배전계통 사고복구 구성탐색을 위한 개선된 다익스트라 알고리즘과 퍼지규칙의 적용

김 훈*, 전영재*, 김재철*, 최도혁**, 정용철***, 추동욱****
숭실대학교*, 한국건설기술연구원**, 철도청***, 경문대학****

An Application of advanced Dijkstra algorithm and Fuzzy rule to search a restoration topology in Distribution Systems

Hoon Kim*, Young-Jae Jeon*, Jae-Chul Kim*, Do-Hyuk Choi**, Yong-Chul Chung***
Dong-Wook Choo****

Abstract - The Distribution System consist of many tie-line switches and sectionalizing switches, operated a radial type. When an outage occurs in Distribution System, outage areas are isolated by system switches, has to restored as soon as possible. At this time, system operator have to get a information about network topology for service restoration of outage areas. Therefore, the searching result of restorative topology has to fast computation time and reliable result topology for to restore a electric service to outage areas, equal to optimal switching operation problem. So, the problem can be defined as combinatorial optimization problem. The service restoration problem is so important problem which have outage area minimization, outage loss minimization. Many researcher is applying to the service restoration problem with various techniques.

In this paper, advanced Dijkstra algorithm is applied to searching a restoration topology, is so efficient to searching a shortest path in graph type network. Additionally, fuzzy rules and operator are applied to overcome a fuzziness of correlation with input data. The present technique has superior results which are fast computation time and searching results than previous researches, demonstrated by example distribution model system which has 3 feeders, 26 buses. For a application capability to real distribution system, additionally demonstrated by real distribution system of KEPCO(Korea Electric Power Corporation) which has 8 feeders and 140 buses.

1. INTRODUCTION

As industries progress, power distribution systems are becoming more complicated and large-scaled. Also, customers' demand for various load circumstances is increased perpetually. Under these circumstances, it is more important to outage restoration problem for customers' satisfaction and service reliability. Service restoration problem after outage occurrence is a complex decision-making and emergency control operation in distribution control center to restore outage area as soon as possible. Therefore, it requires fast computation time and superior solution for customers satisfaction. The problem can be defined as a combinatorial, constrained optimization problem. The main objective in service restoration procedures is to restore as many loads as possible with satisfaction of various constraints.

Castro et al.[1] suggested algorithms based on tree searching techniques utilizing switch tables that can be defined by an operator in 1980. Castro Jr. et al.[2] proposed a method in which they combine a service restoration and load balance between each feeder in 1985. Aoki et al.[3] presented an algorithm for load transfer by automatic sectionalizing switch operations in distribution systems on an outage occurrence subject to the transformer and line-capacity constraint in 1987. Also Aoki et al.[4] developed a method in which loads in an outage area are transferred to the transformers adjacent to the affected area based on current and voltage constraints in 1988. Aoki et al.[5] suggested a non-combinatorial algorithm based on the effective gradient method, also Aoki et al.[6] presented an another algorithm for emergency service restorations in which load restoration priority can be considered in 1989. N.D.R. Sarma et al.[7] presented a new technique, wherein the network is reduced by merging certain set of nodes together and this reduced network is analyzed for finding alternate paths of power supply to the affected load points in 1991. Yuzuru Imamura et al.[8] suggested an application method of fuzzy evaluation for efficient line transfer in 1993. Jung-Nyun Kim et al.[9] presented an outage restoration method by Object-Oriented Programming Technique in 2000.

In this paper, we applied the advanced Dijkstra method and Fuzzy Rule to search a restoration topology in distribution systems. So, We adopt a fuzzy rule to restore priority restoration area when distribution system is not restored perfectly. Finally, we obtained the superiority consequence of computation time and solution for service restoration than previous approaches, shows applicable capability to real operational distribution system. The results of numerical simulation show by simple distribution model system and modified real distribution system model of KEPCO's

2. PROBLEM FORMULATION

The service restoration problem is formulated as a constrained non-differentiable multi-objective optimization problem. The service restoration problem could regarded as a searching problem of minimum spanning tree or shortest path in graph theory. In this paper, the objective function for service restoration problem is considered as the following Eq.(1).

$$\text{minimize} \quad E = \sum_{(i,j)\in U} d_{ij} x_{ij} \quad (i < j) \tag{1}$$

where,

- E : objective function
- i, j : vertex or node
- U : set of all vertex or node ($U=1,2,\cdots,n$)
- d_{ij} : cost between i and j
- x_{ij} : the decision variable between i and j (x_{ij}=0 or 1)

Eq.(1), the objective function, is considered the constraints for reality solution of service restoration problem. The constraints are radial operation conditions, line and feeder capacity in this paper. The constraints represented in Eq.(2).

