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Research Paper

Two Stage Methodology for simultaneous placement and sizing of distributed generation and capacitors using Artificial Bee Colony in order to reduce losses and increase the voltage stability

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***Abstract*— In this paper, a new approach is proposed to simultaneous placement of distributed generation and capacitors. This method is contained two stages using two sensitive index Sv and Ss. Sv and Ss are calculated according to nominal voltage and network losses. In the first stage, candidate buses is determined for installation DG and capacitors according to Sv and Ss, Then in the second stage, placement and sizing of distributed generation and capacitors are specified using Artificial Bee Colony (ABC). The proposed algorithm is tested on 33-bus and 69-bus radial distribution networks. The test results indicate good performance of the proposed method.**

***Keywords*— DG placement; Capacitor placement; Distribution network; ABC; sensitive index; Two-stage simultaneous placement.**

I. Introduction

In recent years, private investors have expressed a strong tendency in the field of connecting distributed generation (DG) and sale electricity to the distribution network and also capacitor placement in medium voltage networks are interested of distribution companies. On the other hand, according to the DG and capacitor relation to each other as sources of active and reactive power, simultaneous placement of DG and capacitors cause to obtain a more optimal solution.

A. Placement of DGs

The Installation of DGs in distribution systems has become a practical option in distribution system planning. DG is a small generator that can produce electricity in Stand Alone and On Grid [1].

Analytic method is employed to solve optimal placement and sizing of DGs in [2,3] considering loss minimization as objective of the problem. In [4], genetic algorithm has been used for DG placement with purpose of increasing spinning reserve, improvement of voltage profile, decreasing load flow and also decreasing transmission loss. In [5], Bellman-zadeh algorithm and fuzzy logic are implemented for DG placement distribution network. In [6], objective function is optimized by the usage of load flow method which includes voltage profile and power loss. In this reference optimal weighting factors of objective function are calculated and then transmission loss is decreased and voltage profile is improved by optimal DG placement. In [7], DG placement problem is solved based on voltage stability analysis as a security measure. Conservation voltage reduction (CVR) and DG integration are popular strategies implemented by utilities to improve energy efficiency. In [8] investigates the interactions between CVR and DG placement to minimize load consumption in distribution networks, while keeping the lowest voltage level within the predefined range. In [9], economic and network-driven DG placement planning problem is investigated from the local distribution company's (DISCO's) viewpoint considering reliability level and power loss of the electrical distribution network.

B. Placement of Capacitor

Capacitor placement in the distribution network has a long history. The application of capacitors for power factor (PF) improvement is quite common in industrial plants and commercial establishments. Similarly, capacitors are commonly used by electric utilities for feeder voltage control and for efficiency improvement of the distribution system. Several studies [10-22] have been conducted over the last thirty years, and there have been many proposed methods using different models and mathematical solution techniques. Schmill [10] considered a feeder with uniform characteristics and uniform load distribution and developed the two-thirds rule in which a single capacitor is placed at two-thirds of the length of the feeder from the substation. Duran [11] used dynamic programming (DP) to find the optimal solution.

Grainger and Lee [12] removed the assumptions of uniform load and fixed conductor size, and decomposed the problem into three sub problems (size. switching time, and location) that were solved successively.

Rembert and Rinker [13] used a reactive current recorder to gather load data from the distribution feeder. The recorder measures the instantaneous apparent and reactive currents.

Sundhararajan [14] used a directed grid search method to find the solution and sensitivity factors to reduce the number of candidate nodes. Only the top two or three nodes in each lateral branch are used, and the rest are rejected.

Xu [21] proposed a method for optimal placement of capacitor banks to the distribution transformers to reduce power loss. The capacitor bank locations are considered at the low-side of transformers.

Kaur [22] optimized capacitor placement based upon the methods for cost, size and location of capacitor bank to be installed in order to compensate for the reactive power demand by the load.

Su [20] presented a comprehensive optimization based sequential strategy and a multi-objective optimization based real-time strategy for the optimal placement and control of delta-connected switched capacitors.

C. Simultaneous placement of DGs and Capacitors

Simultaneous placement of DGs and capacitors cause to obtain a more optimal solution. Lots of researches were provided in recent years about optimal placement and sizing of the DGs and capacitor.

