Fault Location Method Using Fuzzy Logic Membership Function

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ABSTRACT-
Increasing energy demands has led to expansion of power infrastructure which also means that there is an increase in the number of lines subjected to faults due to short circuits or unintentional causes such as birds, falling of branches, etc,. Two types of methods, respectively, for non radial systems and radial systems have been proposed by utilizing voltage and current measurements at the local substation. Simulation studies have demonstrated that both types of methods are accurate and quite robust to load variations and measurement errors.
There are fault related data available in the distribution systems when fault occurs. Efficient and effective methods are needed to utilize these available data to locate the possible faulted line sections. In this paper, fuzzy set methods are applied to derive the fault location algorithm. It uses fault related data from fault sensors as well as study results from short circuit analysis and handles the uncertainty in these data with fuzzy set formulation. The algorithm has been implemented. Test results on PG&E distribution systems are very promising.

keywords-*Distribution Systems, fuzzy sets , fault location.*

1. INTRODUCTION

Quick and accurate identification of fault locations is essential for service restoration in distribution systems. Any sustained fault on a distribution feeder requires prompt identification and section isolation. Usually, operators locate the fault based on the information obtained from the SCADA systems, feeder maps, customer phone calls, and their experience. Effective identification of fault locations can expeditiously reduce outage duration for usefulness customers and usefulness operating costs incurred while patrolling the distribution lines, and increases revenue. Some analytical approaches have been presented [l-3] to determine the possible faulted line sections. Most of the sets about use fault distance estimation calculated from fault related data in protection devices. The accuracy of these methods can be affected by some characteristics of distribution systems, such as unbalanced systems, non-homogeneous feeder conductors, dispersed generation, etc.

As the evolution of computer telecommunication and electronic technologies, many data from distribution feeders as well as substations become available to the control centers. They can be used to effectively situate the possible faulted line sections. In this paper, a fuzzy set based fault location algorithm is presented. It utilizes the fault related data from fault sensors on the feeders, limited SCADA data from distribution automation systems, and simulation results from short circuit analysis. The first phase of the algorithm is a rule based algorithm that traces the possible faulted line sections between sensors. The second phase of the algorithm uses simulated short circuit current and measured fault currents to promote reduce the possible faulted line sections. A fuzzy set method is developed to handle different degree of uncertainty from simulation as well as fault sensor measurement. Operators' experience can also be considered. The algorithm produces much better results than the distance based fault location approaches.

2. PROBLEM METHODOLOGY

The fault location process can be described as: use the available fault related data from the distribution systems, apply analytical methods, combine with operators experience, then effectively identify possible fault locations. It is indeed an information integration effort.
Knowledge base of the fuzzy expert system contains all the data of the protection system. The information is based on known statistics of protection performance used in the system. If this data are not available when a fault occurs, the fuzzy expert system asks the dispatcher to provide them and then saves them in the database for future use. Models for estimation of possible Faults and heuristic rules about the relay characteristics for actual fault determination are also included in the knowledge base.

The available fault related data include SCADA switch status, fault signals from fault sensors, and feeder configuration. The SCADA system can provide pre-fault and post-fault switch status. The fault sensors with communication capability can detect the occurrence as well as measure the magnitude of the fault currents. The fault signals and current magnitudes will be transmitted to distribution control centers through communication systems. The knowledge of feeder configuration provides connectivity and can eliminate the possibility of having inconsistent fault types on certain feeders.

The short circuit analysis can calculate fault currents based on real-time snapshot or saved cases. It can correctly consider the unbalanced systems, non homogeneous impedance, and dispersed generations on distribution feeders [5].

Distribution operators have certain experience that provides the knowledge of possibility of having a fault on each line section. This possibility can also be impacted by the geographical locations of the line sections.

All these data, information, and knowledge are fuzzy in nature: The measured data may have different degree of uncertainty; the short circuit calculation results may contain some magnitude of inaccuracy; the operators' experience can tell only the possibility. Consequently, the fault location problem is how to combine all these available fuzzy data, information, knowledge together, then identify the fault locations.

3. FUZZY FORMULATION

Fuzzy set theory provides a method for modeling uncertainty in the decision "g process. It is a natural and appropriate tool to represent inexact relations. Each uncertainty is associated with a membership function μ(x) that represents the degree of certainty for that relation.

A fuzzy set can be defined as follows: If X is a collection of objects denoted generically by x, then a fuzzy set A in X is a set of ordered pairs [5]:

$$A = \{x, \mu(x))/x \in X\} \quad (1)$$

If the set of elements that belong to the fuzzy set A at least to the degree *U*, this set is called an u-level set or fuzzy set "decision":

$$A_\alpha = \{x \in X \mid \mu_A(x) \geq \alpha\} \quad (2)$$

When μ (x) takes only 0 or 1, the set A becomes a crisp set. In the fault location algorithm, the universe X consists of all line sections on the faulted feeders. In this paper, two types of membership functions are used: (a) online calculated membership function $\mu_A(x)$ and (b) offline defined membership function $\mu_B(x)$.

