ISBN: 978-93-83758-09-8

OPTIMAL CAPACITORS PLACEMENT IN IEEE 6 Bus USING GENETIC ALGORITHM

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Abstract: The work reported in this paper is carried out with the objective of identifying the optimal locations and sizes (kVAr ratings) of shunt capacitors to be placed in radial distribution system to have overall economy considering the saving due to energy loss minimization and cost of capacitors. For the purpose two stage methodologies is used. In first stage, the load flow of pre-compensated distribution system is carried out. On the basis of load flow solutions, loss sensitivity factors (LSF) indicating the potential locations for compensation are computed. From LSF, the candidate number of buses is identified. In the second stage, genetic algorithm is used to identify the sizes of the capacitor for minimizing the energy loss cost and capacitor cost. The developed algorithm is tested for 6-bus radial distribution systems while taking the different step sizes for capacitors.

Key Words: 6 bus IEEE system, GA, sensitivity analysis, objective function, load flow solution

I. INTRODUCTION

The power generation utilities aimed to raise operational efficiency to the possible extent by reducing the amount of losses in real power transmitted across the transmission lines, and also aim to maintain the quality of power supplied to users through voltage controlling within the permissible limits [1]. Therefore need to use shunt capacitors as effective tool has been grown towards optimal control of reactive power. Shunt capacitors are installed at suitable locations in large electric network for the improvement of voltage profile and to reduce power losses in the transmission and distribution lines [2]. The first using of shunt capacitors began in 1914 for improvement of power factor with limited use due to high cost per MVAR and large size and weight [3]. Since 1939, shunt capacitors are widely used in the power system due to reduced cost relative to its size [4]. With the increase in load, the system power factor usually declines. The load growth and decrease in power factor lead to voltage regulation problems, increased system losses, power factor penalties in power contracts, and reduced system capacity [5]. The capacitors improve the power factor, provide some voltage drop correction and reduce system line losses. The properly placed and sized capacitors can usually reduce system line losses sufficiently to justify the cost of their installation [6]. The maximum benefits of capacitors are obtained by locating the capacitors as possible as near the inductive loads. The capacitors are commonly used in power system network for reactive power compensation [7]. The optimal capacitor placement consists of determining the number, location, type, size and control setting at different load levels of the capacitors to be installed. The objective is to minimize energy losses while considering capacitor installation costs, voltage profile improvement and system stability enhancement. A large variety of research work has been done on optimal capacitor placement in electrical power system in the past. References [8]-[10] have considered optimal capacitor placement in power system using genetic algorithm. J.C. Carlisle *et al.* [11] used graph search algorithm for optimal placement of fixed and switched capacitors on radial distribution systems. Om Prakash Mahela *et al.* [12] used an approach for optimal capacitor banks placement in radial distribution feeders for loss reduction using MATLAB. Eajal *et al.* [13] used particle swarm optimization for optimal capacitor placement and sizing in unbalanced distribution system with harmonics consideration. In this paper, genetic algorithm is used for optimal capacitor placement in proposed power system model. The objective function aims at minimizing the total annual cost due to capacitor placement, and power loss. The constraint is voltage limits. The proposed method is tested on IEEE 6-bus system for optimum capacitor places and sizes.

II. PROPOSED METHOD

The method used here first identifies a sequence of nodes to be compensated. The sequence is determined by repetitive applications of loss minimization technique by a singly located capacitor. Once the sequence of nodes to be compensated is identified, the corresponding optimal capacitor size at the compensated nodes can be determined simultaneously by minimizing the loss saving equation with respect to the capacitor currents. The procedures of loss minimization by placing a single and multiple capacitors are described in the following sections.

ISBN: 978-93-83758-09-8

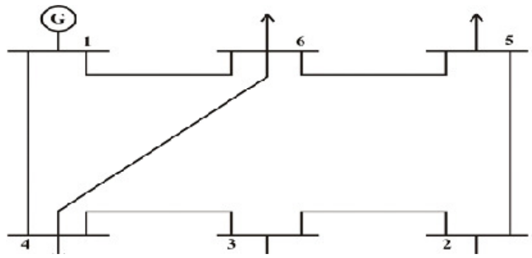

Figure 1 Single-line diagram of the 6-bus system

2.1 Objective Function

The aim of the present work is to find out the location and sizes of the shunt capacitor so as to maximize the net saving by minimizing the energy loss cost for a given period of time and considering cost of shunt capacitors. Therefore, the objective function consists of two main terms: energy loss cost and capacitors cost. Mathematical formulation of the terms used in objective function is given below:

Term 1: Energy loss Cost (ELS):

If Ii is the current of section-i in time duration T, then energy loss in section-i is given by:

$$EL = \sum_{i=1}^{n} EL_i \qquad (2.1)$$

The Energy loss (EL) in time T of a feeder with n sections can be calculated as:

$$ELC = C_e \times EL \qquad (2.2)$$

The Energy loss cost (ELC) can be calculated by multiplying eq. (4.2) with the energy rate (Ce)

ELC = Ce × EL (2.3)

Where ELi, is energy loss (kW) in section–i in time duration T.
I_i is the current of the section-i
R_i is the resistance of section-i.
T is the time duration.
Ce is the energy rate.
ELC is the energy loss cost.

