Distinguishing Between Lightning Strokes and Earth Faults on Transmission Line Using Artificial Neural Network

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Abstract - **This paper proposes a technique for discriminating between an earth fault and a lightning stroke on a transmission line using an artificial neural network. In the technique, a specially designed transient detector is employed to capture the lightning and fault induced transients. The detector outputs are used to train a three layer neural network. The ANN detects the different characteristics of lightning from the fault. The digital modelling of typical 400 kV transmission system which includes a lightning model is presented in the paper. The results show that the trained ANN is able to discriminate between an earth fault and a lightning stroke under various system and fault conditions.**

Keywords : Lightning, Fault, Neural Network, Transient Identification

I. INTRODUCTION

High frequency transients on overhead lines can be caused by atmospheric discharges such as static charges or lightning strokes. They are often of such magnitude as to cause considerable stress to insulation. In the case of lightning, the transients will vary in intensity depending on how the line is struck, i.e. directly by the main discharge, directly by a branch or streamer, or by induction due to a flash passing near to but not touching the line. A surge due to lightning is the movement of a charge that is suddenly released in a conductor and which travels along that conductor in the form of a wave. The shape of the voltage wave is affected by a number of factors, including the inductance and capacitance of the line. As the wave travels along the line its front is modified by the inductance of the line and the distributed capacitances to earth. It may be further modified by the capacitances of bushings, insulators, etc., which the wave encounters on its journey, thus reducing the steepness of the wave front.

Electric power utilities appreciate the part that lightning plays in the design and operation of their systems. They believe that measurement of lightning induced quantities and determination of the nature of surges would be invaluable. It would not only provide useful information in terms of optimal design and functionality of protective surge arresters, but also provide information for designing new protection schemes. The signals generated by lightning are high frequency transient in nature and can not be detected by conventional transducers, which are mainly designed for measurement at power frequency. However, newly developed 'Transient Based Protection' technology, which relies on the measurements of fault generated high frequency transient components for fault detection, makes possible the on-line measurement of lightning transients for protection purposes[1]. A genuine earth fault on the transmission line will also generate high frequency noise signals and subsequently be captured by the detector unit. There is no clearly discernible feature between the two waves, therefore, distinguishing between the signals generated by the two events can not be performed using conventional techniques.

In recent years, extensive research has been carried out to apply the Artificial Neural Network (ANN) techniques in the area of fault identification[2]. The ANN has a great potential learning ability to ascertain the differences amongst highly complex patterns of various fault waveforms. Other advantages of using an ANN also include very fast real-time responses. In this respect, the advent of ANNs, provides an attractive solution to the problem of fault transient identification.

This paper presents an ANN-based on-line transient identification method for discriminating between an earth fault and a lightning stroke on a transmission line. The digital modelling of a typical 400 kV transmission system which includes a lightning model is presented in the paper. The simulation studies also include a specially designed transient detector, which is installed at one end of the line and employed to capture the lightning and fault induced transients. Extensive simulation studies were conducted for earth faults and lightning strokes with variation in type, inception angle, position and waveshape etc. The detector outputs were then used to train a three layer neural network. The paper emphasises the design of an appropriate ANN which takes into account the special different characteristics of the lightning stroke from the fault. The results presented in the paper show that the trained ANN is able to discriminate between an earth fault and lightning stroke under various system and fault conditions. The technique, when applied in practice, could provide very useful information for the design of new relays based on the detection of fault transients and improvement of conventional relay functions such as fault location, fault discrimination, and autoreclosure.

II. DETECTION OF LIGHTNING STROKES AND EARTH FAULTS

A lightning stroke on a transmission line produces high frequency travelling wave signals. These signals are outside the bandwidth of receptibility of the present generation transducers, in particular, the CVT. However, research has shown that a specially designed transient detector can be used to capture the lightning and fault generated high frequency current signals[1,3]. Fig.1 shows the basic arrangement of this technique. As can be seen, the detector is installed at busbar S and is connected to the CTs on each phase of the line P.

