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Solving capacitor placement problem considering uncertainty in load variation

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ABSTRACT

The paper reports on the solution of the capacitor placement problem in distribution system considering uncertainty in the variation of loads. Solution techniques available in the literature generally consider load variation as deterministic. In the present paper uncertainty in load variation is considered using fuzzy interval arithmetic technique. Load variations are represented as lower and upper bounds around base levels. Both fixed and switchable capacitors have been considered and results for standard test systems are presented.

Introduction

Shunt capacitors are used in distribution systems as a source of reactive power. If they are connected with proper location and size, load terminal voltage can be maintained within the acceptable limit and the line loss and total system cost can be reduced. As the load demand on distribution system may vary with time for effective compensation, capacitors are to be of fixed as well as switchable in nature, where a minimum capacitor kvar is always kept connected to the system (fixed capacitor) and additional capacitors are switched in or out as the load demand varies. Determination of the size, location and type of such capacitors for a distribution system is a complex optimization problem and requires information regarding the load variation of the system with time.

Different solution techniques had been presented by many researchers in the past for solving the problem of placing capacitor in distribution system. Modified discrete PSO based solution was proposed in [3,20]. In [4,5], the capacitor placement was formulated as a mixed integer non-linear problem. [6,16,17] proposes Particle Swarm Optimization (PSO) based capacitor placement. Loss saving equation based technique was proposed in [7]. In [8] heuristics and greedy search technique based solution was proposed. Fuzzy reasoning based method was proposed in [9]. Simulated annealing was proposed in [15] and Genetic Algorithm based solution has taken in [10,24] respectively. Interior point based solution was proposed in [11,14]. Extended Dynamic Programming Approach was proposed in [12], Plant Growth Simulation Algorithm and using of loss sensitivity factor was proposed in [13], heuristic search and node stability based method was proposed in [18], and bacterial foraging solution was proposed in [21]. Hybrid honey bee colony algorithm based solution was proposed in [23] Uncertainty was taken into account in [19].

In all of the solution techniques load demand was assumed to follow a definite pattern-represented by a number of fixed load levels. In reality however, the load demand is quite uncertain and depends upon many factors in such a way that it is impossible to predict the actual load before the actual occurrence. Load forecasts, based upon historic records of load variation can predict a coarse picture of the probable situation. The actual scenario may well deviate the predicted one by a considerable margin. Thus instead of load representation by a number of definite load levels, probabilistic variation of loads would be a better representation. The capacitor placement decision based upon the fixed pattern of load variation thus may lead to an inferior solution than the solution where probability of load variation over the predicted one is considered. The present paper thus proposes a method to take uncertainty of the load variation in the capacitor placement problem.

Problem formulation

For a distribution network, the loss associated with the reactive components of branch currents can be written as

$$P_{\mathrm{Lr}} = \sum_{i=1}^{n} I_{\mathrm{ri}}^2 * R_i \tag{1}$$

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Nomenclature

P_{Lr}	active power loss of the system associated with the reactive components of branch currents for original system	Ic	reactive current drawn by the capacitor
I_{ri}	reactive component of branch current of the *i*th branch for original system	P_{Lr}^{com}	active power loss of the system associated with the reactive components of branch currents for compensated system
I_{ri}^{new}	reactive component of branch current of the *i*th branch for compensated system	S	loss saving
R_i	resistance, respectively of the *i*th branch	V_m	magnitude of voltage of bus *m* before compensation
I_{ril}, I_{riu}	lower and upper limit of I_{ri} respectively	k	number of capacitor buses
		Qc	capacitor size
		Vc	voltage magnitude vector of capacitor bus

where I_{ri} and R_i are the reactive component of branch current and resistance, respectively of the *i*th branch.

But, actually I_{ri} is not of fixed value. Because, the load variation in any power system cannot be truly represented by a single load curve. Conventional way of representing load variation by a single load curve basically represents the mean of load variation. A better representation would be to use a curve like Fig. 1, where instead of representing by a mean variation, the range of variation is shown. So in the load duration curve, each load level is represented by a range of load levels (like Fig. 2) rather than a single load. So it is better to represent I_{ri} as

$$I_{ri} = [I_{ril}, I_{riu}]$$

where I_{ril} and I_{riu} are lower and upper limit of I_{ri} respectively.

