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Capacitor Placement in Radial Distribution System for Improve Network Efficiency Using Artificial Bee Colony

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Abstract
Increasing application of capacitor banks on distribution networks is the direct impact of development of technology and the energy disasters that the world is encountering. To obtain these goals the resources capacity and the installation place are of a crucial importance. In this paper a new method is proposed to find the optimal and simultaneous place and capacity of these resources to reduce losses, improve voltage profile. The advantage of ABC algorithm is that it does not require external parameters such as cross over rate and mutation rate as in case of genetic algorithm and differential evolution and it is hard to determine these parameters in prior. To demonstrate the validity of the proposed algorithm, computer simulations are carried out on actual power network of Kerman Province, Iran and the simulation results are presented and discussed.

Keywords: Distribution systems, Loss Sensitivity Factors, Capacitor placement, Artificial Bee Colony Algorithm

I. Introduction

The loss minimization in distribution systems has assumed greater significance recently since the trend towards distribution automation will require the most efficient operating scenario for economic viability variations. The power losses in distribution systems correspond to about 70% of total losses in electric power systems (2005). To reduce these losses, shunt capacitor banks are installed on distribution primary feeders. The advantages with the addition of shunt capacitors banks are to improve the power factor, feeder voltage profile, Power loss reduction and increases available capacity of feeders. Therefore it is important to find optimal location and sizes of capacitors in the system to achieve the above mentioned objectives. Since, the optimal capacitor placement is a complicated combinatorial optimization problem, many different optimization techniques and algorithms have been proposed in the past. H. Ng et al (2000) proposed the capacitor placement problem by using fuzzy approximate reasoning. Sundharajan and Pahwa (1994) proposed the genetic algorithm approach to determine the optimal placement of capacitors based on the mechanism of natural selection. Ji-Pyng Chiou et al (2006) proposed the variable scale hybrid differential evolution algorithm for the capacitor placement in distribution system. Both Grainger et al (1981) and Baghzouz and Ertem (1990) proposed the concept that the size of capacitor banks was considered as a continuous variable. Bala et al (1995) presented a sensitivity-based method to solve the optimal capacitor placement problem.

In this paper a new method is proposed to find the optimal and simultaneous place and capacity of these resources to reduce losses, improve voltage profile. The artificial bee colony algorithm is a new meta heuristic approach, proposed by Karaboga [9]-[11]. It is inspired by the intelligent foraging behavior of honey bee swarm. The proposed method is tested on actual power network of Kerman Province, Iran and the simulation results are presented and discussed.

II. Objective function

The objective of capacitor placement in the distribution system is to minimize the annual cost of the system, subjected to certain operating constraints and load pattern. For simplicity, the operation and maintenance cost of the capacitor placed in the distribution system is not taken into consideration. The three-phase system is considered as balanced and loads are assumed as time invariant. Mathematically, the objective function of the problem is described as:

$$Minimize\ f = Min\,(COST + \lambda \Delta v_{min}^{2}) \qquad (1)$$

Where COST includes the cost of power loss and the capacitor placement, and will be discussed further later. λ is a penalty function and (ΔV^{2}) min is the squared sum of the violated voltage constraint. Moreover, the penalty function satisfies the following properties:

(1) If the voltage constraint is not violated, $\lambda = 0$;
(2) If the constraint is violated, a significant penalty is imposed to cause the objective function to move away from the undesirable solution.

The voltage magnitude at each bus must be maintained within its limits and is expressed as:

$$V_{min} \leq |V_i| \leq V_{max} \qquad (2)$$

Where │Vi│ is the voltage magnitude of bus i, V_{min} and V_{max} are bus minimum and maximum voltage limits, respectively.

III. Formulation

The power flows are computed by the following set of simplified recursive equations derived from the single-line diagram depicted in Fig. 1.