The detector unit is divided into two parts, the transient detector and NN-based identification unit. The transient detector mainly consists of an analogue interface, mode mixing circuit and anti-aliasing filter. The signal mixing circuit receives the signals from the analog interface and combines the three phase signals to form modal signals. The modal transformation method[1] is employed to decouple the phase signals attained through the analog interface, into their respective modal components. The modal signals then go through the anti-aliasing filter to remove unwanted noise. The NN-based fault identification unit essentially consists of feature extraction, Neural Network and decision making unit, the function of which are described in the following section.

III. TRANSIENTS DISCRIMINATION USING NEURAL NETWORK

A. Feature Extraction

Feature extraction is the first step to any pattern recognition method to effectively reduce the size of the neural network and improve its performance. In order to catch the features of the fault and lightning induced transients, the first step is to analyze the transient frequency-responses of the captured signals by the detector.

Generally speaking, when an earth fault or lightning stroke occurs on a transmission line, a disturbance will be imposed on the line voltage and current waveforms which travels towards both ends of the line. The transient signals generated by the disturbance cover the entire frequency domain from DC to very high frequency. However, a lightning stroke is high frequency in nature and the disturbance caused in the line voltage and current waveform will contain relatively large portions of higher frequency components. An earth fault, although generating all frequency components, will involve relatively large earth currents which are predominantly power frequency.

Fig.2 shows a comparison of the frequency spectra of faulted phase currents for both an 'a' to earth fault and a lightning stroke occurring at the middle of the line. As shown in the figure, there is significantly larger magnitudes at higher frequency for a lightning stoke than that of earth faults. This is due to the high frequency nature of the lightning stroke.

In practice, the lightning strike and earth fault occur with variation in magnitude, path impedance, inception angle and positions, there is no clearly discernible feature to discriminate one from the other. However, Neural networks have the ability to learn the desired inputs/outputs mapping based on training examples, without looking for an exact mathematical model. Once an appropriate neural network is trained, the interconnections or links of the NN will contain a representation of the nonlinearity of the desired mapping between inputs and outputs. The NN based transient discrimination scheme takes into consideration all the above mentioned frequency components.

B. Neural Network Based Transient Discrimination Scheme

Fig.3 shows the diagram of the NN topology used for the scheme. The task of NNs is to learn to classify these common underlying characteristics. The feedforward multilayer perceptron[2] is chosen for this study. The 20 inputs represent the modal current in a window of 5 ms. The 2 outputs has a continuous value output in the region [0,1]. The combinations of the output A and B could be 00, 10 and 01 which represent no fault, earth fault and lightning stroke respectively. The hidden layer here plays a very important role. It was proved that only one hidden layer is sufficient to approximate and continuous function[2]. Thus, selecting the number of hidden neurons is critical to the success of the network. Our experience indicates that the number of hidden units selected at first should be around (number of input units + number of output units)/2 and then increased or decreased dynamically in order to achieve an optimal configuration. After many tests, 14 nodes have been chosen for the hidden layer.

NeuralWare was used for this investigation. A large number of simulations were performed off-line to generate a good representative data set, for training (2000 patterns) and testing (500 patterns) the NN, which covers wide lightning and earth fault conditions. After the training data has been scaled to the neurodynamic range, they are presented to the neural network randomly. The commonly used back-propagation training algorithm is employed, which basically adjusts the weights in all connecting links and thresholds in the nodes of the NN so that the differences between the actual output and the desired output are minimised for all input training data. After RMS error converges to the predefined value, in this case 0.02%, the network is assumed to be well trained. Then training and testing were interleaved. Training was stopped when the MRS error generated for test patterns stopped improving.

