Transmission Line Protection Using Wavelet Transform

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Abstract

Transmission lines are vital links for transmission of electric power in power systems. The chances of occurrence of faults in transmission line are very high as they are exposed to atmosphere. The performance of a power system is affected by the faults on transmission lines, which result in interruption of power flow. Fault detection and classification is essential for determining the location of the fault which helps in maintenance and restoration of supply resulting in reliability of power supply and improved economy. This project work presents a technique to detect and classify the different types of faults in transmission lines. Discrimination among different faults is achieved by wavelet transform.

***Key Words*—Wavelet Transform, Fault Location, Transmission Line, Support Vector Machines Artificial Neural Network, Fault Index, Multi Resolution Analysis, Threshold**

1. INTERACTION

Transmission lines are the vital links for transmission of electric power. The protection of transmission lines is an important issue in power system engineering because 85-87% of faults occur on transmission line. Fault detection and classification on transmission line are important tasks to safeguard electric power system. It must be done as fast and accurate as possible to de-energize the faulted line, protecting the system from the harmful effects of the fault. A fault occurs when two or more conductors come in contact with each other or one or more conductors come in contact with ground. In three Phase systems, faults are classified as Single line-to-ground faults, Line-to-line faults, Double line-to-ground faults and three phase faults. These faults give rise to serious damage on power system equipment. Faults which occur on transmission lines not only effect the equipment but also the power quality. So, it is necessary to determine the fault type and location on the line and clear the fault as soon as possible in order not to cause such damages.

Determination of type of fault in transmission lines is vital for economic operation of power systems. Accurate fault classification will facilitate quicker repair, improve system availability, reduce operating costs and save time. In the past, several methods have been used for classification of fault with different techniques such as line impedance based numerical method, Travelling wave methods and Fourier analysis. Fourier transform are used to abstract fundamental frequency component but it has been shown that Fourier transform based analysis are not sometimes exactly enough. Travelling wave methods require high sampling rate and have problems in distinguishing between waves reflected from the fault and from the remote end of the line. Nowadays, high frequency components instead of fundamental components are being used for fault analysis. Recently wavelet transform has been evolved as an alternative tool to analyze the transient nature of signals accurately. The most important characteristic of wavelet transform is to analyze the waveform on time-scale rather than frequency. Wavelets have been widely used in areas like seismic, image compression, acoustics, and mechanical vibrations. Recently, several applications of wavelets for power system analysis, fault detection, fault classification, fault location and power quality assessment have been proposed.

Wavelet Transform (WT) is inherently more appropriate for non-stationary and non-periodic wide-band signals. It helps in achieving the localization in frequency and time, and is able to focus on short-time intervals for high frequency components and long intervals for low frequency components, making it a well suited tool for analyzing high frequency transients in the presence of low frequency components. WT is an efficient means of analyzing transient currents and voltages. Unlike DFT, WT not only analyzes the signal in frequency bands but also provides non-uniform division of frequency domain, i.e. WT uses short window at high frequencies and long window at low frequencies. This helps to analyze the signal in both frequency and time domains effectively. A set of basic functions called Wavelets, are used to decompose the signal in various frequency bands, which are obtained from a mother wavelet by dilation and translation. Hence, the amplitude and incidence of each frequency can be found accurately.

There are various techniques for fault classification. Some of the techniques are: (i) Fuzzy logic-based [1-3] (ii) Artificial Neural Network based and (iii) Wavelet Transforms based. Although, the Fuzzy and neural-network-based approaches have been quite successful in determining the correct fault type, the main disadvantages of ANN based methods are; require a considerable amount of training effort for good performance. Chul-Hwan Kim, Hyun kim, et al in proposed a method to detect high impedance arcing faults in high voltage transmission lines using wavelet transforms. Joe-Air Jiang, et al have used Haar Wavelet for fault detection and faulted phase selection in transmission lines. Shaikh Abdul Gafoor and Ramana Rao used WT multi resolution approach for detection, classification and ANN for localization of faults in the transmission line. It was accomplished with data of half a cycle using detail coefficients of currents at both the ends. Das B and Reddy V.J proposed a fuzzy logic based fault classifier . This uses magnitude and angle of fundamental phasors. However, the drawback of this scheme is that its accuracy cannot be guaranteed in the case of wide variation in the system conditions.

