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Combination of Optimal Conductor Selection and Capacitor Placement in Radial Distribution Systems for Productivity Improvement Using Genetic Algorithm

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ABSTRACT: In This paper presents an approach for optimal placement and sizing of fixed capacitor banks and also optimal conductor selection in radial distribution networks for the purpose of economic minimization of loss and enhancement of voltage profile. The objective function includes the cost of power losses, capacitors and conductors. Constraints include voltage limit, maximum permissible carrying current of conductors, size of available capacitors and type of conductors. The optimization problem is solved by the genetic algorithm method and the size and the type of the capacitors and conductors is determined. By applying the proposed method, the economic costs and power losses are reduced to a considerable degree while enhancing the voltage profile. To demonstrate the validity of the proposed algorithm, computer simulations are carried out on actual power network of Kerman Province, Iran and the simulation results are presented and discussed.
Keywords: genetic algorithm, radial distribution systems, Loss Reduction, Capacitor placement.

INTRODUCTION

The main objective of an electrical distribution system (EDS) is providing a reliable and cost-effective service to consumers with considering power quality within standard ranges. Thus, it is necessary to properly plan the EDS and thus evaluate several aspects such as, new equipment installation cost, equipment utilization rate, and quality of service, reliability of the distribution system and loss minimization, considering an increase of system loads, and newly installed loads for the planning horizon [1]. The loss minimization in distribution systems has assumed greater significance recently since the trend towards distribution automation will require the most efficient operating scenario for economic viability variations. The power losses in distribution systems correspond to about 78% of total losses in electric power systems (M. Mozaffari Legha, 2012).

The advantages with the addition of shunt capacitors banks are to improve the power factor, feeder voltage profile, Power loss reduction and increases available capacity of feeders. Therefore it is important to find optimal location and sizes of capacitors in the system to achieve the above mentioned objectives. Since, the optimal capacitor placement is a complicated combinatorial optimization problem, many different optimization techniques and algorithms have been proposed in the past. (Baghzouz and Ertem, 1990) proposed the concept that the size of capacitor banks was considered as a continuous variable. H. Ng et al (2000) proposed the capacitor placement problem by using fuzzy approximate reasoning. (Ji Pyng Chiou et al, 2006) proposed the variable scale hybrid differential evolution algorithm for the capacitor placement in distribution system. However, considered only the losses in the lines and the quantification were defined for the line losses only.

There are several parameters to be taken into account to model the conductor size selection (CSS) problems such as: conductor's economic life, discount rate, cable and installation costs and type of circuit (overhead or underground). Dynamic programming approach was utilized to solve the CSS problem in [3]. They presents models to represent feeder cost, energy loss and voltage regulation as a function of a conductor cross-section. In (Mahdi Mozaffari Legha et al, 2013), the conductor size selection performed with consideration of financial and engineering criteria in the feeder. In (S. Sivanagaraju et al, 2002) and [6] the CSS problem is solve using heuristic methods. Reference (S. Sivanagaraju et al, 2002) uses a selection phase by means of economic criteria, followed by a technical selection using a sensitivity index that seeks to ensure a feasible operation of the EDS, whereas presents a heuristic method using a novel sensitivity index for the reactive power injections. The heuristic methods are robust, easily applied; however, they normally converge to a local optimum solution. In (Su. Ching et al, 2001), a mixed integer linear model for the problem of conductor selection size in radial distribution systems is presented.

In this paper, a combination of both capacitor placement and conductor selection methods is developed to reduce the loss of a distribution network. In this method the objective function of capacitor placement and conductor selection is to reduce the power loss within minimum costs and enhancing the voltage profile. The constraints are voltage limits, allowable current energy capacity of selected conductors. To solve this optimization problem, Genetic Algorithm (GA) method is used. The proposed method is tested on a 69-bus radial system with 3-type of available conductors and 69 different sizes of capacitors. The results show that proposed objective function minimizes the loss of the system by considering all of the constraints and incorporating capacitors and conductor's selection.

