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Location of High Impedance Faults in Distribution Systems using Fuzzy Logic Technique

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Abstract

Distributed generation affects power flows and fault currents in the distribution network and its effect on network operation can be positive or negative depending on the location and time variation of the generator. Fast reliable location of high impedance faults (HIFs) is a persistent challenge to electric utilities. HIF often an overhead conductor not disconnected but it comes contact with high impedance object such as tree branches, leaves or touches the earth's surface. Due to existence of air between ground and conductor the high potential difference in such a short distance excites the appearance of the arc, such a fault case cannot be reliably detected and located, in particular in distribution systems, using conventional relays because its fault current is very small. It may also create a public hazard, and any unsafe condition is of concern to utilities. For this reason, the location of high impedance arcing faults in electric distribution systems has been the subject of intense interest over the history of utility systems. This work presents a fuzzy logic technique for area location of HIFs on unbalanced distribution system.

Keywords: *High impedance faults, Fault location, Fuzzy logic, Fuzzy Inference System, Distribution system*

1. Introduction

Now a day's distribution of power is one of the most aspects in power system, because most of the customers are connected to the distribution system only, so they need continuous power supply. Consumers are looking for quality of power supply, so it is an important task to maintain the quality of supply for the distribution network operators, in power systems faults are not entirely eliminated it can only be minimized, so detect and locate the faulty section quickly consumer achieve continuous supply. HIFs usually occur at primary conductor of the distribution system, by using conventional protection schemes. Faults are low estimations of fault streams and the closeness of arcing marvels. The faults which particularly happen in medium voltage networks in rural areas with overhead lines frequently because of inclining trees. They are arranged as high impedance arcing faults because of the tree opposition (a few hundred ohms) and the related circular segments. Such faults frequently draw little streams which can't be recognized by overcurrent relays. Towards modelling and location of HIFs, the arc representation has to be studied and the fault characteristics have to be measured form the simulation. The most suitable arc model is simulated to obtain fault characteristics [1]-[5] .The simulated arc model is inserted in the test systems to reproduce the fault circumstances. Based on the proposed location technique is suitable for MATLAB/SIMULINK is implemented and the extracted fault features are utilized. Arcing faults due to leaning (top of the tree) trees it can pose a threat to the safety of general public and animals. In this work arcing fault due

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to leaning trees in MV networks is studied. The occurrence of arcing phenomena, the second main feature of high impedance faults, is a result of existence of air gap between conductor and a semi-insulated object or earth's surface makes a huge electrical potential distinction over a short separation because of the inclination contrast in the electric field. The most famous HIF location method includes the variation of over current self-protective devices, yet this plan has driven into a few unexpected disturbances on the grounds that the electric current level coming, because of HIFs can't be separated from other non-fault cases in the power system, which influences the security of energy system [6]-[10].

2. Fuzzy Logic Technique

Fuzzy logic technique is used for fault identification to differentiate the type of fault. The fuzzy logic system has certain advantages over neural system. The fuzzy inference system (FIS) works on by simply defining certain rules and results can be acquired, however in neural network a different training is required. Other than there is merging of the calculation is additionally an issue. In the proposed method the approximations are involved, different inputs and outputs are represented by fuzzy variable or membership functions. As the input parts are variables which are fuzzy in nature, other variables are resultant parts should be fuzzy in nature. The above approximate rule base system is actually a "Fuzzy Rule Base System." The triangular membership function has been used to represent all these fuzzy variables (in both antecedent and consequent parts of the fuzzy rules), in this proposed work [11].

3. HIF Location by using Fuzzy Logic Technique

Considered single diagram of IEEE-15 bus system with unbalanced load condition as shown in below figure. Figure 1 shows single line diagram of IEEE-15 bus system, in this diagram single source, 9 loads and 15 buses are connected. Source voltage is 12.47Kv overhead distribution systems, this system includes 3 phase, two phase and single phase laterals and loads. For E.g. Load 7 is a single phase-A load and is supplied by a single – phase lateral tap from the main feeder. The lengths of feeders in miles, and the load ratings and phases are labeled. Line length of each feeder is 1.5Km, power factor of 0.9 is assumed for all nine loads. Different line lengths are connected in between the buses with the help of transmission line, this single diagram implemented in MATLAB by using Simulink tools. It provides an interactive graphical environment and a customizable set of block libraries considered in this work design, simulate, implement and test a variety of time-varying systems including power, communications, controls, signal processing, etc. The simulations for the various types of faults were carried performed and the various values for both faulted and non-faulted current were taken and recorded. These currents values taken at each phases and calculate the output value using FIS, observe all the currents values set the membership functions to inputs and output.

