Artificial Neural Network based Fault Classifier and Distance

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Abstract---An Artificial Neural Network (ANN) based accurate fault classifier and fault distance locator for a transmission line is presented in this paper. The proposed strategy is implemented on a transmission line fed by the ideal voltage sources at both ends. The database to train the artificial neural network is generated with a MATLAB program. The neural network is trained for an accuracy of detection of ± 1 km in terms of fault distance. The complete scheme is implemented using MATLAB-SIMULINK. Transient fault currents are used to train the network. Hence, if we measure the fault currents with the digital instruments and feed them to the neural network, this module will be helpful to quickly determine the type and distance of fault which is the main contribution of this paper. Since quick detection of type and location of fault is possible, system reliability improves.

Keywords: Artificial Neural Network, Fault distance locator, Fault type classifier.

I. INTRODUCTION

An overhead transmission line is a significant component in every electric power system. The transmission line is exposed to the environment and the possibility of experiencing faults on the transmission line is generally higher than that on other components. Line faults are the most common faults, they may be triggered by lightning strokes, trees may fall across lines, fog and salt spray on dirty insulators may cause the insulator strings to flash over, and ice and snow loadings may cause insulator strings to fail mechanically. When a fault occurs on an electrical transmission line, it is very important to detect it and to find its location in order to make necessary repairs and to restore power as soon as possible. The time needed to determine the fault point along the line will affect the quality of the power delivery. Anamika Yadav & A.S.Thoke [1] mentioned accurate fault distance and direction estimation based on application of artificial neural networks for protection of doubly fed transmission lines. Author uses voltage and current of the source end to find the direction and location of the fault on the transmission line. From the reference [1] this paper represents application of ANN for protection of transmission line with accurate detection of the fault and fault location from source end of single circuit transmission line. The effect of inception angle, fault resistance and varying fault location is considered in this work. Algorithm of fault classifier and fault location detection shows the complete flow of process to find fault location. Also graph of fault signal input and fault location output shows accuracy of the process.

The strategy reported in this paper is implemented on a single circuit transmission line, which is fed from both ends by ideal voltage sources as shown in figure.

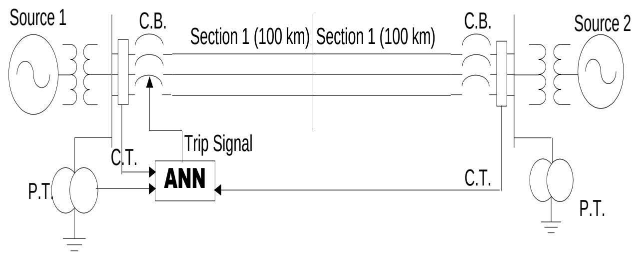

Fig.1: Single Line diagram of system

The database for transient fault currents is generated with a MATLAB program using the method explained in [2]. There is a provision in the program to incorporate different values of fault inception angles and fault resistances. The fault currents are saved up to 10 ms after the instant of fault inception. However, this time duration can be changed as per our choice. The transient fault current's database is generated for each type of fault separately i.e. LL, LG, LLG etc. These databases are then used to train the corresponding ANN. The inputs to the ANN are transient fault currents and output is the fault location from source end. Fault ANN has 2 input neuron for current input, 1 output neuron for fault location and 12 for hidden layer. In addition fault ANN use hyperbolic tangent sigmoid transfer functions.

The fault classification logic is based on the amplitude of the currents in various phases. SIMULINK model is developed which compares the amplitudes of all phase currents against a threshold value. The phase, for which the amplitude of fault current exceeds a threshold value, is a faulty phase. This way, different faults like LL, LG and LLG are classified. For each category of fault, there is a trained neural network as mentioned earlier. SIMULINK model then selects the appropriate ANN corresponding to the type of fault and finally we get the fault type as well as fault distance from source end as output.

Final target of the work is to integrate this module with actual measured fault currents. However, in order to validate the proposed work, it is tested with random input signals selected from the database itself. It is observed that the results are accurate.

Section II includes an introduction to the ANN. Steps to obtain fault currents with different types of faults are explained in section III. Simulation and results are presented in the next section. The paper ends with a conclusion.

II. ARTIFICIAL NUERAL NETWORK

The flow of information in this section is as follows.

(1) Introduction and figure of biological neuron
(2) Structure of ANN
(3) Detailed description and logic (tool) used to train ANN

The biological neural network is the motivation of its computer science version, popularly known as artificial neural network (ANN). Basically, we can design and train the neural networks for solving particular problems which are difficult to solve by the human beings or the conventional computational algorithms.

