TOWARDS POWER LOSSES MINIMIZATION AND VOLTAGE PROFILE IMPROVEMENT IN CCED, PRACTICAL CASE STUDY

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ABSTRACT

This paper presents a two-stage methodology for the optimal capacitor placement problem in distribution systems using fuzzy and Selective Particle Swarm Optimization (SPSO) to reduce the power losses and to improve the voltage profile. In the first stage, fuzzy approach is used to find the optimal capacitor locations and in the second stage, SPSO is used to find the sizes of the capacitors. The proposed algorithm applied to IEEE 34-buses test system, the obtained results are compared to some previous techniques used by other authors to demonstrate the effectiveness of the proposed algorithm. Then the proposed algorithm applied to a real distribution system in Canal Company for Electricity Distribution (CCED) to select the nodes to be compensated, as well as the optimal capacitor size to be placed at these nodes. The simulation results investigate the effectiveness of the proposed algorithm in reducing the power losses and improving the voltage profile.

INTRODUCTION

The distribution network is the terminal stage of power system which ended by consumers. Because of the lower voltage, and hence higher current, the I^2R loss in a distribution system significantly high compared to that at high-voltage transmission system. Power losses are a source of economic inefficiency that impact negatively in the business results of distribution companies. In addition to the power loss, which has a great concern by utilities, the voltage drop is another problem in distribution system which affects both consumers and utilities. To reduce the power loss and to enhance the voltage in the distribution networks several methods are used, one of these methods is the installation of shunt capacitors. Capacitors are widely used in distribution systems to reduce power loss, release the kVA capacities of distribution apparatus and to maintain voltage profile within permissible limits.

The capacitor placement problem is a well researched topic and has been addressed by many authors. In last decades a variety of methods have been devoted to solve the capacitor placement problem [1-11]. Ng *et al.* [1] classify the solution techniques for the capacitor allocation problem into four categories: analytical, numerical programming, heuristic, and artificial intelligence based (AI based). AI-based methods are now the most attractive methods. They include genetic algorithms, simulated annealing, expert systems, artificial neural networks, fuzzy and particle swarm optimization.

Some of the previous literatures applied a combination of more than one method to solve the capacitor placement problem, Mekhamer *et al* [6] proposed a combination of fuzzy solution and a technique that based on the heuristic strategy to solve the capacitor placement problem, where the advantages of fuzzy and heuristic methods presented were combined in a new fuzzy-heuristic idea. In [9] Prakash *et al* present Loss Sensitivity Factors and Particle Swarm Optimization for capacitor placement and sizing. Reddy *et al* [10] present a fuzzy and Particle Swarm Optimization (PSO) method for optimal capacitor placement in radial distribution systems to reduce the power losses and to improve the voltage profile.

In this work a combination of two methods are used to find the optimal capacitor placement and sizing. Fuzzy approach is proposed to find the optimal capacitor locations and SPSO method is proposed to find the optimal capacitor sizes. The proposed methodology applied to IEEE 34-buses test system and to a real distribution system in CCED in Egypt to reduce the power losses and to improve the voltage profile.

PROBLEM FORMULATION

The objectives of this work are to reduce power losses and to maintain the node voltage within the permissible limits. The I^2R losses can be separated to active and reactive component of branch current, where the losses produced by reactive current can be reduced by the installation of shunt capacitors.

The power loss function Eqn. (1) is selected as fitness function; while the node voltage is selected as constrain Eqn. (2)

$$P_{loss} = \sum_{b=1}^{B} I_b^2 R_b \tag{1}$$

$$Vol_{\min} \leq |Vol_i| \leq Vol_{\max} \tag{2}$$

Where, P_{loss} the total losses, B is the number of branches, I_b is the branch current, R_b is the branch resistance, Vol_{min} and Vol_{max} are minimum and maximum permissible node voltage and Vol_i is the node voltage.

The objective function is formulated as a mixed integer nonlinear programming problem with both capacitor size and location handled as discrete variables (considering practical discrete capacitors size).

