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Comprehensive framework for capacitor placement in distribution networks from the perspective of distribution system management in a restructured environment

Hossein Karimi [a,*], Reza Dashti [b]

[a] Tarbiat Modares University, Tehran, Iran
[b] Faculty of School of Electrical Engineering at Iran University of Science and Technology, Tehran, Iran

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ABSTRACT

This paper presents a new and comprehensive Objective Function (OF) for capacitor placement in distribution networks. In this study, distribution network management's viewpoint toward identifying comprehensive OF to maximize the benefit of a distribution company is considered. In addition to considering active power loss cost and capacitor cost, two other important terms, i.e. cost of buying reactive power and voltage drop penalty for maximizing the benefit of distribution companies are considered in the OF. All actual conditions including time varying nature of load, annual load growth, time varying price of active and reactive power, and switchable and fixed capacitor are taken into account based on the reality. The profit derived from the proposed OF is compared with two other common OFs, and it is shown that the benefit achieved from the proposed OF is more than the two other OFs. The proposed OF is validated and tested on radial distribution systems with differing topologies and varying sizes and complexities.

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Introduction

Capacitor banks are widely used in power systems to reduce power losses, compensate reactive power, improve voltage profile, increase system capacity, and correct power factor. Capacitor placement can be beneficial only when it correctly applied. Correct application means choosing the correct position and size of the reactive power support.

It is generally accepted that most of the power losses occur on the distribution systems [1]. The reactive power is responsible for large portion of these losses. A part of these losses can be reduced by application of shunt capacitors on distribution systems.

The first capacitor placement studies were carried out to minimize the active loss, and after which the famous two-thirds rule was defined for uniform loads [2]. Many studies have been done to solve capacitor placement with different simplified assumption. For example, the time varying nature of the loads was ignored in [3,4] and future network extension was not considered in [5,6].

Several formulations have been suggested for this problem, and they have been solved by different computational techniques. Ref. [7] included system capacity release, peak load reduction, and reduction of annual energy loss in their formulation and solved by genetic algorithm. Genetic algorithm is also used in [8] with two-stage method to discuss the problem of determining the optimal location by means of loss sensitivity technique and size of capacitors. Particle Swarm Optimization (PSO) is applied in [9] to solve discrete size of capacitor banks and variation of load during the year.

Ref. [10] adapted an objective function to maximize net yearly savings and to enhance the overall system static voltage stability index with weighting and magnifying factors. In [11], the objective function is determined to minify the system operating cost at different loading conditions and to enhance the system voltage profile by identifying higher potential buses for capacitor placement using power loss index. A combination of fuzzy multi-objective and genetic algorithm approach is proposed in [12] for optimal shunt capacitor placement to improve the substation power factor, reduce the real power loss, and reduce the burden on the substations.

Many researchers have focused on various types of heuristic optimization techniques to solve the optimal capacitor allocation problem such as tabu search [13], big bang–big crunch optimization [14], and backtracking search optimization algorithm [15]. In [16], bio-inspired optimization technique is applied to optimize

* Corresponding author.
E-mail addresses: Hosein.karimi@modares.ac.ir (H. Karimi), rdashti@iust.ac.ir (R. Dashti).

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the distribution network operation over a planning horizon by minimizing the system losses with minimum cost of investment in capacitors. Artificial bee colony is applied to allocate static capacitors along radial distribution systems [17]. Uncertainty in the variation of load is considered in [18]. Ref. [19] used sensitivity analysis to reduce search space and then used gravitational search algorithm to solve capacitor placement problems.

Different capacitor placement OFs are identified and suggested so far, and various kind of computational techniques are used to solve the problem, but optimal OF for capacitor placement from perspective of distribution company manager has not yet been proposed. Since distribution networks are under supervision of distribution company managers, they are responsible for design and implementation of any plan in networks, and intend to accomplish capacitor placement in a way that gives the maximum profit. In this study, this issue is viewed by manager of distribution networks. Distribution company relationships with other systems for obtaining an optimal OF, which gives maximum benefit, is identified. OFs which are currently used in the literature mostly consists of almost two terms i.e. active power cost and capacitor cost. In this study, new OF is identified and two terms i.e. reactive power cost and penalty of voltage drop are added to the common OFs of previous works.