1.2 ORGANIZATION OF REPORT

The project report is organized as three chapters. The first chapter gives insight into the project. The various kinds of faults and the protection techniques that are currently available and employed are briefly discussed in this chapter.

The second chapter deals with PSCAD simulation model in which simulation is carried out and data has been collected for given transmission line of 300 km and results were obtained for all ten faults by varying parameters such as fault resistance, fault inception angle and loading levels. Waveforms of current and voltages for faulted phase are shown under fault condition such as LG fault, LLG fault, LL fault and LLL fault.

The third chapter deals with fault detection and classification using Wavelet transform. The complete fault detection and classification scheme is described and flowchart of the scheme is presented. The results are presented at the end. At the end, conclusion is drawn and scope of future work is also given.

2. MODELING OF TRANSMISSION LINE SYSTEM

For designing a fault detection and classification scheme, it is important to have adequate data for different faults and system conditions. So, a transmission line model is developed for a two area system using the PSCAD/EMTDC software. The source voltages, impedances and parameters for transmission line are given in Appendix. The transmission line has been represented using Bergeron line model in PSCAD/EMTDC. The modeled two area system is simulated for different cases involving different fault resistances, different fault inception angles (FIA), different load angles between the two ends of transmission line and different types of faults. The 'multiple run' component is used for manipulating these different conditions from one simulation run to another.

The single line diagram of transmission line system model is shown in Figure 2.1

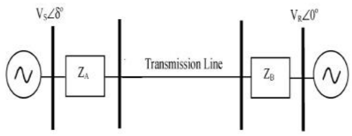


Figure 2.1: Single line diagram of transmission line system model

2.1 ELEMENTS USED IN SIMULATION MODEL OF TRANSMISSION LINE SYSTEM

The simulation model corresponding to the single line diagram of Figure 2.1 is shown in Figure 2.2. The various elements of the simulation model are as given below.

a) Three phase Voltage Source Model: This component models a 3-phase AC voltage source, with specified source and/or zero-sequence impedance. A zero-sequence impedance branch is added directly within the component.
The external source control is used in this model. The external inputs are as follows.
V: Line-to-Line, RMS Voltage Magnitude=400 kV
F: Frequency=50 Hz
Ph: Phase angle is variable for one source and is 0° for another

b) Multimeter: The Multimeter performs virtually all possible system quantity measurements, all contained within a single, compact component. Here, it is used to measure the values of instantaneous currents of the three phases at two different locations.

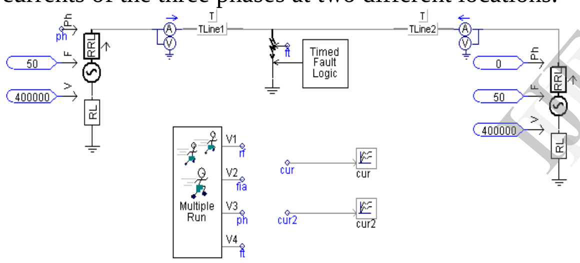


Figure 2.2: Simulation model of transmission line system in PSCAD

c) Multiple Run: This component can be used to control a multiple run, while manipulating variables from one run to the next. These variables are output from the component and can be connected to other PSCAD components.