On-line Membership Function μA(x)

The membership function μA(x) is determined by matching the fault currents measured by sensors with the fault currents calculated by short circuit analysis.

Fault Current Measured by Sensor:

The sensed fault current is fuzzy, while the detection of occurrence of fault is crispy. The membership function of the sensed fault current $\mu_s(I)$, is defined as in figure(1).

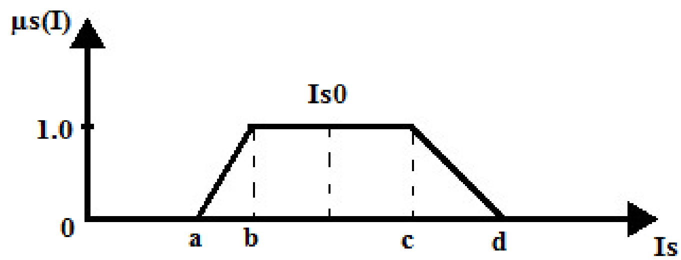

Fig 1: sensed fault current membership function

The user definable parameters **a,** b, c and d are determined based on the fact that the sensors contain possible **±y%** error. For example, we can set:

Ia= Is0- Is0*(y+ε)% Ib=Is0- Is0*y%

Ic= Is0+Is0*y% Id= Is0+Is0*(y+ε)%

where Is0 is the fault current measured by the sensor and ε represents the ranges of fuzziness.

Fault Currents Calculated bv Short-circuit:

The fault impedance causes most of the uncertainty in short circuit calculation. The maximum fault currents can be calculated using zero fault impedance, but the exact fault impedance can not be obtained. However, it is clear that the impact of the fault impedance on the fault current is greater when the fault is closer to the beginning of the feeder. By considering the impact of fault impedance, the membership function of the fault current calculated by short circuit analysis is shown in figure (2):

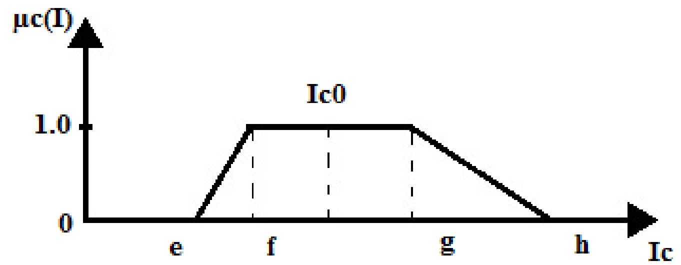

fig 2: Short circuit calculation membership function

where e, f, g and h are user definable parameters; Ic0is the current calculated by short circuit analysis. (h-g) is larger than (f-e) because when the fault current is larger, the fault is closer to the feeder head, then the uncertainty is higher. When a fault occurs, all sensors from feeder head to the fault location will detect fault currents. All those currents from the sensors can be compared with the currents calculated by short circuit analysis. Thus, we have a pair of membership functions($\mu_{si}(I)$, $\mu_{cin}(I)$) for each sensor, where $\mu_{si}(I)$ is the membership function of fault current measured by sensor, $\mu_{cin}(I)$ the membership function of fault current calculated by the short-circuit analysis program[5], i is the sensor which sends the fault signals, and n is the node of the study faulted line section in short circuit analysis (note that there are two nodes in a line section). The membership function $\mu_A(x)$ of a faulted line section x, can be defined as:

$$\mu_A(x) = \max(\min(\mu_{si}(I), \mu_{cin}(I))) \quad (3)$$

Off-line Membership Function $\mu_B(x)$:

This type of membership function can be determined by user knowledge, such as the operators' experience, geographical locations, etc. It is similar to assigning different weights to line sections to represent the possibility of being a faulted line section.

Operators' Experience: According to the operators' experience, different weights may be assigned to different line section for the possibility of being a faulted line section. For example, an old line section is more likely to have a fault than a new one. Figure (3) shows the membership function.

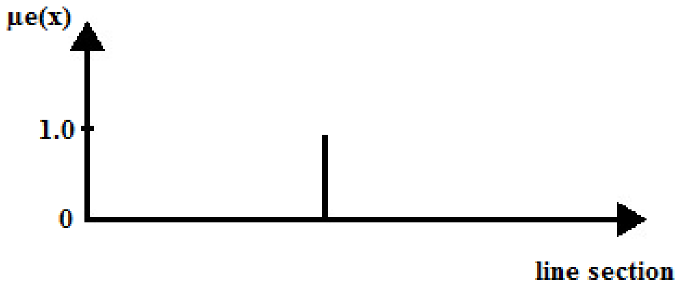

Fig 3:Line section membership function

Geographical Locations: Similar membership function $\mu_o(x)$ as $\mu_e(x)$ canbeused. The algebraic sum operation[4] is used to obtain the membership functionp $\mu_B(x)$:

$$\mu_B(x)=\mu_e(x)+\mu_o(x)-\mu_e(x)\mu_o(x) \qquad (4)$$

Final Grade of Membership $\mu_l(x)$
The final grade $\mu_l(x)$ of membership for a line section x is also calculated by algebraic sum operation:

$$\mu_l(x)=\mu A(x)+\mu B(x)-\mu A(x)\mu B(x) \qquad (5)$$

The most likely place of the fault will be selected based on the grades of membership.

