method.

Table 1. General values for different load exponents [16]

Load	n_p	n_q
Lamps (Flourcent)	2.07	3.21
Air conditioning	0.5	2.5
Coolers and Pumps	0.08	1.6
Lamps (Incandescent)	1.54	0
Light Bulbs	1	0.35
Small type motors	0.1	0.6
Large type motors	0.05	0.5
Constant P(Power)	0	0
Constant I (Current)	1	1
Constant Z(Impedance)	2	2

3.2. Polynomial load model

There are different kinds of loads in electrical power systems and each node has a certain percentage of such loads and these changes over time. One of the most exceedingly used models is the ZIP model and it is called ZIP that represents an integration of constant power load (P), constant current load (I) and constant impedance (Z) models. This model is expressed as in reference [17]:

$$P = \alpha P_0 V^2 + \beta P_0 V + \gamma P_0 \quad (3)$$

$$Q = \alpha Q_0 V^2 + \beta Q_0 V + \gamma Q_0 \quad (4)$$

$$\alpha + \beta + \gamma = 1 \quad (5)$$

where $(\alpha, \beta$ and $\gamma)$ represent the proportion contribution of constant impedance (Z), constant current (I) and constant power load (P) at any given system node. The real active and reactive powers are exclusive examined based on the variations in voltage, but the difference in power based on the variations in frequency is not investigated. In this paper the values of these parameters are selected: $\alpha=0.6$, $\beta=0.2$ and $\gamma=0.2$ which produce the best results for losses reduction and voltage profile improvement.

4. DOLPHIN OPTIMIZATION ALGORITHM (DOA)

Dolphins originally explore all locations in the searching space around it to detect out the prey. In the instant of a dolphin reaches the target, the dolphin narrow the searching process and increment the swell clicks for the purpose of concentration on the prey location. This optimization method emulates the control of tracking the dolphin echolocation relative to the distance from the bait [18].

The search space should be sorted before the start of an optimization process based on the following arranging method [19]. During this process, sort the alternatives in the searching space with an inclined order for each optimizable variable. If the alternates are more than one feature included, then the arranging based on the extreme remarkable one is performed. By using this method, the variable j of vector A_j and length LA_j is produced that includes all likely choises of the j th variable. Such vectors are positioned beside for each

other alternatives matrix columns. The matrix of $(MA - NV)$ that created in which MA represents the maximum of $(LA_j)_{j=1:N}$ and NV represents the number of variables. The rate of convergence must decreased significantly with the optimization steps of the searching and as a result the curve should be specified and this decreased is investigated as:

$$PP (LOOP_i) = PP_1 + (1 - PP_1) \frac{LOOP_i^{power} - 1}{LOOPsNumber^{power} - 1} \quad (6)$$

where PP is the predefined probability, PP_1 represents the convergence rate of the initially loop in which the solutions are selected randomly, $LOOP_i$ is the current loop number, $power$ is the curve degree and $LOOPsNumber$ is the loop number for which the algorithm should be reached to the convergence point and the selecting of this number is done by user based on the difficulty and complexity of computational efforts that can be implemented from the optimization algorithm. The main steps of DOA algorithm are [20]:

Step1: Initialization DOA setting parameters as listed in Table 2.

The initial swarm dolphin is generated randomly and evenly:

$$\text{Swarm } Dol = \{Dol_1, Dol_2, \dots, Dol_N\} \text{ in the D-Dimensional space} \quad (7)$$

Calculate each dolphin fitness and obtain:

$$Fit_K = \{Fit_{K,1}, Fit_{K,2}, \dots, Fit_{K,N}\} \quad (8)$$

Step 2: Start chain

When the end condition is not achieved do the following:

Step 2.1: Search phase

Within the highest search time, the sound V_j that Dol_i makes search for a new solution at time t X_{ijt} which equals

$$X_{ijt} = (Dol_i + V_{jt})$$

and its fitness function can be calculated

$$E_{ijt} = \text{Fitness} (Dol_i + V_{jt}) \quad (9)$$

$$Fit_l = \{ \min. \{ E_{1jt} \}, \min. \{ E_{2jt} \} \dots \min. \{ E_{Njt} \} \} \quad (10)$$

$$Fit_{K,i} = \begin{cases} Fit_{L,i} & \text{if } Fit_{L,i} < Fit_{K,j} \\ Fit_{K,j} & \text{otherwise} \end{cases} \quad (11)$$

Step 2.2: Call phase

$$TS_{i,j} = \begin{cases} \frac{DD_{i,j}}{A.speed} & \text{if } Fit_{K,j} < Fit_{K,i} \text{ and } TS_{i,j} > \frac{DD_{i,j}}{A.speed} \\ Fit_{K,j} & \text{otherwise} \end{cases} \quad (12)$$

where $TS_{i,j}$ is $N \times N$ -order matrix called the transmission time matrix represents the residual time for the sound to be transferred from Dol_j to Dol_i .

$DD_{i,j}$ is a distance between Dol_i and Dol_j which can be represented as follows:

$$DD_{i,j} = \|Dol_i - Dol_j\|, i, j = 1, 2 \dots N, i \neq j$$

A is a constant symbolizing the acceleration that can cause sounds to spread more rapidly when the speed is rather slow. Speed is a constant of the quality of speed sound.

