International Journal of Applied Electrical and Electronics Engineering
Volume1, Issue 4 , 2025

# GENETIC ALGORITHM-BASED APPROPRIATE CAPACITOR PLACEMENT FOR LOSS REDUCTION IN ELECTRIC TRANSMISSION SYSTEM

Marco, Aurélio . Department of Computer Engineering, Federal University of Fronteira Sul, Chapecó, Brazil

***Research Article***

Date of Submission: 20-04-2025 Date of Acceptance: 15-05-2025 Date of Publication: 19-06-2025

**ABSTRACT**

The intermediate step in the transport of electrical power from the central producing plant to the customers is the electric transmission system. One of the most important goals for any electric utility is to minimize active power losses since it is crucial for improving system characteristics in order to handle higher load requirements and minimize production costs. Because there is not enough reactive power in the network, the voltage at buses decreases and loss rises. The shunt capacitor banks provide the necessary reactive power. The best location for capacitors in the transmission system has long been researched. The goal of this optimization issue is to determine the best capacitor sizes and placements. In this paper, we have investigated the possibility of lowering the value of real power losses for global system transmission lines by employing a genetic algorithm to determine the optimal location and sizing of shunt capacitors while taking into account the value of real power losses with reactive power injection as a measure of the capacity to lower losses at load buses. The IEEE 6-bus system is used to test the findings.

**KEYWORDS:** IEEE 6-Bus System, Capacitor Banks, Genetic Algorithm, Loss Reduction, Ideal Capacitor Positioning, Reactive Power, and Transmission System

## INTRODUCTION

[12] In addition to maintaining the quality of power supplied to users through voltage control within allowable limits, the power generation utilities sought to increase operational efficiency to the greatest extent possible by minimizing losses in real power transmitted across the transmission lines [1]. In order to provide the best possible control over reactive power, shunt capacitors have become an increasingly important instrument. In large electric networks, shunt capacitors are placed in strategic areas to optimize the voltage profile and lower power losses in the distribution and transmission lines [2]. Shunt capacitors were originally used in 1914 to increase power factor, but their usage was restricted because of its massive size, weight, and expensive cost per MVAR [3]. Shunt capacitors have been utilized extensively in the power system since 1939 because of their lower cost in relation to their size [4]. The system power factor typically decreases as the load increases. Voltage control issues, higher system losses, power factor fines in power contracts, and decreased system capacity result from load increases and power factor decline [5]. The capacitors lower system line losses, increase power factor, and provide some voltage drop correction. Capacitors that are positioned and designed correctly may often lower system line losses to the point where their installation costs are justified [6]. Placing the capacitors as close to the inductive loads as feasible maximizes their advantages. Capacitors are often employed for reactive power adjustment in power system networks [7].

[13] Determining the quantity, location, type, size, and control setting of the capacitors to be fitted at various load levels constitutes the ideal capacitor placement. The goal is to reduce energy losses while taking into

[14] expenses associated with installing capacitors, improving voltage profiles, and boosting system stability. The best location for capacitors in electrical power systems has been the subject of several studies in the past. References [8]–[10] have used evolutionary algorithms to determine the best location for capacitors in power systems. For the best location of fixed and switched capacitors in radial distribution networks, J.C. Carlisle et al. [11] used a graph search technique. Eajal et al. [13] employed particle swarm optimization for the best placement and sizing of capacitors in an unbalanced distribution system while taking harmonics into account, while Om Prakash Mahela et al. [12] used a method for optimal capacitor banks placement in radial distribution feeders for loss reduction using MATLAB. The suggested power system model in this study uses a genetic algorithm to determine the best location for capacitors. The goal function is to reduce the overall yearly cost resulting from power loss and capacitor placement. Voltage limitations are the restriction. The suggested approach is evaluated for ideal capacitor locations and sizes on an IEEE 6-bus system.

