A Novel Approach to Detection High Impedance Faults Using Fuzzy Logic

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ABSTRACT

This paper presents a new approach to detection high impedance fault in distribution system using fuzzy-logic scheme. The proposed fuzzy unit, was trained by data from simulation of a distribution system under different faults conditions, and tested by data with different condition system. Details of the design procedure and the results of performance studies with the proposed method are given in the paper. Performance studies results show that the proposed algorithm is very good performance in detecting high impedance fault with nonlinear arcing resistance. It is clearly shown that with this integrated approach, the accuracy in detection fault is significantly improved over other techniques based on a conventional algorithm.

1. INTRODUCTION

Detection and identification of High Impedance Faults (HIF) in electrical distribution networks are a challenge for protection engineers. This is due to the nature of this kind of faults and their variability and relatively low fault current levels with respect to feeder load current. HIF in power networks represent safety hazards, utility liability problems and possible equipment and property damage due to arcing and resistance fires. Various schemes and algorithms have been proposed by different researchers to cope with the problems associated with HIF. Some of the existing detection schemes employed conventional over current, ground relays, dominate one harmonic detection and high frequency based ripple detection in the range of 2-10 kHz [1-4]. These schemes utilize the frequency spectra generated by the nonlinearity of the ground path associated with the arcing, soil fusing and temporal variations in the equivalent fault impedance [5].

AI based detection and classification schemes offer one of the best alternatives to the HIF problem as they provide well trained noise tolerant detection algorithms with the potential of training and retraining using actual field HIF fault data. In this application, capabilities of fuzzy logic algorithms are used to identify high impedance faults in electrical distribution networks. Design of a Fuzzy unit based approach for an accurate HIF detection algorithm is presented in the paper.

2. SYSTEM MODELING

2.1. NONLINEAR ARC RESISTANCE MODEL

There have been many studies in the field of arcing and ground resistance [5, 6, 7]. Continuous conduction of a fault arc requires a certain amount of voltage gradient to be applied. Research shows that the voltage across the arc has a flattop waveform [6]. The magnitude of the arc voltage may vary depending on arc length but it is independent of current through the arc. For example, in a simple distribution system the current through the arc is determined only by source voltage and fault loop impedance because the arcing resistance R_f is small.

The HIF model, as shown in Fig. 1, consists of a nonlinear resistor, two diodes, and two dc sources that change amplitudes randomly every half cycle. Thus, some dynamics and randomness are represented. Changing the mean and standard deviation of the dc source voltage amplitudes could be used to more closely approximate different ground surfaces such as asphalt, sand, or grass. A typical HIF current generated from simulations is shown in Figs. 2.

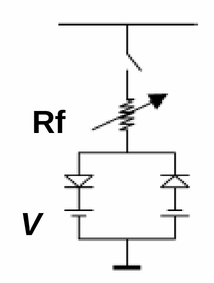

Fig. 1. Nonlinear arcing resistance model

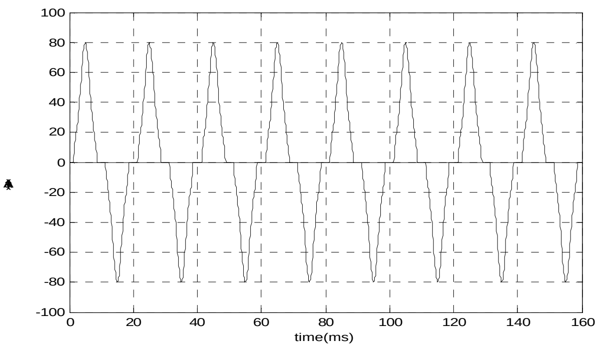

Fig. 2. Approximation to the clipped current of a nonlinear arc

2.2 POWER SYSTEM MODEL

The training data set of an FN should contain the necessary information to generalize the problem. The training data set was obtained by performing various simulation studies based on a typical distribution system as shown in Fig. 4. This figure depicts the modeled system of a sample radial distribution feeder including load, tap-changing transformer, voltage correction capacitor banks and equivalent HIF arc model. Since disturbances resulting from HIFs may resemble those from capacitor switching and transformer tap changing, it is therefore necessary to include cases with these contingencies to ensure that the Fuzzy logic schem will not be confounded even under the high level of harmonics so generated. The studied system's parameters are shown in Table 1.