Distribution networks should provide consumers with active and reactive power. If distribution systems satisfy reactive power by capacitor placement, they can save the money of reactive power that buy from power plants. Another important factor is that distribution network companies will be fined if they provide consumer with bad quality and low voltage electricity; therefor, two new terms are needed to be added to the previous OFs. This OF is proven in the following section.

The paper is organized as follows; Section "Problem definition" gives the distribution company relationships and proposed OF, Section "Power flow formulations and constraints" gives power flow formulations and its constrains. PSO algorithm and the proposed flowchart are presented in Section "Optimization method and flow chart". Simulation results and discussion are given in Section "Test cases and numerical results", and finally Section "Conclision" conclude the paper.

Problem definition

Capacitor placement objective function from the perspective of distribution system management

Governments implement some policies to increase the efficiency of the energy systems and improve quality of public service. One of these policies is related to distribution networks. The government obliges distribution companies to:

1. Enhance efficiency of the distribution systems.
2. Improve quality of distributed electricity to consumers.

There is an interconnection between distribution company, government, power plants, and consumers. Distribution companies purchase active and reactive power with price of K_p and K_q and sell it to consumers with price of K'_p and K'_q. To maximize distribution networks profit, managers of the distribution companies carried out capacitor placement studies on the distribution networks. Capacitor placement decreases network losses, which is in line with the government policy for enhancing the efficiency of distribution systems. In addition to the reduction of energy loss, capacitor placement reduces the input reactive power to the distribution networks. Governments consider some penalties for distribution company in case of any voltage drop or bad quality of power delivery to meet the second policy.

According to the Fig. 1, Benefit of Distribution Company (*BDC*) is the difference between buy and sale of energy, cost of capacitor placement ($Cost_{Cap.}$) and penalties caused by the voltage drop ($Cost_{Pen.}$), and defined as follows:

$$BDC = F_{Sale} - F_{Buy} - Cost_{Cap.} - Cost_{Pen.} \quad (1)$$

Fig. 1 shows the relationship between a distribution company, government, power plants and consumers.

In Fig. 1, K_p/K_q are purchase price of active/reactive power and K'_p/K'_q are sale price of active/reactive power. F_{Buy} is buy function and F_{Sale} is sale function of active and reactive power, and are defined as follow:

$$F_{Buy} = K_p P_{in} + K_q Q_{in} \quad (2)$$

$$F_{Sale} = K'_p P_{out} + K'_q Q_{out} \quad (3)$$

P_{in} and Q_{in} are as follow:

$$P_{in} = P_{out} + P_{loss} \quad (4)$$

$$Q_{in} = Q_{out} + Q_{loss} + Q_{compensation} \quad (5)$$

P_{out} and Q_{out} are consumed by consumers. To reduce purchase cost of distribution company, the values of P_{in} and Q_{in} should be decreased. But the values of P_{out} and Q_{out} are demanded by consumers, and depend on consumption management policies and government incentive policies, and distribution network managers consider it as constant value. But the reduction of P_{loss} and optimized value of $Q_{loss} + Q_{compensation}$ can be fulfilled by capacitor placement.

Benefit derived from capacitor placement

The benefit of distribution company before and after capacitor placement is as follows:

$$BDC_{Before} = F_{Sale,1} - F_{Buy,1} - Cost_{Pen.,1} \quad (6)$$

$$BDC_{After} = F_{Sale,2} - F_{Buy,2} - Cost_{Cap.} - Cost_{Pen.,2} \quad (7)$$

Before capacitor placement there is no capacitor placement cost; therefor, $Cost_{Cap.}$ is ignored in BDC_{Before}. Output power of distribution system depends on consumer, and considered as constant value; therefore, the sale of power does not change with capacitor placement.