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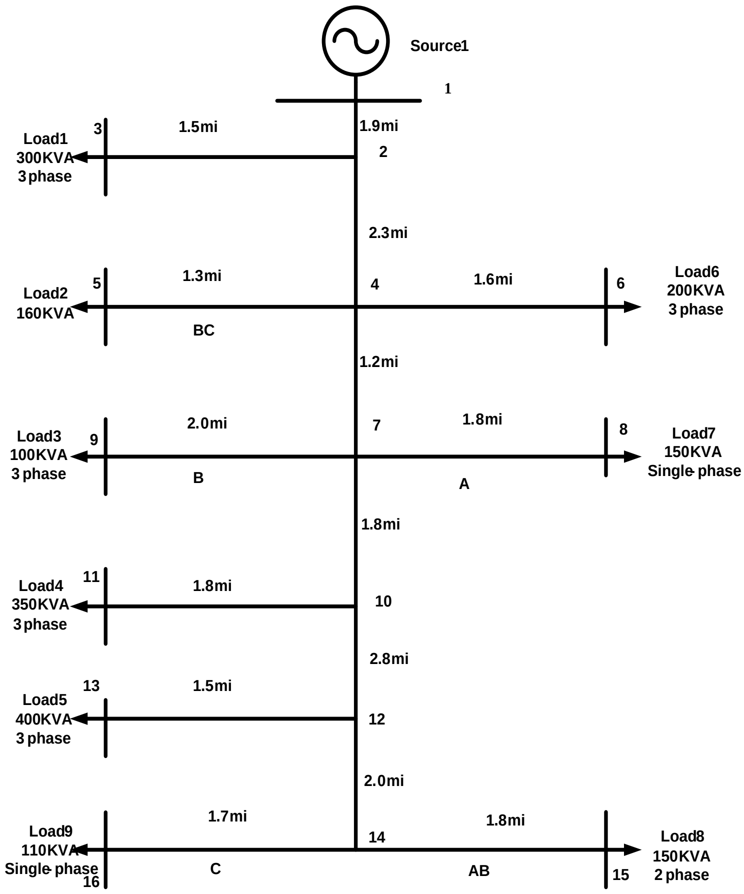

Figure 1. Single Line Diagram of IEEE-15 Bus System [12]

Calculations of fuzzy inputs by using phase a, phase b, and phase c currents respectively.

$$u_1 = sum(i_a) \tag{1}$$

$$u_2 = sum(i_b) \tag{2}$$

$$u_3 = sum(i_c) \tag{3}$$

If Eq. (1) is represented as U_1, sum of the phase a, currents and Eq. (2) is represented as U_2, sum of phase b, currents and Eq. (3) represented as U_3, sum of phase c, currents respectively, b_{ij} is the phase currents between the buses i=1, 2, 3…16, j=1, 2, 3,…16. By using the above equations this work consider inputs to the FIS based on current values by setting memberships functions low (L), normal (N), high (H) [13].

Considered a flowchart for HIF location in distribution system as shown in below Figure.

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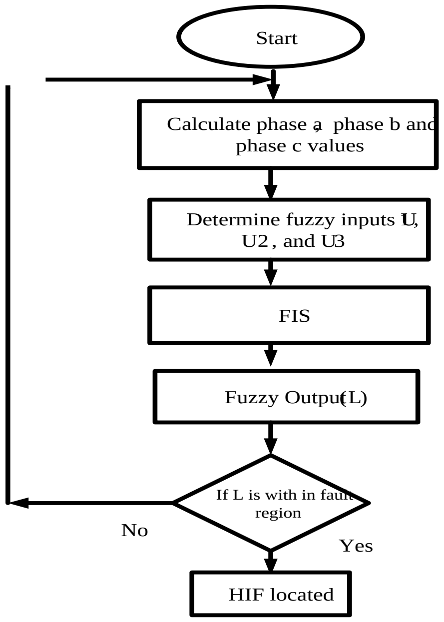

Figure 2. Proposed Flowchart for HIF Location

Figure 2 shows flowchart of proposed method for location of HIF in distribution system. First step to calculate phase a, phase b and phase c values from simulation after calculating the current values, determine the fuzzy inputs U_1, U_2, U_3, are set in to membership functions by setting the limits L, N, H. Implemented FIS by using fuzzy outputs. Output of fuzzy set serves as a input to the defuzzifier, defuzzifier combines the fuzzy inputs to obtain a single output value. Aggregate all outputs of fuzzy as input to the defuzzifier. Defuzzifier shows the result is true or false. Consider FIS for HIF location by using the equations.

