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An Algorithm on Optimal Placement Decision of Automatic Switches for 6 Sections/3 Links Configuration in DAS

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Abstract – A Distribution Automation System (DAS) is operated by monitoring and control of the field statesusing Feeder Remote Terminal Units (FRTUs) installed together withautomatic switches.An optimal placement of automatic switchescan enhance efficiencyof the operation and restoration, and improve the power supply reliability ofa DAS.This paper proposes an algorithm to decide the optimal placement of automatic switches ina DAS.The proposed algorithm was developed ona DAS witha six sections and three links configuration. The proposed algorithm was provided inaneight-feeder power distribution system.

Keywords: Distribution automation system, Automatic switch, FRTU, Power distribution system

1. Introduction

A Distribution Automation System (DAS) operatesre-motelyby monitoring and control of power distribution system through Feeder Remote Terminal Units (FRTUs). FRTU measuressystem information from the field andre-ports them to a DAS server. The DAS can control and changethe power distribution system configuration for optimal operation through the FRTUs installed together with automatic switches [1].

The placement of automatic switches with FRTUs (A/S) is the most important element in increasing the operation efficiency of a DAS. When fault occurs on the power distribution line of a DAS, a restorationmakesa minimized blackout areadepends on controls of the A/S switches. The minimized blackout area means power is supplied to the customers to except customers of fault section; hence, the placement of the A/S switches should be considered a vital factor in the operation of a DAS.

To date, automatic switches in a DAShave beeneither installed when a DASis initiallyconstructed or addedlater. Although a distribution of the automatic switches in a DASis required to be constructed with six sections and three links configuration, the automatic switches have been installed a position to be required by operation and as a result, six sections and three links configuration weren't kept in the field.

To increase the operation efficiency of a DAS,many papers have been published for deciding the optimal placement of automatic switches. Several studies have sought to address this problem from various aspects. Reference [1] studied the placement of power facilities from a geographical perspective. In [2-6], the placements of switches were located using the intelligence algorithms. The switch location,which takes the operating reliability into account, was introduced in [7–9]. Moreover, methods considering various economic viewswere explored in [10].

The mostefficient function of a DAS is restoration through remote monitoring and control. However, previous researches have studied placements of automatic switches from initial system planning, butdid not consider restoration efficiency.

In this paper, an algorithm is proposed to decide the optimal placement of automatic switches considering the outage load equalization forthe restoration of the DAS. The proposed algorithm is applied tothe six sections and three links system configuration. Section 2 explains the relationship between the placements of automatic switches and restoration under the configuration of six sections and three links. Section 3 illustrates the optimal placement of automatic switches algorithm through three steps. In Section 4, the effectiveness of the proposed algorithm is proven by case studies.

2. Relation of the placement of automatic switches and restoration in DAS

In a distribution feeder, asection is defined by a group of line segments between adjacent switches or circuit breakers.

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Each section has manycustomers and a section loadis decided fromthe summation of a contract load or the maximum load of customers within a section[10]. A link is defined as the connection with an automatic tie switch thatis opened normally and closed for restoration. In the current study, a voltage level is 22.9 kV, a normal permit capacity(C_n) is 10 MVA, and an emergency capacity(C_e) is 14 MVA on a power distribution line.

The optimal number of links to different feeders can be obtained as follows:

$$L_n \geq \frac{C_n}{(C_e - C_n)} \quad (1)$$

where

L_n : number of links
C_n : normal capacity
C_e : emergency capacity.

Eq. (1) indicates a number of necessary links considering a margin for restoration. If feeders are being operated with full loads (10MW) and a fault occurs at a feeder, the faulted feeder may need 10 MW loads for restoration in the worst case. Then, a number of necessary links will be 3 because a result by Eq. (1) is 2.5.

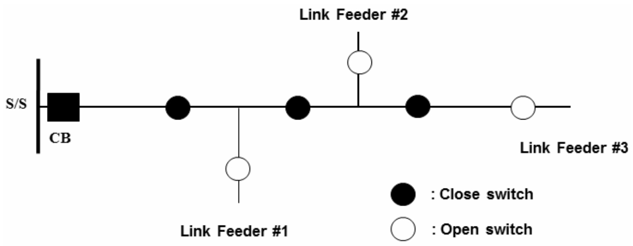


Fig. 1. Three links on a power distribution line

From(1), the optimal number of links can be ascertained as three, and the feederneeds to be divided intoat least four sections. Thus, each link connects a section to the other feeder, except for the first section which only connects to the source, as shown in Fig. 1.