From the simulation model of transmission line system shown in Figure 2, it is seen that there are four variables that are controlled using Multiple Run block. These are:

- Fault resistance
- Fault inception angle
- Phase angle of one three phase source
- Fault type

d) Three- phase fault block: Type of faults considered are A-G, B-G, C-G, AB-G, AC-G, BC-G, AB, AC, BC and ABC. For simulating these faults, the three-phase fault block is used. Data required for simulation of these faults is type of fault, fault resistance and their values are controlled using Multiple Run component.

e) Timed Fault Logic: The output of this component is used specifically for controlling the fault state at different instants and duration of fault.

f) Modeling of Transmission Line: There are three types of model available for overhead line configuration in PSCAD; Bergeron model, Phase model and Mode model. The Bergeron model is very simple, constant frequency model based on travelling wave. It is useful for studies where it is required to get the steady state impedance/admittance of the line. The termination style used is Direct Connection type.

2.2 SIMULATION RESULTS

The fault simulations are uphold considering the disparate cases consists of various pre-fault power loading conditions, FIA, fault impedances and finally, faults of all types. The various numerals of these parameters are as follows.

Values of various parameters:

Power loading angle prior to fault (degree) =10^{o}, 15^{o}, 20^{o}, 25^{o}, 30^{o}, 40^{o}
FIA (degree) = 15^{o}, 20^{o}, 35^{o}, 40^{o}, 65^{o}, 95^{o}, 110^{o}, 160^{o}, 195^{o}, 240^{o}

Fault resistance = 0.01 Ω, 0.15 Ω, 5 Ω, 10 Ω, 12 Ω, 24 Ω, 29 Ω, 36 Ω, 45Ω, 50Ω.
Fault type= A-G, B-G, C-G, AB, AC, BC AB-G, AC-G, BC-G and ABC

Thus a total of 6x10x10x10=6000 combinations have been chosen for fault simulation studies under training category.
Figure 2.3 shows the wave shapes of the three phase voltages and currents recorded at the metering point when there is no fault on the system.

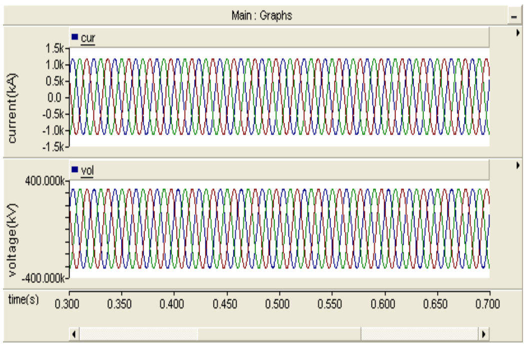
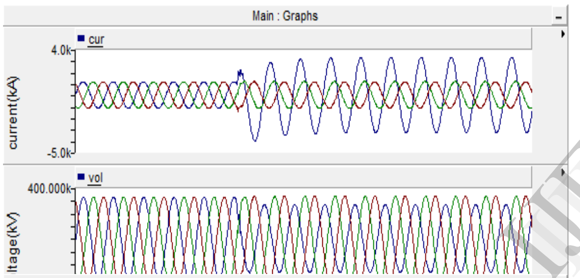


Fig. 2.3. Waveforms of current and voltages when there is no fault

Figure 2.4 shows the wave shapes of three phase currents and voltages recorded on source side after the occurrence of Phase to ground (LG) fault at 0.5s with 0.01Ω fault resistance and 90^o fault inception angle.

Fig. 2.4. Waveforms of currents and voltages with LG fault at 0.5s with 0.01Ω fault resistance



