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OPTIMAL CAPACITORS PLACEMENT IN DISTRIBUTION NETWORKS USING GENETIC ALGORITHM: A DIMENSION REDUCING APPROACH

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ABSTRACT

A distribution system is an interface between the bulk power system and the consumers. Among these systems, radial distributions system is popular because of low cost and simple design. In distribution systems, the voltages at buses reduces when moved away from the substation, also the losses are high. The reason for decrease in voltage and high losses is the insufficient amount of reactive power, which can be provided by the shunt capacitors. But the placement of the capacitor with appropriate size is always a challenge. Thus the optimal capacitor placement problem is to determine the location and size of capacitors to be placed in distribution networks in an efficient way to reduce the power losses and improve the voltage profile of the system. For this purpose, in this paper, two stage methodologies are used. In first stage, the load flow of pre-compensated distribution system is carried out using 'dimension reducing distribution load flow algorithm (DRDLFA)'. On the basis of this load flow the potential locations of compensation are computed. In the second stage, Genetic Algorithm (GA) technique is used to determine the optimal location and size of the capacitors such that the cost of the energy loss and capacitor cost to be a minimum. The above method is tested on IEEE 69 bus system and compared with other methods in the literature.

Keywords: *Dimension Reducing Distribution Load Flow Algorithm (DRDLFA)' Genetic Algorithm, Electrical Distribution Network, Optimal Capacitors Placement.*

1. INTRODUCTION

Capacitors are generally used for reactive power compensation in distribution systems. The purpose of capacitors is to minimize the power and energy losses and to maintain better voltage regulation for load buses and to improve system security. The amount of compensation provided with the capacitors that are placed in the distribution network depends upon the location, size and type of the capacitors placed in the system [1]. A lot of research has been made on the location of capacitors in the recent past [2], [3]. All the approaches differ from each other by the way of their problem formulation and the problem solution method employed. Some of the early works could not take into account of capacitor cost. In some approaches the objective function considered was for control of voltage. In some of the techniques, only fixed capacitors are adopted and load changes which are very vital in capacitor location was not considered. Other techniques have considered load changes only in three different levels. A few proposals were schemes for determining the optimal design and control of switched capacitors with non-simultaneous switching [4]. It is also very important to consider the problem solution methods employed to solve the capacitor placement problem, such as gradient search optimization, local variation method, optimization of equal area

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criteria method for fixed capacitors and dynamic programs [4], [5], [6]. Although these techniques have solved the problem, most of early works used analytical methods with some kind of heuristics. In doing so, the problem formulation was oversimplified with certain assumptions, which was lacking generality. There is also a problem of local minimal in some of these methods. Furthermore, since the capacitor banks are non continuous variables, taking them as continuous compensation, by some authors, can cause very high inaccuracy with the obtained results. Genetic Algorithms (GA) has been applied in various power system problems [7],[8]. GA is a very well known and capable method for optimization problems. It is capable of determining near global solution with lesser computational burden. In this respect, it is very suitable to solve the capacitor placement or location problem.

IEEE 69 bus distribution system is considered for case study. The test system is a 12.66 KV, 10 KVA, 69-bus radial distribution feeder consisting of one main branch and seven laterals containing different number of load buses. Buses 1 to 27 lie on the main branch. Bus #1 represents the substation feeding the distribution system.

2. DISTRIBUTION POWER FLOW

The distribution power flow is different from the transmission power flow due to the radial structures and high R/X ratio of transmission line. Because of this conventional transmission power flow algorithms does not converge for distribution systems. In this project the complex power flow algorithm [14] is implemented to determine the transmission losses and the voltage profile. The distribution power flow algorithm is the heart of optimal capacitor placement.

3. GENETIC ALGORITHM

The theoretical foundations for genetic algorithms were first described by John Holland [10] and then presented tutorially by David Goldberg [1]. Genetic algorithms are search algorithms based on the process of biological evolution.

GA uses a “Chromosomal” representation which requires the solution to be coded as a finite length string. The basic structure of GA used in this paper is as follows: First, a randomly constructed initial population of solutions is generated. Within this population new solutions are obtained during the genetic cycle using crossover and mutation operators. Crossover produces a new solution providing the inheritance of some basic properties of the parents in the new solution. Mutation results in slight changes in the new solution structure and maintains diversity of solutions. Each new solution is decoded and its objective function “fitness” values are estimated. These values are the measures of quality which is used to compare different solutions. The comparison is done by a selection procedure that decides which solution is better: the newly obtained one or the worst solution in the population. The better solution joins the population and the worse one is discarded. If the population contains equivalent solutions following selection, redundancies are eliminated and the population size decreases. After several repetitions of the crossover-selection sequence, new randomly constructed solutions are generated to refill the shrunken population, and a new genetic cycle is started. The iterative loop is executed until the termination condition is satisfied. The termination condition is met when either the process has converged or the specified maximum number of generations has been reached. The degree of change in the quality of the individuals within the population over successive generations can serve as a measure for convergence. Before the algorithm finally terminates, the best individual of the last generation is returned as the solution of the optimization. Fig. 1 shows the flow chart of a typical genetic algorithm.

