Hybrid Algorithm for Detection of High Impedance Arcing Fault in Overhead Transmission System

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Abstract: High impedance fault (HIF) is a long standing problem which known by very complex phenomena, because of its distinctive characteristics asymmetry and nonlinearity behavior. Besides that, arc is the most serious problem which is mostly associated with high impedance fault, this arc is considered as a source of human life risks and fire hazardous, and additionally result in property damage. From the point of few, detection and discrimination of high impedance fault still remain challenging of protection engineers. In this paper new of high impedance model is introduced and combination of wavelet transform and neural network is presented to detect high impedance fault. Discrete wavelet transform (DWT) is used as feature extraction which extracts useful information from distorted current signal that generated from transmission system network under effect of high impedance fault. In order to improve training convergence and to reduce the number of input to neural network, coefficients of wavelet is calculated and used as input for training back propagation neural network. Multi-layer back propagation neural network (BP-NN) is used as classifier for high impedance fault and discriminate it from such events like capacitor switching and load switching etc.

Keywords: High Impedance Fault, Wavelet Transform, Neural Network, Power System Fault Analysis.

1 Introduction

High impedance fault is abnormal unwanted events that happen when the broken conductor touches the ground, or touches the branches of tree, which Inhibits the flow of the fault current to less than the sensitivity level of conventional protection systems [1].
Moreover, arc which is commonly associated with high impedance faults, is considered as a source of human live risks and fire hazardous, and additionally result in property damage. Therefore, from the view of public safety and operational

reliability and stability, detection and recognition of such faults are critically important [2]. High impedance fault has been a topic of study for more the 5 decades [3], several algorithms and techniques have been proposed for detection and discrimination of high impedance fault.

 Majority of detection techniques was based on the modification of overcurrent protection devices [4], but, because of the similarity of current that result from high impedance fault to other normal operation this techniques has given an unexpected results. Another protection technique was based on the ground relay to detect abnormal events [5], however, this is not suitable for multi-grounded systems and unbalanced loads.

Such schemes was based on fractal techniques [6], this technique is a concepts of fractal geometry to analyze chaotic properties of high impedance fault, but the relatively short data sets available for estimation in this technique, however, make direct calculation of fractal dimensions not effective for HIFs detection.

Some other signal processing techniques for fault feature extraction is carried out of using different filters such as Fourier Transform and Kalaman Filter [7,8], these signal processing was applied to obtain the best variation of the fundamental and harmonic components, Although, the network waveforms are not stationary due to disturbances. Therefore, FFT and kalaman filter are not suitable for well-timed tracking and no detailed detection scheme was proposed and implemented.

Also, based on changes in harmonic currents, several algorithms were suggested. Among these are the third harmonic current method [9] and nearest neighbor rule approach [10]. Each of these techniques could improve fault detection, but then, each has its drawbacks as well.

However due to distinctive characteristics of high impedance fault, detection of such faults would be very difficult, due to these difficulties, researchers have introduced new intelligent techniques such as neural network and fuzzy logic...et al, in 2006, M. Eissa et al [11] has presented new technique for detection of high impedance fault, the technique has used neural network based relay, the relay is based on low frequency component (3th and 5th harmoincs). In 2008, A.H. Etemadi et al, [12], has presented a method for HIF detection based on the nonlinear behavior of current waveforms, A wavelet multi-resolution signal decomposition method is used for feature extraction. Extracted features are fed to an adaptive neural fuzzy inference system (ANFIS) for identification and classification.

Recently, wavelet transform has been introduced for detection and classification of high impedance fault, in [13]C.H. Kim et-al, has described a novel fault-detection technique of high-impedance faults in high-voltage transmission lines using the wavelet transform, the techniques is based on using the absolute sum value of coefficients in multi-resolution signal decomposition (MSD) based on the discrete wavelet transform (DWT). A fault indicator and fault criteria are then used to detect the HIF in the transmission line. In order to discriminate between HIF and no-fault transient phenomena, such as capacitor and line switching and arc furnace loads, the concept of duration time is used.