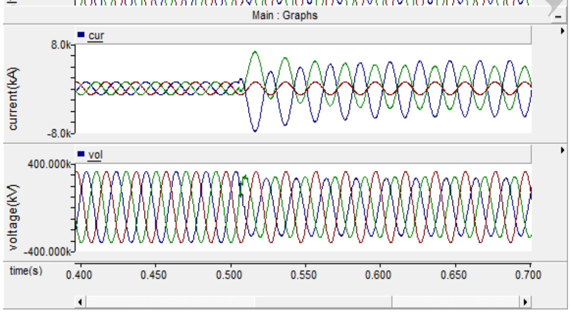
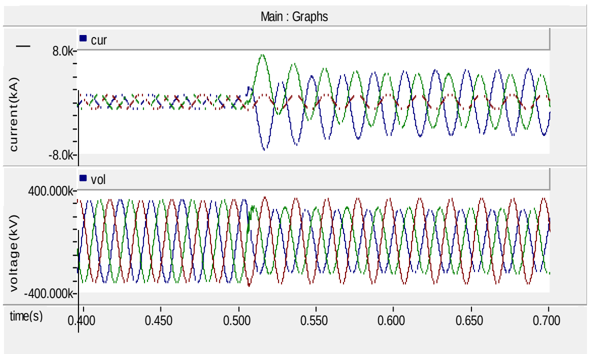


Figure 2.5 shows the current and voltage waveforms recorded after the occurrence of double



phase to ground (LLG) fault at 0.5s with 10Ω fault resistance and 60^o fault inception angle.

Fig. 2.5. Waveforms of current and voltage with LLG fault at 0.5s with 0.01Ω fault resistance

Figure 2.6 shows the wave shapes of current and voltages recorded after phase to phase (LL) fault occurred at 0.5s with 0.01Ω fault resistance and 90^o fault inception angle.

Fig. 2.6. Waveforms of current and voltage waveforms with LL fault at 0.5s with 0.01Ω fault resistance

Figure 2.7 shows the wave shapes of current and voltages recorded after symmetric (LLL) fault occurs at 0.5s with 0.01Ω fault resistance and 90^o fault inception angle.

3. FAULT DETECTION AND CLASSIFICATION

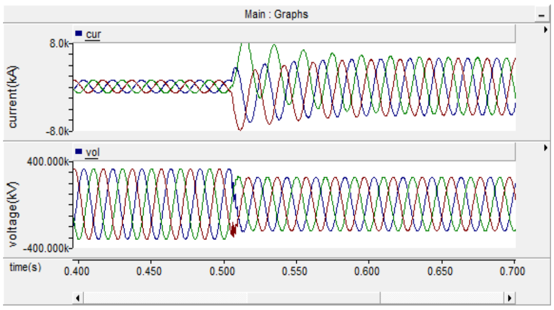
3.1 WAVELET TRANSFORM

Wavelet analysis is a relatively new signal processing tool and is applied recently by many researchers in power systems due to its strong capability of time and frequency domain analysis . The two areas with most applications are power quality analysis and power system protection . The definition of continuous wavelet transform (CWT) for a given signal x(t) with respect to a mother wavelet Ψ(t) is given by

$$CWT(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t)\psi\left(\frac{t-b}{a}\right)dt \quad (3.1)$$

where is the scale factor and is the translation factor.

For CWT, *t*, *a* and *b* are all continuous. Unlike the Fourier transform, the wavelet transform requires the selection of a mother wavelet for different applications. One of the most popular mother wavelets found for power system transient analysis in the literature is Daubechies wavelet



family. In this project, the db1 wavelet is selected as the mother wavelet for detecting the short duration, fast decaying fault generated transient signals.

The application of wavelet transform in engineering areas usually requires a discrete wavelet transform (DWT), which implies the discrete form of *t*, *a* and *b* in (3.1). The representation of DWT can be written as

$$DWT(m,n)=\frac{1}{\sqrt{a_0^m}}\sum_k x(k)\psi\left(\frac{k-nb_0a_0^m}{a_0^m}\right) \tag{3.2}$$

where the original and parameters in (3.1) are changed to be the functions of integers *m* ,*n*. *k* is an integer variable and it refers to a sample number in an input signal.

