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A new fuzzy based solution of the capacitor placement problem in radial distribution system

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ABSTRACT

A fuzzy based method has been proposed for identification of probable capacitor nodes of radial distribution system. Simulated annealing technique has been used for final selection of the capacitor sizes. New fuzzy membership functions have been formulated where the active power membership is an exponential function of the nodal per unit active power and branch active power loss, the reactive membership function is a function of nodal reactive power and reactive branch loss. Voltage membership has been formulated in two ways – as function of the node voltage only and also as function of the nodal voltage and reactive power as well. The method has been applied to different test systems. It has been found that the proposed membership functions are less dependent upon weighting factors. The weighting factor may even be avoided at all. The proposed method thus is more general a other fuzzy based capacitor placement methods.

1. Introduction

Placement of shunt capacitors is a popular method of improving the performance of radial distribution systems. Determination of location and size of the capacitor banks is a challenging job as the resulting optimization problem involves non-convex cost function. Analytical techniques (Grainger & Lee, 1981), heuristics (Chis, Salama, & Jayram, 1997; Mekhamer, El-Hawary, & Soliman, 2002), mathematical programming (Hogan, Rettkowski, & Bala, 2005) and a host of other methods have been developed to solve the problem. The optimization problem, however, still remains tempting enough for the application of the new solution tools. Artificial intelligence (AI) techniques have been tried in recent years in search of a superior solution tool. Among the AI techniques, evolutionary computing methods such as genetic algorithm (Delfanti, Granelli, Marannino, & Montagna, 2000), Particle swarm optimization (Venayagamoorthy & Harley, 2007), ant colony optimization (Annaluru, Das, & Pahwa, 2004), differential evolution technique (Su & Lee, 2002) have been reported to produce superior results. Simulated annealing (Chen & Liu, 1994) and Tabu (Gallego, Monticelli, & Romero, 2001; Yann-Chang, Hong-Tzer, & Ching-Lien, 1996) searches had also been very successful. However, one common drawback of these techniques lies in the huge computing task involved in obtaining the solution. Another AI approach involves fuzzy logic. Fuzzy based approaches involve less computational burden. A number of fuzzy based methods have been reported. These methods, however, do not always find the best possible solutions. But they generally can find an acceptable sub-optimal solution using less computing cost.

Fuzzy based solution methods need modeling of the system through fuzzy membership functions. Identification of proper membership function is the most challenging task in the development of fuzzy based solution techniques. Whatever may be the objective of placing capacitors in distribution system, they basically inject reactive power to the network as a result of which the system voltage improves and loss decreases. Thus, node voltage measures and power loss in the network branches have been utilized as indicators for deciding the location and also determining the size of the capacitors almost in any method of solution and fuzzy approaches are no exception. As in the fuzzy based approaches membership functions of dissimilar quantities like voltage, power loss, reactive power, etc. are compared in deciding a solution, some weighting factors are occasionally used. These weighting factors, while add flexibility in the solution methods, at the same time incorporate limitations in the sense that values of the weighting factors become system dependent. Thus, it is difficult to identify a weighting factor that suits all the networks. This, certainly, is a serious limitation of the fuzzy based method. Fuzzy based methods basically identify probable capacitor location using fuzzy approach. The final selection of the node and selection of the capacitor size is done using heuristic method.

In this paper we propose a new fuzzy based method where candidate capacitor locations are based upon the fuzzy decision rules.

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A new set of membership functions is proposed for this purpose. Effect of the weighting factors on the performance of newly proposed membership functions is investigated. It is shown that proposed membership functions are less influenced by the weighing factors. The final selection of the nodes and capacitor sizes are based upon a simulated annealing algorithm. The performance of the proposed methods is compared with some other fuzzy and heuristics based capacitor placement methods found in literature.

2. Formulation of the capacitor placement problem

Conventionally capacitor placement problem is formulated as a problem of minimization of the total system cost defined as the summation of the capacitor installation cost, cost of peak power loss and cost of energy loss. The objective function is minimized subject to the nodal voltage regulations maintained within the permissible limits. The problem may be stated as

$$\text{min}: \quad C_{\text{system}} = \sum_{i=1}^{n} f_{\text{cost}_i}(Q_{c_i}) + P_{\text{loss,peak}} \cdot C_{\text{p}} + E_{\text{loss}} \cdot C_{\text{e}}$$

$$\text{subject to}: \quad V_{\min} \leqslant V_i \leqslant V_{\max}$$

where f_{cost_i} is the capacitor installation cost at node i, Qc_i the capacitor *kvar* at node i, $P_{\text{loss,peak}}$ the peak power loss, E_{loss} the energy loss, C_{p} the cost coefficient of peak power loss, C_{e} the cost coefficient of energy loss.