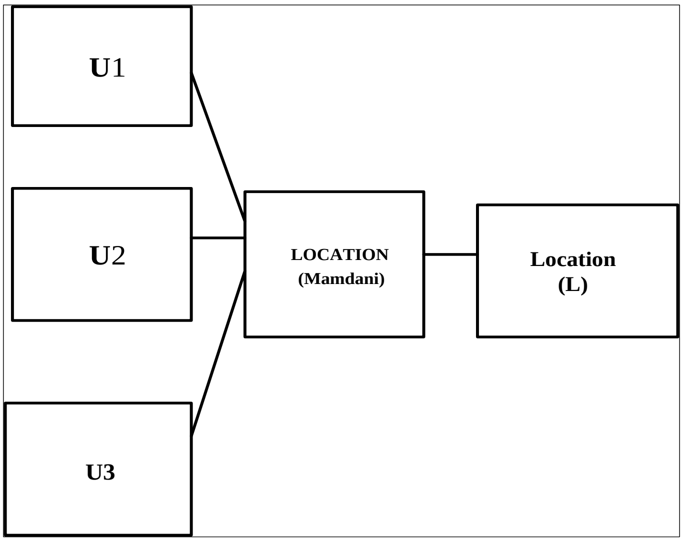

Figure 3. Developed FIS for HIF Location

Figure 3 includes FIS for HIF location 3 inputs U_1, U_2, U_3, and output L, in this diagram mamdani system is used for fuzzy location. A crisp set permits only full membership or no membership of a component of a set, though fuzzy sets allow a steady or smooth transition from no membership to full membership.

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Considered fuzzy input membership function ranges for FIS as tabulated in below table.

Table 1. Input Membership Function Range for HIF Location

Input Membership Functions	Range
Low_1	[-685 -400 -100]
Low_2	[-99.9 -50 -40]
Low_3	[-39.9 -30 -27]
Low_4	[-26.9 -25 -20]
Low_5	[-19.9 -15 -10]
Low_6	[-9.9 -5 -1]
Low_7	[-0.9 -5.564e-14 8.648e-15]
Low_8	[-0.01 0.01 0.9]
$Normal_1$	[1 3 5]
$Normal_2$	[5.1 7 10]
$Normal_3$	[10.1 15 20]
$Normal_4$	[20.1 25 27]
$Normal_5$	[27.1 35 40]
$High_1$	[40.1 50 62]
$High_2$	[62.1 80 90]
$High_3$	[90.1 100 110]
$High_4$	[110.1 120 130]
$High_5$	[130.1 200 700]

Table 1 shows input membership function ranges, in this table ranges are divided into 3 categories low, normal and high. If currents values are between range [-685 0.9] FIS will occur in low, current values are between [1 40] FIS will occur in normal, current values are between [40.1 700] FIS will occur in high. Based on the membership functions this work apply rules for FIS. Considered output membership function ranges for FIS are tabulated in Table 2.

Table 2. Output Membership Function Range for HIF Location

Output membership functions	Range
L_1	[0 0.1 0.15]
L_2	[0.16 0.2 0.25]
L_3	[0.26 0.3 0.35]
L_4	[0.36 0.4 0.45]
L_5	[0.46 0.5 0.55]
L_6	[0.56 0.6 0.65]
L_7	[0.66 0.7 0.75]
L_8	[0.76 0.8 0.85]
L_9	[0.86 0.9 1]
L_{10}	[1.1 1.25 1.3]
L_{11}	[1.31 1.35 1.4]
L_{12}	[1.41 1.5 1.6]
L_{13}	[1.61 1.7 1.8]
L_{14}	[1.81 1.9 2]
L_{15}	[2.1 2.25 2.3]
L_{16}	[2.31 2.4 2.45]
L_{17}	[2.46 2.5 2.7]

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L_{18}	[2.71 2.75 3]
L_{19}	[3.1 3.25 3.5]
L_{20}	[3.6 3.75 4]
L_{21}	[4.1 4.25 4.5]
L_{22}	[4.6 4.75 5]

