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Optimal capacitor placement in a dominant induction motor loads power system

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Abstract

The challenge of optimal capacitor allocation is one of the complex problems in power systems, especially in large industries since they have many big capacity induction motors. In the literature, many works have been delivered for optimal capacitor placement, however, these works were simulated in a distribution network, not in an industry network with many large capacity induction motors. Therefore, this work proposes the optimal allocation of capacitors in a large industry with a significant amount of induction motor loads to minimize network losses. To determine the optimal capacitor location, this research uses the genetic algorithm (GA) method. This algorithm is interesting because of its simplicity and ability to discover optimal solutions comprehensively.

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Keywords: Optimal capacitor placement; Genetic algorithm; Network losses; Voltage stability

1. Introduction

Excessive reactive power demands, especially from large industries with significant motor loads, have led to reduced system capacity, lower voltage, higher system losses, and ultimately operating costs become higher. The optimal placement of capacitors is one of the most imperative matters related to electricity distribution network planning. Installation of capacitors in the distribution system is done to improve voltage regulation [1], improve power factors, improve voltage stability [2], and minimizing energy cost [3]. Especially during peak loads, the

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reactive power required by the load increases and may be greater than that generated by the system. One way that can be done to supply reactive power in distribution systems is by providing reactive power into the grid. Additional reactive power can be in the form of additional capacitor banks at the most sensitive points in the system.

The problem of optimal capacitor allocation is complex. This problem consists of determining the placement and dimensions of each capacitor unit and its configuration in the distribution grid with the aim of optimizing the voltage profile and minimizing network losses. Like many other problems in electricity distribution network planning, the allocation of capacitor banks is characterized by high complexity in finding optimal solutions. Furthermore, optimal capacitor placement becomes more important and challenging in large industries. One of the major industries in Indonesia is the Bosowa cement industry. The Bosowa cement industry has power quality problems in its electricity system. This is because the Bosowa cement industry has many large capacity induction motors for its production process.

In the literature, many methods have been developed for optimal capacitor placement. However, these research were simulated in a radial distribution network, not in an industry network with many large capacity induction motors. Table 1 summarizes some of the recent works on capacitor placement with its method and case study system.

Table 1. Recent research on optimal capacitor placement.

Method	Systems	Ref.
Fuzzy Expert System	Gondar feeder in Gondar, Ethiopia	[4]
Modified Affine Arithmetic Division	15, 33, and 118 bus radial distribution systems	[5]
Flower Pollination Algorithm	33, 34, 69, and 85 bus radial distribution systems	[6]
Genetic Algorithm	380 kV West–East transmission line inter-tie networks, Saudi Arabia	[7]
Symbiosis Organism Search and Neural Network	33, and 69-bus networks	[8]
Shark Smell Optimization Algorithm	IEEE 34-bus and 118-bus radial distribution systems	[9]
Particle Swarm Optimization	IEEE 16-bus system with wind generator	[10]

Therefore, in this study, an optimization study is done to decide the location and optimal size of capacitors in an industry with many induction motors to minimize voltage drops and system power losses. As industry is used as a case study, hence the proportion of induction motor loads is significantly larger than the usual distribution network. The proposed method in this study is the genetic algorithm (GA) method. The reason for using the GA method is because of the key features of GA being able to survey numerous parts of the search space with a fairly concise calculation time. With a stochastic search approach, they can reconnoiter various areas of search space concurrently and therefore are less likely to end with a local minimum. In addition, various complex objectives can be easily incorporated. Furthermore, in several previous works, GA was more correct in solving the problem of capacitor allocation in the distribution network [7].

