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Capacitor Placement Optimization using Fuzzy Logic and Genetic Algorithm in Distribution System

Susatyo Handoko[1], Nugroho Agus Darmanto[2], Bambang Winardi[3], Enda Wista Sinuraya[4], Agung Warsito[5], Denis[6], Abdul Syakur[7], Unggul Dzackiy K[8]

Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia

Abstract: Load growth in distribution system increase steadily. This load growth is followed by increased demand for reactive power supply due to increased inductive load. If a network does not have a reactive power source in around load area then all the needs of reactive load provided by the generator so that reactive current will flow to the line resulting in decreased voltage dropand power losses. One way to improve power factor and voltage is placing the optimal capacitor in the right location.

In this research, the optimal capacitor placement is done by usingfuzzy logic and genetic algorithm. Fuzzy logic is used to determine the optimal candidate bus, while the genetic algorithm is used to determine the magnitude of the capacitor bank to be installed.Parameters used for the objective function in genetic algorithms is the cost of capacitor installation, the purchase cost of the capacitor, the cost of capacitor operation and maintenance, and the cost of power losses in the distribution system. By minimizing this parameters, it will get the minimum cost in the optimal capacitor placement and meet the limits of the voltage magnitude and power factor that are determined.

Test results showed that the capacitor placement optimization usinfuzzy logic and genetic algorithm can find the optimal size of capacitor banks so thatvoltage on each bus has met limits that have been determined after the placement of the capacitor (Vmin = 0.95, Vmax = 1.05). Location of the optimal capacitor placement is bus 7 (300 kVAR), bus 8 (1200 kVAR), bus 12 (600 kVAR), and bus 14 (300 kvar) with savings for a period of 5 years is $ 50,185.

Keyword: capacitor, fuzzy logic, genetic algorithm

I. Introduction

Load growth in the distribution system is increasing continuously. This load growth is followed by an increase in demand for reactive power supply due to the increased inductive load. If a network does not have a reactive power source in the area around the load, then all of its reactive load needs are provided by the generator so that the reactive current will flow in the line resulting in a decreased power factor, voltage drop, and large power losses. One way to improve the power and voltage factors is to place the capacitor in the right location on the distribution system. Capacitors are installed in right locations and appropriate to maintain the voltage within the allowable limit so that power losses can be reduced.

In previous studies, many methods have been developed to solve the problem of optimizing capacitor placement, including using fuzzy logic, genetic algorithms [1-3], and combinations of fuzzy logic - genetic algorithms [4,5]. Each method has advantages and disadvantages of each so that one method is not necessarily better than the other methods. Even in one method there are various different ways of solving which also depend on the parameters used to solve.

In this research, optimization of capacitor placement is done by using a combination of fuzzy logic and genetic algorithms. The advantage of fuzzy logic is the ability in the process of reasoning in language (linguistic reasoning), so that the design does not require mathematical equations of the object to be controlled [6]. Genetic algorithm is one of the computational techniques that is suitable with a very large solution space. The parameters used for the objective function in the genetic algorithm are the cost of installing a capacitor, the cost of purchasing a capacitor, the cost of operating and maintaining a capacitor and the cost of power losses in a distribution system.

By minimizing these parameters, we will get the minimum cost in placing an optimal capacitor and meeting the specified voltage and power factor limits. To do the analysis, a simulation is made using Matlab because Matlab provides many basic functions for matrix operations in order to implement genetic algorithm components that use many matrix operations, and also Matlab provides toolboxes for fuzzy logic.

II. Design and Method

2.1 Fuzzy Logic for Bus Candidate Selection

In selecting a bus candidate as the location of the capacitor placement, many parameters can be used as consideration, for example power loss indices (PLI) or power loss index [2,4,5]. In this simulation, the bus candidate can be determined by himself but it should refer to the power loss index. The selection of bus candidates depends on the objectives to be achieved. The value of the power loss index (PLI) can be formulated in a mathematical equation as follows:

$$PLI_{(n)} = \frac{(X_{(n)} - Y)}{(Z - Y)} \qquad (2.1)$$

where PLI = power loss index
X = reduction of active power losses
Y = reduction of minimum active power losses
Z = reduction of maximum active power loss
n = bus number

Before determining the index value of power losses it must first calculate the reduction of active power losses. Reduction of active power losses is obtained from the difference between active power losses in the initial condition and active power losses after reactive power compensation is carried out.