As the capacitors are commercially available in discrete sizes f_{cost_i} varies in discrete steps. Capacitor cost has two parts, a fixed part and a variable part depending upon the *kVAr* capacity. In this paper we use the capacitor installation costs as shown in Table 1. These data are taken from Mekhamer, Soliman, Moustafa, and El-Hawary (2003).

Peak power loss is an important factor for the capacitor placement problem as any reduction in the peak power loss represents a capacity release. Energy loss represents operational loss of the system. As the results reported in fuzzy based capacitor placement methods did not consider the energy loss component, in the present study we also have ignored the same while reporting the comparative analysis. Thus, the cost coefficients as reported in Mekhamer et al. (2003) has also been used in the present paper. Moreover, fuzzy based capacitor placement methods considered the fixed capacitor placement only and ignored the variation in the system load because of the fact that in all these methods fuzzy approaches have been used for identifying the probable capacitor locations and the sizes of the capacitors have been decided using some heuristic type search approaches.

In the present paper we too have considered the fixed capacitor placement problem and ignored the variation in the load levels though these can easily be incorporated in our proposed method.

3. Background of the proposed development

The purpose of placing capacitors is to improve the node voltages and to reduce system losses. It is well known that for voltage drop in power system reactive power flow is more responsible than the flow of active power. Moreover, a large portion of power system loads being of constant power type, low voltage becomes responsible for high power losses. Thus, the fuzzy based capacitor placement methods have developed membership functions using node voltages, and active and reactive branch power losses. The fuzzy based methods, however, are very sensitive to the weighting factors used in membership functions. These weighting factors are to be tuned properly in order to have the best results. There is no guarantee that the same weighting factors will perform uniformly for all the networks. The present author's intention is therefore to explore the development of methods based on fuzzy membership functions, which are less dependent or not dependent at all on the weighting factors.

4. Proposed fuzzy based solution method

A close study of the capacitor placement problem reveals that the capacitor locations are not dependent upon the node voltages and branch power losses only. The magnitudes of the active and reactive loads of the nodes also are equally important deciding factors.

In order to reflect these factors in the selection of the capacitor nodes the following membership functions are proposed:

Active power membership function :

$$\mu_{\text{P}}(i) = \exp\left(-w_1 \cdot \frac{P(i)}{P_{\text{base}}} \cdot \frac{p_l(i)}{p_{loss}}\right)$$

Reactive power membership function :

$$\mu_{\text{Q}}(i) = \exp\left\{-w_2 \cdot \left(\frac{Q(i) - Q_{\text{c}}(i)}{P_{\text{base}}}\right) \cdot \frac{q_l(i)}{q_{\text{loss}}}\right\}$$

Voltage membership function :

$$\mu_{\text{V}}(i) = \exp\left\{-w_3 \cdot \left(\frac{Q(i) - Q_{\text{c}}(i)}{P_{\text{base}}}\right) \cdot \left(\frac{V(i) - 1}{V_{\max} - V_{\min}}\right)^2\right\}$$

where $P(i)$ is the active power load at node i, $Q(i)$ the reactive power load at node i, $p_l(i)$ the active power loss in branch terminating at node i, $q_l(i)$ the reactive power loss in branch terminating at node i, p_{loss} the total active power loss of the system, q_{loss} the total reactive loss of the system, P_{base} the base power for the system, $Q_c(i)$ the value of capacitor placed at node i and w_1, w_2, w_3 are weighting factors for active loss, reactive loss and voltages in the membership functions, respectively.

It may be noted here that the above definition of the membership functions are unique in the sense that unlike the membership functions proposed in other methods, effective weighting factors in the proposed method are different at different nodes. Moreover, while considering the reactive load of a node, we consider the effect of the capacitor already installed at the node at the foregoing iterations, as the iterations of the capacitor placement algorithm progresses. As a result, a node having large reactive load becomes a strong contender and is selected as a candidate locations. As some capacitors are installed, the effective reactive load decreases

Table 1
Possible choices of capacitor sizes and cost/kVAr

J	1	2	3	4	5	6	7	8	9
Qc (kVAr)	150	300	450	600	750	900	1050	1200	1350
$/kVAr	0.500	0.350	0.253	0.220	0.276	0.183	0.228	0.170	0.207
J	10	11	12	13	14	15	16	17	18
Qc (kVAr)	1500	1650	1800	1950	2100	2250	2400	2550	2700
$/kVAr	0.201	0.193	0.187	0.211	0.176	0.197	0.170	0.189	0.187
J	19	20	21	22	23	24	25	26	27
Qc (kVAr)	2850	3000	3150	3300	3450	3600	3750	3900	4050
$/kVAr	0.183	0.180	0.195	0.174	0.188	0.170	0.183	0.182	0.179