Since the wavelet transform is performance better the other signal processing tools but also it has own disadvantages which is more complex and difficult to interpret the

result. In [14], Ming-Ta Yang et al, have investigated applies 3I0 zero sequence current to solve HIF problems. The feature extraction system based on discrete wavelet transform, feature identification technique found on statistical confidence and Based on continuous wavelet transform (CWT) pattern recognition of HIFs is proposed. In [15], Tai Neng Ling et al, have presented a method for high impedance single-phase ground fault (HIF) detection based on wavelet transform (WT) in high voltage transmission line. With the WT the modulus maxima of the zero sequence current, the faulted phase current, and the zero sequence voltage has presented special characteristics which can be used to detect HIF. In [16],El. T. Eldin. Et al, have presented a scheme for HIFs detection in transmission lines the scheme recognizes the distortion of the voltage waveforms caused by the arcs usually associated with HIFs. The discrete wavelet transform (DWT) based analysis, yields three phase voltages in high frequency range which are fed to Clarke's transformation to produce ground and aerial modes voltage components for pattern recognition. The classifier is based on an algorithm that uses recursive method to sum the absolute values of high frequency signals generated over one cycle and shifts one sample.

In [17], M. F. Akorede, This paper has presented a wavelet transform based technique for HIFs detection in power distribution feeders. Discrete Wavelet Transform was used to yields single-phase current and voltage in the low frequency range, which are fed to a classifier for pattern recognition. The classifier algorithm in this paper is based on a moving window approach whereby the one-cycle window of the DWT output is moved continuously by one sample.

Although much literature has been discussed for high impedance fault detection using wavelet or / and neural network, but there is a few researchers have introduced the new algorithms which is a combination of wavelet transform and neural network. In 2007, [18], M.Yang and J. Gu, have introduced new algorithm by combination of wavelet and neural network, the technique is based on wavelet transform to extract useful information by features of the voltage and current from distribution feeders, then transferred into series of detail and approximation, this information has used for training of neural network to identify high impedance fault. In 2010, [19], Navid, et al, has used same technique of combination, but with different mother wavelet, which has used a wavelet packet transform for feature extraction, then fed this information to train neural network for detection of high impedance fault in overhead distribution feeders.

In this paper a new approach for detection of high impedance fault in transmission system level is introduced by combining the appropriate selection of mother wavelet that has chosen after many simulation test, this mother wavelet has used for extracting the coefficients feature of the current signal that generated from simulation test in PSCAD/EMTD under effect of high impedance fault, then after calculating the coefficients its transferred to train a back-propagation neural network for detection of high impedance fault from normal operation.

2 Modeling of High Impedance Fault

As we mentioned in the introduction regarding to the circumstances of arc irregularity, that is extremely difficult to accurately simulate a complete model of high impedance fault. In addition, the arc behavior which is usually associated with

high impedance fault are changed from one half cycle to others, which is mean the arc parameters that extracting by positive half cycle is inappropriate for the others. The model of HIF is proposed to be modeled using a PSCAD/EMTDC developed custom model based on [20]. The model given in [20] is based on arc energy balance. Onwards, by deriving the arc discretion based on the differential equation to obtain the dynamic features of the ground fault nonlinear impedance.

$$\frac{dg(t)}{dt} = \frac{1}{t}\big(G(t) - g(t)\big)$$

(1)

Where: G(t) is a stationary arc conductance, g(t) is a time varying arc conductance, r(t)= 1/g(t) is a time varying arc resistance and t is a time constant.
The stationary arc conductance follows as;

$$G(t) = \frac{|i(t)|}{(v + R|i(t)|)l}$$

(2)

Where: arc current = i(t), voltage / arc length = v, resistive component / arc length = R. Arc l the length and T time constant are constant.
The proposed model is designed in PSCAD/EMTDC is shown is figure (1).
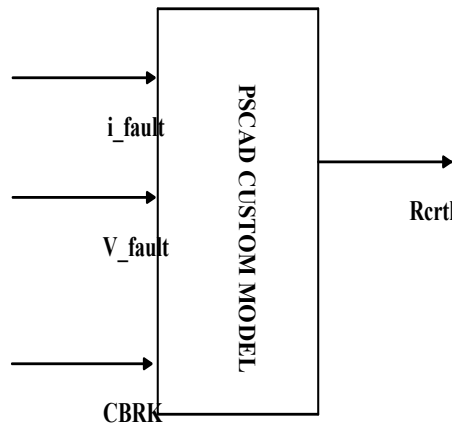
Fig. 1. PSCAD/EMTDC Developed Arc Fault Custom Model.

 In this model there are two inputs and one output,
 1. Instantaneously variable inputs, which are the fault current, fault voltage and the circuit breaker.