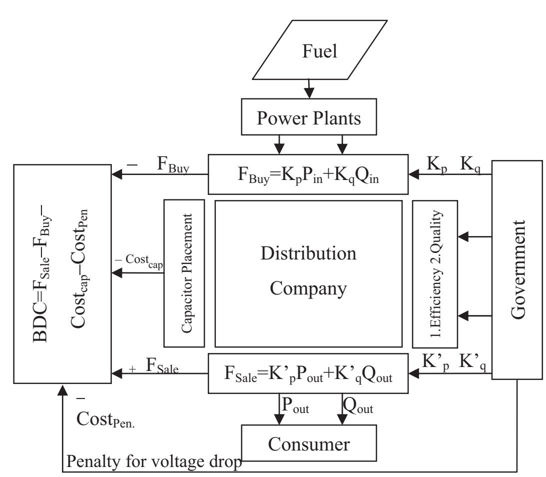


Fig. 1. The relationships of distribution company.

$F_{Sale,1} = F_{Sale,2}$

Benefits increase due to the capacitor placement is as follows:

$$S = BODC_{After} - BODC_{Before}$$
$$= F_{Buy,1} - F_{Buy,2} - Cost_{Cap.} - (Cost_{Pen.,2} - Cost_{Pen.,1}) \quad (8)$$

The term $Cost_{Pen.,2} - Cost_{Pen.,1}$ is shown by $\Delta Cost_{Pen}$. Using (2) and (3), cost changes can be shown as follows:

$$F_{Buy,1} - F_{Buy,2} = K_p(P_{out} + P_{loss,1}) + K_q(Q_{out} + Q_{loss,1}) - K_p(P_{out} + P_{loss,2}) - K_q(Q_{out} + Q_{loss,2} + Q_{comp.})$$

Thus:

$$F_{Buy,1} - F_{Buy,2} = K_p(P_{loss,1} - P_{loss,2}) + K_q(Q_{loss,1} - Q_{loss,2} - Q_{comp.}) \quad (9)$$

Two values of (9) are defined as follows:

$$\Delta Cost_{loss} = K_p(P_{loss,1} - P_{loss,2}) \quad (10)$$

$$\Delta Cost_{reactive} = K_q(Q_{loss,1} - Q_{loss,2} - Q_{comp.}) \quad (11)$$

And finally, the benefit increase due to capacitor placement is shown as follows:

$$S = \Delta Cost_{loss} - Cost_{Cap.} + \Delta Cost_{reactive} - \Delta Cost_{Pen.} \quad (12)$$

The benefit increase due to capacitor placement is called "benefit derived from capacitor placement" or simply "net saving".

Power flow formulations and constraints

Load flow formulations

For single-line diagram Fig. 2, loadflow formulas are as follows [20]:

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1}\frac{P_i^2 + Q_i^2}{|V_i|^2} \quad (13)$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1}\frac{P_i^2 + Q_i^2}{|V_i|^2} \quad (14)$$

where P_i and Q_i are active and reactive power passing through ith bus bar, P_{Li} and Q_{Li} are active and reactive powers connected to ith bus bar, $R_{i,i+1}$ and $X_{i,i+1}$ are resistance and reactance between i and $(i+1)$th busbar.

The voltage magnitude of $(i+1)$th busbar is as follows:

$$|V_{i+1}|^2 = |V_i|^2 - 2(R_{i,i+1}P_i + X_{i,i+1}Q_i) + (R_{i,i+1}^2 + X_{i,i+1}^2)\frac{P_i^2 + Q_i^2}{|V_i|^2} \quad (15)$$

Loss power between i and $(i+1)$th bus bar is obtained from the following equation:

$$P_{loss}(i, i+1) = R_{i,i+1}\frac{P_i^2 + Q_i^2}{|V_i|^2} \quad (16)$$

The total loss of feeder is obtained from the sum of line loss power:

$$P_{T,loss} = \sum_{i=1}^{n} P_{Loss}(i, i+1) \quad (17)$$

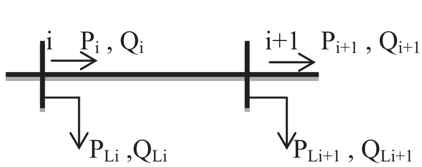


Fig. 2. Single-line diagram.

Constraints

OF is subjected to power flow balance equations and some inequalities [17].

