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ORIGINAL ARTICLE

Optimal siting of capacitors in radial distribution network using Whale Optimization Algorithm

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KEYWORDS

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Optimal allocation and sizing of capacitors;
Power loss reduction and voltage stability improvement;
Radial distribution system;
Operating cost minimization

Abstract In present days, continuous effort is being made in bringing down the line losses of the electrical distribution networks. Therefore proper allocation of capacitors is of utmost importance because, it will help in reducing the line losses and maintaining the bus voltage. This in turn results in improving the stability and reliability of the system. In this paper Whale Optimization Algorithm (WOA) is used to find optimal sizing and placement of capacitors for a typical radial distribution system. Multi objectives such as operating cost reduction and power loss minimization with inequality constraints on voltage limits are considered and the proposed algorithm is validated by applying it on standard radial systems: IEEE-34 bus and IEEE-85 bus radial distribution test systems. The results obtained are compared with those of existing algorithms. The results show that the proposed algorithm is more effective in bringing down the operating costs and in maintaining better voltage profile.

1. Introduction

Electric power distribution system normally operates at low voltage levels and current is generally high. Majority of the distribution systems feed inductive loads which leads to higher power losses in the distribution network and poor power factor accompanied by voltage sags. So, the cost of the power increases. It is reported that about 13% of the total generation is lost in the low voltage distribution network as line losses [1]. Therefore it is necessary to find alternate approaches to overcome these problems and ensure stability, reliability and quality of electric power supply. Connecting capacitors is a well-known solution to the above stated problems [2,3]. Shunt capacitors effectively reduce power loss in the system. Generally, these are used as reactive power compensators in the network. Capacitors will improve the overall system performance by maintaining voltage levels within the acceptable limits [4,5]. But improper placing of capacitors leads to even higher system losses and voltage drops [6].Therefore proper planning and designing is required to place the capacitors. In the recent past, research has concentrated on placing the capacitors in the

Abbreviations WOA, Whale Optimization Algorithm; RDS, Radial Distribution System; BFOA, Bacterial Foraging Optimization Algorithm; MILP, Mixed Integer Linear Programming; MINLP, Mixed Integer Non-Linear Programming; PGS, Plant Growth Simulation; PSO, Particle Swarm Optimization; GA, Genetic Algorithm; FPA, Flower pollination Algorithm; IHA, Improved harmony Algorithm; GSA, Gravitational Search Algorithm; BSOA, Backtracking Search Optimization Algorithm; TLBO, Teaching Learning Based Optimization

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Nomenclature

P_p	real power flow from bus p	V_p	voltage at bus p
Q_p	reactive power flow from bus p	V_{p+1}	voltage at bus $p + 1$
P_{Lp}	real power load connected at bus p	K_i	cost co-efficient in $/kWh
Q_{Lp}	reactive power load connected at bus p	K_c	cost co-efficient in $/kVAr
$P_{L(p+1)}$	real power load connected at bus $p + 1$	Q_{pc}	reactive power compensation
$Q_{L(p+1)}$	reactive power load connected at bus $p + 1$	$V_{\min}$	minimum value of bus voltage
$R_{p,p+1}$	resistance connected between the buses p and $p + 1$	$V_{\max}$	maximum value of bus voltage
$X_{p,p+1}$	reactance connected between the buses p and $p + 1$	$P_{\text{Total loss}}$	total power loss in the system

distribution network. Many optimization techniques are proposed to find the optimal size and location of the capacitors in the distribution network.

Few researchers have used classical techniques to obtain optimal placement of capacitors considering only loss reduction as the objective [7,8]. Classical methods have disadvantages such as difficulty in escaping local minima and difficulty to handle discrete control variables [9]. However, research has been carried out by using Mixed Integer Non-Linear Programming and Heuristic approaches as well. Devabalaji et al. have presented Bacterial Foraging Optimization Algorithm (BFOA) to find optimal size and site for capacitor placement [10]. Franco et al. have used Mixed Integer Linear Programming (MILP) technique for placing voltage regulators and capacitors in a distribution network [11]. Oliveira et al. have used Mixed Integer Non-Linear Programming (MINLP) approach to obtain optimum size of the capacitor to further reduce system losses [12]. Plant Growth Simulation (PGS) is another method used for optimal siting of the capacitors for voltage improvement and loss reduction [13]. Prakash et al. have used Particle Swarm Optimization (PSO) method for finding capacitor placement and size [14]. Genetic Algorithm (GA) based approach for capacitor placement is reported in [15]. Sayyad et al. have proposed Mixed Integer Non-Linear Programming (MINLP) for finding location of capacitors to reduce power loss [16]. Shuaib et al. used Gravitational Search Algorithm (GSA) for finding optimal location of capacitors [17]. Backtracking Search Optimization Algorithm (BSOA) is used for optimal allocation of multi-type distributed generators in distribution system for reducing system losses and increasing voltage stability [18]. Niknam et al. [19] presented Teaching Learning Based Optimization (TLBO) approach to find optimal place of automatic voltage regulators in distribution systems. Ali et al. [20] presented Improved Harmony Algorithm (IHA) to find the optimal allocation and sizing of capacitors in distribution network. Abdelaziz et al. [21] presented Flower Pollination Algorithm (FPA) technique for robust tuning of static VAR compensator to mitigate power system oscillations. To find out the optimal place and size of capacitors in radial distribution system Flower Pollination Algorithm is presented in [22]. However the above mentioned algorithms appear to be effective, but they may not guarantee reaching optimal cost value and are difficult to escape from the local minima.

