Fault Detection and Classification Using Discrete Wavelet Transform

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Abstract: **This research work aims to present an approach supported by discrete wavelet transform and rule based decision tree for the detection and classification of the various types of the power system faults. Fault location on overhead power transmission lines remains a subject of great interest and has been intensively studied over the years. The power system faults include the line to ground (LG), double line (LL), double line to ground (LLG) and three phase fault involving ground (LLLG).**

The issue of fault detection and classification in the utility system network has also become important due to the integration of renewable energy sources in the recent years. The current captured on a bus of the test system is used for the detection of the faults. The current signal is decomposed up to third level of decomposition for the detection of the faults. A fault index based on the sum absolute values of the detail coefficients used to detect the various types of the faults. The detailed simulation methodology has been carried out in MATLAB/Simulink environment using the IEEE-34 bus test system. It is established that the proposed approach effectively detects and classify the power system faults.

I. INTRODUCTION

A fast and continuous expansion of the power system network has been observed in the recent years where the power system is adopting the extra high voltage (EHV) and ultra high voltage (UHV) levels. Identification of location of transmission and distribution line faults in a power system grid is of great importance to facilitate self-healing of the system and for maintaining reliability of power supply. If a fault is not properly detected and removed, widespread damage or a power system blackout may take place [1]. The nature of protective devices may change with the various types of loads such as linear and non-linear loads connected with the distribution system [2]. The transmission line protection schemes are categorised into three stages: (i) fault detection and classification, (ii) fault zone estimation or fault location and (iii) decision logic and subsidiary modules [3]. The components of transient generated during the faults in the system contain the abundant fault information which has been widely used in the fault detection and classification by means of travelling-wave or high-frequency transients [4]. The transients during faulty conditions also depend on the type of load as well as the power system network complexity [5]. A transmission line is most important part of an electric power system. Since 1945, power transmission lines have been rapidly expansion in number and length. One necessity factor of an electrical power transmission system is to continuously deliver electrical power to consumers [6]. So, efficient and effective protection of the transmission lines is required. For this the analysis of power system faults in various power system conditions, loads, generating sources, and faulty conditions. Therefore, the detection of faults is important part for protection scheme.

This work presents a novel algorithm based on discrete wavelet transform and rule based decision tree for detection and classification of the power system faults. The proposed technique has been successfully implemented for the investigation of the power system faults such as line to ground (LG), double line (LL), double line to ground (LLG) and three-phase fault involving ground (LLLG). The proposed methodology has been successfully carried out using the IEEE-34 bus test system.

Some comprehensive survey of the research work reported on the topic of detection and classification of the power system faults are presented in [7]-[22].