In [23] simultaneous placement of DG and capacitor is considered in radial distribution network with different load levels. In [24] presented a novel manner to reach the optimal quantity, placement, and sizing for DG units and capacitors simultaneously in a radial distribution network as a multi objective optimization problem. The objective function includes the DG units' and capacitors' costs, power losses, and voltage stability margins as a multi objective optimization problem, which uses a developed genetic algorithm as the first stage in the proposed hierarchical optimization strategy. In [25] presented a model for the simultaneous allocation of capacitor banks and distributed generation, which takes into account the stochastic nature of DG. To solve the model presented, proposed an efficient hybrid method based on Tabu search and genetic algorithms.

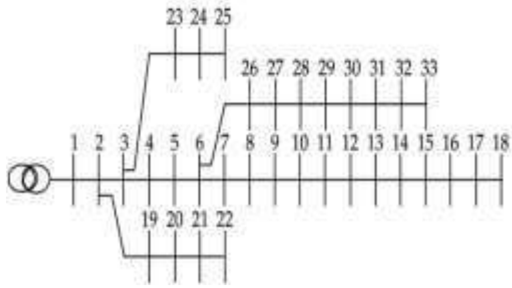
This paper presents a new methodology for the optimal and simultaneous allocation of DGs and Capacitors in distribution systems. In this study introduces two new sensitivity index according to nominal voltage of buses and network losses. (Sv) sensitivity index of voltage defines according to nominal voltage of buses. (Ss) Sensitivity index of losses network defines according to losses network. This methodology does in two stages. In the first stage, selects candidate buses for installation DG and Capacitors base on sensitivity indexes Sv and Ss. So in the second stage placement and sizing of distributed generation and capacitors does using ABC. IEEE 33-bus of [7] and 69-bus of [25] is used as case study and simulation results are reported.

The remaining parts of the paper are divided as follows. Section 2 presents the problem formulation, Section 3 describes the proposed methodology, Section 4 presents ABC, Section 5 presents the results for a well-known system in literature and several conclusions are presented in Section 6.

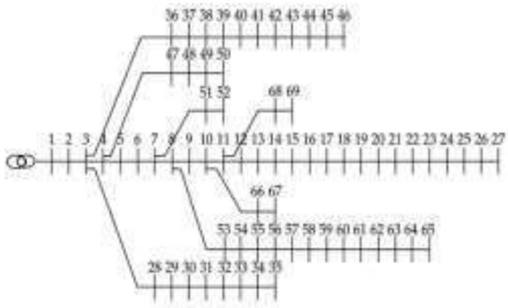
II. PROBLEM FORMULATION

The main objective of optimal sizing and placement of DG units in a distribution network system is to minimize the overall system loss as well as to improve the system voltage profile. For solving the distribution load flow analysis, it is very essential to adjust the bus and branch number in a particular fashion (see Fig. 1.). The branch numbering process can be done in the following way:

- Select the root bus i.e. bus where main source is connected, also called swing bus or slack bus.
- Numbering start from First layer of tree in which all branches connected to root bus.
- Second layer of tree which is connected to receiving end bus of first layer and so on.



a)



b)

Fig. 1. a) IEEE 33-bus distribution network, b) IEEE 69-bus distribution network.

Consider a Π model of a network in which a branch i of the tree is connected between buses k and m. Assume bus k is closer to the root bus i.e. net power is flowing from bus k to bus m. From the Fig. 2, the power flow through the series impedance of the branch can be given by (1) and (2);

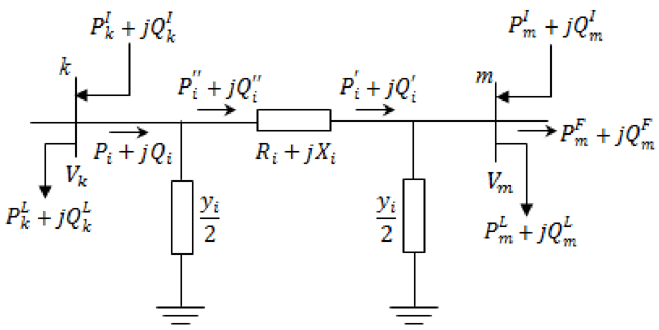


Fig. 2. Π model of a network

$$P_i' = P_m^L + P_m^F - P_m^I \qquad (1)$$

$$Q_i' = Q_m^L + Q_m^F - Q_m^I - V_m^2 \frac{y_i}{2} \qquad (2)$$

The subscripts L, F and I represents the load, flow and injection respectively. The power flow through branch i near bus k can be expressed as:

$$P_i = P_i'' = P_i' + R_i \frac{P_i'^2 + Q_i'^2}{V_m^2} \qquad (3)$$

$$Q_i = Q_i'' - V_k^2 \frac{y_i}{2} = Q_i' + X_i \frac{P_i'^2 + Q_i'^2}{V_m^2} - V_k^2 \frac{Y_i}{2} \qquad (4)$$