In this work, a new method of optimization based on the behavior of Whales called as Whale Optimization Algorithm (WOA) is applied to find optimal location and size of capacitors in a power distribution network for the first time. It is a nature enthused meta-heuristic optimization algorithm. The purpose of developing such heuristic algorithms is to decrease the search space. The proposed method is tested on standard 34 bus and 85 bus test systems by considering multi objectives-cost reduction, loss minimization and voltage profile improvement. From the literature survey, it is clear that application of WOA has not been discussed so far to solve for capacitor placement in distribution system. This encourages taking up this algorithm for the above said problem. Comparison of the results obtained by the proposed algorithm with those of PSO, PGS, MINLP and BFOA methods reveals that, optimal size and location of capacitors as obtained by the new Whale Optimization Algorithm (WOA) are more effective in cost reduction and maintaining voltage profile.

2. Whale Optimization Algorithm (WOA)

This is a nature enthused meta-heuristic optimization algorithm and it is derived based on the behavior of the humpback whales. Whales are considered as the biggest animal in the world. According to Hof and Van Der Gucht [23], certain cells in the brain of whales are similar to those of human beings. These whales search their food by the special behavior called bubble-net feeding method [24]. This method of searching is based on creating bubbles by encircling or through '9'-shaped path [25].

This behavior of searching is modeled mathematically as two phases [26].

2.1. Searching and encircling prey

Searching prey can be modeled by using Eqs. (1) and (2):

$$D = |C \cdot X_{rand} - X| \tag{1}$$

$$X(t+1) = X_{rand} - A \cdot D \tag{2}$$

where variables A and C are coefficient vectors represented as

$$A = 2 \cdot a \cdot r - a \tag{3}$$

$$C = 2 \cdot r \tag{4}$$

where 'a' is linearly decreasing from 2 to 0 and 'r' is the random number between $[0, 1]$.

$$D = |C \cdot X^*(t) - X(t)| \tag{5}$$

$$X(t+1) = X^*(t) - A \cdot D \tag{6}$$

Here if $A \geqslant 1$, searching prey represented by Eqs. (1) and (2), otherwise encircling prey by shrinking mechanism represented by Eqs. (5) and (6) are used, where t is the current iteration, X is the position vector and X^* is the best value of the position vector so far.

2.2. Spirally updating position

Position updating is represented by Eq. (7):

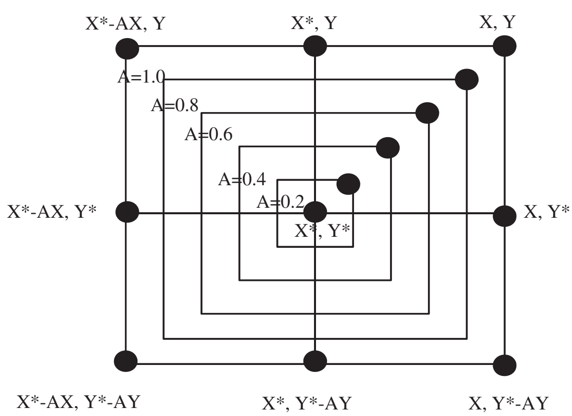

Figure 1 Bubble net searching mechanism in WOA.

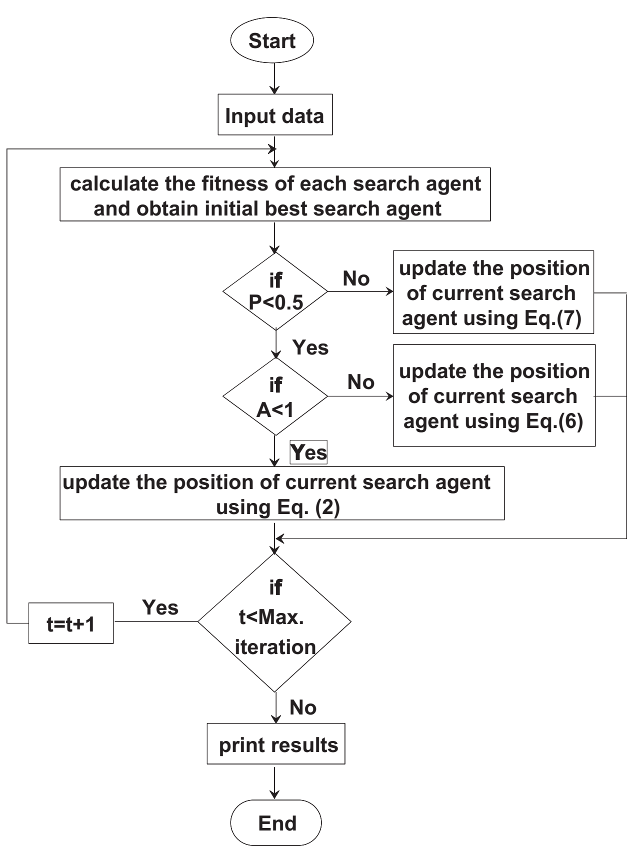

Figure 2 Flowchart of proposed WOA.

