FUZZY-LOGIC-BASED FAULT CLASSIFICATION FOR TRANSMISSION LINE PROTECTION

Shashi R *

Neelam L *

Nidhi C *

Richa N *

Ramesh P. **

ABSTRACT

In this paper, an approach for fault classification of transmission line faults using fuzzy logic has been presented. This method is able to identify the single line to ground faults that may occur in a transmission line under different fault resistances, inception angle and load angles. This method requires only samples of three phase currents. To illustrate the effectiveness of the proposed technique, extensive simulation studies, using PSCAD/EMTDC and MATLAB, have been carried out for different types of single line to ground fault considering wide variations in fault resistances, inception angle and loading levels. Fault data generated by PSCAD/EMTDC have been used for fault classification by a MATLAB program.

Keywords: *Fault Classification, PSCAD/EMTDC, Fuzzy Logic, Transmission Line.*

* Department of Electrical and Electronics Engineering, College of Engineering Roorkee, Uttarakhand, India.

** Assistant Professor, Department of Electrical and Electronics Engineering, College of Engineering Roorkee, Uttarakhand, India.

I. INTRODUCTION

Fault classification is the recognition of the type of fault and faulty phase/phases. It is an essential operational requirement in the present day power transmission system as, for the determination of fault location algorithms and proper operation of protective relays, the correct fault type is required. Fault classification being the fundamental requirement in present day power transmission system gave rise to many techniques for the assortment of the faults accurately. Some of them which are widely employed are; (a) artificial neural networks [1-4], (b) wavelet transform based techniques [5-7], (c) fuzzy and fuzzy neural techniques [8-12]. These techniques are reliable and efficient for different working conditions. The techniques based on neural network require a large diversity of training for real-world operations while those based on wavelet transform are computationally complicated. The fuzzy logic approach involves only some linguistic rules and so is much simpler than the neural network based techniques as well as the wavelet based techniques.

Ferrero et al. [8] proposed a fuzzy logic based approach for identifying the type of fault. However in [8] only, the nature of the fault (whether *l-g* or *l-l-g*), has been identified.

Thus, this method tries to determine the asymmetrical faults involving ground. Also, no LL fault has been considered in this work. To improve upon this, a fuzzy-neural net-work approach to determine whether the fault is of *l-g*, *l-l* or *l-l-g* type has been suggested by Wang et al. [9]. As a further improvement Dash et al. [10] proposed a fuzzy-neural network based method and Das et al. [11] proposed a fuzzy logic based method for fault classification. Both of these approaches can identify all ten types of short circuit faults. Mahanty et al [12] proposed a fuzzy logic based fault classification approach based on current samples using EMTP and MATLAB software.

In this paper fuzzy logic based fault classification has been proposed. This method identifies single line to ground faults on the transmission line. Fault data is generated using EMTDC/PSCAD software. Fault data generated by EMTDC have been used for fault classification by a MATLAB program, which makes use of the "fuzzy logic toolbox [13]".

II. FAULT CLASSIFICATION TECHNIQUE

The classification technique has been developed on the basis of simulation studies carried out on the transmission line model shown in Fig. 1, using PSCAD/EMTDC and MATLAB. The parameters of the model are given in Appendix [11].

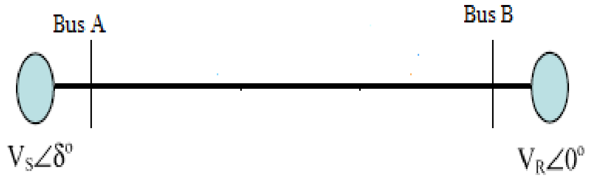

Fig. 1. Transmission line model for study

Simulation studies have been carried out on the transmission line model using PSCAD/EMTDC. Fault data generated by EMTDC are considered for fault classification by a MATLAB program which uses "fuzzy logic tool box". The sampling time is 1ms and the number of samples per cycle is 20. The first five post fault samples of current after inception angle has not been taken, so that dc offset can be reduced. Only 10 samples i.e. starting from 6^{th} to 15^{th} after fault inception angle are taken for fault classification [11]. This means data window is of half cycle. The fault classification technique for single line to ground faults has been developed as follows. The features of single line to ground faults are obtained in terms of X_1, X_2 and X_3, which are calculated as described below.

