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Submission date: 11-May-2023 08:47AM (UTC+0700)
Submission ID: 2089980155
File name: Distribution_System_Using_Integer_Encoding_Genetic_Algorithm.pdf (1.98M)
Word count: 3420
Character count: 18021

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2020 International Conference on Applied Science and Technology (iCAST) | 978-1-7281-9567-4/20/$31.00 ©2020 IEEE | DOI: 10.1109/iCAST51016.2020.9557646

***Abstract*— There are some problems in the distribution system such as, real power losses, lagging components of the current circuit that happened due to the growth of the load. These problems will impact in increasing the annual cost of the distribution system. One of the methods to avoid these problems is by installing the capacitors on several buses. These capacitors can reduce real power losses and also improve the bus voltage profile. The effectiveness of the capacitor installation depends on the location and size of the capacitor. In this paper, the tracing of the optimal capacitor location and size was carried out using an integer encoding genetic algorithm. Numerical simulation with a test system of 10 and 34 buses have been conducted and found that the proposed method was able to trace the optimal capacitor location and its size. This proposed method was able to provide more saving annual cost and better voltage improvement compared to the Modified ABC Algorithm.**

Keywords*— integer encoding genetic algorithm, optimal capacitor placement, radial distribution system

I. INTRODUCTION

The growth in the load of the electric power distribution system causes an increase in real power losses, increase the lagging component of circuit current and a decrease in voltage quality. One of the efforts to anticipate this and to increase the efficiency of the distribution system operation is by installing capacitors in several locations. The additional shunt capacitors will have a major impact in supplying the reactive power that required by the load. The reactive power supply from the capacitor will cause the current flowing in several channels to be decreased so that copper losses in the line and voltage drop will be dropped. The effectiveness of the impact of capacitors installation depends on the location of their installation and the size of the capacitors.

Several researchers have proposed solving the optimization problem of capacitor installation. The approaches used differ from one to another depending on the way the problem is formulated and the problem-solving method used. Some researchers have been formulated the objective of capacitor installation by considering only the technical aspects of reducing real power losses and voltage deviation [1-4], and some researchers considered the costs of real power losses, energy losses, and capacitors [5-12]. Based on the consideration of accuracy, practicality, and complexity, several researchers proposed a different approach between the optimal capacitor location tracking method and the optimal capacitor size tracking method [3, 4, 5, 6, 9, 10, 11]. To search for the optimal location of the capacitors, some researchers use an analytical approach [3, 6, 9, 10] and others use the artificial intelligence method [4, 5, 11]. Several other researchers used one method for tracking the optimal capacitor location and size [1, 2, 7, 8,12]. The methods was used to get the optimal solution including; Genetic Algorithm (GA), Harmony Search Algorithm (HSA), Artificial Bee Colony (ABC) Algorithm, Fuzzy, Dragonfly Algorithm (DA).

Determining the location and size of capacitors in radial distribution networks are a non-linear and mixed-integer combinatorial optimization problems. To trace the optimal capacitor location and size, the authors propose to use GA. Since the potential location and available capacitor capacity options can be expressed by an ordinal number consisting of whole numbers (integer), the authors propose a chromosome form with a whole number sequence, but different from the method that were proposed in [1, 3, 6, 9]. With a chromosome form consisting of whole numbers, which is also known as an integer matrix chromosome encoding scheme [13], it is expected to increase traceability effectiveness and computational efficiency.

II. PROPOSED METHOD

A. Capacitor Cost

The purpose of installing capacitors in distribution systems is to minimize the annual cost of real power losses and capacitor installation. The cost of installing the capacitor consists of the cost of installing and the cost of the capacitor according to the capacitor capacity (kVAr). The objective function can be expressed by the following equation.

$$f = K_e P_L + \sum_{i=1}^{NC} (K_{cf} + C_i) \quad (1)$$

$$\text{Optimal cost} = \min(f) \quad (2)$$

where:

K_e = energy cost ($ / kW-year)
P_L = total real power losses (kW)
K_{cf} = capacitor installation cost ($/year)
C_i = capacitor charge at location i ($/year)
NC = many installation locations

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Tracking the location and capacitor size to minimize annual costs, must pay attention to the following limitations.

B. Voltage Limits

To maintain the quality of the power supplied, the voltage on each bus must meet the minimum voltage limit requirements, V_{min} and the maximum voltage limits, V_{max}. The bus voltage is stated as follows.

$$V_{min} \leq |V_i| \leq V_{max} \tag{3}$$

In the following part of the simulation, $V_{min} = 0.95$ pu and $V_{max} = 1.05$ pu are selected.

