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Neural Network Application to Short Turn Localization Using Fuzzified Data

M. A. El-Sharkawi, S. J. Huang, R. J. Marks II, S. Oh
Department of Electrical Engineering, FT-10
University of Washington
USA
Phone: (206) 685-2286 - FAX: (206) 543-3842

I. Kerszenbaum A. Rodriguez
Research Center
Southern California Edison Company
USA

Abstract: We propose the fuzzified neural network approach to detect and localize shorted turn in windings, such as in transformers and electric machinery. The method is based on sending two identical signals through the terminals of the windings. The selected feature of receiving signals are then analyzed by the fuzzified NN to detect and localize the shorted turns. The proposed method is tested in the laboratory on autotransformer and field test on a 60 MVA turbogenerator. The results demonstrate the feasibility of the proposed method in short turn detection applications.

Keywords: Neural Network, Fuzzy Logic, Short Turn Detection

1. Introduction

Shorted turns in windings often occur due to machine stress and external transients. A winding short may lead to the deterioration of the machine efficiency and effective operation. This degeneration of machine performance may bring the high cost of repair. The problem of shorted turns in machine windings and coils has been the research subjects in the power industry [1-2]. Most of the shorts can be detected by sensing the terminal voltage and input current of the machines. Some shorts, however, may not be easily detected, especially if the short is intermittent, or if the short has undetectable signature by the present technology.

Several methods were proposed to solve this problem [3-8]. One method is based on sensing the increased mechanical vibrations [3]. Another is based on installing pick-up coils inside the machine to detect the shorts by monitoring the induced voltage on the coil [4]. Another method is based on reconfiguring the structure of the windings [5] in such a way that the short can be detect by flux unsymmetry. All of the above methods are expensive to implement. Moreover, none of them can localize the shorted turn [6].

A promising method based on the traveling wave theories was proposed [7-8]. By this method, two traveling waves are sent through the windings from opposite ends. The difference between the reflected signal is observed. The reflected signals should be identical unless a short is present. An expert can then analyze the signals and recognize the existence of short. The time-consuming task of installing the equipment or the special design of the winding in the turbogenerator can thus be avoided.

In this paper, the idea of traveling waves is further enhanced by using the NN and Fuzzy logic technologies. By doing that, we not only detect the shorts, but also localize it.

The proposed method was verified in the laboratory and in the field. Shorts in a transformer were detected and localized in the laboratory. The excitation windings of a turboalternator were used during the field test.

2. Basic Concept

Figure 1 shows the basic idea. The figure shows the windings connected from both ends to a high frequency pulse generator. Two identical signals are injected into the winding from both sides. The reflected waveforms are received, subtracted and processed. This signal is called signature signal. Note that the frequency of the injected signal must be selected to ensure no interference between the falling edge of the injected signal and the reflected wave [19].

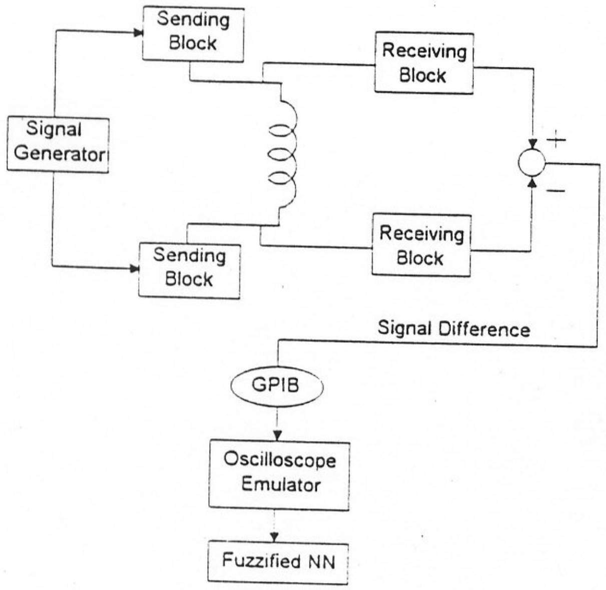

Figure 1. Outline of Procedure

3. Fuzzified Neural Network Approach

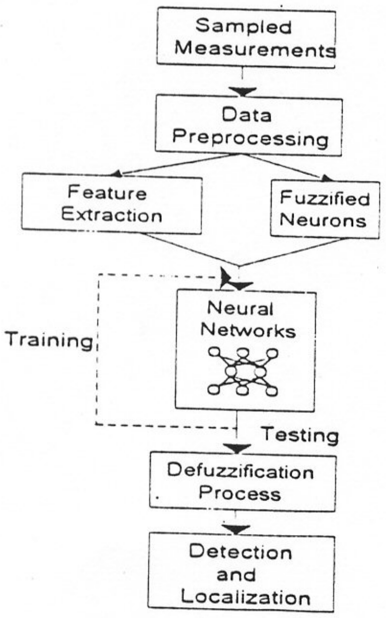

Figure 2. Localization procedure.

