

Protection of Six Phase Transmission Line Against Phase to Phase Faults

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Abstract—Power transmission lines are the vital links providing the essential continuity of service from generating station to the end users. As the demand of electricity is increasing day by day, the multiphase power system is a viable alternative. Six phase transmission lines are quite promising for improvement in power carrying capacity of existing systems keeping the same right-of-way. The implementation of 6-phase transmission line goes critical as its protection against various faults is quite intricate task. In this paper we are proposing an ANN based protection scheme against phase to phase faults. MATLAB® software and its associated Simulink® and Simpowersystem® toolboxes have been used to simulate the six phase transmission line. Fundamental components of six phase voltages and currents have been used as inputs for training of the Artificial Neural Network for detection and classification of faulted phase using neural network toolbox of MATLAB®. A sample 138 kV system of 68 km length, the model of Allegheny Power System, has been selected for study. The effect of variation in fault inception angle, fault distance location and fault resistance has been taken into account. (*Abstract*)

Keywords—Artificial Neural Network, high phase order transmission system, fault detection and classification.

I. INTRODUCTION

The deregulation and spirited atmosphere in the modern-day power system network are balanced to a new scenario leading to the problems of line capacity and therefore Multiphase power transmission systems have been suggested as prospective substitute to increase transmission capacity [1]. Existing double circuit lines can be upgraded to function as single six phase transmission line with the prospect of integration with a three phase system. The concept of six phases for transmission was proposed in 1972 by Barns & Barthold as one alternative to utilize cost of right-of-way more effectively and efficiently [2]. The six phase transmission lines are more popular due to its various advantages over double circuit lines e.g. increased power transfer capability by $\sqrt{3}$ [(or) 1.732] times, maintaining the same conductor configuration, right of way, better efficiency, better voltage regulation, greater stability and greater reliability. The variety of fault types that could occur in six phase line is discussed in [2]. His paper deals with problems encountered and suggested alteration in existing protection and control schemes, in particular the single phase tripping and auto-reclosing logic

scheme for single line to line faults. Vazquez, Altuve and Chacon (1996) used neural network to sense faults using current [3]. Coury and Jorge (1997 & 1998) used power simulation program instead of mathematical function to generate faults, thus realistic training data were obtained [4] [5]. PSCAD software has been used to simulate the six phase transmission line model to examine various significant faults in [6]. The Symmetrical components method has been used to analyze various faults on six phase power system in [7]. A 138-kV double circuit three phase line has been proposed to be upgraded to 138-kV six phase line in [8]. Distance protection of six phase transmission lines using fault introduces high frequency transients and wavelet transform has been reported in [9]. It estimates the fault distance considering the variation in fault type, fault inception angle and fault resistance. A non-unit protection scheme for six phase line has been reported in [10]. An ANN based fault detector and classifier against Phase to ground fault is reported recently in [11]. But no protection scheme against phase to phase fault is reported. This paper is an extension of [11]. ANN is very much useful for power system as they can be trained with off-line data [12]. This paper reports a fresh technique based on ANN for protection of six phase transmission line against phase to phase faults. Fundamental components of six phase voltages and currents are used. Fault inception angle, fault resistance and fault location is varied in order to get training and testing data.

II. MODELING AND SIMULATION OF SIX PHASE TRANSMISSION LINE

A 138kV, 60 Hz six phase transmission line of 68 km line length connected to load at the other end is simulated using Simulink and simpowersystem toolboxes of MATLAB®. A single line diagram is shown in Fig.1. The six phase of the AC source must be displaced by 60° with respect to each other. As there is no six phase AC source available in MATLAB®, two three phase AC source are used. The three phase of source-1 is denoted by A, C and E and that of source-2 is denoted by B,D and F. In order to obtain phase displacement of 60° between each phase, the phase “A” of source-1 is taken as reference and phase “B” of source-2 is displaced by 60° from phase “A”. The six phase transmission line is modeled using the distributed parameter model. At the far end two three phase load of 100MW and 100MW are connected.