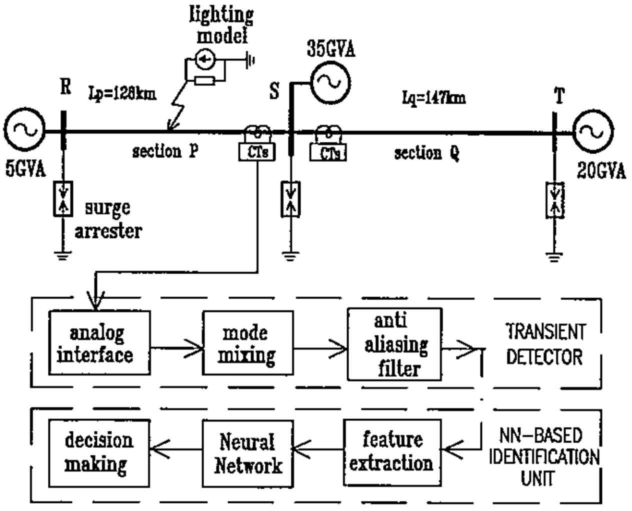

Fig.1 Basic arrangement of the NN-based technique

IV. SIMULATION AND RESULTS

The simulation of the complete power system for attaining the lightning and fault transients are carried out using the EMTP software, which contains mathematical models of the various power system components allowing the behaviour of different network configurations to be studied under various conditions. The software also has a facility whereby a realistic lightning model can be embodied into the simulation. The transmission system considered is a two section 400 kV transmission line. The source parameters, line length, etc. are as shown in Fig.1. The simulation also includes surge arresters installed at each busbar to prevent substation equipment being subject to dangerous over voltages as may be caused by lightning strokes. The sampling frequency used is 1 MHz.

A. Fault and Lightning Transient Simulation Technique

The modelling and simulation of an arcing earth fault has been well documented in the literature[4] and is therefore not described here.

The lightning stroke is simulated by a current source in parallel with an impedance as shown in Fig.1. The lightning current is injected at different positions on the transmission line and the impedance of the lightning discharge path is also varied to cover a variety of conditions.

Lightning introduces steep-front voltage waves, the steepness being dependent on whether the surge is induced or is the result of a direct stroke. For obtaining a guide to system surge behaviour it is usually sufficient for most practical purposes to consider the behaviour of a step-input wave, without attempting any closer approximation to the actual waveshape. A direct stroke to an overhead line conductor could result in a voltage surge waveform having a front rising to its maximum value in 2 μs, whereas its tail might take about 50 μs to decay to only half of the peak value, as given in [1]. However, the purpose of the studies is to accurately discriminate between an earth fault and a lightning stroke, so the lightning simulation should cover a wide variety of lightning conditions. Fig.4 shows the comparison between simulation studies and lightning current strokes recorded during an experiment at the Empire State Building, New York, 1937[5]. As shown in the figure, the simulation closely matches these obtained from experiment.

B. Results

The proposed NN was trained by using data obtained from examples of EMTP simulation under various conditions such as variation in fault/lightning location, inception angle, fault path resistance and lightning magnitude. After the NN was trained, a separate set of test data was supplied as input to the NN and its performance was evaluated. The moving window technique[2] is employed here for data processing. The width of the window for training the NN is 0.1 ms and the step of the moving window is 0.05 ms. The response of the NN is chosen to be 3 ms.

Fig.5 shows the responses attained for a lightning stroke on phase "a" at 64 km from the end S on line P. Fig.5a shows the primary system currents on all phases in the immediate post-fault period. The travelling wave components are produced on the faulted and unfaulted phases and are swamped by the dominant power frequency components.

Fig.5b(i) shows the modal current signal from the output of the detector. It is clearly shown that the wave shape of the lightning transient is super imposed on top of the power frequency signals. Figs 5b(ii) and (iii) show the responses of the NN, the amplitude of the channel 'B' signal is close to unity which indicates that this is a lightning stroke.

Fig.6 shows the corresponding signal attained for an 'a'-earth fault at the same point as in Fig.5. From Fig.6a, it is evident that server distortion appears on current signals. The magnitude of the faulted phase current distortion is significantly higher than that of the unfaulted phases. The post fault mode current signals increase significantly due to the fault path to earth as shown in Fig.6b(i). The NN response is given in Figs 6b(i) and (iii), the amplitude of the channel 'A' signal is close to unity indicates that there is an earth fault detected.

