Distribution System Restoration Using Fuzzy Multi-criteria Evaluation

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***Abstract*-This paper presents algorithm for distribution system restoration of out of service area after the identification of fault and isolation of faulted area. Power system restoration is multiobjective, multi constraint problem so various objectives like minimization of switches, minimization of maximum loading among laterals and feeders has been studied. Various restoration plans are obtained after switching operations and simple numerical operations followed with fuzzy multicriteria evaluation. To demonstrate the proposed algorithm a typical distribution system of Taiwan Power Company was examined.**

***Index Terms*- Distribution System, Service Restoration, Fuzzy Logic, Fuzzy Set Theory, Restoration Algorithm**

I. INTRODUCTION

When a fault occurs in a distribution system, for a system operator it becomes necessary to locate to locate the fault, isolate the faulted zone and restore the supply to the out of service area which is outside the fault zone[1-8]. As it is not possible to completely prevent the blackout it is very important to keep special emphasis on fast, effective and reliable power system restoration after the fault. Power system restoration needs to be done with well defined procedures that require overall co ordination within the restoration area, as well as with the neighbouring networks. In the literature lot of work has been published on the identification of fault and service restoration [8]-[12]. Our paper is mainly concerned with the service restoration problem assuming that the identification of fault and the isolation of faulted zone have been done [12]-[13]. Main purpose in the paper is to determine the restoration plan for a distributed feeder after the occurrence of fault. It is important to keep in mind that there may be more than one restoration plan. The restoration plan is necessary for guiding the system operator to make the final decision on the restoration of out of service area. The plan should meet the following requirements of the system operator as given below.

1) Time taken by the restoration plan should be very less. To avoid the customer inconvenience the electricity service at the out of service area should be restored as soon as possible.
2) Out of service area should be restored with maximum possible loads to reduce the number of customers interrupted.
3) The switching operation during the restoration process should be minimum. Frequent operation of switching can reduce the life of switch and takes more time.
4) Switch close to out of service area may be operated first to keep the configuration of restored system close to the original configuration.
5) No overloading equipments should be there.
6) The radial structure of the system should be maintained.
7) Service priority customers should be supplied first

The rest of the paper is organised as follows. In section II the problem formulation is given in detail. Section III discusses the fuzzy logic for completeness of this paper. In section IV the application of fuzzy logic for restoration is explained and main results and conclusion are given in section V.

II. PROBLEM FORMULATION

In this paper, the distribution system restoration problem has been formulated as a multiobjective, multiconstrained and combinatorial optimization problem. The objective functions considered in the work are given below with the constraints to be maintained during the restoration process.

A. Objective functions

1)*Minimization of out of service area*

$$Min\ f1(x) = \sum_{i=1}^{b1} Li - \sum_{i \in B} Li \ldots\ldots\ldots (1)$$

Where X is switch state vector of the system for service restoration (i.e. $x = SW_1, SW_2 ... SW_{Ns}$). SW is the status of switch, close switch is presented by1 and open by 0. Ns is the total number of switches in the network. *b1* is number of energized buses among B. Li is the load on i th bus .

2) *Minimize Number of switching operations f 2(X)*

$$Min f\ 2(X) = \sum_{i=1}^{Nsw} xi \ldots\ldots\ldots (2)$$

Where *f2*(*X*) denotes the number of switching operations under the switch state vector X, X =[x_1, x_2, $x_3 \ldots\ldots x_{Nsw}$] , Nsw = the total number of switches in the system.

3) *Minimize the Maximum loading among supported feeders f3(x)*

$$Min\ f3(x) = Max(IFDi) \ldots\ldots\ldots (3)$$

Where f3(x) is the maximum loading among supported feeder. I_{FDi} is the load current of the supported feeder FD_i after switching operation. N_{FD} represents the total no of supported feeders.The minimization of f 3(x) is desirable

4) *Minimize the Maximum loading among supported laterals f4(x)*

$$Minf(4) = Max(ILATi) \ldots\ldots (4)$$

Where f4(x) is the maximum loading among supported laterals, I_{LATi} is the load current of the supported lateral LATi after switching operation. N_{LAT} represents the total no of supported laterals. The minimization of f 4(x) is desirable.