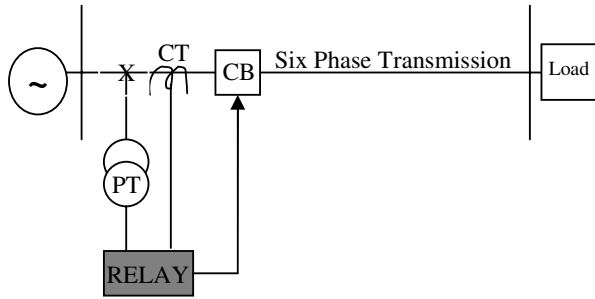


Figure 1. Single line diagram of six-phase transmission line.

The six phase voltage and current waveforms are shown in Fig.2, where it is clear that phase voltage and current are displaced by 60° from each other. To create various phase to phase faults, three number of three-phase fault breakers are used.

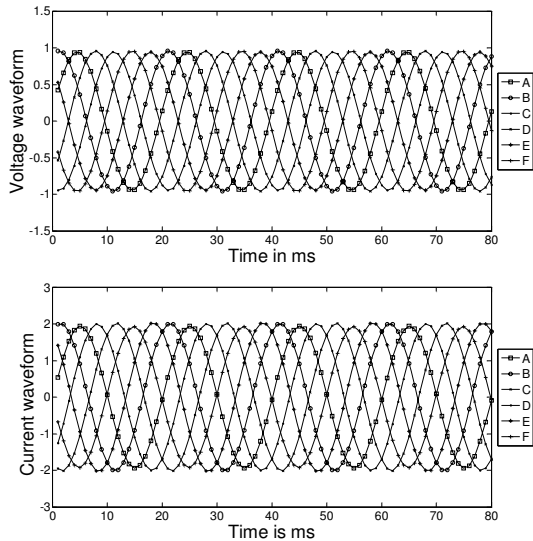


Figure 2. Six phase voltage and current waveform

III. FAULT DETECTION AND CLASSIFICATION ALGORITHM AND PROCESS

A. Algorithm

The proposed algorithm can be described by the following steps:

1) *Simulation*: It starts with the simulation of all types of phase to phase fault feasible in six phase transmission line in MATLAB model with varying fault parameters as fault location, resistance and fault inception angle.

2) *Pre-processing*:

a) *Anti-aliasing filter*: The Low pass Butter-Worth filter with cut-off frequency of 480 KHz is used to restrict the bandwidth of the signals both for voltage and current.

b) *Sampling*: Voltage and current signals are now sampled by sampling frequency of 1.2KHz in order to get 20 samples per cycle.

c) *Transformation*: One full cycle discrete fourier transform of both the signals has been taken to represent into frequency domain.

d) *Fundamental components*: Fundamental components of six phase voltages and currents have been generated followed by the normalization process by ± 1 in order to make the ANN input level.

3) *ANN Model*: After pre-processing the value of six phase voltages and currents are now fed as the input for ANN model. The model will detect and classify the faulty phase as described the following subsections.

B. Architecture of Artificial Neural Network

Architecture of ANN model is to be determined by the number of input and output. The inputs to conventional distance relay are mainly the voltages and currents, hence the ANN input chosen here are the magnitude of the fundamental components of six phase voltages and currents are used which are measured at the relay location only i.e. one end of the line. Further the function of ANN is to determine the type of fault along with faulty phase, the number of neuron in the output layer of ANN is six. Thus the ANN inputs "X" and outputs "Y" are:

$$X = [V_A, V_B, V_C, V_D, V_E, V_F, I_A, I_B, I_C, I_D, I_E, I_F] \quad (1)$$

$$Y = [A, B, C, D, E, F] \quad (2)$$

The optimized ANN architecture determination means to look for near minimal number of neurons in the ANN. After deciding the number of input and output, the number of hidden layer and number of neuron per layer is to be determined. Based on various literature and studies it was decided to use an ANN with three layers (Input, output and one hidden layer), with twelve neuron in input layer, thirty neuron in the hidden layer and six neuron in the output layer as shown in the Fig.3. After analyzing the various combinations for the transfer function (such as *logsig*, *tansig*, *purelin*), the *tansig* function was chosen as transfer function for both the hidden layer as well as output layer.