Term 2: Capacitor Cost (CC):

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:

$$CC = C_{ci} + (C_{cv} \times Q_{ck}) \qquad (2.4)$$

where,

Cci is the constant installation cost of capacitor. Ccv is the rate of capacitor per kVAr.

Qck is the rating of capacitor on bus-k in kVAr.

The cost function is obtained by combining eqs. (2.3) and (2.4) . This cost function is considered as the objective function to be minimized in the present work. The cost function 'S' is therefore expressed as:

Minimize

$$S = C_e \times \sum_{i=1}^{n} EL_i + \sum_{k=1}^{ncap} C_{ci} + (C_{cv} \times Q_{ck}) \qquad (2.5)$$

Where S is the cost function for minimization. By minimizing the cost function, the net saving due to the reduction of energy losses for a given period of time including the cost of capacitors is given below:

Net Saving = BEL – CC (2.6)

where
BEL = ELC (without capacitor) - ELC(with capacitor)
BEL is benefit due to energy loss reduction.
ELC (without capacitor) is energy loss cost without capacitor.
ELC (with capacitor) is energy loss cost with capacitor.
CC is the total capacitors cost as expressed by eq. (4.4)

III. LOSS SENSITIVITY FACTOR AND CANDIDATE BUS SELECTION

The loss sensitivity factor and the criterion to select the candidate buses for compensation are summarized in this section.

3.1 Loss Sensitivity Factor

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

ISBN: 978-93-83758-09-8

of $P_{eff} + jQ_{eff}$ connected between 'i' and 'j' buses as given below in Fig. 4.2.

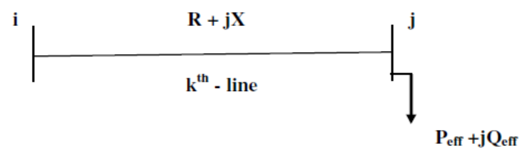

Figure 2: A distribution line with an impedance and a load

Real power loss in the line of the above Fig. 4.2 is given by $[I_k^2] * [R_k]$, which can also be expressed as,

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

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

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

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:

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

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

IV. CAPACITOR ALLOCATION USING GA

The developed algorithm for identifying the sizing and location is based on Genetic Algorithm (GA). The development of algorithm is explained with a review on GA. A GA is an iterative procedure which begins with a randomly generated set of solutions referred as initial population. For each solution in the set, objective function and fitness are calculated. On the basis of these fitness functions, pool of selected population is formed by selection operators, the solution in this pool has better average fitness then that of initial population. The crossover and mutation operator are used to generate new solutions with the help of solution in the pool. The process is repeated iteratively while maintain fixed number of solutions in pool of selected population, as the iteration progress, the solution improves and optimal solution is obtained. During the selection process of the GA, good solutions are selected from the initial generated population for producing offspring. Good solutions are selected randomly from the initial generated population using a mechanism which favours the more fit individuals. Good individuals will probably be selected several times in a generation but poor solutions may not be selected at all. The second GA operator is crossover. In the crossover two parents are selected randomly from the pool of selected/obtained population by the selection process. Crossover produces two offsprings which has some basic properties of the parents. The mutation operator generates an offspring using a random solution from pool. Each new solution is evaluated i.e. objective function and fitness values are calculated. These newly created offsprings and the populations are combined. The combined population is put for selection by selection operator. With the above description, a simple Genetic Algorithm is given as follow:

Step 1: Randomly generate initial population strings.

Step 2: Calculate the fitness value for each string in the population.

Step 3: Create the pool after selection.

Step 3: Create offsprings through crossover and mutation operation.

Step 4:` Evaluate the offsprings and calculate the fitness value for each solution.

Step 5: If the search goal is achieved, or an allowable generation is attained, return the best chromosome as the solution; otherwise go to step 3.

The standard procedure of GA is depicted in Flowchart as shown in Fig. 3

V. RESULTS

To implement the proposed work MATLAB simulink is used as a tool. MATLAB (Matrix Laboratory) was invented in late 1970s by Cleve Moler. Simpower toolbox is used here. IEEE 6 bus system is designed in simulink as shown in figure 4. The IEEE data used for 6 bus system is shown in below table.