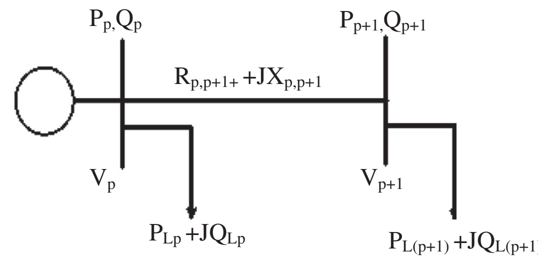

Figure 3 Simple radial distribution network.

$$X(t+1) = \begin{cases} X^*(t) - A \cdot D & \text{if } p < 0.5 \\ D \cdot e^{bl} \cdot \cos(2\Pi l) + X^*(t) & \text{if } p \geqslant 0.5 \end{cases} \tag{7}$$

where 'p' is the random number between [0, 1], 'l' is between [−1, 1] and 'b' is constant for describing the spiral shape. Fig. 1 shows bubble net searching mechanism in WOA and Fig. 2 shows flowchart of the proposed algorithm.

3. Power flow calculation

To arrive at the equations to calculate power flow in the distribution network, single line diagram of the simple radial distribution system as shown in Fig. 3 is considered, where p is sending end node and p + 1 is receiving end node.

Real and reactive power flows are calculated by using the following set of equations, Eqs. (8) and (9) derived from the single line diagram shown in Fig. 3:

$$P_{p+1} = P_p - P_{L(p+1)} - R_{p,p+1} * \frac{\left(P_p^2 + Q_p^2\right)}{|V_p|^2} \tag{8}$$

$$Q_{p+1} = Q_p - Q_{L(p+1)} - X_{p,p+1} * \frac{\left(P_p^2 + Q_p^2\right)}{|V_p|^2} \tag{9}$$

Line voltages are calculated using Eq. (10):

$$|V_{p+1}|^2 = |V_p|^2 - 2(R_{p,p+1} \cdot P_p + X_{p,p+1} \cdot Q_p) + \left(R_{p,p+1}^2 + X_{p,p+1}^2\right) \cdot \frac{\left(P_p^2 + Q_p^2\right)}{|V_p|^2} \tag{10}$$

Real power loss in the line can be calculated by using Eq. (11):

$$P_{\text{loss}}(p, p+1) = R_{p,p+1} * \frac{\left(P_p^2 + Q_p^2\right)}{|V_p|^2} \tag{11}$$

Total power loss in the system is calculated by summing up all the line losses as shown in Eq. (12):

$$P_{\text{Total loss}} = \sum_{p=1}^{n-1} P_{\text{loss}}(p, p+1) \tag{12}$$

3.1. Objective function

The objective function of the projected work is to minimize the operating cost and minimizing real power loss of the system. The mathematical construction of the objective function is given as

$$OF = \text{Min } (F_1, F_2) \tag{13}$$

Table 1 Possible sizes of capacitors in kVAr and costs in $/kVAr.

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

where F_1 and F_2 are defined as

$$F_1 = \text{Min (Cost)}$$

$$F_2 = \text{Min}(P_{\text{Total loss}})$$

where cost function is defined as

$$\text{Cost} = K_i P_{\text{Total loss}} + \sum_{p=1}^{n} K_C Q_{pC} \quad (14)$$

Subjected to the following constraints:

(i) Voltage limits.

$$V_{\min} \leqslant |V_p| \leqslant V_{\max} \quad (15)$$

(ii) Reactive power compensation limits.

$$Q_{pC} \leqslant \sum_{p=1}^{n} Q_{Lp} \quad (16)$$

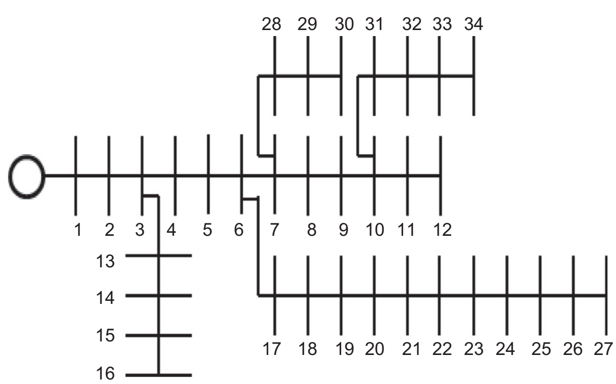

Figure 4 IEEE-34 bus radial distribution test system.

Cost function defined in Eq. (14) is divided into two modules. The first term is cost of real power provided by the substation. This can be reduced by minimizing the total active power loss of the system and the second term is cost of the reactive power provided by the capacitors which has been installed in the system.

4. Proposed work implementation

WOA based approach for placing capacitors optimally in the network to reduce operating cost and minimizing power losses by enhancing voltage profile, takes the following steps:

Step 1: Initialize input data such as line impedance and load power.
Step 2: Calculate total power loss, operating cost and bus voltages using Forward–Backward sweep method [27].
Step 3: Initialize the number of search agents to be optimized. If the search agents go beyond the boundaries then bring back to within the boundary by inserting the limits.
Step 4: Initialize the counter.
Step 5: Calculate the fitness function for each search agent using Eq. (14) and obtain the initial best agent.
Step 6: For each search agent update a, A, C, l and p using Eqs. (3) and (4), where l and p are random numbers.
Step 7: If ($p < 0.5$) go to Step 8 otherwise go to Step 10.
Step 8: If $|A| < 1$, then update the position of current search agent by using Eq. (2).
Step 9: If $|A| \geqslant 1$, then calculate new search agent and update its position by using Eq. (6).
Step 10: Update the position of current search agent by using Eq. (7).