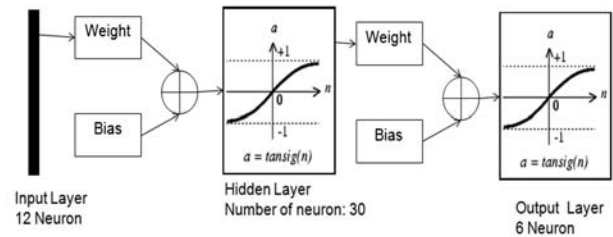


Figure 3. ANN Model (12-30-6)

C. Training process

In order to train the network, we have used supervised learning rule, where we have to feed training pattern along with the input pattern to the network. The weight update

process is done in batch mode, where weights are updated after 1 epoch (a complete data set). A suitable number of epochs must be selected so that the network can learn the fundamental characteristics of problem. Various types of faults (AB, AC, AD, AE, AF, BC, BD, BE, BF, CD, CE, CF, DE, DF and EF) at different fault location (5km, 10km, 20km, 30km, 40km, 50km, 60km and 65km) with resistance of 0Ω & 100Ω and fault inception angle 0° & 90° have been simulated as shown in Table I. Total number of fault cases are $15 \times 8 \times 2 \times 2 = 480$ and from each case, ten post fault samples have been extracted along with 50 samples of no fault condition to form a training data set. Therefore number of training patterns used to train neural network is $(480 \times 10) + 50 = 4850$.

TABLE I. PATTERNS GENERATION

Parameter	Set Value
Type of Fault	AB, AC, AD, AE, AF, BC, BD, BE, BF, CD, CE, CF, DE, DF and EF.
Fault Location	5km, 10km, 20km, 30km, 40km, 50km, 60km and 65km
Fault resistance	0Ω & 100Ω
Fault inception angle	0° & 90°
Number of fault cases	$15 \times 8 \times 2 \times 2 = 480$
Number of training pattern	$(480 \times 10) + 50 = 4850$

The *Neural network toolbox* of MATLAB® is used to process the fault data, generated by the *Simulink* and *simpowersystem* toolboxes of MATLAB®. Neural network was trained by the Levenberg-Marquardt training algorithm [13]. The root mean square error of the artificial neural network with the preprocessed data set is shown in Fig.4. A single hidden layer network with 12, 30 and 6 neurons respectively in input, hidden and output layer (12-30-6) is capable of minimizing the mean square error. The desired performance error goal was set to $1 \times e^{-005}$, which is met in just 54 epochs as shown in Fig.4.

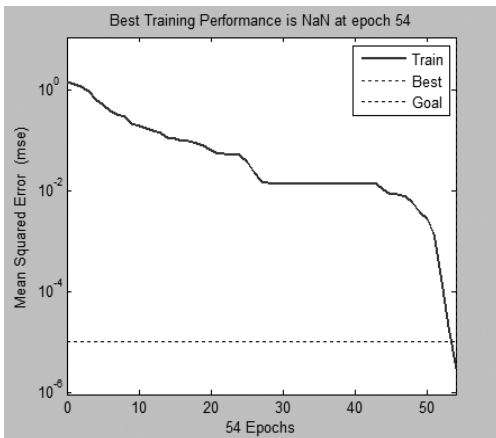


Figure 4. Training of ANN Model (RMS error to epoch's graph)

IV. TEST RESULTS

The ANN Based fault detector and classifier was then extensively tested using independent data set, which were not used while training process. To construct testing data set, random values for resistance, fault inception angle and fault location is taken for the every combination of phase to phase fault. The network was tested and validated. All the faults are correctly classified. The testing data set includes every extreme cases of faults like fault near the protection zone boundary including high fault resistance were also included in test data set [12]. For example AB fault at 30 km from the transmission end with fault resistance and inception time of 30Ω and 0.0447s respectively is examined. The current in the corresponding phase which are involved in the fault (A & B) increases and voltage decreases as shown in Fig. 5.