A prototype Kerr cell has been tested and constructed by the authors in [7] for detecting and identify faults by monitoring high voltages such as a create in electric power delivery systems . This method may prove timely and cheap in fault detection and location. In [8], authors have discussed about optical magnetic field sensors and ground fault occurred. A fault section, Sensors and a fault section detector of a system are connected with optical fibers able of non-repeated transmission of over 6 km. A fault section is detected by a software program which operates on A/D-converted current data. In [9] authors presented and discussed for finding the accurate location of the effect of capacitance explicitly and enable the detection of faults in transmission lines more accurately. It require lower rate of sampling frequency and the maximum error of this method is less than Dx/2 where Dx is the distance connecting two consecutive points along the transmission line. In [10], authors have discussed about determine the section of fault at a ground fault, and detects the fault current which flows from the power source to the point of ground fault and determines the fault section from the magnitude and phase information of the fault current. Fault analysis functions, fault detection, classification and location are implemented for a transmission line using coordinated samples from two ends of a line has been presented in [11]. The new fault analysis advance is extremely rapid, selective and precise providing, low sensitivity of errors coming from a variety of power system situation. In [12] authors presented that transmission line faults is very important to the correct performance of the power system. It is necessary if protective relays are to take the appropriate action and in monitoring the presentation of circuit breakers, relays and other protective and control elements. In [13] authors presented detection of the direction of a fault on a transmission line is necessary to the correct performance of a power system. System simulation studies show that the proposed advance is able to detect the direction of a fault on transmission line fast and correctly the performance of the proposed network is also checked for faults as well as high amount of resistance and also faults at the relay location. A new method to real-time fault detection and classification in power transmission systems by using fuzzy-neuro techniques have been presented in [14]. In [15], author presented a pattern recognition approach for current differential relaying of power transmission line. The proposed scheme is evaluated for current differential protection of a transmission line fed from both ends for a variety of faults, fault resistance, inception angles, and significant noise in the signal using computer simulation studies lines. A fault detection method for heat loss at a work-shop level has been presented in [16]. In. [17], author proposed a new set of time-frequency features for fault-type identification, fault-loop status supervision, and fault-zone detection modules in a compensated transmission line with a unified power-flow controller. An intelligent identification scheme for transient faults in transmission systems using Gabor Transform (GT) and Artificial Neural Network (ANN) has been proposed by the authors in [18]. The measurements are processed in a system protection central (SPC). This capability is used to set up a wide area control, protection and optimizing the platform by means of new fast communication system and GPS [19]. A new technique based upon the distributed model of transmission lines to overcome the problems encountered in traditional approaches. This approach considers the effect of capacitance explicitly and therefore enables the detection of faults in transmission lines more precisely. Author proposed a technique for fault detection and classification by using artificial neural network and wavelet transform [20]. The technique uses a fault detection technique by using different levels of wavelet transforms on different neural networks where comparison of them shows the best technique for fault detection and classification. The decision to trip is based on the relative arrival times of these high frequency components as they propagate through the system. A new fault detection technique which involves capturing the current signals generated in a transmission line under HIFs its main thrust lies in the utilization of the absolute sum value of signal components based on the discrete wavelet transform (DWT). Sophisticated decision logic is also designed for the determination of a trip decision. A novel fault-detection technique of high-impedance faults (HIFs) in high-voltage transmission lines using the wavelet transform. Recently, the wavelet transform (WT) has been successfully applied in many fields. The technique 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 (i.e., the transient time period), is presented. On the basis of extensive investigations, optimal mother wavelets for the detection of HIF are chosen. It is shown that the technique developed is robust to fault type, fault inception angle, fault resistance, and fault location. The paper demonstrates a new concept and methodology in HIF in transmission lines. The performance of the proposed technique is tested under a variety of fault conditions on a typical 154-kV Korean transmission-line system .In [21] the authors presented application of supervised learning algorithms based on different neural network topologies for detection and classification of the faults in transmission lines in power system. Different wavelet transforms on different Multi Resolution Analysis levels are applied for detection of the potential features from the voltage waveforms of the Phasor Measurement Units (PMUs). These wavelet transforms are then applied to several neural networks classification engines to classify faults. . In [22], the authors presented application of supervised learning algorithms based on different neural network topologies for detection and classification of the faults in transmission lines in power system. Different wavelet transforms on different Multi Resolution Analysis levels are applied for detection of the potential features from the voltage waveforms of the Phasor Measurement Units (PMUs). These wavelet transforms are then applied to several neural networks classification engines to classify faults.

Followings are the research objectives of the paper:-

1) This manuscript presents a novel algorithm based on discrete wavelet transform and rule based decision tree for detection and classification of the power system faults. The proposed technique has been successfully implemented for the investigation of the power system faults such as line to ground (LG), double line (LL), double line to ground (LLG) and three-phase fault involving ground (LLLG).
2) The proposed technique has been successfully carried out using the IEEE-34 bus test system.
3) The proposed technique has been carried out in the MATLAB/Simulink environment using the proposed algorithm based on discrete wavelet transform and rule based decision tree.

II. TEST SYSTEM AND METHODOLOGY USED FOR METHODOLOGY

A wavelet is a mathematical function used to divide a given function or continuous-time signal into different scale components. A wavelet transform is the representation of a function by wavelets.

2.1 Discrete Wavelet Transform

It is computationally impossible to analyze a signal using all wavelet coefficients, so one may wonder if it is sufficient to pick a discrete subset of the upper half plane to be able to reconstruct a signal from the corresponding wavelet coefficients. One such system is the affine system for some real parameters $a > 1$, $b > 0$. The corresponding discrete subset of the half plane consists of all the points (am, $namb$) with m, n in Z. The discrete wavelet transform (DWT) is implemented by filter bank technique known as multi resolution analysis (MRA). In DWT, the low pass (LP) and high pass (HP) filters produce two sets of coefficients: high frequency and low frequency components followed by dyadic decimation (down-sampling). The multi-resolution analysis of the signal using DWT is detailed in the Fig. 1. The choices of filter h and g coefficients with four are called analyzing by daubechies wavelet with four filter coefficients (db4). A and d respectively represent the approximation and detail coefficients.