Table 2 Simulation results of 34-bus system.

	Base case	PSO[14]	MINLP[16]	PGS[13]	BFOA[10]	Proposed
Optimal size (bus)	–		300 (4)			
			600 (10)			640 (25)
		781 (19)	100 (14)	1200 (19)	625 (10)	665 (10)
		803 (22)	500 (18)	639 (22)	940 (20)	590 (17)
		479 (20)	300 (22)	200 (20)	610 (25)	619 (20)
			1000 (27)			
Total size of capacitors (kVAr)	–	2063	2800	2039	2175	2514
P_{loss} (kW)	221.67	168.87	163.21	169.12	160.95	159.47
% Reduction in P_{loss}	–	23.82	26.37	23.71	27.40	28.06
Q_{loss} (kVAr)	65.1	48.91	47.39	48.97	47.22	46.75
% Reduction in Q_{loss}	–	24.87	27.20	24.78	27.46	28.19
$V_{\min}$ (pu)	0.9417	0.9496	0.9521	0.9492	0.9499	0.9504
Total operating cost/year ($)	1,35,928	1,03,946	1,00,810	1,04,155	99,250	98,448
Savings/year ($)	–	31,982	35,118	31,773	36,678	37,480
% Savings/year	–	23.53	25.83	23.37	26.98	27.57

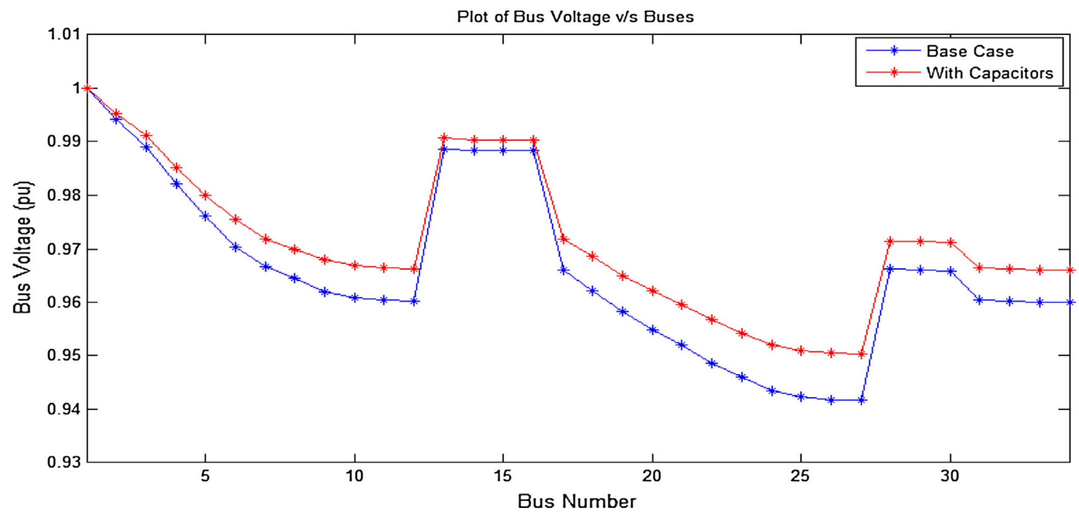

Figure 5 Voltage magnitude of IEEE-34 bus system.

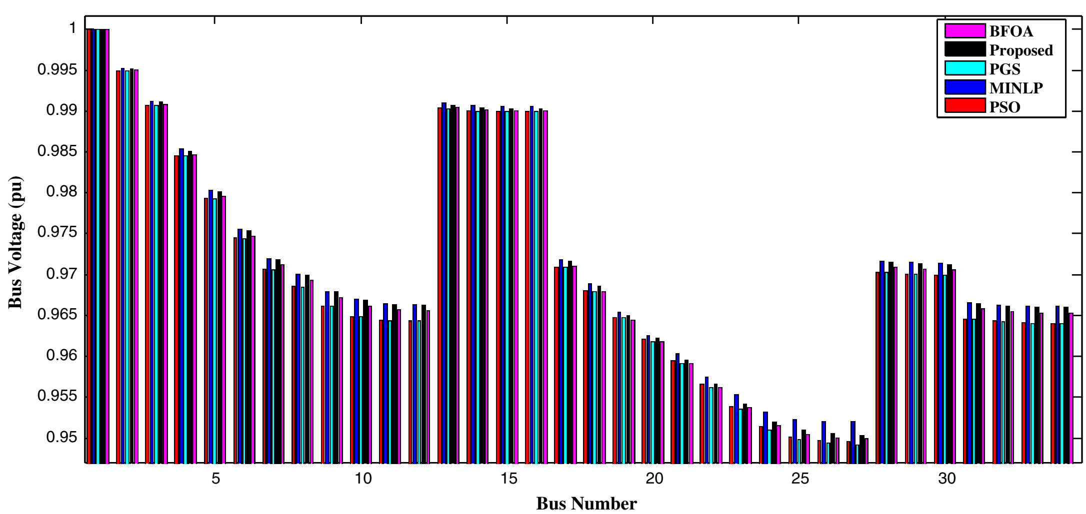

Figure 6 Bus voltages at each bus after compensation by different techniques for 34-bus test system.

