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Optimal Capacitor Placement Using Fuzzy logic and Genetic Algorithms for Radial Distributiuon Systems

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Abstract

This paper presents a fuzzy logic based approach to determine suitable nodes in a radial distribution system for capacitor placement and genetic algorithms for sizing the capacitors. Voltages and power loss indices of Radial Distribution System (RDS) are modeled by fuzzy membership functions. A Fuzzy Inference System (FIS) containing a set of rules is used to determine the capacitor placement suitability (CPS) of each node in the Radial Distribution System. Capacitors are placed on the nodes with the highest suitability. The installation of power capacitors in RDS improves voltage profile and reduces the real power losses. The capacitor sizing is done using genetic algorithms (GA) for improving the annual cost savings of Radial Distribution System.

Keywords:

Radial distribution system;
Fuzzy inference system;
Genetic algorithms;
Power loss index;
Capacitor placement.

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1. Introduction:

Reactive currents in a radial distribution system produce losses and result in increased ratings for distribution components.Capacitors can be installed in a distribution system to reduce real power losses by minimizing the kVA capacities of distribution apparatus, and also improve the system voltage profile [2]. The problem of optimal capacitor placement consists of determining the suitable locations, sizes, of capacitors to install in a distribution system such that the annual cost savings are improved while improving the radial distribution system performance. Many analytical approaches and numerical programming methods [3–7], are proposed to solve the capacitor placement and sizing problem.Though the previous methods have their own advantage of solving capacitor placement problem the accuracy of the previous methods depends on the data provided to them.Recently Artificial intelligent based techniques became popular in solving the capacitor placement problem. Fuzzy logic has the advantage of handling uncertainty in the data and human experience can be incorporated in the design of fuzzy inference system.Fuzzy approximate

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reasoning can be employed for capacitor placement problem and rules can be developed to determine the suitable capacitor locations[8-9].Genetic algorithms are probabilistic based search algorithms based on natural selection and evolution. Many combinatorial optimization problems are solved successfully by using genetic algorithms [10-11].In this present work the sizing of capacitors is obtained by improving annual cost savings of the radial distribution system which includes cost of annual energy loss, installation cost of capacitors and cost of capacitors.

2. Capacitor Placement using FIS

Fuzzy inference system is considered for capacitor placement of radial distribution system.First a load flow program calculates the line losses of every section and they are normalized into a [0 1] range with the largest power loss having a value 1 and no power loss with a value 0 .The p.u voltage values at every node is calculated using the load flow algorithm. For the capacitor placement problem, fuzzy approximate reasoning is employed in the following manner.By analyzing the real power the losses and voltage profile of a radial distribution system it is possible to determine suitable locations for installation of capacitors. It is intuitive that a section in a distribution system with high losses and low voltage is highly suitable for capacitors placement and sections with low loss and good voltage are not.

For determining the suitability of capacitor placement at a particular node, a set of multiple antecedent fuzzy rules have been established.The fuzzy variables,real power loss index, voltage,and capacitor placement suitability are described by the fuzzy terms high,high-medium,medium,low,medium,low normal,normal, high normal,high.These fuzzy variables described by linguistic terms are represented by membership functions.The membership functions are graphically shown in following figures.In Fig.1.The membership functions for power loss index are shown graphically. In Fig.2 the membership functions for volatage in p.u are shown graphically. In Fig.3 the membership functions for capacitor placement suitability index is shown graphically.The centroid method is used for consequence of the fuzzy rules .The fuzzy associative memory table representing the rules corresponding to capacitor placement suitability index is developed using intuition. The power loss index and voltage are the inputs to the Fuzzy Inference System and Capacitor placement suitability is the output. The nodes with higher capacitor placement suitability obtained from fuzzy inference system developed are considered for installation of capacitors to improve the distribution system performance.