[Constraints]
(Flow constraint between i and k [i-j-k section])

$$\sum_{(k,j)\in U} x_{jk} - \sum_{(i,j)\in U} x_{ij} = \begin{cases} 1 : \text{j is start point} \\ -1 : \text{j is end point} \\ 0 : \text{otherwise} \end{cases} \quad (2.A)$$

(Line and Feeder capacity constraints)

$$\sum L_j \le b_i \quad (i \in U,\ j \in J) \quad (2.B)$$

where,

i, j : vertex or node
U : set of all vertex or node ($U=1,2,\cdots,n$)
x_{ij} : the decision variable between i and j (x_{ij}=0 or 1)
J : set of downstream load points of node i
L_j : load amount at point j
b_i : limit capacity at node i

The meaning of Eq.(2.A) is equal to radial operation condition in distribution system. The minimized result of an objective function becomes a topology of service restoration when an outage occurs in distribution system. Therefore, we could think that result of this formulation is applied to optimal service restoration scheme. Hence, we can give a operator of distribution control center an information about restoration topology when an outage occurrence in distribution systems.

3. OVERVIEW OF DIJKSTRA ALGORITHM AND FUZZY RULES

3.1 Dijkstra Algorithm

Dijkstra method is so useful method to solve the problem of finding the shortest path from a vertex in a graph to a destination. It turns out that one can find the shortest paths from a given graph to all vertexes in a graph in the time, hence this problem is sometimes called the single-source shortest path problem.

The Dijkstra method works on undirected, non-negative weight graph $G=(V, E)$. It finds shortest paths from the source node to all the other nodes. The main idea of the Dijkstra method is to change the temporary labels associated with nodes into permanent ones. The permanent label of a node denotes the shortest path weight from the source node to the current node. For node i, we denote as follows Eq.(3).

$$A(i) = \{j : e = (i,j) \in E, \text{ j has temporary label}\} \quad (3)$$

We give node s a permanent label 0, $j \in A(s)$ a temporary label $C(s, j)$, and all other nodes a temporary label ∞. Denote P to be the set containing all the nodes with permanent labels, and $T=V-P$ to be the set containing all the nodes with temporary labels. At each step, the algorithm chooses the node $i \in T$ with the minimum temporary label, and makes it permanent, record its predecessor index, and update the temporary values of all the node $j \in A(s)$. Repeat this procedure until all nodes become permanent ones. In the end, the last result of this procedure has a shortest path in given weight graph $G=(V, E)$. Steps of the Dijkstra method are shown as follows.

[STEP 1] Initialize a temporary label.
If starting vertex s have a connecting path to a vertex, temporary label become $C(s,j)$, the others become ∞.
[STEP 2] Select a shortest path.
Prepare a temporary label $C(s,j)$ and select a minimum value then selected temporary label set a permanent label.
[STEP 3] Compare a detour path.
Adjacent vertexes of the determined permanent label reconstruct a value of the temporary label. Compared a temporary label to detour path.
[STEP 4] Ending.
If all vertexes are compared then Dijkstra procedure is ending, otherwise go to STEP 2

3.2 Fuzzy Rules

Fuzzy Theory generally used for linearization of linguistic values. In this paper, we consider a linguistic variable to describe the load amount of some object. According to common usage, we denote this variable by Load amount. Its fuzzy values shall be subsets of the real interval from 0 to 10. As basic linguistic values we consider, the figuration of the following, fuzzy set named : low, low of medium, high of medium, high. Then it is easy to show the result of sentential combinations of these names. We regard this fuzzy function as weight for solution of service restoration. Fuzzy membership function is shown the following.