$A = \max\{abs(I_a)\} + \max\{abs(I_b)\} + \max\{abs(I_c)\}$,

$A_1 = \frac{A}{\max\{abs(I_a)\}}$, $A_2 = \frac{A}{\max\{abs(I_b)\}}$,

$A_3 = \frac{A}{\max\{abs(I_c)\}}$

Where Ia, Ib and Ic are the post fault current samples.

The normalized values of A_1, A_2 and $A_3$are as follows:

$A_{1n} = \frac{A_1}{\max(A_1, A_2, A_3)}$, $A_{2n} = \frac{A_2}{\max(A_1, A_2, A_3)}$,

$A_{3n} = \frac{A_3}{\max(A_1, A_2, A_3)}$

Finally the differences are are found as follows.

$X_1 = A_{1n} - A_{2n}$, $X_2 = A_{1n} - A_{2n}$, $X_3 = A_{1n} - A_{2n}$

Table I: Values Of X_1, X_2 and X_3 In Case Of *a-g* Fault

d, R_f, δ, FIA	X_1	X_2	X_3
0.15, 0, 10^0, 0^0	−0.6139	−0.3432	0.9571
0.15, 100, 10^0, 0^0	−0.6918	−0.1410	0.8328
0.15, 0, 30^0, 0^0	−0.6196	−0.2810	0.9007

0.15, 100, 30^0, 0^0	−0.5968	−0.0244	0.6213
0.15, 0, 10^0, 90^0	−0.6302	−0.3090	0.9393
0.15, 100, 10^0, 90^0	−0.6566	−0.1702	0.8269
0.15, 0, 30^0, 90^0	−0.6598	−0.2120	0.8718
0.15, 100, 30^0, 90^0	−0.5964	−0.0334	0.6299
0.85, 0, 10^0, 0^0	−0.9151	0.5834	0.3316
0.85, 100, 10^0, 0^0	−0.5476	0.0756	0.4719
0.85, 0, 30^0, 0^0	−0.6894	0.2566	0.4328
0.85, 100, 30^0, 0^0	−0.2993	0.0311	0.2682
0.85, 0, 10^0, 90^0	−0.7987	0.2209	0.5777
0.85, 100, 10^0, 90^0	−0.5198	0.0226	0.4972
0.85, 0, 30^0, 90^0	−0.4851	0.0800	0.4050
0.85, 100, 30^0, 90^0	−0.2750	0.0075	0.2674

Table II: Values Of X_1, X_2 And X_3 in Case Of *b-g* Fault

d, R_f, δ, FIA	X_1	X_2	X_3
0.15, 0, 10^0, 0^0	0.9362	−0.6384	−0.2977
0.15, 100, 10^0, 0^0	0.8184	−0.6221	−0.1963
0.15, 0, 30^0, 0^0	0.8180	−0.6661	−0.1519
0.15, 100, 30^0, 0^0	0.6256	−0.5644	−0.0611
0.15, 0, 10^0, 90^0	0.9675	−0.4464	−0.5210
0.15, 100, 10^0, 90^0	0.8279	−0.6782	−0.1497
0.15, 0, 30^0, 90^0	0.9072	−0.6160	−0.2911
0.15, 100, 30^0, 90^0	0.6341	−0.5959	−0.0381
0.85, 0, 10^0, 0^0	0.5898	−0.8337	0.2493
0.85, 100, 10^0, 0^0	0.4607	−0.5172	0.0557
0.85, 0, 30^0, 0^0	0.3449	−0.5003	0.1539
0.85, 100, 30^0, 0^0	0.2662	−0.3015	0.0332
0.85, 0, 10^0, 90^0	0.3933	−0.8991	0.5079
0.85, 100, 10^0, 90^0	0.4380	−0.5405	0.1048
0.85, 0, 30^0, 90^0	0.4280	−0.6829	0.2596
0.85, 100, 30^0, 90^0	0.2620	−0.2986	0.0359

