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Fuzzy Logic Based Fault Type Identification in the Radial LT Power Distribution Feeder

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Fault classification is necessary for the rapid restoration of service to LT consumers after the occurrence of a fault. This paper presents a step by step procedure for the identification of ten different types of faults commonly occurring in the LT distribution system. Information on the distribution transformer secondary current for different faults at different load buses is used to define the input fuzzy variables. Fuzzy inference engine and the centroid de-fuzzifier are used to relate the input to the fuzzy rule base and to obtain crisp outputs respectively.

Key words: *fault classification method, fuzzy logic, LT Feeder, MATLAB, RSCAD*

1.0 INTRODUCTION

Accurate, fast, and reliable fault classification technique is an important operational requirement in modern day automated power transmission and distribution systems. Now a day, due to the increased amount of power carried by the distribution grid, fault classification to facilitate rapid fault location and service restoration of distribution feeders, assumes greater importance to ensure reliability of supply to the end consumers.

There are about ten types of different commonly encountered faults, namely, a-g, b-g, c-g, a-b, b-c, c-a, a-b-g, b-c-g, c-a-g and a-b-c-g. Fault classification algorithms shall identify these faults to ensure fast fault clearance. The algorithms shall also consider the effect of change in power flow in the healthy phases due to faults in any one or two phases of a three phase system to make the fault classification effective.

Literature survey indicates many attempts in this direction [1, 2] which have many limitations as regards to the number of types of faults that can be identified and the quantum of data required. The method proposed by Biswarup Das [3] based on the fuzzy logic system applied to the IEEE benchmark radial LT feeder is an improvement over the earlier methods and identifies the phase(s) involved in all the ten types of shunt faults. This scheme needs only three line current measurements, which is generally done at the substation, thus reducing the data requirement. In this paper, it is attempted to apply the same method to a typical radial LT (400 V) distribution system commonly prevalent in our country.

In the absence of field data on fault current, the three phase simulation of the distribution feeder and all the ten types of faults at different locations using RSCAD is carried out. Fuzzy Logic Tool Box of MATLAB is employed for the implementation of fault detection and identification.

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2.0 FUZZY LOGIC AND FAULT TYPE IDENTIFICATION

Fuzzy Logic (FL) is a problem-solving control system methodology that lends itself to implementation in a variety of systems. It can be implemented in hardware, software, or a combination of both. FL provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. FL incorporates a simple, rule-based IF X AND Y THEN Z approach to solve control problems rather than attempting to model a system mathematically. Fuzzy systems theory allows uncertainties in problem formulation to be expressed and processed. The degrees of certainty are expressed usually on a scale of 0 to 1 and represent the degree of membership of the set.

The problem of identification of fault type in a LT distribution feeder poses uncertainties due to a large number of types of faults and equally large number of probable fault locations. Hence information generated for fault at discrete locations of the feeder is used in the FL approach to determine the type of fault occurring at any location of the feeder, fairly accurately.

3.0 METHODOLOGY

The methodology adopted in this paper for the development and testing of the fault classification algorithm is similar to that followed in reference [3]. The following steps are involved:

Step 1: For an identified LT feeder, the waveforms of transformer secondary phase currents and voltages are computed by RSCAD simulation for all the ten types of faults on the feeder and at identified major load points.

Step 2: The sequence components of the currents are computed from the fault currents obtained in step1.

Step 3: The input parameters for the fuzzy logic system, namely, Ang_A, Ang_B, Ang_C, R_{0f} and R_{2f} are calculated from the sequence components.

Step 4: Fault identification using fuzzy logic:

- Fuzzification of input parameters is done where the values of Ang_A, Ang_B and Ang_C are grouped under the categories of approximately 0^0, approximately 60^0, approximately 120^0 and approximately 180^0 and the values of R_{0f}, R_{2f} are categorised as low or high.
- Input and output membership functions are defined.
- The fuzzy rule base is made.
- The fuzzy inference engine relates the input values with the fuzzy rule base and the rule which matches the given inputs is fired.
- The fuzzy output of the inference engine is given to the centroid de-fuzzifier which gives the crisp output.