ISBN: 978-93-83758-09-8

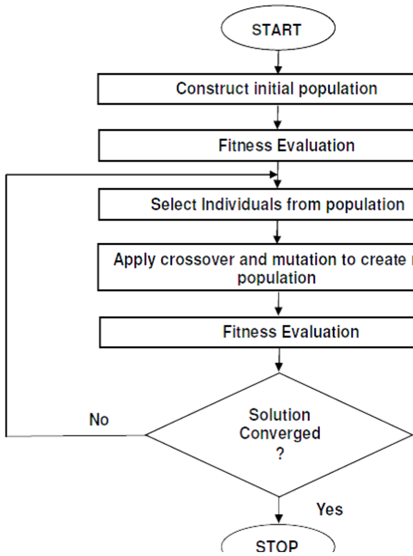

Figure 3: Genetic Algorithm Flowchart

Table 1: IEEE 6-Bus System Line Data

S.No.	Start Bus	End Bus	Branch Impedance (in p.u.)
1	1	6	0.1230+j0.518
2	1	4	0.0800+j0.370
3	2	3	0.0723+j1.050
4	2	5	0.2820+j0.064
5	3	4	0.0000+j0.133
6	4	6	0.0970+j0.407
7	6	5	0.0000+j0.300

Table 2: Variable Constraints

	Generator Bus Voltage		PQ Bus Voltage
	V_1	V_2	
Lower Limit	1.0	1.1	0.9
Upper Limit	1.1	1.15	1.1

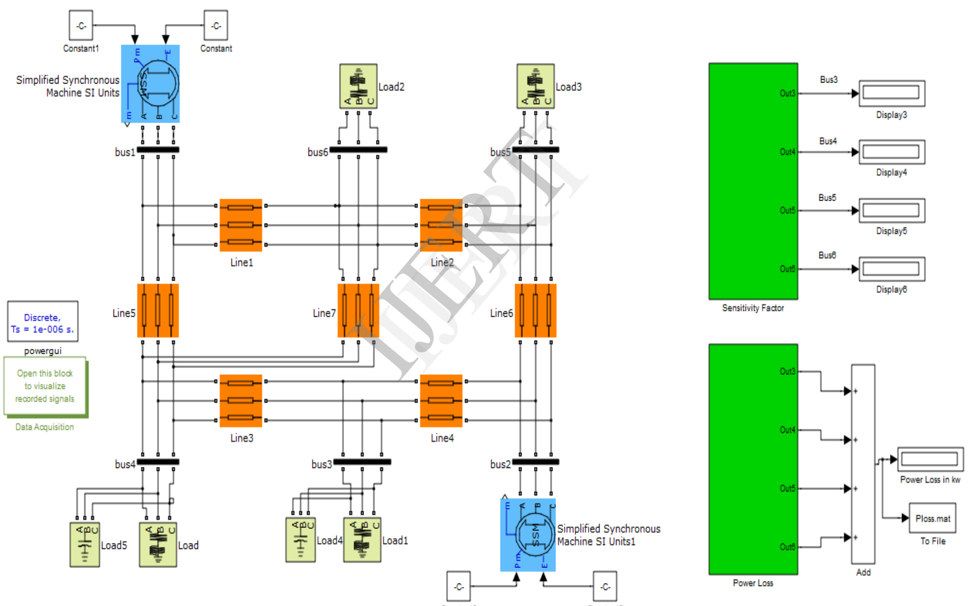

Figure 4: MATALB simulnik model of IEEE 6 bus system along with sensitivity factor calculation and power loss calculation

To reduce the number of buses sensitivity factor of buses are arranged in descending order. It indicates, the bus number at top is having highest power losses, followed by others. So that bus will require compensation and capacitor can be placed there. Table 3 shows the value of sensitivity factor of every bus arranged in descending order.

Table 3: Sensitivity factors arranged in order of compensation requirement

Sr. No.	Bus No.	Sensitivity Factor
1	3	1.381e+009
2	5	631
3	6	-550.8
4	4	-2.567e+008

Above table shows bus 3 and 5 requires compensation and shunt capacitors are placed on these buses. After placing the shunt capacitors of value 100kvar, optimisation is done by genetic algorithm. An objective function above is designed in MATLAB editor with name *obj_fun.m.* The GUI of GA is used to optimise

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this objective function of 13 variables. The print screen view of that GUI is shown in figure 5.

