Optimizing Placement of Automatic Sectionalizers in Distribution System Using Genetic Algorithm

Tối ưu hóa vị trí đặt cầu dao phân đoạn tự động trong lưới điện phân phối sử dụng thuật toán di truyền

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Abstract

In recent years, improving the reliability of the distribution power system is one of the most concerned problems of the power utilities. This paper presents the strategy to deal with the problem of automatic sectionalizers placement in radial distribution feeders. Specifically, the genetic algorithm is used to find out the optimized location of automatic sectionalizers on a medium-voltage feeder of northern power distribution system in Vietnam. This study aims to improve the reliability of the distribution network by reducing the SAIDI and ENS indices.

Keywords: optimal placement, genetic algorithm, automatic sectionalizer, distribution network.

Những năm gần đây, các đơn vị điện lực đặc biệt quan tâm đến các biện pháp nâng cao độ tin cậy lưới điện phân phối. Bài báo giới thiệu phương pháp tối ưu hóa vị trí đặt cầu dao phân đoạn tự động trong lưới điện phân phối hình tia. Thuật toán di truyền được sử dụng tính toán vị trí đặt tối ưu cầu dao phân đoạn tự động cho một xuất tuyến thuộc lưới điện phân phối miền Bắc Việt Nam. Nội dung nghiên cứu nhằm mục nâng cao độ tin cậy trong lưới điện phân phối thông qua việc giảm trị số SAIDI và ENS.

Từ khoá: vị trí tối ưu, cầu dao phân đoạn tự động, thuật toán di truyền, lưới điện phân phối

1. Introduction

In recent years, the reliability of the distribution network is the top concern of electric power utilities. Outage duration due to maintenance activities and the fault location is a fundamental index of the network reliability. A number of studies have been carried out to reduce the outage time. The maintenance time may be decreased by implementing a suitable planning and good devices. On the other hand, the outage time due to the fault can be reduced by optimizing the fault recovery process which includes mainly the fault location time and the repair time. While the repair time is affected by the labor qualification, the fault location time can be reduced by using several methods [1].

Distribution grids consist of numerous feeders so that the main problem of fault location is to determine the feeder fault. Many methods for finding out the fault position in the distribution grid have been developed. For instance, a traveling-wave-based method [2], [3] is based on filtering the high-frequency voltage from the transient signal caused by the short circuit, then calculating the distance of the fault from measurement devices. Indeed, the impedance-based method [4], [5] relies on calculating the impedance when the fault occurred in order to identify the position of the fault in the distribution system. Those methods present high accuracy; however, it needs the high-quality devices installed at the terminal of the distribution feeder. Indeed, reconfiguration of the setting of those methods even when a minor change occurs in the grid will be complicated.

Using fault location devices (fault indicators, circuit breakers, reclosers, automatic sectionalizers), will improve the disadvantages of the mentioned methods. In [6] and [7], algorithms used for locating the fault section in the distribution grid when the fault location devices having communication function are implemented. Specifically, [6] presents the method of fault section identification by scanning from the sending end of the distribution feeder to check if there is a different status between two sequents of fault location devices based on a relational table. Another method relied on the matrix calculated by the status of the fault location devices in order to find out the fault section is introduced in [7]. This algorithm is easier to apply but it requires the performance tool for calculating the inverse matrix. Indeed, using fault location devices, which are locating the fault section but not the fault position, does not require high quality device such as high-frequency filter. The most

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concerned problem when using this method relate to the reliability of the fault location devices. Specifically, the probability of the missing information of one or many devices is a bit high and [6] has presented the algorithm for fault section locating when the missing information occurs in devices.

