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Optimal Planning of a Load Transfer Substation Pair between Two Normally Closed-Loop Feeders Considering Minimization of System Power Losses Using a Genetic Algorithm

Wei-Tzer Huang
Department of Electrical Engineering
Chienkuo Technology University
Changhua City, TAIWAN
vichuang@ctu.edu.tw

Kai-Chao Yao
Department of Industrial Education and Technology
National Changhua University of Education
Changhua 500, Taiwan
kcyao@cc.ncue.edu.tw

Shiuan-Tai Chen, Hsiau-Hsian Nien, Deng-Chung Lin, Po-Tung Huang
Department of Electrical Engineering
Chienkuo Technology University
Changhua City, TAIWAN
chen6502@ctu.edu.tw, nien@ctu.edu.tw, ldt@ctu.edu.tw, ddo8291442@yahoo.com.tw

Abstract—**This paper proposes an effective approach for planning a load transfer substation pair(LTSP) between two normally closed-loop feeders considering minimization of system power losses. Firstly, the annual equivalent load of each load point is calculated. Then, a genetic algorithm-based (GA-Based) approach has been proposed to solve this optimization problem. The objective is minimization of the annual system power losses. Finally, the optimal LTSP was chosen considering minimizing annual system power losses and the maximum voltage drops at each bus as well as ampere capacities of each feeder segment. The method presents in this paper are valuable to distribution engineers for planning the LTSPs between normally closed-loop feeders.**

Keywords- distribution feeder, normally closed-loop feeder, distribution substation, genetic algorithm, power losses.

I. INTRODUCTION

In Taiwan, high reliable and quality of electrical power supply is essential for supporting the high-tech industrial development and living standards; especially in science-based industrial parks, business districts, and computerized skyscrapers. Some customers cannot afford either a short-period interruption or a long-duration voltage dip. Thus, the existing radial or open-loop type primary feeders are unqualified to serve their customers, even more the load-transfer facilities used to limit the effects of primary distribution feeder faults, momentary interruptions still exist while a fault occurs. Additionally, most of the power outages that customers have experienced were due to faults occurring in distribution systems [1]. Figure 1 shows the statistics of the frequency of customer outages in the Taipei City District of Taipower. It is clear that the customer outages were mainly owing to faults occurring at the primary feeder. This major cause of customer outage accounted for more than forty percent of the total customer outages. If we can make sure no service will be interrupted when a single fault occurs at the primary feeder, then service reliability can be improved considerably.

In general, in order to serves different kinds of customers, six common types of feeder arrangements were adopted [2-4], they are radial, open loop, normally closed-loop, mesh, link arrangement, and interconnected network. In which a normally closed loop is designed so that no customers connected to the loop will be out of service when a fault occurs at the primary feeder. Consequently, some of existing Taipower distribution systems had been upgraded their feeder arrangements from radial or open loop to a normally closed-loop type in 2002 [5]. According to [5], the normally closed-loop arrangements which fed by the same power transformer was recommended to Taipower, and was also undertaken by Taipower to create three normally closed-loop feeders in the service area of Hulin Substation, Sinyi District, Taipei City. However, this feeder arrangement can't avoid interrupting while a fault occurs upstream the primary feeder. Once a fault occurs in the distribution substation or sub-transmission system, customers connected to the closed-loop circuit will be out of service. In order to improve the service reliability, the LTSPs must be designed and decided in system planning stage. In this paper, a genetic algorithm is proposed to search for a LTSP between two normally closed-loop feeders.

