SERVICE RESTORATION FOR MULTI-OUTAGE AREAS

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Abstract: Service restoration is one of the most important missions in distribution system operation. There are a lot of researches on it about single-outage area. Those mature strategies have already been applied in practice. This paper dedicates to present a new service restoration strategy for multi-outage areas, which are defined as two or more independent outage groups occur at the same time. This proposed algorithm consists of two methods. One is sequential restoration scheme; the other is simultaneous restoration scheme. Sequential restoration scheme determines restoration order of outage areas and then establishes restoration plan for each outage area. If it is not able to establish a quite feasible plan, simultaneous restoration scheme would be launched for establishing a new configuration through tie exchange method.

Keywords: Service restoration, Distribution automation system, Distribution system operation, fuzzy decision-making

1. INTRODUCTION

SINCE primary distribution systems are operated in radial fashion, load on the downstream of the faulted section also experiences power interruption. The service restoration through transferring outage load to the adjacent feeder is one of the most important missions in distribution system operation in case of the fault occurrence. Service restoration planning has a combinatorial nature to deal with the status of the switches.

There have been many research efforts in this area. Most of them adopt heuristic search methods, see (A.L.Merelato, *et al*., 1989; K.Aoki, et al., 1987; V.Susheela Devi, et al., 1995). And expert system approaches not only successfully enhance the credibility of the restoration plan by enhance the capability in recent years, see (C.C Liu, *et al*., 1998; H.Fudo, et al., 1991; S.J. Lee, et al., 1994), but also operator's empirical knowledge.

Authors had proposed a service restoration algorithm which can determine a preferable plan applying the fuzzy-logic technique in dealing with multi-criteria such as the number of switching, load balance, live load transfer and contingency preparedness; see (S.J. Lee, et al., 1998). But there are an assumption and a limitation in that proposed algorithm. The assumption is that backup feeders have enough margins to cope with all outage areas. And the limitation is that the algorithm only can deal with single-outage area.

This paper proposes a new service restoration algorithm to deal with multi-outage area that means there are two or more independent groups of outage section at the same time. And the causes of multi-outage area are main transformer trouble and simultaneous faults in the stormy weather. When the backup feeders do not have enough margins to supply the outage load, this proposed algorithm is able to determine stopping some outage sections power supply according to the load priority.

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2. SERVICE RESTORATION SCHEMES

The proposed algorithm of service restoration consists of two phases. One is sequential restoration scheme, which considers multi-outage area problem as a set of independent single-outage area problem. The other is simultaneous restoration scheme, which will be used to establish another solution if the sequential restoration scheme can not find a feasible plan.

2.1 Sequential restoration

This scheme searches a restoration plan for each outage area independently. It is one of the key points to determine the restoration planning order of outage area, which is dependent on the restoration index that is calculated by fuzzy evaluation of multi-criteria.

Single/Common Backup Feeder; In Fig. 1, there are outage A and B. Outage A is connected to Feeder F1, F2, F9 and F10. After fault 1 occurs, Outage A is isolated from Feeder F1, so there are three available backup feeders, which are Feeder F2, F9 and F10. Outage B is connected to Feeder F2, F3 and F6. After fault 2 occurs, Outage B is isolated from Feeder F3, so there are two available backup feeders which are Feeder F2 and F6. Therefore, there are two necessary terms about the type of backup feeders which would be defined at first. One is 'single backup feeder', which is connected to only one outage area. The other is 'common backup feeder', which is connected to two or more outage areas. So in Fig. 1, Feeder F9, F10 are single backup feeders of Outage A, feeder F6 is a single backup feeder of Outage B, feeder F2 is a common backup feeder of Outage A and Outage B. But the key point lies on deciding which outage area should be supplied electric power by the common backup feeder.

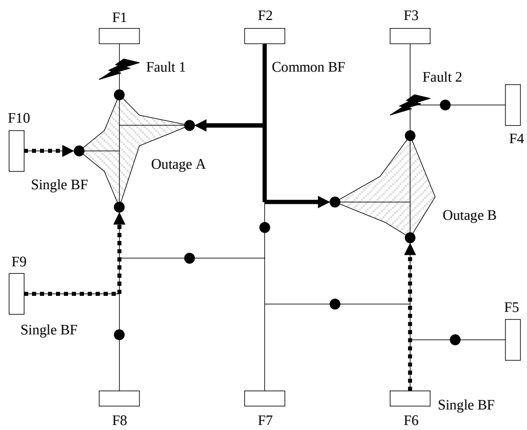

Fig. 1. Single/Common Backup Feeder

Restoration index; It is possible to restore the outage area which has a small load and big backup capacity. In order to calculate the restoration index, fuzzy decision-making of multi-criteria is adopted. Table 1 and Fig.2 show the fuzzy rule and the fuzzy membership functions respectively.