2. Constant inputs which is has been derived from differential equation, i(t) is the arc current, v is the constant voltage parameter per arc length, l is the arc length, R is the resistance component per arc length and T is the time constant.

3. The output of the model is the value of the time dependent arcing fault resistance Rctrl.

In figure (2), the developed high impedance arc model is shown by using the PSCAD/EMTDC custom model combination with two diodes to control arc ignition, linear resistance that represents the ground path resistance, two sources AC and DC are included to confirm the asymmetry of voltages and arc current, then two inductance to leads the nonlinearity loop of shape in high impedance fault current.
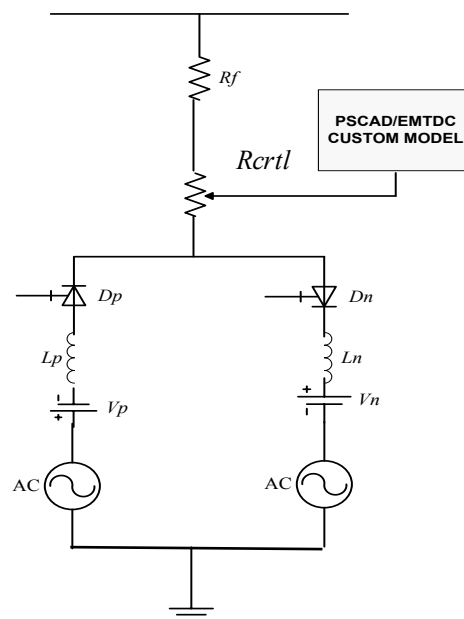
Fig. 2. New HIF Developed Model

From figure (3), we can see a typical of high impedance fault current which is indicated main features of high impedance fault, if we look to the particular distortion around the current crossing zero point we can see the evident of arc features, in addition from figure (4), we can see another evident of high impedance fault which is the asymmetry and nonlinearity due to ground resistance nonlinearity. We can conclude by comparison of previous published work, and simulated result in this paper which gave a good agreement in high impedance arc fault characteristics to ensure the validity of HIF proposed mode
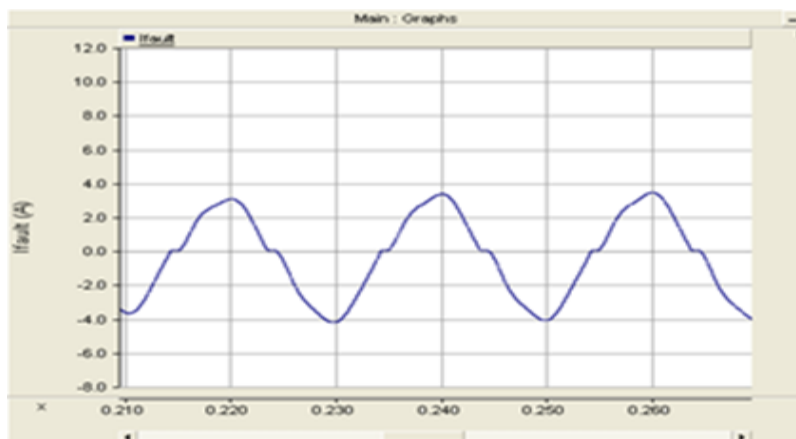
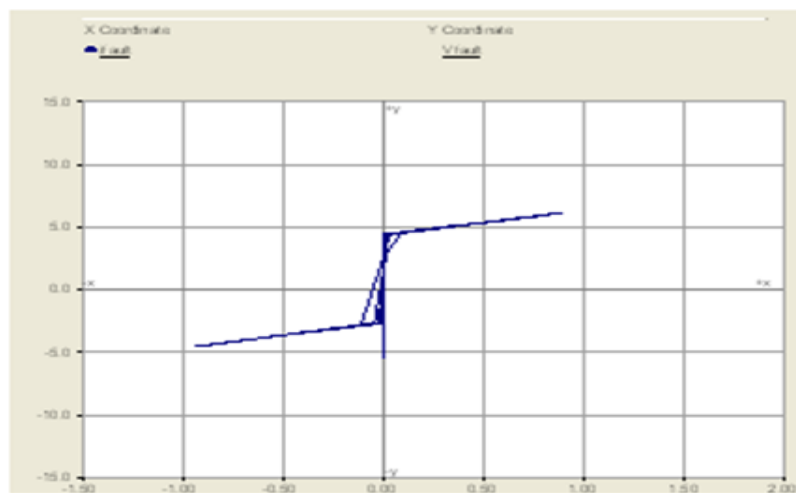**Fig. 3.** HIF Arc current waveform

Fig. 4. v-i characteristic of the arc Fault

3. System Simulation

The test system as shown in figure (5), is one line diagram of the simulated power system network which is modeled in PSCAD/EMTDC program, and it is consist of two areas connected by a transmission line.