Step 2.3: Reception phase

$TS_{i,j}$ reduces one unit time

$$Fit_{K,i} = \begin{cases} Fit_{K,j} & \text{if } TS_{i,j} = 0 \text{ and } Fit_{K,j} < Fit_{K,i} \\ Fit_{K,i} & \text{otherwise} \end{cases} \quad (13)$$

Step 2.4: Predation phase
 Calculate DK_i and DKL_i ,
 if $DK_i \leq R_1$

$$R_2 = \left\{1 - \frac{2}{e}\right\} DK_i \quad (14)$$

where DK_i , represents distance between Dol_i and K_i which can be expressed as:

$$DK_i = \|Dol_i - K_i\|, i = 1, 2, \dots, N$$

DKL_i is the distance between L_i and K_i which can be expressed as:

$$DKL_i = \|L_i - K_i\|, i = 1, 2, \dots, N$$

R_1 : Represents the search process maximum range and can be calculated as:

$$R_1 = T_1 \times \text{speed}$$

R_2 : Represents the surrounding radius which, according to the known information, defines the distance between the optimal solution of the dolphin neighborhood and its position after the predation phase, and then gets a new position.

e : Constant referred to as (radius reduction coefficient) greater than two, typically set to three or four.

Else if $DK_i \geq DKL_i$

$$R_2 = \left\{1 - \frac{\frac{DK_i}{\text{Fitness}(K_i)} - \frac{DKL_i - DK_i}{\text{Fitness}(L_i)}}{e \cdot DK_i \frac{1}{\text{Fitness}(K_i)}}\right\} DK_i \quad (15)$$

End if

Dol_i gets a new position, calculate its fitness, and update $Fit_{k,i}$

output the best one of K_i ($i=1, 2, \dots, N$) (16)

where K_i represents the optimum solution

The optimal parameters of DOA are listed in Table 2.

Table 2. Optimal parameters of DOA

Parameter	Value
Population No.	10
Predefined Probability	0.1
Max. loop=No. of Iteration (IEEE 16-Bus)	60
Max. loop=No. of Iteration (IEEE 33-Bus)	75

5. OBJECTIVE FUNCTIONS

The use of multi objective functions is useful reducing actual active real power losses and enhancing of voltage profile based on the suggested optimization methods and techniques. Such objective functions (*ob. fun.*) are:

a. Reduction of actual power losses (*ob. fun. 1*):

$$ob. fun. 1 = P_{loss} \quad (17)$$

$$P_{loss} = \sum_{l=1}^{N_{br}} P_{lossl} \text{ kW} \quad (18)$$

$$P_{lossl} = I_l^2 * R_l \text{ kW} \quad (19)$$

where: (P_{loss}) represents the total actual real power losses, (N_{br}) is the number of system branches, (R_l) is resistance of branch l and (I_l) is current flow in the branch l .

b. Voltage profile improvement(*ob. fun. 2*):

The voltages buses must be within the acceptable range limits.

$$ob. fun. 2 = V_C * Re_v + C_C * Re_i \quad (20)$$

where:

V_C : Limits of the bus voltages.

C_C : Limits of the branch currents.

Re_v : Bus voltage retribution variable. If the bus voltage is within acceptable limits, this parameter is zero.

Re_i : Factor of retribution for branches currents. It equal to zero if the thermal limit value is not reached by current of branch.

c. Annual saving cost increment (*ob. fun. 3*):

The objective of loss reduction using the reactive compensation is to increase the annual saving cost that regarding to the cost of active power losses and investment cost of installed capacitors. The investment cost of capacitors includes purchase cost, installation and operation cost of capacitors. The annual saving cost is equal to the disparity between base case losses cost and losses cost application the proposed strategies plus the investment costs as explained as follows [21]:

$$C_P = \sum_{c=1}^{N_c} Q_c * C_{Pc} \quad \$ \quad (21)$$

$$C_I = C_P + \sum_{c=1}^{N_c} (C_{Ic} + C_{Oc}) \quad \$ \quad (22)$$

$$C_A = C_{En} * Time * P_{loss} + C_I \quad \$ \quad (23)$$

$$C_A^B = C_{En} * Time * P_{loss}^B \quad \$ \quad (24)$$

$$C_A^A = C_{En} * Time * P_{loss}^A + C_I \quad \$ \quad (25)$$

$$ob. fun. 3 = max(C_{sav}) = C_A^B - C_A^A \quad \$ \quad (26)$$

where,

C_P : Total capacitor purchase cost in dollar (\$).

C_{Pc} : Capacitor purchase cost per kVAr in (\$/kVAr).

C_I : Total capacitor investment cost in (\$).

C_{Ic} : Capacitor installation cost per location in (\$/Loc_c).

C_{Oc} : Annual capacitor operation cost per location in (\$/Loc_c/Year).

C_A^B : Annual losses cost before application any technique in (\$)

C_A^A : Annual losses cost after application of the techniques in (\$)

C_{sav} : Annual saving cost in (\$)

C_{En} : Energy losses cost in (\$/kWh)

$Time$: Operation time per year in (h)

P_{loss}^B : Real power losses before application any technique in (kW).

P_{loss}^A : Real power losses after application of techniques in (kW).

N_c : Number of injected capacitors.

Q_c : Size of injected capacitors in (kVAr).

The sizes and costs of capacitors are shown in Table 3. The worths of cost parameters capacitors are tabulated in Table 4 that used for whole cost calculations [22].

