AN EFFICIENT APPROACH FOR CAPACITOR SIZING AND LOCATION ON A RADIAL DISTRIBUTION SYSTEM USING ARTIFICIAL INTELLIGENCE TECHNIQUE

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ABSTRACT
This paper undertakes the problem of optimal shunt capacitor placement for loss reduction in a radial distribution feeder. The objective is to determine the optimum size and location of the capacitors to be placed on a radial distribution system. The objective function is to have maximization of saving due to reduction of energy losses thereby taking into consideration cost of capacitor. The solution methodology used divides the problem into two parts. In first part, load flow solution for the radial feeder is obtained and followed by a loss sensitivity analysis to select the candidate capacitor installation locations. In second part, Genetic algorithm is used as an optimization tool, which obtains the optimal value of capacitors to be installed. The solution algorithms have been implemented into and tested on a 33-bus radial distribution system. Test results demonstrate the effectiveness of the developed algorithm. Computational results are calculated in MATLAB 7.

KEYWORDS: Radial Distribution System (RDS), Capacitor placement, Loss reduction, Loss sensitivity factor (LSF), Genetic algorithm (GA).

I. INTRODUCTION
The analysis of the customer failure statistics of most utilities indicates that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer. Therefore, the analysis of a distribution system is an important area of activity. It is well known that losses in a distribution system are significantly high. The economic reduction of loss in power systems is considered one of the most important issues in the economy of all countries. Because of the growing effort to reduce system losses, many papers have been published in recent years referring to optimal distribution planning. Researches in this field show that loss reduction is more economical than increasing generation. Reduction of loss in the distribution systems with the maximum saving is achieved through various methods. One of the methods is the optimal selection of capacitors in such networks. The installation of shunt capacitors on radial distribution systems is essential for power flow control, improving system stability, power factor correction, voltage profile management and losses minimization. Therefore it is important to find the optimal size and location of capacitors required to minimize energy losses. A variety of methods have been devoted for load flow analysis and capacitor placement problems by many researchers. D. Shirmohammadi and A. Semlyen [3] presented a new compensation-based power flow method for the solution of weakly meshed distribution and transmission networks.S. Ghosh and D. Das [4] proposed a simple and efficient method for the load flow of radial distribution network using the evaluation based on algebraic expression of receiving end. Goswami and Basu [5] have presented a direct method for solving radial and meshed distribution networks. Sundhararajan and Pahwa [7] have solved the general capacitor placement problem in a distribution system using a genetic algorithm. Ching-Tzong Su, Chu-S. Lee and Chin-S. Ho [8] has presented an optimal capacitor placement method which employs simplified power flow formulations, genetic algorithms and sensitivity factors for a given load pattern. Prakash and M. Sydulu[12] presented a novel Particle Swarm Optimization based approach for capacitor placement on Radial Distribution Systems. In this paper capacitor placement problem for loss minimization of distribution system is solved using GA. In order to demonstrate the effectiveness of GA an example from the literature is solved and the computational results are obtained.

II. PROBLEM FORMULATION
The problem of capacitor placement consists of determining the location, size and number of capacitors to be installed in a distribution system.

III. OBJECTIVE FUNCTION
The objective is to reduce the energy losses on the system while striving to minimize the cost of capacitor in the system. It thus consists of two terms. The first is the cost of capacitor placement and the second is the cost of the total energy losses. The cost associated with capacitor placement is composed of a fixed installation cost and a purchase cost. The total cost of the energy losses is obtained by summing up the real power losses for each load level multiplied by the corresponding duration.
Mathematical Representation:

It is expressed mathematically by the equations below:

1. **Capacitor Cost (KC):**

   Capacitor cost is divided into two terms: constant installation cost and variable cost which is proportional to the rating of capacitors. Therefore capacitor cost is expressed as:
   
   \[ KC = \sum_{i=1}^{n_{cap}} K_i + K_c \times Q_{ci} \]  
   
   Where,
   
   \( K_i \) is the constant installation cost of capacitor.
   \( K_c \) is the purchase rate of capacitor per kVAR.
   \( Q_{ci} \) is the rating of capacitor on bus in kVAR.