This power flow is calculated recursively in a backward direction to find the power flow through each branch in the tree. And, hence the complex voltage at bus m can be calculated as:

$$V_m = \left[V_k - \frac{P_i'' R_i + Q_i'' X_i}{V_k^*}\right] - j\left[\frac{P_i'' X_i - Q_i'' R_i}{V_k^*}\right] \qquad (5)$$

This voltage is calculated in a forward direction to find the magnitude and angle of voltage of all the buses in the tree. The power and voltage of all buses are calculated iteratively again and again until the voltage difference at loop breaking points (breaking points of the tree) is within the acceptable limit. The active power loss (P_{Li}) and reactive power loss (Q_{Li}) in the branch i can be calculated as:

$$P_{Li} = P_i'' - P_i' = R_i \frac{P_i'^2 + Q_i'^2}{V_m^2} \qquad (6)$$

$$Q_{Li} = Q_i'' - Q_i' = X_i \frac{P_i'^2 + Q_i'^2}{V_m^2} \qquad (7)$$

And, hence the net active, reactive and apparent power loss in the system can be expressed as:

$$P_L = \sum_{i=1}^{N} P_{Li} \qquad (8)$$

$$Q_L = \sum_{i=1}^{N} Q_{Li} \qquad (9)$$

$$S_L = (P_L^2 + Q_L^2)^{\frac{1}{2}} \qquad (10)$$

Where S_L is the apparent power loss at distribution system.

By installing the DGs and Capacitors of optimal size at optimal location, the main objective is to minimize the net power loss and modified the voltage profile of the system. Artificial Bee Colony (ABC) optimization technique is one of the robust technique in which very few user dependent parameter is used. It is seen that ABC has very good convergence characteristic and also it doesn't stagnate to local minima. That is why; this technique is used in this paper to minimize the net power loss and modified the voltage profile of the system.

III. METHODOLOGY

In this study, stimulatory placement and sizing of DG and Capacitors are determined in two stages base on two sensitivity indexes.

A. sensitivity indexes

Sv and Ss are defined as:

$$Sv^j = \sum_{i=1}^{NB} |V_i - 1| \qquad (11)$$

$$Ss^j = \frac{S_L^i}{S_L^b} \qquad (12)$$

Where Sv^j the sensitivity index of voltage in perchance Capacitor in Bus j, NB is the number of buses, Ss^j is the sensitivity index of loss power in perchance DG in bus j, S_L^i is the apparent power loss in perchance DG in bus j, and S_L^b is the apparent power loss in base case.

B. first stage

DGs and capacitors must be installed at the appropriate position. This position must have an acceptable impact on the characteristics of the network. So it is important to identify a suitable location for installing DGs and capacitors. In the first stage, candidate locations are determined. For this purpose Sv and Sv for all buses are calculated. Then, priorities of each bus for installing DG and capacitor are identified according to the Sv and Ss.

C. Second stage

In the first stage, priorities of buses are determined. Prioritization of Buses makes the search space reduces and also increase accuracy. Now size and place of DGs and capacitors should be determined. For this purpose ABC is used. The objective function introduce as:

$$objective\ function = k_1 Ss^n + k_2 Sv^n \qquad (13)$$

$$k_1 + k_2 = 1 \qquad (14)$$

Where k_1 and k_2 is the weight factors, Sv^n and Ss^n are the normalized sensitivity indexes.

IV. ARTIFICAL BEE COLONY (ABC)

Artificial Bee Colony (ABC) algorithm is a new swarm intelligence method inspired by intelligent foraging behavior of honey bees [26]. In the ABC algorithm, the colony of artificial bees is formed of three bee groups: employed bees, onlookers and scouts. A bee waiting on the dance area to determine to choose a food source is an onlooker and a bee goes to the food source visited by it previously is an employed bee. A bee who carries out random search is called a scout [28- 30]. The goal of bees in the ABC model is to find the best solution. Therefore, the position of a food source represents a possible solution to the optimization problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution.