Table.1 shows the test results of the NN for various fault and lightning conditions, which involve the variation in type, inception angle, position and waveshape etc. The first column is the test number, and the second and third columns in the Table indicate desired output, and the fourth and fifth are the actual outputs. As shown in the Table, the NN based discriminator is able to clearly discriminate lightning strokes from earth faults in all cases.

V. CONCLUSION

The paper presents a technique for discriminating between lightning strokes and earth faults. A specially designed transient detector unit is used to capture the lightning/earth fault generated transient current signals from the transmission line. Results show that the proposed technique is able to accurately distinguish between a lightning stroke and an earth fault.

Further research is under way which involves the identification the transients on transmission system caused by other sources such as lightning induced earth fault, phase-phase fault, line energisation, capacitor switching etc.

VI. REFERENCE

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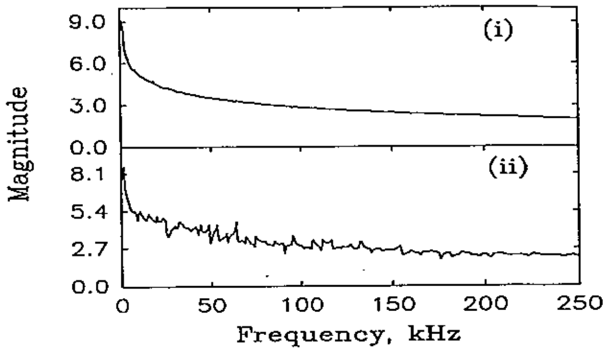


Fig.2 Comparison of the frequency spectra of faulted phase current for (i) an 'a' to earth fault and (ii) a lightning stroke occurring at the middle of the line

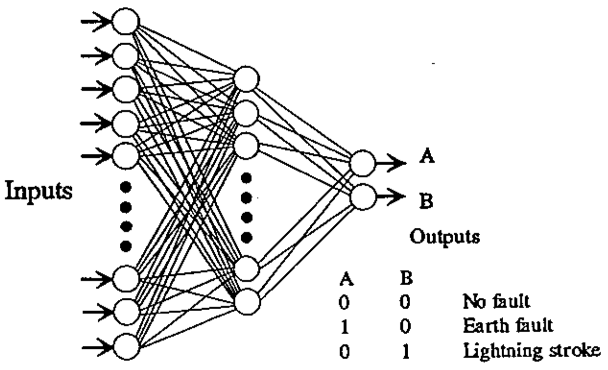
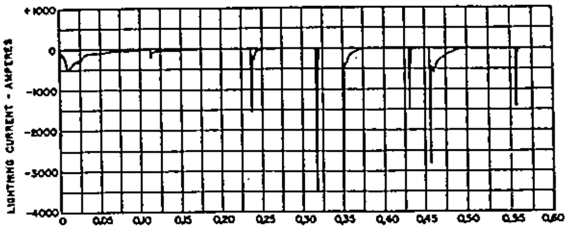
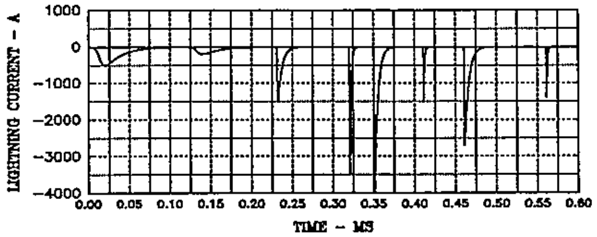


Fig.3 diagram of the NN topology used in the scheme

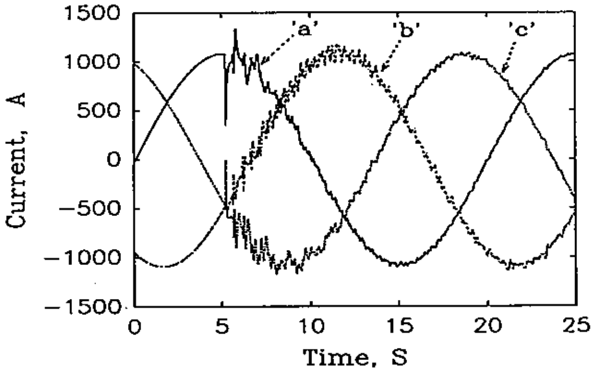


a. Reproduction of oscillogram taken in Empire State Building tower of lightning stroke, stroke no. 13 of season, August 11, 1937