Table 2 shows output membership function ranges $L_{1,}$ $L_{2,,}$…..$L_{22,}$ if currents values are between ranges from [0 5] if output value with the range FIS will occur particular location, based on current values apply the rules for FIS. The considered fuzzy input membership functions for HIF location as shown in below figure. Figure 4 shows membership functions for fuzzy input for HIF location. Membership functions set in input 1, input 2 and input 3 with the limits of low, normal, high and output set L. In this diagram considered 9 membership functions based on ranges of phase current values, for location. Consider membership function on fuzzy output for HIF location shown in figure. Aggregation is a process whereby the outputs of each rule are combined. Aggregation is performed once for each output variable. The input to the aggregation process is the truncated output fuzzy sets returned by the implication process for each rule formulated. The output of the aggregation process is the combined output fuzzy set. The aggregated output fuzzy set serves as input to the defuzzifier. The defuzzifier combines the information in the fuzzy inputs to obtain a single crisp (non-fuzzy) output variable. The simplest and most widely used center of gravity method is used for the defuzzification process.

For example, if fuzzy levels low, normal and high have membership values that are labelled U_1, U_2, and U_3 then the crisp output signal (L). The considered rules for HIF location in distribution systems tabulated in below Table 3 [14].

Table 3. Rules for HIF Location

S. No	$Input_1$ (U_1)	$Input_2$ (U_2)	$Input_3$ (U_3)	Output (L)
1.	Low_5	$High_5$	$High_4$	Fault located at L_{10}
2.	Low_6	$Normal_4$	$Normal_4$	Fault located at L_9
3.	Low_5	$High_3$	$High_3$	Fault located at L_{12}
4.	Low_7	$Normal_2$	$Normal_2$	Fault located at L_7
5.	Low_6	$Normal_3$	$Normal_3$	Fault located at L_7
6.	Low_5	$High_2$	$High_2$	Fault located at L_8
7.	Low_8	Low_7	Low_7	Fault located at L_5
8.	Low_7	$Normal_5$	Low_7	Fault located at L_{15}
9.	Low_4	$High_1$	$High_2$	Fault located at L_{13}
10.	Low_5	$Normal_4$	$Normal_4$	Fault located at L_{15}
11.	Low_5	$Normal_5$	$Normal_5$	Fault located at L_{14}
12.	Low_5	$Normal_5$	$Normal_4$	Fault located at L_{15}
13.	Low_1	$High_5$	$Normal_4$	Fault located at L_{17}
14.	Low_6	$Normal_1$	Low_7	Fault located at L_4
15.	Low_7	Low_7	$Normal_2$	Fault located at L_{13}

Table 3 shows rules for fault location same rules are implemented in FIS. If $input_1$ is low_5 and $input_2$ is $high_5$ and $input_3$ is $high_4$ then output (L) will shows the fault occur particular location between L_1 to L_{22}. The above rules are implemented in FIS this work get output in terms of L values. Different levels of the fault currents and voltages for different fault conditions on the distribution lines are classified into various degrees of

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membership functions- Low, Normal, and High. Practically implement the rules in FIS, it shows whether the fault is occurred or not. These are the rules implemented in FIS practically. This work validate the accuracy and performance of the fuzzy logic based fault diagnostic system as described in this work based on the test radial distribution system on which the fault simulation was performed.

Consider single line diagram of 7-node test system. Figure 4 shows single line diagram of 7-node test system, it consists 7 loads and source1 and one transformer, HIF connected at 2nd node of the system and loads are connected through buses.

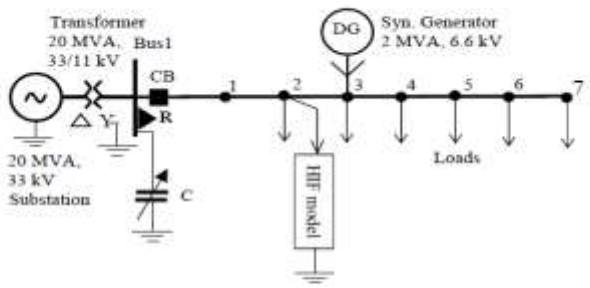

Figure 4. Single Line Diagram of 7-node Test System [15]

Considered interpretation of Results for HIF Location as tabulated in below Table 4. Table 4 shows the results obtained from the simulation that values implemented in FIS, after implementing the rules output obtained fault located or not based HIF and Non-HIF.