The transmission line is selected to be a Frequency dependent model which is the most accurate model, which represents all frequency dependent effects of a transmission line and is very useful to study the transient or harmonic behavior of the line. The design of transmission line depends on three important parameters, which is resistance, inductance, and shunt capacitor. The length of the line is considered to be 100 Km, frequency 50 Hz, and with 230 KV of both sources.
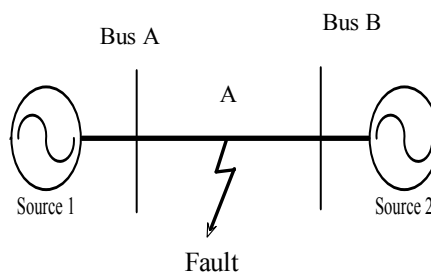
Fig. 5. Simulation of Tested System

4. Wavelet Transform

4.1. Introduction to Wavelet Transform

Wavelets are mathematical tool that provides the data into different frequency components, then study each component with a resolution matched to its scale. In the conventional Fourier transform its completely based on the spectrum analysis, which is mean it does not have the inherent time information associated with transient signals, the advantages of wavelet transform over Fourier transform its possess time and frequency information, which is considered as useful tool for analyzing non stationary transient phenomena such as these associated with transmission line faults. The mainly different between wavelet transform and Fourier transform, in that the wavelet adopts variable window for signal analysis which is using short windows where high frequency information is desired and low widows where low frequency is desired. From the point of few, wavelet transform is a suitable tool analysis for rapid changing transient signal.

4.2. Selection of Mother Wavelet

There are many types of mother wavelets, such as Daubichis, Coiflet and Symmlet wavelets, but the proper choice of the mother wavelet plays an important role in detection and localizing different types of transient signals. The optimal wavelet for extracting signal information is that can generate as many coefficients as possible to represent the characteristics of the signal. In this case since we are studying the

detection and analyzing of low amplitude and short duration of high frequency current signal, and after many simulation test of selection of mother wavelet, we found the most suitable mother wavelet is Daubichies's wavelet four (db4). Here Discrete Wavelet Transform(DWT) is used for feature extraction which is discrete data signal is consist in a series of filtering and down-sampling operations, which repeatedly split a signal into low frequency and high frequency components. DWT uses scaling functions and wavelet functions in achieving this. These two sets of functions are associated with low pass and high pass filters, respectively. In figure (6), the original signal x[n] is first passed through a half band high pass filter g[n]. and a low pass filter h[n], then the output of low-pass filter is further cut in half of the frequency bandwidth, and send to the second stage. This procedure is repeated till the signal is decomposed to a predefined certain levels. This can be expressed, mathematically as follows:

$$D_j[n] = \sum_k x[n].g[2n-k]$$

(3)

$$A_j[n] = \sum_k x[n].h[2n-k]$$

(4)

Where Dj is the output from the high-pass filter called Detail and Aj is the output from the low-pass filter called Approximation, at resolution j, j=1, 2, …J; k=1, 2, …K, where K is the length of the filter vector, after down sampling by two.

