COMBINATION OF CAPACITOR PLACEMENT AND RECONFIGURATION FOR LOSS REDUCTION IN DISTRIBUTION SYSTEMS USING SELECTIVE PSO

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ABSTRACT

Capacitor placement and distribution network reconfiguration (DNR) are two useful methods in reducing the power losses of distribution networks. This paper proposes a selective particle swarm optimization (SPSO) to solve the optimal capacitor placement problem, the optimal feeder reconfiguration problem, and the problem of a combination of the two. The problem is posed as an optimization problem with an objective to maximize the loss reduction and improve the voltage profile. The optimization procedure is subject to some technical (maximum permissible branch current, maximum and minimum voltage limits and maximum permissible size of capacitors) and operational constraints (load connectivity and radial network structure). The proposed algorithm has been implemented and tested on two test systems from the literatures. The results obtained using the proposed algorithm are compared with the results obtained using different methods given in literature. The simulation results demonstrate the effectiveness of the proposed algorithm. In addition, simulation results show that the results of simultaneous capacitor placement and DNR is more effective than considering them separately.

INTRODUCTION

In the distribution systems several methods are used to reduce the power loss and to enhance the voltage, two of these methods are the installation of shunt capacitors and DNR. Capacitors are widely used in distribution systems for reactive power compensation to achieve power loss reduction, system capacity release and voltage profile improvement. DNR is the process of changing the topology of distribution systems by altering the open/closed status of the switches. The problem of DNR consists in finding a radial configuration that leads to the smallest power losses, while respecting the operational constraints on line flows and voltages and the radial topology. Capacitor placement problem is a multiobjective optimization problem with a number of equality and inequality constraints. All the earlier approaches differ from each other in the way of problem formulation and the solution techniques employed. The solution techniques for the capacitor placement problem can be classified into four categories [1]; analytical, numerical programming, heuristic, and artificial intelligence-based (AI-based). Published papers describing capacitor placement algorithms are abundant. The reconfiguration problem is usually a nonlinear combinatorial problem, subject to operational and multiobjective constraints. The size of the problem is intimately related to the number of switches involved in the search for a best configuration. In recent years, many algorithms have been developed for loss minimization in the area of network reconfiguration of distribution systems. Most of these algorithms are based on heuristic techniques and artificial intelligence techniques. In [2], an exhaustive survey of the modern heuristic methods for the DNR is presented. Artificial intelligence techniques were also applied to DNR problem extensively, for example, simulated annealing (SA) [3], artificial neural networks (ANN) [4], genetic algorithms (GA) [5], ant colony search algorithm (ACSA) [6], fuzzy logic [7] and particle swarm optimization [8].

In the present work, SPSO is proposed to solve the optimal capacitor placement problem, the optimal feeder reconfiguration problem, and the problem of a combination of the two simultaneously. The objective function is formulated to maximize the power loss reduction, with constrains which include the minimum and maximum limits of bus voltages, the maximum allowable current for each branch, the maximum allowable size of shunt capacitors to be installed in the system, the load connectivity and the radial structure of the network. The proposed algorithm implemented and tested on two test systems from literatures. The simulation results show the effectiveness of the proposed algorithm in solving this problem.

PROBLEM FORMULATION

This work discusses the capacitor placement and reconfiguration of distribution systems. The objective function is to maximize the power loss reduction of the system P_L considering the following constraints.

1. Branch current constraint

$$I_b \le I_{b\max} \tag{1}$$

where I_b is the current of branch b, and $I_{b\max}$ is the maximum permissible current of branch b.

2. Node voltage constraint

$$U_{j\min} \le \left|U_j\right| \le U_{j\max} \tag{2}$$

where $U_{j\min}$ and $U_{j\max}$ are the minimum and maximum permissible *rms* voltages of node j, respectively.

3. Size of installed capacitor constraint (the total reactive power injection Q_t^c is not to exceed the total reactive power demand in the distribution system Q_t^d)

$$Q_t^c \le Q_t^d \tag{3}$$

4. Load connectivity (each bus should be connected via one path to the substation).
5. Radial network structure (loops are not allowed in the network).

SOLUTION METHOD

The particle swarm optimization method was first introduced by Kennedy and Eberhart in 1995. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous nonlinear optimization problems. One of reasons that PSO is attractive is that there are very few parameters. In PSO algorithm, each member is called "particle", which represents a candidate solution to the problem, and each particle flies around in the multi-dimensional search space with a velocity, which is constantly updated by the particle's own experience and the experience of the particle's neighbors.