2.1.1 Membership Function

The bus candidate selection is done using fuzzy logic. The method used is the Mamdani method using the toolbox on Matlab. Fuzzy logic here has input voltage and PLI, while the output is CSI (Capacitor suitability index). PLI has a range between 0 to 1, for the voltage used has a range between 0.9 to 1.1 pu, while the output (CSI) has a range between 0 to 1.

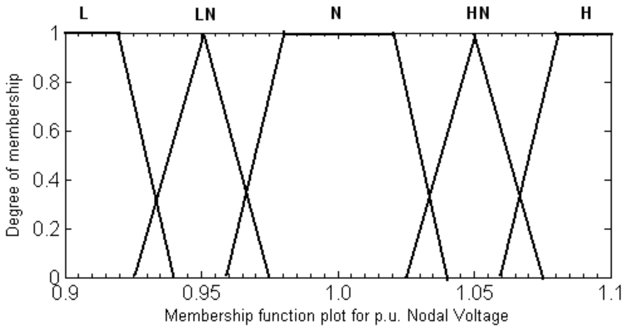

Figure1Voltage membership function

The membership function of the voltage is divided into five namely: L (low), LN (low normal), N (normal), HN (high normal), H (high).The membership function of the voltageis shown in figure 1.

The membership function of PLI is divided into five namely: L (low), LM (low medium), M (medium), HM (high medium), H (high). Figure 2 shows the membership function of PLI.

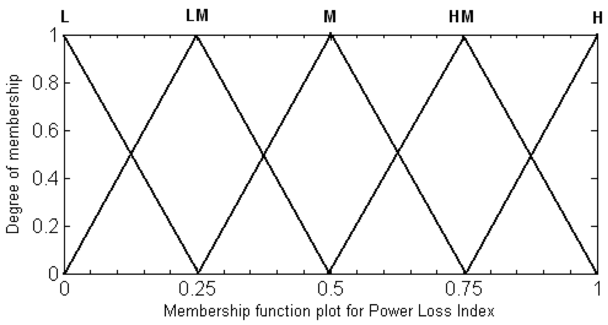

Figure2 PLI membership function

The membership function of CSI is divided into five namely: L (low), LM (low medium), M (medium), HM (high medium), H (high) as shown in figure 3.

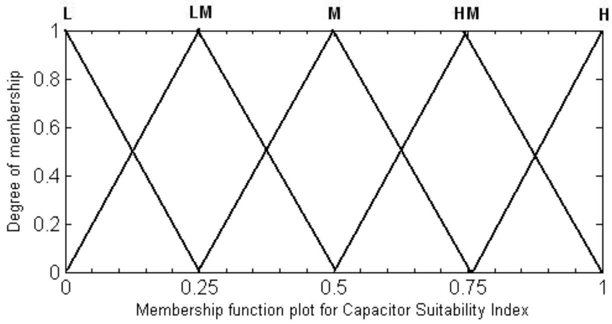

Figure3CSI membership function

2.1.2 Fuzzy Reasoning

For the problem of capacitor placement, the rules set for determining bus candidates for capacitor installation are stated in Table 1.

Table 1 Fuzzy rules for determining the optimal capacitor location

AND		Voltage				
		L	LN	N	HN	H
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

2.2 Simulation

The design of this optimization simulation uses the Matlab program with genetic algorithm optimization methods. This simulation program is made in 9 stages, the first stage is initial population initialization, the second stage is chromosomal decoding, the third stage is the process of power flow, the fourth stage is calculating the value of fitness, thefifth stage is the selection of the best individuals, the sixth stage is linear fitness ranking, the second stage is the seventh is the roulette wheel, the eighth stage is crossing, and the ninth stage is mutation. In this simulation, the objective function used in genetic algorithms in calculating fitness values is measured from several parameters, including:

a) Capacitor installation costs
b) Cost of purchasing capacitors
c) Operational and maintenance costs of bank capacitors
d) Cost of active power losses

The objective functions for the optimization process can be formulated in the following mathematical form:

$$Min.\ F = \sum_{ii=1}^{N_{bus}} \left(I_{(ii)}.KI + KB.C_{(ii)} + KO.B_{(ii)}T\right) + KE\sum_{l=1}^{N_{load}} T_l P_L^l \qquad (2.2)$$