It is obvious that the more fault location devices are implemented, the more accurate the fault location is. In distribution system, the reliability requirement is not as strict as in transmission system. Applied methods must take into account both the investment cost and the efficacy. Indeed, two main questions of using fault location devices have been revealed. Firstly, it is important to determine the optimized number of these devices to achieve the expected reliability. In other hands, it is nesscessary to find out the optimal placement of a pre-fixed number of devices to minimize the reliability index such as SAIDI. In [8] and [9], Genetic Algorithm (GA) was used to find the number of the fault location devices and their optimal placement in a distribution feeder. In this paper, the problem of finding out the optimal placement of a pre-fixed quantity of automatic sectionalizers in a distribution system will be discussed.

2. Problem formulation

2.1. Fault location method

Based on [10] and [11], optimal placement of fault location devices in a feeder was solved in [8] using Genetic Algorithm (GA) [12]. Automatic sectionalizer presents some different features from fault indicator. Specifically, automatic sectionalizer has a more complex structure than fault indicator, it includes two current transformers, one is used for current measurement and other is used for supplying mechanical system. Furthermore, automatic sectionalizer is able to break the circuit on-load or off-load (with upgrade version including arc-quenched function) in order to isolate the fault section, keep supplying power for the front loads of the feeder. On the other hand, instead of being able to be mounted onto the overhead line as fault indicator, automatic sectionalizer can only be installed on the pole. Thus, the optimized position of the fault indicator on a distribution feeder is a continuous variable, while being a discrete variable in case of automatic sectionalizer. The fault section can be determined by methods presented in [6] and [7] or by observing status of installed fault indicator. The fault position is located on the nearest downstream of a fault location device if it is triggered and all of its downstream are not. For instance, in Fig 1, a radial feeder using 8 fault location device records a short circuit in the section connecting the 4th and 5th device. The fault section is determined by checking the status of the 4th and 5th device. The 5th device is not triggered by the short circuit current while the 4th is, which means the fault is located on the downstream of 4th device and on the upstream of the 5th device. In order to locate even faster the fault section thereby reducing the outage time, the communication between each fault indicator with server is required. Indeed, by using sectionalizers instead of fault indicators, only downstream loads of the 4th device will be out of voltage.

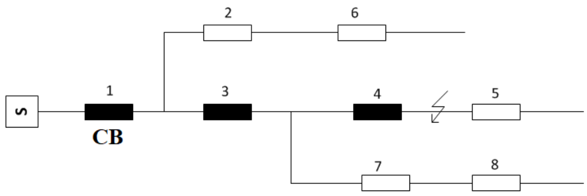

Fig. 1. Radial feeder using fault indicators

2.2. Determining the main feeder

In case of limited number of fault indicators, it should be considered to install available devices on the main feeder. The latter is defined as the feeder that connects the 1st bus to the farthest one from it. The main feeder might be identified by an algorithm, which was introduced in [10]. This algorithm uses the line data including the position (the upstream and downstream buses of each bus) and the distance between a bus and its upstream position. Reminding that in radial distribution feeder, a bus might have many downstream ones, but no more than one upstream bus (the 1st bus has no upstream bus). Before determining the main feeder, it is necessary to clarify the information regarding the bus data as listed in Table 1.

Table 1. Bus data

Bus no	Upstream bus	D (km)	P	N	S

Where, "Bus no" is the sequence number of the bus on the feeder. This column should arrange the number of bus from 1 to the maximum number. "Upstream bus" represents the upstream bus of the one on the 1st column. *"D"* is the distance (km) between two bus on the same row of the 1st and 2nd column. *"P"* and *"N"* is the proportion of the total load and customers respectively affected when the bus on the 1st column cut out. *"S"* is the sum of *"P"* and *"N"*.

Assuming that vector x has the length of n (n is the total number of the bus in that feeder), in which x_i is the distance from the i^{th} bus to the 1st one. Vector D having the same size as vector x, and D_i is the distance from the i^{th} bus to its upstream bus, in other words, vector D is presented by the 3rd column of Table 1. Matrix A (n x n) was defined from equations in [10]. In this paper, the method of determining matrix A is introduced in perspective of programming. Specifically, the value $A(i, i) = 1$ and $A(i, j) = -1$ if the upstream bus of the i^{th} bus is the j^{th} bus, with $i = 1..n$. The rest values of A which does not meet the mentioned condition of i and j return to 0. Then, the vector x can be calculated following the equation (1) below [8] [10]

$$x = A^{-1}.D \tag{1}$$

As mentioned, each bus in a distribution feeder has only one upstream position except for the 1st bus. Thus, each row from the 2nd to the end of the matrix A has only two values and the 1st row has only one value, which means x_1 is known.