Because of this variation in this pattern of the loads, the loss P_{Lr} should be considered as an interval quantity instead of fixed quantity. Therefore, in capacitor placement problem every quantity should be considered as an interval quantity. For this purpose basic operation of interval number is to be known which is described in the next section.

Interval arithmetic

An interval number $X = [\mathrm{xl}, \mathrm{xu}]$ is the set of real numbers x such that $\mathrm{xl} \leqslant x \leqslant \mathrm{xu}$; xl and xu are known as the lower limit and upper limit of the interval number, respectively. A rational number k is represented as an interval number $K = [k, k]$.

Let $X = [\mathrm{xl}, \mathrm{xu}]$ and $Y = [\mathrm{yl}, \mathrm{yu}]$ be the two interval numbers. Then addition, subtraction, multiplication and division of these two interval numbers are defined as below [22]:

$$X + Y = [\mathrm{xl} + \mathrm{yl}, \mathrm{xl} + \mathrm{yu}] \quad (2)$$

$$X - Y = [\mathrm{xl} - \mathrm{yu}, \mathrm{xu} - \mathrm{yl}] \quad (3)$$

$$X * Y = [\min(\mathrm{xl} * \mathrm{yl}, \mathrm{xl} * \mathrm{yu}, \mathrm{xu} * \mathrm{yl}, \mathrm{xu} * \mathrm{yu}), \max(\mathrm{xl} * \mathrm{yl}, \mathrm{xl} * \mathrm{yu}, \mathrm{xu} * \mathrm{yl}, \mathrm{xu} * \mathrm{yu})] \quad (4)$$

$$X \div Y = X * Y^{-1} \quad (5)$$

where

$$Y^{-1} = [1/\mathrm{yu}; 1/\mathrm{yl}] \text{if } 0 \notin [\mathrm{yl}, \mathrm{yu}] \quad (6)$$

Also, the distance between these two interval numbers is defined as [24]:

$$q(X, Y) = \max[|x1 - y1|, |x2 - y2|] \quad (7)$$

For power system application, calculations involving complex numbers, rather than real numbers are needed. Hence, in the next sub-section, basic operations involving complex interval numbers are presented.

Complex interval number

Any complex number $Z = X + iY$; where i is the complex operator, is said to be a complex interval number if both its real part (X) and the imaginary part (Y) are interval numbers. Hence, X can be represented as $X = [x1, x2]$ and Y can be represented as $Y = [y1, y2]$, where, $x1$, $y1$ are the lower limits and $x2$, $y2$ are the upper limits, respectively. The conjugate of a complex interval number is given by $Z^* = X - iY$: Let $Z_1 = A_1 + iB_1$ and $Z_2 = A_2 + iB_2$ be two complex interval numbers. Then the addition, subtraction, multiplication and division of these two complex interval numbers are defined as [22]

$$Z_1 + Z_2 = (A_1 + A_2) + i(B_1 + B_2) \quad (8)$$

$$Z_1 - Z_2 = (A_1 - A_2) + i(B_1 - B_2) \quad (9)$$

$$Z_1 * Z_2 = (A_1 * A_2 - B_1 * B_2) + i(A_1 * B_2 + A_2 * B_1) \quad (10)$$

$$Z_1 \div Z_2 = C + \mathrm{i}D \quad (11)$$

where $C = (A_1 * A_2 + B_1 * B_2) \div (A_2^2 + B_2^2)$ and $D = (A_2 * B_1 - A_1 * B_2) \div (A_2^2 + B_2^2)$.

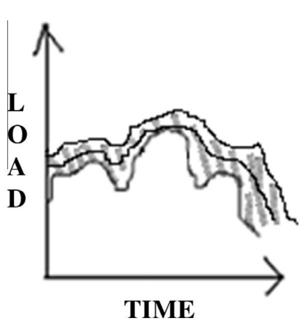

Fig. 1. Load curve considering load variation.

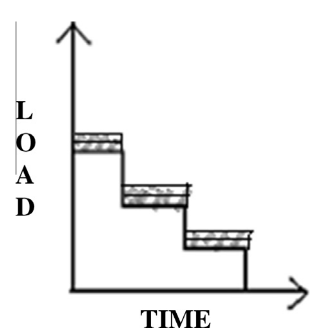

Fig. 2. Load duration curve considering load variation.