Where
N_{bus} = Number of bus candidates
I = 0 or 1, 0 means that there are no capacitors installed on the bus
KI = Cost of installing capacitors for each bus
KB = Cost of purchasing bank capacitors for each kVar
C = The size of the capacitor bank in kVar
KO = Operating and maintenance costs per bank, per year
B = The number of capacitor banks
T = planning time (years)

KE = Cost of energy losses per kWh
l = Load level (maximum, average and minimum)
T_l = Time duration at each load level (hour)
P^l_L =The amount of active system power loss at each load level

By minimizing objective functions such as equation (2.2) we will get a minimum cost in the placement of capacitors with optimal values according to the planned time. The requirements for placing an optimal capacitor value are to meet the specified voltage limits on each bus, namely:

$$V_{min} \le V_m \le V_{max}$$

III. Analysis

The data used in this test is IEEE 15 bus distribution test system [5]. Data taken in the form of data distribution network forms, load data, and line data.

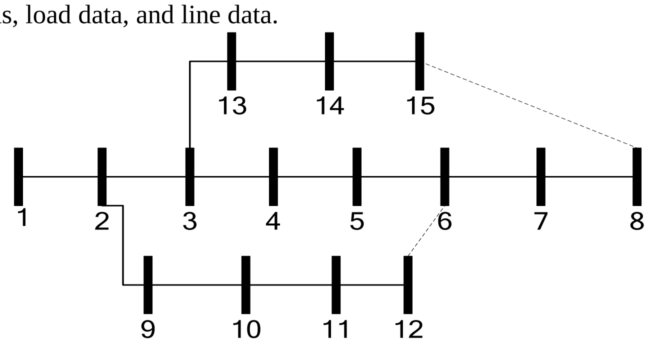

Figure 4 The IEEE 15 bus distribution test system

MVAbase = 100 MVA
kVbase = 12,66 kV

This test is intended to obtain the optimal value of the capacitor to improve the voltage in accordance with predetermined limits. In this test the voltage limits are adjusted to the standard, which is the voltage limit that can be tolerated in distribution systems is 5% so that Vmin = 0.95 pu and Vmax = 1.05 pu.

The selection of bus candidates as capacitor placement locations refers to the capacitor suitability index (CSI). The test was carried out as many as several variations with CSI tolerance limits that differ from 0-1 in descending order from large to small. The best tolerance limit for CSI is chosen based on several tests with different tolerance values. This test is carried out with the number of generations (MaxG) 200, the total population (UkPop) 50, the opportunity to cross (Pcross) of 0.95, and the chance of mutation (mutation) of 0.007. Determination of genetic algorithm parameters using a trial-end-error technique by doing experiments for a combination of the four parameters above and looking at some references [7]. Table 2 shows the results of all stress improvement tests with different tolerance limits

Table 2 The results of voltage improvement tests

Tolerance Limits CSI	Capacitor Placement Location	saving ($)
0.8	bus 8 (1500 kVar) bus 15 (600 kVar)	47,100
0.7	bus 8 (1500 Var) bus 14 (300 kVar) bus 15 (300 kVar)	48,409
0.6	bus 8 (1500 Var) bus 14 (300 kVar) bus 15 (300 kVar)	48,409
0.5	bus 7 (300 kVar)] bus 8 (1200 kVar) bus 12 (600 kVar) bus 14 (300 kVar)	50,185
0.4	bus 6 (600 kVar) bus 8 (600 kVar)	49,104

Tolerance Limits CSI	Capacitor Placement Location	saving ($)
	bus 11 (300 kVar) bus 15 (9000 kVar)	
0.3	bus 5 (300 kVar) bus 6 (300 kVar) bus 7 (300 kVar) bus 8 (1200 kVar) bus 14 (300 kVar)	47,736
0.2	bus 6 (600 kVar) bus 8 (300 kVar) bus 13 (300 kVar) bus 15 (1200 kVar)	46,612
0.1	bus 5 (300 kVar) bus 6 (300 kVar) bus 7 (300 kVar) bus 8 (1200 kVar) bus 13 (300 kVar)	46,144
0	bus 7 (900 kVar) bus 8 (600 kVar) bus 11 (300 kVar) bus 13 (300 kVar) bus 15 (300 kVar)	45,592

From all the test results with CSI tolerance limits that differ from 0-1 it can be concluded that the best CSI tolerance limit, which is 0.5 with the most optimal location of capacitor placement is bus 7 (300 kVar), bus 8 (1200 kVar), bus 12 (600 kVar), and bus 14 (300 kVar) because they have the largest savings value of $ 50,185.