Table III: Values Of X_1, X_2 And X_3 In Case Of *c-g* Fault

d, R_f, δ, FIA	X_1	X_2	X_3
0.15, 0, 10^0, 0^0	−0.4678	0.9604	−0.4925
0.15, 100, 10^0, 0^0	−0.1024	0.8259	−0.7234
0.15, 0, 30^0, 0^0	−0.2524	0.8932	−0.6408
0.15, 100, 30^0, 0^0	−0.0340	0.6310	−0.5970
0.15, 0, 10^0, 90^0	−0.2249	0.9476	−0.7227
0.15, 100, 10^0, 90^0	−0.0901	0.8226	−0.7324
0.15, 0, 30^0, 90^0	−0.2106	0.8780	−0.6673
0.15, 100, 30^0, 90^0	−0.0253	0.6247	−0.5994
0.85, 0, 10^0, 0^0	0.3101	0.5269	−0.8371
0.85, 100, 10^0, 0^0	0.0872	0.4867	−0.5740
0.85, 0, 30^0, 0^0	0.1845	0.4366	−0.6212
0.85, 100, 30^0, 0^0	0.0285	0.2893	−0.3178
0.85, 0, 10^0, 90^0	0.5850	0.3291	−0.9142
0.85, 100, 10^0, 90^0	0.0972	0.4576	−0.5548
0.85, 0, 30^0, 90^0	0.2472	0.4070	−0.6542
0.85, 100, 30^0, 90^0	0.0341	0.2638	−0.2979

d= fault location in p.u. of line from bus A, R_f = fault resistance, δ = load angle and FIA = fault inception angle

The values of X_1, X_2 and X_3 for *a-g*, *b-g* and *c-g* faults under variable operating conditions are shown in Tables I, II and III. The characteristic features of the single line to ground faults can be determined on the basis of values of X_1, X_2 and X_3 from the Tables I, II and III as illustrated below.

- for *a-g* fault X_1 = low, X_2 = low, X_3 = high;
- or X_1 = low, X_2 = medium, X_3 = high;
- for *b-g* fault X_1 = high, X_2 = low, X_3 = low;
- or X_1 = high, X_2 = low, X_3 = medium;
- for *c-g* fault X_1 = low, X_2 = high, X_3 = low;
- or X_1 = medium , X_2 = high, X_3 =low.

where "high" means a value between 1 and 0.2, "medium" means a value between 0.6 and 0.007 and "low" means a value between −0.95 and −0.02.

III. FUZZY LOGIC SCHEME

As Table I, II and III gives interrelationship between the fault type and X_1, X_2 and X_3, it is possible to formulate fuzzy rules for determining the fault type from the values of X_1, X_2 and X_3.

Fuzzy rule base for single line to ground faults:

- If X_1 is low, X_2 is low and X_3 is high it is an *a-g* fault;
- If X_1 is low, X_2 is medium and X_3 is high it is an *a-g* fault;
- If X_1 is high, X_2 is low and X_3 is low it is an *b-g* fault;
- If X_1 is high, X_2 is low and X_3 is medium it is an *b-g* fault;
- If X_1 is low, X_2 is high and X_3 low it is an *c-g* fault;
- If X_1 is medium, X_2 high is and X_3 is low it is an *c-g* fault.

The triangular membership function, shown in Fig. 2, has been used to represent various fuzzy variables in the antecedent and consequent parts of the fuzzy rules.