(1) Power balance constraints

Power flow (active and reactive) constraints are formulated as follow:

$$P_i = P_{loss,i} + P_{L,i} + P_{i+1} \quad (18)$$

$$Q_i + Q_{C,i} = Q_{loss,i} + Q_{L,i} + Q_{i+1} \quad (19)$$

(2) Voltage magnitude constraint
The voltage magnitude at each bus must be maintained within its limits and expressed as:

$$V_{min} \leqslant |V_i| \leqslant V_{max} \quad (20)$$

(3) Reactive compensation limit
Reactive power constraint in which injected reactive power at each candidate bus must be within their permissible ranges.

$$Q_{C,min} \leqslant Q_{C,i} \leqslant Q_{C,max} \quad (21)$$

(4) Maximum total compensation
From practical limitation, maximum compensation by using capacitor bank is limited to the total load reactive power demand.

$$Q_{C,i} \leqslant \sum_{j=i}^{N} Q_{C,j} \quad (22)$$

Optimization method and flow chart

There are several approaches toward the minimization (or maximization) of capacitor placement OF. Many search algorithms have been proposed in order to solve this kind of optimization problem such as GA, Ant Colony, Bee Colony, Particle Swarm Optimization (PSO), etc.

In this paper based on the capacitor placement OF features and previous experience on this subject [21–23], the PSO as a flexible and powerful intelligent algorithm is used. Further explanation of PSO for this problem with added benefits is addressed in fallowing paragraphs.

The PSO is an optimization algorithm, based on probability laws, which is inspired by the natural models. Some outstanding features of the PSO algorithm can be pointed as follow [24,25]:

- It uses the OF information to navigate search action in the problem space.
- As the PSO algorithm uses probability laws, more flexible and robust control can be achieved in comparison with other algorithms.
- The PSO provides more accurate results without using complex operation.
- Achieving to the optimal response from any given initial search point is guaranteed.
- To achieve the optimal response, the PSO is not used complex operations.

Particle swarm optimization

Particle swarm optimization is an algorithm developed by Kennedy and Eberhart [26] that has the idea of social behavior of bird in finding food. In the PSO algorithm suppose that the search space is *d*-dimensional:

- Each member is called *particle*, and each particle (*i*-th particle) is represented by *d*-dimensional vector and described as $Xi = [x_{i1}, x_{i2}, \ldots, x_{id}]$.
- The set of n particle in the swarm are called *population* and described as $pop = [X_1, X_2, \ldots, X_n]$.
- The best previous position for each particle (the position giving the best fitness value) is called *particle best* and described as $PB_i = [\, pb_{i1}, pb_{i2}, \ldots, pb_{id} \,]$.
- The best position among all of the particle best position achieved so far is called *global best* and described as $GB = [gb_1, gb_2, \ldots, gb_d \,]$.
- The rate of position change for each particle is called *the particle velocity* and described as $V_i = [\, v_{i1}, v_{i2}, \ldots, v_{id} \,]$.

  At iteration k the velocity for d-dimension of i-particle is updated by:

$$v_{id}^{k+1} = w v_{id}^{k} + c_1 r_1 (pb_{id}^{k} - X_{id}^{k}) + c_2 r_2 (gb_{d}^{k} - X_{id}^{k}) \quad (23)$$

  where $i = 1, 2, \ldots, n$ and n is the size of population, w is the inertia weight, c_1 and c_2 are the acceleration constants, and r_1 and r_2 are two random values in range [0, 1]. The optimal selection of the previous parameters found in [27,28].
- The i-particle position is updated by

$$X_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1} \quad (24)$$

  For binary discrete search space, Kennedy and Eberhart [29] have adapted the PSO to search in binary spaces, by applying a sigmoid transformation to the velocity component Eq. (23) to squash the velocities into a range [0, 1], and force the component values of the locations of particles to be 0's or 1's. The equation for updating positions Eq. (24) is then replaced by Eq. (26).

$$sigmoid(v_{id}^{k}) = \frac{1}{1 + e^{-v_{id}^{k}}} \quad (25)$$

$$x_{id}^{k} = \begin{cases} 1, & if\ rand < sigmoid(v_{id}^{k}) \\ 0, & otherwise \end{cases} \quad (26)$$

