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Loss Reduction due Optimization of Capacitor Placement Using DPSO Algorithm; Case Study in Kerman

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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. Line loss reduction is one of the major benefits of capacitor, amongst many others, when incorporated in the power distribution system. The quantum of the line loss reduction should be exactly known to assess the effectiveness of the distributed generation. 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 too the total loss of a practical distribution system is calculated with and without capacitor placement and an index, quantifying the total line loss reduction is proposed. 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.*

Keyword: *Distribution systems, Loss reduction index, Capacitor placement, Discrete Particle Swarm Optimization*

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. 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.

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. However, considered only the losses in the lines and the quantification were defined for the line losses only. These indices, therefore, do not indicate the loss reduction of the system itself. A practical distribution system consists of several distribution transformers, supplying consumers at low voltage on the secondary side. The losses occurring in these transformers and the line losses of the secondary low voltage distribution system should also be considered to arrive at the overall loss reduction of the system.

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 too the total loss of a practical distribution system is calculated with and without capacitor placement and an index, quantifying the total line loss reduction is proposed. 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.

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:

$$Minimize\ f = Min\ (COST)$$

Where COST includes the cost of power loss and the capacitor placement. The voltage magnitude at each bus must be maintained within its limits and is expressed as:

$$V_{min} \le |V_i| \le V_{max}$$

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

FORMULATION

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

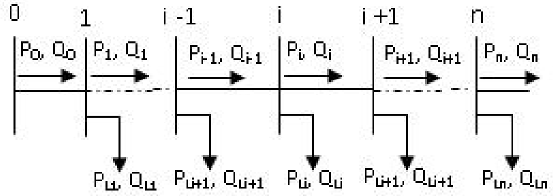

Figure 1: Single line diagram of main feeder

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

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

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

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

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

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

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

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

$$Q_c^{max} = LQ_c$$

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

$$COST = K_p \times P_T^{LOSS} + \sum\nolimits_i^c \left(K_{cf} + K_i^c Q_i^c\right)$$

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

$$Q_i^c \le \sum\nolimits_{i=1}^n Q_{Li}$$

Where 1Q$_c$ and LQ$_c$ are the reactive power compensated at bus i and the reactive load power at bus i, respectively.

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 [5].

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 [5].

DISCRETE PARTICLE SWARM OPTIMIZATION (DPSO)

In the present paper, as mentioned, particle swarm optimization algorithm is the second EA which is used to solve the DG allocation problem. Its key concept is that potential solutions are flown through hyperspace and are accelerated towards better or more optimum solutions. It lies somewhere on between evolutionary programming and the genetic algorithms. Some of the features of PSO are adaptability, diverse response, proximity, quality, and stability (Clerk and Kennedy, 2002). There are three versions of PSO: real, binary and discrete codifications. As the decision variables of the present problem are of discrete type, hence, Discrete Particle Swarm Optimization (DPSO) method is used in this paper.

LOSS REDUCTION ANALYSIS

The total loss of the distribution system without capacitor is given by

$$Loss_{without\ Cap} = \sum_{i=1}^{N-1} I_i^2 \times r \times L_i + \sum_{i=1}^{N-1} \left(P_{ci} + P_{Lv_i}\right)$$

Where I_i is the current flowing through ith section, r is the resistance of line in ohms per unit length, L_i is the length of ith section, P_{ci} is the core loss of ith transformer, P_{Lv_i} is the Losses on the low voltage side of the ith transformer and N is the number of busses in the system.

In order to determine the losses of the system, the core loss of each transformer and the LV side losses on each transformer must be known. It is evident from the above equation that the total losses can be reduced only by reducing the first term which represents the feeder line losses, since the other term representing the core loss and the LV side loss of each transformer remain same independent of the presence of capacitor. If a capacitor is inserted at Kth bus, the feeder segments up to bus K will carry the difference of the initial current and the injected current by the capacitor. Where I_{Cap} is the current injected by the capacitor and I_i remains the same at earlier value. The total loss of the distribution system with capacitor is now

$$Loss_{with\ Cap} = \sum_{i=1}^{K-1} \left(I_i - I_{Cap}\right)^2 rL_i + \sum_{i=k}^{N-1} I_i^2 rL_i + \sum_{i=1}^{N-1} \left(P_{ci} + P_{Lv_i}\right)$$

