Optimal Capacitor Placement in Radial Distribution System Using Genetic Algorithm Method

Mahdis Delkhooni[1], Onur Ayan[2], Mikail Purlu[3], Belgin Turkay[4]

[1, 2, 3, 4]Istanbul Technical University, Istanbul, Turkey
[1]delkhooni16@itu.edu.tr, [2]ayanon15@itu.edu.tr, [3]purlu@itu.edu.tr, [4]turkayb@itu.edu.tr

Abstract

Generated Power in power stations are passed through large and complex Transmission and Distribution networks' equipment such as transformers, overhead lines, cables, etc… and reaches at the end users. Due to inductive loads in the power system the unit of electric energy generated by power station does not match with the units distributed to the consumers. Some percentage of the units is lost in the network. The largest part of this loss is "Distribution network losses". Capacitor placement is the most practical method to reduce Losses. It also improves power factor and voltage profiles. Important point in optimal capacitor installation is finding sizes, location and the number of capacitors that have to be placed on the network. This paper presents an approach for optimal placement of capacitor banks in a radial network for the purpose of economic minimization of loss and enhancement of voltage with Genetic Algorithm.

1. Introduction

As distribution systems are growing large, higher system loss and poor voltage accurse so the need for an efficient and effective distribution system become more urgent and important. There are many techniques which is applied in network to reducing losses, such as: changing network topology, changing cross section of conductors, optimal placement of distributed generation in the network etc. Studies have indicated that the power losses in distribution systems correspond to about 70% of total losses in electric power systems and as much as 13% of total power generated is consumed as I^2R losses at the distribution level [3]. The losses produced by reactive currents can be reduced by Reactive power compensation.

If the Distribution system's reactive load can be supplied by a capacitor, placed near to the reactive load center, the full capacity of the generator would be available to serve real power loads and it leads to release additional kVA capacity from distribution apparatus. If a capacitor is connected to the distribution system, either too far ahead of, or too far beyond the system's inductive load center, the system will not gain the full advantage of voltage and loss improvement which afforded by proper capacitor placement One of the techniques which used to achieve the above objectives is using capacitor banks in distribution network.

In order to using capacitor bank in distribution network power factor and system stability are improved also installing capacitors in correct location will improves voltage profile and Increase power transmission capability [4]. The application of installing capacitor banks in distribution feeders-determining size, type (fixed or switched),location-has always been an important research area. The solution techniques can be classified into four categories: Analytical, numerical programming, heuristics and artificial intelligence based.

Capacitor allocation problem is a well-researched topic and all earlier approached differ from each other either in their problem formulation or problem solution methods employed. Some studies proposed the capacitor placement in radial distribution system using Ant Colony Search Algorithm [5]. Other some studies proposed Multi-Level Ant Colony Algorithm for optimal placement of capacitors in distribution systems [6]. Moreover, some researchers proposed Optimal Capacitor Placement in Radial Distribution Systems using Artificial Bee Colony (ABC) Algorithm [7].

This paper is directed towards reducing losses in the distribution system by capacitor placement. It is clear that in large distribution networks it is very difficult to predict the optimum size and location of capacitor, which finally results in reducing losses and improving the overall voltage profile together. In this research the combinatorial problem is solved using genetic algorithm, which is an artificial intelligence technique. The objective function is taken as cost function that is to be minimized. In this paper capacitor size is taken as known discrete values.

The optimum location for these capacitors is determined such that it minimizes the power losses and reduces the overall cost of the distribution system under study. Genetic algorithm is used as an optimization tool for minimizing losses [3, 5, 8].

This paper presents an approach for optimal placement of capacitor banks in a radial network for the purpose of economic minimization of loss and enhancement of voltage with Genetic Algorithm [1, 2]. In addition to these studies, many studies related to optimal capacitor placement were carried out in the literature [9, 14].

2. Problem Formulation

In optimal capacitor placement topic, the problem is finding: location, number and size of capacitor in order to minimize the total power loss of network, peak power losses and cost of capacitor installation while all operational constraints are satisfied at a particular loading level [3].

A. Cost of Total Power Loss:

Per kWh of produced energy, cost is calculated. Sum of network loss in each loading level is calculated for a specific period of time. Loading level is calculated using equation (1) in which:
n: number of loads,

P_i: loss of Ith load, (kW)
T_i: period of time for Ith load, (H)

$$P_{E_{loss}} = \sum_{i=1}^{n} P_i T_i \qquad (1)$$

The cost of loss is calculated with considering the annual cost per unit of power loss (kWh)

$$\text{Cost of Loss} = K_e . P_{E_{loss}} \qquad (2)$$

B. Cost of Capacitors:

Total cost of capacitor insulation

$$C_{fix\_Total} = K_c \sum_{j=1}^{M} C_j \qquad (3)$$

In this equation we have:
K_c: is cost per kvar (Rs/kvar),
C_i: is the value of shunt capacitor at the ith bus in kvar.