Problem Formulations

POWER FLOW ANALYSIS METHOD

Power flow evaluation includes the calculation of bus voltages and line flows of a network. A single-phase representation is adequate because power systems are usually balanced. Associated with each bus, there are four quantities to be determined or specified: the real and reactive powers, the voltage magnitude and phase angle. Fig 1 shows an m-bus radial distribution system wherein bus i has a load and a shunt capacitor (Su. Ching Tzong et al, 2001).

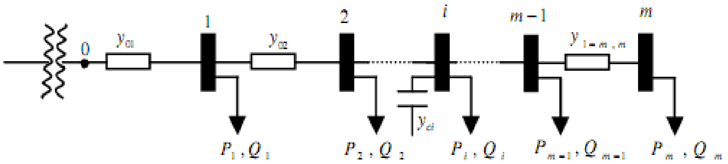

Figure1. Single line diagram of a radial distribution feeder

Notation:

$Y_{i,i+1}=1/(R_{i,i+1}+jX_{i,i+1})$; Admittance of the line section between buses i and i+1,
$R_{i,i+1}$, $X_{i,i+1}$; Resistance and reactance of the line connecting buses i and i+1,
P_i , Q_i ; Load active and reactive powers at bus i. At bus i, we have

$$P_i-Q_i=V_i^{*}I_i \qquad (1)$$

Where I_i is positive when it flows into the system and m is the number of buses in the feeder. The bus voltages and line losses can be solved by the Gauss-Seidel iterative method employing the following formula (Mahdi Mozaffari Legha et al, 2013):

$$V_i^{(k+1)}=\frac{1}{Y_{ij}}\left(\frac{P_i-jQ_i}{V_i^{*(k)}}-\sum_{\substack{n=1\\ n\neq m}}^{m} Y_{in}V_n\right) \quad i=1,\ldots.,m \quad (2)$$

At the power frequency, the power loss in the line section between buses i and i+1 may then be computed by:

$$P_{(i,i+1)}=R_{i,i+1}.\left[\left|V_{i+1}-V_i\right|.\left|Y_{i,i+1}\right|\right]^2 \qquad (3)$$

The purpose of placing compensating capacitors and optimal conductors is to obtain the lower the total power loss and bring the bus voltages within their specified while minimizing the total cost. The total power loss is given by Eq. (4) (Y. Baghzouz and S. Ertem, 1990).

$$P_i=\sum_{i=0}^{m-1}P_{(i,i+1)} \qquad (4)$$

Formulation

Capacitor Placement

Considering the practical capacitors, there exists a finite number of standard sizes which are integer multiples of the smallest size Q_0^c. Besides, the cost per Kvar varies from one size to another. In general, capacitors of larger size have lower unit prices. The available capacitor size is usually limited to

$$Q_c^{max}=LQ_c \qquad (5)$$

Where L is an integer. Therefore, for each installation location, there are L capacitor sizes [$1Q_c$, $2Q_c$, $3Q_c$, …, LQ_c] available. Given the annual installation cost for each compensated bus, the total cost due to capacitor placement and power loss change is written as

$$f1= K_p \times P_T^{LOSS}+\sum_i^c\left(K_{cf}+ K_i^c Q_i^c\right) \qquad (6)$$

Where n is number of candidate locations for capacitor placement, Kp is the equivalent annual cost per unit of power loss in $/(Kw-year); K_{cf} is the fixed cost for the capacitor placement. Constant K_i^c is the annual capacitor installation cost, and, i = 1, 2, ..., n are the indices of the buses selected for compensation. The bus reactive compensation power is limited to

$$Q_i^c \le \sum_{i=1}^n Q_{Li} \qquad (7)$$

Where $1Q_c$ and LQ_c are the reactive power compensated at bus i and the reactive load power at bus i, respectively.