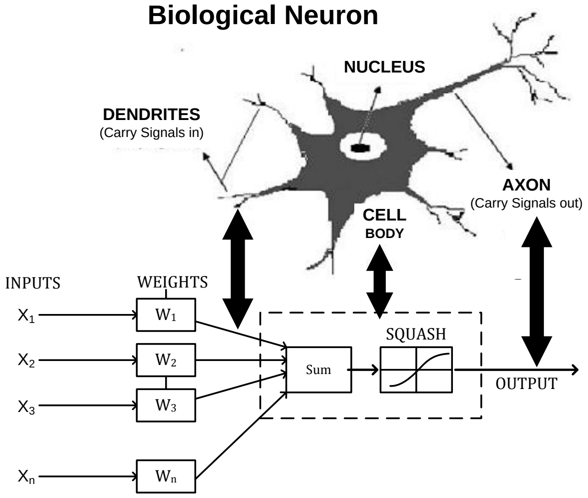

Fig.2: Structure of a Neuron

For ANN, the structure of a neuron mainly consists of the sum and squash unit. The inputs pass through the specific weights and then the weighted inputs are summed. A weight is the strength of the connection between two neurons. The weighted sum is then passed through a transfer function (also often called “squashing” functions, since they compress an infinite input range into a finite output) to produce the final output. The transfer function is chosen to map the input(s) to the output(s).

j: Neuron j ,

i : Index of the inputs,

n: Number of the inputs,

Xi : Input i ,

Wi : Weight of the input Xi ,

Sj : Sum of the weighted inputs for neuron j ,

Tj (S): Transfer function,

Oj : Output of neuron j ,

$$S_j = \sum_{i=0}^{n} X_i * W_i$$

$$O_j = T_j (S_j)$$

When this is multiplied by the weights of the hidden layer, it provides a bias (like DC offset). Hence, it is called the bias node.

ANN also develops from the interconnections of several unit neurons or nodes. The arrangement of the neurons is quite arbitrary. It depends on several factors, like, the nature of application, number of output and input, type of accuracy and speed, etc. ANN has many arrangement combinations like Feed forward network, Feedback network, Lateral Network, etc.

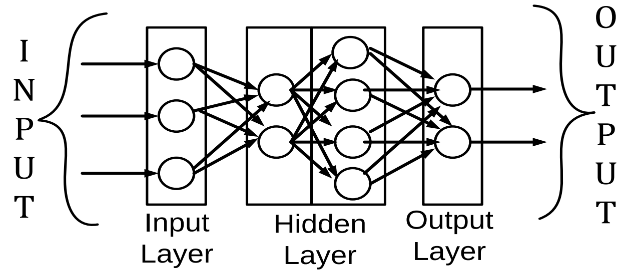

Fig.3: Basic Structure of the Artificial Neural Network

Input layer just hold input data for process and depends on the input variable. Hidden layer calculate output depends in the input and transfer function and this layer may be singular or multilayer. Output layer is calculate final output from hidden layer output and depends on the output variable.

Transfer function in the ANN maps the input(s) to the output(s). Hence, it is an important element of the network for successful network design. Transfer function is key element to invoke the nonlinear relationship between the input and the output. Without transfer function the whole operation is linear and could be solved using linear algebra or similar methods. We can use discrete function like linear transfer function and hard limit transfer function or continuous function like sigmoid transfer function and tan-sigmoid transfer function to link output with input using nonlinear relationship.

The computational meaning of the training comes down to the adjustments of certain weights which are the key elements of the artificial neural network. This is one of the key differences of the neural network approach to problem solving than conventional computational algorithms which work step-by-step. Depending on the learning method (supervised or unsupervised), the neural network tries to correlate the correspondence between the input and target data by adjusting its weights.

To simplify the whole ANN operation, first we produce the weighted sum of the input value which acts like a single lumped input value for the whole input data. And then we apply the transfer function on this lumped input value and get final output which mainly depends on the weights of the neuron which is adjusted by the training of the ANN discussed earlier and transfer function which is established nonlinear relationship between input and output of the ANN.

NNTOOL available in MATLAB is used to train the artificial neural networks.

III. COMPUTATION OF FAULT CURRENTS

Unbalanced three phase systems can be split into three balanced component, namely Positive Sequence, Negative Sequence and Zero Sequence.