3.1 Fitness Evaluation

The fitness evaluation is provided by the objective functions. A fitness function design for optimal allocation of static shunt VAR for distribution network is described next.

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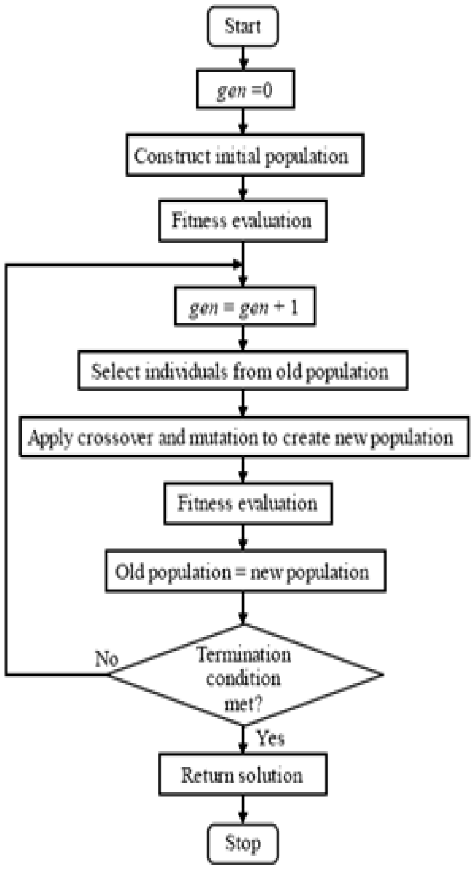

Fig. 1: Genetic Algorithm Flow Chart

3.2 Control Parameters

The values of the control parameters influence the performance of genetic algorithms. For example, the number of generations required by the optimization depends on the values of the control parameters. The following quantities are referred to as control parameters:

- The population size *np*
- The chromosome length *lc*
- The crossover probability *Pc*
- The mutation probability *Pm*

Test runs of genetic algorithms have indicated that a high crossover rate and a low mutation rate are normally required to obtain good results. Typical values for *Pc* lie within the range of [0.6, 0.95] and typical values for *Pm* lie within the range of [0.01, 0.1]. High *Pc* values which are close to the upper limit force convergence, while high mutation rates promote diversity among the population.

The population size must be large enough to supply sufficient genetic material to work upon at present. The population size should depend on the chromosome length. The larger the chromosome length, larger is the solution space covered, and therefore, the larger the population size should be.
The given proposals for the settings of the parameters can only serve as guidelines. Appropriate settings may vary significantly for different kinds of problems for which the genetic algorithm is used. It is therefore advisable to run several tests with different settings and compare the performance of the genetic algorithm.

4. GA IMPLEMENTATION

The representation and implementation of the GA for the optimal capacitor banks location and size is proposed in this section. Each capacitor is represented by a string C of a number of binary bits. The first bit represents the state of the capacitor (1 for ON, 0 for OFF); Remaining bits represent the capacity level of the capacitor. As an example, the string C= [10000] represents a capacitor working at minimum MVAR; C= [00000] represents a capacitor which is not operating (or not existing); the string C= [11111] represents a capacitor working at full capacity. In order to represent the type of each capacitor, a new string T is defined as consisting of the concatenation of 2 strings C (thus T contains 10 bits). Therefore, let T=C1C2, where C1represents type A of capacitor. For example, at a given node the string T=[1111100000] represents the situation where only one capacitor should be place on that node, and this capacitor should be a type A working at full capacity. It is assumed, based on this representation, that a maximum of one capacitor of each type can be placed on any given node. As each string T represents the capacitor (and size) to be placed at a given node, the representation of the general location the capacitor over the network is straightforward. A string S is defined as consisting of the concatenations of 20 T strings. This sequence S contains 20(nodes) x 10(bits per node) = 200 bits. As any string S describes a valid placement and size configuration of capacitors over the network, therefore the string S is the chromosome used within the Ga. The implementation of GA consists of a number of individuals (each one a different string S). The fitness of each individual is given by the objective function, and it also considers a penalization if the

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voltage or Power Factor (PF) goes outside the allowed range, plus another penalization if the number of capacitors exceeds 10.