Conductor Size Selection

Considering the objective is selection of conductor's size from the available size in each branch of the system which minimizes the sum of depreciation on capital investment and cost of energy losses while maintaining the voltages at different buses within the limits. In this case, the objective function with conductor c in branch i is written as

$$f2= w1*CE(i, c)+ w2*DCI\ (i, c) \qquad (8)$$

Where CE (i,c) is the Cost of Energy Losses and DCI (i,c) is Depreciation on Capital Investment of c conductor type of i-th branch, n is buss number, i is the branch number and w is the weighting factor[13]. The annual cost of loss in branch i with conductor type k is,

$$CE(i,c)=P\ L(i, c)*\ \{KP+ KE*\delta*T\} \qquad (9)$$

Where K_p is annual demand cost due to Power Loss ($/kW), K_E is annual cost due to Energy Loss ($/kWh), δ is Loss factor, ($PL_{(i,c)}$) is real Power Loss of branch i under peak load conditions with conductor type c and T is the time period in hours (8760 hours). Depreciation on capital investment is given as

$$DCI(i,c)= \gamma*A(c)*\{C_c+L_i\} \qquad (10)$$

Where γ is Interest and depreciation factor, C_c is cost of type conductor ($/km), ($A_c$) is cross-sectional area of c type conductor and L_i is length of branch i (km).

Objective Function

In each optimization problem, objective function should be defined. Eq. (11) illustrates the proposed objective function in this paper. This objective function aims at minimizing the total annual cost due to capacitor placement, conductor selection and power losses with constraints that include limits on voltage Eq. (13), maximum permissible carrying current of conductors Eq. (14), size of installed capacitors and type of selected conductors. These constraints are added as penalty functions to the objective function.

$$F= f1+f2 \qquad (11)$$

$$V_{min}\le|V_i| \le V_{max} \qquad (12)$$

$$I_{(l)} \le I_{max(l)} \qquad (13)$$

Where:

$V_{min,}$ V_{max}: minimum and maximum permissible bus voltage.

I_{max}^l: Maximum permissible carrying current of installed conductors in L^{th} section.

Genetic Algorithm

GA's are generalized search algorithms based on the mechanics of natural genetics [14]. GA maintains a population of individuals that represent the candidate solutions to the given problem. Each individual in the population is evaluated to give some measure to its fitness to the problem from the objective function. GA's combine solution evaluation with stochastic operators namely, selection, crossover and mutation to obtain optimality. The flow chart of proposed GA is depicted in Fig. 2.