Flow chart of PSO-based optimization

The flow chart of Fig. 3 employs 8 step processes:
Step (1) Initializing with data input.
The method starts with a collection of data received from control centers such as the capacitor capacities, installation cost, power loss, penalty cost, and operation constraints.
Step (2) Solve load flow for the primary system to determine initial values of OF, power loss, bus voltage, and penalties.
Step (3) Initializing PSO parameters and maximum iteration, and choosing capacitor sizes randomly.
Step (4) Run load flow for each position.
Step (5) Update velocity and position.
Step (6) Run load flow for each position, and calculate the OF value.
The problem of handling inequality constraints is solved by a conventional penalty function [30].
Step (7) Save the new results if these are better than past values. Go to the Step 5 if Iteration (Iter.) is not reached to its maximum value.
Step (8) Process is terminated when the maximum number of iterations is reached.

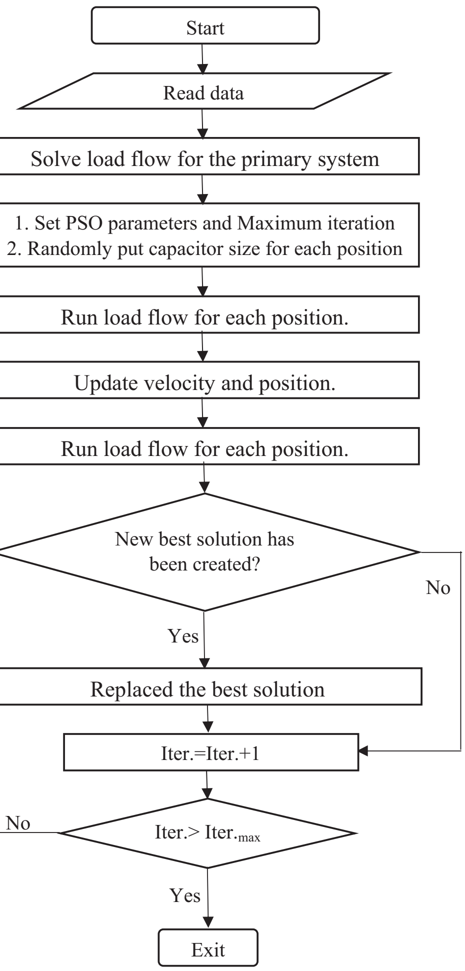


Fig. 3. Flow chart of problem solution.

Table 1
Available three-phase capacitor sizes and annual cost.

Size (kVar)	150	300	450	600	900	1200
Cost	75	97.5	114	132	165	204

Test cases and numerical results

To evaluate the effectiveness of the proposed OF, the method has been applied to three test systems. To compare the results, two common OF are used as OF_1 and OF_2. OF_1 was commonly used in the past and just defined to minimize active energy loss [2,18]. Second OF consists of active power loss and capacitor cost, which are commonly used in the literature [12,14,16,19,27]. Finally, OF_3 is the proposed fitness function of this study and includes active and reactive loss, capacitor cost, and penalty due to the voltage drop. For each OF, a scenario is allocated. First scenario is for the OF_1, second scenario for the OF_2, and third scenario is for the OF_3.

$$OF_1 = \Delta Cost_{loss} \quad (27)$$

$$OF_2 = \Delta Cost_{loss} - Cost_{Cap.} \quad (28)$$

$$OF_3 = \Delta Cost_{loss} - Cost_{Cap.} + \Delta Cost_{reactive} - \Delta Cost_{Pen.} \quad (29)$$

Table 2
Possible choices of capacitor size and cost.

j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Q_C^j	150	300	450	600	750	900	1050	1200	1350	1500	1650	1800	1950	2100	2250	2400
Cost	75	97.5	114	132	207	165	240	204	279	301.5	318	370	411	369	444	408

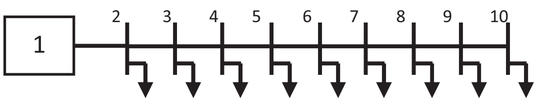


Fig. 4. Single line diagram of 10-bus system.

Three load level i.e. heavy, medium, and light load with 1, 0.8 and 0.5 of peak load is considered with time interval of loading 1000 h, 6760 h, and 1000 h for each year, respectively [31]. The allowable voltage magnitude of each node is $0.95 \leqslant |V_i| \leqslant 1.05$ p.u. Active power cost for heavy, medium, and light loads are 0.082 US$/kW h, 0.049 US$/kW h and 0.019 US$/kW h, respectively [13]. Reactive power prices for each level are considered a third of the active ones. Voltage drop penalty is considered 100 $/h [31].