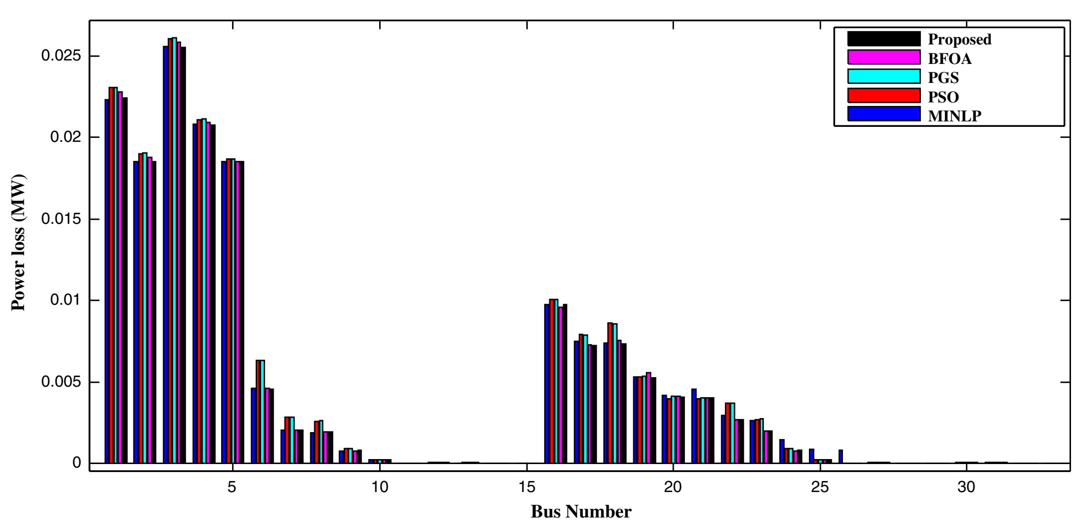

Figure 7 Power loss at each bus after compensation by different techniques for 34-bus test system.

Table 3 Simulation results of 85-bus system.

	Base case	PGS[13]	PSO[14]	MINLP[16]	BFOA[10]	Proposed
Optimal size (bus)	–		314 (7)	300 (7)		566 (67)
		200 (7)	796 (8)	700 (8)	840 (9)	490 (25)
		1200 (8)	901 (27)	900 (29)	660 (34)	417 (80)
		908 (58)	453 (58)	500 (58)	650 (60)	709 (34)
Total size of capacitors (kVAr)	–	2308	2464	2400	2150	2182
P_{loss} (kW)	316.12	174.66	163.54	159.41	152.90	149.52
% Reduction in P_{loss}	–	44.75	48.27	49.57	51.63	52.70
Q_{loss} (kVAr)	198.6	104.10	99.27	97.43	94.73	92.72
% Reduction in Q_{loss}	–	47.58	50.01	50.94	52.30	53.31
V_{min} (pu)	0.8713	0.9090	0.9156	0.9176	0.9193	0.9214
Total operating cost/year ($)	1,93,845	1,07,582	1,00,813	98,323	94,273	92,219
Savings/year ($)	–	86,263	93,032	95,522	99,572	1,01,626
% Savings/year	–	44.50	47.99	49.28	51.37	52.43

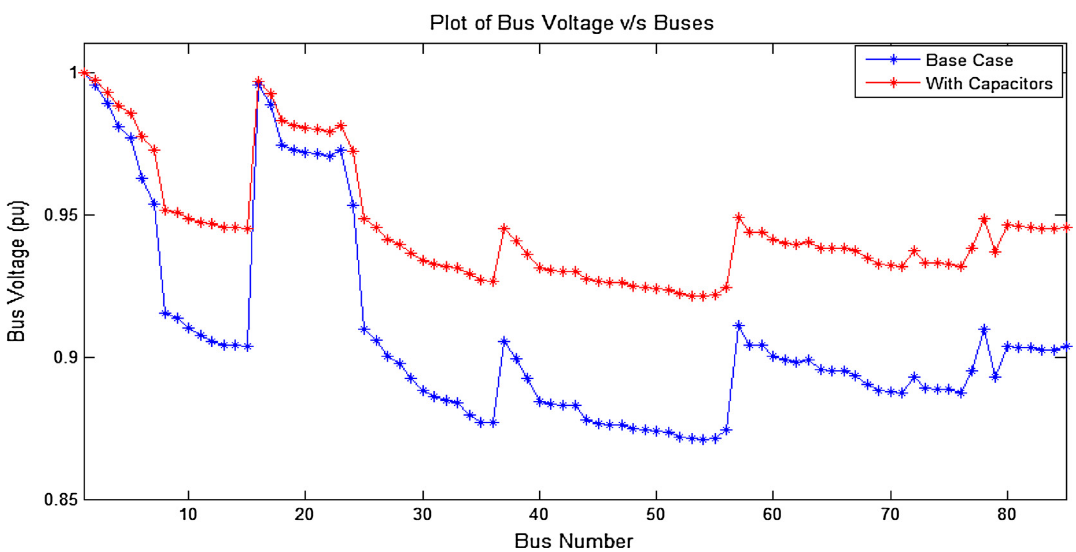

Figure 8 Voltage magnitude of IEEE-85 bus system.

Step 11: Go to Step 12, if the counter reaches the maximum value. Else go to Step 5.
Step 12: Print the optimal solution.

5. Results and discussion

The proposed method is programmed in MATLAB domain and the effectiveness of this algorithm for cost minimization and loss reduction by placing capacitors optimally is tested on 34-bus and 85-bus radial distribution test systems. The results obtained are explained in the following sections. For all the test systems K_i value is selected as 0.07 $/kWh and available capacitor size and their K_c in $/kVAr referred from [13] are listed in Table 1.