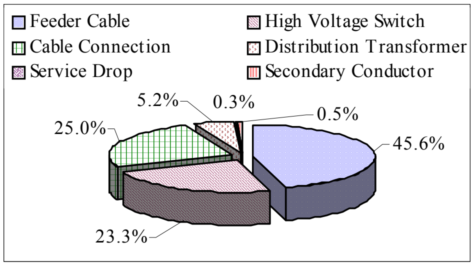

Figure 1. The frequency of customer outages in Taipei City District of Taipower

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II. PROBLEM DESCRIPTION

A. *Structure of the Normally Closed-Loop Feeders*

Figure 2 shows the typical normally closed-loop feeder arrangements fed by the same main transformer with a LTSP. Once there is a fault occurs upstream the normally closed-loop feeders, a faulted closed-loop feeder will become two radial feeders, and the customers connected to faulted feeder will be transferred to a healthy normally closed-loop feeder fed by another substation via the load transfer facilities to restore power supply. Therefore, the selection of the LTSPs is vital important in system planning stage. It will affect the operating performance under abnormal operation conditions, such as the system power losses, current flow distributions, voltage drops, as well as short-circuit capacities, and so on. Consequently, the better the LTSPs selected, the better the operation performance of the system becomes. In general, the major considering for planning the LTSPs is to keep the line flow distributions of transferred feeders uniformly as possible as it could be. This consideration will avoid unbalancing load distribution along the faulted feeder that became two radial feeders and over loading some feeder segments. Accordingly, the optimal planning of the LTSPs must consider the ampere capacities of conductors and voltage drops in each feeder segment to ensure the system operating safely during the faulted period. Additionally, a long-term operation under the load transfer condition must be considered, thus, this paper proposed an objective of minimizing system power losses to search for the optimal LTSPs under the load transfer condition. And this approach also subject to ampere capacity and voltage drop. It will not only ensure the system is able to operate safely, but also increases the operating efficiency even under abnormal conditions.

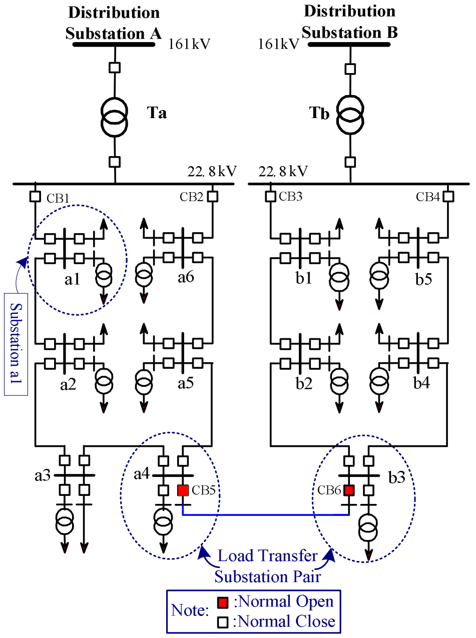

Figure 2. Schematic diagram of the typical normally closed-loop feeder arrangements fed by the same main transformer with a LTSP

B. *Load Transfer Procedure*

The operating scheme of the typical normally closed-loop feeders could be classified into normal and abnormal conditions. As shown in figure 2, under normal condition, each closed-loop circuit is normally closed, and the tie breakers at two ends of the tie line are normally open. Under abnormal condition, there were five kinds of contingencies, which were busbar, lateral, feeder main, main transformer, and sub-transmission line faults. Only sub-transmission line, main transformer, and busbars at 161kV/22.8kV distribution substation faults occur will cause outage, and then the load transfer procedure must be executed. Followings are the procedure of load transfer for the specific structure:

1) *Load Transfer Scheme* $A \rightarrow B$ *:*

Once a fault occurs at upstream area of a closed-loop circuit in distribution substation A, all the circuit breakers in the protective zone will be opened, and then the circuit breakers CB1 and CB2 at two feeding ends of the closed-loop circuit will be opened. The closed-loop circuit became two radial circuits, and the two radial circuits transferred to the interconnected substation B by closing the tie breakers CB5 and CB6 at two ends of the tie line.

2) *Load Transfer Scheme* $B \rightarrow A$ *:*

Similarly, once a fault occurs at upstream area of a closed-loop circuit in distribution substation B, all the circuit breakers in the protective zone will be opened, and then the circuit breakers CB3 and CB4 at two feeding ends of the closed-loop circuit will be opened. The closed-loop circuit became two radial circuits, and the two radial circuits transferred to the interconnected substation A by closing the tie breakers CB5 and CB6 at two ends of the tie line.

III. PROPOSED GA-BASED APPROACH

A. *Objective Function*

Generally, the LTSPs has two load transfer conditions, one is the fault occurs in distribution substation A, and the faulted closed-loop circuit was transferred to distribution substation B, the system power losses was represented by (1); the other is the fault occurs in distribution substation B, and the faulted closed-loop circuit was transferred to distribution substation A; similarly, the system power losses was represented by (2). Combining (1) and (2), the total system power losses can be formulated as (3).

$$P_{loss}^{A\rightarrow B} = \sum_{j=1}^{m} I_j^2 \cdot R_j + I_{TL}^2 \cdot R_{TL} \tag{1}$$

$$P_{loss}^{B\rightarrow A} = \sum_{j=1}^{m} I_j^2 \cdot R_j + I_{TL}^2 \cdot R_{TL} \tag{2}$$

$$TP_{loss} = P_{loss}^{A\rightarrow B} + P_{loss}^{B\rightarrow A} \tag{3}$$

Where I_j and I_{TL} are the current of the *j*th feeder segment and the tie line, respectively. Besides, R_j and R_{TL} are the resistance of the *j*th feeder segment and the tie line, respectively. Using (3), the optimization problem can be expressed as (4).