4.0 LT FEEDER CONSIDERED FOR THE STUDY

Fig. 1 shows the single line diagram of the 400 V LT distribution feeder considered. It is supplied by a 3Φ, 250 kVA, 11 kV/ 400 V, 50 Hz transformer. The 3-phase short circuit level on the primary side of the transformer is 475 MVA. The total length of the feeder is 110 meters, and the conductor used is Ant All Aluminum. The total load on the feeder is 214 kVA, distributed over the length of the line as shown in Fig. 1.

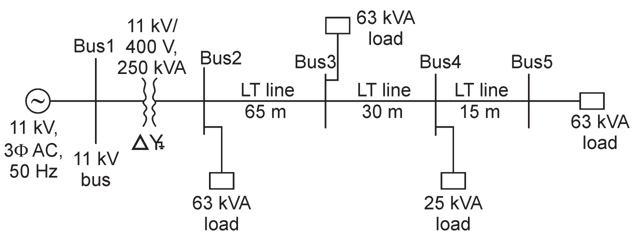


FIG. 1 TYPICAL LT DISTRIBUTION FEEDER

The 11 kV AC source is considered to be inductive with inductance (Ls) of 0.80 mH per phase corresponding to the short circuit level of 475 MVA. The transformer percentage impedance is 5% and its no load loss is 0.1 p.u. The load is represented by a 3 phase star connected series R and L circuit and load power factor is assumed to be 0.95. For example, the resistance and inductance of 63 kVA load on the LT feeder is represented by 2.42 Ω resistance and 2.53 mH inductance. Similarly 25kVA load is represented by a resistance of 6.095 Ω and inductance of 6.37 mH.

The three phase LT line with Ant conductor (having cross-sectional area of 30 sq.mm), 300 mm spacing between the conductors and 4.0 m average height of the conductor from ground is represented by a Π section model in RSCAD. The Π section parameters are as follows:

Pos. seq. Resistance = 0.5879 ohms/km

Pos. seq. Inductive reactance = 0.3115 ohms/km

Pos. seq. shunt capacitive reactance = 0.4109 MΩkm.

The corresponding zero sequence quantities are considered to be three times the positive sequence quantities mentioned above [4].

5.0 FAULT CURRENT CALCULATION

LT distribution feeder shown in Fig. 1 is simulated in RSCAD. All the ten types of faults were simulated at each of the four load buses (Bus 2 to 5) and waveforms of feeder currents as seen by a current transformer at the secondary of the feeder transformer were obtained for fault durations of 100 ms. They are shown in Fig. 2 for a-g fault at Bus 2. The rms fault currents derived from the waveforms for all the 10 types of faults and for all fault locations are shown in Table 1.

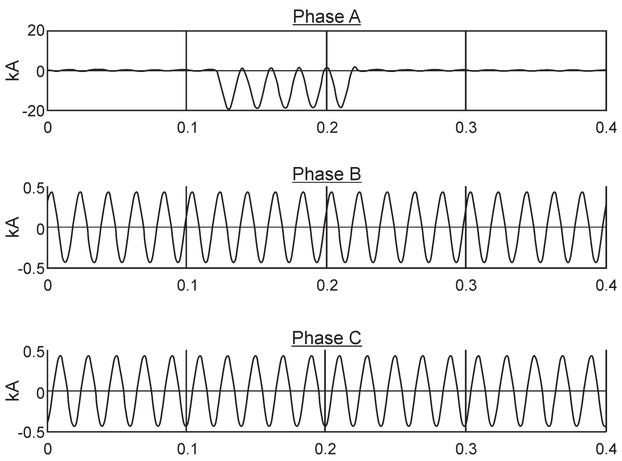


FIG. 2 TRANSFORMER SECONDARY CURRENT WAVEFORMS FOR A-G FAULT AT BUS 2 AS COMPUTED BY RSCAD

6.0 DETERMINATION OF PARAMETERS FOR FUZZIFICATION

The input quantities of the fuzzy logic system are Ang_A, Ang_B, Ang_C, $R_{0f,}$ and $R_{2f.}$ They are obtained after calculating the sequence currents from the transformer secondary currents during fault using the formulae given in reference [5].