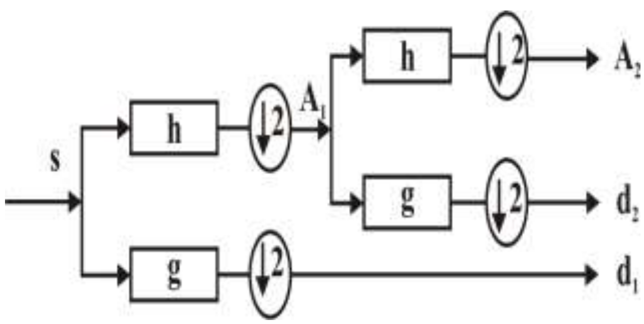


Fig.1 Signal decomposition using DWT

The proposed test system is standard IEEE-34 bus test system as shown in Fig. 2. In this all the feeders used in the test system are three phase in nature having the length equal to the original length of the feeders. All the loads used in the test system are three phase load. The distributed loads are simulated by spot loads placed at the middle of the feeders. The faults are created on the bus-838 of the test system as detailed in the simulation results section. In this system discrete wavelet transform is used to detect the power system faults. The wavelet transform (WT) decomposes a signal into different scales with different levels of resolution by dilating a single prototype function. The current signal is captured on the bus 800 of the test system and faults are created on the bus 838 of the test system. The current signal is decomposed using the discrete wavelet transform up to the level three of the decomposition using a sampling frequency of the 1.92 kHz. The detail coefficients up to level three are plotted and peak values of the detail coefficients are used for the detection of the power system faults. A fault index is proposed for the detection and discrimination of the various types of the power system faults. This fault index is calculated by the summing the absolute values of the details coefficients over a window of 32 cycles and moving this window by 1 sample. The peak values if this fault index are used to detect and discriminate the various types of the power system faults.

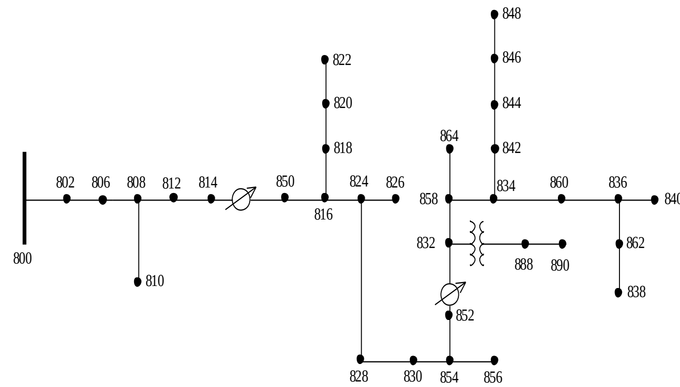


Fig.2. Proposed test system of IEEE-34 bus test system used for the methodology of fault analysis.

III. RESULT ANALYSIS & DISCUSSION

The IEEE-34 bus test system is used for the proposed methodology. Various types of the faults have been created on the bus 838 of the test system. The current signals are recorded on the bus 800 of the test system. Results have been recorded for the 12 cycles and all the faults have been created at 5th cycles from the start of the simulation. The current signals are decomposed up to level 3 using the discrete wavelet transform with db4 as mother wavelet. The current signals have been analyzed for all the three phases. The approximation coefficient at level 3 and detail coefficients up to level 3 are plotted for each case of the methodology. The fault index is calculated for all the detail coefficients for all the cases of methodology.

3.1 Line to Ground Fault

A line to ground fault on the phase-A has been created on the bus 838 of the test system at 5th cycle from start of the simulation. The current signal of phase-A captured on the bus 800 has been analyzed for the detection of the LG fault. The plots obtained by the discrete wavelet transform based decomposition of current signal of phase-A up to third level of decomposition has been during the LG fault condition are shown in Fig.3. It is observed from the Fig. 3(e) that the values of the detail coefficient at first level of decomposition (cD1) are nearly equal to zero except at the instant of fault occurrence where the values of cD1 achieves the value of 0.05. This helps in the detection of the LG fault. It is also observed from the Fig.3.(d) that the values of the detail coefficient at second level of decomposition (cD2) are nearly zero except the instant of fault occurrence. At the instant of fault occurrence a peak of value 0.4 has been observed which helps in the detection of occurrence of LG fault. It is observed from the Fig.3. (c) that the values of the detail coefficient at third level of decomposition (cD3) are nearly zero except the instant of fault occurrence. At the instant of fault occurrence a peak of value 4 is observed which helps in the detection of the LG fault.

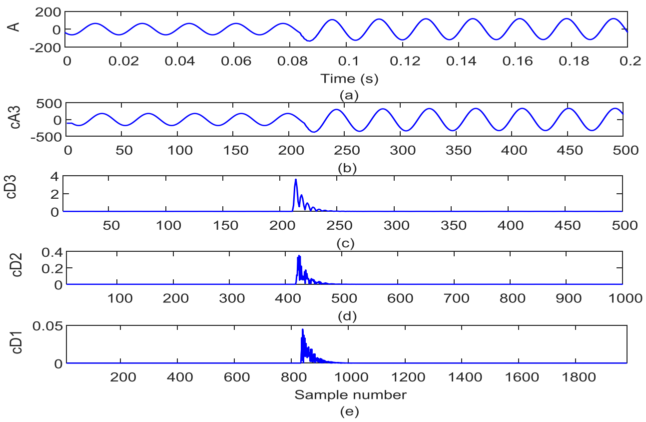
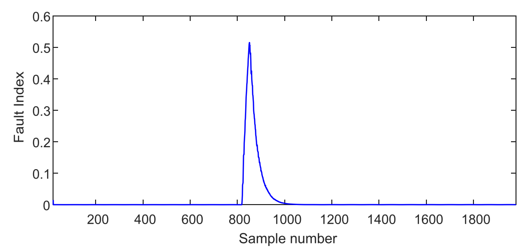
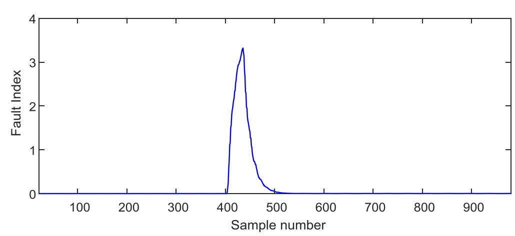