4. FAULT LOCATION ALGORITHM

The fault location algorithm includes two phases. In the first phase, sensor signals, limited SCADA information, and some heuristic rules are used to form the basic possible faulted zone. The formulation is deterministic, i.e. crispy. In this phase, the collection of objects X is effectively reduced into a much smaller set than that of the original collection. In the second phase, the fuzzy set method is applied to further reduce the size of this zone and provide the priority list of possible faulted line sections. The algorithm is summarized as follows:

Basic Faulted Zone:

- Process fault related data to determine fault type (single-phase, two phase or three-phase fault) and faulted feeder. Identify the basic faulted zone by the information from sensors based on the assumption that sensor can detect fault current correctly.
- Without Co-generators, the basic faulted zone is located among the last sensor sending signals and the first sensors without signals at down stream location. The basic faulted zone may contain more than one line sections.
- With co-generators, the magnitude of sensed fault currents are also used together with the logic above. A rule based algorithm is derived to identify the basic faulted zone.
- Check the type of the fault and eliminate all of the laterals with which this type of fault is inconsistent. For example, if the even is a three-phase fault, the fault can not be on two-phase or single-phase laterals. Compare the pre-fault SCADA information with the post-fault SCADA information and the fault must be on those line sections

Possible Faulted Line Sections:

- Further reduce the *size* of the *basic faulted zone* by matching fault currents based on the fuzzy set method:
- Form fault current membership functions measured by sensors and fault current membership functions calculated by short circuit analysis program. Then calculate $\mu_A(x)$ by equation (3). The "x" are the line sections in the basic faulted zone.
- Form off-line membership function $\mu_B(x)$ by equation (4). Find the final membership functions of the line sections in the basic faulted zone by equation *(5).*
- Provide the priority list of possible faulted line sections according to the grade of membership and α-level set.

5. TEST RESULTS

The fault location function based on the proposed algorithm has been implemented on a UNIX workstation, and tested on PG&E distribution feeders. The results are very promising. In the following, some test results are presented.
The example testing feeder includes 495 line sections, 496 nodes, and 100 switches. There are 3x20 sensors at the feeder. There are three sensors per location (one on each phase) Figure: (4) shows the network configuration for a portion of the tested area:

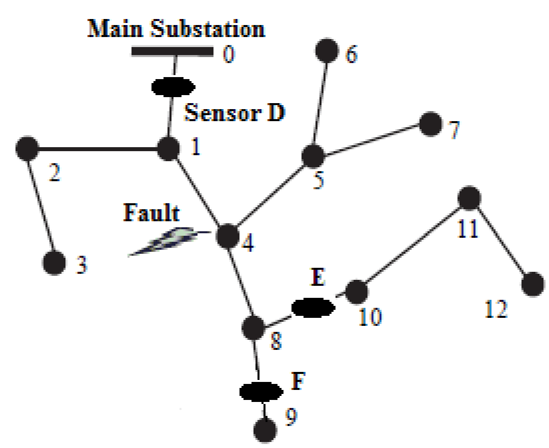

Fig 4:-portion of tested network

In this figure sensor A,B,C are located feeder head and sensor D. The fault currents measured by sensors are shown in the table 1

Table:1 the fault currents measured by sensors

	I_a	I_b	I_c
Sensor A	2700.04	2700.20	2701.23
Sensor B	2700.15	2700.60	2703.24
Sensor C	2695.25	2705.50	2700.34
Sensor D	2683.30	2704.40	2706.23
Sensor E,F	No signals	No signals	No signals

and others			

According to the signals and measured currents from the sensors, the following facts can be determined:
(a) The fault location is among the sensors D, E, and F.
(b) It is a three-phase fault.
Combining sensor signals, SCADA information, and some heuristic rules, the basic faulted zone can be formed, i.e., the reduced collection of objects is:

$$X_r=\{1,2,3,4,5,6\}$$

After applying fuzzy set method on the collection of objects X_r, the membership functions of line sections at X_r are shown in the table 2.

Table:2 the membership function of line sections at X_r

	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6
μ(x)	0.897	0.895	0.897	0.889	0.898	0.903

The α-level set with α=0.89 include:
line 2: μ(2) = 0.895 line 3: μ(3) = 0.897
line 4: μ(4)= 0.889

6. CONCLUSION

Fault models used in this fuzzy expert system are based on the post fault status of circuit breakers and operated relays. So the database is relatively small compared with the full database that describes the whole protection system. This paper presents an effective method for fault location identification in distribution systems. The sensor signals determine the basic faulted zone on the feeder so that we can match the sensor currents with the currents simulated by short circuit, one node by one node in the basic faulted zone. A priority list of possible faulted line sections can be provided to the operators. It is useful for operators to perform necessary switching for fault isolation and service restoration.
The definition of membership functions is an essential part of the presented method. With the on-line calculated membership function $\mu_A(x)$ and the off-line defined membership function $\mu_B(x)$ the faulted zone can be effectively and accurately reduced. The test results have shown the effectiveness.

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