With the result of vector x, it is necessary to find out the maximum value of x, x_{max} *(eg,* $x_k=x_{max}$*)*. It means the k^{th} bus is the final bus on the main feeder because it is the farthest bus from the 1st one. In order to determine all the bus included on the main feeder, it is required to identify the k^{th} row of the matrix A^{-1}. The position having the value of 1 is the bus included on the main feeder.

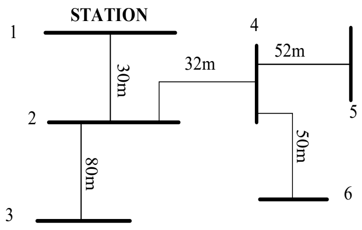

Fig. 2. Examples of 6-bus distribution feeder

The mentioned method is used to identify the main feeder of a distribution feeder having 6 bus (Fig 2). The result of matrix A and vector D is:

$$\mathbf{A} = \begin{pmatrix} 1 & & & & & \\ -1 & 1 & & & & \\ & -1 & 1 & & & \\ & -1 & & 1 & & \\ & & & -1 & 1 & \\ & & & -1 & & 1 \end{pmatrix}; \mathbf{D} = \begin{pmatrix} 0 \\ 30 \\ 80 \\ 32 \\ 52 \\ 50 \end{pmatrix}$$

Applying Equation (*1*), the result of vector x is:

$$x = A^{-1}.D = \begin{pmatrix} 0 \\ 30 \\ 110 \\ 62 \\ 114 \\ 112 \end{pmatrix}$$

The maximum value of vector x is 114 (m) at the 5th position, which means that the 5th bus is the farthest bus from the 1st bus and it is the final bus on the main feeder. In order to determine the bus included on the main feeder, it's necessary to identify the 5th row of the inverse matrix of matrix A, which is shown as following:

$$\mathbf{A}^{-1} = \begin{pmatrix} 1 & & & & & \\ 1 & 1 & & & & \\ 1 & 1 & 1 & & & \\ 1 & 1 & & 1 & & \\ 1 & 1 & & 1 & 1 & \\ 1 & 1 & & 1 & & 1 \end{pmatrix}$$

The 5th row of matrix A^{-1} is:

$$A_5^{-1} = \begin{pmatrix} 1 & 1 & 0 & 1 & 1 & 0 \end{pmatrix}$$

The terms showing the value "1" are the 1st, 2nd, 4th and 5th thereby the main feeder consists of four buses such as 1-2-4-5.

2.3. Fitness function

The implementation of automatic sectionalizer aims to improve the reliability of distribution system by reducing the reliability indices. In this paper, SAIDI (System Average Interruption Duration Index) and ENS (Energy Not Supplied) [13] are used for establishing the fitness function. These indices can be calculated as Equation (2) and (3):

$$SAIDI = \frac{\sum N_i.T_i}{N} \text{ (h)} \tag{2}$$

$$ENS = \sum P_i.T_i \text{ (MWh)} \tag{3}$$

Where N_i and T_i *(h)* are respectively the number of customers and annual outage time for bus i. N is the total number of customers served. P_i *(MW)* represents the total load relating to bus i. In this paper, only interruptions due to faults are considered. T_i includes the reflex time of the protection system, the fault location duration and the repair time. This study focuses on reducing the fault location time.

In order to minimize SAIDI and ENS, it is important to reduce the term $N_i.T_i$ and $P_i.T_i$ of each outage as much as possible. The recovery time when a fault occurs is affected by the distance from a bus i to the nearest fault indication device including circuit breaker, recloser, sectionalizer or fault indicator. Thus, instead of reducing the terms $N_i.T_i$ and $P_i.T_i$, the fitness function's goal is to minimize the terms $N_i.d_i$ and $P_i.d_i$, where d_i is the distance from the bus i to the nearest fault indicated device.