Table 1 Fuzzy rules

BM \ OL	Small	Medium	Large
Small	Good	Medium	Very Poor
Medium	Very Good	Medium	Poor
Large	Very Good	Good	Poor

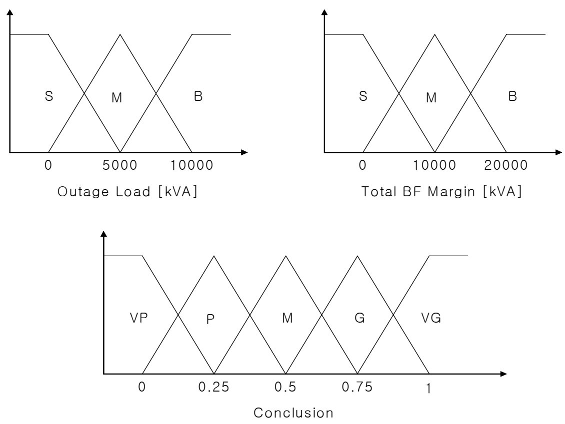

Fig. 2. Membership functions

Single-outage service restoration strategy; Service restoration planning strategy consists of two steps: candidate set generation and fuzzy decision-making. The former tries to find a feasible restoration plan through six basic search schemes, and the latter determines the most preferable plan through the fuzzy evaluation of multi-criteria.

Basic Restoration Scheme:

Self-restoration: This scheme handles the case when a fault occurs on loop formed within a feeder (referred to as 'self-loop' here). The restoration is to be carried out by simply closing an open loop switch to restore the outage area after isolating the fault

Single grouping restoration: Single level-1 backup feeder picks up the whole outage load

Double grouping restoration: Outage load is divided into two groups and transfers to a pair of level-1 backup feeders according to margin ratio

Triple grouping restoration: Three level-1 backup feeders are involved to restore outage load

Single grouping restoration & live load transfer: This scheme assigns a whole outage load to one level-1 backup feeder and releases over loading through live load transfer

Double grouping restoration & live load transfer: This scheme assigns a part of the outage load to a level-1 backup feeder within its margin and the rest of the outage load to another backup feeder. And then the overload of the backup feeder is released through live load transfer

Fuzzy multi-criteria evaluation; At first, evaluation of each criterion using fuzzy rules is performed separately for all alternative plans and the weighted sum of each evaluation result is calculated for each plan in order to determine the most preferable plan. In the evaluation of the fuzzy rules, the conventional max-min composition is used and the center of gravity is applied for defuzzyfication. Four criteria – number of switching, maximum loading of the

backup feeder, live load transfer, and contingency preparedness have been used in the evaluation of the plan. Note that the live load transfer criterion considers two factors – the number and amount of the load transfer and the contingency preparedness of the post restoration configuration considers the total number of backup feeders and the ratio of the total margin of backup feeders over the feeder loading.
The flowchart of sequential restoration is shown in Fig. 3. Single backup feeders and common backup feeders are searched firstly, and then restoration index for all outage areas are calculated. This scheme establishes the restoration plan for the outage area of high restoration index, at the same time, the outage area of low restoration index would be considered. During all the procedures, the restoration plan does not exist if only considering using single backup feeders, and then the common backup feeders have to be used in this scheme for the restoration of some outage area which is not able to get enough power from the connected single backup feeders.