A very useful implementation of DWT, called multiresolution analysis, is demonstrated in Figure 3.1. The original sampled signal *x(n)* is passed through a highpass filter *h(n)* and a lowpass filter *l(n)*. Then the outputs from both filters are decimated by 2 to obtain the detail coefficients and the approximation coefficients at level 1 (*D1* and *A1*). The approximation coefficients are then sent to the second stage to repeat the procedure. Finally, the signal is decomposed at the expected level. In the case shown in Figure 3.1, if the original sampling frequency is *F*, the signal information captured by *D1* is between *F/4* and *F/2* of the frequency band. *D2* captures the information between *F/8* and *F/4*. *D3* captures the information between *F/16* and *F/8*. *A3* and retains the rest of the information of original signal between 0 and *F/16*.

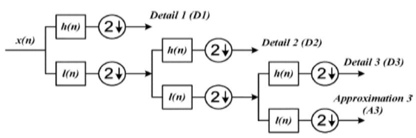


Figure 3.1: Wavelet multiresolution analysis

3.2. FAULT CLASSIFICATION SCHEME

A 400 kV, 50 Hz power system shown in Fig. 2.2, consisting of two sources representing two areas connected by 300 km long transmission line is used for simulation studies. All the data is collected from the sending end of the system. The simulations are for a duration of 1 second, in which fault occur at 0.5s (Neglecting fault inceptions at different cases). The voltage and current signals are sampled at a frequency of 1 kHz. The voltage and current signals are collected at 50 Hz and one cycle values are used. These signals are taken in discrete form, 20 samples of current and 20 samples of voltages are taken for all the three phases for all 10 types of faults for both health and faulty conditions.

The fault classification scheme is implemented using both SVM classifier and feedforward neural network classifier. The scheme of implementation, the training and testing data sets and features same for both cases. Hence the fault classification scheme is described in respect of SVM classifiers. The same description is also valid for feedforward network classifier.

3.2.1. Training and Testing Datasets

The training and testing datasets for fault classification scheme have been obtained by simulations that are performed on the transmission line model by means of PSCAD. The different cases constituting various sets of parameters for SVM classifiers are also same as given in Table 3.1 and Table 3.2 separately.

Table 3.1. Values of various parameters used for getting training feature sets

Fault type	A-G, B-G, C-G, AB-G, AC-G, BC-G, AB, AC, BC & ABC
Fault resistance (Ω)	0.01 Ω, 5 Ω, 10 Ω, 25 Ω, 50Ω
Fault inception angle	10^o, 30^o, 60^o, 90^o, 190^o
Pre-fault Load angle	10^o, 20^o, 30^o
Fault Location	150 km (from source 1)

Table 3.2. Values of various parameters used for getting training feature sets

Fault type	A-G, B-G, C-G, AB-G, AC-G, BC-G, AB, AC, BC & ABC
Fault resistance (Ω)	0.15 Ω,50 Ω,100 Ω,150 Ω,200 Ω
Fault inception	20^o, 40^o, 110^o, 160^o, 240^o,280^o, 340^o

angle	
Load angle variation	15^o, 25^o, 40^o
Fault location (km)	50,100,150,200,250 (from source 1)

3.2.2. **Selection of Mother Wavelet for Feature Extraction**

It has been mentioned in the literature that for the purpose of examining the fault waveforms' transients 'db' is most appropriate wavelet. Even though there is no accepted criteria for opting out them, the optimal choice is the one which best outfits the features used in a particular scheme. After observing coefficients of the signals at various levels using different mother wavelet functions of 'db' in repeated try-outs, it is established that 'db4' is a noble option to perceive the alteration between the conditions of pre-fault and post-fault. Although some other wavelets also provide alteration between these conditions, this variation is more when db4 mother wavelet is utilized for extracting features in the scheme.