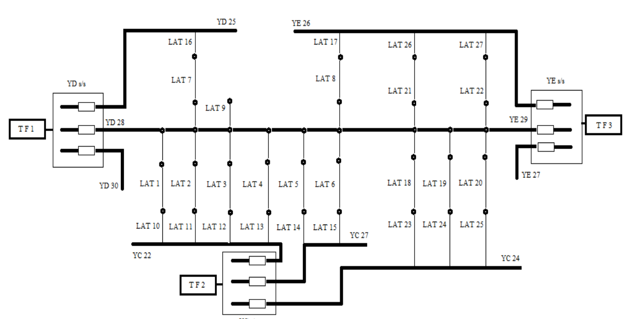

Fig.1.Distribution system

The model shown in figure 1 has three secondary substations, eight main feeder, and 16 laterals, which is the part of the 11 KV distribution systems[13]. When a fault occurs in system at point A of feeder FD3. Due to this fault the circuit breaker CB3 will trip and switch will be operating to isolate the fault. The loads LAT1, LAT2, LAT3, LAT4, LAT5 and LAT6 are interrupted. To restore this type of fault the system needs to be energised through different feeders. LAT1 is supplied by LAT10, LAT2 is supplied by LAT11, LAT3 is supplied by LAT12, LAT4 is supplied by LAT13, LAT5 is supplied by LAT14 and LAT6 is supplied by LAT15 using switches SW1,SW2,SW3,SW4,SW5 and SW6.There are some more plans to energize the out of service area. we will evaluate the plan using proposed restoration algorithm.

III.FUZZY MULTICRITERIA EVALUATION

The fuzzy set theory offers a mathematically formalised method to handle imprecise information. The fuzzy set is a mapping of real numbers onto membership values in the range of [0, 1].An element of a fuzzy set is an ordered pair containing a set element and the degree of membership in the fuzzy set. Higher membership value means greater satisfaction [14].

The system operator uses past experience and heuristic rules to select a proper restoration plan. The heuristic rules expression generally involves linguistic terms. The fuzzy set theory is applied to effectively get the linguistic and heuristic knowledge. The objective of having fewer numbers of switches used minimization of switching operations, minimization of loading on laterals and feeders are considered for restoration plans. Out of these objectives the minimal number of switching operation is considered as fuzzy objective function while better load balancing on feeders and laterals are considered as fuzzy constraints. The term fewer and better are imprecise in nature and can be easily handled by the fuzzy set theory [15]-[16].

The proposed fuzzy multi criteria evaluation has a rule base, membership functions and inference procedure. The rule base is formed with the fuzzy rule based on operator knowledge. These rules are written in IF-THEN statements. The fuzzy rules are expressed in following forms.

R1: IF f1(x) is very low, THEN the plan is very good.
R2: IF f1(x) is low, THEN the plan is good.
R3: IF f1(x) is moderate, THEN the plan is moderate.
R4: IF f1(x) is high, THEN the plan is bad.
R5: IF f1(x) is very high, THEN the plan is very bad.

The membership function of the objective functions is given in figure 2. All values of the objective functions are described with the use of five fuzzy

TABLE I Status of operation switch

S.No	Lateral	Alternate lateral	Switch	Switching operation	Switching status
1	LAT1	LAT10	SW1	close	1
2	LAT2	LAT11	SW2	close	1
3	LAT3	LAT12	SW3	close	1
4	LAT4	LAT13	SW4	close	1
5	LAT5	LAT14	SW5	close	1
6	LAT6	LAT15	SW6	close	1

TABLE II Laterals and their pre fault load current

Lateral	Pre Fault Load Current	Lateral	Pre Fault Load Current
LAT1	25	LAT 10	51
LAT 2	45	LAT 11	39
LAT 3	62	LAT 12	24
LAT 4	47	LAT 13	37
LAT 5	65	LAT 14	34
LAT 6	67	LAT 15	31
LAT 7	60	LAT 16	60
LAT 8	55	LAT 17	80
LAT 9	20	-	-

sets: very low, low, moderate, high and very high. The related values for objective function 1 are assigned as follows.