Minimize

$$f = TP_{loss} \tag{4}$$

Subject to

$$VD_k < VD_k^{\max.} ; k = 1,2,...,n$$

$$I_j < I_j^S ; j = 1,2,...,m$$

Where $VD_k^{\max.}$ is the maximum value for voltage drop, it is 3% of the system nominal voltage. Besides, the I_j^S is the maximum allowable line current in feeder segment j under load transfer condition, and the value is 450 A.

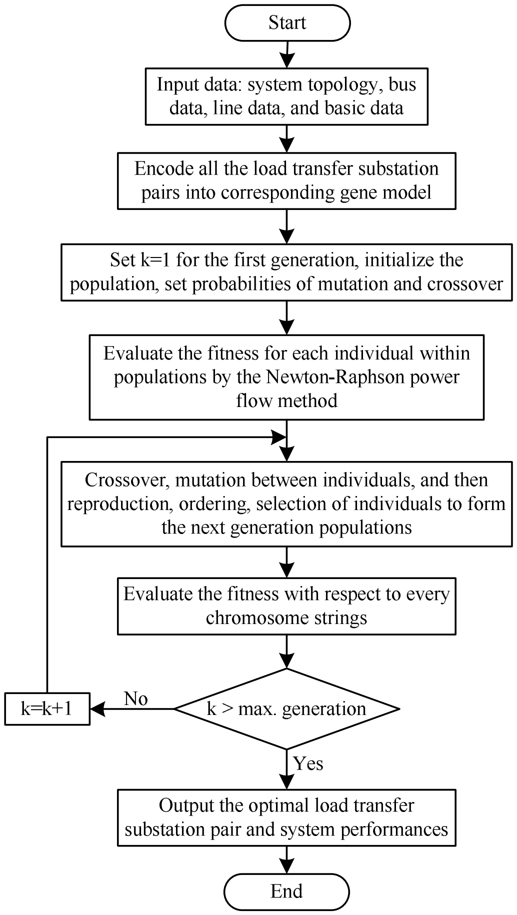

Figure 3. A flow chart of the proposed GA-Based Approach

B. *Genetic Model*

Genetic algorithm is based on the Darwinian principle of natural evolution [6-7]. This optimal search algorithm has been successfully applied to many fields applications, such as optimal sizing of PV-Diesel-Battery system [8], optimization of short-haul airline crew pairing problems [9], multi-user detection in DS-CDMA systems [10], simulating fuzzy numbers for solving fuzzy equations [11], fuzzy PID controller [12], and so on.

According to the GA, each MV/LV substation was mapped to a gene according to the bus number in different distribution substations. Hence, the length of chromosome (string) was decided by the number of interconnected distribution substations. In this paper, the gene of ith MV/LV substation in an interconnected distribution substation was encoded by binary code, B_i , and was decoded by:

$$LTS_i = D_{i,\min} + \frac{(D_{i,\max} - D_{i,\min}) \times B_i}{2^{n_i} - 1} \tag{5}$$

In which, $D_{i,\min}$ and $D_{i,\max}$ denote the lower and upper limits of the substation number; n_i is the binary bits of B_i . Therefore, the length of chromosome (a LTSP) is twice of the length of LTS_i . Equation (6) showed the fitness function (FIT) for the proposed algorithm.

$$FIT = TP_{loss} \tag{6}$$

Minimize

$$FIT \tag{7}$$

It is essential to evaluate the fitness of individuals within the population for every generation. Therefore, a Newton-Raphson power flow was developed and used to evaluate the total system power losses, voltage drops and line currents, etc. A flow chart of the proposed approach is illustrated in figure 3.

IV. NUMERICAL RESULTS

A sample system with 11 MV/LV substations as shown in figure 4 was used to demonstrate the proposed approach. Table 1 showed the distance corresponding to all possible LTSPs, and the equivalent annual loads as shown in table 2, calculated based on the type of distribution transformer bank, the load on secondary side and their corresponding load patterns. The initial population and its corresponding string were generated randomly. The propagating procedure will last until generations meet maximum generation. The simulation results are shown in figure 5 and 6 with 300 and 500 generations, respectively. The outcomes demonstrate that the optimal LTSP is A4&B4, and the corresponding annual system power losses are 377.7 kW without violating the constrains.