The Optimal Capacitor Placement toolbox in ETAP requires an objective function and the encoding techniques of voltage regulation and power factor correction. The methodology of the capacitor design in distribution system is as follows:

a. Input the distribution system branch impedance values and the bus real and reactive power data.

b. Run the power flow calculation without any capacitor in different load levels.

c. Determine the losses without capacitor compensation.

d. Form a random initial chromosomes population (number of chromosomes population is usually set to 2-2.5 times the number of nodes in the network).

e. For each chromosomes population set in the previous stage, place one capacitor in the distribution system and repeat the load flow calculation. Then, determine the losses for each chromosome. If any of the load flow results is out of the specified ranges of power factor or voltage constraints then the proposed solution is not considered as a candidate solution.

f. For each chromosomes population set in the previous stage, place one capacitor in the distribution system and repeat the load flow calculation. Then, determine the losses for each chromosome. If any of the load flow results is out of the specified ranges of power factor or voltage constraints then the proposed solution is not considered as a candidate solution.

g. If chromosomes population has converged, then print the capacitor results for each bus. Otherwise go to the next stage.

h. Select the new population based on reproduction mechanism.

i. Apply the crossover and mutation on the new population.

j. Define a new population and go to step 5.

The objective of optimal capacitor placement is to

minimize the cost of the system.

The cost includes four parts:

- Fixed capacitor installation cost
- Capacitor purchase cost
- Capacitor bank operating cost (maintenance and depreciation)
- Cost of real power losses

The cost can be represented mathematically as:

$$S = K_T \Delta P + K_E \Delta E - K_C Q_C \qquad (1)$$

Where S is the savings in \$/year,
K_T is a factor to convert peak power losses to dollars,
K_E is a factor to convert energy losses to dollars
K_C Cost of Capacitor/KVAR
ΔP is the reduction in peak power losses,
ΔE is the reduction in energy losses, and
Qc is the size of the capacitor in kVAr
Qc Total Capacitor bank size in kVar

The main constraints for capacitor placement have to comply with the load flow constraints. In addition, all voltage magnitudes of load (PQ) buses should be within the lower and upper limits. Power Factor (PF) should be greater than the minimum. There may be a maximum power factor limit.

- *Vmin<= V<=Vmax and PFmin<=PF<=PFmax* for all PQ buses.

The GA algorithm can handle large low voltage (LV) distribution networks and medium voltage (MV) networks. In case of significant variations in daily load curve, fixed and switched capacitor banks are considered, the GA codification and cost objective function have to be adapted.

5. CASE STUDY AND RESULTS

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Prior to capacitor installation, a load flow program based on complex power flow method is run to obtain the present system conditions. System conditions are shown in Table 1. The table specifies the minimum per-unit bus voltage, maximum per-unit bus voltage, real power losses in KW and the cost of energy losses during all load levels. It is clear from the table that the minimum bus voltages during the simulation are less than the pre-specified minimum allowable bus voltage. Therefore, capacitors shall be installed to provide the required voltage correction and to reduce the overall energy losses in the system.

The proposed solution methodologies have been implemented in MATLAB 7.4. The solution algorithms based on GA, algorithm and tested on IEEE 69 Bus System in Fig.2 which has been designed to find the optimal solution for this problem. In this case, only fixed type capacitors are installed in the system and all the loads are assumed to be linear. Computer programs have been written for these algorithms based on the respective procedures highlighted earlier. The parameters are defined as shown below:

P_s : Population Size = 100

M_g : Mutation rate = 0.01

C_r : Crossover rate = 0.8

G : No. of generations before algorithm is terminated = 500

Again, the parameters are set empirically by trial and error procedure. Parameters that have resulted in the best solution were chosen. A genetic algorithm designed based on steady-state replacement usually converges faster than the one designed based on generational replacement. Due to this, steady-state replacement method requires less number of generations before it converges to the optimal solution.

With these parameters, the optimal solution is obtained. A 300 KVAR fixed capacitor is to be installed at bus #18, a 600 KVAR is to be installed at #60 and a 600 KVAR fixed capacitor is to be installed at bus #64.Table 1 shows the system conditions when capacitor placement is implemented as per the optimal solution. As can be seen from the table, the required voltage regulation at the medium and the peak load levels has been attained. In addition, energy loss reductions at different load levels have been achieved. The cost of optimal solution obtained here is better than the one obtained by others.