To measure the bus voltage limit violation in a radial distribution system, the voltage deviation index VDI is defined as [10]:

$$VDI = \sqrt{\sum_{i=1}^{NV} \frac{(V_i - V_{iLimit})^2}{N}} \tag{4}$$

$$V_{iLimit} = \begin{cases} V_{min}, & if\ |V_i| < V_{min} \\ V_{max}, & if\ |V_i| > V_{max} \end{cases} \tag{5}$$

where:

V_i = bus voltage at i^{th} (pu)

N = number of buses in the distribution system

NV = number of buses with a voltage exceeding the minimum or maximum limits.

C. Reactive Power Limits

The total reactive power injected by the capacitor does not exceed the total reactive power required by the distribution system:

$$\sum_{i=1}^{NC} Q_{ci} \leq Q_{total} \tag{6}$$

where:

Q_{ci} = reactive power injected into bus i

Q_{total} = total reactive power required by the distribution system.

The total real power losses, the respective bus voltages, and the total reactive power required by the distribution system are calculated by the topology based power flow method [14].

D. Integer Encoding Genetic Algorithm (IEGA)

GA is a tracking algorithm based on a biological evolutionary process. GA uses a chromosome representation where the chromosomes consist of codes that represent genes or decision variables. Chromosome length is limited, depending on many decision variables and the coding method of genes. A chromosome and the resulting objective value represents an individual. Individuals will follow an evolutionary process to produce the best individual who is the optimal solution to a problem. The evolutionary process consists of crossover, mutation and selection. During the genetic cycle, new individuals are produced by means of crosses and mutations.

In this paper, genes or decision variables will be encoded with a whole number (integer) and the chromosome is a whole number vector, and the length of a chromosome is equal to 2 times of the number of potential capacitor locations *NC*. Two consecutive elements on the chromosome represent the location of the capacitor placement and the size of the potential capacitor.

E. Crossover process

Individuals as parents to follow the crossing process are randomly selected from the existing population, and crosses take place with a probability of crossover.

The vector elements of the parent chromosomes that are crossed are determined by the binary vector. Binary vectors are vectors with elements of 0 and 1. Binary vectors are formed randomly and have the same length as the chromosome length. This binary vector is like the binary window in [13]. This cross can be expressed by the following equation.

$$x_{new1,i}, x_{new2,i} =$$

$$\begin{cases} x_{new1,i} = x_{old2,i}, x_{new2,i} = x_{old1,i} & if\ x_{bv,i} = 1 \\ x_{new1,i} = x_{old1,i}, x_{new2,i} = x_{old2,i} & if\ x_{bv,i} = 0 \end{cases} \tag{7}$$

where:

$x_{new1,\,i}$, $x_{new2,i}$ = i element of new 1st and 2nd chromosomes

$x_{old1,i}$, $x_{old2,i}$ = i element of 1st and 2nd parent chromosomes

$x_{bv,\,i}$ = i^{th} element of the binary vector.

F. Mutation Process

The mutation process of new chromosomes is needed to explore the search space. The mutation effectiveness depends on the probability of the occurrence of the probability of mutation.

Vector elements of mutated chromosomes are determined by randomly generated binary vectors. Changes in chromosomal elements resulting of the mutations can be expressed by the following equation.

$$x'_{new,i} = \begin{cases} \text{rand } i & if\ x_{bv,i} = 1 \\ x_{new,i} & if\ x_{bv,i} = 0 \end{cases} \tag{8}$$

where:

$x'_{new,i}$ = the i^{th} element of the mutated chromosome

The main steps of the proposed method are outlined as follows:

- Create an initial population consisting of as many chromosomes as NP. The chromosomes are in the form of a whole number vector and are formed randomly according to the bus numbering and the capacitor numbering. The length of the chromosome is 2 x *NC*.
- Perform power flow calculations to calculate power losses and check optimization limits. Inappropriate chromosomes or solutions are replaced by new feasible chromosomes.
- Calculate the objective value of each chromosome according to Eq. (1).

- Carry out a cross between 2 chromosomes that are randomly selected with probability pc to produce 2 new chromosomes according to Eq. (7).
- Carry out the mutation process in the chromosome resulting from crosses with probability pm according to Eq. (8).
- Perform power flow calculations to calculate the value of each chromosome as well as check optimization limits.
- Merge the new individuals with old individuals who are selected with a tournament system based on the objective value of each individual. The combined population will follow the next evolutionary process from steps 4-7.
- The evolution process will last up to the G_{max} generation.

III. SIMULATION AND RESULTS

To see the performance of the proposed algorithm, a numerical simulation has been carried out on 2 different radial distribution systems, the 10 bus system and the 34 bus system. The proposed algorithm has been programmed in the MATLAB programming language and run on an Intel ® Core ™ i3 M350 2.27 GHz personal computer.