Table 3. Sizes and annual cost of fixed capacitors [23]

Size (kVAr)	Purchase Cost (\$/kVAr)	Size (kVAr)	Purchase Cost (\$/kVAr)	Size (kVAr)	Purchase Cost (\$/kVAr)
150	0.5	1500	0.201	2850	0.183
300	0.35	1650	0.193	3000	0.180
450	0.253	1800	0.187	3150	0.195
600	0.220	1950	0.211	3300	0.174
750	0.276	2100	0.176	3450	0.188
900	0.183	2250	0.197	3600	0.170
1050	0.228	2400	0.170	3750	0.183
1200	0.170	2550	0.189	3900	0.182
1350	0.207	2700	0.187	4050	0.179

Table 4. Normal cost-parameters worths

Parameter	Worth
C_{Ic}	1600(\$/Loc _c)
C_{Oc}	300(\$/ Loc _c /year)
C_{En}	0.06(\$/kWh)
Time	8760(h)

The following objective functions which are reduction of the actual power loss(*ob.fun.1*), improvement of voltage profile(*ob.fun.2*), and annual saving cost (*ob.fun.3*) are blended to form the compound final objective function(*ob.fun.f*).

$$ob.fun.f = ob.fun.1 + ob.fun.2 + ob.fun.3 \quad (27)$$

6. GENERAL CONSTRAINTS

The general restrictions(constraints), including advanced performance for the RDS are defined as follows in terms of technical and operational restrictions(constraints).

6.1. Technical constraints

Such types of restrictions (constraints) are characterized as limiting variance and are splitted into three categories:

a. Constraints of bus voltage

The voltage value for each one of the system buses should be inside their specified level range to maintain the quality of power:

$$|V_{jmin.}| \leq |V_j| \leq |V_{jmax.}| \quad j \in N_{bus}, \quad (28)$$

where (N_{bus}) represents the number of buses on the system. The specific standard limits (min. - max.) of the bus system voltage are (0.95-1.05) p. u.

b. Constraints of branch current

Branch current from the safety side must not surpass its limited value while at the same time maintaining the consistency of load power delivery.

$$|I_l| \leq |I_{lmax.}| \quad l \in N_{br.} \quad (29)$$

where ($N_{br.}$) is the number of system branches. Where the maximum capacity for each branch of power system have been specified in the reference [24].

c. Constraints for total sizing of capacitors

The total sizing of capacitors (Q_{CT}) that incorporated in the RDS should not exceed than the actual total reactive power of load(Q_{load}).

$$Q_{CT} \leq Q_{load} \quad (30)$$

6.2. Operational constraints

Such types of constraints are known as equality limits and are split into two types:

a. Radial constraints affecting all system loads

The radial configure condition of the system is validated through finding the determinant result of bus incidence matrix [A] that have rows represent the number of branches and columns represent the number of buses as follows [22]:

$$[A] = \begin{cases} 1 & \text{if branch } i \text{ is out from bus } j \\ -1 & \text{if branch } i \text{ is enter bus } j \\ 0 & \text{if branch } i \text{ is not connected to bus } j \end{cases} \quad (31)$$

b. Constraint of balancing real power

$$P_{Sup} = P_{Dem} + P_{loss} \quad (32)$$

Where (P_{Sup}) is the total supplied of active real power to the network and (P_{Dem}) is the overall load active real power.

7. RESULTS AND ANALYSIS

The DOA algorithm is implemented using m-file programs in MATLAB R2015b. This algorithm is implemented to minimize the search space to choose the size and location of capacitors for two standard IEEE RDSs (16 and 33 bus).The bus and line data are provided in reference to two test cases [25].

7.1. IEEE 16 Bus RDS

Figure 1 shows the RDS one line diagram of this network study. This network contains 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. Considering various load models (constant P, constant I, constant Z, and ZIP models), the network is tested. Backward-Forward load flow method is used to analyse the network without and with capacitors that placed in optimal locations based on dolphin optimization algorithm. Table 5 shows the obtaining results and comparison among different load models without and with reactive power compensation by placement three capacitors based on the optimal placement using dolphin algorithm.

It is inferred from Table 5 that ZIP Load is the most effective load for providing optimum solution for significant loss reduction, voltage profile improvement and cost saving. Table 6 indicates the reactive power compensation that made by optimal placement for three capacitors in the system buses based on the Dolphin algorithm. Figures 2 to Figure 7 display network bus voltage profiles, branch currents, branch power loss without and with the compensation of reactive power.

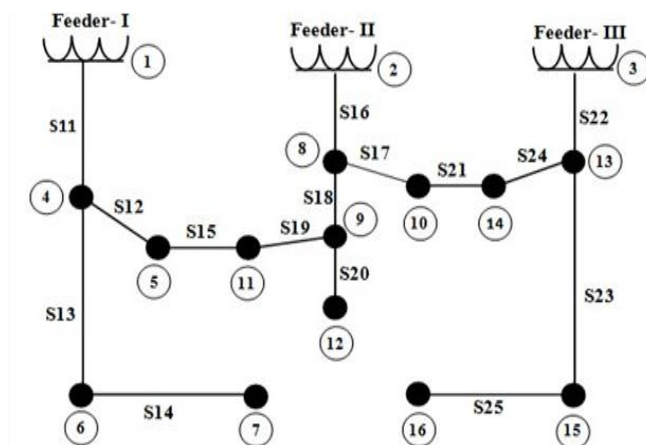


Figure 1. Single line diagram of IEEE 16 bus RDS

Table 5. IEEE 16-bus RDS results and comparisons among various load models without and with reactive power compensation

Item	Constant Power Load		Constant Current Load		Constant Impedance Load		ZIP Load	
	Without	With	Without	With	Without	With	Without	With
Active power loss (kW)	511.003	156.62	483.63	127.14	459.329	109.14	426.470	99.523
Reactive power loss (kVAr)	577.99	152.56	547.62	123.87	520.615	105.55	483.106	97.129
Minimum voltage (p. u.)	0.9617	0.962	0.96301	0.967	0.96418	0.9692	0.96537	0.9717
Maximum voltage (p. u.)	1	1	1	1	1	1	1	1