## GENETIC ALGORITHM

- John Holland [14] was the first to define the theoretical underpinnings of genetic algorithms, and David Goldberg [15] subsequently gave an instructional presentation. The principle of natural selection, which propels biological development, serves as the foundation for the genetic algorithm, a global search method for resolving optimization issues. Genetic methods explore many peaks in parallel using a population of binary strings [16]. Important terms related to the genetic algorithm are as follows [17]:
- Any place to which an objective function may be applied is considered a person. In essence, it is the collection of values for every variable that the function will be optimized for. An individual's score is the value of the objective function. Genes are the vector entries of a person, which is frequently referred to as a genome.
- A population is any group of people. For instance, the population may be represented as a 100-by-3 matrix, where each row represents an individual, if the population size is 100 and the objective function has three variables.
- Generation: In order to create a new population, the genetic algorithm applies genetic operators on the present population at each iteration. Every subsequent population is referred to as a "new generation."
- Parents and children: The genetic algorithm employs certain people from the present population, referred to as parents, to generate persons in the following generation, referred to as children.
- To create offspring for the future generation, parents are subjected to the following three genetic operators:
- The process of reproduction involves choosing the most fit members of the present population to create the next one. The kids are referred to as Elite kids.
- Crossover is the process by which two people share genetic information. We refer to these kids as crossover kids.
- Individual genetic representations are altered by mutation in accordance with a probabilistic rule. In this instance, the offspring are referred to as "mutation children."
- This research uses the evolutionary algorithm approach to determine the best location for capacitors in the electric transmission network in order to minimize overall yearly cost and reduce loss. The suggested algorithm's primary computing phases are as follows:

- Examine network and system data. Enter the minimum and maximum permissible operating voltages as well as the cost of capacitors. Population size, crossover, and mutation rates are examples of input algorithm parameters.
- Prior to installing capacitors, compute the system power losses at each load level, the overall energy losses, and the bus voltages at each bus in the event of nonlinear loads.
- Create a collection of first plausible solutions at random to constitute the beginning population.
- Determine each solution's corresponding fitness value.
- Determine the population's average fitness value. Additionally, determine each person's chance of selection.
- All individuals whose fitness values fall below the computed average fitness value should be passed on to the next generation without alteration.
- Choose one parent. Select the other parent at random. To create new offspring, use crossover and mutation operators.
- Proceed to step 7 if the offspring is not conceivable; otherwise, proceed to step 9.
- Determine the offspring's fitness value.
- To replace a person whose fitness value exceeds the computed average fitness value, create a new member of the population.
- To locate the remaining people, repeat steps (7) through (10).
- If the halting requirement is not met, repeat steps (5) through (11). If not, go to step
- Print the best solution that has been discovered so far.

**PROBLEM FORMULATION**

The bus voltage and line losses can be calculated by the Gauss-Seidel iterative method employing the following formula [18]:

$$V_i^{(k+1)} = \frac{1}{Y_{ii}}\left(\frac{P_i - jQ_i}{V_i^{*(k)}} - \sum_{\substack{n=1 \\ n\neq i}}^{m} Y_{in}V_n\right) \qquad (1)$$

Where

$V_i^{(k)}$: Voltage of bus i at the $k^{th}$ iteration

$P_i$ , $Q_i$ : Bus active and reactive power of bus i

$Y_{im} = y_{i,m}$ for $i \neq m$

and $Y_{ii} = y_{i,m-1} + y_{i,m+1} + y_{ci}$ for i = m

The current in branch (i,k) connecting buses i and k is given by [19]:

$$I_{ik} = \frac{P_{ik} - jQ_{ik}}{V_i} \qquad (2)$$

Where $I_{ik}$ = Current through branch (i, k)

$P_{ik}$ = Total real power flow in the branch (i, k)

$Q_{ik}$ = Total reactive power flow in the branch (i, k)

$V_i$ = Voltage at node (i)