Fig.3. Discrete wavelet transform based decomposition of current signal of phase-A during line to ground fault (a) original current signal (b) approximation coefficient at third level of decomposition (c) detail coefficient at third level of decomposition (d) detail coefficient at second level of decomposition (e) detail coefficient at first level of decomposition.



(a)



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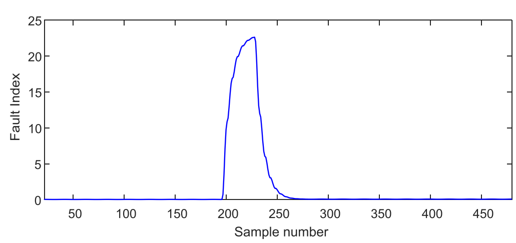


(c)

Fig. 4.Fault index for current signal of phase -A during line to ground fault corresponding to (a) detailed coefficient cD1, (b) detailed coefficient cD2, (c) detailed coefficient cD3

The fault index corresponding to the detail coefficient cD1 of current in phase-A during the LG fault is shown in Fig. 4(a) It is observed that the value of fault index is nearly zero except the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 0.5. This high peak helps in the detection of the LG fault.

The fault index corresponding to the detail coefficient cD2 of current in phase-A during the LG fault is shown in Fig. 4(b) It is observed that the value of fault index is nearly zero except the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 3.5. This high peak helps in the detection of the LG fault.

The fault index corresponding to the detail coefficient cD3 of current in phase-A during the LG fault is shown in Fig.4(c) It is observed that the value of fault index is nearly zero except the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 24. This high peak helps in the detection of the LG fault.

3.2 Double Line Fault

A double line (LL) fault has been created on the bus 838 of the test system at 5^{th} cycle from start of the simulation by short circuiting the phases A and B. The current signal of phase-A captured on the bus 800 has been analyzed for the detection of the LL fault. The plots obtained by the discrete wavelet transform based decomposition of current signal of phase-A up to third level of decomposition has been during the LL fault condition are shown in Fig.5. It is observed from the Fig.5 (e) that the values of the detail coefficient at first level of decomposition (cD1) are nearly equal to zero except at the instant of fault occurrence where the values of cD1 achieves the value of 0.2. This helps in the detection of the LL fault. It is also observed from the Fig.5.(d) that the values of the detail coefficient at second level of decomposition (cD2) are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence a peak of value 1.0 has been observed which helps in the detection of occurrence of LL fault. It is observed from the Fig.5 (c) that the values of the detail coefficient at third level of decomposition (cD3) are nearly zero except the instant of fault occurrence. At the instant of fault occurrence a peak of value 1.0 is observed which helps in the detection of the LL fault.

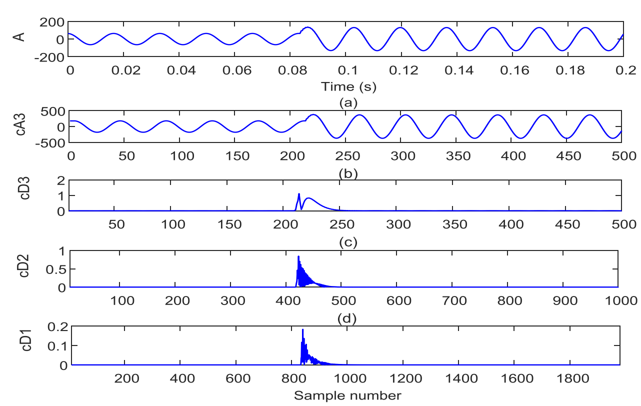
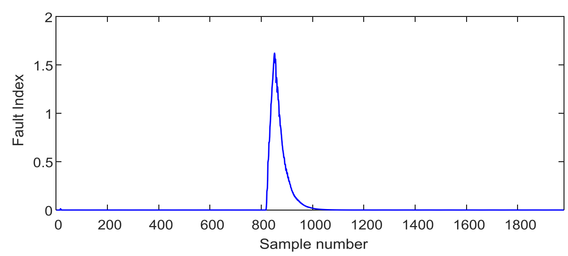


Fig.5 Discrete wavelet transform based decomposition of current signal of phase-A during double line fault (a) original current signal (b) approximation coefficient at third level of decomposition (c) detail coefficient at third level of decomposition (d) detail coefficient at second level of decomposition (e) detail coefficient at first level of decomposition.