The basic PSO technique is the real valued PSO, whereby each dimension can take on any real valued number. In *d*-dimensional search space the position, velocity, best previous position for each particle (particle best) and best position for all particles (global best) are represented by vectors and described as as $X_i = [x_{i1},\ x_{i2},\ \dots,\ x_{id}]$, $V_i = [\upsilon_{i1},\ \upsilon_{i2},\ \dots,\ \upsilon_{id}]$, $PB_i = [pb_{i1},\ pb_{i2},\ \dots,\ pb_{id}]$ and $GB = [gb_1,\ gb_2,\ \dots,\ gb_d]$, respectively. At iteration *k* the velocity and the position for *d*-dimension of *i-th* particle are updated by (4) and (5) respectively:

$$\upsilon_{id}^{k+1} = w\upsilon_{id}^k + c_1 r_1 (pb_{id}^k - x_{id}^k) + c_2 r_2 (gb_d^k - x_{id}^k) \tag{4}$$

$$x_{id}^{k+1} = x_{id}^k + \upsilon_{id}^{k+1} \tag{5}$$

where $i = 1,\ 2,\ \dots,\ n$; n is the set of particles in swarm (i.e. "population") described as $pop = [X_1,\ X_2,\ \dots,\ X_n]$; w is the inertia weight; c_1 and c_2 are the acceleration constants; r_1 and r_2 are the two random values in range [0,1].

In 1997, Kennedy and Eberhart have adapted the PSO to search in binary spaces, by applying a sigmoid transformation to the velocity component 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 (see (6)). Equation (5) is then replaced by (7) for updating positions:

$$sigmoid(\upsilon_{id}^{k+1}) = \frac{1}{1 + \exp(-\upsilon_{id}^{k+1})} \tag{6}$$

$$x_{id}^{k+1} = \begin{cases} 1, \text{ if } rand < sigmoid(\upsilon_{id}^{k+1}) \\ 0 \qquad \text{otherwise} \end{cases} \tag{7}$$

In [9] Khalil and Gorpinich proposed a simple modification to the binary PSO to search in a selected space, this modification called SPSO. In SPSO a search space at each *d*-dimension $S_d = [s_{d1},\ s_{d2},\ \dots,\ s_{dn}]$ is the set of *dn* positions, where *dn* is the number of the selected positions in dimension *d*. As in the basic PSO, a fitness function *F* must be defined. In this case it maps at each *d*-dimension from *dn* positions of the selective space S_d, where the position of each particle has been changed from being a point in real-valued space to be a point in the selective space. Therefore, the sigmoid transformation will be changed to (8), and the *i-th* coordinate of each particle's position at a dimension d is a selective value updated by (9)

$$sigmoid(\upsilon_{id}^{k+1}) = dn \frac{1}{1 + \exp(-\upsilon_{id}^{k+1})} \tag{8}$$

$$x_{id}^{k+1} = \begin{cases} s_{d1}, \text{ if } sigmoid(\upsilon_{id}^{k+1}) < 1 \\ s_{d2}, \text{ if } sigmoid(\upsilon_{id}^{k+1}) < 2 \\ s_{d3}, \text{ if } sigmoid(\upsilon_{id}^{k+1}) < 3 \\ \dots\dots\dots\dots\dots\dots \\ s_{dn}, \text{ if } sigmoid(\upsilon_{id}^{k+1}) < dn \end{cases} \tag{9}$$

where $s_{d1},\ s_{d2},\ s_{d3},\ \dots,\ s_{dn}$ are the selected values in dimension *d*.

Velocity values are restricted to some minimum and maximum values $[V_{\min},\ V_{\max}]$ using (10)

$$\upsilon_{id}^{k+1} = \begin{cases} V_{\max}, \text{ if } \upsilon_{id}^{k+1} > V_{\max} \\ \upsilon_{id}^{k+1}, \text{ if } \left|\upsilon_{id}^{k+1}\right| \le V_{\max} \\ V_{\min}, \text{ if } \upsilon_{id}^{k+1} < V_{\min} \end{cases} \tag{10}$$

Equation (11) is used to avoid invariability of the value of *i-th* particle velocity in a *d*-dimension at the maximum or minimum values and force each particle going through the search space:

$$\upsilon_{id}^{k+1} = \begin{cases} rand \times \upsilon_{id}^{k+1}, \text{ if } \left|\upsilon_{id}^{k+1}\right| = \left|\upsilon_{id}^{k}\right| \\ \upsilon_{id}^{k+1} \qquad \text{otherwise} \end{cases} \tag{11}$$

Thus in the basic PSO a search space is the real-valued space and the binary PSO search space is the set of 0^s and 1^s, while in the selective PSO a search space is the set of selected values.

TEST RESULTS

The proposed SPSO has been tested on two systems published in the literature to ascertain its effectiveness. For these two systems, all tie and sectionalizing switches which belong to any loop are considered as candidate switches for reconfiguration problem and all busses are considered as candidate busses (except the substation buses) to install capacitor banks. To demonstrate the effectiveness of the SPSO algorithm, the results obtained using proposed SPSO are compared with the results obtained using other techniques (SA, GA and ACSA) given in [10] with the same assumptions.