The five input parameters for the fuzzy logic system are calculated as follows:

$$Ang\_A = |Arg(I_{a1})-Arg(I_{a2})| \qquad (1)$$

$$Ang\_B = |Arg(I_{b1})-Arg(I_{b2})| \qquad (2)$$

$$Ang\_C = |Arg(I_{c1})-Arg(I_{c2})| \qquad (3)$$

$$R_{of} = |I_{a0}/I_{a1}| \qquad (4)$$

$$R_{2f} = |I_{a2}/I_{a1}| \qquad (5)$$

For LLG fault,

$$R_{0f} = K \qquad (6)$$

$$R_{2f} = K_1 \qquad (7)$$

$$\text{Where, } K = Z_2/(Z_2+Z_0+3Z_f) \qquad (8)$$

$$K_1 = (Z_0+3Z_f)/(Z_2+Z_0+3Z_f) \qquad (9)$$

TABLE 1

TRANSFORMER SECONDARY RMS CURRENTS IN kA FOR DIFFERENT FAULTS AT ALL LOAD BUSES

Bus No.	**Phase**	**Type of fault**									
		a-g	**b-g**	**c-g**	**a-b**	**b-c**	**c-a**	**a-b-g**	**b-c-g**	**c-a-g**	**Symmetric**
2	A	7.4115	0.2955	0.2955	6.359	0.2955	6.0622	7.4123	0.2955	7.3975	7.3855
	B	0.2952	7.1859	0.2952	6.0884	6.3992	0.2952	7.1727	7.1748	0.2953	7.1616
	C	0.2951	0.2951	7.3286	0.295	6.1176	6.3387	0.2951	7.3186	7.3134	7.3033
3	A	2.7437	0.3422	0.3132	3.31	0.2955	3.0807	3.557	0.3393	3.288	3.5796
	B	0.3129	2.6832	0.3426	3.1568	3.189	0.2952	3.0558	3.5531	0.3379	3.6237
	C	0.3432	0.3095	2.736	0.295	3.0192	3.243	0.3394	3.1709	3.66	3.5785
4	A	2.0642	0.3366	0.315	2.5428	0.2955	2.4039	2.7149	0.336	2.5468	2.8209
	B	0.3147	2.0303	0.3364	2.4073	2.575	0.2952	2.4246	2.7421	0.3349	2.8369
	C	0.3371	0.3123	2.061	0.295	2.444	2.534	0.3361	2.496	2.7878	2.8175
5	A	1.8428	0.3334	0.3147	2.2852	0.2955	2.2314	2.4365	0.334	2.293	2.6199
	B	0.3145	1.8171	0.3333	2.1609	2.2758	0.2952	2.1999	2.4492	0.3329	2.5634
	C	0.3339	0.3123	1.8382	0.295	2.1459	2.3465	0.3338	2.2422	2.4933	2.6129

TABLE 2

FUZZY VARIABLES FOR FAULT AT BUS 2

Type of fault	**Ang_A**	**Ang_B**	**Ang_C**	**R_{0f}**	**R_{2f}**
a-g	0.0013	120.02	120.00	1.124	1.00
b-g	120.02	0.0198	119.98	1.128	1.00
c-g	120.02	119.98	0.02	1.011	1.00
a-b	61.7	58.3	178.3	0.052	1.00
b-c	178.36	61.64	58.36	0.053	1.00
c-a	58.32	178.32	61.68	0.053	1.00
a-b-g	72.89	47.11	192.89	0.384	0.66
b-c-g	192.89	72.89	47.11	0.384	0.66
c-a-g	47.11	192.89	72.89	0.384	0.66
Symm-etric	-	-	-	0	0

Where, Z_2, Z_0 and Z_f are the negative sequence impedance of the line, zero sequence impedance of the line and fault impedance respectively.