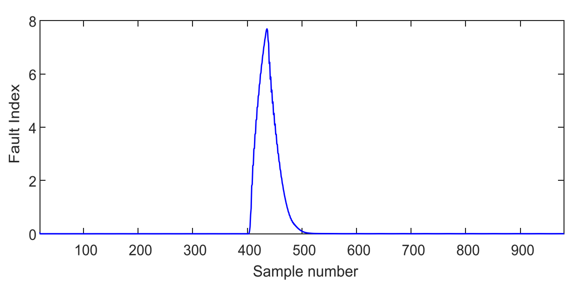
The fault index corresponding to the detail coefficient cD1 of current in phase-A during the LL fault on phases A and B is shown in Fig. 6(a) It is observed that the values of fault index are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 1.8. This high peak helps in the detection of the LL fault.

The fault index corresponding to the detail coefficient cD2 of current in phase-A during the LL fault on phases A and B is shown in Fig. 6(b). It is observed that the values of fault index are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 7.8. This high peak helps in the detection of the LL fault.

The fault index corresponding to the detail coefficient cD3 of current in phase-A during the LL fault on phases A and B is shown in Fig. 6(c). It is observed that the values of fault index are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 16. This high peak helps in the detection of the LL fault.



(a)



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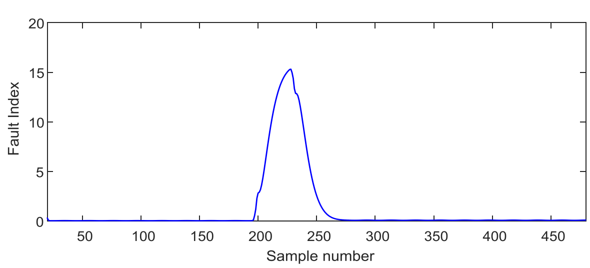


(c)

Fig.6. Fault index for current signal of phase-A during line to line fault corresponding to (a)Detailed coefficient cD1, (b) detailed coefficient cD2, (c) detailed coefficient cd3

3.3 Double Line to Ground Fault

A double line to ground (LLG) fault has been created on the bus 838 of the test system at 5th cycle from start of the simulation by simultaneously grounding the phases A and B. The current signal of phase-A captured on the bus 800 has been analyzed for the detection of the LLG fault. The plots obtained by the discrete wavelet transform based decomposition of current signal of phase-A up to third level of decomposition during the LLG fault condition are shown in Fig. 7. It is observed from the Fig.7. (e) that the values of the detail coefficient at first level of decomposition (cD1) are nearly equal to zero except at the instant of fault occurrence where the values of cD1 achieves the value of 0.2. This helps in the detection of the LLG fault. It is also observed from the Fig.7. (d) that the values of the detail coefficient at second level of decomposition (cD2) are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence a peak of value 1.0 has been observed which helps in the detection of occurrence of LLG fault. It is observed from the Fig. 7.(c) that the values of the detail coefficient at third level of decomposition (cD3) are nearly zero except the instant of fault occurrence. At the instant of fault occurrence a peak of value 1.5 is observed which helps in the detection of fault.

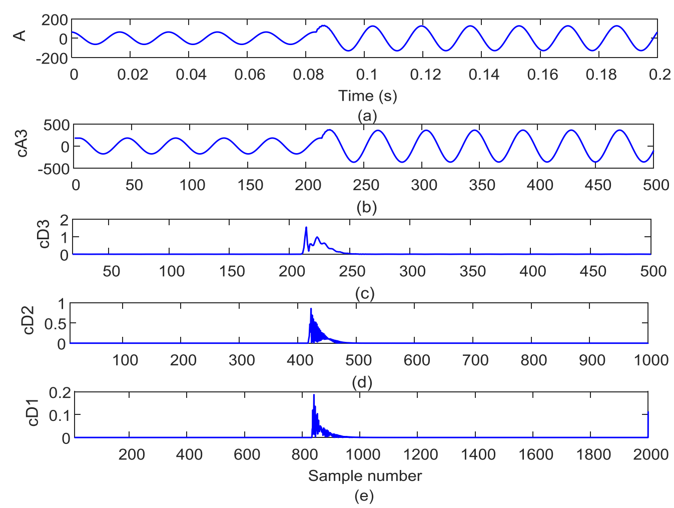
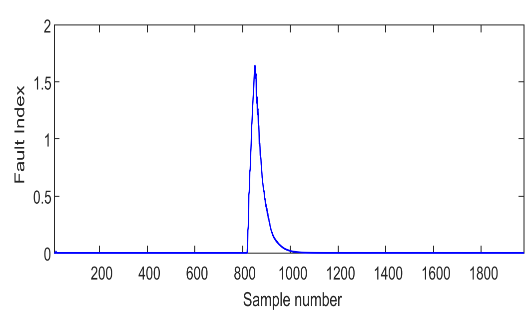
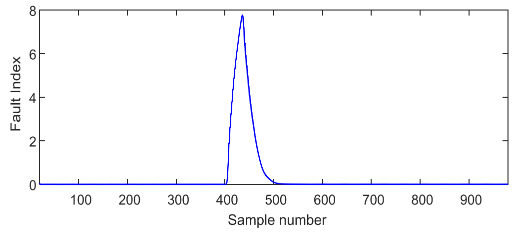