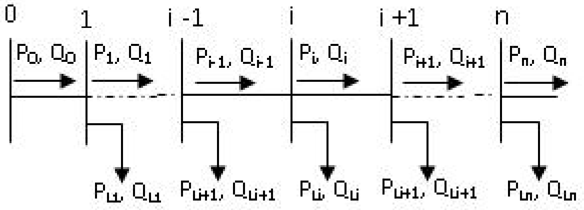

Figure 1: Single line diagram of main feeder

$$P_{i+1} = P_i - P_{Li+1} - R_{ij+1} \frac{P_i^2 + Q_i^2}{|V_i|^2} \qquad (3)$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{ij+1} \frac{P_i^2 + Q_i^2}{|V_i|^2} \qquad (4)$$

$$|V_i|^2=|V_i|^2- 2(R_{ij+1}\ P_i+X_{ij+}\ Q_i)+(R^2_{ij+1}+X^2_{ij+1})\times\frac{P_i^2+Q_i^2}{|V_i|^2} \qquad (5)$$

Where Pi and Qi are the real and reactive powers flowing out of bus i, and P_{Li} and Q_{Li} are the real and reactive load powers at bus i. The resistance and reactance of the line section between buses i and i+1 are denoted by $R_{i,i+1}$ and $X_{i,i+1}$ respectively. The power loss of the line section connecting buses i and i+1 may be computed as

$$P_{Loss}(i, i+1) = R_{i,i+1} \frac{P_i^2 + Q_i^2}{|V_i|^2} \qquad (6)$$

The total power loss of the feeder, P_T^{LOSS} may then be determined by summing up the losses of all line sections of the feeder, which is given as

$$P_T^{LOSS} = \sum_{i=0}^{n-1} P_{LOSS}(i, i+1) \qquad (7)$$

Considering the practical capacitors, there exists a finite number of standard sizes which are integer multiples of the smallest size Q0 c. Besides, the cost per Kvar varies from one size to another. In general, capacitors of larger size have lower unit prices. The available capacitor size is usually limited to

$$Q_c^{max} = LQ_c \qquad (8)$$

Therefore, for each installation location, there are L capacitor sizes {$1Q_C$, $2Q_c$, $3Q_c$, …, LQc} available. Given the annual installation cost for each compensated bus, the total cost due to capacitor placement and power loss change is written as

$$COST = K_p \times P_T^{LOSS} + \sum_i^c (K_{cf} + K_i^c Q_i^c) \qquad (9)$$

Where n is number of candidate locations for capacitor placement, Kp is the equivalent annual cost per unit of power loss in \$/(kW-year); K_{cf} is the fixed cost for the capacitor placement. Constant K_i^c is the annual capacitor installation cost, and, i = 1, 2, ... , n are the indices of the buses selected for compensation. The bus reactive compensation power is limited to

$$Q_i^c \leq \sum_{i=1}^n Q_{Li} \qquad (10)$$

Where $1Q_c$ and LQ_c are the reactive power compensated at bus i and the reactive load power at bus i, respectively.

IV. Power Flow Analysis Method

The methods proposed for solving distribution power flow analysis can be classified into three categories: Direct methods, Backward-Forward sweep methods and Newton-Raphson (NR) methods. The Backward-Forward Sweep method is an iterative means to solving the load flow equations of radial distribution systems which has two steps. The Backward sweep, which updates currents using Kirchoff's Current Law (KCL), and the Forward sweep, which updates voltage using voltage drop calculations [12].

The Backward Sweep calculates the current injected into each branch as a function of the end node voltages. It performs a current summation while updating voltages. Bus voltages at the end nodes are initialized for the first iteration. Starting at the end buses, each branch is traversed toward the source bus updating the voltage and calculating the current injected into each bus. These calculated currents are stored and used in the subsequent Forward Sweep calculations. The calculated source voltage is used for mismatch calculation as the termination criteria by comparing it to the specified source voltage. The Forward Sweep calculates node voltages as a function of the currents injected into each bus. The Forward Sweep is a voltage drop calculation with the constraint that the source voltage used is the specified nominal voltage at the beginning of each forward sweep. The voltage is calculated at each bus, beginning at the source bus and traversing out to the end buses using the currents calculated in previous the Backward Sweep [12]. Single line diagram of main feeder depicted in Fig. 2.