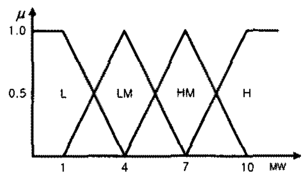

Fig 1. Membership function

As shown the fuzzy membership function, fuzzy values of intersection and union are fixed. So, we considered a usage of fuzzy operator to restore the specific area(priority restorative area). Fuzzy operator used for changing a weight of specific area. The restorative possibility of specific area is increased by weight change. Therefor, specific area almost restored as the result of numerical simulation. In this paper, we applied a fuzzy operator that is presented by J. Dombi [14]. Fuzzy operator , used in this paper, is shown Eq.(4).

$$\mu_R(x) = \frac{1}{1+\left(\left(\frac{1}{\mu_A(x)}-1\right)^{\lambda}+\left(\frac{1}{\mu_B(x)}-1\right)^{\lambda}\right)^{\frac{1}{\lambda}}} \quad (4)$$

where,

$\mu_R(x)$: fuzzy inference value
$\mu_A(x)$: fuzzy value of group A
$\mu_B(x)$: fuzzy value of group B
λ : fuzzy operating variable

In fuzzy operator, a value of λ is controlled for distinction between priority restoration area and general area. As the shown above formulation, if λ >0 then $C=A \cup$

B and if λ <0 then $C = A \cap B$.

The value of λ can controlled for allowance with weight of priority restoration areas. In this paper, a value of λ is use two value. one is λ =-0.9, another is a λ =-0.5. At this, λ =-0.9 is a weight for restoration of generally areas and λ =-0.5 is a weight for restoration of priority restoration area. A value of λ could controlled to characteristic of distribution system situations.

4. SOLUTION PROCESS

Since constraints concerned with a radial operation conditions, line and feeder capacity in the formulation of service restoration problem, it is difficult to apply the typically method to it like the general shortest path problem. Therefore we handled a mathematical method to solve the formulated problem that is to decide the least cost path for service restoration. In order to solve the service restoration problem effectively, we proposed an advanced method based on Dijkstra Method. Flow chart of the proposed method is shown as follows Fig. 2.

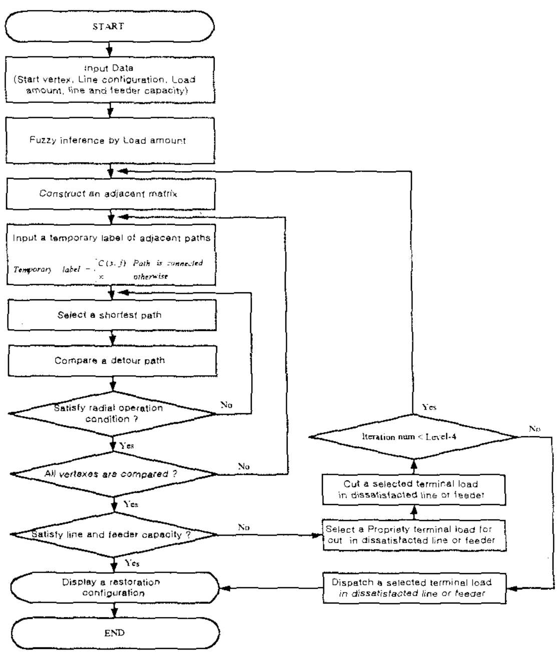

Fig 2. Flowchart of the proposed method

5. NUMERICAL SIMULATION

The proposed method has been applied to simple and real distribution system models using the advanced Dijkstra method and fuzzy rule for effectiveness and applicable capability. The simple distribution system model was used by reference [8-9]. So, real distribution system model is modified by a real system of kyong-gi district office of Korea Electric Power Corporation (KEPCO).

5.1 Simple Distribution Model

The simple distribution system model consists of 3 feeders, 26 buses and 31 branches as shown Fig. 3. The proposed method simulated some general cases, which are primary and secondary adjacent outage, and priority restorative case. By the result of simulation, all cases of secondary adjacent outage is restored in this simulation, but the cases of primary adjacent outage is not restored all cases for reasons of capacity constraints and limit of load transfer. So, the simulation proved a difficulty while outage location is close to feeder. The simulation result of simple distribution system model is compared with results of previous approaches[8-9], is shown below Table 1.