Table 2 shows the values of Ang_A, Ang_B, Ang_C, $R_{0f,}$ and R_{2f} for the ten types of faults applied on Bus 2. Similar calculations were made for faults at other load buses.

7.0 FUZZY LOGIC AND FAULT CLASSIFICATION

Fig. 3 shows the fuzzy logic system for fault classification. The points P and S represent crisp inputs and output respectively. A fuzzifier converts the crisp inputs into fuzzy values as represented by point Q. The fuzzified inputs are fed to the inference engine, which follows the rule base, to identify the fault type and gives a fuzzy output R. The output of the FLS will be a decimal number corresponding to the fault type. Table 3 shows the fuzzy rule base for fault identification.

The relations given in Table 3 are valid only for faults in an unloaded system. Depending upon the pre-fault power level, fault resistance, fault location, fault inception angle, etc., the values of the five quantities deviate from their corresponding ideal values. Because of the approximations involved, the different inputs and the output are represented by approximate corresponding fuzzy variables. Table 4 shows the membership functions for the input variables.

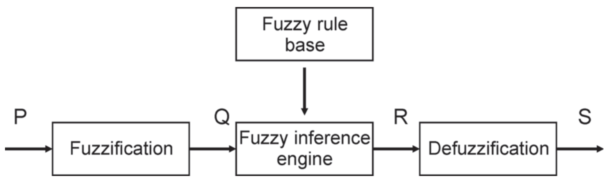


FIG. 3 FUZZY LOGIC SYSTEM FOR FAULT CLASSIFICATION

Fig. 4(A) shows the membership function for Ang_A. The membership functions for Ang_B and Ang_C are similar to that of Ang_A.

Fig. 4(B) shows the membership function for R_{of}. The figure for membership function of R_{2f} is similar to this figure.

TABLE 3

FUZZY RULE BASE

Type of fault	**Ang_A**	**Ang_B**	**Ang_C**	**R_{0f}**	**R_{2f}**
a-g	0°	120°	120°	1.0	1.0
b-g	120°	0°	120°	1.0	1.0
c-g	120°	120°	0°	1.0	1.0
a-b	60°	60°	180°	0.0	1.0
b-c	180°	60°	60°	0.0	1.0
c-a	60°	180°	60°	0.0	1.0
a-b-g	60°	60°	180°	K	K1
b-c-g	180°	60°	60°	K	K1
c-a-g	60°	180°	60°	K	K1
Sym-metric	-	-	-	0.0	0.0

TABLE 4

INPUT MEMBER FUNCTIONS

Fuzzy variable	**Triplets**		
	A	**B**	**C**
Approx. 0°	0	0	35
Approx. 60°	25	60	95
Approx. 120°	85	120	155
Approx. 180°	150	180	210
Low R_{0f}	0.0	0.0	0.2
High R_{0f}	0.1	0.9	1.7
Low R_{2f}	0.0	0.0	0.2
High R_{2f}	0.1	0.9	1.7