Digital simulations were performed using an electro-magnetic transient program EMTDC [8]. For different simulations various parameters and contingencies were considered. Different parameters such as fault location, fault inception angle, load, transformer tap and were changed to obtain training patterns covering a wide range of different power system conditions. Various contingencies such as capacitor switching, single phase load switching, tap changer operation were also modeled. Combination of different fault conditions considered for training pattern data generation is shown in Table 2.

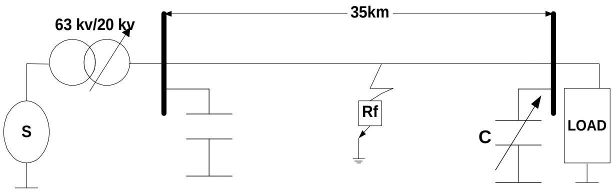

Fig. 3. Simulated power system model

Table 1. Simulated power system parameters

Positive & negative sequence line impedances (• /km)	0.32+j0.48
Zero sequence line impedances (• /km)	0.32+j0.48
Transformer impedance (%)	7.5
Sources X/R ratio	30
Sources impedance	22

Table 2. Training patterns data generation

Fault location (km)	Different values between (1-35)
Arc voltage (V)	Different values between (1000-6000)
Inception angle (deg)	Different values between (0-360)
C (kVar)	Different values between (0-300)
Tap changer	-4.5, 0, 4.5
Load (MW)	15,20,30,50

3. FUZZY-BASED FAULT DETECTOR DESIGN

In this paper, an adaptive fuzzy method is chosen as a high impedance fault detection module.. Block diagram of the proposed approach is shown in Fig. 4. Adaptive network Fuzzy is inflected in three basic elements: fuzzification, fuzzy inference and defuzzification. In neural nets, the weights between the input and the first hidden layer as well as the last hidden layer and output layer, determine the input/output behavior. In a fuzzy system, these parameters are found in the fuzzification and defuzzification routines and can thus be trained. Calculated degrees of membership in the rule layers are according to IF-THEN rules.

In this work, Takagi-Sugeno model with multiple inputs and a single output is used. This model is composed of the linguistic variables in premise part and polynomial variables in consequent part. The generic fuzzy rule used under this scheme has the following structure:

R^h: IF x_1 is $A^h{}_1$ and . . . and x_p is $A^h{}_p$ THEN y is $f_h(x)$.

h= 1,…R

where: $f_h(x) = a_{0h}+a_{1h}x_1+a_{2h}x_2+\ldots+a_{ph}x_p$

in which $x_{1,\ldots p}$ are the input variables, y is the output variable, $A^{1,\ldots p}$ are membership functions, and $a_{(1,\ldots p)h}$ are consequent parameters. In the learning procedure, the forward pass learning estimates the consequent parameters and backward pass learning updates the premise parameters.

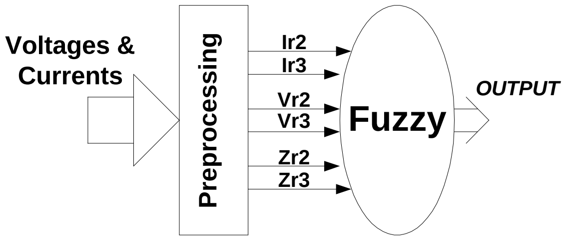

Fig. 4. The proposed algorithm structure

3.1. INPUTS AND OUTPUTS

In this study, six input signals are considered at the input layer of the proposed Fuzzy unit. The fuzzy unit processes lower order harmonics of the voltage and current signals. The input signals are prepared at the preprocessing stage.

The six input signals required at the input layer are namely *Ir2*, *Ir3*, *Vr2*, *Vr3*, *Zr2 and Zr3*. *Ir2* and *Ir3* are the second and third harmonics of the residual current. Similarly, *Vr2* and *Vr3* are the second and third harmonics of residual voltage. The residual current and voltage are defined as:

$$\begin{aligned} Ir &= Ia + Ib + Ic \\ Vr &= Va + Vb + Vc \end{aligned} \quad (1)$$

where V_a, V_b and V_c are the voltages at the relay location and I_a, I_b and I_c are the currents through the relay.