From all the test results it can be concluded that the most optimal bus candidate location for capacitor placement is 4 locations namely bus 7 (300 kVar), bus 8 (1200 kVar), bus 12 (600 kVar), and bus 14 (300 kVar) because they have the largest value of savings but the voltage of each bus meets the standard with a tolerance limit of 5%. Figure 5 and table 3 show the comparison of system conditions before and after capacitor placement.

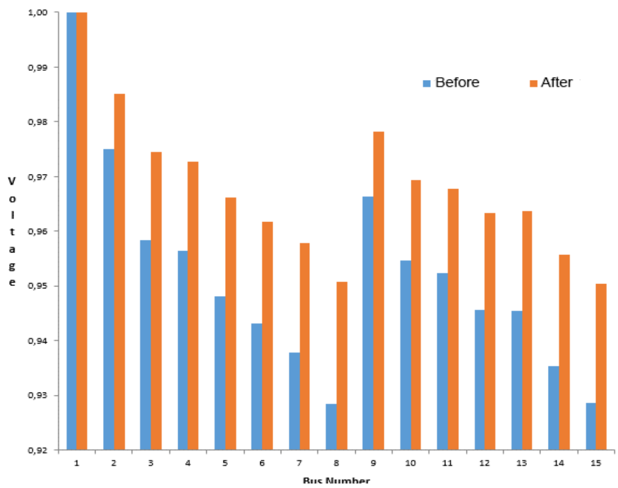

Figure 5 Comparison of bus voltages before and after the placement of capacitors in the test for voltage improvement at maximum load level

Table 3 Comparison before and after capacitor placement

Description	Before	After
Losses at the maximum load level (kW)	213.6	139.2
Losses at average load level (kW)	132.9	82.9
Losses at minimum load level (kW)	83.3	51.0
Minimum voltage at maximum load level (pu)	0,93	0,95
Minimum voltage on average load level (pu)	0,94	0,97
Minimum voltage at minimum load level (pu)	0.96	0.98
Savings in 5 years ($)	-	50,185

As shown in table 3, it can be seen that there are differences in active power losses at each load level and the minimum bus voltage after capacitor placement. The value of active power losses at each load level has decreased, namely 213.6 kW to 139.2 kW at the maximum load level, 132.9 kW to 82.9 kW at the average load level, and 83.3 kW to 51.0 kW at the minimum load level. The minimum voltage value at each load level has improved, namely for the maximum load level there is an improvement of 0.02 pu from 0.93 pu to 0.95 pu, for the average load level there is an improvement of 0.03 pu from 0.94 pu to 0.97 pu, and for the minimum load level there was an improvement of 0.02 pu from 0.96 pu to 0.98 pu.

The use of bank capacitors with fixed capacity has the disadvantage that whatever the amount of load is installed, the reactive power that is remains constant. So it is possible that there will be a drastic change in the load and will cause over compensated so that the leading power factor.

IV. Conclusions

Based on testing and analysis that has been done, it can be concluded several things as follows:

1. The most optimal locations for capacitor placement are bus 7 (300 kVar), bus 8 (1200 kVar), bus 12 (600 kVar), and bus 14 (300 kVar).
2. From the test results, the magnitude of the voltage on each bus meets the specified limits of 5%. With a minimum minimum voltage of 0.95 pu at the maximum load level, 0.97 pu at the average load level, and 0.98 at the minimum load level.
3. Savings after the installation of a bank capacitor is $ 50,185 for a period of 5 years.

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Author Profile

Susatyo Handokoreceived the S.T degree in Electrical Engineering from Institut Teknologi BandungIndonesia, M.T degree from Institut Teknologi BandungIndonesia and D.R degree from Gadjah Mada university Indonesia. Now day, his Researchs are power system plan and artificial intelligence in power plan.