fa=1, fb=5, fc=9, fd=13, fe=17

TABLE III Load current on alternate lateral

Plan	Switch Operation	L 10	L11	L12	L13	L14	L15
1	7	76	84	86	37	34	31
2	7	76	39	86	84	34	31
3	7	76	84	24	37	99	31
4	5	51	39	86	37	99	31
5	7	51	84	24	84	99	31
6	7	51	39	86	84	99	31
7	5	76	84	24	37	34	98
8	7	76	39	24	84	34	98
9	5	51	84	24	84	34	98
10	7	51	39	86	84	34	98

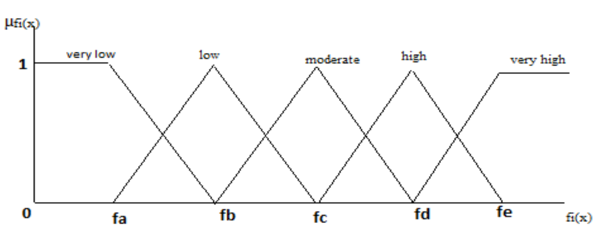

Fig.2. Membership function of objective function

In the consequent the singleton fuzzy sets very good, good, moderate, bad and very bad are crisply defined as 1, 0.75, 0.5, 0.25 and 0 respectively. In the inference procedure the real value of each objective function is first calculated to get the firing strength in fuzzy IF-THEN rule. To derive the crisp defuzzification values the weighted average is used.

$$f_i^* = \frac{\sum_{j=1}^{N_r} \mu_j \times y_j}{\sum_{j=1}^{N_r} \mu_j} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

IV.RESTORATION USING FUZZY

The restoration plan in section II is described after the fault at point A. the laterals used before the fault and after the fault are changed with the operation of various switches. Table I describes the change in operation with switch.

The switch change operation includes six switches that are changing their position from zero to one for the restoration plan 1. there are other alternate plans that are having different switch status and according to their load the switch can be turned on and off. Table II gives values of various pre fault currents of various laterals. Table III gives load currents on alternate laterals during the restoration process.

TABLE IV Objective function values

plan	X1	X2	X3	X4
1	7	3	441	86
2	7	3	439	86
3	7	3	438	99
4	5	2	446	99
5	7	3	416	99
6	7	3	399	99
7	5	2	436	98
8	7	3	434	96
9	5	2	414	98
10	7	3	397	98

Restoration algorithm

Step 1- Generate all feasible restoration plans by changing the on/off status of the switch required by the operation condition.

Step 2- Compute the values of objective function using the equation for all possible restoration plans.

Step 3- Use fuzzy multicriteria evaluation to compute the values of fuzzy data.

Step 4- Rank the plans in preference order according to the number of less switch operations with the balanced load.

Table IV presents the values of objective functions for the plans and table V gives their fuzzy evaluation data. Figure 3 presents the restoration plans and the values of fuzzy evaluation data. It describes different fuzzy values of objective functions obtained by fuzzy multi criteria evaluation.

TABLE V Fuzzy evaluation data

Plan	F1*	F2*	F3*	F4*
1	0.625	0.322	0.0391	0.3469
2	0.625	0.322	0.0478	0.3469
3	0.625	0.322	0.0522	0.2143
4	0.750	0.375	0.0174	0.2143
5	0.625	0.322	0.1478	0.2143
6	0.625	0.322	0.2217	0.2143
7	0.750	0.375	0.0609	0.2245
8	0.625	0.322	0.0696	0.2245
9	0.750	0.375	0.1565	0.2245
10	0.625	0.322	0.2304	0.2245

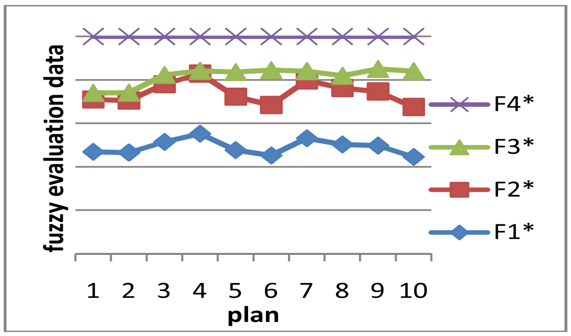

Fig.3. Fuzzy data for plans

V.CONCLUSION

The objective of this paper was to present an approach based on the fuzzy multi criteria evaluation based on the fuzzy reasoning for determining the proper service restoration of distribution system. Various restoration plans were obtained after switching operations and load distribution on feeders and laterals. the plans with fewer number of switching operation and better load operations were considered best among all the plans. Since it is easy to evaluate the alternative restoration plans by simple numerical operations, the proposed algorithm is promising and observed to be feasible.