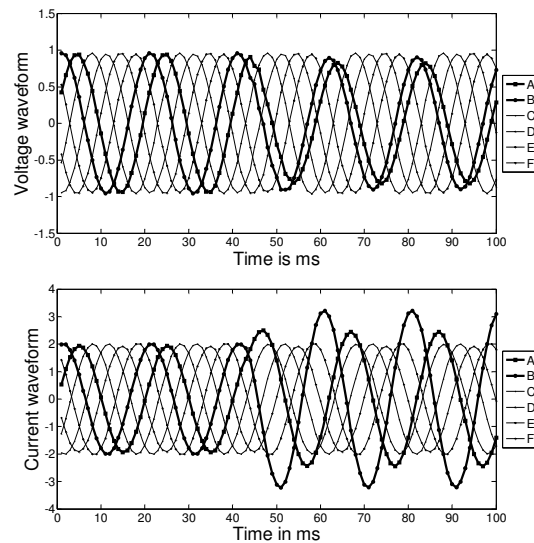


Figure 5. Six phase voltage and current waveforms of AB fault with 30Ω fault resistance, 0.0447s of inception time at 30km far from sending end.

The test result of ANN based fault detector and classifier during AB fault with 30Ω fault resistance, 0.0447s of inception time at 30km far from sending end is shown in Fig.6. The six outputs of ANN corresponds to six phases. During pre-fault condition the output is low for all phases. As we have tested for AB fault it is clear from A and B phase output waveforms that, as soon as the fault occurs at 0.0447s, the output goes high and remains constantly high. For other phases output remains intact, i.e. low.

V. CONCLUSION

A Sample model of Allegheny Power System consisting of 138kV transmission line of 68 km length has been designed and simulated using *Simulink* and *simpowersystem* toolboxes of MATLAB®. Various phase to phase faults for various combination of fault resistance, fault inception angle and fault distance have been created and used to train the network. The trained network has been tested using another different random combination of fault resistance, fault inception angle



and fault location for each phase to phase fault. The complexity and efficiency of the algorithm is studied. And result shows that phase to phase fault are correctly detected by the ANN based detector & classifier.

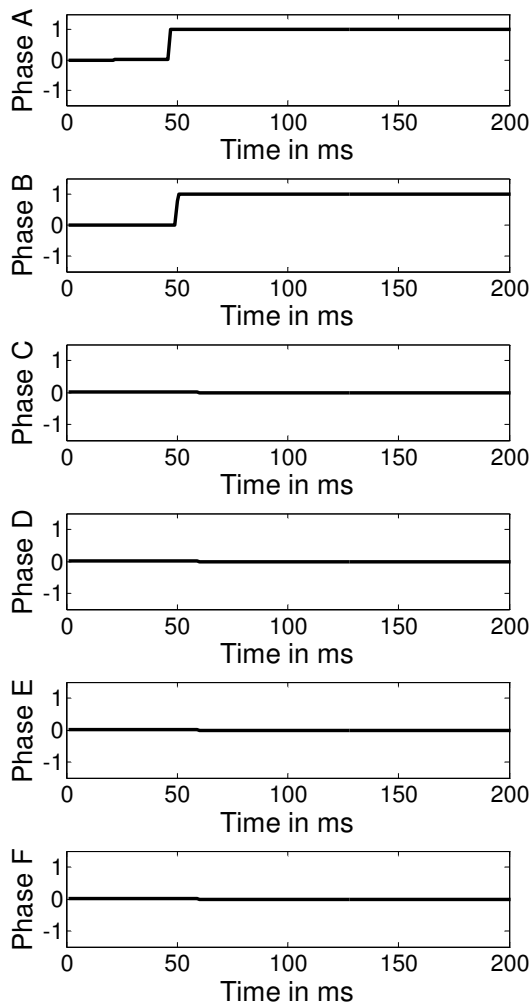


Figure 6. Six phase output waveform of ANN Model for AB fault with 30Ω fault resistance, 0.0447s of inception time at 30km from sending end.

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