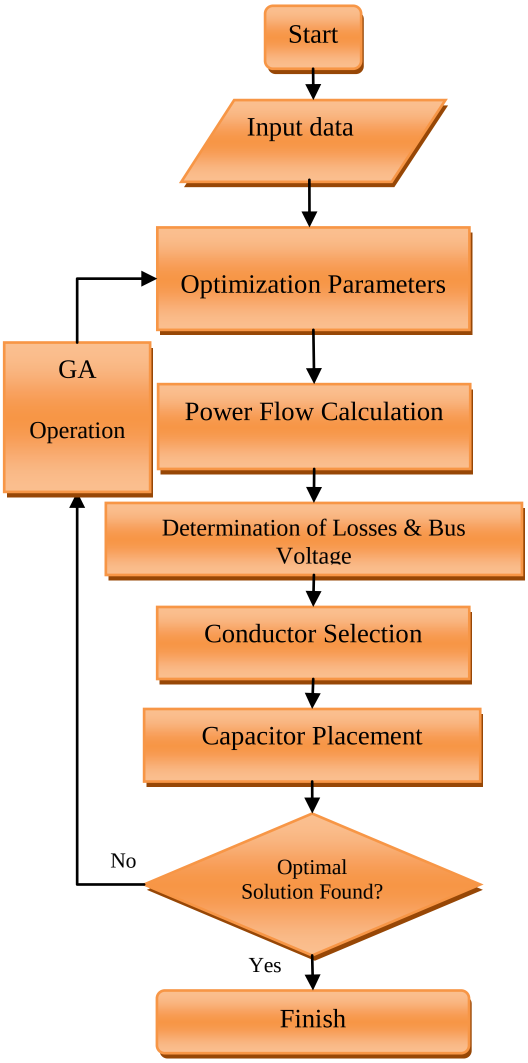

Figure2. Flowchart of the proposed method

TESTS AND RESULTS

Simulations are carried out on 69-bus radial distribution network using ICA approach in order to show the accuracy as well as the efficiency of the proposed solution technique. The single line diagram for proposed radial distribution systems is shown in Fig. 3. The base values of the system are taken as 20kV and 20MVA. The details of the distribution conductors are given in table 1. The system consists of 60 distribution transformers with various ratings. The details of the distribution transformers are given in table 2. The total connected load on the system is 2550 KVA and the peak demand for the year is 2120 KVA at a PF of 0.8 lag (Mahdi Mozaffari Legha, 2011).

Table 1. Conductor properties

Type	R [Ω/km]	X [Ω/km]	Cmax [A]	A [mm2]
Hyena	0.1576	0.2277	550	126
Dog	0.2712	0.2464	440	120
Mink	0.4545	0.2664	315	70

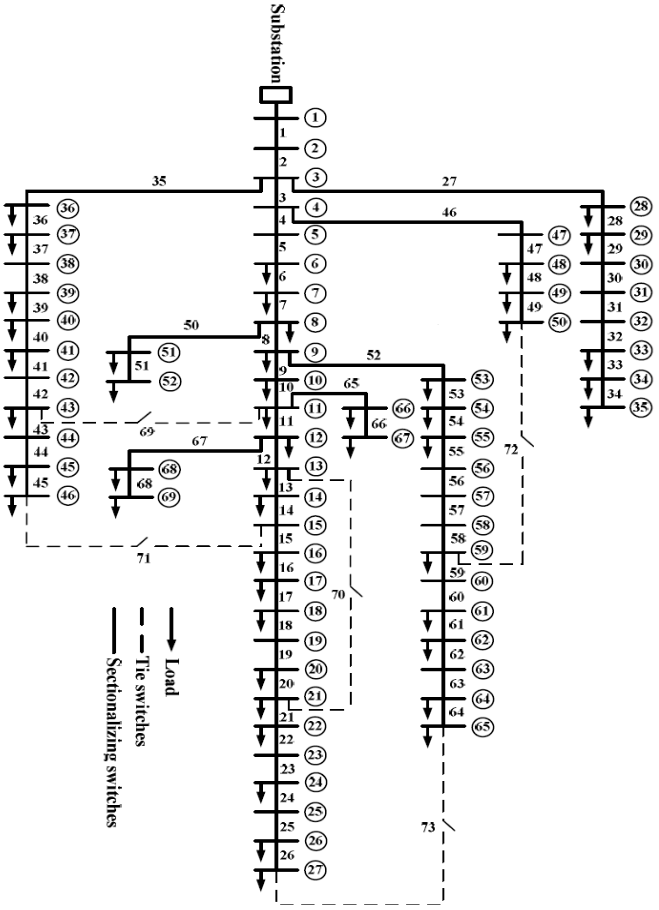

Figure3. Single line diagram for a 69-bus radial distribution system

The single line diagram for proposed radial distribution systems is shown in Fig. 3. The properties of the new conductors used in the analysis of this system are given in Table 1.The initial data for load flow solution based on the Backward-Forward sweep are selected as: S_b=100MVA , V_b=20KV, $\varepsilon=10^{-5}$. The other parameters used in computation process are: KP = 1.04 ($/kW); KE = 0.012 ($/kWh).

Table 2. Details of transformers in the system

Rating [KVA]	50	100	250
Number	5	9	6
No load losses [watts]	150	250	480
Impedance [%]	4.5	4.5	4.5

The parameters used in genetic algorithm (GA) are: Number of Decate is 33; Population size is 100; Number of Empire 10; Revolution rate is 0.1. Also, loss factor, which represents adequately the energy losses for the load level in terms of the maximum power losses are selected. The results of conductor selection are shown in Table 3.