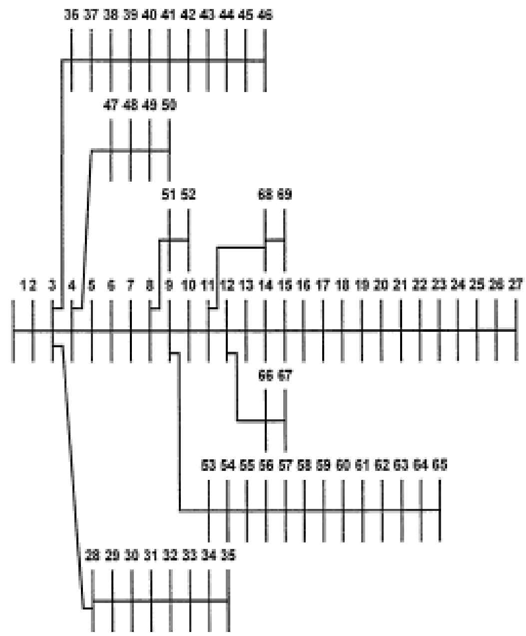

Fig. 2: IEEE 69 bus system

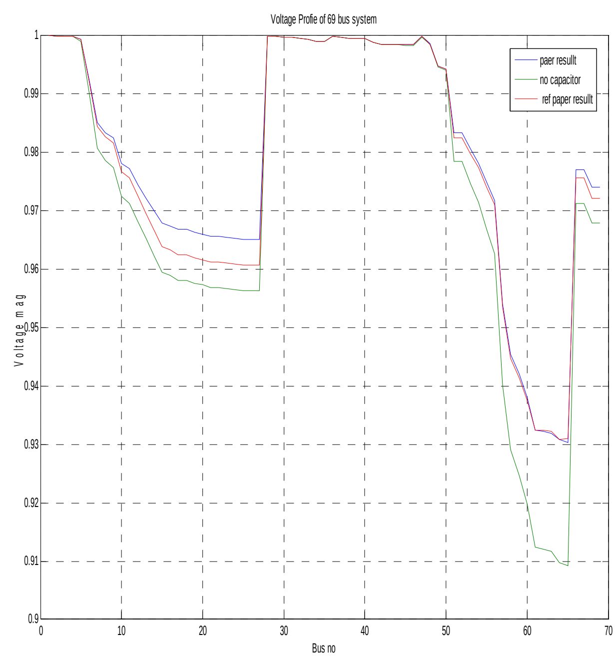

Fig. 3: Comparison of Voltage profiles for IEEE 69 bus system

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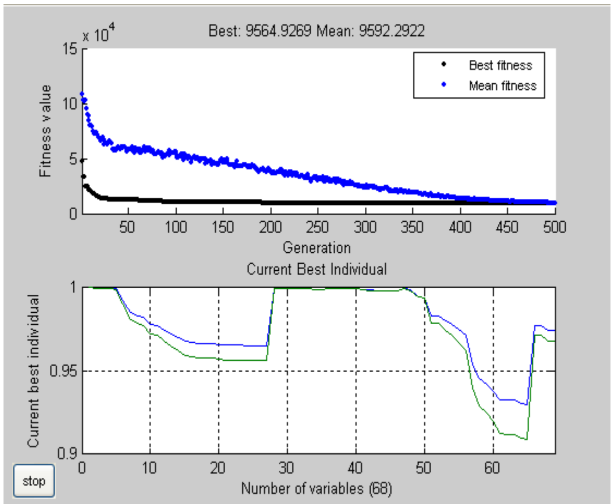

Fig. 4: Genetic Algorithm Tool Output for the IEEE 69 bus system

6. CONCLUSION

This study presents GA method for Multi-objective programming to solve the IEEE 69 Bus Problem regarding Capacitor placement in the distribution system. The determined optimal location has reduced the system energy losses and consequently increased the net savings even though there is some increase in total capacity of the capacitors to be placed.

7. FUTURE WORK

The advanced tools like Differential Evaluation (DE) can be applied to same multi- objective problem of IEEE 69 Bus system for faster execution and the better results.

Table 1: System conditions without and with capacitors placement for IEEE 69 Bus System

Case	Before Capacitor	After Capacitor (GA)	After Capacitor (Fuzzy GA) [1]
Minimum bus voltage(pu)	0.9092	0.9303	0.9309
Maximum bus voltage(pu)	1	1	1
Real Power Loss(KW)	225.0044	146.02	152.0541
Optimal Location of Capacitor & value Bus number-KVAR	-	#18-300KVAR #60-600 KVAR #64-600 KVAR	#61 -1029 KVAR #64-207 KVAR
Total KVAR placed	-	1500 KVAR	1236 KVAR
Savings due to Reduction in Power loss ($/Year)	-	53,361.91	49,322.83
Total cost of the Capacitors ($/Year)	-	7500	6180
Net Savings ($/Year)	-	45,861.91	43,105.27

From Table I it can be observed that the results obtained using GA are compared and found to be better than the results obtained in the work under ref. [1] regarding net savings by placing the capacitors optimally with achievement of better Voltage Profile and better Voltage Regulation. The optimal placement and KVAR rating of shunt capacitor banks had been best determined for the studied distribution network using the proposed 'dimension reducing distribution load flow algorithm (DRDLFA)'and GENETIC ALGORITHM.

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