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Application of Loss Sensitivity Factor and Genetic Algorithm for Capacitor Placement for Minimum Loss in radial Distribution System

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Abstract

Capacitors are widely used in distribution systems to reduce power losses, improve voltage profile and increase system capacity. The benefits of compensation depend greatly on the placement and size of the added capacitors. This paper presents a new methodology using Loss Sensitivity Factor (LSF) method and Genetic Algorithm (GA) 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. A two-stage methodology is used for the optimal capacitor placement problem. In the first stage, LSF approach is used to find the optimal capacitor locations and in the second stage, Genetic Algorithm is used to find the sizes of the capacitors. The sizes of the capacitors corresponding to minimum real power loss are determined. The proposed method is tested on IEEE 15-bus, 34-bus and 69-bus test systems and the results are presented.

Keywords: Capacitor placement, Loss sensitivity factor, Genetic algorithm, optimization, loss reduction.

Introduction

Electric distribution systems are becoming large and complex leading to higher system losses and poor voltage regulation. Therefore to reduce power losses, shunt capacitors are installed in power distribution networks to compensate reactive power. Shunt capacitors in distribution networks are used not only for power loss reduction but also for other purposes such as voltage profile improvement and maximize transmitted power in cables and transformers.

Application of shunt capacitors to the primary distribution feeders is a common practice in mostof the countries. The advantages anticipated include boosting the load level of the feeder so that additional loads can be carried by the feeder for the same maximum voltage drop, releasing a certain kVA at the substation that can be used to feed additional loads along other feeders and reducing power and energy losses in the feeder.

Even though considerable amount of research work was done in the area of optimal capacitor placement [1]-[12], there is still a need to develop more suitable and effective methods for the optimal capacitor placement.

In this paper Loss Sensitivity Factor Method is used to determine the locations of optimal capacitors and Genetic Algorithm is used to determine size of optimal capacitors for loss reduction. A modified load flow technique, Branch Current Load Flow method is considered for solving radial distribution networks.

Loss Sensitivity Factor Based Capacitor Location

To identify the location for capacitor placement in distribution system, Loss Sensitivity Factors have been used. The loss sensitivity factor is able to predict which bus will have the biggest loss reduction when a capacitor is placed. Therefore, these sensitive buses can serve as candidate buses for the capacitor placement. The estimation of these candidate buses basically helps in reduction of the search space for the optimization problem. As only few buses can be candidate buses for compensation, the installation cost on capacitors can also be reduced.

Consider a distribution line with an impedance R + jX and a load of Peff + jQeff connected between 'i' and 'j' buses as given below in Figure.1.

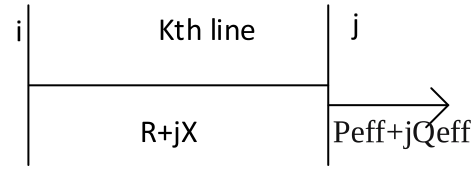

Figure 1: A distribution line with an impedance and a load.

Real power loss in the line of the above Fig. 1 is given by $[I_k^2] * [R_k]$, which can also be expressed as,

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$$P_{loss}[j] = \frac{(P_{eff}^2[j] + Q_{eff}^2[j])R[k]}{(V[j])^2} \quad (1)$$

Similarly the reactive power loss in the kth line is given by

$$Q_{loss}[j] = \frac{(P_{eff}^2[j] + Q_{eff}^2[j])X[k]}{(V[j])^2} \quad (2)$$

Where

P_{eff} [j] = Total effective active power supplied beyond the bus 'j'

Q_{eff}[j] = Total effective reactive power supplied beyond the bus 'j'

Now, the Loss Sensitivity Factors can be calculated as

$$\frac{\partial P_{loss}}{\partial Q_{eff}} = \frac{(2 * Q_{eff}[j]) * R[k])}{(V[j])^2} \quad (3)$$

$$\frac{\partial Q_{loss}}{\partial Q_{eff}} = \frac{(2 * Q_{eff}[j]) * X[k])}{(V[j])^2} \quad (4)$$

Candidate Bus Selection Using Loss Sensitivity Factor

The Loss Sensitivity Factor ($\partial P_{loss} / \partial Q_{eff}$) as given in (3) has been calculated from the base case load flows. The values of loss sensitivity factors have been arranged in descending order and correspondingly the bus numbers are stored in bus position 'bpos [i]' vector. The descending order of($\partial P_{loss} / \partial Q_{eff}$)elements of 'bpos [i]' vector will decide the sequence in which the buses are considered for compensation. At these buses of 'bpos [i]' vector, normalized voltage magnitudes are calculated by considering the base case voltage magnitudes given as below

Norm[i] = |V[i]|/0.95 (5)

Where V[i] is the base voltages of the corresponding IEEE bus. The 'Norm[i]' decides whether the buses need reactive compensation or not. The buses whose Norm[i] value is less than 1.01 can be selected as the candidate buses for capacitor placement. The candidate buses are stored in "candidate bus" vector. It is to be noted that the "Loss Sensitivity Factors" decide the sequence in which buses are to be considered for capacitor placement and Norm[i] decides whether the buses needs Q-compensation or not. If Norm[i] is greater than 1.01 such bus needs no compensation and that bus will not be listed in "candidate bus" vector. The "candidate bus" vector gives the information about places for the capacitor placement.