The neural network, when adequately designed and trained, can synthesize the relationships between input and output patterns. This is especially useful when the mathematical relationships can not be expressed by a closed form to represent the physical model. This is a key motivation in applying neural network technique to short turn detection and localization.

The proposed general short turn detection procedure is outlined in Figure 2. The training data acquired by the setup of Figure 1 is used for neural network training.

A high sampling rate is used to ensure that the entire signature is captured. However, this results in a vector whose high dimension cannot be easily processed by neural network. Hence, a feature extraction approach is used [15-19].

Some feature extraction techniques are based on the mathematical technique [15-17] while others are based on engineering judgments and heuristics. Our feature extraction technique is the later. Integrals of key portions of the signature signal are used as features for NN training. An example of the feature extraction is shown in Figure 3. The signal time is divided into several intervals. Note that the time interval p1, p2 and p3 are not equally divided. This is due to the dispersion that the signal fluctuation is more significant in the beginning than the signal in a later time. The area of each interval is

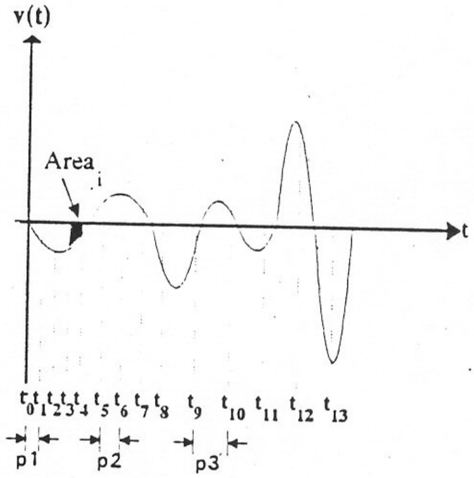

Figure 3. Features extracted from signature signal.

$$\text{Area}_i = \int_{t_{i-1}}^{t_i} v(t)dt \qquad (2)$$

Where V(t) is the signature signal. These calculated areas are then served as the inputs of the neural network. Note that the selection of the number of area is arbitrary. However, a too big number may lead to a longer computation time in neural network learning.

To increase the accuracy and the dynamic range, we also fuzzify the output neurons. An example of the general membership functions for the fuzzification mapping is shown in Figure 4. The location of the short is coded into N fuzzy membership functions. Therefore, the total n turns can be divided into (N-1) sections. Each section (L) contains $\frac{n}{N-1}$ turns. The sections (L1, L2...Ln) are:

L1: turn #1 $\sim \frac{n}{N-1}$

L2: turn # $\frac{n}{N-1}+1 \sim \frac{2n}{N-1}$

Ln: turn # $(n-\frac{n}{N-1})+1 \sim n$

Each output neuron corresponds to the value of membership function [19]. In the testing process, the neuron outputs are defuzzified where each membership function is weighted by the state of the corresponding output neuron [11-14]. The weighted membership function is then added and the center of mass of the sum is the short location. For example, if each membership function is of identical shape and has a center of mass c_i, then the (defuzzified) centroid is equal to $\sum_i k_i c_i / \sum_i k_i$, where k_i is the output of the i^{th} output neuron.

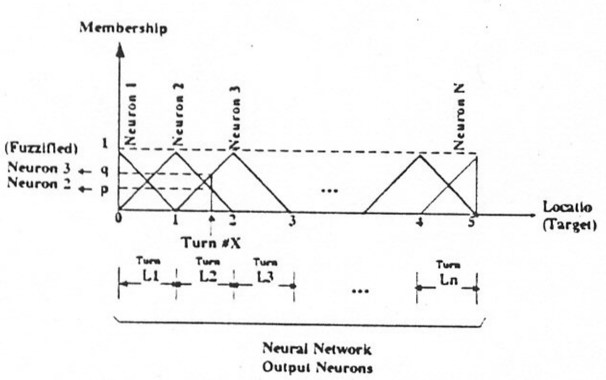

Figure 4. Membership function for the fuzzification mappings.

4. Implementation

The proposed method was tested on a turbogenerator [19] and on an autotransformer in the laboratory. This paper presents the testing on the transformer. The test system schematic is shown in Figure 5.