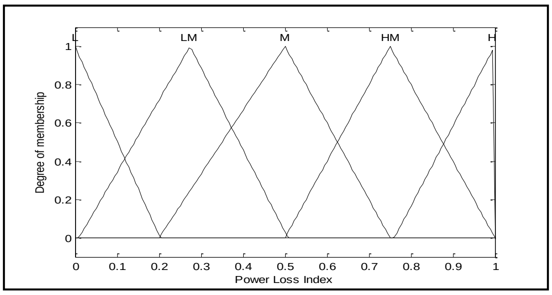

Figure 1 *Membership Function for power loss index*

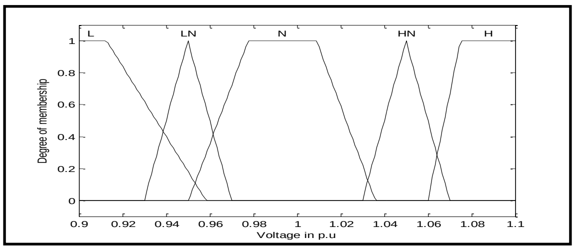

Figure 2 *Membership Function for Voltage V*

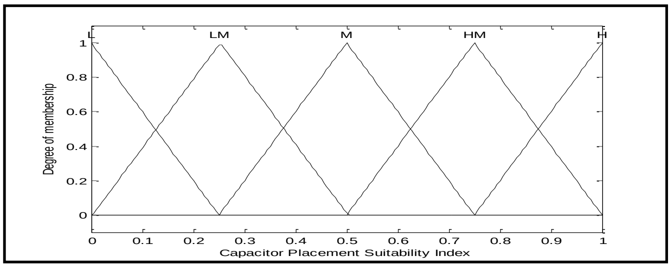

Figure 3 *Membership Function for capacitor placement stability*

The rules are summarized in the following Fuzzy Associative Memory (FAM) Table -1.

TABLE -1 FAM Table for Capacitor suitability factor

V / PLI	L	LN	N	HN	H
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. Capacitor Sizing using GA

Genetic algorithms are probabilistic based search algorithms based on natural selection and evolution. These algorithms are different from most of the calculus based optimization methods. Genetic algorithms don't require derivatives of the objective function. GA uses a population of points at one time, in contrast to the single point approach by traditional optimization methods. The genetic algorithm repeatedly modifies a population of individual solutions through the steps selection, crossover and mutation. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population evolves towards an optimal solution. After identifying the *n* number of candidate locations using fuzzy approach, the capacitor sizes in all these *n* candidate locations are obtained by using genetic Algorithm. The genetic algorithm is explained in the following flow chart.

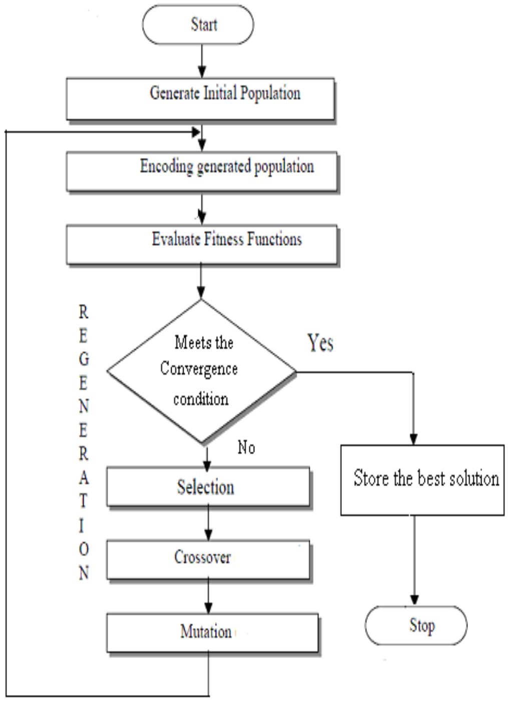

Figure 4 *Flow Chart representing genetic algorithm*

4. Problem Formulation

4.1. Assumptions:

The objective of capacitor placement in the radial distribution system is to minimize the annual cost of the system, subjected to certain operating constraints and load pattern. For simplicity, the operation and maintenance cost of the capacitor placed in the distribution system is not taken into consideration. The system considered is balanced and loads are assumed as time invariant.The size of the capacitor assumed as continues variable within the permissible range.

4.2. Objective Function:

The cost function S is considered as objective function to be optimized by genetic algorithms.The mathematical formulation of the objective function is discussed below.The objective function consists of annual real power loss cost, capacitor installation cost and cost of capacitors required.

$$S = C_e \times \sum_{i=1}^{n} EL_i + \sum_{k=1}^{nc} C_{ci} + (C_{cv} \times Q_{ck}) \qquad \textbf{(1)}$$

Where EL_i is the enery loss cost of section i in a time duration T.Then the energy loss in section i is given by

$$EL_i = I_i^2 \times R \times T \qquad (2)$$

Where I_i is the current in section i and R_I is the resistance of the section i and T is the time duration in hours

N is the number of sections in the RDS.

N_C is the no of capacitors

C_e is the energy rate in $/kWh

C_{ci} is the capacitor installation cost

C_{cv} is the rate of capacitor in $/ kVAr

Q_{ck} is the rating of capacitor on node k in kVAr

5. Simulation

The proposed method is applied to 11kV, 28 bus radial distribution system used in [12].Line data and load data can be found in [12].By using the Newton Raphson loadflow algorithm [1]. The power loss index and Voltage in p.u are obtained. The capacitor placement suitability index is obtained using MATLAB fuzzy inference system.The capacitor placement suitability factors obtained at each node are given in the Table 2.Based on the capacitor placement suitability index given in Table 2. Total six nodes are selected from main feeder and each laterals for the placement of capacitors. The following GA parameters are applied for optimal capacitor sizing.