3.2.3. **Feature Extraction**

The proposed fault classification technique is based on value of transient energy of the detail coefficient of the respective phases of voltage and current signals. Considering a sampling frequency of 1000 samples/cycle of a 50 Hz fundamental frequency signal, the measured signals (three voltages and three currents) are decomposed into approximation (A1) and detail 13 coefficients (D1) using a db4 mother wavelet. Decomposition is performed and the details coefficients extracted by wavelet transform at level 1 decomposition have more value of transient energy under fault duration as compare to pre-fault signals. Hence fault classification has been done effectively using transient energy of these details coefficients at level-1 of voltage and current signals.

3.2.4 Scaling of features

The input patterns (training and test patterns) are normalized to [+1,-1] before inputting to the SVM module. The main advantage is to avoid attributes in greater numeric ranges dominate those in smaller numeric ranges. Another advantage is to avoid numerical difficulties during the calculation. Because kernel values usually depend on the inner products of feature vectors, large attribute values might cause numerical problems.

4. FAULT DETECTION AND CLASSIFICATION SCHEME USING SVM

The fault identification and classification technique is implemented using SVM classifiers. The same features that have been used for ANN classifiers are used as the input features for performing classification using SVM classifiers. The different cases constituting various sets of parameters for SVM classifiers are also same as given in Table 3.1 and Table 3.2 separately.

Figure 4.1 shows the fault detection and classification algorithm using binary SVM classifiers. Four binary SVM classifiers are used in total, three classifiers for determining involvement of fault with three phases and other one is for accomplishing the same task with ground. Here also, all the three phase current signals are disintegrated upto first level using 'db4' mother wavelet. The reconstructed detail coefficients are used as features (inputs) to SVM classifiers along with features of residual ground current. In this case also, the all the inputs are normalized to [-1, +1] to side-step the same problems mentioned earlier.

For obtaining maximum accuracy of classification, supplementary factors of the RBF kernel function such as sigma and the cost parameter C should be optimised. The optimized values are obtained by k-fold cross validation method (k=5). In this process, the cost parameter C is changed from 1 to 100 and cost parameter C is considered over the range 0.01-1000. Table 4.4 has finished the method stating that the set of C=10 and σ =0.01 is considered to be optimal for giving better classification accuracy.

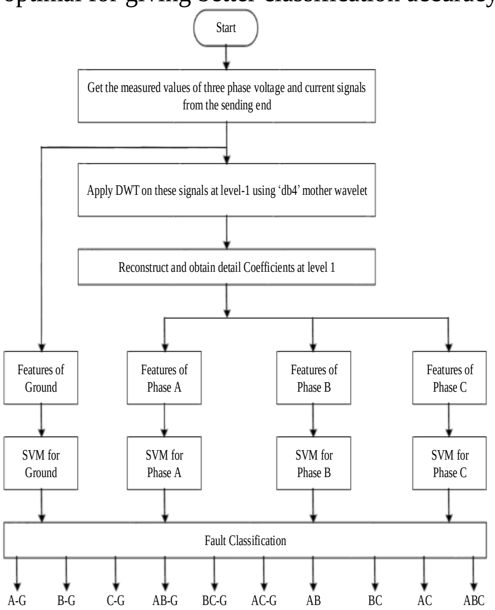


Fig.4.1. Fault detection and classification scheme using SVM classifier

The results of SVM classification scheme are tabulated in Table 4.1 with the optimally chosen supplement parameters, according to the fault location and the values of accuracy obtained for different phases and ground in different cases have been provided.

Location of fault	Phase A	Phase B	Phase C	Ground
50 km	99.74 %	99.56 %	99.89 %	100 %
100 km	99.83 %	99.44 %	100 %	100 %
150 km	100 %	100 %	100 %	100 %
200 km	99.72 %	99.33 %	99.89 %	99.82 %
250 km	99.64 %	99.11 %	99.82 %	100 %

Table 4.1. Accuracy of classification for different Phases and ground using SVM classifiers