4.3 Feature Extraction

It is not practical to use the wavelet extracted signal as directly input to train neural network, because that will increase the number of inputs, then large size of neural network and this is causing the difficulty of network convergence, speed and simplicity. In this study, to overcome these problems we have calculate the coefficients features of wavelet such as Mean, Standard Deviation, skewness and Kurtusis, and this approach reduce the size of neural network and remains important features of original signal. Where these features are estimated from the following equations,
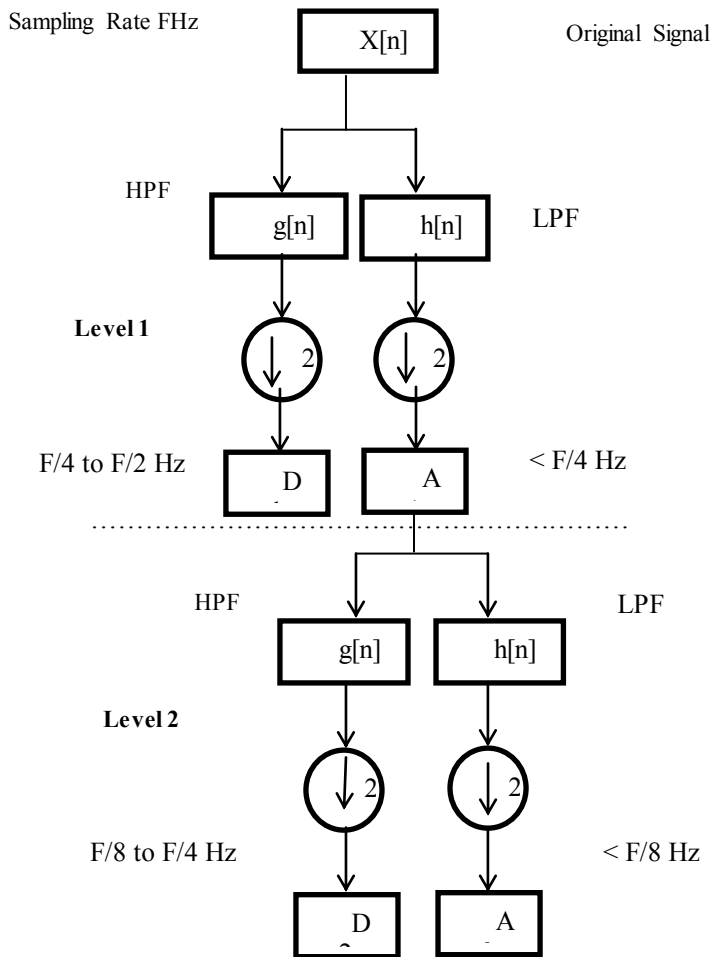
$$\eta = \frac{1}{N} \sum_{N=1}^{N} (x[n])$$

(5)

$$\sigma = (\frac{1}{N} \sum_{N=1}^{1} (x[n] - \eta)^2)^{0.5}$$

(6)

$$\gamma = \frac{1}{N\,\sigma^3} \sum_{N=1}^{1}(x[n] - \eta)^4 \qquad (7)$$

$$\mathcal{K} = \frac{1}{N\,\sigma^4} \sum_{N=1}^{1}(x(n) - \eta)^4 \qquad (8)$$

Fig. 6. Implementation of DWT

5. Artificial Neural Network Structure

Artificial Neural Networks (ANN): every ANN model can be classified by its architecture, processing and training. The architecture describes the neural connections. Processing describes how networks produce output for every input and weight. The training algorithm describes how ANN adapts its weight for every training vector. In this work we have selected the back propagation artificial neural network (BP-ANN), which is considered a most powerful for pattern recognition. Back propagation neural networks are highly effective for pattern recognition. It attempts to minimize error by adjusting each value of a network proportional to the derivative of error with respect to that value. The goal of BP-ANN is to detect and classify HIF from normal system operation. One of the most critical problems in construction the ANN is the choice of the number of hidden layer and the number of neurons for each layer. Using too few neurons in the hidden layer may prevent the training process to converge, while using too many neurons would produce long training time. As well as many hidden layer neurons may result in divergence. The optimum dimension of hidden layer nodes depends on the following conditions: the numbers of input and output nodes, the number of training cases, the amount of noise in the targets, the architecture, the hidden layer node activation function and the complexity of the classification to be learned.

Since we have four features for each phase So, the structure of multilayer feed forward back-propagation neural network is considered twelve neurons in the input layer, three independent layers of feed forward with nine neurons in the first hidden layer, six neurons in the second hidden layer and 1 neuron in the output layer, the output of ANN is a binary output which mean for 1 means HIF, for 0 normal condition. According to the above mentioned methodology the back-propagation neural network has trained with different types of mother wavelet to declare the best choice of wavelet selection as shown in tables from 1 to 5.