The following steps are to be performed to find out the potential buses for capacitor placement

Step 1: Calculate the Loss Sensitivity Factor at the buses of distribution system using (3).

Step 2: Arrange the value of Loss Sensitivity Factor in descending order. Also store the respective buses into bus position vector bpos[i].

Step 3: Calculate the normalized voltage magnitude Norm[i] of the buses of using (5).

Step 4: The buses whose Norm[i] is less than 1.01 are selected as candidate buses for capacitor placement.

Candidate bus vector of 15, 34, 69-bus Radial Distribution System contains set of sequence of buses given as {6, 3}, {19, 22, 20,}, {57, 58, 61}.

Genetic Algorithm

Implementation of GA based capacitor sizing

In this section, the capacitor sizing problem is implemented using GA. GA is applied to calculate the optimum values of capacitors required to be placed at locations on a radial distribution system, so as to minimize the real power loss.

Initial population: The GA operates on apopulation of consisting of a number of chromosomes simultaneously. The initial population of real numbered vectors is createdrandomly. Each of these vectors represents one possible solution to the search problem. Based on the size of search space the population size needs to be selected.

Fitness evaluation: Fitness evaluation is aprocedure to determine the fitness of each string inthe population. The fitness value is the onlyinformation available to the GA and theperformance of the algorithm is highly sensitive tothe fitness values. As the algorithm proceeds, wewould expect to increase the individual fitness ofthe best chromosome as well as the total fitness ofthe population as a whole.

Reproduction: During the reproductive phase ofthe GA, good chromosomes (parents) in pairs areselected from the current generation's populationfor producing offspring and placing them in thenext generation's population. Parents are selectedrandomly from the population using a schemewhich favors the more fit individuals. Goodindividuals will probably be selected several timesin a generation, poor ones may not be at all. This can be achieved by many different schemes, but the method in this paper used is the stochastic universal sampling selection process.

Crossover: The crossover operator is the mainsearch tool. It mates chromosomes in the matingpool by pairs and generates candidate offspring bycrossing over the mated pairs with probability Pc.

Mutation: After crossover, some of the genes inthe candidate offspring are modified with a smallmutation probability Pm. Themutation operator is included to prevent prematureconvergence by ensuring the population diversity.

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Termination criterion: After the calculation of fitness values of each chromosome the next step is to check the termination criterion. Termination criterion of the GA decides whether to continue searching or stop the search.

Algorithm for GA based capacitor sizing

The GA based capacitor sizing algorithm is given below:

1. Generate the random population at candidate nodes for size(s) of capacitors for Gen = 1.
2. Perform load flows to determine various node voltages, active power losses.
3. Determine the fitness function values i.e. total real power loss.
4. Select parent strings by stochastic universal sampling selection process.
5. Perform crossover and mutation on the selection strings and obtain new strings for next generation.
6. Repeat steps 2 to 5 until the difference between best fitness and average fitness is less than specified error or predefined iterations.
7. Stop.

Results

The optimal capacitor placement using Loss Sensitivity Factor Method and GA was applied on IEEE-15, 34, 69 bus systems and the results obtained are very encouraging. The method places capacitors at less number of locations with optimum sizes and offers much saving in initial investment and regular maintenance.

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 shown in table I. The losses (in kW) for uncompensated and compensated networks are shown in table II.

Table I. Control Parameters

Control parameter	Definition
50	Population size
Pc=0.9	Crossover probability
Pm=0.1	Mutation Probability
50<Qc<1500	Capacitor size boundary
$g_{max=}$1000	Maximum number of iterations

Table II. Comparison of Results

IEEE Bus	Uncompensated	Compensated	
		Algorithm in [5]	Proposed LSF + GA Algorithm
15 bus	61.7944	32.7	32.5987
34 bus	221.7235	168.8	168.8123
69 bus	225.0044	152.48	151.3742

Conclusion

In this paper a new strategy for capacitor placement problem has been presented using Loss Sensitivity factor method with Genetic Algorithm. The employed LSF and GA to the buses is effective in reducing the total number of alternatives examined for finding the optimal solution.

By installing shunt capacitors at all the potential locations, the total real power loss of the system has been reduced significantly and bus voltages are improved substantially. The proposed LSF approach is capable of determining the optimal capacitor locations. The proposed GA method iteratively searches the optimal capacitor sizes effectively minimum total real power loss.

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