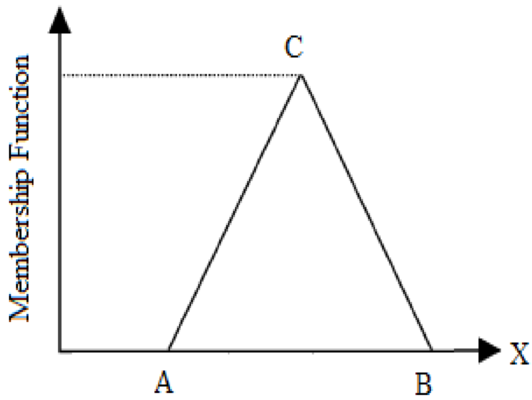

Fig. 2. Triangular fuzzy membership function.

The triangular fuzzy membership function can be defined with reference to the points A, B and C, referred to as triplets [14] as shown in the Fig. 2. The points A and C have a membership value of 0.0 and the point B has a membership value of 1.0. The selected values of A, B and C corresponding to fuzzy variables in the antecedent parts and consequent parts of the fuzzy rules are shown in Table IV and V.

Table IV: Fuzzy Variables In The Antecedent Parts

Fuzzy variable	Triplets		
	A	B	C
Low	−0.95	−0.485	−0.02
Medium	0.007	0.3035	0.6
High	0.2	0.6	1.0

Table V: Fuzzy Variables in the Consequent Parts

Fuzzy variable	Triplets		
	A	B	C
a-g	9.5	10	10.5
b-g	11.5	12	12.5
c-g	13.5	14	14.5

Fuzzy logic scheme (FLS) for fault classification of single line to ground faults is as shown in the Fig. 3. The input quantities are X_1, X_2 and X_3. These inputs are converted to their corresponding fuzzy variables by a technique known as fuzzification before application to the Fuzzy Inference Engine. After fuzzification, the fuzzified inputs are given to the fuzzy inference engine, which, following the given fuzzy rules, gives the type of fault at its output as shown in the Fig. 3.

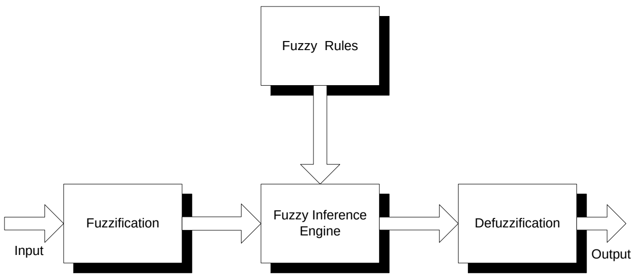

Fig. 3. Fuzzy Logic System for fault classification.

IV. RESULTS

To illustrate the effectiveness of the proposed method, simulation studies have been carried out on a 400kV, 300km transmission line using PSCAD/EMTDC software for different types of single line to ground faults considering wide variations in the values of fault resistance, fault inception angle, fault location and load angle. The FLS outputs for different types of single line to ground faults are shown in Tables VI, VII and VIII. From the results it can be observed that the proposed method has high accuracy.

Table VI: Results In Case Of *a-g* Fault

Fault condition	FLS inputs			FLS output
d, R_f, δ, FIA	X_1	X_2	X_3	
0.1, 5, 15^0, 0^0	−0.528	−0.425	0.954	10
0.1, 75, 15^0, 30^0	−0.783	−0.023	0.806	10
0.2, 20, 25^0, 30^0	−0.719	−0.099	0.819	10
0.2, 50, 15^0, 45^0	−0.783	−0.035	0.819	10