5.1. IEEE-34 bus system

System data are listed in Table A1 in appendix and line diagram is shown in Fig. 4. The base values considered are 100 MVA and 11 kV. Without placing any compensatory devices, the losses in the system are obtained as 221.67 kW, 65.1 kVAr, the operating cost is found as 1, 35,928 $/year, and the minimum voltage is found to be 0.9417 pu. The reference bus voltage at the substation is considered as 1 pu and the lower and upper limits of voltage magnitude at the buses are chosen as 0.9 and 1.05 pu respectively. The results obtained by WOA and other techniques for IEEE-34 bus system are listed in Table 2. Optimal size and location of capacitors obtained from the proposed technique are 640, 665, 590 and 619 kVAr at buses 25, 10, 17 and 20 respectively. Placing capacitors at optimal locations as obtained by WOA, compared to other methods results in reduction of losses as well as reduction in operating cost. Thus, from the proposed method the savings obtained are 37,480 $/year, and this is better than other methods which is shown in Table 2. Even though the total size of the capacitors obtained by WOA is more, compared to PSO, PGS and BFOA techniques, the power loss and operating cost are found to be less and thus result in more savings; also the voltage profile of the system is significantly improved and it is shown in Fig. 5. Figs. 6 and 7 show bus voltages at each bus and power loss at each line by different techniques, after placement of capacitors in the system.

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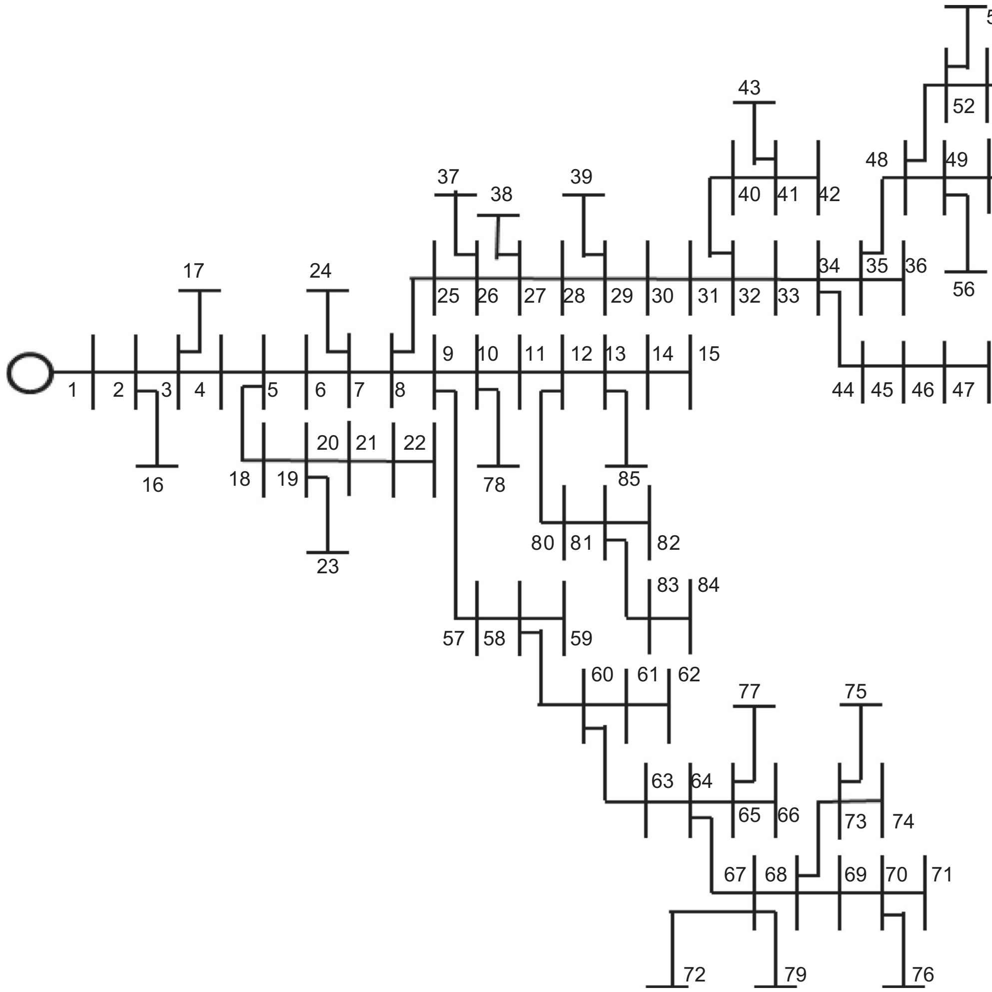

Figure 9 IEEE-85 bus radial distribution test system.