The fitness function F can be written as the following equation: [8]

$$F = \sum_{k=1}^{m} (P_k.\alpha_p + N_k.\alpha_N).d_k \quad (4)$$

Where m is the number of bus on the main feeder, k is the sequence number of the bus on the main feeder, N_k and P_k are respectively the number of customers and load power affected by an interruption at k^{th} bus, d_k is the distance from the k^{th} bus on the main feeder to the nearest sectionalizer, α_P is the load factor and α_N is the customer factor. As P_k and N_k do not have the same unit, these terms need to be normalized. Specifically, these values are calculated as the proportion of the total load power and number of customers in the feeder. Indeed, installing new device will reduce the term d_k of each bus, thus, the placement will be optimized if F is minimized.

The calculation of coefficients α_P and α_N are based on data analysis of the power utility. In this paper, α_P and α_N are assumed to be 1.

Vector Z representing the distance can be shown as below:

$$Z = (x_k,\ x_k - x_{FI1},\ldots,\ x_k - x_{FIp},\ x_k - z_1,\ldots,\ x_k - z_n)^T$$

$$d_k = \min(Z) \quad (5)$$

Where n is the number of the automatic sectionalizer to be installed; $x_{FI1},\ldots, x_{FIp}$ is the distance from the sectionalizer having already been installed on the main feeder to the 1st bus; $z_1,\ldots, z_n$ is the distance from the sectionalizer to be installed to the 1st bus.

The purpose of this study is to find out $z_1, z_2,\ldots, z_n$ in order to minimize the fitness function F. The constraint of this problem is that all the variables must be positive and smaller than the length of the main feeder. As sectionalizers can only be installed at the pole, those variables are discrete.

2.4. Genetic Algorithm (GA)

The mentioned problem is the mix-integer non-linear problem which cannot be solved by a regular method using derivation. Thus, it needs an algorithm carrying out the minimum of the fitness function F without derivation. Algorithm determines the minimum by searching is recommended such as Genetic Algorithm (GA) [12] or Particles Swarm Optimization (PSO) [14].

In this article, Genetic Algorithm (GA) is used to finding out optimal positions for a pre-fixed number of sectionalizers in a radial distribution system.

Genetic Algorithm is an optimization and search technique based on the principle of genetic and natural selection. It simulates the development of nature includes discard, mating, mutation, etc. This algorithm can deal with a large number of variables being either continuous or discrete. The detailed steps of GA is introduced in [12]. Firstly, GA initiate a population of samples (chromosomes) of the variables (genes). The size of the population is inversely proportional to the calculation speed but eventually directly proportional to the accuracy of the result. In this paper, the population size is set as 200. Then, GA ranks the value of the cost function of each chromosome and keeps the best ones. Next, GA selects mates for mating. there are four ways to select mates, namely pairing from top to bottom, random pairing, weight random pairing and tournament. Tournament is used in this study. The selected chromosomes will then be mating to produce new chromosome by swapping the number of genes for each other. Furthermore, in order to avoid converging too fast at local minimum, it is important to have a mutation process, this step will produce new chromosomes without involving to the mating process. Finally, GA checks the converging conditions. In case of divergence, GA uses the discarding process. Indeed, discrete variables need to be decoded into 2-bit term and encoded back at the end of the algorithm.