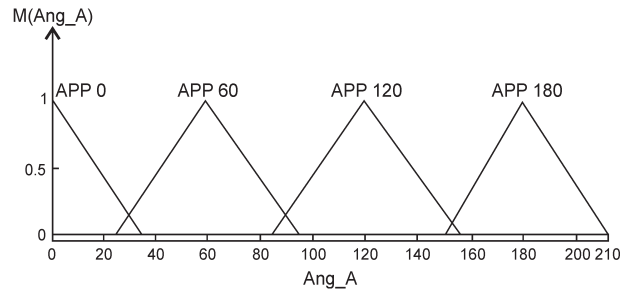


FIG. 4(A) MEMBERSHIP FUNCTION FOR ANG_A

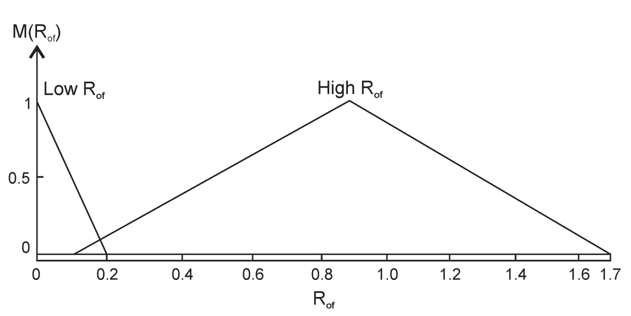


FIG. 4(B) MEMBERSHIP FUNCTION FOR R_{of}

In order to represent the fault type correctly, a binary coding system is considered. In this system, a four bit binary number ($b_3b_2b_1b_0$) is used to represent the type of fault. The bit b_0 represents the ground, the bit b_1 represents the phase 'c', the bit b_2 represents the phase 'b' and the bit b_3 represents the phase 'a'. The complete part of the binary numbers for representing all possible types of faults and their corresponding equivalent decimal numbers (EDN = $\sum_{n=0}^{3} b_n 2^n$) are given in Table 5. Table 6 shows the membership functions for the output variables.

Fig. 4(C) shows the output membership function. Both the input and output membership functions are triangular. The input quantities at point P in Fig. 3, are all crisp values. These are converted into fuzzy variables by fuzzification technique. Singleton fuzzifier is used here for fuzzification. The fuzzified inputs are given to the inference engine, which follows the rule base, to identify the fault type and gives a fuzzy output. Min-max inference engine is used here. The fuzzy output obtained from the inference engine is converted into crisp output by the centroid defuzzifier. Simulation of the FLS shown in Fig. 3 has been carried out using the Fuzzy Logic Toolbox in the MATLAB/ SIMULINK environment.

TABLE 5

FAULT CODE TABLE

Fault type	b3	b2	b1	b0	Equivalent decimal number
a-g	1	0	0	1	9
b-g	0	1	0	1	5
c-g	0	0	1	1	3
a-b	1	1	0	0	12
b-c	0	1	1	0	6
c-a	1	0	1	0	10
a-b-g	1	1	0	1	13
b-c-g	0	1	1	1	7
c-a-g	1	0	1	1	11
Symmetric	1	1	1	1	15

TABLE 6

OUTPUT MEMBERSHIP FUNCTIONS

Fuzzy variable	Triplets		
	A	B	C
a-g	8.5	9.0	9.5
b-g	4.5	5.0	5.5
c-g	2.5	3.0	3.5
a-b	11.5	12.0	12.5
b-c	5.5	6.0	6.5
c-a	9.5	10.0	10.5
a-b-g	12.5	13.0	13.5
b-c-g	6.5	7.0	7.5
c-a-g	10.5	11.0	11.5
Symmetric	14.5	15.0	15.5

7.0 SIMULATION AND DETECTION OF FAULT

Fig. 5(A) shows the FLS for fault identification as seen in the MATLAB/SIMULINK environment. As seen in this figure, Ang_A, Ang_B, Ang_C, $R_{0f,}$ and R_{2f} are the inputs to the FLC, which are computed from the measured values of line currents. The input, output membership functions and the rule base for the FLC are defined individually. The crisp output obtained from the FLC is descriptive of the type of the fault encountered in the distribution system, also indicating the phases involved in it.