Each candidate bus for capacitor placement has an installation price which is considered as 1000$ [32]. There are two types of fixed and switchable capacitor. If the reactive power requirement at a bus remains same for all load levels, a fixed valued capacitor equal to the reactive power requirement of the bus is installed at that bus. On the other hand, if the reactive power requirement at a bus varies with load levels, a switchable capacitor equal to reactive power requirement at highest load level is installed at that bus. Three-phase capacitor size and cost and possible choice of capacitor are shown in Tables 1 and 2, respectively.

10-bus test system

First test system is a 10-bus, 23 kV feeder, and shown in Fig. 4. System data is obtained from [27]. Before compensation, minimum voltage was 0.8375 p.u. which has enhanced to 0.886 p.u. by the first scenario, to 0.8746 by the second scenario, and to 0.8867 by the third scenario. To specify fixed and switchable capacitors, for example in the first scenario for bus 5, bank capacity is 2100 kVar for heavy load, 1650 kVar for medium load, and 1050 kVar for light load. It shows that 1050 kVar is fixed capacitor and 1050 kVar is switchable capacitor. Fixed and switchable capacitor for other buses can be defined by the same way.

The PSO algorithm is successfully applied to three scenarios. OF in the first scenario is just active loss, and the obtained benefit is 513,102$. In second scenario, capacitor price is also considered in the OF. In this scenario, inasmuch as capacitor cost is taken into account, the number of installed capacitor banks has decreased. Because of decrease in reactive compensation, voltage drop has increased, and it has resulted in significant rise in penalty. Therefore, benefit derived from this scenario is less than the first scenario, and is 505,118$. Third scenario encompasses all four terms i.e. active loss price, reactive cost, capacitor placement cost, and voltage drop penalty. Benefit of this scenario is more than two other scenarios and is 611,339$. Results of these scenarios are shown in Table 3.

Table 3
Comparative results for 10-bus system.

	First scenario				Second scenario				Third scenario			
	Location	Heavy	Medium	Light	Location	Heavy	Medium	Light	Location	Heavy	Medium	Light
Cap. (kVar)	3	2400	2400	1350	4	2100	1350	600	4	1200	150	0
	4	1650	900	450	5	2400	1800	1050	5	2400	2400	750
	5	2100	1650	1050	6	1050	1050	600	6	1050	1050	1050
	6	900	750	300					8	450	300	300
	7	150	0	0								
	8, 9	300	150	150								
$\Delta Cost_{loss}$ ($)		8943	17,456	271		80,664	14,800	264		8253	16,877	277
$\Delta Cost_{Reactive}$ ($)		76,595	372,635	27,885		101,156	355,965	13,451		137,941	406,226	13,454
$\Delta Cost_{Penalty}$ ($)		−9662	−27,885	−733		− 6610	−9706	−359		−6479	−29,203	−784
$Cost_{Cap.}$ ($)		8614	0	0		5263	0	0		8158	0	0
Save ($)		513,102				505,118				611,339		

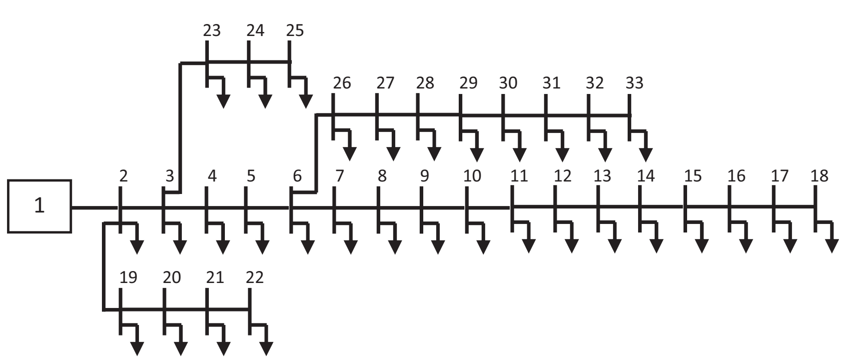


Fig. 5. Single line diagram of 33-bus system.

