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Optimal Capacitor Placement for Loss Reduction in Distribution Systems Using Fuzzy and Hybrid Genetic Algorithm

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Abstract

This paper presents a Fuzzy and Hybrid Genetic Algorithm method for the placement of capacitors on the primary feeders of the radial distribution systems to reduce the power losses and to improve the voltage profile is used.The exponential growth in demand over the past two decades and the widening gap between demand and supply is a growing concern. In addition to adding the generating units, automation technology is playing an important role in reducing T&D losses. In India, with estimated losses of 24% in 2011 and the target of reducing it to 17.1% by 2017, 14.1% by 2022, there is a need for efficient and fast methods in order to reduce losses. In this paper, the application of Hybrid Genetic Algorithm for loss reduction is discussed.

1. Introduction

The loss minimisation in distribution systems has assumed greater significance recently since the trend towards distribution automation requires the most efficient operating scenario for economic viability variations. Studies have indicated that as much as 18% of total power generated is wasted in the form of losses at the distribution level. To reduce these losses, many methods like shunt capacitor banks, FACTS devices etc., are employed. These result in improvement of power factor, voltage profile, power loss reduction and available capacity of feeders. With these various objectives in mind, Optimal Capacitor Placement aims to determine capacitor location and its size.

In this paper, with a little attention given to load flow analysis of distribution network, fuzzy logic is used to determine the locations of optimal capacitors and HGA is used to determine size of optimal capacitors for loss reduction.

With distribution automation, many applications & functions are coming up requiring a robust and efficient power flow solution method. The Newton-Raphson and fast decoupled load flow solution technique and a host of their derivatives have efficiently solved the Well Behaved Power Systems for a long time. Distribution networks, because of the some of the following special features, fail in the category of ill-conditioned Power Systems:

- Radial or near radial structure
- High R/X ratios
- Multi-phase, unbalanced operation
- Unbalanced distributed load and
- Dispersed generation

Hence, special techniques for solving distribution networks which exploit their radial nature have long been identified.

A modified load-flow technique, Branch Current Load Flow method, is considered for solving radial distribution networks. This method involves only the evaluation of a simple algebraic expression of receiving-end voltages; takes zero initial loss for computation of voltage of each node and considers flat voltage start to incorporate voltage convergence. This method is very efficient, has good and fast convergence characteristics.

2. Optimal Capacitor Location

In a radial distribution system, the most commonly used device to reduce power losses is shunt capacitor. In addition to loss reduction, they also improve the power factor and voltage profile of the system.

Even though there has been a considerable amount of research work done in the area of optimal capacitor placement [1]-[10], there is still a need to develop more suitable and effective methods for the optimal capacitor placement. Although some of these methods used to solve capacitor allocation problem are efficient, their efficiency relies entirely on the goodness of the data used.

Fuzzy logic provides a remedy for any lack of uncertainty in the data. Fuzzy logic has the advantage of including heuristics and representing engineering judgments into the capacitor allocation optimization process. Furthermore, the solutions obtained from a fuzzy algorithm can be quickly assessed to determine their feasibility in being implemented in the distribution system.

Two objectives considered while designing the fuzzy logic for identifying the optimal capacitor locations are:

i. To minimise the real power loss and
ii. To maintain voltage within permissible limits

Voltage and power loss indices of the distribution system nodes are modelled by fuzzy membership functions. A Fuzzy Inference System (FIS) containing a set of rules is then used to determine the capacitor placement suitability of each node in the distribution system.

First, load flow solution is used to obtain real and reactive power losses. Again, load flow solutions are used to obtain power loss by compensating the total reactive load at every node of the distribution system. The los reductions are then linearly normalised into a range of [0,1]. Power Loss Index (PLI) for n^{th} node can be obtained using

$$PLI(n) = \frac{\text{lossreduction(n)} - lossreduction(min)}{\text{lossreduction(max)} - \text{lossreduction(min)}}$$

The PLI, generally between [0, 1], and per unit nodal voltage, generally between [0.9, 1.1], are taken as the two inputs and Capacitor Suitability Index (CSI), generally between [0, 1], is taken as output of FIS. Five triangular membership functions L,LM,M,HM,H are selected for PLI; five membership functions, triangular and trapezoidal, L,LN,N,HN,H are selected for voltage; five triangular membership functions L,LM,M,HM,H are selected for CSI as shown in figures below:

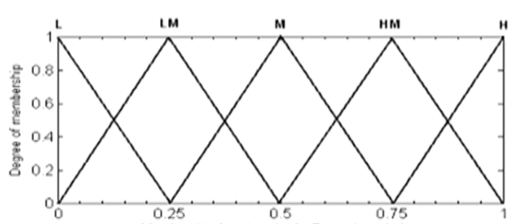

Figure 1. Membership function Plot for PLI

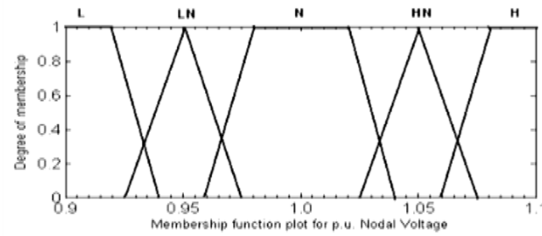

Figure 2. Membership Function Plot for PU Nodal Voltages

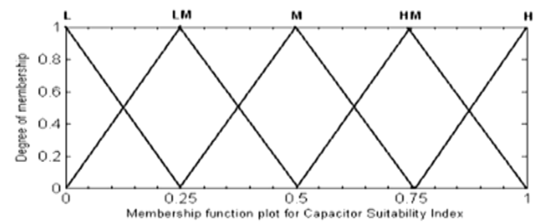

Figure 3. Membership function Plot for CSI

For the capacitor allocation problem, rules are defined to determine the suitability of a node for capacitor installation. Such rules are expressed in the following form: IF premise (antecedent), THEN conclusion (consequent). A set of multiple antecedent fuzzy rules are established and summarised in Fuzzy Decision Matrix as given below:

Table 1. Decision Matrix for determining capacitor locations

AND		Voltage				
		L	LN	N	HN	HH
PLI	L	LM	LM	L	L	L
	LM	M	LM	LM	L	L
	M	HM	M	LM	L	L
	HM	HM	HM	M	LM	L
	H	H	HM	M	LM	LM

3. Hybrid Genetic Algorithm

The GA is a stochastic global search method that mimics the metaphor of natural biological evolution. GAs operates on a population of potential solutions applying the principle of survival of the fittest to produce better and better approximations to a solution. At each generation, a new set of approximations is created by the process of selecting individuals according to their level of fitness in the problem domain and breeding them together using operators borrowed from natural genetics. This process leads to the evolution of populations of individuals that are better suited to their environment than the individuals that they were created from, just as in natural adaptation.

3.1 Population Representation and Initialisation

GA operates on a number of potential solutions, called a population, consisting of some encoding of the parameter set simultaneously. Typically, a population is composed of between 30 and 100 individuals, although, a variant called the microGA uses very small populations, ~10 individuals, with a restrictive reproduction and replacement strategy in an attempt to reach real-time execution.

3.2 Fitness Function

The objective function is used to provide a measure of how individuals have performed in the problem domain. In the case of a minimization problem, the most fit individuals will have the lowest numerical value of the associated objective function. Here in this optimal capacitor placement problem a total real power loss (TPL) is the fitness function. By placing optimal sizes of capacitors using hybrid GA at optimal location using Fuzzy the total real power losses can be reduced.

3.3 Selection

Selection is the process of determining the number of times, or a trial, a particular individual is chosen for reproduction and, thus, the number of offspring that an individual will produce. The selection of individuals can be viewed as two separate processes:

1) Determination of the number of trials an individual can expect to receive, and

2) Conversion of the expected number of trials into a discrete number of offspring.

The first part is concerned with the transformation of raw fitness values into a real valued expectation of an individual's probability to reproduce and is dealt with in the previous subsection as fitness assignment. The second part is the probabilistic selection of individuals for reproduction based on the fitness of individuals relative to one another and is sometimes known as sampling. The remainder of this subsection will review some of the more popular selection methods in current usage.

Tournament selects each parent by choosing individuals at random, the number of which you can specify by Tournament size, and then choosing the best individual out of that set to be a parent.

3.4 Reproduction

Reproduction options determine how the genetic algorithm creates children at each new generation.

3.4.1 Elite count specifies the number of individuals that are guaranteed to survive to the next generation. Elite count to be a positive integer less than or equal to Population size. Elite count used is 2.

3.4.2 Crossover fraction specifies the fraction of the next generation that crossover produces. Mutation produces the remaining individuals in the next generation. Set Crossover fraction to be a fraction between 0 and 1. Here Crossover fraction is 0.8.

3.5 Mutation

Mutation functions make small random changes in the individuals in the population, which provide genetic diversity and enable the genetic algorithm to search a broader space. Ignored with integer constraints. Adaptive feasible strategy is used in this paper.