The total power loss in the transmission lines is:

$$P_{loss} = \sum_{ik=1}^{n} |I_{ik}|^2 R_{ik} \qquad (3)$$

Where
$I_{ik}$ = Current through branch (i, k) $R_{ik}$ = Resistance of branch (i, k)

The branch current has two components active ($I^a$) and reactive ($I^r$). The total loss associated with the active and reactive components of a branch current can be written as:

$$P_{lossa} = \sum_{ik=1}^{n} |I_{ik}^a|^2 R_{ik} \qquad (4)$$

and

$$P_{lossr} = \sum_{ik=1}^{n} |I_{ik}^r|^2 R_{ik} \qquad (5)$$

Where $I_{ik}^r$= reactive component of branch current obtained from load flow solution.

The loss associated with active component of branch current cannot be minimized, however the loss associated with the reactive components of branch currents can be minimized. The capacitor installed at bus k draws a reactive current $I^c$ and it changes only the reactive component of current of branch set α. Thus the new rective

$$I_{rik}^{new} = I_{ik}^r + D_{ik} I_{ik}^c \qquad (6)$$

current of the branch (i, k) is given by

given by

Where

$D_{ik}$ = 1, if branch (i, k) belongs to α

= 0 otherwise.

The loss associated with the reactive component of branch current in the system compensated by the capacitors is

$$P_{lossrcom} = \sum_{ik=1}^{n} (I_{ik}^{r} + D_{ik} I_{ik}^{c})^2 R_{ik} \qquad (7)$$

The loss saving is the difference between equation (4) and (6) and is given by

$$P_{LS} = P_{lossr} - R_{lossrcom}$$
$$= \sum_{ik=1}^{n} (I_{ik}^{r})^2 R_{ik} - \sum_{ik}^{n} (I_{ik}^{r} + D_{ik} I_{ik}^{c})^2 R_{ik}$$
$$= \sum_{ik=1}^{n} (2D_{ik} I_{ik}^{r} + D_{ik} I_{c}) R_{ik} \qquad (8)$$

The capacitor current from loss saving is calculated by differentiating eqn (8) and equating it to zero. The capacitor current from loss saving is given by

$$I_c = \frac{\sum_{ik\epsilon\alpha} I_{ik}^{r} R_{ik}}{\sum_{ik\epsilon\alpha} R_{ik}} \qquad (9)$$

The corresponding capacitor size is

$$Q_c = V_m I_c \qquad (10)$$

Where

$Q_c$ = Capacitor size in MVAR

$V_m$= Voltage magnitude of bus „m" in volts $I_c$ = Capacitor current in amps

## OBJECTIVE FUNCTION FORMULATION

The objective function in the proposed algorithm aims at minimizing the total annual cost due to capacitor placement, and power loses with constraints that include limits on voltage and size of installed capacitors. The objective function is given by

$$F = K_p P_{loss} + \sum_{i=1}^{m} K_i^c Q_i^c + \sum_{i=1}^{n} \{max(0, V_{min} - V_i)^2 + max(0, V_i - V_{max})^2\} \quad (11)$$

$$V_{min} \leq |V_i| \leq V_{max} \quad (12)$$

Where

$K_p$ = Annual cost per unit of power losses n = Total nos. of buses

$K_i^c$ = Capacitor annual cost per KVAR, it is zero when no capacitor is installed on the bus. $Q_i^c$ =Shunt capacitor size placed at bus.

$V_{min}$ =Minimum permissible bus voltage $V_{max}$ = Maximum permissible bus voltage

**OPTIMAL CAPACITOR PLACEMENT USING GA**

The evolutionary algorithm has been utilized in this work to determine the best location and size of capacitors in the electric transmission system. Improvement of the voltage profile and loss reduction are the intended functions. Equation (11) provides an objective function that seeks to minimize overall cost. The feasibility of the suggested technique is shown by testing the capacitor placement results on the IEEE 6-bus system depicted in Figure 1. There are four load buses and two voltage sources in this network. The swing bus is bus number one, the PV bus is bus number two, and the PQ load buses are bus numbers three through six.