C. Penalties:

$$Penalties = P_v \times penalty_V + P_Q \times penalty_Q \qquad (4)$$

So the objective function (obj function) that should be minimized, can be describe as:

$$obj\ function = K_e \sum_{i=0}^{n} P_i T_i + K_c \sum_{j=0}^{M} C_j + P_v \times penalty_v + P_Q \times penalty_Q \qquad (5)$$

also the results should meet the constraints conditions.

D. Constraints:

Constrains were shown below.

$$\forall\ i \in n\ V_{min} \le V_i \le V_{max} \qquad (6)$$

$$\forall\ k \in b\ \ I_k \le I_{kmax} \qquad (7)$$

$$\sum_{i=1}^{M} Q_i \le Q_{max} \qquad (8)$$

3. Computation of Genetic Algorithm

The genetic algorithm is a global search technique for solving optimization problems, which is modeled from nature. Following are the important terminology in connection with the genetic algorithm:

1. Individual - Any possible solution
2. Population - Group of all individuals
3. Search Space - All possible solutions to the problem
4. Chromosome - Blueprint for an individual
5. Trait - Possible aspect of an individual
6. Allele - Possible settings for a trait
7. Locus - The position of a gene on the chromosome
8. Genome - Collection of all chromosomes for an Individual

Three following genetic operators are applied on parents to form children for next generation:

- Reproduction: This operator selects the fittest individuals in the parent population. The children in this operator are called "Elite Children".
- Crossover: causes pairs of individuals in a generation to exchange genetic information with each other. The children produced from this generation are called "Crossover Children"
- Mutation: causes individual genetic representations in a generation to be changed based on some probabilistic rules. The children produced with this method in this case are called "Mutation Children"

The following step are implemented for capacitor allocation algorithm using genetic algorithm.

- The initial population of randomly constructed solutions which is called strings is generated
- The objective function is calculated per each solution in string.
- The results are evaluated with fitness function.
- Within this population new solutions are obtained during genetic cycle using crossover and mutation operator.

As seen in Fig. 1, this process is continued to find optimal results.

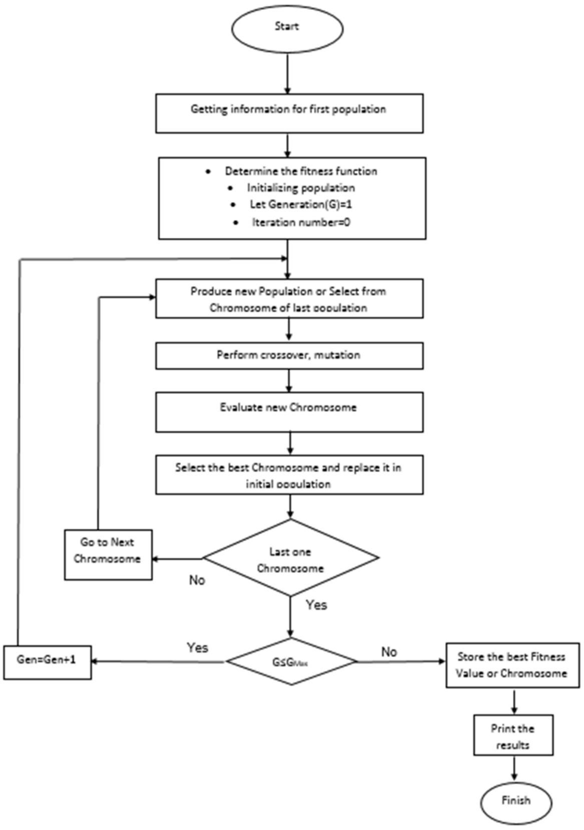


Fig. 1. Flowchart to the proposed method

4. Case Study and Simulation

Our case study is comparing MATLAB analysis results with DIgSILENT results. 34 Bus Standard radial distribution unbalance system was shown in Fig. 2.