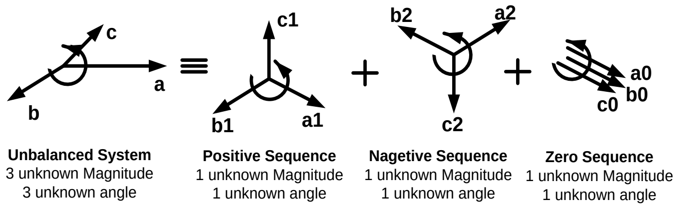

Fig.4: Symmetrical Components of unbalanced 3 phases

The phase components are the addition of the symmetrical components and can be written as follows,

a = a1 + a2 + a0
b = b1 + b2 + b0
c = c1 + c2 + c0

The unknown unbalanced system has three unknown magnitudes and three unknown angle with respect to the reference direction. Similarly, the combination of the 3 sequence component will also have three unknown magnitudes and three unknown angles with respect to the reference direction.

Thus the original unbalanced system effectively has 3 complex unknown quantities a, b and c (magnitude and phase angle of each is independent), and that each of the balanced component have only one independent complex unknown each, as the others can be written by symmetry. a1, a2 and a0 are the positive, negative and zero sequence component of phase A respectively and similar for phase B and C.

We can express all the sequence components in terms of the quantities for a phase using the properties of 0^o, 120^o or 240^o.

Thus, a = a0 + a1 + a2
$b = a0 + \alpha^2\, a1 + \alpha\, a2$
$c = a0 + \alpha\, a1 + \alpha^2\, a2$

Where $\alpha = -0.5 + j*0.866$
$j^2 = -1$

A. .*Single Line to Ground faults (L-G faults)*

The single line to ground fault can occur in any of the three phases. However, it is sufficient to analyses only one of the cases (Phase A). Since the fault impedance is 0, at the fault

$$V_a = 0,\ I_b = 0,\ I_c = 0$$

Since load currents are neglected. These can be converted to equivalent conditions in symmetrical components as follows. As in the previous equations, it can easily be deduced that

$$I_{a1} = I_{a2} = I_{a0} = \frac{Ea}{(Z1 + Z2 + Zo)}$$

Therefore, the sequence networks will be connected in series, as indicated in Figure. The current and voltage conditions are the same when considering an open-circuit fault in phase b and c.

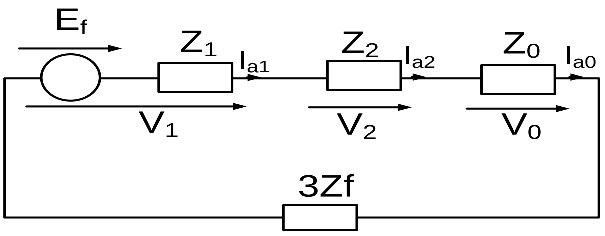

Fig. 5: Conn. of Sequence Network for LG fault with Zf

Simplification, with If = Ia , gives

$$I_f = \frac{3 * E_f}{Z_1 + Z_2 + Z_0}$$

B. *Line To Line Faults (L-L Faults)*

Solution of the L-L fault gives a simpler solution when phase's b and c are considered as the symmetrical component matrix is similar for phase's b and c. The complexity of the calculations reduces on account of this selection. At the fault,

$$I_a = 0, \quad V_b = V_c \quad \text{and} \quad I_b = -I_c$$

Equally, it can be shown that

$$Ia0 = 0 \qquad \text{and} \qquad Ia1 = \frac{E_a}{(Z_1 + Z_2)} = Ia2$$

For this case, with no zero-sequence current, the zero-sequence network is not involved and the overall sequence network is composed of the positive- and negative-sequence networks in parallel as indicated in Figure.

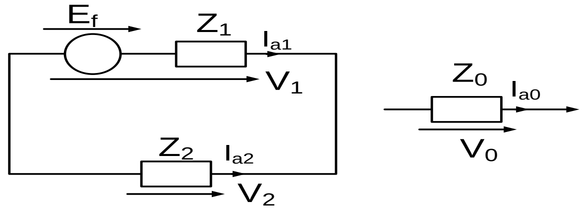

Fig.6: Connection of Sequence Networks for L-L fault

C. *Line To Line To Ground Faults (L-L-G Faults)*

At the fault,

$$Ia = 0, Vb = Vc = 0$$

Gives, Ia0 + Ia1 + Ia2 = Ia = 0

And the condition, Va0 = Va1 = Va2 (can be shown)