The transformer has a 22 mH inductance. During the test, the short was simulated by positioning the carbon brush of the center tap across two windings. The windings are divided into 4 sections. For each shorted turn, the receiving signals are captured. Each sampled signal has 500 points with 8 nanosecond resolution. An example of a sampled waveform is shown in Figure 6. The horizontal axis represents the time in nanoseconds and the vertical axis is the magnitude of the signals in volts. The scale of signals A or B is 1 volt/division, and for A-B is 0.1 volt/division. The signals A and B represent the reflected waves measured on both ends of the winding. The signal (A-B) represents the signature signal.

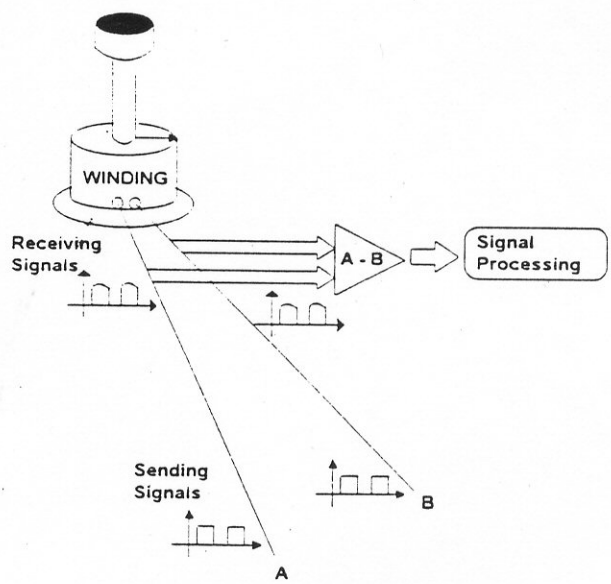

Figure 5. Test System

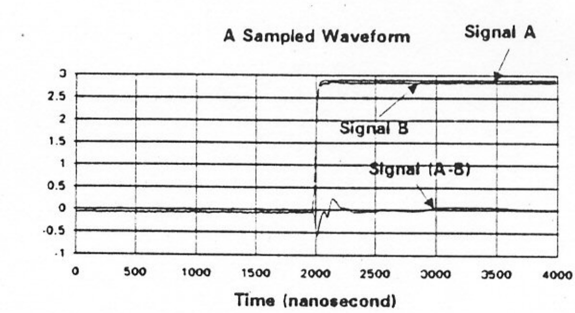

Figure 6. Sampled waveforms

The signature signals are sampled at 5 MHz. By shorting adjacent turns at several locations within the field winding, 120 training patterns were collected. A neural network with one hidden layer, thirteen input neurons, four hidden neuron and six output neurons was used. This architecture gave a lower test error than other architectures. The standard back-error propagation was used to train the neural network.

After the network was trained, it was tested for several short locations. Compared with the actual short location, the network identified the location of the short with a great degree of accuracy. The results of the NN testing are shown in Figure 7. The diagonal line represents the actual location of the short, and the circles represent the NN results. The maximum error for short location was 0.35 and the average standard deviation was 0.034 over a normalized winding length of 4.

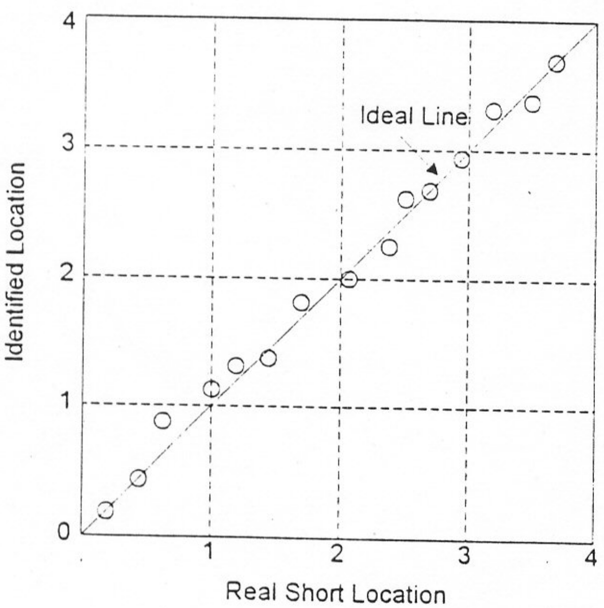

Figure 7. The tested results.

5. Conclusions

A method to detect and localize shorted turns in the windings of electric machinery, surge coils or autotransformers was proposed. This approach is developed based on the hybrid system of neural network and fuzzy logic technology. The tested results demonstrated the feasibility and practicality of the proposed method to the applications.

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