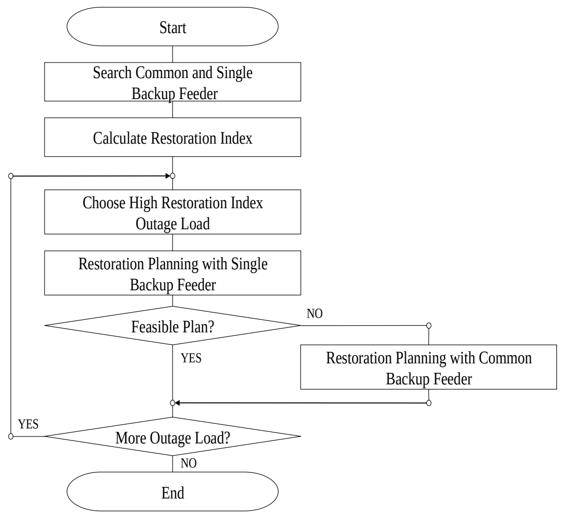

Fig. 3 Flow chart of sequential restoration

2.2 Simultaneous restoration

Simultaneous restoration is triggered when the sequential restoration scheme can not find a feasible plan. Tie exchange method and decoupling property are applied in this scheme. A new configuration of the power system networks can be reconstructed through this scheme. The key point is the new configuration has to always satisfy radial operation condition and the convergence characteristic. Then if overloaded section still exists, according to the importance priority and load capacity of overloaded sections, load shedding would be performed in order to meet line thermal capacity constraint.

Tie exchange method; The simultaneous restoration scheme transfers all outage loads to the adjacent feeders and releases overloading through moving the tie switch along with the direct path between two circuit breakers which are called feeder-pair that is defined below. Tie exchange will be iterated until the loads can be allocated equally and no loss reduction can be achieved in any feeder-pair. And when moving the tie switch, the new system networks has to meet radial operation condition.

Decoupling property; In a radial distribution system, each feeder is decoupled from others through open sectionalizing switches. A pair of feeders joined by an open switch is referred to as a 'feeder-pair' as shown in Fig. 4. Except any feeder-pair, the rest of this system is independent. That means, it does not affect by any change of feeder-pair.

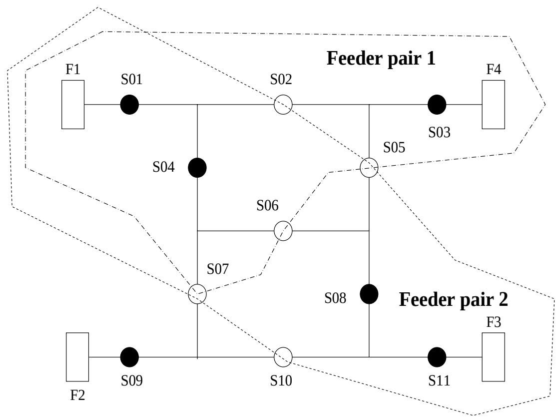

Fig. 4 Feeder pair

Then the following decoupling property results from the decoupled nature of feeder-pairs.
Decoupling property 1:
If the position of the open switch moves along the direct path between two CBs, the resultant network meets radial operating condition constraint.
Decoupling property 2:
If load deviation is reduced by moving the position of normal tie switches within the feeder pair, then the resultant overall system losses are also reduced by the same amount.

Load shedding; In Korea, the standard of the operation capacity of an electric wire is followed ACSR160 [㎟]. In the emergency situation, the maximum of the power supply is 14000[KVA]. After using tie exchange method, the load can be balanced. If the load capacity of some section is still over 14000[KVA], load shedding procedure has to be performed. And the rest of the system can be operated continuously on a normal status. Load shedding means releasing the overload by getting rid of some sections which have to meet the following conditions by the order:
- the type of load is not important
- the load capacity of the candidate section is higher than the overload capacity of the feeder
- it is the minimum about the difference between the load capacity of the candidate section and the overload capacity of the feeder

The analysis of the priority of load shedding is shown in Fig. 5. The load capacity of Feeder 1 is 15000[KVA]. That means the overload capacity is 1000[KVA]. There are three candidate overloaded sections which are Zone 1, Zone 2 and Zone 3. According to the above-mentioned conditions, Zone 2 is an important load, so it cannot be shed. The rest of candidate sections are Zone 1 and Zone 3. The load capacity of both of them is higher than the overload capacity. But the difference of load capacity between Zone 1 and the overload capacity of Feeder 1 is 1000[KVA], nevertheless, the difference between Zone 3 and Feeder 1 is just 500[KVA], so Zone 3 prefers to be shed.