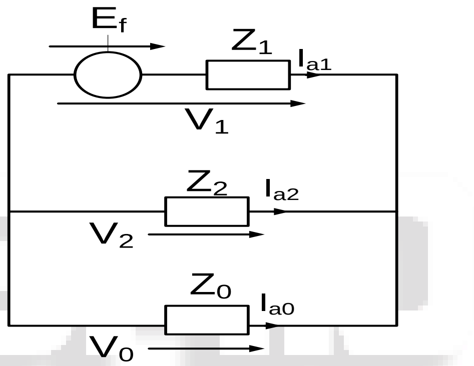

Fig.7: Connection for LLG faults

These conditions taken together can be seen to correspond to all three sequence networks connected in parallel.

$$Ia0 = 0 \ \ \text{And}$$

$$Ia1 = \frac{E_a}{(Z_1 + \frac{Z_2 * Z_0}{Z_2 + Z_0})} = Ia2$$

IV. SIMULATION AND RESULTS

The main theme of the work in this paper is to use Artificial Neural Network (ANN) for fault classification and detection of fault location from the source end. The single line diagram of the system selected for implementation of the work is shown in Fig.

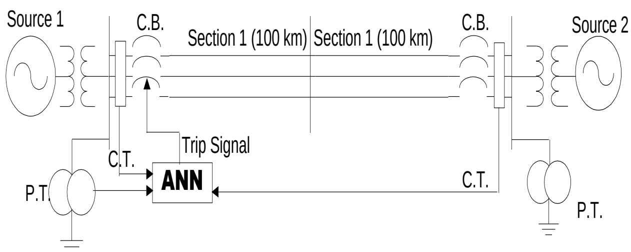

Fig.8: Single Line Diagram of System

In this system, ideal voltage sources are connected to both the ends of a 200 km long single circuit transmission line. Artificial Neural Network (ANN) gets the input parameters with the help of instrument transformers as shown in figure. As the fault detection logic uses the transient fault currents, analog to digital conversion and sampling logic is to be incorporated in addition to the routine measurements. However, this work is not included in this paper. Instead the module is tested with the random input signals from the database itself. From the selected inputs, the ANN gives fault Distance and types of fault.

The system parameters are given in Table-I

Parameter	Value
Positive Seq. Resistance R1, Ω/km	0.01273
Zero Seq. Resistance R0, Ω/km	0.1540
Positive Seq. Inductance L1, mH/k	0.9337
Zero Seq. Inductance L0, mH/km	2.2829
Positive Seq. Capacitance C1, nF/k	12.74
Zero Seq. Capacitance C0, nF/km	7.0

Table 1: Single Line Parameters

A. *Logic Of Ann*

The logic of fault classification and detection is implemented in MATLAB-SIMULINK. The main logic is divided into two parts. First part is used to classify the type of fault from input voltages and currents and second part is used to detect the distance.

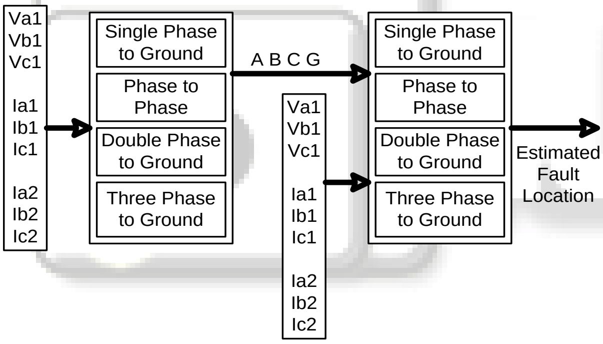

Fig.9: Logic of ANN based system

First part of logic is used to identify the type of fault from the input current of both end of the transmission line and voltage of source end. This part contain data selector which select data from all input and fault classifier ANN which classify the fault type using input. Additionally one fuzzy logic system is implemented for separate signal which given by the fault classifier ANN and apply to separate block of each fault which further process for the signal.

Second part of logic contain separate block for each fault which take signal from fuzzy logic system and current and voltage of the line. This logic has a provision of first separate the faulty phase and then apply to each ANN which is related to appropriate faulty phase and finally determines the length of the fault using all the input signals and respective ANN.

B. *Result*

Following graphs shows the result of the response of the ANN based system for different type of faults and with accuracy of the ±1 km with respect to fault location of the transmission line. All phase current value in graph is in Per Unit based on the system parameters.