2. **Energy Loss Cost (ELC):**

   The Energy loss cost (ELC) can be calculated by multiplying EL with the energy rate (Ke)
   
   \[ ELC = EL \times K_e \]  
   
   where
   
   \( EL_i \) is energy loss (kW) in section–i in time duration T.
   \( K_e \) is the energy rate

   The cost function ‘S’ [7] is expressed as:

   Minimize
   
   \[ S = K_e \times \sum_{j=1}^{n} EL_j + \sum_{i=1}^{n_{cap}} K_i + K_c \times Q_{ci} \]  
   
   \( F \) is the fitness function
   
   \[ F(f) = \frac{1}{1+S} \]  
   
   Net saving = BEL – KC

V. **CAPACITOR SIZING AND LOCATION USING GENETIC ALGORITHM**

The developed algorithm for identifying the sizing and location is based on Genetic Algorithm (GA).

The various steps performed for Genetic Algorithm [12] are given as follow:

The algorithm procedure can be summarized as:

**Step 1:** Read the line and load data of distribution.

**Step 2:** Run the Load Flow of Distribution System to find out voltage magnitudes at the buses and total power loss.

**Step 3:** Select the candidate buses.

**Step 4:** Set GEN = 0

**Step 5:** Form initial population of real numbers, which is randomly selected value of capacitors to be installed at the candidate buses for compensation.

**Step 6:** Update the reactive power at candidate buses.

**Step 7:** Run the Load Flow of Distribution System with updated reactive power at the candidate buses for each population. Also calculate total power loss for each population.

**Step 8:** Calculate the total Energy Loss Cost (ELC) and Capacitor Cost (KC) for population.

**Step 9:** For each population, evaluate the objective function and the fitness value. The objective function for each population is the total energy loss cost and the cost of capacitors given in eq. (3).

**Step 10:** GEN = GEN + 1

**Step 11:** Select the solutions in pool from initial population by using Roulette Wheel Selection procedure.

**Step 12:** Perform Crossover on the solutions selected randomly from the pool using procedure and generate two off springs.

**Step 13:** Perform Mutation on the offspring generated by the crossover operation using the procedure and generate the offspring.

**Step 14:** Calculate Energy Loss Cost (ELC) and capacitors cost (KC). Also evaluate objective function and Fitness Function of each off springs.

**Step 15:** Combine the solutions of the pool and the off springs and refer them as new population.

**Step 16:** Replace new population with initial population for next generation.

**Step 17:** Go to step 10, till the solution converges.

**Step 18:** STOP

The above set of steps for the capacitor placement is depicted in flowchart as shown in Fig. 1 below.
VI. APPLICATION EXAMPLE AND RESULTS

The single line diagram of compensated and uncompensated test system i.e. 33 bus system considered in this work is shown in fig. 2 & 3 resp. It has been found that by placing the capacitor at highly sensitive nodes (i.e. buses 7,12,16,27) maximum benefit can be obtained. Comparison of results of the compensated and uncompensated RDS is presented in Table 1. The proposed method and the algorithm are implemented by using MATLAB 7.

Table 1: Comparison of the results obtained on 33-Bus RDS before and after placing the capacitors

<table>
<thead>
<tr>
<th></th>
<th>Uncompensated</th>
<th>Compensated Case I</th>
<th>Compensated Case II</th>
<th>Compensated Case III</th>
<th>Compensated Case IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum System Voltage (p.u)</td>
<td>0.9041</td>
<td>0.9304</td>
<td>0.9281</td>
<td>0.9209</td>
<td>0.9176</td>
</tr>
<tr>
<td>Power Loss (kW)</td>
<td>177KW</td>
<td>104 KW</td>
<td>114 KW</td>
<td>126 KW</td>
<td>135 KW</td>
</tr>
<tr>
<td>Loss reduction (%)</td>
<td>---</td>
<td>41.2%</td>
<td>35.5%</td>
<td>28.8%</td>
<td>23.7%</td>
</tr>
<tr>
<td>Optimal location and Capacitor size (kVAR)</td>
<td>7 250</td>
<td>16 300</td>
<td>27 200</td>
<td>9 150</td>
<td>12 350</td>
</tr>
</tbody>
</table>