TABLE1

Results of Neural Network Trained with Coif2 wavelet

Events	Number of Tested Patterns	Correct Patterns	Incorrect Patterns
High Impedance Fault	20	17	3
Capacitor switching	10	8	2

TABEL2

Results of Neural Network Trained with Coif5 wavelet

Events	Number of Tested Patterns	Correct Pattern	Incorrect Pattern
High Impedance Fault	20	18	2
Capacitor switching	10	9	1

TABLE3

Results of Neural Network Trained with Sym24 wavelet

Events	Number of Tested Patterns	Correct Patterns	Incorrect Patterns
High Impedance Fault	20	18	2
Capacitor switching	10	8	2

TABLE4

Results of Neural Network Trained with db14

Events	Number of Tested Patterns	Correct Patterns	Incorrect Patterns
High Impedance Fault	20	19	1
Capacitor switching	10	9	1

TABLE5

Results of Neural Network Trained with db4

Events	Number of Tested Patterns	Correct Patterns	Incorrect Patterns
High Impedance Fault	20	19	1
Capacitor switching	10	10	0

If we compare the output results from previous tables, it is clear that db4 mother wavelet gives better results than other mother wavelets, and because of this we select it for mentioned propose.

In figure 7, the proposed protection algorithm based on relay logics for detection and discrimination of high impedance fault from other such events that behave as high impedance fault, by combining wavelet transform with neural network, the process steps is illustrated as in flow chart.
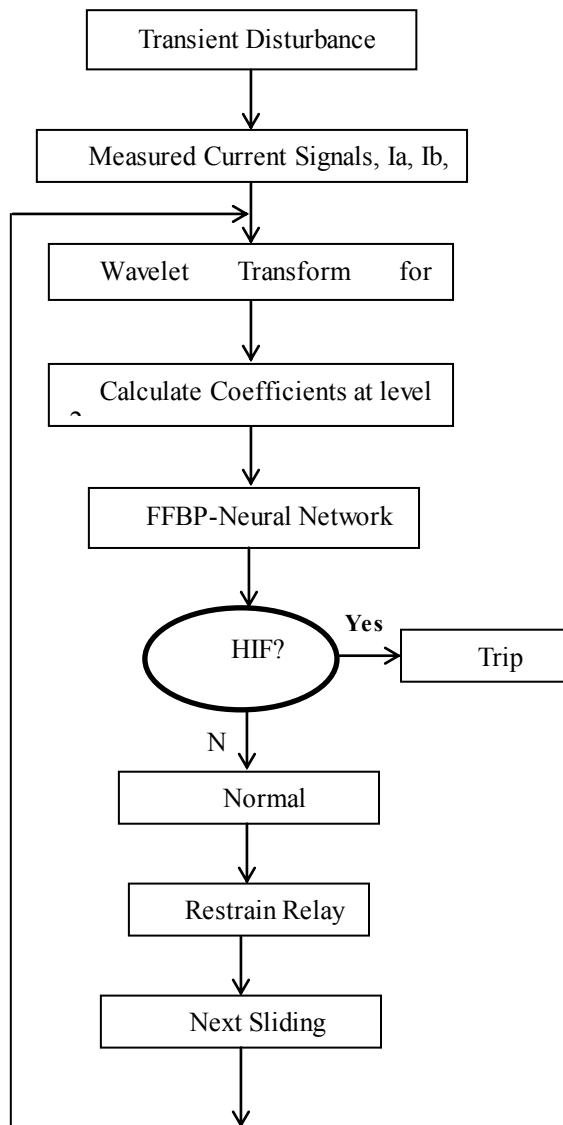
Fig. 7. Relay Logic Algorithm of HIF Detection

6. Results and Discussion

In order to verify the developed technique, a total of 100 instances of high impedance fault and capacitor switching were simulated and analyzed using PSCAD/EMTDC and MATLAB software, 70 of them has used for training and the rest for testing the network. High impedance fault is occurred in phase A with the fault resistance of 380Ω and located of 10 km from Bus A.