Fig .7. Discrete wavelet transform based decomposition of current signal of phase-A during double line to ground fault (a) original current signal (b) cA3 (c) cD3 (d) cD2 (e) cD1



(a)



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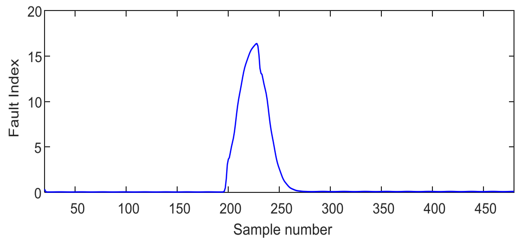


(c)

Fig.8. Fault index for current signal of phase-A during double line to ground fault corresponding to (a) detailed coefficient cD1, (b) detailed coefficient cD2, (c) detailed coefficient cD3

The fault index corresponding to the detail coefficient cD1 of current in phase-A during the LLG fault on phases A and B is shown in Fig. 8. (a)It is observed that the values of fault index are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 1.8. This high peak helps in the detection of the LLG fault.

The fault index corresponding to the detail coefficient cD2 of current in phase-A during the LLG fault on phases A and B is shown in Fig. 8(b). It is observed that the values of fault index are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 8. This high peak helps in the detection of the LLG fault.

The fault index corresponding to the detail coefficient cD3 of current in phase-A during the LLG fault on phases A and B is shown in Fig. 8(c). It is observed that the values of fault index are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 17. This high peak helps in the detection of the LLG fault.

3.4 Three Phase Fault Involving Ground

A three-phase fault involving ground (LLLG) has been created on the bus 838 of the test system at 5th cycle from start of the simulation by simultaneously grounding all the three phases. The current signal of phase-A captured on the bus 800 has been analyzed for the detection of the LLLG fault. The plots obtained by the discrete wavelet transform based decomposition of current signal of phase-A up to third level of decomposition during the LLLG fault condition are shown in Fig.9. It is observed from the Fig. 9.(e) that the values of the detail coefficient at first level of decomposition (cD1) are nearly equal to zero except at the instant of fault occurrence where the values of cD1 achieves the value of 0.25. This helps in the detection of the LLLG fault. It is also observed from the Fig.9.(d) that the values of the detail coefficient at second level of decomposition (cD2) are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence a peak of value 1.0 has been observed which helps in the detection of occurrence of LLLG fault. It is observed from the Fig.9.(c) that the values of the detail coefficient at third level of decomposition (cD3) are nearly zero except the instant of fault occurrence. At the instant of fault occurrence a peak of value 1 is observed which helps in the detection of the LLLG fault.

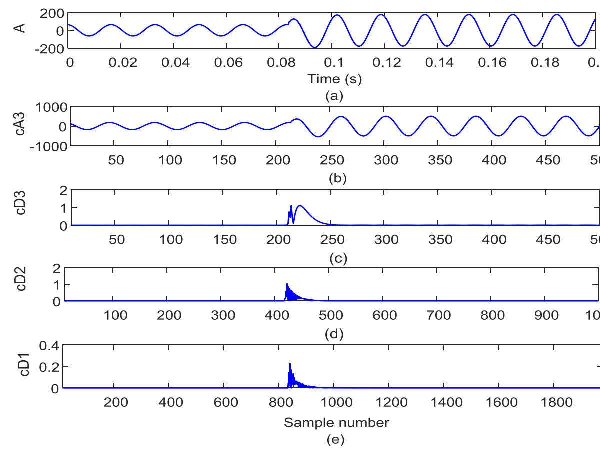
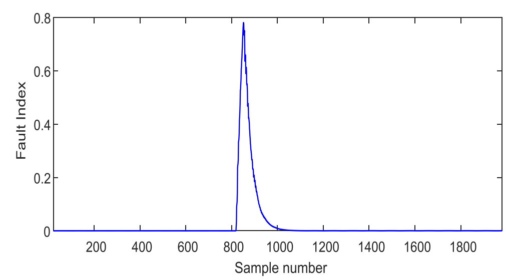
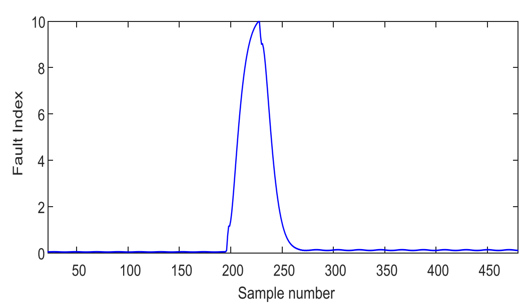