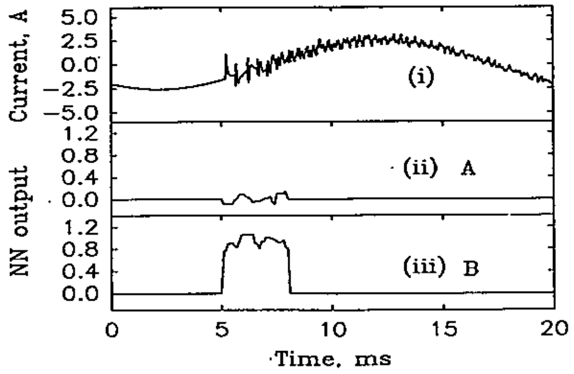


b. simulation

Fig.4 Simulation of lightning strokes (comparison)

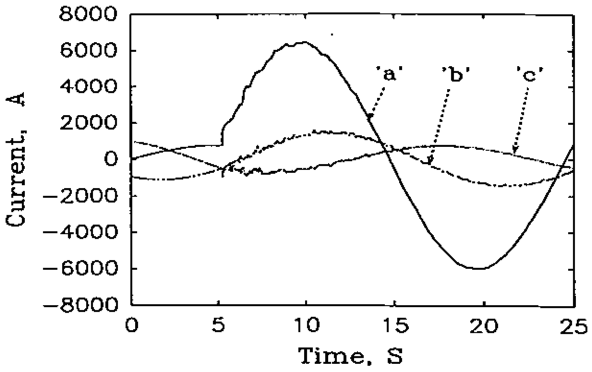


a. primary system current

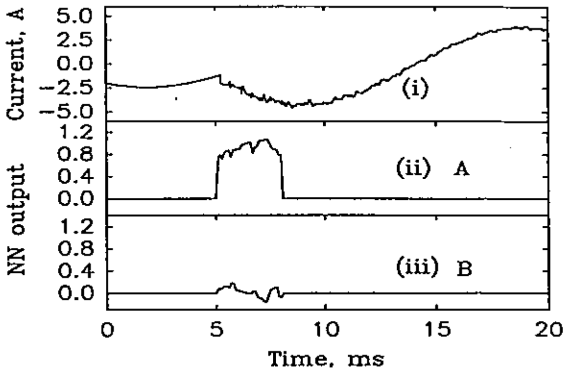


b. (i) mode current; (ii) and (iii) NN output

Fig.5 Responses attained for a lightning stroke on phase "a" at 64 km from the end S on line P



a. primary system current



b. (i) mode current; (ii) and (iii) NN output

Fig.6 Responses attained for an earth fault on phase "a" at 80 km from the end S on line P

Table I Responses for variety of system and fault condition

	Desired output		Actual output	
No.	A	B	A	B
1	0.0	0.0	0.250	0.089
2	1.0	0.0	0.994	0.016
3	1.0	0.0	0.756	0.026
4	1.0	0.0	1.019	0.003
5	1.0	0.0	1.028	0.024
6	1.0	0.0	1.042	0.028
7	1.0	0.0	0.971	-0.026
8	1.0	0.0	0.996	-0.117
9	1.0	0.0	1.027	-0.096
10	0.0	1.0	-0.007	0.954
11	0.0	1.0	-0.001	0.992
12	0.0	1.0	0.017	1.031
13	0.0	1.0	-0.061	1.011
14	0.0	1.0	-0.060	0.987
15	0.0	1.0	-0.002	1.001
16	0.0	1.0	0.014	0.972
17	0.0	1.0	0.012	0.992
18	0.0	1.0	0.019	1.005