1. Population size = 50
2. Maximum Generations = 100
3. Crossover probability ‘Pc’ = 0.8
4. Mutation probability ‘Pm’ = 0.01
5. Roulette wheel selection
6. Energy rate ‘C_e = US $0.06/kWh.
7. Capacitor installation cost ‘C_{ci}’ = US $1000.
8. Capacitor rate ‘C_{cv}’ = US $3.0/kVAr.

TABLE 2 Capacitor placenment suitability factors for 11kV 28 bus systems

Bus.No	Power loss index	Voltage at receiving end	Capacitor Placement Suitability index
1-2	0.72884	0.98622	0.4717
2-3	1	0.96645	0.5000
3-4	0.70048	0.95236	0.6610
4-5	0.49929	0.93819	0.6148
5-6	0.33552	0.92766	0.6069
6-7	0.2037	0.91849	0.5048
7-8	0.02328	0.91604	0.2711
8-9	0.00055586	0.91576	0.2526
9-10	0.00024331	0.91551	0.2526
4-11	0.089101	0.94617	0.3388
11-12	0.017389	0.94440	0.2644
12-13	0.007333	0.94334	0.2526
13-14	0.0011314	0.94306	0.2527
14-15	0.00069594	0.94282	0.2526
5-16	0.0032903	0.93706	0.2526
6-17	0.015325	0.92588	0.2615
17-18	0.0076562	0.92490	0.2527
18-19	0.011837	0.92323	0.2563
19-20	0.0035508	0.92237	0.2526
20-21	0.00074592	0.92174	0.2526
7-22	0.035248	0.91561	0.2855
22-23	0.014225	0.91407	0.2593
23-24	0.0099913	0.91290	0.2526
24-25	0.00097353	0.91264	0.2526
25-26	0.00049533	0.91247	0.2526
8-27	0.0029525	0.91554	0.2526
27-28	0.00036911	0.91542	0.2526

The nodes 4, 5 from main feeder 11,14,17,22 from laterals are selected for capacitor placement. The size of the capacitors are optimized using MATLAB GA toolbox.The capacitor size is limited to 50kVAr to 300kVAr. The size of the capacitors obtained are given in the following Table .3

TABLE 3 Capacitor sizing obtained using GA

Node	4	5	11	14	17	22
Size(kVAr)	50.34	73.6	61.28	104.27	138.17	275.15

The Fig.4 gives the graph between no of generations and best fitness value obtained using MATLAB gatool box.

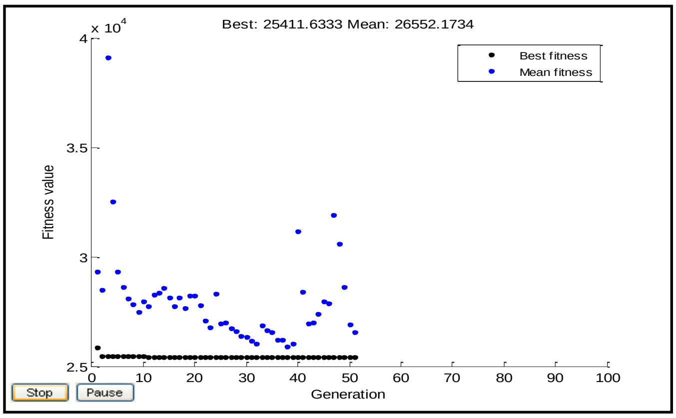

Figure 4 *Objective function variations with no generations*

The objective function consists total cost of energy loss for one year,capacitor installation cost and cost of the capacitors installed.The total capacitor cost before capacitor placement is zero.The following Table.4 gives the comparision results before and after capacitor placement.

TABLE.4 Comparsion results before and after capacitor placement

	Without capacitor	With capacitor
Total real power loss (kW)	68.804	32.9208
MinimumVoltage (p.u)	V_{26}=0.9125	V_{26}= 0.9466
Energy loss cost	$36,163	$17,303
Capacitor installation cost	$0.0000	$6000
Capacitors cost	$0.0000	$2108
Total annual cost	$36163	$25411
Annual savings		$10752

5. Conclusion

In this paper a method based on fuzzy logic and genetic algorithms is proposed to determine suitable nodes and sizing of capacitors to improve the performance of radial distribution systems and annual cost savings. The fuzzy logic based inference system is used to find the capacitor placement suitability index and hence to obtain the suitable nodes for capacitor placement.The nodes are selected on the basis of magnitude of the capacitor placement suitability index.The sizing of the capacitors is done by using genetic algorithms.

Simulation results shown to demonstrate the advantage of proposed method.The voltage profile is improved and the real power losses are reduced to considerable value.The capacitor placement improved the annual cost savings.

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