In following graphs, upper graph shows phase current value before and after fault occurred and lower graph shows fault location of faulty phase from source which is determined by the entire ANN system.

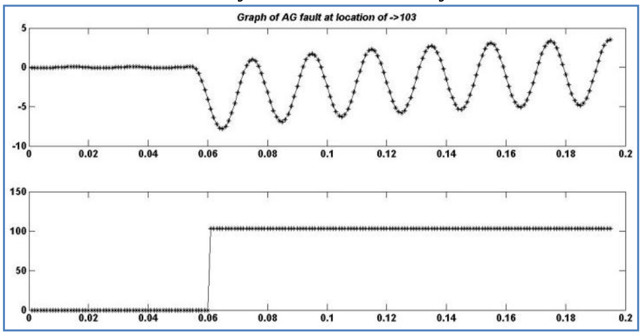

Fig.10: Waveform of AG fault with location of 103 km from source

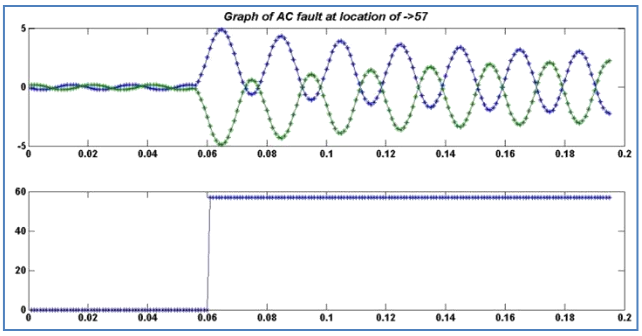

Fig.11: Waveform of AC fault with location of 57 km from source

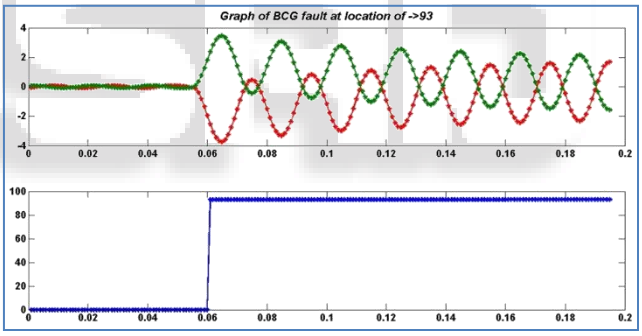

Fig.12: Waveform of BCG fault with location of 93 km from source

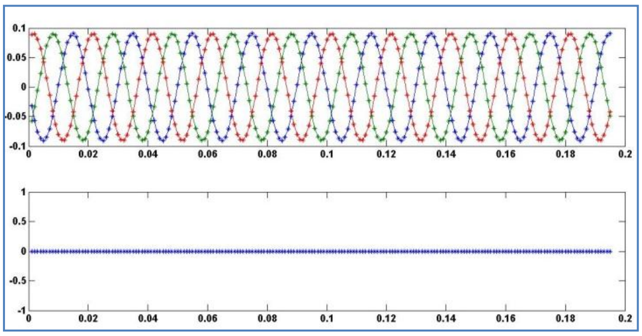

Fig.13: Waveform of No fault

C. *Validation of Results*

In order to validate the results obtained by our module, we compared them with the results obtained in [3]. The comparison of results is given in Table-2. It is observed that the suggested strategy gives reasonably accurate results for detection of fault location.

Type of fault	Distance from Sending (La in Kms)	Simulation Result of the Reference [1]		Simulation Result of implemented model	
		Distance Estimated by ANN (La in Kms)	Error in ANN (Er) %	Distance Estimated by ANN (La in Kms)	Error in ANN (Eo) %
BG	25	26.0373	1.0373	25.3025	0.3025
CG	170	169.5389	0.4611	170.1916	0.1916
AG	35	35.8004	0.8004	35.2045	0.2045
AG	185	184.4528	0.5472	184.7843	-0.2157
AG	165	164.2858	0.7142	164.7184	-0.2816
AG	190	190.0519	0.0519	190.0484	0.0484

Table 2: Data Validation with reference and actual output

V. CONCLUSION

An application of ANN as a tool to power system protection is presented in this paper. The fault type classification and detection of fault distance for a single circuit transmission line fed from ideal voltage sources is presented. The results are validated with the help of random test inputs from the database as well as with the help of the work reported in earlier literature. It is observed that the results are acceptable in terms of real application.

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