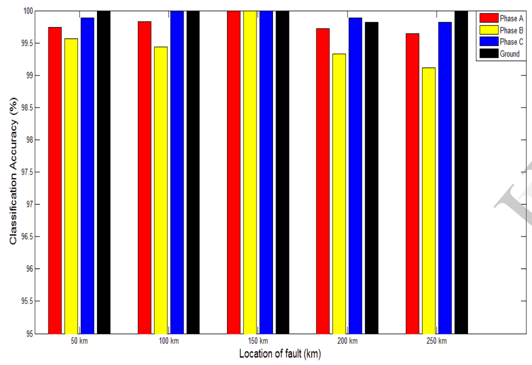


Fig.4.2. Accuracy of classification for different

Phases and ground with SVM classifiers

5. FAULT DETECTION AND CLASSIFICATION SCHEME USING ANN

A 400 kV, 50 Hz two area connected, double end transmission line system shown in Figure 2.2 of chapter-2, which consists of two Thevinen's equivalent voltage sources each representing an area connected by a long transmission line of length 300 km. Digital simulation studies are performed on this system using PSCAD/EMTDC software. The source voltages, impedances and parameters for transmission line are specified in Appendix. All the data required for classification scheme is attained from active source end. The simulations are performed for a duration of 1 second, in which fault is assumed to be occurred at 0.5s (Neglecting fault inceptions in different cases).The voltage and current signals are discredited at of 1 kHz frequency whereas their fundamental frequency is 50 Hz. So, each fundamental cycle of voltage and current have 20 samples. The current and voltage samples over one fundamental cycle are considered for all the three phases for both health and faulty conditions.

Figure 5.1 shows the flowchart of the proposed fault identification and classification scheme by the assistance of ANN classifiers. The magnitudes of transient constituent of all three phase voltages and currents at sending end are pulled out using 'db4'. The decomposition of all the signals is performed at level 1. Upon investigating the level-1 detail coefficients of the signals, it has been visibly spotted out that magnitudes of transient constituent of these voltage and current signals are high whenever some fault has occurred as compared to healthy conditions. Hence these values of transient constituent of current and voltage of three phases are used as features of ANNs. The output of each ANN specifies whether any phase is associated with a specified fault or not.

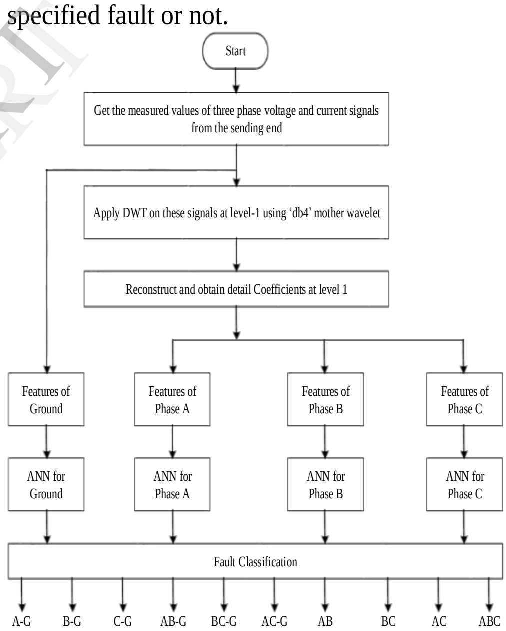


Fig.5.1. Fault detection and classification scheme using ANN classifiers

The information about involvement of ground in a specific fault is attained using zero sequence component of current. The zero sequence component can be obtained by taking the average of the all three phase currents. The fault case involving the ground in the specific fault results in high value of zero sequence current, whereas the grounded fault outputs it as null. This property can be used by ANN for determining whether that particular fault is grounded or not.

The input features extracted from signals are regularized to [+1,-1] for giving them to the ANN classifiers as inputs. It sidesteps attributes in large numerical values govern those in small numerical values. It as well as eliminates numerical difficulties during computations.

The results of ANN classification scheme are tabulated in Table 5.3 according to the fault location and the values of accuracy obtained for different phases and ground in different cases have been provided.