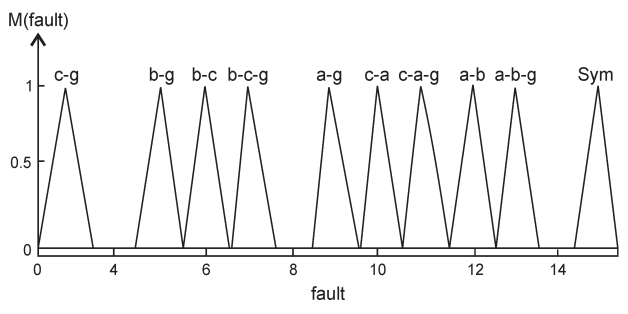


FIG. 4(C) OUTPUT MEMBERSHIP FUNCTION

Fig. 5(B) shows how the fuzzy rules are used to get the crisp output for a-g fault at Bus 2. The output of the fuzzy logic system for the ten types of faults applied on the various buses is shown in Tables 7 and 8.

TABLE 7

FLS OUTPUT FOR THE DISTRIBUTION SYSTEM FOR SINGLE LINE TO GROUND AND LINE TO LINE FAULTS

Bus No.	Type of fault					
	a-g	b-g	c-g	a-b	b-c	c-a
2	9	4.996	3.003	12	6.002	10
3	9	4.995	3.006	12	6.002	10
4	9	4.98	3.02	12	6.001	10
5	9	4.992	3.02	12.03	6.039	10.01

TABLE 8

FLS OUTPUT FOR THE DISTRIBUTION SYSTEM FOR DOUBLE LINE TO GROUND AND SYMMETRIC FAULTS

Bus No.	Type of fault			
	a-b-g	b-c-g	c-a-g	Symmetric
2	13	7.002	11	15
3	13.01	7.003	11	15
4	13.01	7.006	10.99	15
5	13.02	7.008	10.99	15

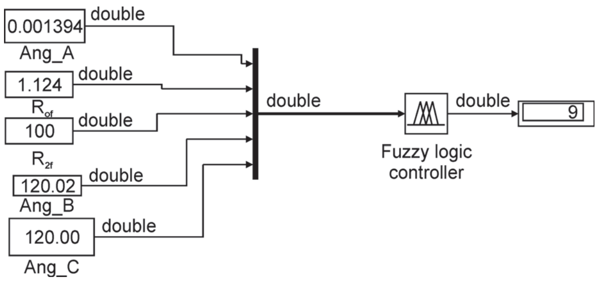
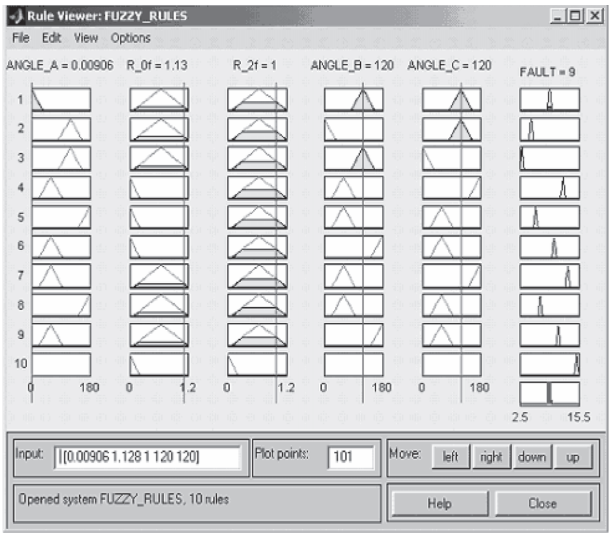


FIG. 5(A) FUZZY LOGIC CONTROLLER FOR FAULT IDENTIFICATION



Input: [0.00906 1.128 1 120 120]

Plot points: 101

Opened system FUZZY_RULES, 10 rules

FIG. 5(B) INPUT AND OUTPUT OF FLS FOR A-G FAULT AT BUS 2

8.0 CONCLUSIONS

Application of fuzzy logic to fault classification in an LT distribution system is presented in detail. Feasibility of using only three line current inputs for fault classification is demonstrated for all ten types of faults. The methodology developed is amenable to hardware implementation.

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