Table 1 [20] displays the line data for the IEEE 6-bus system. Table 2 displays the variable restrictions, while Table 3 displays the system's starting state prior to optimization using a 100MVA base. The objective function's coefficient for the yearly cost per unit of power losses is 25%, while the annual cost per KVAR for capacitors is 20%. If a capacitor is not put on a certain bus, the yearly cost of the capacitor is $0.

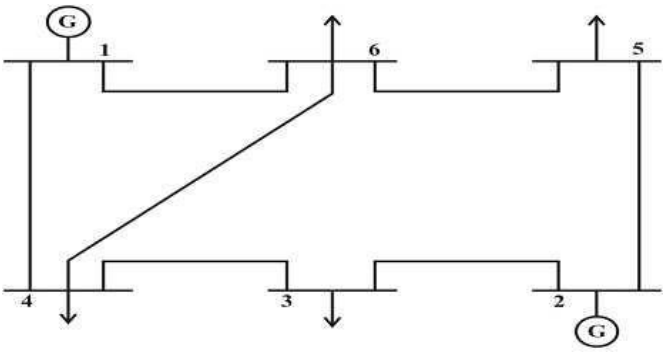



**Figure 1: Line Diagram of IEEE 6-Bus System**

**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 |

**Table 3: IEEE 6-Bus System Initial Status before Optimization (Base MVA $S_B$=100MVA)**

| Bus No. | Voltage (p.u.) | | Load (p.u.) | | Power Supply (p.u.) | |
|---|---|---|---|---|---|---|
| | V | □ (degree) | $P_L$ | $Q_L$ | $P_G$ | $Q_G$ |
| 1 | 1.0500 | 0 | 0 | 0 | 0.9662 | 0.3792 |
| 2 | 1.1000 | -06.1494 | 0 | 0 | 0.5000 | 0.3499 |
| 3 | 0.8563 | -13.8236 | 0.55 | 0.13 | 0 | 0 |
| 4 | 0.9528 | -09.9245 | 0 | 0 | 0 | 0 |
| 5 | 0.8992 | -13.4205 | 0.30 | 0.18 | 0 | 0 |
| 6 | 0.9338 | -12.6485 | 0.50 | 0.05 | 0 | 0 |
| System Total Loss =19.23MW | | | | | | |

The genetic algorithm has been coded for optimization using MATLAB. The Gauss Seidel method is used for power flow calculations. The simulation results of the proposed method tested on IEEE 6-bus system after optimization are shown in Table 4.

**Table 4: IEEE 6-Bus System Status after Optimization (Base MVA $S_B$=100MVA)**

| Bus No. | Voltage (p.u.) | | Load (p.u.) | | Power Supply (p.u.) | |
|---|---|---|---|---|---|---|
| | V | □ (degree) | $P_L$ | $Q_L$ | $P_G$ | $Q_G$ |
| 1 | 1.0200 | 0 | 0 | 0 | 0.9463 | 0.4865 |
| 2 | 1.0160 | -9.0341 | 0 | 0 | 0.4802 | 0.3207 |
| 3 | 0.9267 | -12.3289 | 0.55 | 0.13 | 0 | 0.0313 |
| 4 | 0.9485 | -7.5249 | 0 | 0 | 0 | 0.2106 |
| 5 | 0.9836 | 6.9875 | 0.30 | 0.18 | 0 | 0.3423 |
| 6 | 0.9713 | -8.5346 | 0.50 | 0.05 | 0 | 0.2311 |
| System Total Loss =7.43MW | | | | | | |

The fitness value of objective function, best individual, average distance between individuals and selection function of genetic algorithm are shown in Figure 2.