Location of fault	Phase A	Phase B	Phase C	Ground
50 km	99.73 %	99.56 %	99.68 %	100.00 %
100 km	99.81 %	99.44 %	99.89 %	99.89 %
150 km	100.00 %	99.11 %	100.00 %	100.00 %
200 km	99.85 %	99.42 %	99.67 %	100.00 %
250 km	99.67 %	99.54 %	99.43 %	100.00 %

Table 5.1. Accuracy of classification for different Phases and ground with ANN classifier

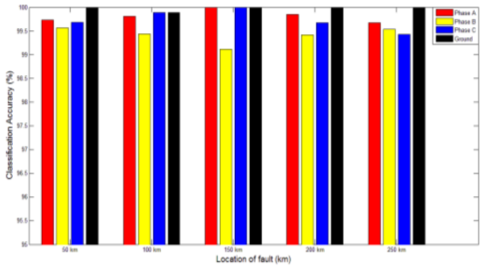


Fig.5.2. Accuracy of classification for different Phases and ground with ANN classifiers

The results of classification using ANNs are represented in graphical form for a fault location of 150 km are presented in Fig.5.3, Fig.5.4, Fig.5.5 and Fig.5.6. In every case, the ideal output values are '0' for the first half cases (healthy condition) and '1' for the next half cases (faulty condition).

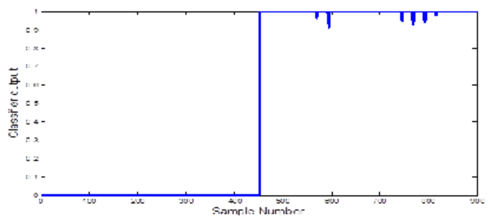


Fig. 5.3: Classified outputs for Phase-A using ANN

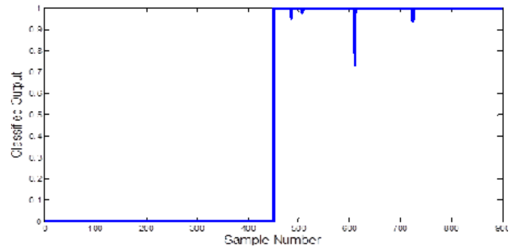


Fig.5.4: Classified outputs for Phase-B using ANN

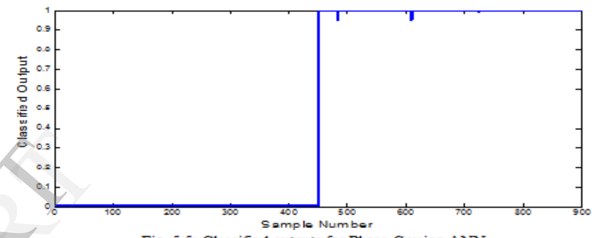


Fig. 5.5: Classified outputs for Phase-C using ANN

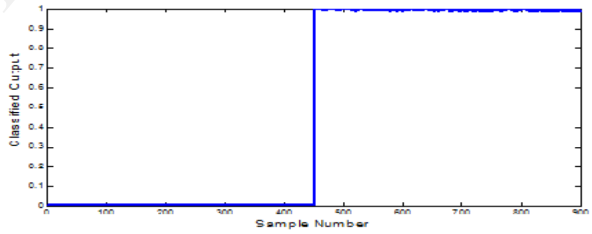


Fig. 5.6. Classified outputs for Ground using ANN

6. CONCLUSION

This presented work describes method for fault detection and classification in transmission line using wavelet transform in conjunction with SVM and feedforward neural network. The proposed scheme is based on values of both the current signal and voltage signals from one end. It is shown that the proposed technique correctly classifies the fault type in spite of variable fault resistances and variable loading conditions. The scheme is proved to be accurate and efficient when compared to the schemes implemented earlier for the classification of faults.

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BIOGRAPHIES

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