FUZZY BASED CAPACITOR LOCATION

The concept of fuzzy set theory was introduced by Zadeh in 1965 as a formal tool for dealing with uncertainty and soft modeling. A fuzzy variable is modeled by a membership function which assigns a degree of membership to a set. Usually, this degree of membership varies from zero to one. Ng *et al.* [5] applied fuzzy expert system (FES) to the capacitor placement problem by using fuzzy approximate reasoning. Voltage and power loss indices of the distribution system nodes were modeled by membership functions and a FES containing a set of heuristic rules performs the inferencing to determine a capacitor placement suitability index of each node. Capacitors are placed on the nodes with the highest suitability. Reddy *et al.* [10] adopted the proposed method by Ng *et al.* [5] to determine the optimal capacitor locations. This paper applies the method used in [5] and [10] to determine the optimal capacitor placement; this method can be summarized in the following steps:

1. Obtain the real and reactive power losses for the original system using load flow.
2. Compensate the total reactive load at every node of the distribution network.
3. Apply the load flow solution to the compensated system in step 2 to obtain the power loss reduction for every node.
4. The loss reductions are then, linearly normalized into a [0, 1] range with the largest loss reduction having a value of 1 and the smallest one having a value of 0. Power Loss Index (PLI) value for n^{th} node can be obtained using Eqn. 3 [10].

$$PLI_{(n)} = \frac{Lossreduction_{(n)} - Lossreduction_{(\min)}}{Lossreduction_{(\max)} - Lossreduction_{(\min)}} \qquad (3)$$

5. For determining the suitability of capacitor placement at a particular node, a set of multiple-antecedent fuzzy rules have been established. The inputs to the rules are the p.u. nodal voltage and power loss reduction indices, and the output consequent is the suitability of capacitor placement.

IMPLEMENTATION OF SPSO BASED CAPACITOR SIZING

Particle swarm optimization (PSO), first introduced by Kennedy and Eberhart [12], is one of the modern heuristic algorithms. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous nonlinear optimization problems.

In d-dimensional search space the position, the velocity and the best previous position for each particle (*i-th particle*) and best position for all particles are represented by vectors and described as $X_i = [x_{i1}, x_{i2}, \ldots, x_{id}]$, $V_i = [v_{i1}, v_{i2}, \ldots, v_{id}]$, $PB_i = [pb_{i1}, pb_{i2}, \ldots, pb_{id}]$ and $GB = [gb_1, gb_2, \ldots, gb_d]$ respectively.

At iteration k the velocity and the position for d-dimension of i-particle is updated by Eqns. (4) and (5) respectively.

$$v_{id}^{k+1} = w v_{id}^{k} + c_1 r_1 (pb_{id}^{k} - x_{id}^{k}) + c_2 r_2 (gb_{d}^{k} - x_{id}^{k}) \qquad (4)$$

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k+1} \qquad (5)$$

In 1997, Kennedy and Eberhart [13] 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 Eqn. (6). The equation for updating positions Eqn. (5) is then replaced by Eqn. (7).

$$sigmoid(v_{id}^{k+1}) = \frac{1}{1 + e^{-v_{id}^{k+1}}} \qquad (6)$$

$$x_{id}^{k+1} = \begin{cases} 1, & if\ rand < sigmoid\left(v_{id}^{k+1}\right) \\ 0, & otherwise \end{cases} \qquad (7)$$

In [14] Khalil and Gorpinich proposed a simple modification to the binary PSO to search in a selected space to be applied for engineering optimization problems such as distribution network reconfiguration. In the Selective PSO the search space at each d-dimension $S_d = [s_{d1}, s_{d2}, \ldots, s_{dn}]$ is the set of dn positions, where dn is the number of the selected positions in the 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 Eqn. (8), and the *i-th* coordinate of each particle's position at a dimension d is a selective value, which updated by Eqn. 9

$$sigmoid(v_{id}^{k+1}) = dn \frac{1}{1 + e^{-v_{id}^{k+1}}} \qquad (8)$$

$$x_{id}^{k+1} = \begin{cases} s_{d1} & if \quad sigmoid(v_{id}^{k+1}) < 1 \\ s_{d2} & if \quad sigmoid(v_{id}^{k+1}) < 2 \\ s_{d3} & if \quad sigmoid(v_{id}^{k+1}) < 3 \\ . & . \quad . \\ . & . \quad . \\ . & . \quad . \\ s_{dn} & if \quad sigmoid(v_{id}^{k+1}) \le dn \end{cases} \qquad (9)$$

Where, $s_{d1}, s_{d2}, s_{d3}, \ldots, s_{dn}$ are the selected values in the dimension d.