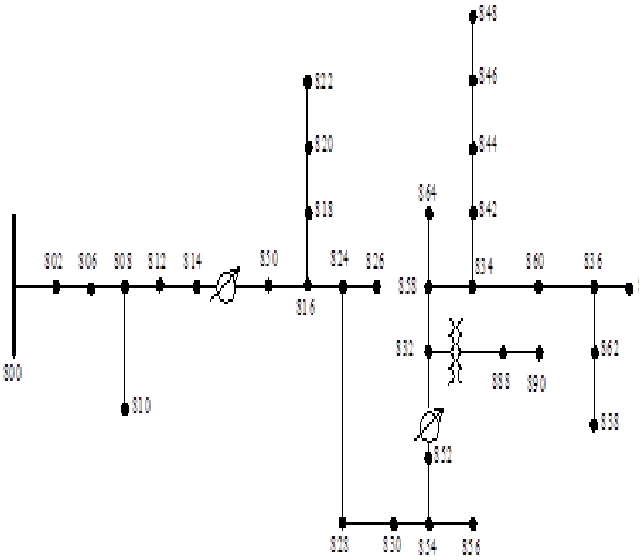


Fig. 2. IEEE 34 node test feeder

As we want to adapt this network to the Turkey distribution network we make some changes as voltage level of IEEE 34 node test feeder from 24.9 to 34.5 kV which is major voltage level of distribution networks in Turkey in the other hand as voltage regulators are not so common in Turkey for sensible results it seems better to omit voltage regulators between bus number 814-850 and also bus number 832-852. The results of these reconfigurations are modeled in DIgSILENT program the schematic of the network was shown in Fig. 3.

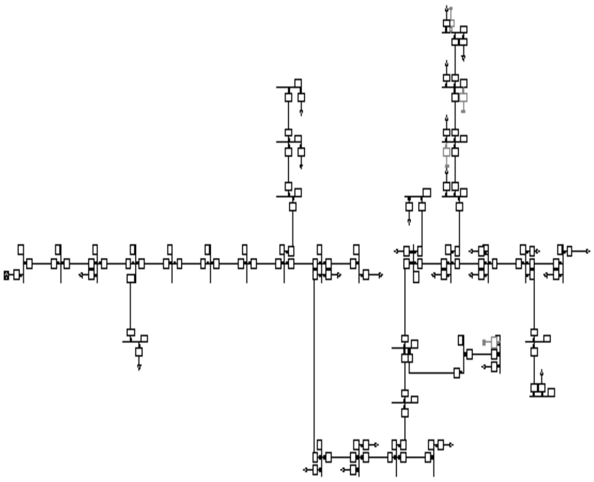


Fig. 3. IEEE 34 node test feeder modeled in DIgSILENT

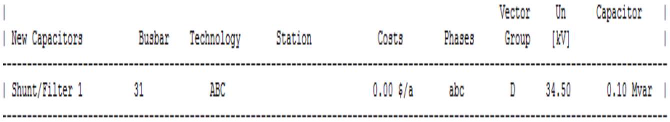
4.1. Analysis with DIgSILENT Program

Without capacitor placement bus no, voltage and angle were shown in Table 1.

Table 1. Bus voltage and magnitude without capacitor

Bus No.	Voltage (pu)	Angle (rad.)
1	1.000	0.000
2	0.999	-0.012
3	0.993	-0.020
4	0.993	-0.165
5	0.986	-0.164
6	0.980	-0.323
7	0.980	-0.440
8	0.980	-0.440
9	0.977	-0.441
10	0.977	-0.442
11	0.977	-0.466
12	0.977	-0.466
13	0.977	-0.450
14	0.977	-0.450
15	0.977	-0.451
16	0.971	-0.463
17	0.971	-0.463
18	0.971	-0.468
19	0.961	-0.453
20	0.961	-0.453
21	0.961	-0.454
22	0.961	-0.458
23	0.960	-0.449
24	0.960	-0.449
25	0.959	-0.444
26	0.959	-0.444
27	0.959	-0.442
28	0.959	-0.442
29	0.959	-0.442
30	0.959	-0.443
31	0.959	-0.443
32	0.959	-0.443
33	0.959	-0.443
34	0.959	-0.443

Then, optimal capacitor placement was used. In this case, using capacitor placement module of DIgSILENT software we will have results shown in Fig. 4. In the result of this analysis as seen below capacitor placement at bus number 31 is suggested by the software. In Table 2, the results of power flow in the network by capacitor at bus number 31 were shown.



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-----------------------------------------------------------------------------------------------
|                                                                  Vector   Un     Capacitor   |
| New Capacitors        Busbar  Technology    Station        Costs   Phases  Group  [kV]        |
-----------------------------------------------------------------------------------------------
| Shunt/Filter 1        31        ABC                     0.00 $/a    abc      D    34.50   0.10 Mvar |
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Fig. 4. Optimal capacitor placement in DIgSILENT

Table 2. Bus voltage and magnitude with capacitor at bus number 31

Bus No.	Voltage (pu)	Angle (rad.)
1	1.00	0.00
2	1.00	-0.02
3	1.00	-0.03
4	0.99	-0.28
5	0.99	-0.28
6	0.99	-0.56
7	0.98	-0.77
8	0.98	-0.77
9	0.98	-0.77
10	0.98	-0.77
11	0.98	-0.79
12	0.98	-0.79
13	0.98	-0.84
14	0.98	-0.84
15	0.98	-0.85
16	0.98	-0.98
17	0.98	-0.99
18	0.98	-1.20
19	0.97	-1.20
20	0.97	-1.20
21	0.97	-1.20
22	0.97	-1.21
23	0.97	-1.23
24	0.97	-1.23
25	0.97	-1.26
26	0.97	-1.26
27	0.97	-1.26
28	0.97	-1.26
29	0.97	-1.26
30	0.97	-1.27
31	0.97	-1.29
32	0.97	-1.29
33	0.97	-1.29
34	0.97	-1.29

4.2. Analysis with Matlab

Firstly, the network was observed without any capacitor connected. Results of voltage per unit for each bus were shown in Fig. 5 as a result of running power flow using Newton-Raphson algorithm.