Table 6. Optimal capacitor sizes, locations and costs in the IEEE 16-bus network

Item	Constant Power Load	Constant Current Load	Constant Impedance Load	ZIP Load
	Capacitor Locations	9, 13, 8	9, 13, 8	9, 13, 8
Capacitor Size (kVAr)	750, 150, 1500	600, 150, 1650	900, 150, 1350	900, 150, 1350
C_p (\$)	583.5	525.45	519.15	519.15
C_A^B	268583.229	254199.659	241418.59	224152.84
C_A^A	88602.972	73050.234	63583.134	58528.438
Saving ($C_A^B - C_A^A$) %	67.01 %	71.26 %	73.662 %	73.889 %

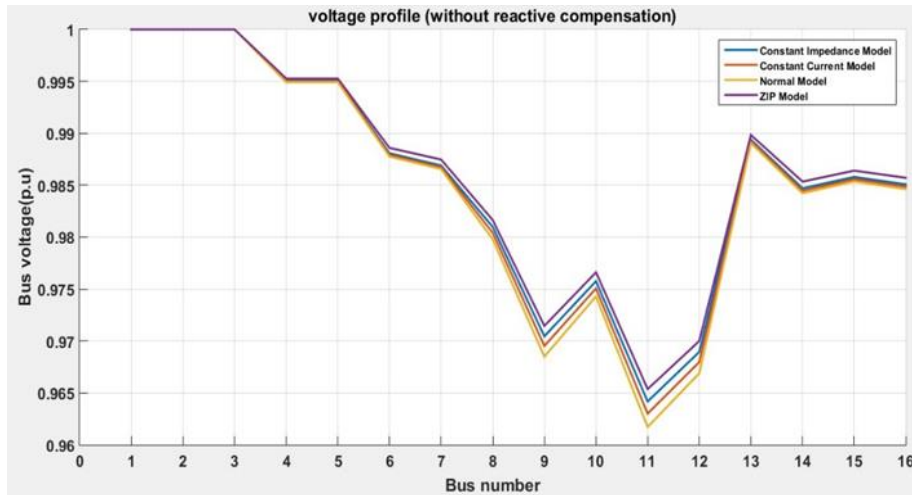


Figure 2. Voltage profile for IEEE 16-bus network without reactive power compensation

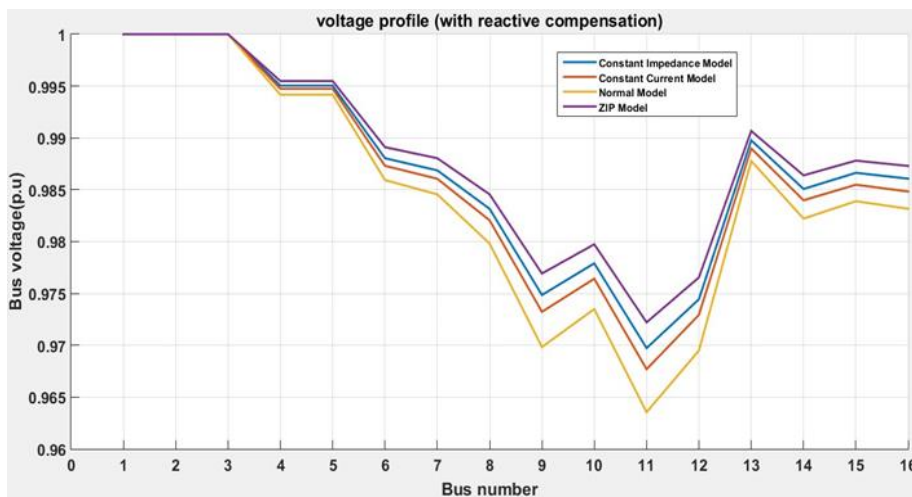


Figure 3. Voltage profile with reactive power compensation for IEEE 16-bus network

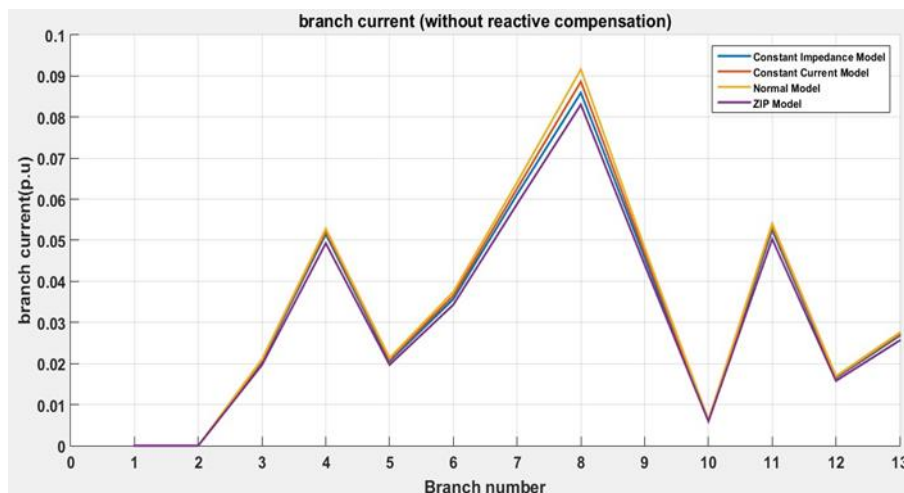


Figure 4. Branch currents without reactive power compensation for IEEE 16-bus network