In the ABC algorithm, the first half of the colony consists of employed bees and the second half consists of onlooker bees. There is only one employed bee for each food source whose first position is randomly generated. At each iteration of the algorithm, each employed bee determines a new neighboring food source of its currently associated food source by (15), and computes the nectar amount of this new food source.

$$v_{ij} = X_{ij} + \theta_{ij}(x_{ij} - x_{kj}) \quad (15)$$

where θ_{ij} is a randomly produced number between [-1,1]. If the nectar amount of this new food source is higher than that of its currently associated food source, then this employed bee moves to this new food source, otherwise it continues with the old one. After all employed bees complete the search process, they share the information about their food sources with onlooker bees. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount by (16). which is known as roulette wheel selection method. This method provides better candidates to have a greater chance of being selected.

$$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \quad (16)$$

where fit_i is the fitness value of the solution i which is proportional to the nectar amount of the food source in the position i and SN is the number of food sources which is equal to the number of employed bees. Once all onlookers have selected their food sources, each of them determines a new neighboring food source of its selected food source and computes it's nectar amount. Providing that its nectar is higher than that of the previous one, the bee memorizes the new position and forgets the old one.

The food source which is exhausted by the employed and onlooker bees is assigned as abandoned. Then, the employed bee of that source becomes a scout. In other words, if any position cannot be improved further through a predetermined number of cycles which is called limit parameter, the food source is assumed to be abandoned and employed bee of that source will be a scout. In that position, a new solution is randomly generated by the scout, given in (17). Assume that the abandoned source is and x_i j ∈ {1,2,...,D}, D is the solution vector, the scout discovers a new food source which will be replaced with x_i.

$$x_i^j = x_{min}^j + rand(0,1)(x_{max}^j - x_{min}^j) \quad (17)$$

where j is determined randomly, it should be noticed that it has to be different from i. There are three control parameters in the ABC: the first one is the number of food sources which is equal to the number of employed or onlooker bees (SN), the second one is the value of limit parameter, and the third one is the maximum cycle number (MCN). Based on the above explanation ABC algorithm is summarized as follows [27]:

- Generate initial population x_i i=1...SN
- Evaluate the population
- Set cycle to 1
- Repeat
- FOR each employed bee
- Produce new solutions v_i by using (1)
- Calculate the fitness
- Apply the greedy selection process
- FOR each onlooker bee
- Choose a solution x_i depending on p_i
- Produce new solutions v_i
- Calculate the fitness
- Apply the greedy selection process
- If there is an abandoned solution for the scout, then replace it with a new solution produced by (17).
- Memorize the best solution so far
- Assign cycle = cycle + 1
- Until cycle = MCN

V. SIMULATION RESULT

In order to simulate the proposed problem, the IEEE 33-bus and IEEE 69-bus radial network is used. The networks data, including the resistance and reactance of the lines and the loads connected to nodes, were presented in [7, 25]. In order to show the importance of studying the simultaneous placement and sizing of the DG units and the capacitors, first, for the proposed networks, placement, and sizes of the DG units and the capacitors are presented separately, and finally, the simultaneous placement and sizing of the DGs and capacitors is determined and the results are compared.

A. *Placement and sizing of DG*

In this section, placement and sizing of DG units regarding the minimum value of the problem objective function are defined. In this section k_2 =0. The results for this case are shown in Table I and II.

Table I. placement and sizing of DGs in IEEE 33-bus radial network

Row	Capacity (kW)	Bus No.
1	656.4803	30
2	203.0234	31
3	1987.197	29

Table II. placement and sizing of DGs in IEEE 69-bus radial network

Row	Capacity (kW)	Bus No.
1	200	61
2	260.4957	62
3	273.7831	63
4	200	64
5	1179.8726	60

B. Placement and sizing of DG

In this section, placement and sizing of capacitors regarding the minimum value of the problem objective function are defined. In this section k_1 =0. The results for this case are shown in Table III and IV.