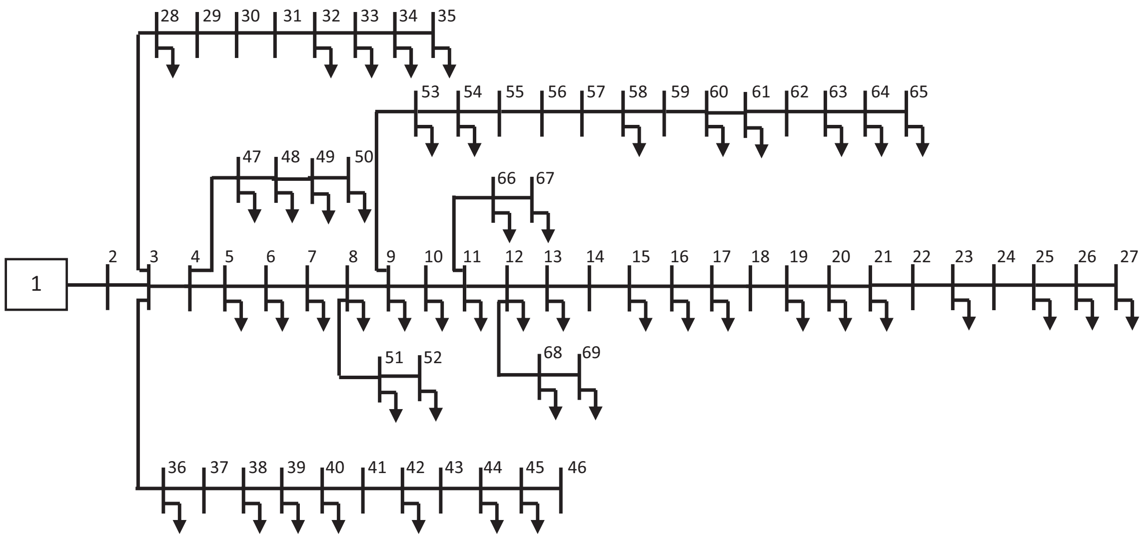


Fig. 6. Single line diagram of 69-bus system.

Table 4
Comparative results for 33-bus system.

	First scenario				Second scenario				Third scenario			
	Location	Heavy	Medium	Light	Location	Heavy	Medium	Light	Location	Heavy	Medium	Light
Cap. (kVar)	3, 31	150	150	0	6	900	600	450	6	1200	1050	450
	5, 7, 11, 16, 20, 29	150	0	0	29	300	150	0	9	300	150	0
	9	150	0	150	30	600	600	450	12	300	150	150
	24	450	450	300					28	450	300	0
	30	600	600	450					30	450	450	450
$\Delta Cost_{loss}$ ($)		6536	13,979	281		6178	10,850	262		5277	14,223	250
$\Delta Cost_{Reactive}$ ($)		83,514	218,520	6714		83,411	183,380	5760		83,199	251,670	9050
$\Delta Cost_{Penalty}$ ($)		−41,944	−96,947	0		−41,541	−83,205	0		−46,117	−127,730	0
$Cost_{Cap.}$ ($)		11,905	0	0		5544	0	0		5658	0	0
Save ($)		456,530				409,043				531,858		

Table 5
Comparative results for 69-bus system.

	First scenario				Second scenario				Third scenario			
	Location	Heavy	Medium	Light	Location	Heavy	Medium	Light	Location	Heavy	Medium	Light
Cap. (kVar)	2, 16, 63	150	150	0	7	900	900	600	14	300	150	300
	4, 5	300	150	150	49	450	450	450	56	600	300	600
	8, 10, 11, 12, 13, 48, 56, 59, 64	150	150	0	59	450	150	150	59	600	300	300
	49	600	600	450	61	1200	1050	900	60	600	600	0
	61	1050	1050	1050					61	1350	1350	900
$\Delta Cost_{loss}$ ($)		11,335	24,368	695		10,605	18,762	879		5397	17,687	669
$\Delta Cost_{Reactive}$ ($)		74,933	235,560	5805		87,693	168,520	11,534		84,045	284,180	12,542
$\Delta Cost_{Penalty}$ ($)		− 32,750	− 106,720	− 7081		− 32,621	− 62,454	− 10,768		− 47,287	− 171,730	− 12,827
$Cost_{Cap.}$ ($)		16,437	0	0		5678	0	0		7991	0	0
Save ($)		482,810				398,158				628,307		