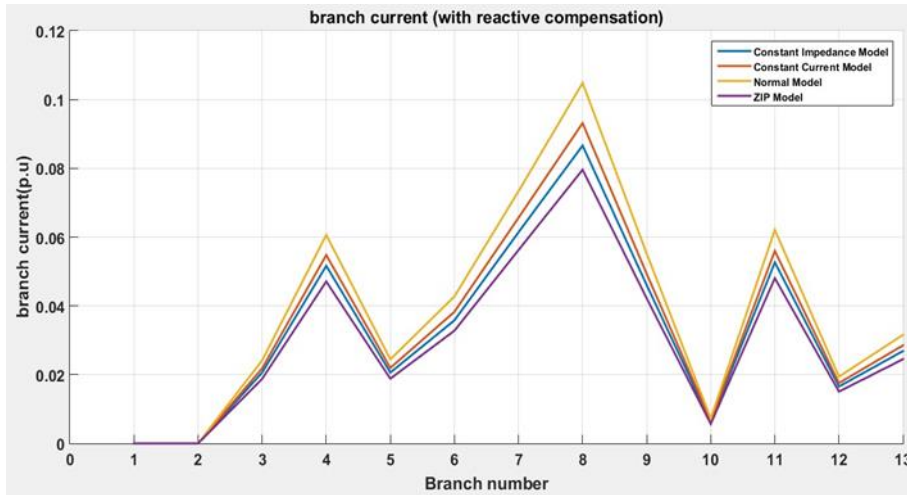


Figure 5. Branch currents with reactive power compensation for IEEE 16-bus network

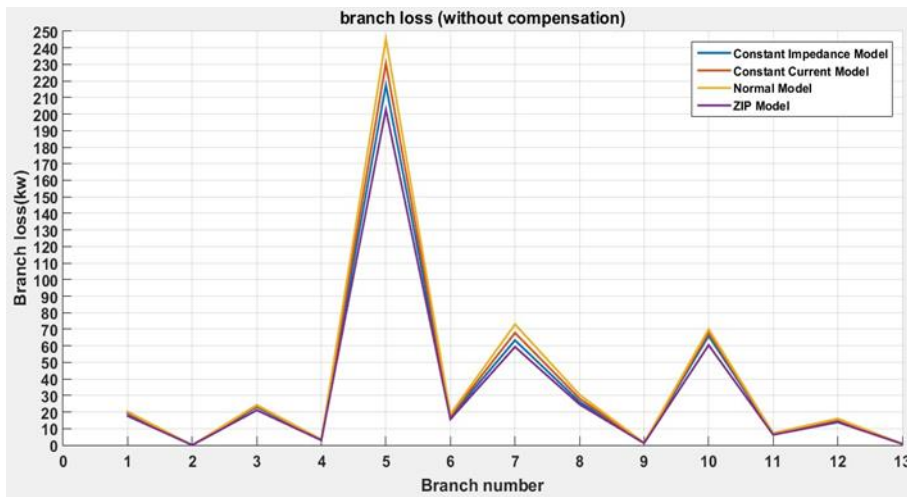


Figure 6. Branch loss without reactive power compensation for IEEE 16-bus network

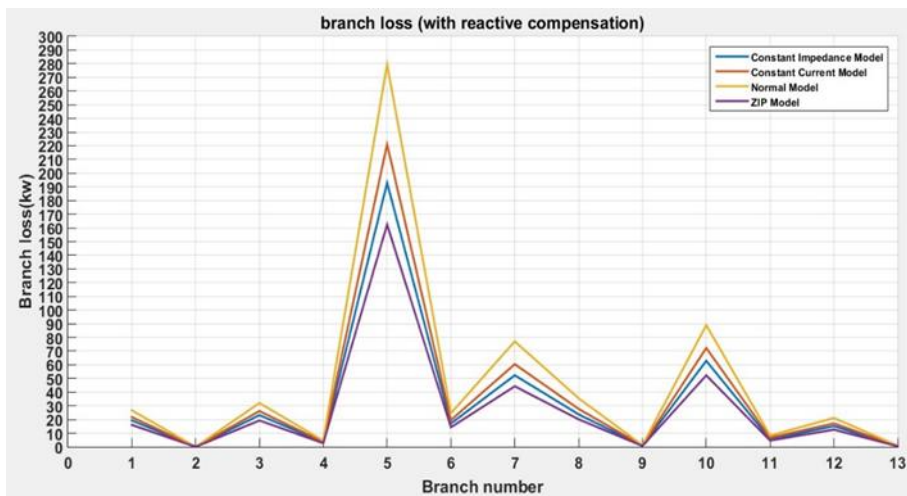


Figure 7. Branch loss with reactive power compensation for IEEE 16-bus network

These figures show the improvement in the voltage profile, decreasing of the currents in the system branches and reduction in the active power losses for the system branches after reactive power compensation using optimal capacitor placement technique for different load models. In addition, the results indicated that ZIP model is the best one among all load models for the voltage profile and reduction of losses without reactive compensation and it produced the superior solution after optimal reactive power compensation.

The comparison between the proposed DOA with different methods in the literature such as improved binary particle swarm optimization (IBPSO) [25] algorithm and ant colony search algorithm (ACSA) [26] are listed in Table 7. The comparison of results with some literature works by using different load models for distribution system instead of using constant power loads which showed the robustness and effectiveness of the proposed dolphin algorithm to achieve the best settlement to get worthy losses rebate, better buses voltage values, and cost savings.

Table 7. The comparison of different algorithms for optimal reactive compensation in 16-bus system

Parameters	Base Case	IBPSO [26]	ACSA [27]	DOA (ZIP Model)
Power losses(kW)	511.003	448.07	448.1	99.523
Location of buses	-	4, 7, 8, 9, 13	15, 21, 26	9, 13, 8
Capacitor sizes (kVAr)	-	1500, 900, 1800, 900, 900	NR*	900, 150, 1350

NR*: Not Reported.