0.3, 5, 25^0, 60^0	−0.672 −0.100 0.773	10
0.3, 75, 15^0, 75^0	−0.608 −0.144 0.753	10
0.4, 20, 25^0, 30^0	−0.624 −0.121 0.746	10
0.4, 5, 15^0, 45^0	−0.725 −0.104 0.830	10
0.5, 75, 25^0, 60^0	−0.546 −0.029 0.576	10
0.5, 50, 15^0, 75^0	−0.629 −0.091 0.720	10
0.6, 20, 25^0, 90^0	−0.579 −0.028 0.608	10
0.6, 50, 15^0, 30^0	−0.689 0.072 0.616	10
0.7,75, 25^0, 45^0	−0.480 0.101 0.379	10
0.7, 20, 15^0, 60^0	−0.698 0.015 0.682	10
0.8, 5, 25^0, 75^0	−0.544 0.102 0.441	10
0.8, 75, 15^0, 30^0	−0.540 0.143 0.396	10
0.9, 50, 25^0, 45^0	−0.431 0.199 0.231	10
0.9, 20, 15^0, 60^0	−0.672 0.195 0.477	10

Table VII: Results In Case Of *b-g* Fault

Fault condition	FLS inputs	FLS output
d, R_f, δ, FIA	X_1 X_2 X_3	
0.1, 50, 25^0, 0^0	0.788 −0.665 −0.123	12
0.1,75,15^0,30^0	0.825 −0.610 −0.215	12
0.2, 20, 25^0, 30^0	0.817 −0.645 −0.172	12
0.2, 50, 15^0, 45^0	0.846 −0.643 −0.203	12
0.3, 5, 25^0, 60^0	0.831 −0.649 −0.181	12
0.3, 75, 15^0, 75^0	0.749 −0.728 −0.020	12
0.4, 20, 25^0, 30^0	0.724 −0.614 −0.110	12
0.4, 5, 15^0, 45^0	0.820 −0.721 −0.099	12
0.5, 75, 25^0, 60^0	0.577 −0.526 −0.051	12
0.5, 50, 15^0, 75^0	0.714 −0.724 0.009	12
0.6, 20, 25^0, 90^0	0.632 −0.676 0.044	12
0.6, 50, 15^0, 30^0	0.669 −0.631 −0.038	12
0.7,75, 25^0, 45^0	0.452 −0.475 0.023	12
0.7, 20, 15^0, 60^0	0.716 −0.724 0.007	12

0.8, 5, 25⁰, 75⁰	0.480 −0.690 0.210	12
0.8, 75, 15⁰, 30⁰	0.500 −0.439 −0.060	12
0.9, 50, 25⁰, 45⁰	0.393 −0.413 0.020	12
0.9, 20, 15⁰, 60⁰	0.444 −0.674 0.229	12

Table VIII: Results in Case Of *c-g* Fault

Fault condition	FLS inputs	FLS output
d, R_f, δ, FIA	X_1 X_2 X_3	
0.1, 75,15,0⁰	−0.122 0.828 −0.705	14
0.1, 50, 15, 30⁰	−0.204 0.872 −0.668	14
0.2, 20, 25⁰, 30⁰	−0.167 0.841 −0.674	14
0.2, 50, 15⁰, 45⁰	−0.120 0.796 −0.676	14
0.3, 5, 25⁰, 60⁰	−0.159 0.847 −0.688	14
0.3, 75, 15⁰, 75⁰	−0.145 0.772 −0.626	14
0.4, 20, 25⁰, 30⁰	−0.030 0.748 −0.718	14
0.4, 5, 15⁰, 45⁰	−0.026 0.850 −0.824	14
0.5, 75, 25⁰, 60⁰	−0.040 0.738 −0.697	14
0.5, 50, 15⁰, 75⁰	−0.063 0.737 −0.674	14
0.6, 20, 25⁰, 90⁰	0.020 0.611 −0.631	14
0.6, 50, 15⁰, 30⁰	0.054 0.644 −0.698	14
0.7,75, 25⁰, 45⁰	0.031 0.442 −0.473	14
0.7, 20, 15⁰, 60⁰	0.098 0.658 −0.756	14
0.8, 5, 25⁰, 75⁰	0.170 0.514 −0.685	14
0.8, 75, 15⁰, 30⁰	0.104 0.450 −0.554	14
0.9, 50, 25⁰, 45⁰	0.096 0.349 −0.446	14
0.9, 20, 15⁰, 60⁰	0.299 0.417 −0.717	14

V. CONCLUSION

In this paper a fuzzy logic based single line to ground fault identification scheme has been proposed. This technique requires post fault current samples at one end of the transmission line. Simulation studies carried out on 400 kV, 300 Km transmission line model in PSCAD/EMTDC for different types of single line to ground faults have proved the accuracy of the proposed technique.