2. Problem formulations

2.1. Constraints

In this study, the optimal conditions are set as follows:

• Power balance constraint: This limitation is useful to limit the injected power of the capacitors into the system does not exceed the reactive load on the system.

$$\sum_{k=1}^{nc} Q_k^C \leq 0.8 * \sum_{k=2}^{n} Q_k \tag{1}$$

• Capacity limit constraints: This constraint confines the reactive power to be injected into the system is limited to up to 1 MVAr for each step.

$$Q_{k,min}^C \leq Q_k^C \leq Q_{k,max}^C \tag{2}$$

• Voltage constraints: Voltage constraints are defined to ensure the voltage on each bus to meet the requirements which are between 0.95 p.u. to 1.05 p.u.

$$|V_1 - V_k| \leq \Delta V_{max} \tag{3}$$

2.2. Objective function

The objective function of this study is to optimize the difference between initial power losses and power losses after capacitor installation. Maximizing the difference is the same as minimizing the power losses generated after the installation of capacitor banks. The objective function of this study is as follow

$$Maximize\ F = \max(\Delta P_L^C) = \max(P_{T.Loss} - P_{T,loss}^C) \tag{4}$$

3. Proposed methodology: Genetic algorithm (GA)

Genetic algorithm (GA) was initially developed by John Holland and it is an optimization procedure that utilizes the natural selection process known as the evolutionary process [11,12]. In the process of evolution, individuals continue to experience gene changes in order to adapt to their environment. GA is used to determine the most optimal function value. By using the principle of evolution that exists in nature, GA uses the same terms as the scientific selection process that exists in nature. Diversity in biological evolution is chromosome variation between individual organisms. Variations in chromosomes will affect the rate of reproduction and the level of the organism's ability to stay alive. GA works with individual populations, each of which presents possible solutions to the problems encountered. In this connection, the individual is symbolized by the value of fitness that will be employed to discover the best solution for the problem at hand. To examine the results of optimization, a fitness function is needed, which signifies the encoded result (solution).

A genetic algorithm is used to resolve the location and optimal size of the capacitor. The fitness function in this proposed method is minimizing power losses. In determining the capacitors' location and size, 50 testing steps were carried out in each simulation. The parameters of the genetic algorithm used are population, maximum generation, crossing over, and mutation opportunities. The steps for the placement and size optimization simulation of the genetic algorithm will be shown by the flowchart in Fig. 1.

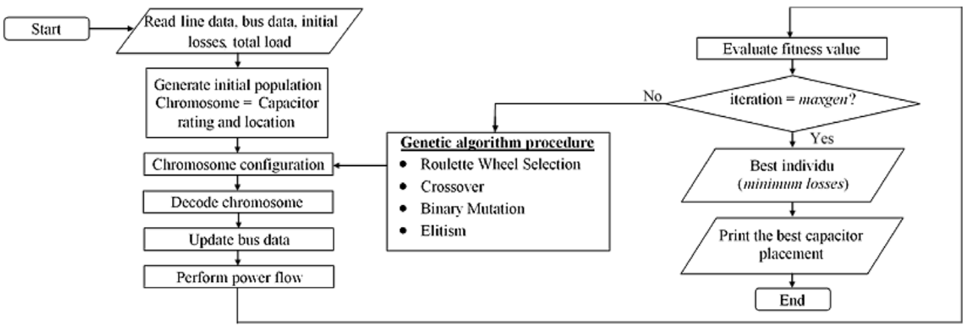

Fig. 1. Flowchart of capacitor placement with genetic algorithm.

The procedure for determining the location and size of the capacitor with the GA can be explained as follows:

1. Form the initial population (chromosome) representing *nx* variables (capacitor size at the *x* distribution substation locations).

2. Assess the fitness value of each chromosome by evaluating the objective function (minimum losses).

3. In each generation, the chromosomes are sorted according to their fitness value. By using an elitist strategy, if the lowest individual fitness value is smaller than the highest fitness value in the previous iteration, the individual with the lowest fitness value in a generation is replaced with the individual with the highest fitness value in the previous iteration.

4. Repeat Step 3 until the maximum amount of generations is attained.

4. Results and analysis

The proposed methodology was implemented in the Bosowa cement industry electricity network that has many large capacity induction motors. The load was modeled with a low power factor as induction motors. The single-line diagram of the case study can be seen in Fig. 2. In this study, 50 steps were performed to calculate the optimal capacitor location and size where the maximum capacitor capacity is set at 1 MVAr for each iteration. The use of decentralized capacitors with small capacities is better than using 1 capacitor with large capacities in one location. In addition, the use of capacitors that are too large can cause over-voltage on certain buses. Fig. 3 shows the results of the optimal placement and accumulative capacitor size for each bus using GA in the case study.