Adaptive feasible randomly generates directions that are adaptive with respect to the last successful or unsuccessful generation. A step length is chosen along each direction so that linear constraints and bounds are satisfied.

3.6 Crossover

The basic operator for producing new chromosomes in the GA is that of crossover. Like its counterpart in nature, crossover produces new individuals that have some parts of both parent's genetic material. The simplest form of crossover is that of single-point crossover, but in this paper Scattered Crossover is used. Crossover combines two individuals, or parents, to form a new individual, or child, for the next generation. Ignored with integer constraints.

Scattered creates a random binary vector. It then selects the genes where the vector is a 1 from the first parent, and the genes where the vector is a 0 from the second parent, and combines the genes to form the child. For example:

p1 = [a b c d e f g h]

p2 = [1 2 3 4 5 6 7 8]

Random crossover vector = [1 1 0 0 1 0 0 0]

Child = [a b 3 4 e 6 7 8]

3.7 Migration

Migration is the movement of individuals between subpopulations, which the algorithm creates if you set Population size to be a vector of length greater than 1. Every so often, the best individuals from one subpopulation replace the worst individuals in another subpopulation. You can control how migration occurs by the following three parameters. Direction specifies the direction in which migration can take place.

In this paper forward direction is used then the migration takes place toward the last subpopulation. That is the nth subpopulation migrates into the $(n+1)^{th}$ subpopulation.

3.8 Hybrid function

Hybrid function enables to specify another minimization function that runs after the genetic algorithm terminates. Not available with integer constraints. In this paper fminunc hybrid function is used.

A hybrid function is an optimization function that runs after the genetic algorithm terminates in order to improve the value of the fitness function. The hybrid function uses the final point from the genetic algorithm as its initial point. This capacitor placemen problem the function fminunc is used, an unconstrained minimization function in the Optimization Toolbox. The problem first runs the genetic algorithm to find a point close to the optimal point and then uses that point as the initial point for fminunc.

3.9 Termination of the GA

Because the GA is a stochastic search method, it is difficult to formally specify convergence criteria. As the fitness of a population may remain static for a number of generations before a superior individual is found, the application of conventional termination criteria becomes problematic. A common practice is to terminate the GA after a prespecified number of generations and then test the quality of the best members of the population against the problem definition.

3.10 Hybrid Genetic Algorithm to find Capacitor Sizes

The following outline summarizes how the genetic algorithm works:

1. The algorithm begins by creating a random initial population.

2. The algorithm then creates a sequence of new populations, or generations. At each step, the algorithm uses the individuals in the current generation to create the next generation. To create the new generation, the algorithm

Performs the following steps:

a) Scores each member of the current population by computing its fitness value.

b) Scales the raw fitness scores to convert them into a more usable range of values.

c) Selects parents based on their fitness.

d)Produces children from the parents. Children are produced either by making random changes to a single parent mutation or by combining the vector entries of a pair of parents crossover.

e) Replaces the current population with the children to form the next generation.

3. The algorithm stops when one of the stopping criteria is met.

Results

The optimal capacitor placement using Fuzzy and HGA was applied on IEEE-15, IEEE-34 and IEEE-69 bus systems and the results obtained are very encouraging. The method places capacitors with optimum sizes.

The proposed method has been programmed using MATLAB 7.12 and run on an Intel core i5 personal computer. The various parameters used in the algorithm are Pop =50, Elite Count = 2, Crossover fraction =0.8, Maxgen = 1000. The losses (in kW) for uncompensated and compensated networks are tabulated below.

Table 2. Comparison of Results

IEEE Bus	Before compensation	Fuzzy & GA Paper [4]	Proposed Method HGA
15 bus	61.7993	32.5987	29.9077
34 bus	221.7235	168.8123	167.9258
69 bus	225.0044	151.3742	151.7267

Conclusion

Hybrid Genetic Algorithm is a new and efficient method for optimization. A capacitor placement method that employs Fuzzy Approach and HGA to reduce power losses and enhance voltage profile for primary distribution system is presented. The method seeks the most effective buses to install compensation capacitors so that maximum loss reduction and voltage profile were to be improved. The Fuzzy Approach to the buses is effective in reducing the total number of alternatives examined for finding the optimal solution. Hybrid Genetic Algorithm is used to find the optimal capacitor sizes.

The algorithm is tested with three Radial distribution systems consisting of 15, 34 and 69 buses and the results are presented.

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