Table III. placement and sizing of Capacitors in IEEE 33-bus radial network

Row	Capacity (kVAr)	Bus No.
1	2000	14
2	712.2927	15

Table IV. placement and sizing of Capacitors in IEEE 69-bus radial network

Row	Capacity (kVAr)	Bus No.
1	1449.4401	65
2	2000	64
3	2000	63
4	2000	62

C. Simultaneous placement and sizing of DG and Capacitors

In this section, placement and sizing of Capacitors regarding the minimum value of the problem objective function are defined. In this section k_1 =0. The results for this case are shown in Table V and VI.

Table V. placement and sizing of DGs in IEEE 33-bus radial network

Row	Capacity (kW)	Bus No.	Capacity (kVAr)	Bus No.
1	1130.8423	30	892.5297	17
2	200	31	344.2624	18
3	610.3225	29	-	-

Table VI. placement and sizing of DGs in IEEE 69-bus radial network

Row	Capacity (kW)	Bus No.	Capacity (kVAr)	Bus No.
1	221.2428	61	786.594	25
2	1057.542	62	702.4423	24
3	908.7166	63	1140.778	26
4	1470.5555	64	340.5747	27
5	893.4444	60	-	-

Losses and Sv of the system different case of study are shown in Table VII. The voltages profile of network before and after the installation of the DGs and capacitors are shown in Fig. 3. and 4.

Table VII. Losses and Sv of the network

Network	Case study	Power losses (kVA)	Sv
IEEE 33-Bus	Base	243.6003	1.7009
	DG	106.5249	0.5301
	CAPASITOR	468.1845	0.7368
	DG and CAPACITOR	149.6582	0.2162
IEEE 69-Bus	Base	247.0873	1.8367
	DG	31.7836	0.5513
	CAP	1705.5726	0.7068
	DG and CAPACITOR	176.6673	0.1278

D. Discussion

According to the above simulation results, the operation from the network that is in the presence of DG provided better conditions than the operation in the presence of the capacitors, which shows that the role of DG is more effective than that of the capacitors. Also, the simulation results show that the optimal operation of the network occurs in the simultaneous expansion planning of DGs and capacitors. Comparing the results, it is obvious that optimal operation from the network is obtained by the simultaneous placement of DG units and capacitors.

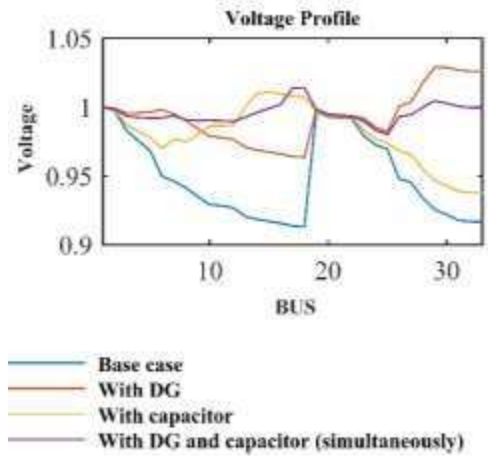


Fig. 3. Voltage profile of IEEE 33-Bus

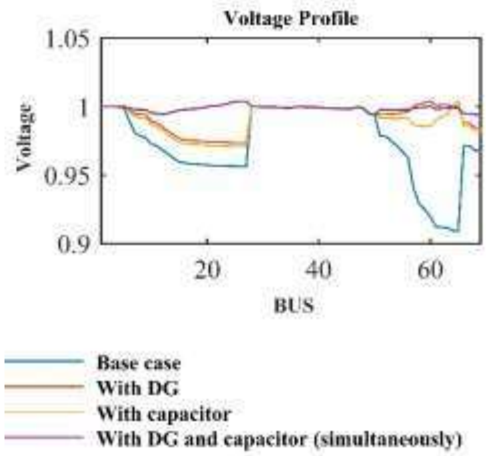


Fig. 4. Voltage profile of IEEE 69-Bus

VI. CONCLUSIONS

In this paper, we have presented a new approach for simultaneous placement and sizing of distributed generation and capacitors. Two sensitivity indexes has been defined according to voltage profile and loss power of network. Proposed methodology has been implemented in two stage. In the first stage, the candidate buses for installation DG and capacitors has been determined. Then in the second stage, the places and sizes of DGs and Capacitors have been located using ABC. The proposed algorithm is tested on IEEE-33 bus and IEEE-69 bus distribution system. The voltage profile and power loss of the system has improved to acceptable limit.

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