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

$$v_{id}^{k+1} = \begin{cases} V_{\max} & if \quad v_{id}^{k+1} > V_{\max} \\ v_{id}^{k+1} & if \quad \left|v_{id}^{k+1}\right| \le V_{\max} \\ V_{\min} & if \quad v_{id}^{k+1} < V_{\min} \end{cases} \qquad (10)$$

To avoid invariability of the velocity value of the particle i at the dimension d at the maximum or the minimum values and to avoid the oscillation of the velocity value of the particle *i* at the dimension *d* between the maximum and the minimum values we use Eqn. (11) to force each particle to go through the search space.

$$v_{id}^{k+1} = \begin{cases} rand * v_{id}^{k+1} & if \quad Iv_{id}^{k+1}I = Iv_{id}^{k}I \\ v_{id}^{k+1} & otherwise \end{cases} \qquad (11)$$

SPSO is used as follows for optimal capacitor sizing

In the first stage the number of candidate locations was identified by Fuzzy. In the second stage SPSO is applied to find the optimal capacitor sizes at the buses previously selected considering discrete sizes of capacitors. To apply SPSO, there would be three steps:

A) Specify the number of dimensions.
B) Find the search space for each dimension.
C) Use SPSO to select the optimal solution from the search spaces.

For capacitor placement problem the number of dimension is the number of candidate locations and the search space for each dimension is a set of standard capacitor sizes. After specifying the number of dimensions, and finding the search space for each dimension, SPSO would be used to select the optimal solution from the search space for each dimension using equations number 4, 10, 11, 8 and 9 respectively.

RESULTS AND DISCUSSION

The proposed method for loss reduction by capacitor placement has been initially applied to a 34 bus distribution test network. The results are compared with the results obtained in [12, 13]. In addition, the proposed algorithm has been implemented for a 51 bus real distribution system in Canal Company for Electricity Distribution (CCED).

34 BUS DISTRIBUTION SYSTEM

The test system for the proposed algorithm is an IEEE 34-bus radial distribution system [4]. The simulation results of the proposed method are compared with the results obtained in [9, 10], these results are shown in Table 1.

Table 1 Simulation Results for 34 bus Test System

Item	Before Capacitor Placement	After Capacitor Placement		
		Reff. [9]	Reff. [10]	Proposed
optimal locations and sizes in kvar		19 781 20 479 22 803	20 683 21 145 22 144 23 143 24 143 25 143 26 228	20 450 21 900 22 0 23 150 24 150 25 0 26 300
Total kvar	0	1629	2063	1950
power losses (KW)	221.67	168.95	168.8	168.573
Power Losses Reduction (%)	0	23.78	23.85	23.95

The simulation results shown in Table 1 clear that:

- The power loss obtained with the proposed method is almost equal to that obtained in [9, 10]
- In [9] Loss Sensitivity Factors is proposed to find the optimal capacitor locations and PSO method is proposed to find the optimal capacitor sizes.
- In [10] Fuzzy approach is proposed to find the optimal capacitor locations and PSO method is proposed to find the optimal capacitor sizes.
- The methods in [9] and [10] considered the capacitor size as continuous variables. Therefore, the calculated capacitor sizes may not match the available standard sizes.
- The proposed method in this paper used the advantage of the SPSO to handle the sizes of the capacitors as a discrete variable.

51 BUS REAL DISTRIBUTION SYSTEM

Canal Company for Electricity Distribution (CCED) is a government utility serving the Suez Canal and the Sinai region in Egypt. It is the largest of the nine distribution utilities in Egypt, with a power distribution network covering seven governorates and new cities district. The total area served by CCED is approximately 290 thousands square kilometres.

The proposed method is applied to a 51 bus radial distribution system that covers a rural area in El-Sharqia governorate which belongs to CCED. The single-line diagram and the line and load data for this system are given in Figure 1 and Table 2 respectively.

The distribution system is 11kV, the limits on bus voltages are selected to be Vol_{min}=0.95 p.u and Vol_{max}=1.05 p.u.

The power loss before capacitor placement is 201.45 kW with percentage of 7.14% of the total load. The minimum and maximum voltages before capacitor placement are 0.89 p.u and 0.997 p.u.