According to an effect by number of section switches, three links based on each case of four sections, five sections, and six sections are shown in Fig. 2. In a four sections case, the section load is 2.5 MVA on a standard that the maximum load on a power distribution line is 10 MVA at a normal state. In a five sections case, the section load is 2 MVA, and in a sixsections case, the section load is 1.6 MVA. In all of the four, five, and six sections cases, a DAS can secure the restoration capacity from other feeders in any fault location. Thus, the outage load is 2.5 MVA when a fault occurs in a structure of four sections. A structure with six sections is better than that with four sections from the standpoint of restoration because DAS can reduce an outage load when a fault occurs.

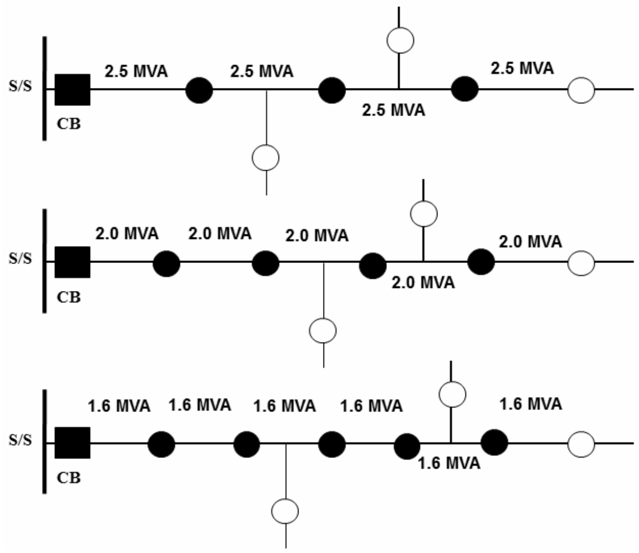


Fig. 2. Structures of four, five, and six sections with three links

Structures with different sections are shown in Fig. 2. As seen from the load distribution in each section, we can infer that more section switches canreduce outage load capacity, but the cost of facilities and management will increase correspondingly. Thus, in this paper, an algorithm on optimal placement decision of automatic switches wasdevelopedby considering a structure of six sections and three links on the power distribution line in DAS following KEPCO's technical report [11].

3. An algorithm for optimal placement of automatic switches

The optimal placement of the automatic switches algorithm is composed of three steps.The first step is to find the normal open switches in the radial distribution lines. The next step is to choosean automatic tie switch among the normal open switches. Finally, the automatic switches to divide sections aredecidedby section load equalization, a position of link line, and the configuration of the six sections.

3.1 Tie Switch Allocation

To determinethe optimal placement of automatic switches, the first step is torearrange the distribution system with eight feeders (Fig. 3) as radial structure.

The optimal placement of the tie switch should enable all feeders to have evenly distributedloads, which also ensure the largest marginconsidering restorationunder the sixsections andthreelinks configuration.

Fig. 4 shows a method to find the location of the tie switch using the following steps:

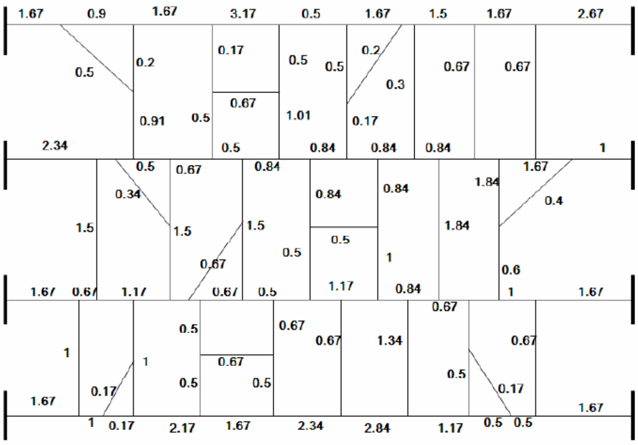


Fig. 3. Eight feeders on the power distribution system

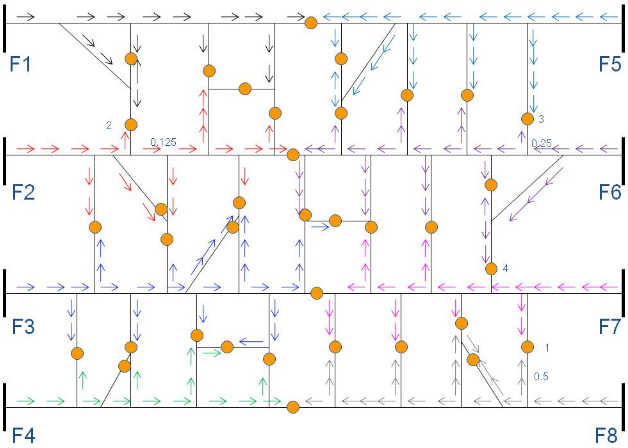


Fig. 4. A method to findthe manual tie switch between feeders

(1) Assume each feeder has a virtual tie switch at the beginning of the feeder;
(2) Move the assumed tie switch along the feeder with evenly distributed loads;
(3) If there are multi-branches along the feeder during the switch movement, add a number of virtual tie switches corresponding to the branch number;
(4) Decide the point where the tie switches meet one another as the normal open point.

If location of the tie switches with the above method is decided, the loads of all feeders would not always be evenly distributed so the tie switch should move from the feeder with larger loads to a feeder with smaller loads.

To ensureevenly distributed loads, we can calculate the minimum sum of the squares of all the feeders. For example, if there are two feeders with loads as 3 and 5 respectively, the sum of the squares would be "9+25=34." If these two loads become evenly distributed, which means that each feeder has a load as 4, the sum of the squareswould be"16+16=32."According to this rule, we can obtain the optimal location of the tie switch.

3.2 Decision of Three Links

The tie switches selected through the procedure in 3.1 are manual tie switches, among which the automatic switches are selected to decide the three links. When a fault occurs in the system, the three links among the feeders are supposed to provide reserved capacity to the faulty feeder. If the links are not properly decided, there would be failure of fault restoration.

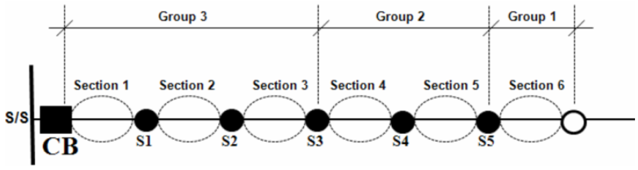


Fig. 5. A process for finding the link with the automatic tie switch line

In the current study, the proposed method which decides the three links location divides a power distribution line as shown in Fig. 5. Assuming that the normal open point is decided, the feeder is divided into sixsections with evenly distributed loads. Then, all sections are grouped into threegroups as shown in Fig. 5.

Three groups should be made byevenly distribution of the loads in all the feeders and a possible that a fault can be in all the feeders. So there would be only one link in each group. According to the six sectionsthree links configuration, the three links can be connectedto sections givenby the rules below:

Rule 1. Section 2, section 4, section 6
Rule 2. Section 3, section 4, section 6
Rule 3. Section 3, section 5, section 6

The tie switches which satisfythe above rules will be selected as the automatic tie switch. Consequently, the restoration can be successfully processed no matter where the fault occurs.

3.3 Decision of Section Automatic Switch Placement

The distribution system would operate efficientlyif all feeders are well configured. However, there arevariouscases that do not satisfy the presented rules in the field.

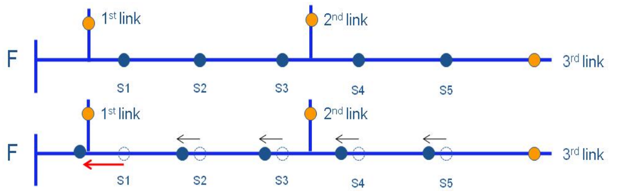


Fig. 6. Decision of the automatic tie switch by moving section A/S (Case I)

Fig. 6 shows a case where there is no linkin Section 2. In this case, if there is a fault occurring in Section 1, with reserved capacity, Sections 4 and 6 cannot conduct the restoration successfully.Thus, S1 moves to the source side and the link is connected to Section 2 to satisfy Rule 1.

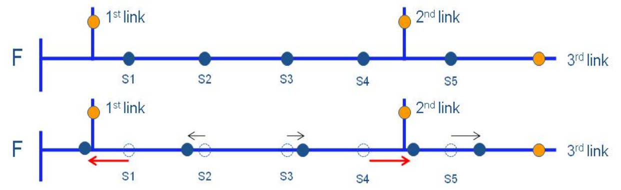
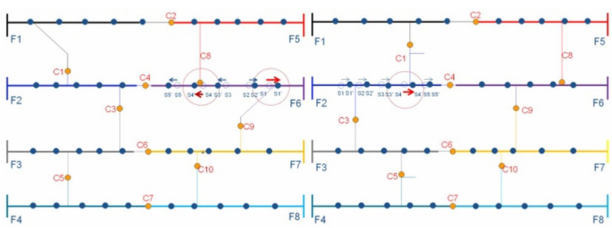


Fig. 7. Decision of the automatic tie switch by moving section A/S (Case II)

In Fig. 7, all sections do not satisfy any rule except the last section. Similarly, we need to move the switches in order to enable all the sections to satisfy the rules of the link connection and the requirement of the load distribution.