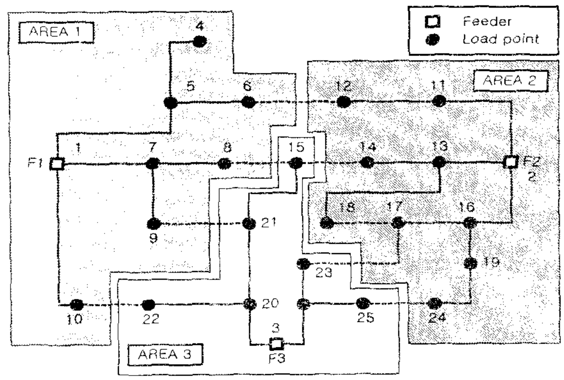

Fig. 3. Initial configuration of simple distribution model system

Table 1. Comparison result with other papers

Outage Section	Reference [8]		Reference [9]		Proposed Method	
	Not service area	Not service amount [MW]	Not service area	Not service amount [MW]	Not service area	Not service amount [MW]
1-5	4	2	4 5	2 4	4	2
1-7	7 9	6 8	8	10	8	2
1-10	-	-	-	-	-	-
2-11	11	4	-	-	-	-
2-13	13	2	-	-	-	-
2-16	-	-	-	-	-	-
3-20	20	3	20	3	-	-
3-26	25 26	6 4	25 26	6 4	26	4
4-5	4	2	4	2	4	2
20-21	-	-	-	-	-	-

Most cases of outage are restored by proposed method, but four cases of outage are not restored in this paper as shown Table 1. In this paper, the proposed method is handling only topological reconfiguration problem but also priority restorative case for outage restoration in distribution system. Consequently, result of the proposed method is so practical results. The computation time for results of proposed method is about 0.02~0.08 [sec] for example cases. The numerical simulations were done on desktop computer with Celleron 300A Mhz Processor.

5.2 Real Distribuition Model

Additionally, real distribution system model simulated for effectiveness and applicable capability of proposed method. The distribution system model is a real operation system of kyong-gi district office of KEPCO. The real distribution system model consist of 8 feeders, 140 buses. Loading ratio of simple model system is set 80% of full loading for various simulation results in this simulation. Also, this network is consist of CNCV 325㎟, ALOC 160㎟ and ALOC 95㎟. Initial topology of the modified system is shown the Fig. 4.

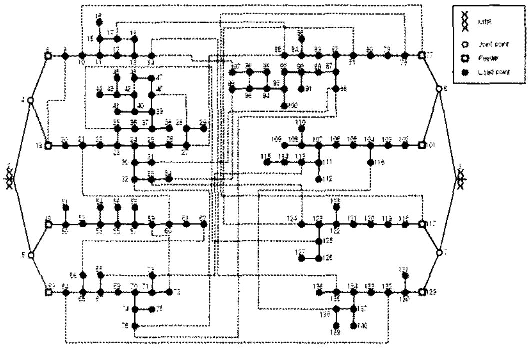

Fig. 4. Initial configuration of KEPCO's real system

As the simple distribution model simulation, we obtain a superior performance of proposed method and taken a computation time with under 1~2 seconds in the real distribution system model simulations.

3. CONCLUSION

In this paper, advanced technique for service restoration is presented by advanced Dijkatra and fuzzy rule. Main topic of this paper is the follows.

1) That is present a new advanced restoration technique which has optimal restorative scheme and fast computation time by advanced Dijkstra method.
2) Reliability of input data is improved by using fuzzy membership function.
3) We adopt a fuzzy rule to restore priority restoration area when distribution system is not restored perfectly. So that, there is increased a restorative possibility of priority restoration.area, can stand a restorative scheme with distinction.
4) That is consider constraints of real system to proposed method, so the results of proposed method is can applied to real system.
5) Numerical simulation is performed a simple distribution system model, have 3 feeders and 26 buses, and modified real distribution system model of kyong-gi distinct of KEPCO's, have 8 feeders and 140 buses.

The proposed method can apply to automation system restorative part for to present of restorative optimal topology in Distribution Automation System after distribution automation completed.