As we can see from the figures (8 , 9) , the high impedance fault has generated the high spikes with a certain amplitude, and the values of detailed coefficients of first level d1 and second level d2 are close to zero before the fault occurs, but when the fault happen the values goes up for short period. But we cannot discriminate between high impedance fault and other normal operation by just comparing the value of coefficient levels of the distorted signal, and because of this we have used the mentioned features to train neural network for fault discrimination, the advantages of this approach reduce the size of neural network and remains important features of original signal. Referring to the tables from 1 to 5 it was clear that db4 wavelet gives better performance and higher accuracy and gives excellent feature as input to the neural network to discriminate high impedance fault current from other similar events.
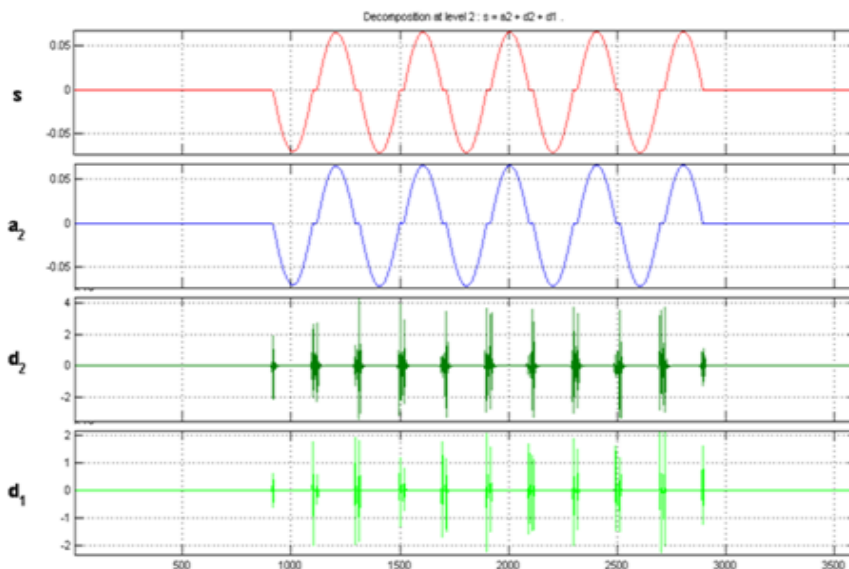
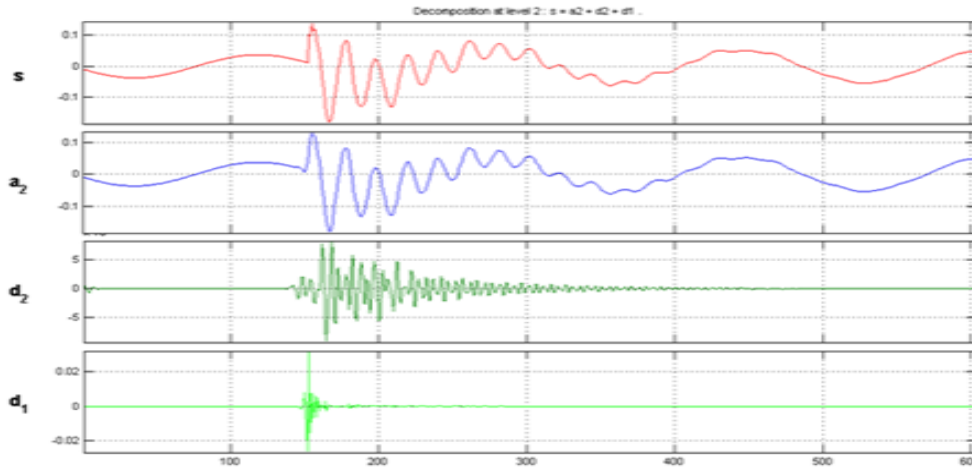**Fig. 8.** HIF Current with Detail Coefficients 1&2