In Fig. 8, there are two successful results based on the method to find the three links, and the optimal configuration should guarantee that the loads are evenly distributed.



(a) Success 1 (b) Success 2

Fig. 8. Two results by the proposed algorithm

The distributed parameter to judge the load distribution is calculated by

$$\delta = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n}} \tag{3}$$

where

$\bar{x}$: Average section load of a power distribution line
n : Total section
δ : Distributed load factor
x_i : Load at section i

The two results shown in Fig. 9 correspond to the load distribution of the two systems in Fig. 8. Evidently, Success 2 has a smaller distributed parameter which means that the loads are better dispatched in all the sections.

SUCCESS 1

Feeder	distributed parameter
1	0
2	0
3	0
4	0
5	0
6	0.316
7	0
8	0
Total Distributed parameter (system)	0.112

SUCCESS 2

Feeder	distributed parameter
1	0
2	0.237
3	0
4	0
5	0
6	0
7	0
8	0
Total Distributed parameter (system)	0.084

Fig. 9. Distributed parameters of two configurations

4. Case Study

In order to test the validity of the proposed algorithm, the model system shown in Fig. 10 is adopted for the case study.

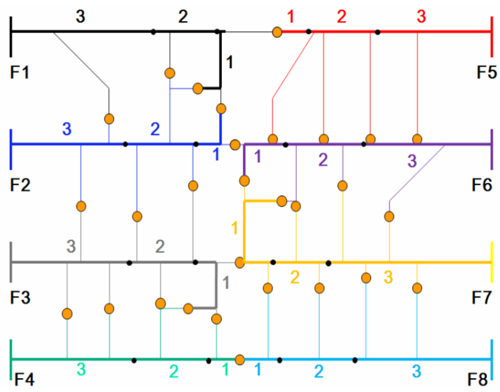


Fig. 10. Initial configuration of the model system

The proposed algorithm is conducted through three steps.The distributed loads of all sections, which are shown in Fig. 11, finally achieved the optimized six sections andthree linksconfiguration.

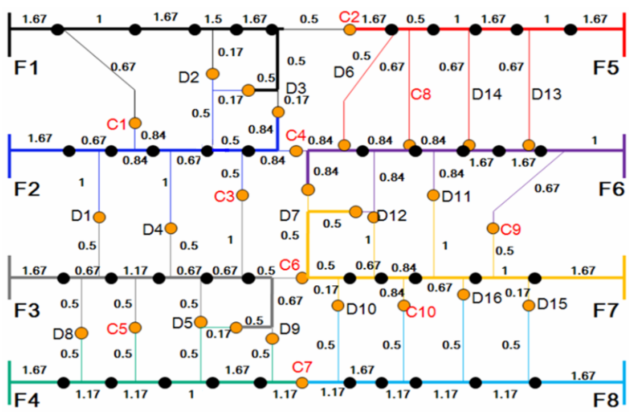


Fig. 11. Load dispersion after optimal placement of the automatic switches

In Table 1, the total load of each feeder is given and the load dispersion is calculated with the loading level 1.67.

Table 1. Load dispersion final results

Feeder number	Total load	Load dispersion
1	10.02	0
2	10.04	0.02
3	10.02	0
4	10.02	0
5	10.02	0
6	10.05	0.03
7	10.03	0.01
8	10.02	0

Through the case study, this paper proves the effectiveness of the algorithm in establishing the optimal placement of automatic switches in the six sections andthree linkscon-figuration.

5. Conclusion

The optimal placement of the automatic switches plays an important role in the restoration of the DAS. To date, the system configuration differs with the variation of the operating condition so that most of them do notcomply with the criterion of the six-section three-link configuration.

In this paper, an algorithm is proposed for the optimal placement of automatic switches to meet the requirement of the six-section three-link configuration. The proposed optimal A/S placement algorithm is composed of three steps: The first step is to find the normal open point of the switches to make the distribution system a radial system. Second, decide the link as the position of the automatic tie switch. Finally,distribute the load evenly to ensure its restoration capacity.

The proposed algorithm is applied to a system with eight feeders to test its effectiveness; it is also loaded to the "Intelligent Distribution Management System" of KEPCO and will be applied in the field soon.

Acknowledgments

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