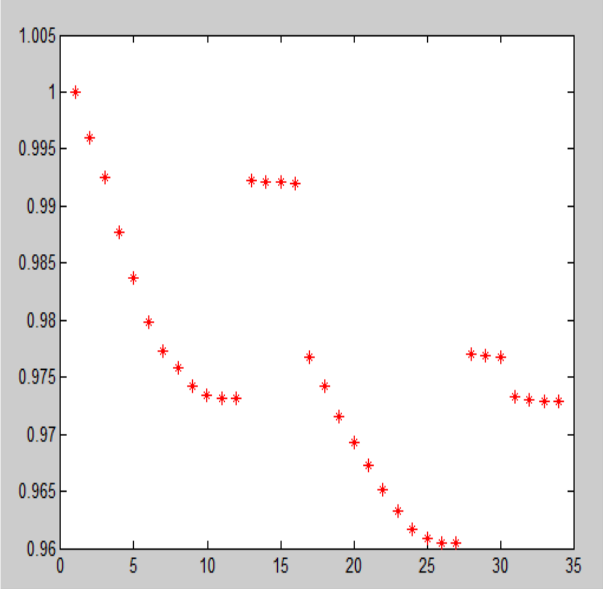

Fig. 5. Bus voltage without capacitor

Then, optimal capacitor placement was used. Using GA in MATLAB by limiting the number of buses which the capacitor can be connected to by five with no other limitation in capacitor placement except economic conditions as discussed in section II. The benefits and different costs of the capacitor placement were calculated through MATLAB. Result of the cost-benefit was also shown in Table.3.

Table 3. Results using Matlab

Candidate buses for capacitor placement and their value (Mvar)	9 (0.0491), 18 (0.0363), 19 (0.1941), 20 (0.1441), 25 (0.3111)
Total installed capacitor (Mvar)	0.7348
Energy losses before capacitor installation (MWh)	299.5731
Cost of energy losses before capacitor installation ($/MWh)	20,970
Energy losses after capacitor installation (MWh)	241.3674
Cost of energy losses after capacitor installation ($/MWh)	16,896
Cost of capacitor installation ($/Mvar/Year)	4041.5
Total benefit ($/year)	32.8719

After connecting the capacitors addressed in the results of GA analysis by running power flow in the new situations blue color dots resulted in the Fig. 6. Red colored dots in the bellow figure are representing the result of power flow without capacitor connected.

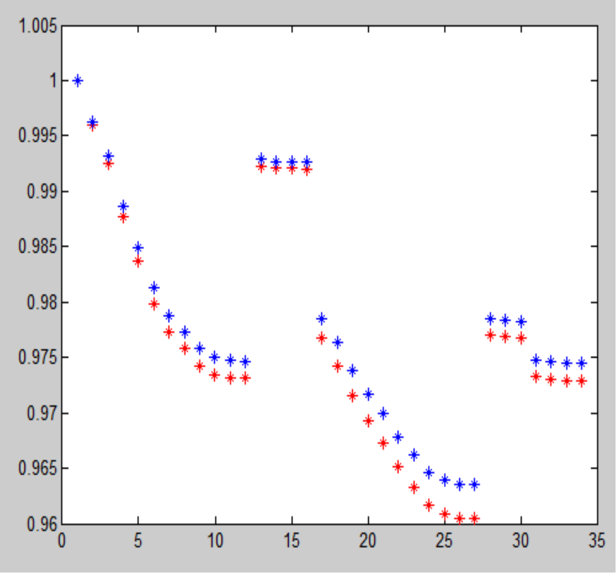

Fig. 6. Bus voltage with capacitor.

5. Conclusions

In this paper, a method for optimal capacitor placement has been proposed. By making a new objective function and solving the optimization problem by GA method, the size and the place of capacitors have been determined. The simulation results show a considerable improvement in active and reactive power losses and voltage profile as well. The GA result for the capacitor placement problem, in compare with the result of analysis software for the same network shows some different as the capacitor value and the number of buses which is suggested to install the capacitor in. In the DIgSILENT software after running the capacitor placement module the result says to install in just one bus whereas in the GA result there are five buses recommended in the output of the algorithm with smaller capacitor banks which in practice will be easier to install and manage. In the future works it is suggested to work on a real network with cost and benefit calculations.

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