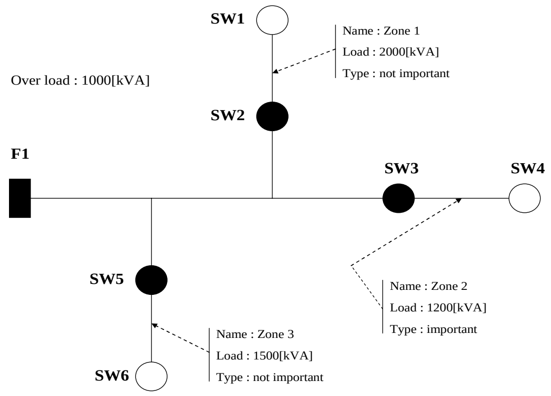

Fig. 5. Load shedding according to load priority

Flowchart of simultaneous restoration; This scheme is using tie exchange method with satisfying decoupling property. And then if the overloaded sections still exist, the procedure of load shedding would be applied for dealing with that. The detailed flowchart of this scheme is show in Fig. 6.

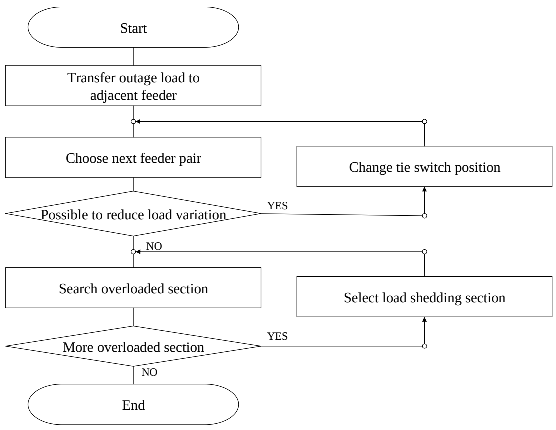

Fig. 6. Flowchart of simultaneous restoration

3. CASE STUDY

There are two case studies. Case study 1 is for sequential restoration scheme, case study 2 is for simultaneous restoration scheme.

Both of the case studies are based on the following example distribution system as shown in Fig. 7. There are 6 feeders and 57 switches in the whole example system.

Table 2 illustrates the main characteristics of the example distribution system such as feeder name, substation name, circuit breaker and feeder loading.

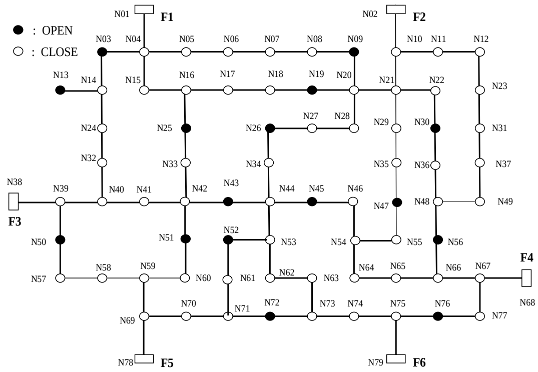

Fig. 7. The example distribution system of six feeders

Table 2 Data of example distribution system

Feeder	Substation	Breaker	Load
F1	S1	N01	9000
F2	S2	N02	6000
F3	S3	N38	6000
F4	S4	N68	8000
F5	S5	N78	8000
F6	S6	N79	9000

3.1 Case study 1: Sequential Restoration Scheme

When multi-fault occurs, this scheme is used to establish restoration plan for multi-outage area represented in Fig. 8.

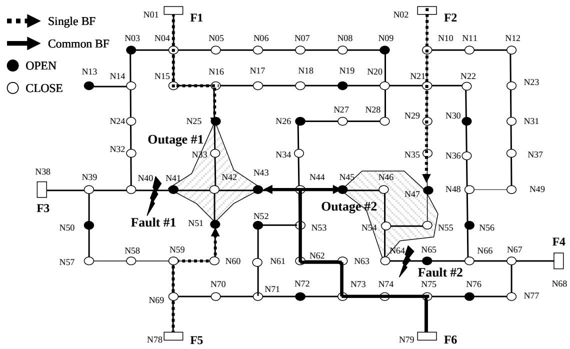

Fig. 8 Example system of simultaneous restoration

In Table 3, outage area 1 has higher restoration index than outage area 2. So this scheme establishes restoration plan for outage area 1 using feeder F1 and F5 at first. And then outage area 2 is considered using feeder F2 and F6.

Table 3 Calculation results of Restoration index

Outage area / Data	Outage area #1	Outage area #2
Outage load	3000[kVA]	1500[kVA]
Single BFs	F1, F5	F2
Common BFs	F6	F6
Number of BFs	2[EA]	1[EA]
Margin of BFs	11000[kVA]	8000[kVA]
Restoration index	0.66	0.64
Restoration sequence	1	2

The service restoration plan for outage area 1 and outage area 2 are represented in Table 4 and Table 5 respectively.