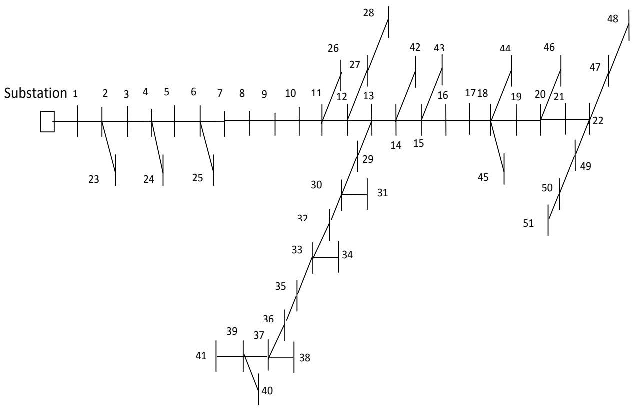

Figure 1: Single-line diagram of 51 bus real distribution system

Table 2: The line and load data for 51 bus real distribution system

Node		R(Ω)	X(Ω)	P (KW)	Q (KVAR)
from	to				
0	1	0.07950	0.0582	0	0
1	2	0.61676	0.8946	57.6	43.2
2	3	0.02172	0.0315	53.76	40.32
3	4	0.30404	0.4410	0	0
4	5	0.10858	0.1575	134.4	100.8
5	6	0.04343	0.0630	37.8	28.35
6	7	0.04343	0.0630	102.4	76.8
7	8	0.02184	0.0104	25.2	18.9
8	9	0.04626	0.0340	75.6	56.7
9	10	0.09251	0.0680	180	135
10	11	0.09251	0.0680	61.6	46.2
11	12	0.23128	0.1700	0	0
12	13	0.46256	0.3400	57.6	43.2
13	14	0.06938	0.0510	45.6	34.2
14	15	0.09251	0.0680	25.2	18.9
15	16	0.23128	0.1700	25.2	18.9
16	17	0.37475	0.1440	25.2	18.9
17	18	0.23128	0.1700	0	0
18	19	0.50882	0.3740	132	99
19	20	0.23128	0.1700	0	0
20	21	0.09251	0.0680	25.2	18.9
21	22	0.13877	0.1020	0	0
2	23	0.16442	0.0410	118.4	88.8
4	24	0.13877	0.1020	60.8	45.6
6	25	0.09392	0.0234	117.6	88.2
11	26	0.16435	0.0410	110.4	82.8
12	27	0.18502	0.1360	25.2	18.9
27	28	0.13877	0.1020	49.6	37.2
13	29	0.55507	0.4080	0	0
29	30	0.11740	0.0293	55.2	41.4
30	31	0.09251	0.0680	33.6	25.2
30	32	0.46256	0.3400	40.8	30.6
32	33	0.11740	0.0293	73.6	55.2
33	34	0.46256	0.3400	31.2	23.4
33	35	0.46256	0.3400	65.6	49.2
35	36	0.09251	0.0680	99.84	74.88
36	37	0.09251	0.0680	0	0
37	38	0.30523	0.0761	110.4	82.8
37	39	0.04626	0.0340	0	0
39	40	0.01409	0.0035	25.2	18.9
39	41	0.09251	0.0680	61.6	46.2
14	42	0.03287	0.0082	80	60
15	43	0.08452	0.0211	40	30
18	44	0.06938	0.0510	107.52	80.64
18	45	0.06938	0.0510	55.2	41.4
20	46	0.33810	0.0842	99.84	74.88
22	47	0.28175	0.0702	55.2	41.4
47	48	0.03522	0.0088	40	30
22	49	0.13877	0.1020	94.72	71.04
49	50	0.69384	0.5100	25.2	18.9
50	51	0.04626	0.0340	80	60

Table 3: Simulation results for 51 bus real distribution system

Item	Before capacitor placement	After capacitor placement
Optimal locations and sizes in Kvar		13 150 30 150 33 150 35 300 41 0 42 450 45 300 47 450 51 150
Total kvar	0	2100
Minimum Bus Voltage (p.u.)	0.89	0.951
Maximum Bus Voltage (p.u.)	0.997	0.998
Power Losses (KW)	201.45	125.25
Power Losses to the Total Load (%)	7.14	4.44
Power Losses Reduction (%)	0	37.8

Optimal capacitor locations are identified based on FES, then the optimal capacitor sizes are identified by SPSO considering the standard sizes. The initial conditions and the nodes where capacitors were finally located and their respective capacities are included in Table 3.