Fig.9. Discrete wavelet transform based decomposition of current signal of phase-A during three phase fault involving ground (a) original current signal (b) approximation coefficient at third level of decomposition (c) detail coefficient at third level of decomposition (d) detail coefficient at second level of decomposition (e) detail coefficient at first level of decomposition.



(a)



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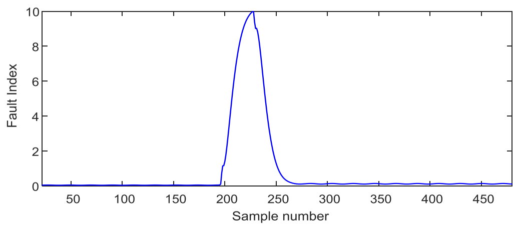

(c)

Fig.10. Fault index for current signal of phase-A during three phase fault involving ground (a) detailed coefficient Cd1, (b) detailed coefficient cD2, (c) detailed coefficient cD3

The fault index corresponding to the detail coefficient cD1 of current in phase-A during the LLLG fault on phases A and B is shown in Fig.10 (a) It is observed that the values of fault index are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 0.8. This high peak helps in the detection of the LLLG fault.

The fault index corresponding to the detail coefficient cD2 of current in phase-A during the LLLG fault on phases A and B is shown in Fig. 10(b). It is observed that the values of fault index are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 3.5. This high peak helps in the detection of the LLLG fault.

The fault index corresponding to the detail coefficient cD3 of current in phase-A during the LLLG fault on phases A and B is shown in Fig. 10(c) It is observed that the values of fault index are nearly zero except at the instant of fault occurrence. At the instant of fault occurrence the fault index achieves a peak value of 10. This high peak helps in the detection of the LLLG fault.

Table-1 Peak Values of the Fault Indices

Type of Fault	Phase	Fault Index		
		cD1	cD2	cD3
Healthy	A	$2x10^{-4}$	0.01	0.01
	B	$2x10^{-4}$	0.01	0.01
	C	$2x10^{-4}$	0.01	0.01
LG	A-g	0.5	3.5	24
	B-g	0.25	1.8	11
	C-g	0.25	1.6	11
LL	AB	1.8	7.8	16
	BC	1.8	7.8	16
	CA	0	0.0025	0.02
LLG	AB-g	1.8	8	17
	BC-g	1.8	8	15
	CA-g	0.12	0.8	6
LLLG	A	0.8	3.5	10
	B	0.8	3.5	10
	C	1.2	6	10

Table 1 shows the peak values of fault indices where detailed coefficients has been calculated for healthy as well as faulty conditions. According to fig 11 it is concluded that single line to ground fault having maximum peaks.