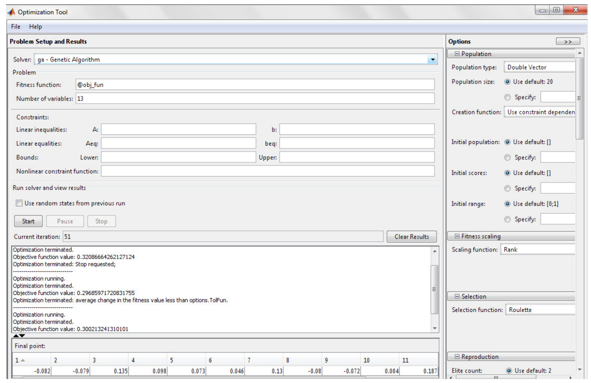

Figure 5: GUI of GA tool in MATLAB

In this lower and upper bounds are set to 0.9 and 1.1 respectively. Population is taken 20 and roulette selection function is used. To check the output plot, best fitness, selection function, distance and selection check box is selected and a separate iteration window is opened to show the values of objective function during different iterations. Output plots are shown in figure 6 below. The number of times the genetic algorithm is run, a slight change in objective function value will be noticed as population is randomly generated every time. The value of objective function and chromosome distance should be decreasing for better optimisation. The objective function of figure 5.6 proves better optimisation as objective function is decreasing and iteration values of objective function in figure 5.7 also proves this point.

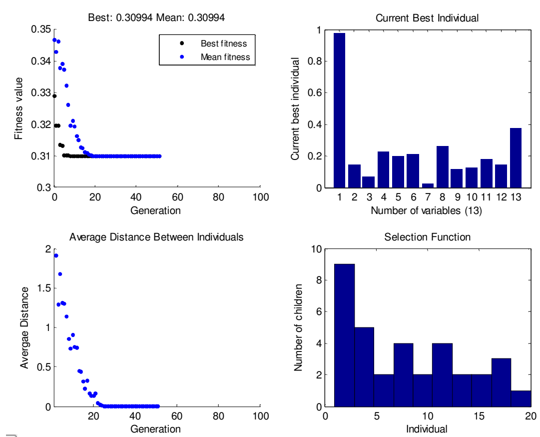

Figure 6: Output plots of genetic algorithm for designed objective function

VI. CONCLUSION

The work has been carried out to find the optimal locations and sizes (kVAr) of capacitors to be placed in radial distribution system to maximize the saving after considering the energy loss cost and capacitor cost. The above problem has been solved by two step methodology, the candidate locations for compensation are found using loss sensitivity factor calculated from base case load flow. The sizing has been attempted using Genetic Algorithm. In GA, coding scheme is developed to carry out the allocation problem, which is identification of location and size by one dimensional array. The study has been carried out on 6-bus radial distribution systems considering. From the study the following conclusions are drawn.

- The compensation is yielding into increase in voltage profile, reduction in losses.
- The developed algorithm is effective in deciding the allocation of capacitors for different number of candidate buses and for different capacitor sizes.

REFERENCES

[1]. Neagle N.M. and Samson D.R., “Loss Reduction from Capacitors Installed on Primary Feeders”, *AIEE Transactions,* Vo1.75, pt. III, 1956, pp. 950-959.

[2]. Cook R.F., “Analysis of Capacitor Application as Affected by load Cycle”, AIEE Transactions, Vo1.78, pt. III, Oct. 1959, pp. 950-957.

[3]. Cook R.F., “Optimizing the Application of Shunt Capacitors for Reactive-Volt-Ampere Control and Loss Reduction”, *AIEE Transactions (Power Apparatus and Systems),* Aug 1961, pp. 430-444.

[4]. Cook R.F., “Calculating Loss Reduction Afforded by Shunt Capacitor Application”, IEEE Tran. PAS, Dec. 1964, pp. 1227-1 230.

[5]. Chang N.E., “Optimum Allocation of Shunt Capacitors and Voltage Regulators on Primary Feeders”, presented at IEEE Winter Power Meeting, New York, N.Y., Jan. 29 - Feb. 3, 1967.

[6]. Chang N.E., “Determination of Primary-Feeder, Losses”, IEEE Tran. PAS, Dec. 1968, pp. 1991-1994.

[7]. Duran H., “Optimum number, location and size of shunt capacitors in radial distribution feeders: A dynamic programming approach”. IEEE Transactions on Power Apparatus and Systems. 1968. 87(9): 1769-1774.

[8]. Grainger J. J. and Lee S. H., “Optimum size and location of shunt capacitors for reduction of losses on distribution feeders,” *IEEE Trans. Power Apparatus and Systems*, vol. PAS-100, no. 3, pp. 1105–1118, Mar. 1981.

[9]. Salama M.M.A., Chikhani A.Y., Hackam R., “Control of Reactive Power in Distribution Systems with an End-load and Fixed Load Condition”, IEEE Tran. PAS, Oct. 1985, pp. 2779-2788.

[10]. Baran M.E. and Wu F.F., “Optimal capacitor placement on radial distribution systems,” IEEE Transactions on Power Delivery, 1989.vol.4, no-1, pp. 725-734. BARAN, M.E., and WU, F.F.: ‘Network reconfiguration in distribution systems for loss reduction and load balancing’, *IEEE Trans.,* 1989, PD-4, (2), pp. 1401-1407.