Table 3. Conductor selection results

Conductor Design Method	Type	Branch Number
Conventional	Hyena	From 1 to 26
	Dog	Rest of 68 branches
	Mink	----
GA Based	Hyena	20,21,28,38,43
	Dog	---
	Mink	Rest of 68 branches

Initially, a load flow was run for the case study in both fundamental frequency and frequencies without installation of capacitor. Table 5 depicts the results of power flow for determination voltage and harmonic before installation of capacitor. Table 4 depicts the locations and capacity of capacitor banks using artificial bee colony algorithm. As it is clear, all the obtained values confines with all the considered constraints. The obtained penetration lever is %18.64, which is less than the assumed allowable value.

Table 4. Optimal place and capacity of capacitor banks

Location [#bus]	Capacity [Mvar]
2	0.1
6	0.025
7	0.1
13	0.35
15	0.15

The voltage profile and Power loss in the system after GA implementation is compared with Conventional conductor design and capacitor placement depicted in Fig. 4 and Fig. 5. It can be seen that the voltage profile achieved by GA optimization algorithms are almost the same while having better improvement in compare with Conventional method. Moreover, a decrease in peak power loss based on peak power loss profiles is illustrated. The costs based on conductor selection and capacitor placement are compared in fig. 6 and Table 5.

The real power loss reductions are 606.7364 kW, which is approximately 3.8% in compare with the Conventional design for GA respectively. Proceedings in a similar manner, the total cost reduction (sum of annual cost of power loss and depreciation on capital investment cost) are obtained 29.15% for GA respectively.