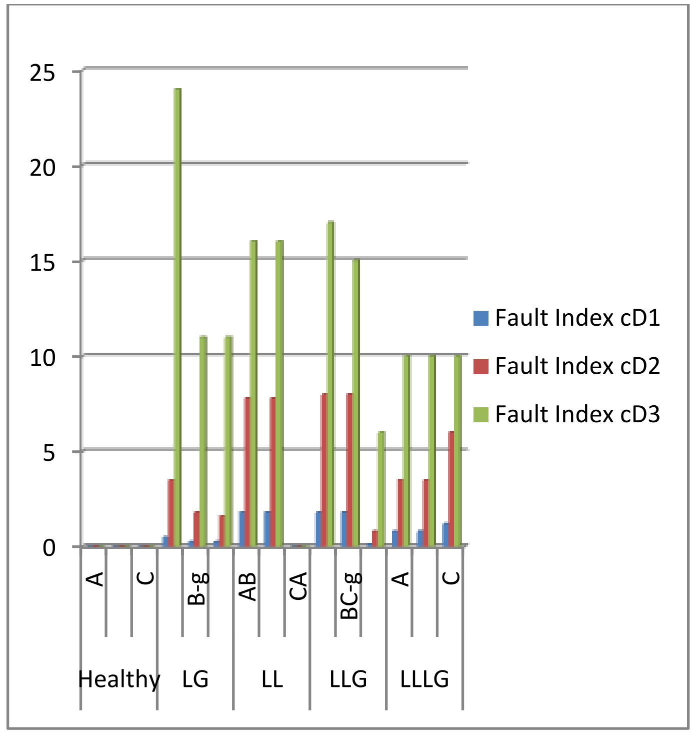

Fig: 11 graphical representations of peak values of fault indices

3.5 Rule Based Decision Tree Based Classification Of Faults

After successfully detecting the faults on power system fault by discrete wavelet transform another technique is used that is rule based decision tree to classify the faults. Rule based decision trees is a classification tree used to predict responses to data. To predict a response, follow the decisions in the tree from the root (beginning) node down to a leaf node. The leaf node contains the response. Classification trees give responses that are nominal, such as 'true' or 'false'. It is based on the set of rules which are applied to a data set of features of the signal extracted with the help of mathematical techniques such as discrete wavelet transform and S-transform.

The rule based decision tree is used for the classification of the power system faults. The peak values of the proposed fault index corresponding to the detail coefficients at the decomposition levels of 1, 2 and 3 are used for the purpose of the classification of It also helps to discriminate the various types of the faults from each other. The rule based classification of the power system faults is shown in Fig.3. It can be observed that the Fault index corresponding to the detail coefficient cD3 is less than 1 for the healthy conditions in which no fault is present. This value is greater than 1 for all the types of the faults. Further, the rules used for the classification purpose are provided in the Fig.12

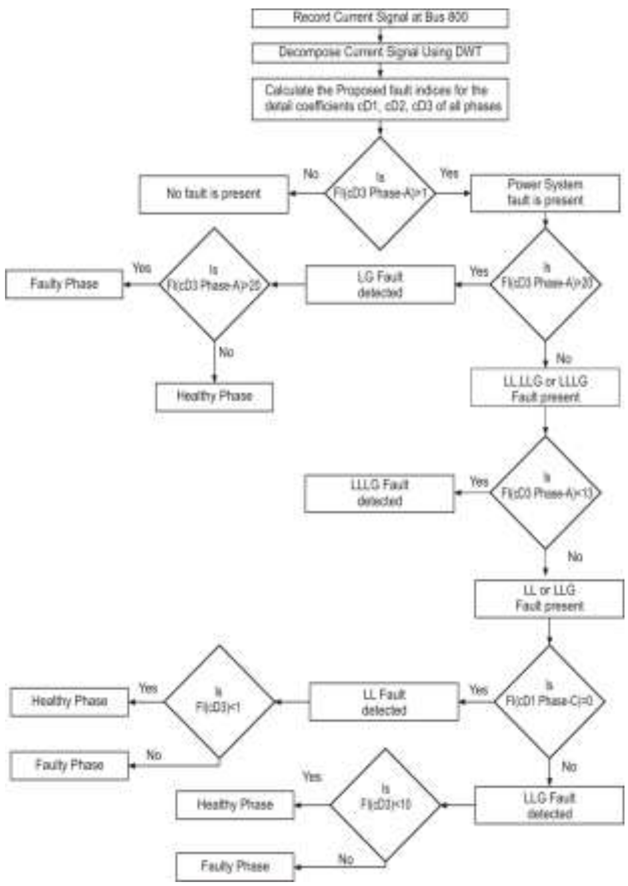

Fig.12. Rule based decision tree based classification of the power system faults

IV. CONCLUSION

This research work investigates the detection and classification of the power system faults. The methodology has been performed using the IEEE-34 bus test system. Current signal captured on bus is decomposed using the discrete wavelet transform with db4 as mother wavelet up to third level of decomposition. The details coefficients up to third level and approximation coefficient at third level are plotted for current in all the three phases during the faulty events. The investigated faults include line to ground (LG) fault, double line (LL) fault double line to ground (LLG) fault and three phase fault involving ground (LLLG). The healthy condition is also investigated to differentiate the faulty events from the healthy events. It is concluded that a peak is observed in the plots of detail coefficients which help in the detection of the power system faults. A fault index based on the sum of absolute values of the detail coefficients over a window of 32 samples is proposed to detect the various types of the power system faults. The maximum values of the proposed fault index are used to detect and differentiate the various types of the faults.

An algorithm using the rule based decision tree has been proposed to classify the various types of the power system faults. The peak values of the proposed fault index are given as input to the rule based decision tree for the classification purpose. It has been observed that the various types of the faults have been classified from each other using the proposed algorithm. This algorithm also helps to detect and discriminate the faulty phases from the healthy phases. Hence, it has been concluded that the proposed approach based on the discrete wavelet transform and rule based decision tree effectively detect and classify the various types of the power system faults. Based on the presented research work in this paper, further methodology can be carried out with in the presence of the renewable energy sources as well as the smart technologies integrated to the utility network. Further, the methodology may also be validated in the real time environment using the devices such as Real time digital simulator.

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