33-bus test system

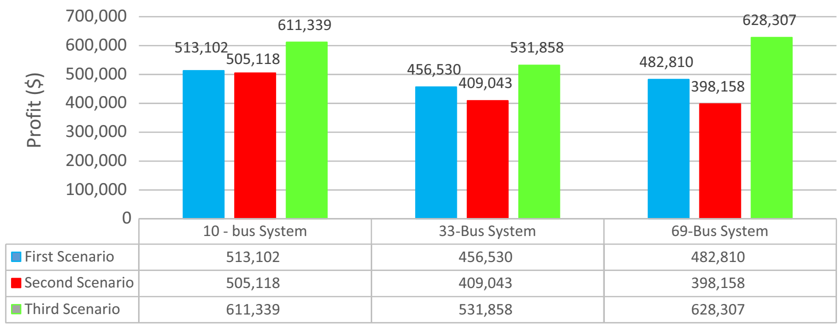
The 33-bus test case has 3-lateral radial distribution system and is shown in Fig. 5. The data of the system are obtained from [33].

Before compensation, minimum voltage was 0.8375 p.u. which has enhanced to 0.886 p.u. by the first scenario, to 0.8746 by the second scenario, and to 0.8867 by the third scenario. Benefit derived from the first, the second, and the third scenario for this system are 456,530$, 409,043$, and 531,858$, respectively. For better comparison see Fig. 7. More detail can be found in Table 4.

69-bus test system

The 69-bus test case has 6-lateral radial distribution system which is shown in Fig. 6. The data of the system are obtained from [34]. Three year planning horizon has been considered with yearly load growth rate of 9.55% as considered in Ref. [35]. To do this, three load level heavy, medium, and light with 1.25, 1 and 0.625 peak load is considered.

Before compensation, the minimum voltage was 0.8831 p.u. It has improved to 0.9133 p.u. by the first scenario, to 0.9126 p.u.



	10 - bus System	33-Bus System	69-Bus System
First Scenario	513,102	456,530	482,810
Second Scenario	505,118	409,043	398,158
Third Scenario	611,339	531,858	628,307

Fig. 7. Benefit derived from capacitor placement for 10-bus, 33-bus, and 69-bus system.

by the second scenario, and to 0.9266 p.u. by the third scenario. Benefit derived from the first, the second, and the third scenario for this system are 482,810$, 398,138$, and 628,307$, respectively. Fig. 7 shows the benefits of these scenarios to give a better comparison. More detail can be found in Table 5.

Discussion

Different OFs have been proposed so far to find optimum location and size of capacitor banks. Early capacitor placements were mostly done to reduce power losses. Cost of capacitors was added to the fitness function at the latter time. A comprehensive OF for capacitor placement from the viewpoint of distribution company managers has not yet been proposed to maximize the net saving. In this study, a new OF is identified to maximize profit of distribution companies. In this OF, four terms are taken into account. First term is cost of active power, second is cost of capacitor placement, third term is penalty for voltage drop, and the last term is cost of reactive power. Three OFs are applied to the three distribution system with different topologies. It has been seen that third OF gives more profit in comparison to the first and second OF. Since managers of distribution networks accomplish capacitor placement, they intent to do this so that it results in maximum net saving; therefore, the third OF is the best OF for capacitor placement from the viewpoint of distribution system managers, and they would like to go for the third OF.

Conclusion

This paper presents a comprehensive OF for capacitor placement to maximize the net saving from the perspective of distribution company managers. In the proposed OF, all of the required factors to maximize the benefit of distribution company are considered. To determine OF, the distribution company relationships with legislator, consumers, and power plants are identified, and then the best OF to maximize the net saving is derived. The proposed OF is verified on 10-bus, 33-bus, and 69-bus test systems. Numerical results of three examples reveal that the total net saving for distribution companies and total loss can be effectively improved by the third OF.

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