Table 4 Restoration plan for outage area #1

Rank	Scheme	BFs	Preference	Switching
1	SGR	F5	0.82	Close N51
2	SGR	F1	0.75	Close N25
3	DGR	F1, F5	0.73	Open N33 Close N25 Close N51

Table 5 Restoration plan for outage area #2

Rank	Scheme	BFs	Preference	Switching
1	DGR	F2, F6	0.68	Open N46 Close N45 Close N47
2	SGR	F6	0.67	Close N45
3	SGR	F2	0.64	Close N47

Since sequential restoration scheme successfully establishes the restoration plan, simultaneous restoration scheme will not be used in this case.

3.2 Case study 2: Simultaneous Restoration Scheme

The whole loads of feeder F3 and F4, as the shadow polygon in the Fig. 9, have to be transferred to the adjacent feeder due to the fault on the substation S3. In this case, since the sequential restoration scheme can not find the feasible solution, the simultaneous restoration scheme has to be applied to establish the restoration plan.

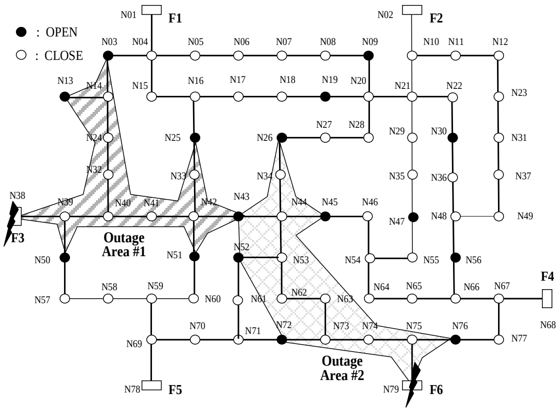

Fig. 9. Example system of simultaneous restoration

Table 6 shows resultant loading of the feeders. The overloading of feeder F4 and F5 is successfully released, and every load in the system can be stably supplied power within a distribution line capacity. Resultant open tie switches are presented in Table 7.

Table 6 Loading changes after restoration

Feeder name	Initial load	Resultant load
F1	9000	11800
F2	6000	11400
F3	Faulted feeder	
F4	17000	11200
F5	15000	11600
F6	Faulted feeder	

Table 7 Resultant switching operation

Operation	Switch name
Open to close	N03, N09, N25, N26, N47, N50, N72, N76
Close to open	N07, N29, N32, N41, N63, N74

4. COUNCLUSION

This paper presents a new service restoration algorithm for multi-outage area problem. Proposed algorithm consists of two restoration schemes which are sequential restoration scheme and simultaneous restoration scheme. This algorithm has shown satisfactory performance on the various distribution systems and now has been being applied to commercial distribution automation system in Korea.

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REFERENCES

A. L. Morelato and A. Monticelli (1989 winter meeting). Heuristic search approach to distribution. IEEE/PES, paper 89 WM 111-6 PWRD.

C.C Liu, S. J. Lee and S. S. Venkata (1988). An expert system operational aid for restoration and loss reduction of distribution systems. IEEE Trans. on Power Systems, Vol. 3, No. 2.

H. Fudo, et al. (1991). An expert system for restoration of distribution network, 3rd Symposium on Expert System Application to Power Systems.

K. Aoki, H. Kuwabara, T Satoh, and M. Kanezashi (1987). Outage state optimal load allocation by automatic sectionalizing switching operation in distribution systems. IEEE Trans. on Power Delivery, pp. 1177-1185

S. J. Lee, K. H. Kim, K. Y. Nam and J. K. Lee (1994). Service restoration expert system adopting branch pattern based grouping strategy in distribution systems. Expert System Application to Power Systems, pp. 273-278.

S. J. Lee, S. I. Lim, B. S. Ahn (1998). Service restoration of primary distribution systems based on fuzzy evaluation of multi-Criteria. IEEE Trans. on Power Systems, Vol. 13, No. 3, pp 1156-1163.s

V. Susheela Devi, D. P. Sen Gupta and G. Anandalingam (1995). Optimal restoration of power supply in large distribution systems in developing countries. IEEE Trans. on Power Delivery, Vol. 10, No. 1, pp. 430-438.

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