7.2. IEEE 33 Bus RDS

The RDS single line diagram for second case study is shown in Figure 8. This system contains (1 main, 3 lateral) feeders, 33 buses, 37 branches, (3715 kW, 2300 kVAr) loads based on the system rating values of (12.66 kV, 100 MVA). The procedures for reactive power compensation are implemented through the placement of three capacitors with considering all the load models. Dolphin optimization algorithm is used for the optimal selection of capacitor placement based on the objective functions of losses reduction and voltage profile enhancement. Backward-Forward load flow method is used to analyze the network without and with capacitors that placed in optimal locations based on dolphin optimization method. Table 8 shows the obtaining results and comparison among different load models without and with reactive power compensation.

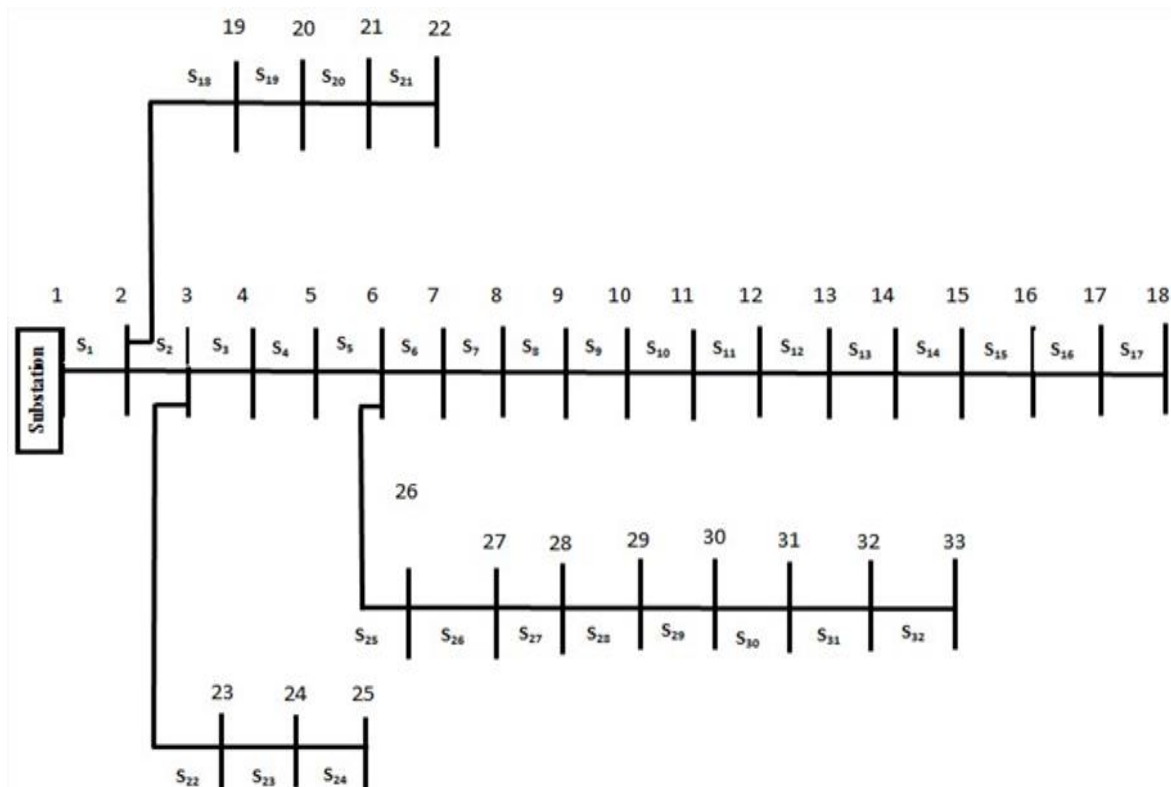


Figure 8. Single line diagram of IEEE- 33 bus RDS

Table 8. IEEE 33-bus RDS results and comparisons among various load models without and with reactive power compensation

Item	Constant Power Load		Constant Current Load		Constant Impedance Load		ZIP Load	
	Without	With	Without	With	Without	With	Without	With
Active power loss (kW)	202.677	123.67	176.627	104.33	156.87	91.27	151.14	86.377
Reactive power loss (kVAr)	135.14	128.09	117.514	108.45	104.175	94.96	100.474	89.909
Min.voltage (p.u)	0.913	0.95	0.9193	0.95	0.9244	0.95	0.9256	0.95
Max.voltage (p.u.)	1	1	1	1	1	1	1	1

From Table 8 it is concluded that ZIP Load is the most effective load to produce the optimal solution for significant loss reduction. Table 9 indicates the reactive compensation that made by optimal placement for three capacitors in the system buses based on the Dolphin algorithm. Also, this table shows the effectiveness of DOA algorithm for achieving the significant loss reduction and more saving in the total capacitor sizes with ZIP Load than others load models. Figure 9 to Figure 14 show the voltage profile of system buses, branch currents, branch active power loss without and with reactive power compensation.

Table 9. Optimal capacitor sizing and locations in the IEEE 33-bus network

Item	Constant Power Load	Constant Current Load	Constant Impedance Load	ZIP Load
Capacitor Locations	24, 31, 13	24, 31, 13	24, 31, 13	24, 31, 13
Capacitor Size (kVAr)	450, 750, 150	450, 750, 150	450, 750, 150	450, 750, 150
C_p (\$)	395.85	395.85	395.85	395.85
C_A^B	106527.03	92835.15	82450.87	79439.18
C_A^A	71096.802	60931.69	54067.36	51495.6012
Saving ($C_A^B - C_A^A$) %	33.25 %	34.36 %	34.42 %	35.176 %

These figures show the improvement in the voltage profile, decreasing of the currents in the system branches and reduction in the active power losses for the system branches after reactive power compensation using optimal capacitor placement technique for different load models. In addition, the results indicated that ZIP model is the best one among all load models for the voltage profile and reduction of losses without reactive compensation and it produced the superior solution after optimal reactive power compensation.