As shown in Table 3; nine locations are identified by Fuzzy for capacitor placement. SPSO select eight capacitor sizes for eight locations, where the bus number 41 identified by Fuzzy but SPSO select no capacitor to be placed in this bus. After capacitor placement the power losses become 125.25 KW, with a percentage of 4.44% to the total load. The percentage of power losses reduction is 37.8%. The minimum and maximum bus voltages were improved to 0.951 p.u. and 0.998 p.u. respectively.

CONCLUSION

In this paper, a two-stage methodology of finding the optimal locations and sizes of shunt capacitors for real power loss reduction and voltage profile improvement in radial distribution systems is presented. In the first stage fuzzy expert system is applied to reduce the search space then SPSO is applied to find the optimal capacitor sizes at the buses previously selected considering discrete sizes of capacitors. The main advantage of this proposed method is that it takes advantage of the merits of each technique.

A 34-bus test system was presented and the results were compared to the solution given by another search technique in literatures. This comparison confirmed the efficiency of the proposed method which makes it promising to solve complex problems of capacitor placement in distribution feeders.

The proposed method has also applied to a real distribution system in CCED in Egypt, by installing shunt capacitors at the selected buses, the total real power loss of the system has been reduced significantly and bus voltages are improved.

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] J. J. Grainger and S. H. Lee, 1981, "Optimum size and location of shunt capacitors for reduction of losses on distribution feeders," *IEEE Trans. Power Apparatus and Systems*, vol. 100, 1105–1118.

[3] M. E. Baran and F. F. Wu, 1989, "Optimal sizing of capacitors placed on a radial distribution system," *IEEE Trans. Power Delivery,* vol. 4, 735–743.

[4] M. Chis, M.M. A. Salama, and S. Jayaram, 1997, "Capacitor placement in distribution systems using heuristic search strategies," *IEE Proc. Generation, Transmission and Distribution*, vol. 144, 225–230.

[5] H.N. Ng, M.M.A. Salama and A.Y.Chikhani, 2000, "Capacitor Allocation by Approximate Reasoning: Fuzzy Capacitor Placement," *IEEE Trans. Power Delivery*, vol. 15, 393-398.

[6] S. F. Mekhamer, S. A. Soliman, M. A. Moustafa, and M. E. El-Hawary, 2003, "Application of Fuzzy Logic for Reactive-Power Compensation of Radial Distribution Feeders," *IEEE Trans. Power Systems,* vol. 18, 206–213.

[7] M. A. S. Masoum, A. Jafarian, M. Ladjevardi, E. F. Funchs, and W.M. Grady, 2004, "Fuzzy Approach for Optimal Placement and Sizing of Capacitor Banks in the Presence of Harmonics," *IEEE Trans. Power Delivery*, vol. 19, 822-829.

[8] M. F. AlHajri, M. R. AlRashidi, and M. E. El-Hawary, 2007, "A Novel Discrete Particle Swarm Optimization Algorithm for Optimal Capacitor Placement and Sizing" Canadian Conference on Electrical and Computer Engineering. CCECE2007. 1286 - 1289

[9] Prakash K. and Sydulu M, 2007, "Particle swarm optimization based capacitor placement on radial distribution systems," *IEEE Power Engineering Society general meeting.* 1-5.

[10] M. Damodar Reddy and V.C. Veera Reddy, 2008, "Capacitor Placement Using Fuzzy and Particle Swarm Optimization Method for Maximum Annual Saving" ARPN Journal of Engineering and Applied Sciences, VOL. 3, 25-30.

[11] I. V. Zhezhelenko, A. V. Gorpinich and Tamer M. Khalil, "Optimal Capacitor Placement in Distribution System Considering Mutual Coupling, Load Unbalancing and Harmonics, 2009, " *The 20th International Conf. on Electricity Distribution*, session 5, paper no. 0441. 8-11.

[12] J. Kennedy and R. Eberhart, 1995, "Particle swarm optimization," *in Proc. IEEE Int. Conf. Neural Networks, vol. IV, Perth, Ustralia*. 1942–1948.

[13] J. Kennedy and R. C. Eberhart, 1997, "A Discrete Binary Version of the Particle Swarm Algorithm," *Proc. of the conference on Systems, Man, and Cybernetics SMC97*, 4104-4109.

[14] Tamer M. Khalil and A. V. Gorpinich, "Reconfiguration for Loss Reduction of Distribution Systems Using Selective Particle Swarm Optimization" *under review in IEEE Transactions on Power Delivery*.