A factor, loss reduction index (LRI), which quantifies the loss reduction with the insertion of capacitor, is defined as

$$LRI = \frac{Loss\ in\ the\ system\ with\ \text{capacitor}}{Loss\ in\ the\ system\ without\ \text{capacitor}}$$

The LRI is now obtained as

$$LRI = \frac{Loss_{System\ without\ Cap} + K_{Loss} I_{Cap}}{Loss_{System\ without\ Cap}}$$

Where K_{Loss} is the loss factor given by

$$K_{loss} = \sum_{i=1}^{K-1} \left(I_{Cap} - 2I_i\right) \times r \times L_i$$

TEST RESULTS

To study the proposed method, actual power network of Kosar feeder of Kerman Province, Iran is simulated in Cymedist. Figure 2 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.

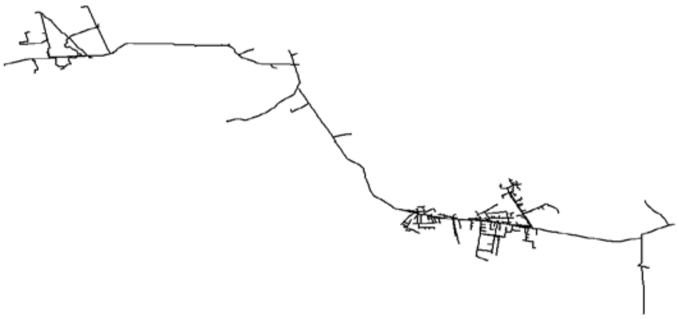

Figure 2: Single-line diagram of actual power network of Kosar feeder of Kerman Province in Cymedist

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

Initially, a load flow was run for the case study in both fundamental frequency and harmonics frequencies without installation of capacitor. Table 5 depicts the results of power flow for determination voltage and harmonic before installation of capacitor. Table 6 depicts the locations and capacity of capacitor banks using artificial bee colony algorithm. As it is clear, all the obtained values confines with all the considered constraints. The obtained penetration lever is 0.27, which is less than the assumed allowable value.

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: Optimal place and capacity of capacitor banks

Location [#bus]	Capacity [Mvar]
5	0.05
10	0.48
11	0.05
15	0.05
20	0.1

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 7 shows the impact of installing capacitor on THD of buses.

Table 7: 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

The detailed pu voltages profile and Percentage of loss of all the nodes of the system before and after capacitor placement are shown in the Figure 3 and Figure 4.

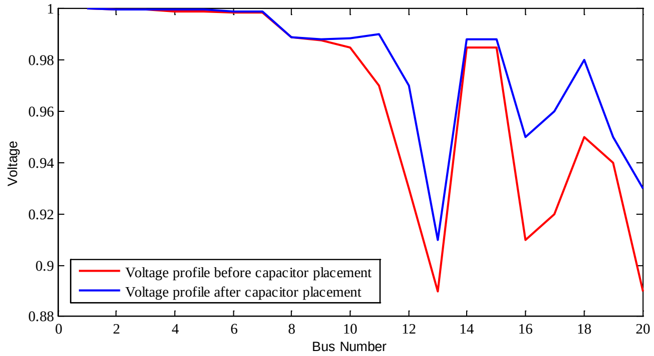

Figure 3: Voltage profile of 20 bus system before and after capacitor placement

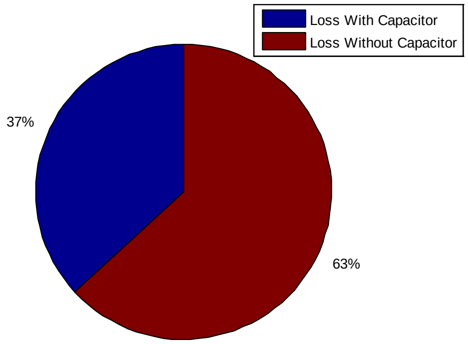

Figure 4: Percentage of loss before and after capacitor placement

The simulation results are given in Table 8. 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 capacitor. It can also be seen that with the increase in the reactive power capacity of capacitor, LRI, decrease.

Table 8: Variation of LRI and capacity & number of capacitor banks

Number	3	3	5	5
Picked	0.3	0.3	0.3	0.35

capacity [Mvar]				
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
LRI [%]	0.5902	0.5931	0.5846	0.5881

CONCLUSION

In the present paper, a new population based Discrete Particle Swarm Optimization (DPSO) 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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