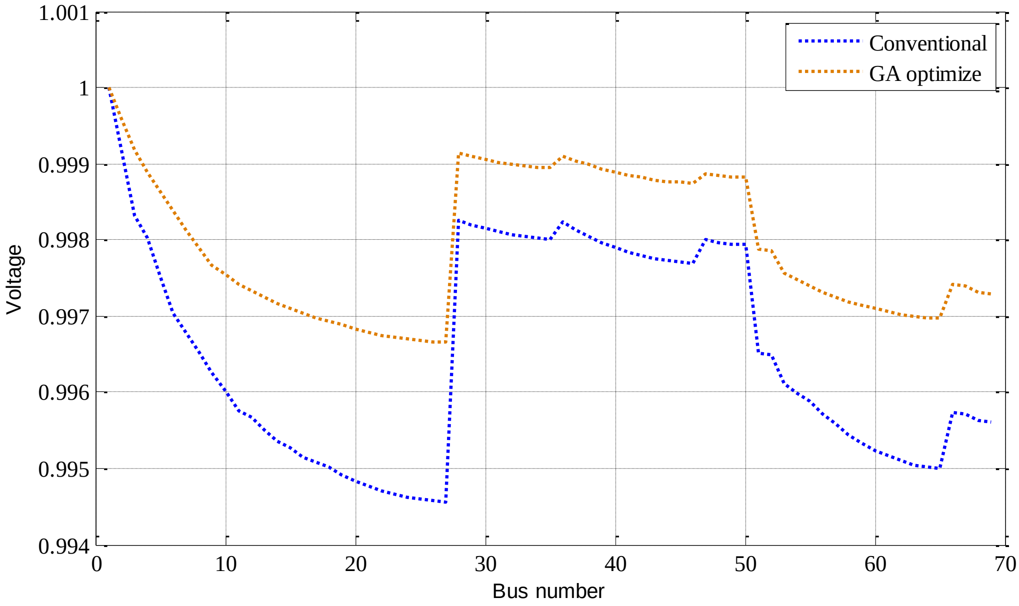

Figure4. Voltage profiles of 69-bus system

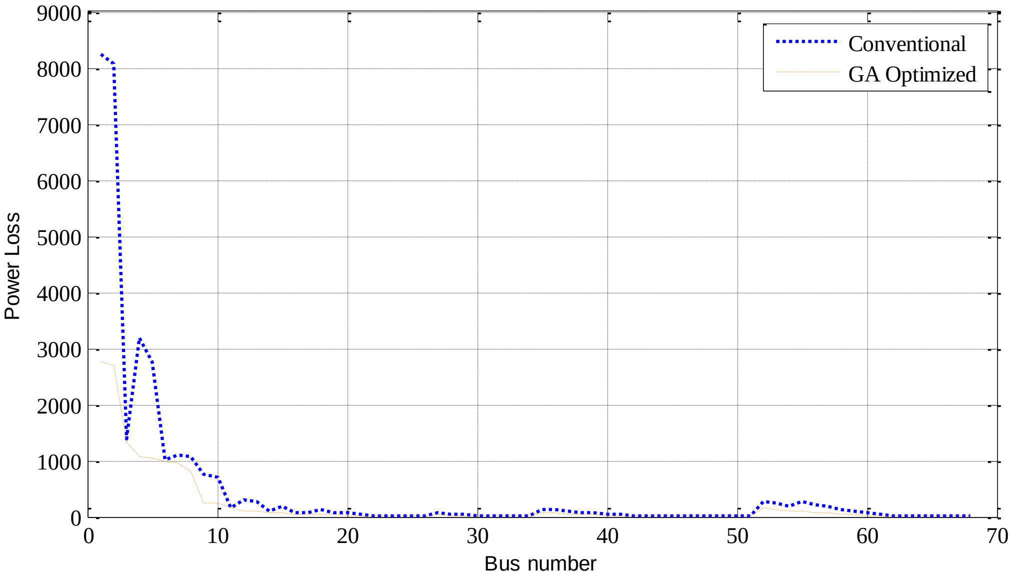

Figure5. Peak power loss profiles in each branch

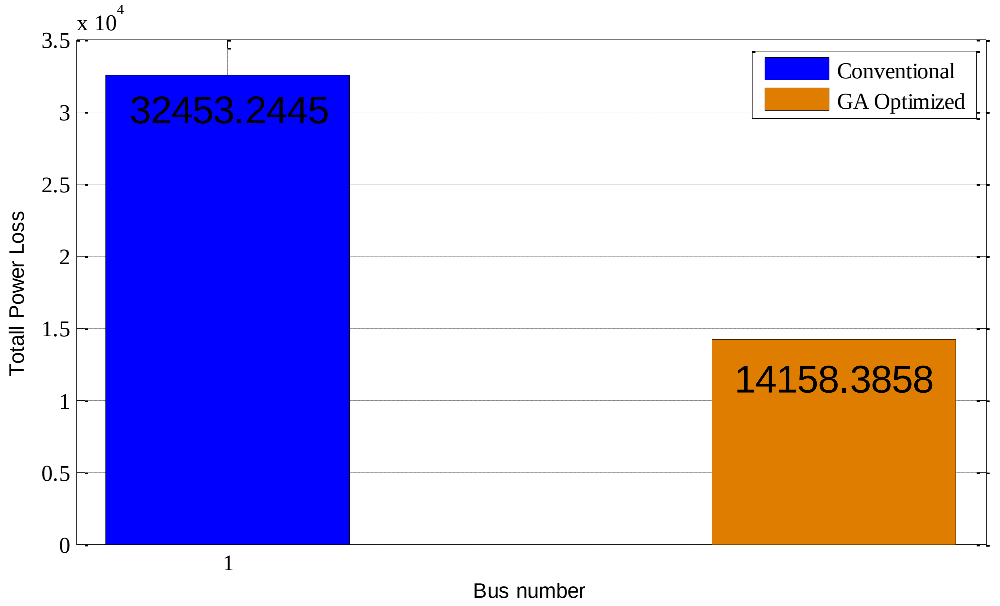

Figure6. Total power loss for different conductor selections method

Table 5. Obtained Loss results

Method	Total Loss [W]
Conventional	32453.24452
GA	9555.23

CONCLUSION

In this paper, the conductor selection has been incorporated in the conventional optimal capacitor placement. By making a new objective function and solving the optimization problem by GA method, the size and place of the capacitors and the conductors has been defined. The method has been applied to a sample radial network and the results show the reduction of total costs in addition to the power loss reduction. According to the results, the bus voltages of the ending buses are in the permissible limits.

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