Fig. 9. Capacitor Switching Current with Detail Coefficients 1&2

By training feed forward back-propagation neural network with normalized inputs, it is clear from the shown result in Figure. 10, that we got perfect training performance which is nearly hit the goal with only 3 epochs and very less error which attained about 0.0087, which means that the neural network has recognized the inputs with 99% accuracy. Besides that the test and training regression in Figure, 11 and 12 are exactly equal to 1 that means the dataset perfectly overlapped the target. The target vector consists of two classes; first class is 1, which shows the high impedance fault, the second class is 0, which shows the capacitor switching events.
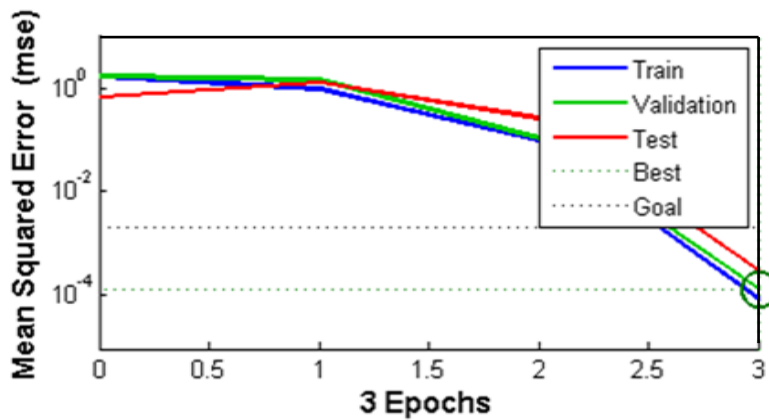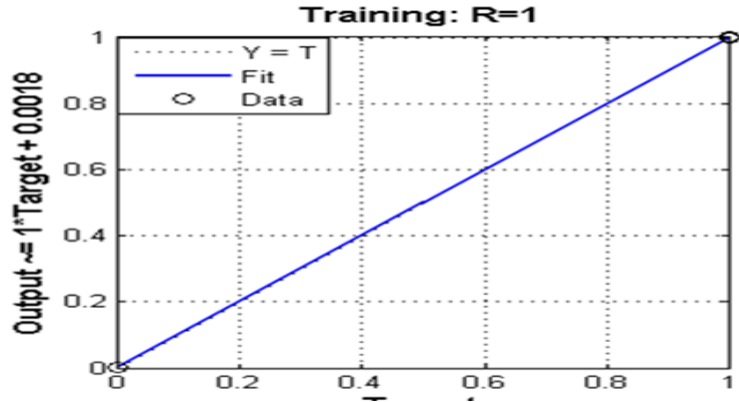

Fig. 10. Training Performance

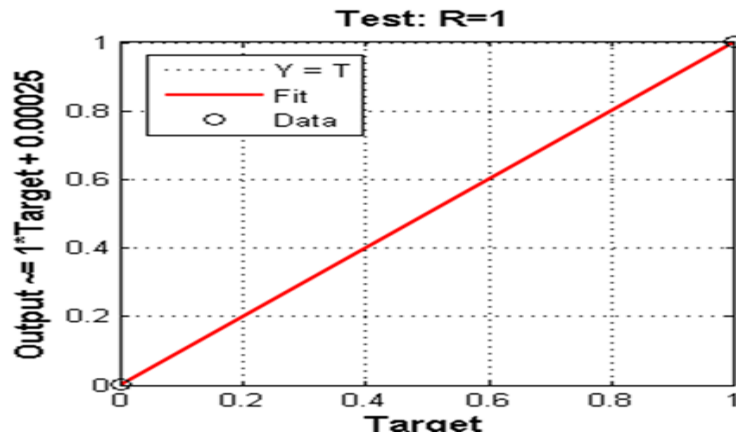**Fig. 11.** Training Regression

Fig.12. Testing Regression

Table 6, provides some of the results of simulated high impedance fault and capacitor switching events, and we can see the results satisfy the requirements of intelligent devices with general protection and capability detection of high impedance fault with overall identification rate of (99%) accuracy

TABLE 6

Result Tests of Neural Network

Events	Desired Output	Actual Output
High Impedance Fault	1	0.9996
High Impedance Fault	1	0.6732
High Impedance Fault	1	0.9997
High Impedance Fault	1	1.0006
High Impedance Fault	1	1.0003
High Impedance Fault	1	.09994
High Impedance Fault	1	1.0096
High Impedance Fault	1	1.0007
High Impedance Fault	1	1.0085
High Impedance Fault	1	1.0008
Capacitor Switching	0	0.0003
Capacitor Switching	0	0.0005
Capacitor Switching	0	0.0001
Capacitor Switching	0	0.0097
Capacitor Switching	0	0.0001
Capacitor Switching	0	0.0008

7. Conclusion

This paper has presented a hybrid novel technique for detection of high impedance fault in transmission system level and discriminate it from normal operation events such as capacitor switching, in addition, a developed new model of high impedance fault has created in PSCAD/EMTDC software with collaborating with some passive elements. The developed technique is based on the linking of wavelet transform with neural network, and advantages of combination was clear of using coefficients feature of db4 wavelet which provides very good linking of wavelet and neural network with very high performance of neural network. The advantages of this approach, it reduces the size of neural network and remains important features of original signal. The

performance showed that proposed technique gives excellent accuracy of transient classification reached to about (≈99%). The proposed technique can be used as an effective approach for alternative protection scheme for large power system. Further work is in progress for large high voltage transmission systems considering a long line distance with different fault locations and fault inception angles. The outcome of current research will be reported in due to follow.

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