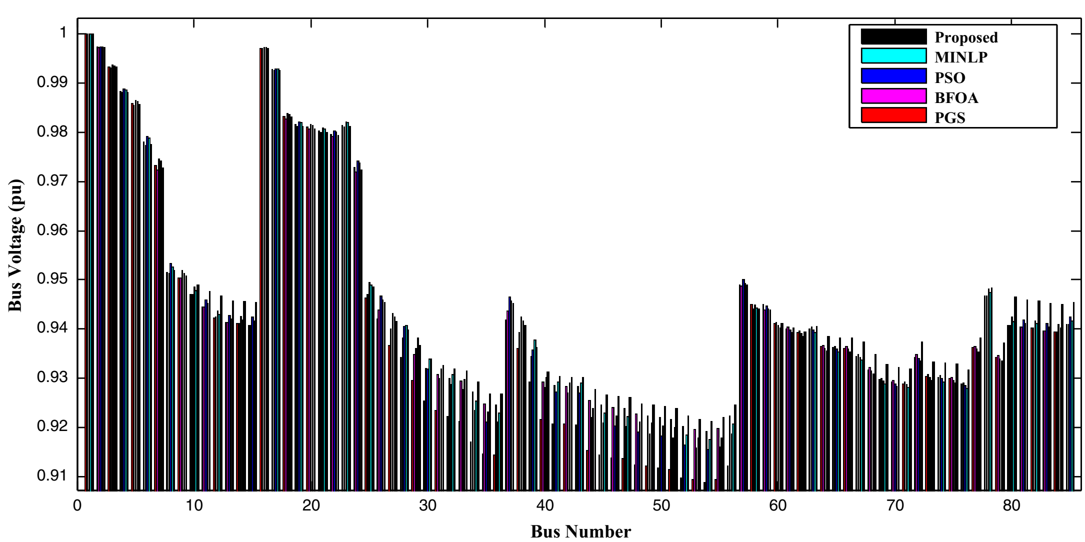

Figure 10 Bus voltages at each bus after compensation by different techniques for 85-bus test system.

5.2. IEEE-85 bus system

Single line diagram of the system is shown in Fig. 9 and the system data are listed in Table A2, in appendix. The base values are considered as 100 MVA and 11 kV. The total real and reactive power loss for the base case is computed using MATLAB and losses are found to be 316.12 kW and 198.6 kVAr respectively, Operating cost is 1,93,845 $/kWh

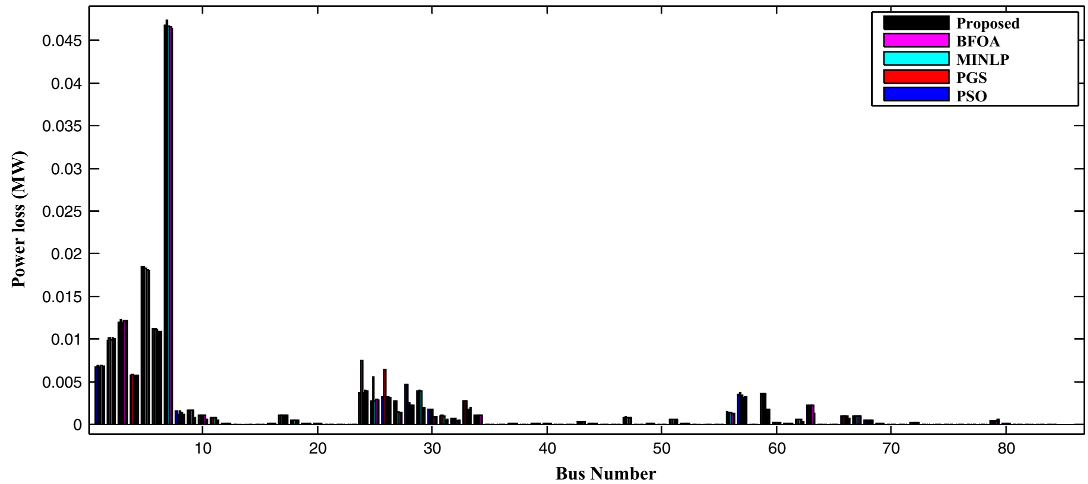

Figure 11 Power loss at each bus after compensation by different techniques for 85-bus test system.

Table A1 IEEE-34 bus test system data.

Bus		R (Ω)	X (Ω)	$P_{receive}$ (kW)	$Q_{receive}$ (kVAr)
Send	Receive				
1	2	0.117	0.048	230	142.5
2	3	0.1073	0.044	0	0
3	4	0.1645	0.0457	230	142.5
4	5	0.1495	0.0415	230	142.5
5	6	0.1495	0.0415	0	0
6	7	0.3144	0.054	0	0
7	8	0.2096	0.036	230	142.5
8	9	0.3144	0.054	230	142.5
9	10	0.2096	0.036	0	0
10	11	0.131	0.0225	230	142.5
11	12	0.1048	0.018	137	84
3	13	0.1572	0.027	72	45
13	14	0.2096	0.036	72	45
14	15	0.1048	0.018	72	45
15	16	0.0524	0.009	13.5	7.5
6	17	0.1794	0.0498	230	142.5
17	18	0.1645	0.0457	230	142.5
18	19	0.2079	0.0473	230	142.5
19	20	0.189	0.043	230	142.5
20	21	0.189	0.043	230	142.5
21	22	0.262	0.045	230	142.5
22	23	0.262	0.045	230	142.5
23	24	0.3144	0.054	230	142.5
24	25	0.2096	0.036	230	142.5
25	26	0.131	0.0225	230	142.5
26	27	0.1048	0.018	137	85
7	28	0.1572	0.027	75	48
28	29	0.1572	0.027	75	48
29	30	0.1572	0.027	75	48
10	31	0.1572	0.027	57	34.5
31	32	0.2096	0.036	57	34.5
32	33	0.1572	0.027	57	34.5
33	34	0.1048	0.018	57	34.5

and minimum voltage obtained is 0.8713 pu. The results obtained from WOA and other methods are listed in Table 3. The optimal size and location of capacitors obtained from the proposed algorithm are 566, 490, 417 and 709 kVAr at buses 67, 25, 80 and 34 respectively which is shown in Table 3. The results are compared with PSO, PGS, MINLP, and BFOA algorithms. Net savings from the proposed algorithm are found to be 1, 01,626 $/year and this is better than other

Table A2 IEEE-85 bus test system data.