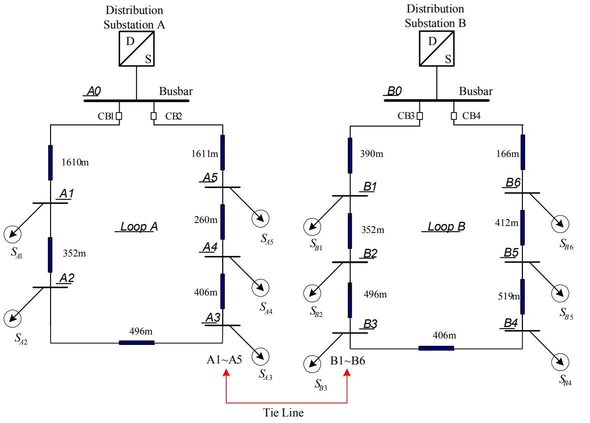

Figure 4. Sample System

Table 1 The distance between the LTSPs

From Bus	To Bus	Length	From Bus	To Bus	Length
A1	B1	20 m	A3	B4	406 m
A1	B2	352 m	A3	B5	925 m
A1	B3	848 m	A3	B6	1337 m
A1	B4	1254 m	A4	B1	1254 m
A1	B5	1779 m	A4	B2	902 m
A1	B6	2185 m	A4	B3	406 m
A2	B1	352 m	A4	B4	20 m
A2	B2	20 m	A4	B5	519 m
A2	B3	496 m	A4	B6	931 m
A2	B4	902 m	A5	B1	1514 m
A2	B5	1421 m	A5	B2	1162 m
A2	B6	1833 m	A5	B3	666 m
A3	B1	848 m	A5	B4	260 m
A3	B2	496 m	A5	B5	1185 m
A3	B3	20 m	A5	B6	1597 m

Table 2 Equivalent annual loads of the sample system

Bus No.	Real Power	Reactive Power	Bus No.	Real Power	Reactive Power
A1	1201 kW	387 kvar	B1	5061 kW	1663 kvar
A2	6902 kW	2269 kvar	B2	2561 kW	965 kvar
A3	5681 kW	1867 kvar	B3	886 kW	378 kvar
A4	2408 kW	792 kvar	B4	1308 kW	489 kvar
A5	741 kW	244 kvar	B5	1702 kW	559 kvar
			B6	4320 kW	1420 kvar

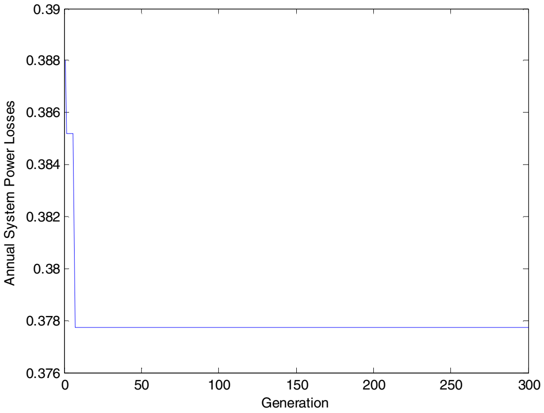

Figure 5. Simulation result with 300 generations

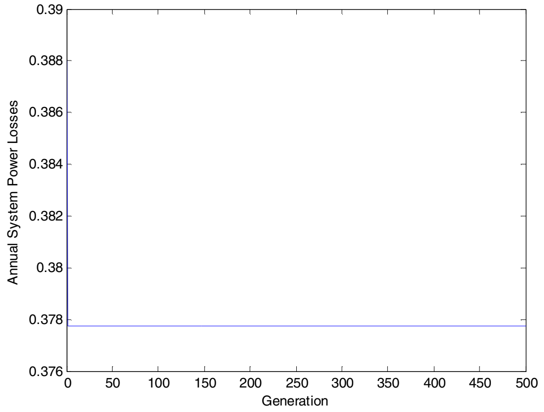

Figure 6. Simulation result with 500 generations

V. CONCLUSIONS

An effective GA-Based approach has been presented to search for an optimal LTSP between two normally closed-loop feeders fed by different distribution substations. Based on the proposed approach, a program that is composed of GA and Newton-Raphson power flow method has been developed to perform the optimal LTSP considering minimizing annual system power losses and the given constrained. Numerical results of the sample system showed that the selected optimal LTSP is with minimum power losses and safely operating range of voltage and current profiles. Thus, the proposed method presents in this paper is helpful for distribution engineers for planning the LTSPs between normally closed-loop feeders.

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