The First System

This system presented by Civanlar *et al.* [11] and shown in Fig. 1. It consists of 16 buses, three of them are substation buses, three feeders, 13 normally closed switches (sectionalizing switches), and three normally open switches (tie switches). The system load is assumed to be constant and S_{base} = 100 MVA. The sizes of capacitor banks are assumed to be 300, 600, 900, 1200, 1500, 1800, 2100 and 2400 kvar. For this test system the number of dimensions is 16 dimensions (13 candidate buses plus 3 switches from the 3 loops).

Table 1 shows the simulation results for this test system before and after optimization. The results after optimization divided to three cases:

1) Considering only capacitor placement (CP);
2) Considering only distribution network reconfiguration (DNR);
3) Considering both CP and DNR.

It can be observed from Table 1, that the power loss reduction and voltage profile of the system are improved in the different cases. But the third case when simultaneously considering both CP and DNR gives the best results. Table 2 shows a comparison between the results obtained by SPSO and the results obtained by other methods given in [11].

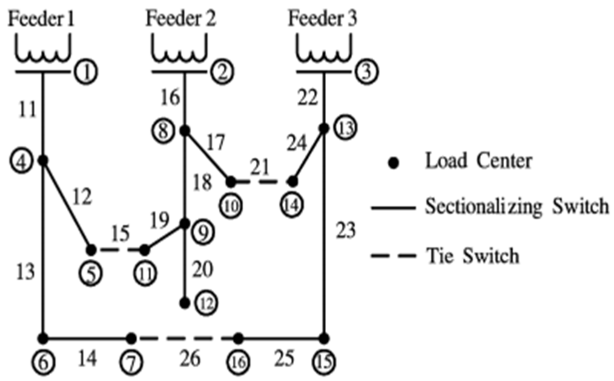

Fig. 1: Three feeder distribution system

Table 1: Simulation results for the first system

Item		Base Case	After CP	After DNR	After CP and DNR
Installed capacitors at each bus (kvar)	4	0	0	0	0
	5	1100	1800	1100	2100
	6	1200	1500	1200	1800
	7	0	1200	0	900
	8	0	1800	0	2400
	9	1200	1800	1200	2400
	10	0	1800	0	600
	11	600	1200	600	0
	12	3700	1800	3700	2400
	13	0	1200	0	600
	14	1800	600	1800	1200
	15	0	900	0	900
	16	1800	900	1800	1200
Tie switches		15, 21, 26	15, 21, 26	19, 7, 26	19, 7, 26
Total of capacitors (kvar)		11400	16500	11400	15500
Min. voltage (p.u.)		0.969	0.97	0.972	0.973
Max. voltage (p.u.)		1	1	1	1
Power loss (kW)		511.4	486.6	466.1	446.3
Loss reduction (%)		—	4.85	8.86	12.73

Table 2: Simulation results obtained by different methods for the first system

Solution Method		After CP	After DNR	After CP and DNR
SA	Power loss (kW)	489.7	466.1	448.3
	Loss reduction (%)	4.24	8.86	12.34
GA	Power loss (kW)	488.2	466.1	448.2
	Loss reduction (%)	4.54	8.86	12.36
ACSA	Power loss (kW)	487.1	466.1	448.1
	Loss reduction (%)	4.75	8.86	12.38
SPSO	Power loss (kW)	486.6	466.1	446.3
	Loss reduction (%)	4.85	8.86	12.73

The Second System

The second system is a practical distribution network of the Taiwan Power Company [10]. Its conductors mainly employ overhead lines ACSR 477 MCM and underground copper conductors 500 MCM. Fig. 2 shows the system, the system is 3-phase and 11.4 kV. It consists of 11 feeders, 83 normally closed switches, and 13 normally open switches. The power loss for the base configuration is 531.99 kW. Three-phase balanced and constant load are assumed. Details of the data of this system are found in [10]. The practical sizes available for the capacitor banks are assumed to be multiple of 50 kvar. For this test system the number of dimensions is 86 dimensions (73 candidate buses plus 13 candidate switches from the 13 loops). Table 3 shows a comparison between the results obtained by SPSO and the results obtained by other methods given in [10].