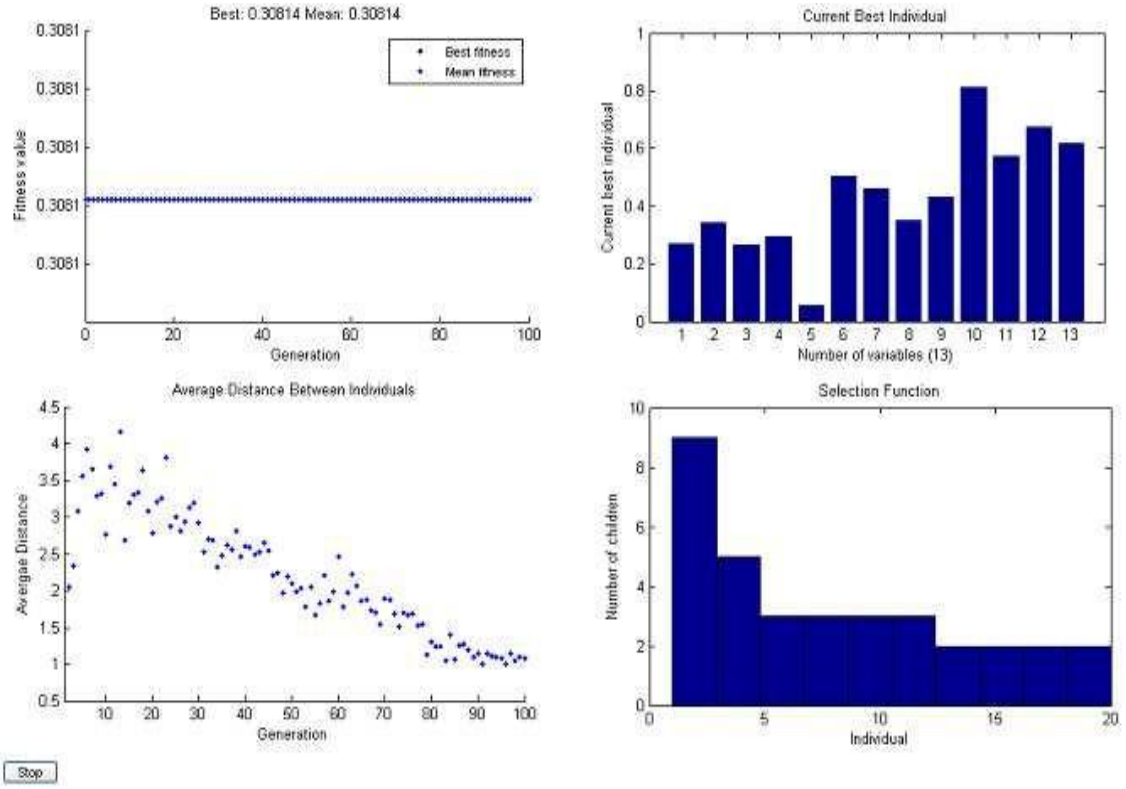



**Figure 2: Results of Genetic Algorithm**

## CONCLUSIONS

Optimizing reactive power is a challenging combinational optimization issue. The ideal location and size of capacitors in the electric transmission system are determined using a genetic algorithm. The objective function calculation provides the location and size of the capacitor. The goal function seeks to meet all power system operating criteria while minimizing the network's active power loss. The IEEE-6 bus system has successfully implemented the suggested method. The findings demonstrate that the network's power loss significantly decreases when capacitors are inserted using a genetic algorithm.

## REFERENCES

1. K. Mamandur and R.D. Chenweth, "Optimal control of reactive power flow for improvement in voltage profiles and for real power loss minimization," IEEE Transaction on Power Apparatus and System, Vol. PAS-100, No. 7, July 1981, pp. 3185-3193.
2. S.M. Kannan, P. Renuga, and A. Rathina Grace Monica, "Optimal capacitor placement and sizing using combined fuzzy-HPSO method," International Journal of Engineering, Science and Technology, Vol. 2, No. 6, 2010, pp. 75-84.
3. "A study of the optimal allocation of shunt capacitor based on modified loss sensitivity algorithm," Iraq Journal of Electrical and Electronics Engineering, Vol. 6, No. 1, 2010, pp. 56-61, Warid Sayel and Emad Allawi Mohsin.
4. A.C. Monteith, Electrical Transmission and Distribution Reference Book, Second Edition, Westinghouse Electrical Corporation Central Station Engineers, Pennsylvania, 1964.