It has been found that if the capacitors are placed at locations other then the above (i.e. first four highly sensitive buses) but in the decreasing order of LSF, although losses are reduced but in each case losses are more than previous and total cost also increases thereby reducing overall annual benefit. Table 2 shown below gives the comparison of the results obtained by capacitor placement at four different buses on different locations in each case. Thus, it is shows that maximum loss reduction and savings are obtained when the capacitors are placed at first four highly sensitive buses are per LSF.

Table 2: Comparison of the results obtained on 33-Bus RDS before and after placing the capacitors at four different buses on different locations in each case

<table>
<thead>
<tr>
<th></th>
<th>Uncompensated</th>
<th>Compensated Case I</th>
<th>Compensated Case II</th>
<th>Compensated Case III</th>
<th>Compensated Case IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum system voltage (p.u)</td>
<td>46,51,560</td>
<td>46,51,560</td>
<td>46,51,560</td>
<td>46,51,560</td>
<td>46,51,560</td>
</tr>
<tr>
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<td>7 250</td>
<td>16 300</td>
<td>27 200</td>
<td>9 150</td>
<td>12 350</td>
</tr>
<tr>
<td>Total kVAR</td>
<td>-----</td>
<td>1050 kVAR</td>
<td>850 kVAR</td>
<td>900 kVAR</td>
<td>700 kVAR</td>
</tr>
<tr>
<td>Total Energy Loss Cost</td>
<td>$93,031</td>
<td>$54,662</td>
<td>$59,918</td>
<td>$66,225.6</td>
<td>$70,956</td>
</tr>
<tr>
<td>Total capacitors cost</td>
<td>$7,150</td>
<td>$6,550</td>
<td>$6,700</td>
<td>$6,670</td>
<td>$6,100</td>
</tr>
<tr>
<td>Total cost</td>
<td>$93,031</td>
<td>$61,812</td>
<td>$66,468</td>
<td>$72,925</td>
<td>$77,056</td>
</tr>
<tr>
<td>Net annual savings</td>
<td>---</td>
<td>$31,219</td>
<td>$26,563</td>
<td>$20,106</td>
<td>$15,975</td>
</tr>
</tbody>
</table>
The 33-bus radial distribution system [6], as shown in Fig. 2, has following characteristics:
Number of buses = 33
Number of lines = 32
Slack Bus No = 1
Base Voltage = 12.66 KV
Base MVA = 100

Fig 2: Single line diagram of 33 bus system

Fig 3: Single line diagram of 33 bus system after compensation

In all the calculations following parameters are used [15]:
1. Population size = 100
2. Maximum Generation = 100
3. Crossover probability ‘P_c’ = 0.006
4. Mutation probability ‘P_m’ = 0.006
5. Energy rate $K_e = US$ 0.06/kWh (= Rs.3/kWh)
6. Installation cost of capacitor ‘K_i’ = US $1000 (=Rs.50,000/each location)
7. Purchase rate of capacitor ‘K_c’ = US $3.00/kVAR (=Rs.150/kVAR)
VII. CONCLUSION
In this paper the capacitor sizing and placement problem is discussed using an efficient GA algorithm. A test case of 33 bus system has been used and results demonstrate the improvement in voltage profile and reduction of the losses thereby maximizing net annual savings. This method places the capacitors at less number of locations with optimum size and offers much net annual savings. It has been found that maximum benefit can be obtained by placing the capacitors at highly sensitive nodes.

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