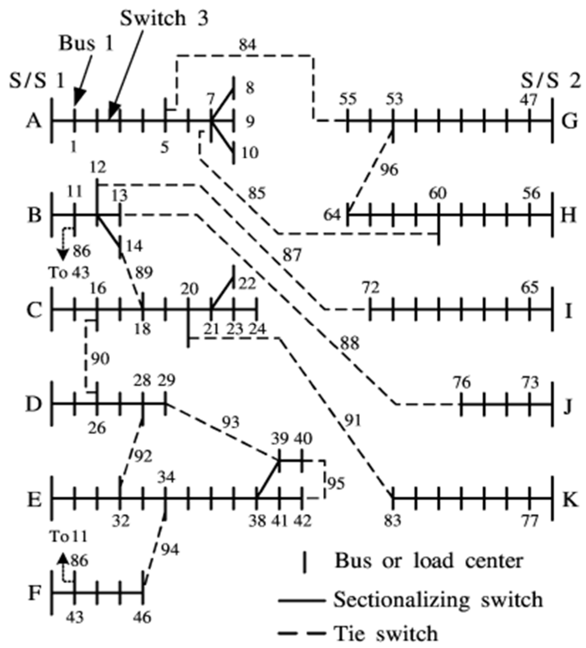

Fig. 2: Distribution system of Taiwan Power Company

Table 3: Simulation results obtained by different methods for the second system

Solution Method		After CP	After DNR	After CP and DNR
SA	Power loss (kW)	342.14	469.88	309.12
	Loss reduction (%)	35.7	11.68	41.9
GA	Power loss (kW)	330.79	469.88	295.39
	Loss reduction (%)	37.8	11.68	44.48
ACSA	Power loss (kW)	330.41	469.88	295.12
	Loss reduction (%)	37.9	11.68	44.5
SPSO	Power loss (kW)	330	469.88	295
	Loss reduction (%)	38	11.68	44.55

The simulation results given in Tables 2 and 3 show that, the best loss reduction ratios after DNR are the same for different optimization methods. But loss reduction ratios after CP or CP and DNR obtained by the SPSO are the best among the other methods. In addition, simulation results clear that simultaneously considering both feeder reconfiguration and capacitor placement is more effective than using only one technique.

CONCLUSIONS

This paper has presented SPSO for the distribution network loss reduction through capacitor placement and network reconfiguration. The proposed method has been implemented on two distribution systems published in the literature. The simulation results have indicated that the proposed method is reliable, easy to implement and can be used as an advantageous alternative in the comprehensive optimization for power loss reduction in distribution networks. Furthermore, the simulation results indicate that, when simultaneously account both feeder reconfiguration and capacitor placement, the loss reduction is much higher than considering them separately.

REFERENCES

[1] H. N. Ng, M. M. A. Salama, and A.Y. Chikhani, 2000, "Classification of capacitor allocation techniques," *IEEE Trans. Power Delivery*, vol.15, 387–392.

[2] G. K. Viswanadha Raju, and P. R. Bijwe, 2008, "An Efficient Algorithm for Minimum Loss Reconfiguration of Distribution System Based on Sensitivity and Heuristics," *IEEE Trans. Power Delivery,* vol. 23, 1280–1287.

[3] H. C. Chang and C. C. Kuo, 1994, "Network reconfiguration in distribution system using simulated annealing," *Electric Power Systems Research,* vol. 29, 227-238.

[4] H. Kim, Y. Ko, and K. H. Jung, 1993, "Artificial neural networks based feeder reconfiguration for loss reduction in distribution systems," *IEEE Trans. on Power Delivery,* vol. 8, 1356-1366.

[5] Y.-Y. Hong and S.-Y. Ho, 2005, "Determination of network configuration considering multiobjective in distribution systems using genetic algorithms," *IEEE Trans. Power System.,* vol. 20, 1062–1069.

[6] Ching-Tzong Su, Chung-Fu Chang and Ji-Pyng Chiou, 2005, "Distribution Network Reconfiguration for Loss Reduction by Ant Colony Search Algorithm," *Electric Power Systems Research*, vol. 75, 190–199.

[7] J. S. Savier and Debapriya Das, 2007, "Impact of Network Reconfiguration on Loss Allocation of Radial Distribution Systems," *IEEE Trans. Power Delivery,* vol. 22, 2473-2480.

[8] S. Sivanagaraju, J. V. Rao and P. S. Raju, 2008, "Discrete Particle Swarm Optimization to Network Reconfiguration for Loss Reduction and Load Balancing," *Electric Power Components and Systems,* vol. 36, 513–524.

[9] Tamer M. Khalil and Alexander V. Gorpinich, 2012, "Selective Particle Swarm Optimization" *International Journal of Multidisciplinary Sciences and Engineering (IJMSE),* vol. 3, issue 4, 1-4.

[10] Chung-Fu Chang, 2008, "Reconfiguration and capacitor placement for loss reduction of distribution systems by ant colony search algorithm," *IEEE Trans. Power System,* vol. 23, 1747–1755.

[11] S. Civanlar, J. J. Grainger, H. Yin, and S. S. H. Lee, 1988, "Distribution feeder reconfiguration for loss reduction," *IEEE Trans. Power Delivery,* vol. 3, 1217–1223.