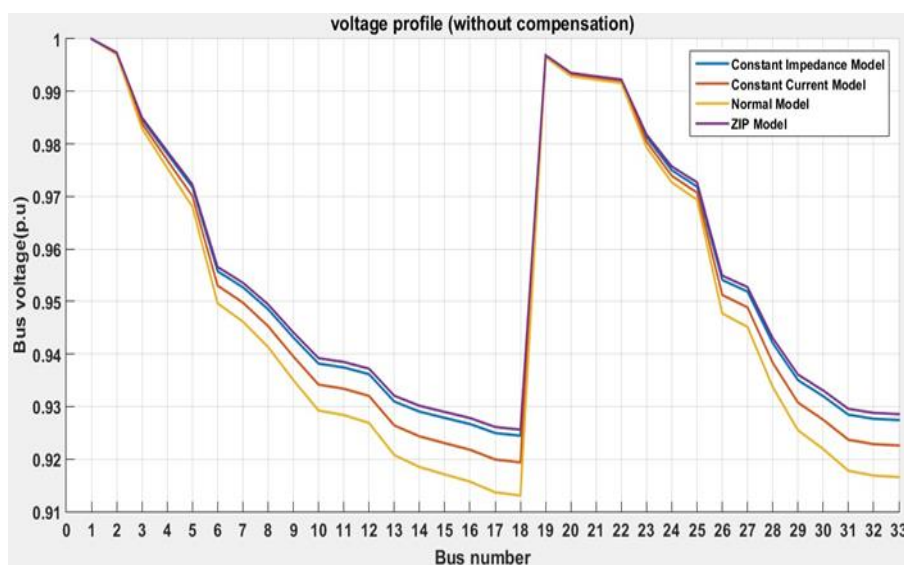


Figure 9. Voltage profile for IEEE 33-bus network without reactive power compensation

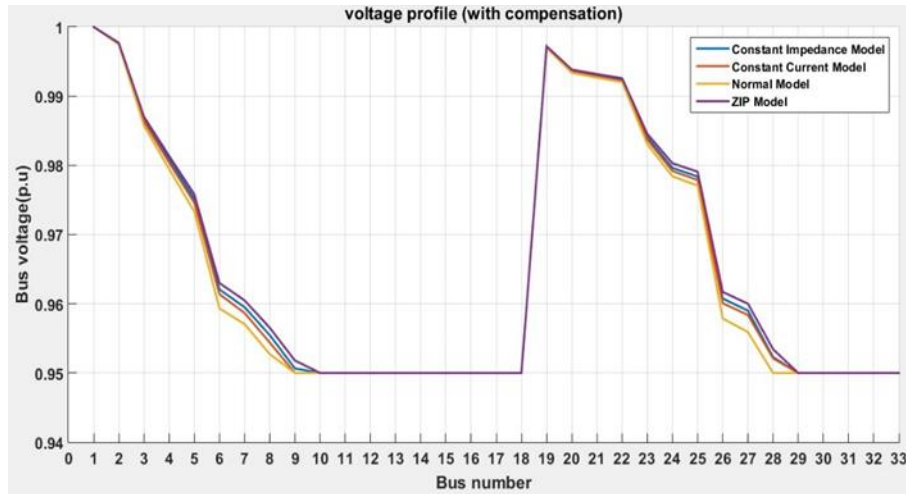


Figure 10. Voltage profile for IEEE 33-bus network with reactive power compensation

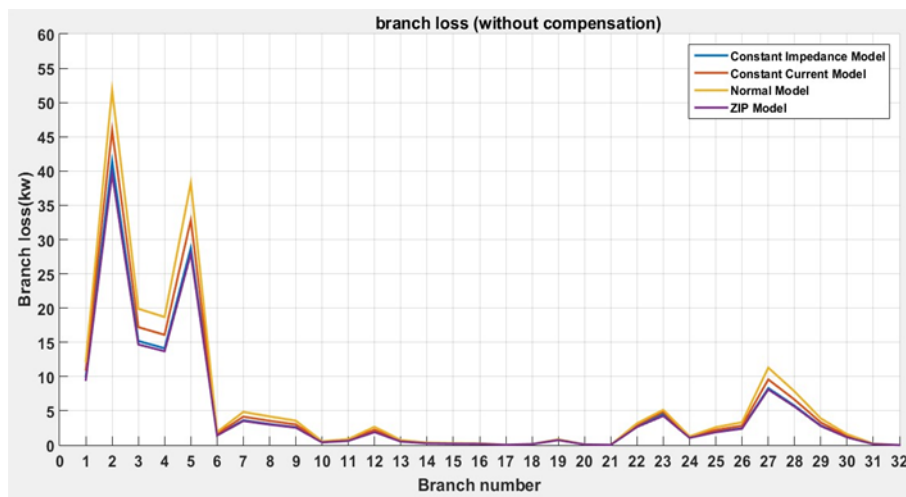


Figure 11. Branch loss without reactive power compensation for IEEE 33-bus network