Bus		R (Ω)	X (Ω)	$P_{receive}$ (kW)	$Q_{receive}$ (kVAr)
Send	Receive				
1	2	0.108	0.075	0	0
2	3	0.163	0.112	0	0
3	4	0.217	0.149	56	57.13
4	5	0.108	0.074	0	0
5	6	0.435	0.298	35.28	35.99
6	7	0.272	0.186	0	0
7	8	1.197	0.82	35.28	35.99
8	9	0.108	0.074	0	0
9	10	0.598	0.41	0	0
10	11	0.544	0.373	56	57.13
11	12	0.544	0.373	0	0
12	13	0.598	0.41	0	0
13	14	0.272	0.186	35.28	35.99
14	15	0.326	0.223	35.28	35.99
2	16	0.728	0.302	35.28	35.99
3	17	0.455	0.189	112	114.26
5	18	0.82	0.34	56	57.13
18	19	0.637	0.264	56	57.13
19	20	0.455	0.189	35.28	35.99
20	21	0.819	0.34	35.28	35.99
21	22	1.548	0.642	35.28	35.99
19	23	0.182	0.075	56	57.13
7	24	0.91	0.378	35.28	35.99
8	25	0.455	0.189	35.28	35.99
25	26	0.364	0.151	56	57.13
26	27	0.546	0.226	0	0
27	28	0.273	0.113	56	57.13
28	29	0.546	0.226	0	0
29	30	0.546	0.226	35.28	35.99
30	31	0.273	0.113	35.28	35.99
31	32	0.182	0.075	0	0
32	33	0.182	0.075	14	14.28
33	34	0.819	0.34	0	0
34	35	0.637	0.264	0	0
35	36	0.182	0.075	35.28	35.99
26	37	0.364	0.151	56	57.13
27	38	1.002	0.416	56	57.13
29	39	0.546	0.226	56	57.13
32	40	0.455	0.189	35.28	35.99
40	41	1.002	0.416	0	0
41	42	0.273	0.113	35.28	35.99
41	43	0.455	0.189	35.28	35.99
34	44	1.002	0.416	35.28	35.99
44	45	0.911	0.378	35.28	35.99
45	46	0.911	0.378	35.28	35.99
46	47	0.546	0.226	14	14.28
35	48	0.637	0.264	0	0
48	49	0.182	0.075	0	0
49	50	0.364	0.151	36.28	37.01
50	51	0.455	0.189	56	57.13
48	52	1.366	0.567	0	0
52	53	0.455	0.189	35.28	35.99
53	54	0.546	0.226	56	57.13
52	55	0.546	0.226	56	57.13
49	56	0.546	0.226	14	14.28
9	57	0.273	0.113	56	57.13
57	58	0.819	0.34	0	0
58	59	0.182	0.075	56	57.13
58	60	0.546	0.226	56	57.13
60	61	0.728	0.302	56	57.13
61	62	1.002	0.415	56	57.13

(*continued on next page*)

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Table A2 (*continued*)

Bus		R (Ω)	X (Ω)	$P_{receive}$ (kW)	$Q_{receive}$ (kVAr)
Send	Receive				
60	63	0.182	0.075	14	14.28
63	64	0.728	0.302	0	0
64	65	0.182	0.075	0	0
65	66	0.182	0.075	56	57.13
64	67	0.455	0.189	0	0
67	68	0.91	0.378	0	0
68	69	1.092	0.453	56	57.13
69	70	0.455	0.189	0	0
70	71	0.546	0.226	35.28	35.99
67	72	0.182	0.075	56	57.13
68	73	1.184	0.491	0	0
73	74	0.273	0.113	56	57.13
73	75	1.002	0.416	35.28	35.99
70	76	0.546	0.226	56	57.13
65	77	0.091	0.037	14	14.28
10	78	0.637	0.264	56	57.13
67	79	0.546	0.226	35.28	35.99
12	80	0.728	0.302	56	57.13
80	81	0.364	0.151	0	0
81	82	0.091	0.037	56	57.13
81	83	1.092	0.453	35.28	35.99
83	84	1.002	0.416	14	14.28
13	85	0.819	0.34	35.28	35.99

methods as shown in Table 3 and even loss reduction is minimized and voltage profile is improved. Fig. 8 shows the voltage profile for with and without capacitors of 85 bus system. Figs. 10 and 11 shows bus voltages at each bus and power loss at each line by different techniques, after placement of capacitors in the system.

6. Conclusion

In this paper, WOA is proposed for optimal siting and sizing of capacitors in distribution network. Here multi objectives such as minimizing cost, power loss reduction and voltage profile improvement in the system are considered. Placing capacitors at optimal locations will improve the system performance, stability and reliability of the network. The proposed method is tested on IEEE-34 and IEEE-85 bus radial distribution test systems to illustrate the effectiveness of the algorithm. The results obtained by the proposed technique are compared with other existing techniques such as PSO, MINLP, PGS and BFOA, and found to be effective.

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Appendix A

Tables A1 and A2 shows bus data and line data of IEEE-34 and IEEE-85 bus distribution test system in light loading.

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