The next step of this work would be to handle the transformer outage with more advanced method for restoration problem. Future work should be directed to extending the method to handle sub-station outage problems.

본 연구는 기초전력공학공동 연구소의 "AI 기법을 이용한 배전 계통의 최적 라우팅 기법 개발"에 따른 연구비로 수행되었음.

[REFERENCE]

[1] Carlos H. Castro et al., "Generalized Algorithms for distribution Feeder Deployment and Sectionalizing", IEEE Trans. on PAS, Vol. PAS-99, No. 2, pp. 549-557, March/April 1980.
[2] C.A. Castro Jr. et al., "Automatic Power Distribution Reconfiguration Algorithm Including Operating Constraints", Proceeding IFAC Conference on Electric Energy Systems, Brazil, pp. 155-160, 1985.
[3] K. Aoki et al., "Outage State Optimal Load Allocation by Automatic Sectionalizing Switches Operation in Distribution System", IEEE Trans. on PWRD, Vol. 2, No. 4, pp. 1177-1185, October 1987.
[4] K. Aoki et al., "Voltage drop Constrained Restoration of Supply by Switch Operation in Distribution Systems", IEEE Trans. on PWRD, Vol. 3, No. 3, pp. 1267-1274, July 1988.
[5] K. Aoki et al., "A New Algorithm for Service Restoration in Distribution Systems", IEEE Trans. on PWRD, Vol. 4, No. 3, pp. 1831-1839, July 1989.
[6] K. Aoki et al., "New Configuration Algorithm for Distribution System-Priority Constrained Emergency Service Restoration", Proceeding of IFAC Conference on Power Systems and Plant Control, Seoul, Korea, pp. 443-448, 1989.
[7] N.D.R. Sarma et al., "A New Network Reconfiguration Technique For Service Restoration in distribution Networks", IEEE Summer Meeting, San Deigo, USA, July 1991.
[8] Yuzuru Imamura et al., "Fuzzy Inference Application to Planning of Distribution Network Switching", The Transactions of The Institute of Electrical Engineers of Japan, Vol. 113-B, No. 5, pp. 493-498, 1993.
[9] Jung-Nyun Kim and Young-Sik Baek, "Service Restorative System in Emergency State using Object-Oriented Structure", The Transactions of The Korean Institute of Electrical Engineers, Vol. 49, No. 1, pp. 1-5, January 2000.
[10] N.D.R. Sarma et al., "Real Time Service Restoration in Distribution Networks A Practical Approach", IEEE Trans. on PWRD, Vol. 9, No. 4, pp. 2064-2070, October 1994.
[11] K. Nara et al., "A New Feeder Route Determination Algorithm by Dijkstra Method and Tabu Search", Proceeding IEEE Conference on ISAP 97, Seoul, Korea, pp. 448-452, July 1996.
[12] Hoon Kim, Young-Jae Jeon, Seung-Yun Lee, Jae-Sung Kim, Jae Chul Kim, "Outage Restoration in electric distribution system using Dijkstra algorithm", Proceeding KIEE Annual Conference '99, Youngpyong, Korea, pp. 1416-1421, July 1999.
[13] Hoon Kim, Young-Jae Jeon, Jae-Chul Kim, "Application of Advanced Dijkstra method in Power Distribution System Restoration", Proceeding IERE Workshop, DaeJeon, Korea, pp. 159-163, September 1999.
[14] J. Dombi, "A general class of fuzzy operators, the De Morgan class of fuzzy operators and fuzziness measures induced by fuzzy operators", Fuzzy Sets and Systems, Vol. 11, pp.115-134, 1983.
[15] KEPRI Report of Project KRC-88D-J01, "A Study on the Large Power Distribution", Korea, March 1991.
[16] KEPRI Report of Project KRC-91D-J01, "A Study of the Establishment of Algorithm and the Standardization for Distribution Automation", Korea, May 1993.
[17] EESRI Report of Project EESRI-93P-109, "A Study on the selection of the basis of proper operating capacity of 22.9kV-Y distribution lines", prepared by KEPCO, Korea, October 1994.
[18] Mark Allen Weiss, *Data Structures and Algorithm Analysis in C*, The Benjamin/Cummings Publishing Company, California, USA, 1993.