Table 4. Results Obtained for HIF Location for 7-node Test System

S. No	Fault applied in between buses	Actual fault location (L) (km)	Input1 (U_1)	Input2 (U_2)	Input3 (U_3)	Fault Located (L)	Fuzzy output (L) (km)
1.	b_{12}	1.5	-2.9632	0.7753	3.1949	Yes	2.5
2.	b_{23}	1.6	-2.6847	0.7537	2.9382	Yes	2.5
3.	b_{34}	1.7	-2.3185	0.4151	1.8673	Yes	2.5
4.	b_{45}	1.4	-2.0319	0.3746	1.6260	Yes	2.5
5.	b_{56}	1.3	-1.3100	0.2539	1.0362	Yes	2.5
6.	b_{67}	1.2	-1.0199	0.2010	0.8034	Yes	2.5

4. Results and Discussions

By using the above equations, rules and FIS, results can be obtained it shown in below table. Table 5 demonstrates the outcomes got from the recreation that qualities actualized

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in FIS, in the wake of executing the guidelines yield got fault recognized or not based HIF and Non-HIF, whether compare to all phase current values in 8th bus have less current values. Fault location for distribution feeders uses the same basic principles as for transmission lines, but presents a great challenge for substation fault locators because of the diverse topology of the distribution system: laterals, spurs, and single-phase taps. On important feeders, some utilities model the line parameters to achieve a more precise fault location. The overall performance of the proposed method in identifying the actual faulted section is presented in below table. A fault is applied at the middle line of each section of the network and then the capability of the proposed method to locate the fault is analyzed, from the table, it shows that the proposed method can still identify the faulted section although the location of the fault varies along the line section. Also, it is observed that the accuracy increases as the fault is shifted near to the end of the line section.

Table 5. Results Obtained from FIS for HIF Location

S. No	Fault applied in between buses	Actual Fault location (L) (km)	Input$_1$ (u_1)	Input$_2$ (u_2)	Input$_3$ (u_3)	Fuzzy output (L) (km)	Error
1.	b_{12}	1.65	-18.2102	141.8089	122.3928	1.2	0.27
2.	b_{23}	1.25	-5.0849	25.7701	25.1730	0.9	0.28
3.	b_{24}	1.3	-18.7603	98.7301	92.7206	1.5	-0.15
4.	b_{45}	1.1	-5.5645e-14	6.6888	6.4920	0.7	0.36
5.	b_{46}	1.6	-4.1663	16.6550	16.1435	0.7	0.56
6.	b_{47}	2.5	-19.9494	74.0705	68.9704	0.8	0.68
7.	b_{78}	0.6	0.7797	8.6482e-15	-5.5494e-15	0.5	0.16
8.	$b_{7\text{-}10}$	2.1	-9.1212e-12	1.4674e+03	-3.9052e-12	1.8	0.14
9.	$b_{10\text{-}11}$	1.8	-26.2248	61.3578	63.1540	1.7	0.5
10.	$b_{10\text{-}12}$	2.3	-12.9701	24.9875	23.5446	2.2	0.4
11.	$b_{12\text{-}13}$	2.0	-18.7583	32.5119	34.5653	1.9	0.5
12.	$b_{12\text{-}14}$	2.1	-16.5375	27.3566	25.4596	2.2	-0.4
13.	$b_{14\text{-}15}$	2.7	-679.6919	656.0158	1.1099e+03	2.2	0.18
14.	$b_{14\text{-}16}$	2.25	-4.1692	4.1692	3.0255e-18	1.9	0.15
15.	$b_{10\text{-}11}$	1.7	7.1268e-14	-1.7091e-14	6.4196	1.5	0.11

5. Conclusion

In this work, a protection scheme dealing with the location of HIFs using fuzzy logic technique is presented and evaluated. The device is continuously monitoring deviations caused to location metrics that are associated with the input impedance of the network at specific frequencies, when a fault occurs, and as compared to normal operational conditions. The advantage of this method is identification of a specific faulted line section rather than estimating a distance from the main substation. Additionally, proposed HIF location approach is tested for different test cases. The accuracy of proposed methodologies has been tested on IEEE-15 bus test system and 7-node test feeder using MATLAB/SIMULINK. Finally, it is shown that the fuzzy logic technique could provide both detection and location.

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