REFERENCES

[1] Chen-Ching Liu, Seung Jae Lee, S. S. Venkata, "An expert system operational aid for restoration and loss reduction of distribution system" *IEEE Transactions on Power Systems,* Vol. 3, No. 2, pp. 619-626, May 1988.

[2] Seong-II Lim et.al., "Service restoration methodology for multiple fault case in distribution systems" *IEEE Transactions on Power Systems*, Vol. 21, no.4, pp. 1638-1644, November 2006.

[3] Jignesh M. Solanki,Sarika Khushalani,Noel N. Schulz " A Multi-Agent Solution to Distribution Systems Restoration" *IEEE Transactions on Power Systems*, Vol. 22, No. 3,pp. 1026-1034, August 2007.

[4] Saber Nouri-Zadeh et.al., "Multi Objective Power System Restoration" *IEEE Electrical Power & Energy Conference*,2008.

[5] Y.kojima et.al., " Development of a guidance method for power system restoration" *IEEE Transactions on Power systems*, Vol.4, No. 3, pp.1219-1227 , August 1989.

[6] A.L. Morelato and A. Monticelli " Heuristic search approach to distribution system restoration" ,*IEEE Transactions on Power Delivery*, Vol. 4, No. 4, pp. 2235-2241, October 1989.

[7] M.M.Adibi et.al., "New approaches in powers system restoration" *IEEE Transactions on Power systems*, Vol.7, No. 4, pp.1428-1434 , November 1992.

[8] Canbolat Ugak, Anil Pahwa "An analytical approach for step by step restoration of distribution systems following extended outages", *IEEE Transactions on Power Delivery*, Vol. 9. No. 3, pp.1717-1723, July 1994.

[9] Lim S, Lee S J and Choi M S,(2006) Service restoration methodology for multiple fault case in distribution systems. IEEE Transactions on Power Systems,Vol. 18,no 2,

[10] Whei-Min Lin, Hong-Chan Chin "Preventive and Corrective Switching for eder Contingencies in Distribution Systems with Fuzzy Set Algorithm" *IEEE Transactions on Power Delivery*, Vol. 12, No. 4,pp. 1711-1716, October 1998.

[11] S. Sivanagaraju a & T. Ramana "A Simple Method for Feeder Reconfiguration and Service Restoration of Distribution Networks" *Taylor and Fransis journal on Electric Power Components and Systems*, Vol. 32, pp.883-892,2004.

[12] S.P.Singh,G.S. raju, G.K. Rao and M. Afsari "A heuristic method for feeder reconfiguration and service restoration in distribution networks" *Elsevier journal on Electrical Power and Energy Systems*,pp. 309–314, 2009.

[13] Wen-Hui Chen "Quantitative Decision-Making Model for Distribution System Restoration", *IEEE Transactions on Power Systems*, Vol. 25, No. 1, pp.313-321, February 2010,

[14] Chen W H, Tsai M S and Kuo H L "Distribution System restoration using the hybrid fuzzy grey method". *IEEE Transactions on Power system* Vol.20, No. 1, pp.199-205 , ,2005.

[15] Liu W.W and Lin Z.Z , "Intuitionistic fuzzy choquet integral operator based approach for black start decision making", *IET generation,Transmission and distribution*,Vol 6,Iss.5,pp.378-386, july 2012

[16] Gonzalez A, Francisco M. Echavarren and Gomez tomas, "A sensitivities computation method for reconfiguration of radial networks". *IEEE Transactions on Power Systems*,Vol. 27,no 5. Pp 213-218, march 2013.