Zr2 and *Zr3* are the second and third harmonics of residual apparent impedance of the faulted distribution line. They are measured at the relay location using (2):

$$\begin{aligned} Zr2 &= \left|\frac{Vr2}{Ir2}\right| \\ Zr3 &= \left|\frac{Vr3}{Ir3}\right| \end{aligned} \quad (2)$$

The fuzzy logic unit processes its six inputs and makes a suitable decision based on the power system state. Its output is activated for a high impedance fault and remains stable for other system states.

If a fault is located in the tripping region, the network target output should be 1, otherwise it should be 0. Membership functions and suitable fuzzy rules were obtained by data set that obtained by simulating. For training, Matlab software has been utilized. Membership functions for input variables are defined as low, medium and high. In the present study fuzzy toolbox has been used to a quire the fuzzy knowledge and to generate the fuzzy reasoning module, which can be used during the simulation.

3.2. PREPROCESSING

The process of generating input patterns from the voltages and currents signals is depicted in Fig. 5. Samples of three phase voltages and currents at the relay location were obtained from the power system simulated by the EMTDC software. These samples were processed by 2nd order low-pass anti-alising filters and were re-sampled at 1 kHz. The anti-alising filters had a cut-off frequency of 450 Hz.

Samples of the residual current and voltage signals are then obtained using (1). Next the second and third harmonics (of magnitude and angle) of these signals have been obtained using the full cycle Discrete Fourier Transform (DFT) algorithm from voltage and current samples. Finally the second and third harmonics of apparent impedance of the faulted distribution line are calculated using (2).

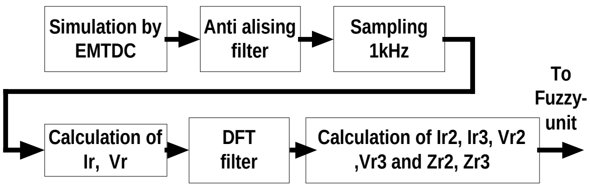

Fig. 5. Pre-processing stage

3. 3. FUZZY UNIT EVALUATION

A validation data set consisting of about 100 different fault types was generated using the distribution system model shown in Fig. 3. The validation set fault patterns were different than the fault patterns used to train the network. For different faults of the validation set, fault type, fault location, fault inception time, and arc voltage were changed to investigate the effects of these factors on the performance of the proposed algorithm.

The proposed HIF detector operation for a few faults with different distribution system conditions is presented in Table 3. As an example, test results for a single phase to ground, BG fault at 3 km from the relay location is presented in the first row of the Table 3. The fault inception angle with respect to phase A voltage zero crossing was 90 deg and the bank capacitor was 30 kVar.

HIF Detector operation for three different amount of arc voltage is shown in the last three columns of the table. For the faults, which involve ground, the detector operation for 1000, 3000 and 5000 arc voltage is investigated. For the faults, which do not involve ground, fault resistance is not a critical factor. Therefore, only detector performance without fault resistance is investigated.

As shown in Table 3, the relay performs quite accurately and reliably. The detector output for a few faults with different distribution system conditions is presented in this section. The main emphasis is on checking the network's performance under extreme fault cases. In general, the fuzzy unit performs good and fast for more usual fault cases.

Table 3. HIF detector operation test results

Fault Type	Fault Location (km)	q (°)	C (KVAR)	V_f 1000 (V)	V_f 3000 (V)	V_f 5000 (V)
BG	3	90	30	Tr	Tr	Tr
AG	4	0	10	Tr	Tr	Tr
BG	5	0	60	Tr	Tr	Tr
CG	7.8	210	40	Tr	Tr	Tr
AG	8.5	340	60	Tr	Tr	Tr
CG	12	210	20	Tr	Tr	Tr
AG	14	210	210	Tr	Tr	Tr
AG	16	90	300	Tr	Tr	Tr
CG	20	90	190	Tr	Tr	Tr
AG	27	90	290	Tr	Tr	Tr
BG	28	0	20	Tr	Tr	Tr
CG	30	0	10	Tr	Tr	Tr
BG	32	300	40	Tr	Tr	Tr
AG	33	340	190	Tr	Tr	Tr

(TR): Trip, (-):No Trip.

4. CONCLUSION

The paper presents practical harmonic HIF detection schemes using fuzzy logic scheme. The proposed fuzzy unit reacts promptly to HIFs and has a high success detection rate. It's based on a distribution system simulation, is very good. The proposed detection scheme only utilizes low harmonics of residual quantities, which greatly enhances its feasibility and flexibility.

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