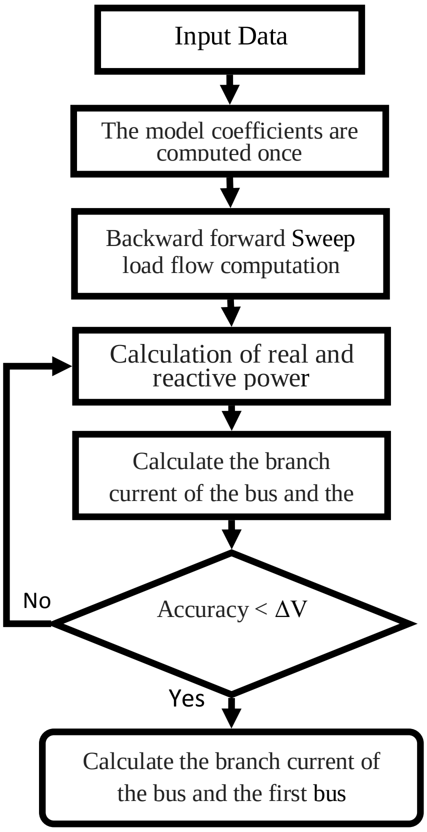

Figure 2: Single line diagram of main feeder

V. Artificial Bee Colony Algorithm (ABC)

Artificial Bee Colony (ABC) algorithm, proposed by Karaboga for optimizing numerical problems in [6], simulates the intelligent foraging behavior of honey bee swarms. In ABC algorithm, the colony of artificial bees contains three groups of bees: employed bees, and unemployed bees: onlookers and scouts. In ABC, first half of the colony consists of employed artificial bees and the second half constitutes the artificial onlookers. The employed bee whose food source has been exhausted becomes a scout bee. In ABC algorithm, 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. The number of the employed bees is equal to the number of food sources, each of which also represents a site, being exploited at the moment or to the number of solutions in the population.

In the ABC algorithm, first half of the colony consists of employed artificial bees and the second half constitutes the onlookers. For every food source, there is only one employed bee. In the ABC algorithm, each cycle of the search consists of three steps: sending the employed bees onto the food sources and then measuring their nectar amounts Hence, the dance of employed bees carrying higher nectar recruits the onlookers for the food source areas with higher nectar amount. After arriving at the selected area, she chooses a new food source in the neighborhood of the one in the memory depending on visual information. Visual information is based on the comparison of food source positions. When the nectar of a food source is abandoned by the bees, a new food source is randomly determined by a scout bee and replaced with the abandoned one. Flowchart of the proposed method depicted in Fig. 3.

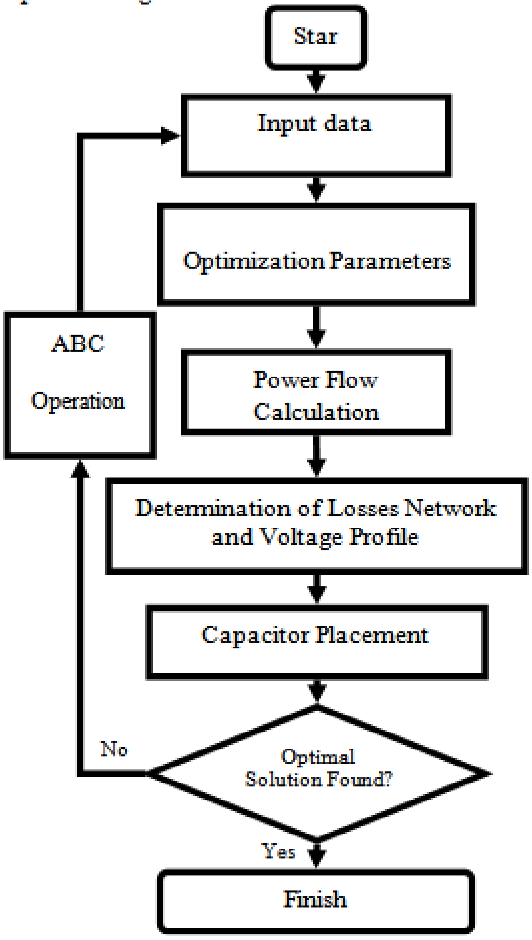

Figure 3: Flowchart of the proposed method

VI. Test Results

To study the proposed method, actual power network of Kosar feeder of Kerman Province, Iran is simulated in Cymedist. Figure 3 illustrates the single-line diagram of this network. The base values of the system are taken as 20kV and 20MVA. The system consists of 20 distribution transformers with various ratings. The details of the distribution transformers are given in table 1. The details of the distribution conductors are given in table 2. The lengths of the feeder segments are given in table 3. The total connected load on the system is 2550 KVA and the peak demand for the year is 2120 KVA at a PF of 0.8 lag. The connected loads on the transformers are listed in table 4.