In this simulation, the constant K_e is chosen to equal 16[illegible] / kW-year. The available capacitors and the cost per bank are shown in Table 1 [10]. Table I also shows the cost of the capacitor per year by assuming an expected capacitor life of 10 years. The cost of installing the capacitor is selected at 1000 $ per bank. The number of potential *NC* nodes is determined differently in each radial distribution system tested.

TABLE I. AVAILABLE CAPACITOR SIZES AND COST PER YEAR

Size (kVAr)	150	300	450	600	900	1200
Cost ($)	750	975	1140	1320	1650	2040
Cost ($/year)	75	97.5	114	132	165	204

The control parameter for the proposed method is that the population size (NP) that it was chosen 10 times of the chromosome length. The maximum of generation G_{max} was 100, the probability of crosses (pc) was 0.9, and the probability of mutation (pm) was 0.1.

In order to see the effectiveness of the proposed method, the results of this simulation are compared with the simulation results conducted in [10] using Modified ABC Algorithm.

A. The 10 Bus Test System.

The 10 bus test system is a 23 kV radial distribution system with system data obtained from [5]. This system consists of a feeder with 9 channel sections as shown in Figure 1.

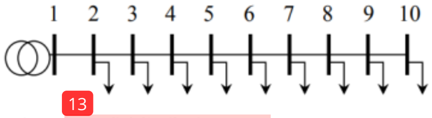

Fig. 1. The 10 bus radial distribution system

Simulations were carried out to obtain 4 potential buses for the capacitor installation locations. Table II shows the optimal size and location search results. From Table II it can be seen that the optimal capacitor capacity increases by 500 kVAr compared to the results obtained in [10]. The proposed installation location and capacitor size resulted in a reduction in real power losses to 11.95%, and the annual cost savings increased to 11.11%. A summary of the simulation results with the 10 bus test system is shown in Table III. Besides reducing the real power losses and annual costs, the proposed capacitor installation also improves the voltage profile on each bus as shown in Figure 2. The initial condition bus voltage is shown in full-line and after installed the capacitor is indicated by a dotted line.

TABLE II. COMPARISON OF CAPACITOR SIZES IN A 10 BUS RADIAL DISTRIBUTION SYSTEM

Modified ABC Algorithm[10]		Proposed Method	
Bus No.	Size (kVAr)	Bus No.	Size (kVAr)
5	1200	4	1200
6	1200	5	1200
9	450	6	600
10	150	8	900
Total = 3,000 kVAr		Total = 3,500 kVAR	

TABLE III. THE SUMMARY OF THE SIMULATION RESULTS FOR THE 10 BUS RADIAL DISTRIBUTION SYSTEM

Description	Initial Condition	Optimal Condition	
		Modified ABC Algorithm[10]	Proposed Method
P-Losses (kW)	783.77	693.93	690.11
Energy losses ($/year)	131,673	117,577	115,938
Saving ($/year)	---	14,096	15,735
Decreased Losses (%)	---	11.46	11.95
Cost Saving (%)	---	10.70	11.11
VDI	0.0526	0.0334	0.0328

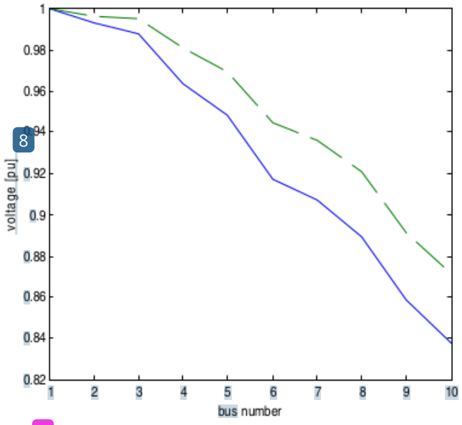

Fig. 2. Bus voltage profile on a 10 bus radial distribution system

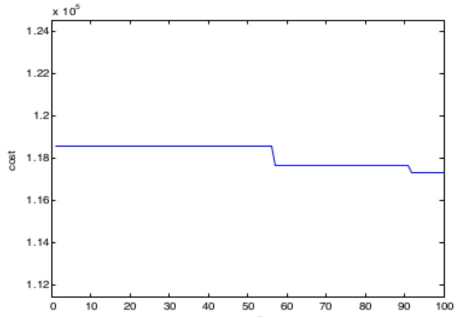

Fig. 3. Convergence of capacitor placement tracing in a 10 bus radial distribution system

The optimal convergence of the objective values during the tracing process using the proposed method is shown in Figure 3. This tracing process requires a computation time of 1.14 s

B. The 34 Bus Test System

The 34 bus test system is an 11 kV radial distribution system with a load of 5.4 MVA. System data were taken from [15]. This system consists of 33 channel sections as shown in Figure 4.