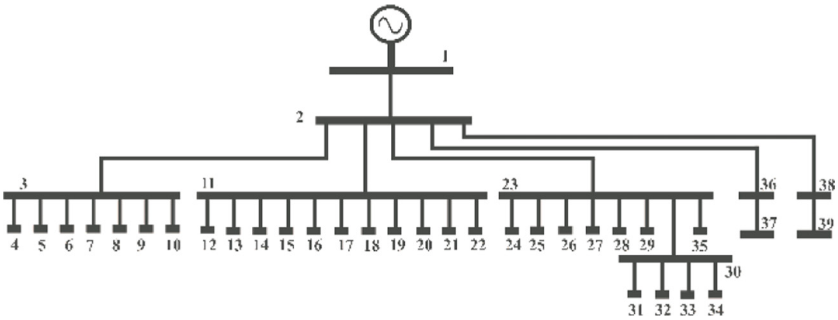

Fig. 2. Single line diagram of Bosowa cement industry electricity network [13].

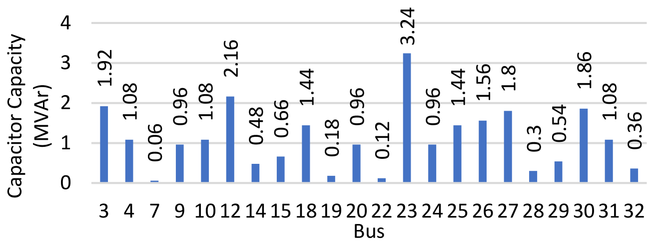

Fig. 3. Results for optimal location and accumulative size of capacitors using GA.

Fig. 4 shows the voltage profile of the provisional case study for before and after capacitor placement while Fig. 5 informs the total active and reactive power losses for before and after capacitor placement as well. For initial conditions, as can be seen in Fig. 4, there are several buses that experience under-voltage situations, namely buses 30–34. After the placement of the capacitors, the system's voltage profile can return to its stability limit. Likewise, by placing these capacitors, active and reactive power losses can be reduced. Active power losses decreased from 1122 kW to 926 kW and reactive power losses decreased from 1308 kVAr to 1095 kVAr.

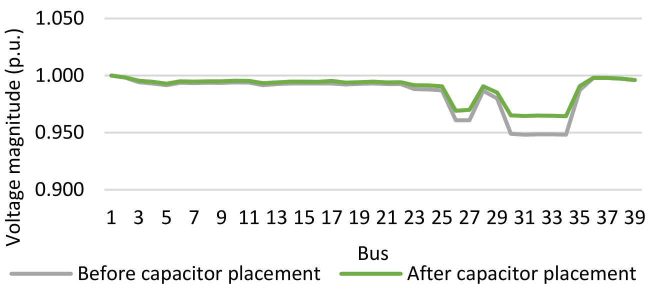

Fig. 4. Voltage profile for before and after capacitor placement with GA.

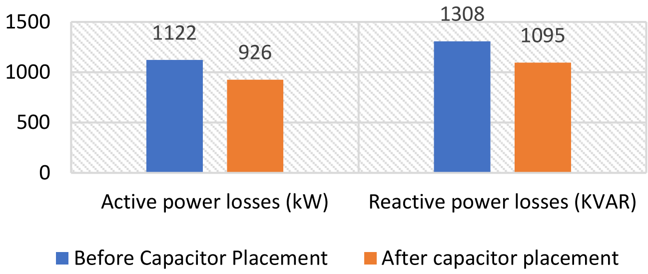

Fig. 5. Active and reactive power losses for before and after capacitor placement using GA.

5. Conclusions

This paper presents optimal capacitor allocation in large industries using the genetic algorithm (GA) method. The developed method was implemented in a real large industrial power grid with a large number of large capacity induction motors. The capacitor capacity for each step is regulated in small quantities to ensure optimal size and to avoid excessive voltage on certain buses. The proposed method can effectively calculate the optimal size and location of capacitors in industrial networks with many large induction motors and can increase the system's voltage profile and lessen network losses.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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