5. "Minimizing cost and power loss by optimal placement of capacitor using ETAP," IEEE, [Online], 978-1-4244-9592-4/11, 2011, pp. 26-31, Pravin Chopade and Marwan Bikdash.
6. R.H. Park, "Improved bulk power supply reliability by fast load control," American Power Conference Proceedings, 1968, pp. 445-457.
7. IOSR Journal of Electrical and Electronics Engineering, Vol. 3, Issue 4, Nov.-Dec. 2012, pp. 01-08. Om Prakash Mahela, Devendra Mittal, and Lalit Goyal, "Optimal capacitor placement techniques in transmission and distribution networks to reduce line losses and voltage stability enhancement: A review."
8. "Genetically optimized fuzzy placement and sizing of capacitor banks in distorted distribution networks," Ladjavardi M. and Masoum M.A.S., IEEE Transactions on Power Delivery, Vol. 23, No. 1, 2008, pp. 449-456.
9. Kenji Iba, "Genetic algorithm-based reactive power optimization," IEEE Transactions on Power Systems, Vol. 9, No. 2, May 1994, pp. 685-692.
10. S. Sundharanjan and A. Pahwa, "Genetic algorithm-based optimal capacitor selection for radial distribution systems," IEEE Transactions on Power Systems, Vol. 9, No. 3, August 1994, pp. 1499-1507.
11. "A graph search algorithm for optimal placement of fixed and switched capacitors on radial distribution systems," J.C. Carlisle and A.A. El-Keib, IEEE Transactions on Power Delivery, Vol. 15, No. 1, January 2000, pp. 423–428.
12. "Optimal capacitor placement for loss reduction in radial distribution feeder," OM Prakash Mahela, Sheesh Ram Ola, and Lalit Goyal, IOSR Journal of Electrical and Electronics Engineering, Vol. 4, Issue 6, March-April 2013, pp. 43-48.
13. A.A. Eajal and M.E. Elhawary, "Optimal capacitor placement and sizing in unbalanced distribution system with harmonics consideration using particle swarm optimization," IEEE Transactions on Power Delivery, Vol. 25, No. 3, July 2010, pp. 1734-1741.
14. D.E. Goldberg, Genetic Algorithm in Search Optimization and Machine Learning, Addison-Wesley, Massachusetts, 1989.
15. Turan Gonen, Electric Power Distribution System Engineering, McGraw-Hill, 1986.
16. Michalewicz Z., Genetic Algorithms of Data Structures Evolution Programs, New York: Springer-Verlag, Third Edition, 1996, pp. 387
17."Optimal capacitor placement for loss reduction," Conference Proceedings of Modern Electric Power Systems (MEPS-10), Wroclaw, Poland, 2010, paper-11.3, Forough Mahmoodianfard, Hossein Askarian Abyaneh, HamidReza Salehi, and AliReza Vahabzadeh.
18. "Shunt capacitor sizing for radial distribution feeders with distorted substation voltages," IEEE Transactions on Power Delivery, Vol. 5, No. 2, 1990, pp. 650-657, Baghzouz, Y., and Ertem, S.
19. "An efficient algorithm for load balancing of transformers and feeders," IEEE Transactions on Power Delivery, Vol. 3, No. 4, 1988, pp. 1865-1872, Aoki K., Kuwabara H., Satoh T., and Kanezashi M.
20. "Application of ANN in economic generation scheduling in IEEE 6-bus system," Sweeks Meshram and Om Prakash Sahu, International Journal of Engineering Science and Technology, Vol. 3, No. 3, March 2011, pp. 2461-2466.