Table 1: Details of transformers in the system

Rating [KVA]	50	100	250
Number	5	9	6
No load losses [watts]	150	250	480
Impedance [%]	4.5	4.5	4.5

Table 2: Details of conductors in the system

Type	R [Ω/km]	X [Ω/km]	Cmax [A]	A [mm2]
Hyena	0.1576	0.2277	550	126
Dog	0.2712	0.2464	440	120
Mink	0.4545	0.2664	315	70

Table 3: Distribution System Line Data

from	To	Length (meters)
1	2	80
2	3	80
3	4	80
4	5	60
5	6	60
6	7	60
7	8	60
8	9	60
9	10	60
10	11	60
11	12	60
12	13	60
13	14	60
14	15	60
14	16	60
16	17	60
17	18	60
18	19	60
19	20	60

Table 4: Details of the connected loads

Transformer no	Load [Kva]
1	35
2	245
3	85
4	165
5	50
6	85
7	180
8	35
9	35
10	90
11	85
12	75
13	200
14	73
15	35
16	85
17	98
18	230
19	220
20	85

In addition the total network loss, which was 10.05MW before installing capacitor, has diminished to the 4.55MW which shows 45.81% decrease. Table 5 and 6 depicts the Results of power flow before and after installation of capacitor.

The simulation results are given in Table 7. These results reveal that the inclusions of capacitor reduce the line losses as expected. It can be shown from the graphs that, LRI decreases marginally, since the core losses of the transformers and the LV side losses remain constant being independent of the presence of v. It can also be seen that with the increase in the reactive power of capacitor, LRI, decrease

Table 5: Results of power flow before installation of capacitor

Bus Number	V (pu)
1	1.0
2	0.9999
3	0.9998
4	0.9988
5	0.9988
6	0.9987
7	0.9985
8	0.9889
9	0.9879
10	0.9849
11	0.97
12	0.93
13	0.89
14	0.9849
15	0.9849
16	0.91
17	0.92
18	0.95
19	0.94
20	0.89

Table 6: Results of power flow after installation of capacitor banks

Bus Number	V (pu)
1	1.0
2	0.9999
3	0.9999
4	0.9999
5	0.9999
6	0.9988
7	0.9988
8	0.9888
9	0.9881
10	0.9885
11	0.99
12	0.97
13	0.91
14	0.988
15	0.988
16	0.95
17	0.96
18	0.98
19	0.95
20	0.93

Table 7: Variation of LRI and Optimal place and capacity of capacitor banks

Number	3	3	5	5	7	7
place	2,12,16	7,13,15	2,6,7,13,15	7,8,9,11,20	5,7,13,15,16,18,20	2,4,9,10,14,18,20
Picked capacity [Mvar]	0.02	0.02	0.575	0.35	2.1	2.25
Presumable Capacity Range [Mvar]	0.025 0.05 0.1 0.2 0.25 0.4 0.5	0.05 0.1 0.2 0.4 0.5 0.8 1	0.025 0.05 0.1 0.2 0.25 0.4 0.5	0.05 0.1 0.2 0.4 0.5 0.8 1	0.025 0.05 0.1 0.2 0.25 0.4 0.5	0.05 0.1 0.2 0.4 0.5 0.8 1
LRI [%]	0.9296	0.8866	0.7627	0.6649	0.7026	0.9754

The detailed pu voltages profile of all the nodes of the system after capacitor placement are shown in the Figure 4.

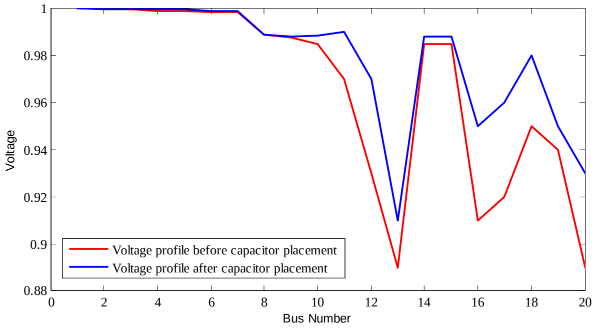

Fig 4: Voltage profile of 20 bus system before and after capacitor placement

VII. Conclusion

In the present paper, a new population based artificial In the present paper, a new population based artificial bee colony algorithm (ABC) has been proposed to solve capacitor placement problem and quantifying the total line loss reduction in distribution system. Simulations are carried on actual power network of Kerman Province, Iran. The simulation results show that the inclusion of capacitor, marginally reduce the losses in a distribution system. This is because; the line losses form only a minor part of the distribution system losses and the capacitor can reduce only the line losses. The other losses viz. the transformer losses and the LV side distribution losses remain unaltered. Hence this fact should be considered before installing a capacitor into a system. The results obtained by the proposed method outperform the other methods in terms of quality of the solution and computation efficiency.

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