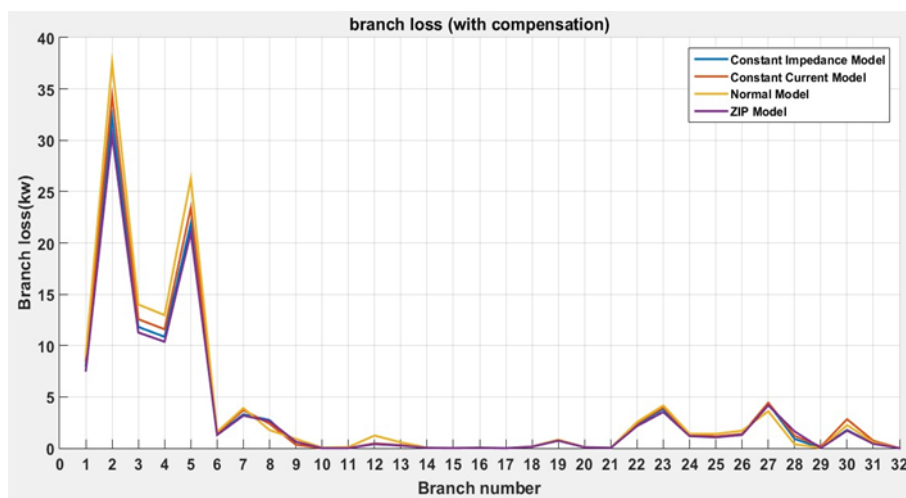


Figure 12. Branch loss with reactive power compensation for IEEE 33-bus network

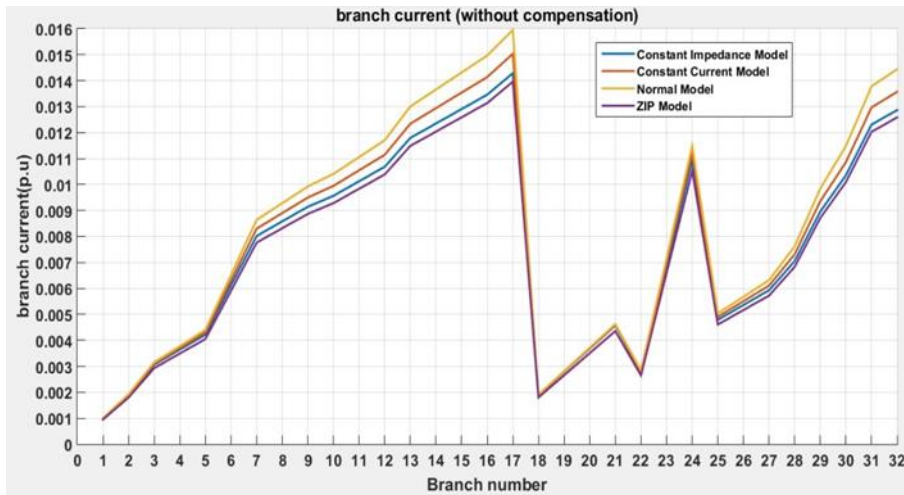


Figure 13. Branch current without reactive power compensation for IEEE 33-bus network

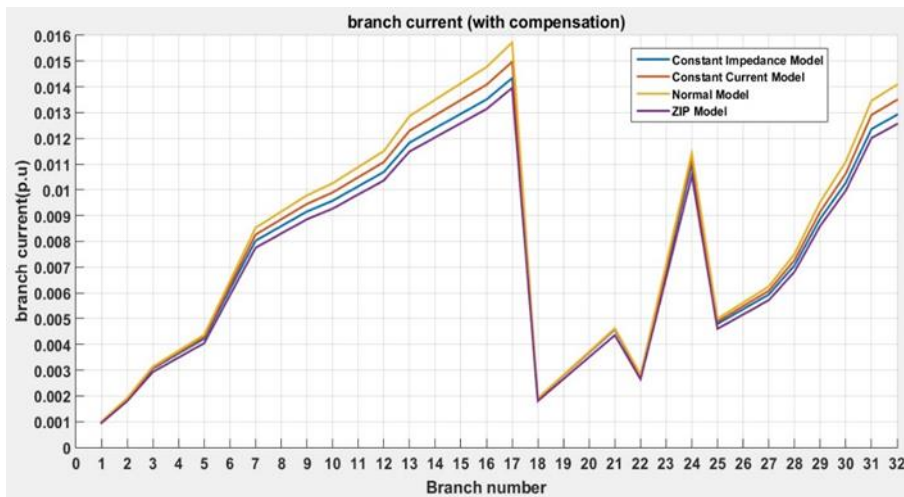


Figure 14. Branch current with reactive power compensation for IEEE 33-bus network

The comparison between the proposed DOA with different methods in the literature such as group search optimization (GSO) [27] algorithm and modified flower pollination (MFP) [28] algorithm are listed in Table 10. The comparison of results with some literature works by using different load models for distribution system rather than using the constant power loads that demonstrated the superiority and effectiveness of dolphin algorithm to achieve the optimum solution to reduce significant losses, enhancement of voltage profile and saving cost.

Table 10. The comparison of different algorithms for optimal reactive compensation in 33-bus system

Parameters	Base Case	GSO Algorithm [28]	MFP Algorithm [29]	Dolphin Algorithm (ZIP Model)
Power Losses (kW)	202.6771	143.76	139.57	86.377
Candidate Buses	-	8, 30, 31	6, 28, 29	24, 31, 13
Capacitor Values (kVAr)	-	900, 760, 250	750, 150, 850	450, 750, 150

8. CONCLUSION

The improvement of voltage profile, achieving more power losses reduction and minimization the total cost in the radial distribution system considering different load models have been presented in this paper based on the reactive power compensation technique. As the nature of different loads, the inaccurate

detailed for load modeling leads to wrong results with waste of investments and costs. The dolphin optimization method is applied for optimal reactive compensation by minimizing the search space for selecting the optimal size and location of capacitors. This technique has been employed for IEEE 16 and 33 bus test systems. The results show the effectiveness of the proposed method to obtain the optimal locations of capacitors in distribution systems and its capability to solve multi-objective problems. The comparison results among the different load models confirmed that ZIP model is the best to produce the optimal solution for placement and size of capacitors. Furthermore, the comparison of results with literature works has shown that the DOA has a greater ability to obtaining the optimum solution for significant reduction of losses, cost savings and improvement of voltage profile.

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