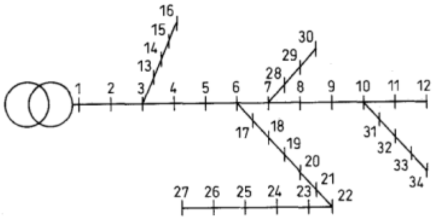

Fig. 4. The 34 Bus Radial Distribution System

Simulations were carried out to obtain potential buses for the capacitor installation locations. The results of the investigation with the proposed method show that the optimal locations for the installation of capacitors are buses 8, 9, and 22. The optimal capacities of capacitors installed on these buses are shown in Table IV. The requirement of the capacity of capacitors are greater than in Modified ABC Algorithm [10].

TABLE IV. COMPARISON OF CAPACITOR SIZES IN A 34 BUS RADIAL DISTRIBUTION SYSTEM

Modified ABC Algorithm[10]		**Proposed Method**	
Bus No.	**Size (kVAr)**	**Bus No.**	**Size (kVAr)**
19	900	9	600
20	150	8	600
22	900	22	1200
Total = 1,950 kVAr		**Total = 2,400 kVAr**	

Based on the location and size of the capacitors shown in Table IV, the proposed method has a better performance compared to the tracing results using the Modified ABC Algorithm. With this location and size using proposed method, the real power losses can be reduced and the annual cost savings can be increased. Table VI shows a summary of the performance of these 34 bus radial distribution systems.

TABLE V. SUMMARY OF SIMULATION RESULTS FOR THE 34 BUS RADIAL DISTRIBUTION SYSTEM

Description	**Initial Condition**	**Optimal Condition**	
		Modified ABC Algorithm[10]	**Proposed Method**
P-Losses (kW)	221.72	168.92	163.11
Energy losses ($/year)	37,248	28,378	27,402
Saving ($/year)	---	8,165	9,846
Decreased Losses (%)	---	23.81	26.43
Cost Saving (%)	---	21.92	24.37
VDI	0.0027	0.00017	0.00011

Figure 5 shows the bus voltage profile on a 34 bus radial distribution system. Installing the capacitor at the right location and using the optimal capacity will be able to improve the voltage profile on each bus. Overall, it have been improved the voltage deviation index from 0.0027 to 0.00011.

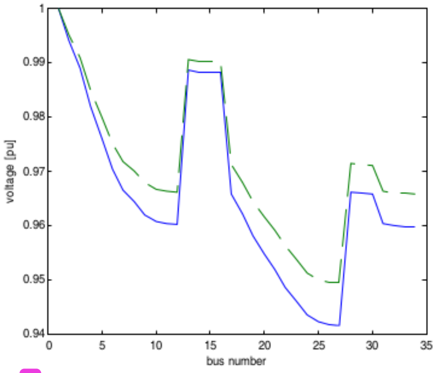

Fig. 5. Bus voltage profile on a 10 bus radial distribution system

Figure 6 shows the convergence of the objective values during the trace using the proposed method. This tracing for finding the optimal capacitor location and its size requires a computation time of 2.73 s.

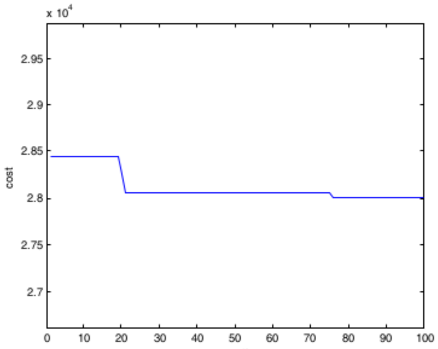

Fig. 6. Convergence of capacitor placement tracing in a 34 bus radial distribution system

IV. CONCLUSION

The optimum results in capacitor placement in the radial distribution system can be done by using the Integer Encoding

Genetic Algorithm. To improve traceability effectiveness and computational efficiency, it is proposed to use whole number vectors for coding decision variables. 10ng this method, the optimal capacitor can reduce active power losses and the annual cost of the distribution syst13, and as a result, it will improve the bus voltage profile. The numerical simulation results show that the proposed method was able to provide more saving annual cost and less voltage deviation index compared to the Modified ABC Algorithm. In tracing the optimal capacitor location and size, the proposed method requires a relatively short computation time of 1.13 s on the 10-bus system and 2.73 s on the 34-bus system.

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