2.5. Optimal placement of fault location device in distribution system

Firstly, it is necessary to identify the reliability indices of each feeder. Then, based on these indices, the quantity of the fault location devices to be installed of each feeder will be determined by the term p_i:

$$p_{Si} = \frac{SAIDI_i}{\sum SAIDI} \quad (6)$$

$$p_{Ei} = \frac{ENS_i}{\sum ENS} \quad (7)$$

$$p_i = \alpha p_{Si} + (1-\alpha).p_{Ei} \quad (8)$$

Where ∑SAIDI is the total SAIDI of the grid, ∑ENS is the total ENS of all the feeder, p_{Si} is the proportion of the SAIDI index of the i^{th} feeder, p_{Ei} is the proportion of the ENS index of the i^{th} feeder, p_i is the proportion of the number of the sectionalizer to be installed on the i^{th} feeder compare to the total number of the devices to be installed in the distribution system. α represents the factor of the importance of SAIDI compared to ENS, it can be calculated as:

$$\alpha = \frac{\alpha_N}{\alpha_N + \alpha_P} \quad (9)$$

As mentioned previously, $\alpha_P = \alpha_N = 1$ thus $\alpha = 0.5$.

The number of devices for each feeder can be calculate as following:

$$n_i = \mathrm{round}(n.p_i) \quad (10)$$

Where n is the total number of sectionalizers to be installed in the whole distribution system, n_i is the number of devices to be installed in the i^{th} feeder. Since the number of devices is an integer, it needs to be rounded using (10).

The process of solving the problem of determining the optimal placement of sectionalizer in distribution system is presented by following diagram.

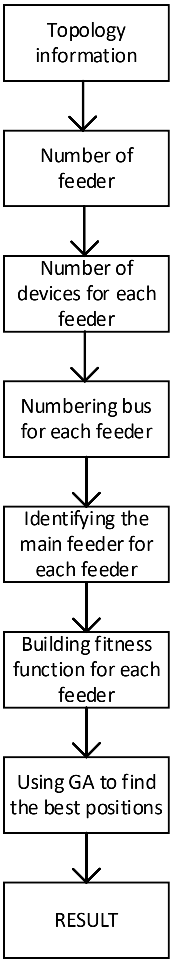

Fig. 3. The process of solving the problem

3. Case study

In this paper, optimal placement of ten sectionalizers on a medium-voltage feeder in northern power distribution system of Vietnam (Fig.5) was calculated.

Main information of the feeder under study is presented on Table 2.

Table 2. Main information of the feeder under study

Length of main feeder (km)	Total load (MW)	Number of bus	Fault indication devices already installed
13,77	26,32	91	01 Circuit breaker at bus 1 and 01 Circuit breaker at 7,185km from bus 1

Table 3. Genetic algorithm (GA) parameters

Number of population	Mate select method
200	tournament

This study deals with minimizing the fitness function consisting of 10 discrete variables. It varies between 0 and the length of the main feeder. The parameter used for GA process in this paper is shown on Table 3.

The main feeder including 13 bus was determined by following the process presented in 2.2. Then, the GA is applied for identifying the optimal location of ten sectionalizers.