APPENDIX

Source Data at both Sending and Receiving Ends

positive –sequence impedance = 1.31 + j15.0 Ω;

zero –sequence impedance = 2.33 + j26.6 Ω;

frequency = 50Hz.

Transmission line data

length = 300 km;

voltage = 400 kV;

positive– sequence impedance=8.25 + j94.5 Ω;

zero– sequence impedance = 82.5 + j308 Ω;

positive– sequence impedance = 13nF/km Ω;

zero– sequence impedance = 8.5nF/km Ω;

frequency = 50Hz.

REFERENCES

1. T. Dalstein, B. Kuliche, "Neural network approach to fault classification for high speed protective relaying," IEEE Trans. Power Delivery, vol. 10, pp. 1002-1011, Apr. 1995.
2. R.K. Aggarwal, Q.Y. Xuan, R.W. Dunn, A. Bennet, "A novel fault classification technique for double-circuit line based on a combined unsupervised/ supervised neural network," IEEE Trans. Power Delivery, vol. 14, pp. 1250–1256, Oct. 1999.
3. A.H. Osman,T. Abdelazim, O.P. Malik, "Transmission line distance relaying using on line trained neural networks," IEEE Trans. Power Delivery, vol. 20, pp. 1257–1264, Apr. 2005.
4. P.K. Dash, A.K. Pradhan, G. Panda, "Application of minimal radial basis function neural network to distance protection," IEEE Trans. Power Delivery, vol. 16, pp. 68–74, Jan. 2001.
5. O.A.S. Youssef, "A modified wavelet-based fault classification technique," Elect. Power Syst. Res. 64 pp. 165–172, 2003.
6. D. Chanda, N.K. Kishore, A.K. Sinha, "Application of wavelet multiresolution analysis for identification and classification of faults on transmission lines," Elect. Power Syst. Res. 73, pp. 323–333, 2005.
7. A.H. Osman, O.P. Malik, "Protection of parallel transmission lines using wavelet transform," IEEE Trans. Power Delivery, vol.19, pp. 49–55, Jan. 2005.

8. A. Ferrero, S. Sangiovanni, E. Zapitelli, “A fuzzy set approach to fault type identification in digital relaying,” IEEE Trans. Power Delivery, vol. 10, pp. 169–175, Jan. 1995.
9. H. Wang and W.W.L. Keerthipala, “Fuzzy neuro approach to fault classification for transmission line protection,” IEEE Trans. Power Delivery, vol. 13, pp. 1093–1104, Oct. 1998.
10. P.K. Dash, A.K. Pradhan, G. Panda, “A novel fuzzy neural network based distance relaying scheme,” IEEE Trans. Power Delivery, vol. 15, pp. 902–907, Jul. 2000.
11. B. Das and J. Vital Reddy, “Fuzzy-logic-based fault classification scheme for digital distance protection,” IEEE Trans. Power Delivery, vol. 20, pp. 609–616, Apr. 2005.
12. R.N. Mahanty and P.B.D. Gupta, “Fuzzy-logic-based fault classification approach using current samples only,” Elect. Power Syst. Res.77, pp. 501-507, 2007.
13. Fuzzy Logic Toolbox for use with MATLAB, The Mathworks, Inc., Natick, MA, 1999.
14. J. M. Mendal, Fuzzy logic systems for engineering: a tutorial, Proc. IEEE, vol. 83, pp. 345-377, Mar. 1995.