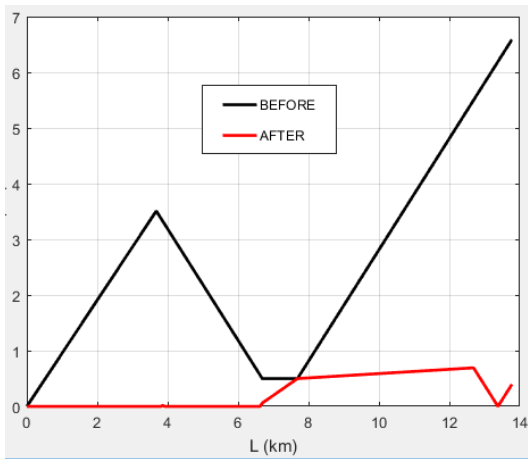

Fig. 4. The result of d_k of each bus in the main feeder

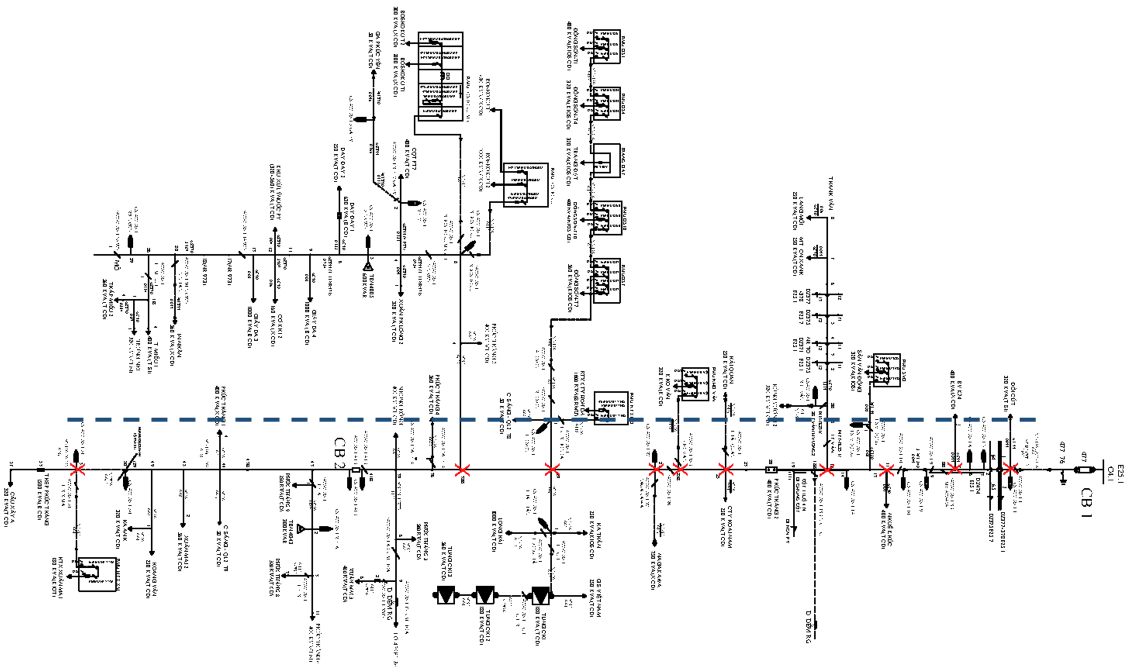

Fig. 5. Studied distribution network including main feeder (dash line) and final sectionalizers' placement (red X mark)

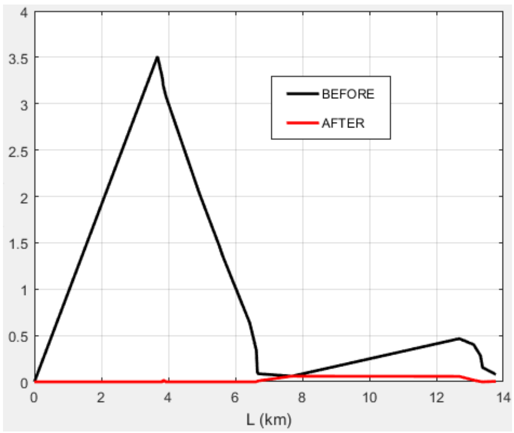

Fig. 6. The result of $(P_k+N_k).d_k$ of each bus on main feeder

4. Result

Applying the Genetic algorithm allowed us to determine optimized position of ten sectionalizers. These devices can be installed at the bus number: 2, 3, 4, 7, 12, 15, 17, 19, 34 and 83 (Fig.5).

Fig. 4 illustrates values of d_k of each bus on the main feeder. It is clear that the term d_i of all the bus on the main feeder decreases drastically when installing 10 new sectionalizers.

As a result, values of the term $(P_k+N_k).d_k$ for each bus on the main feeder show a clear drop-off. It is obvious that the cost function is reduced due to a lower characteristic.

5. Conclusion

This paper shows the study of determining the optimal placement for a pre-fixed quantity of sectionalizers in a real-life distribution system. The main feeder was identified and ten optimal positions on this feeder were located using genetic algorithm. Nevertheless, some important data such as load factor, load forecasting and distributed generation need to be analyzed and considered.

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