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Research Article

Analysis of High Impedance Fault using Discrete Wavelet Transform Technique

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Abstract *- This paper proposes a detection method for high impedance fault, which occurs in the power system when a line conductor breaks down physically and in contact with a high impedance medium, resulting in low magnitude current, and these high impedance faults are difficult to detect by standard methods. A Discrete Wavelet Transform (DWT) technique is implemented in this paper for normal conditions, High impedance fault also, non-High impedance fault conditions like capacitance switching, and non-linear load. Discrete wavelet transform provides a base for identifying these high impedance faults in the power system. This paper shows five levels of decomposition db15(d_1 to d_5) are high-frequency decomposition and A_5 is low-frequency decomposition. Decomposition is the fifth stage D_5 shows the appropriate for detection of normal conditions, High impedance fault also non-High impedance fault conditions in each phase of the system. This result shows the exact identification of faults even at lower magnitude current appropriately under assumed fault conditions.*

Keywords *- High Impedance Fault, Low magnitude current, HIF characteristics, Discrete wavelet transform.*

1. Introduction

Protective engineers have real challenges in identifying high impedance faults in the power system on the utility side. Many conventional relays fail to predict the high impedance faults due to its lower magnitude current compared to the rated load currents [1-4]. This reason makes the power engineers unable to detect the high impedance faults in the power system. For example, when a line conductor breaks down and conducts along with a high impedance object, which leads to a very low magnitude current of fewer than one amperes with no proof of occurrence, these types of faults are considered high impedance faults (HIFs). If these HIFs are undetected for an hour (or) a day in the distribution system, it damages the system equipment [5-7]. This distribution system is nearer to the populated areas, which leads to fatal effects. Hence, power engineers face the biggest challenges in distribution systems, reliability, and public safety. Various detection methods have been proposed by several researchers [8]. Some researchers have experimental data-based detection methods, and most have simulated-based detection methods of the HIF model. However, the most reliable detection algorithm method is more important for accurately modelling HIF models. For detection of High impedance fault, the models need data with certain characteristics of high impedance fault such as non-linearity, lower frequency, and asymmetry of current in high impedance fault. However, the rapid increase of high impedance faults in the distribution systems turns into failure.

This paper describes the discrete wavelet transform used to extract the features from the normal condition, High impedance fault, and non-High impedance fault condition current signal. During fault conditions, features of each phase current are collected for feature extraction using various methods [9-11]. The Fourier Transformer (FT) provides frequency information of a current signal representing frequencies and their magnitude. It fails to represent the time; frequencies exist. This Fourier transform is therefore ideal for stationary signals and cannot provide frequency information for a localized signal region in time. The Fourier Transform lacks time information to analyse the current signal for extraction of features. In the power system, fault analyses are analysed by Fourier Transform. However, it cannot analyse the transient signal under non-stationary conditions that compare both frequency and time components [12,13]. To overcome this, Wavelet Transform (WT) were proposed in the literature to analyse the non-stationary transient signal widely used for both frequency and time components. The wavelet transform is classified into two: 1. Discrete wavelet transform and 2. continuous wavelet transform [14-16]. A discrete wavelet transform is adapted to extract the feature of each phase switching current signal. The results are obtained under normal conditions, High impedance fault and non-High impedance fault conditions like capacitance switching and non-linear load. The structure of the paper is as follows: section 2 – system description, section 3 explains Discrete Wavelet Transform, results and discussion in section 4 and conclusion and future work is discussed in section 5.

2. System Description

Kavaskar *et al.* [21, 22] have taken the model shown in Fig 1 of the 33KV feeder for analysis of high impedance fault and non-high impedance fault conditions. This model has an 11KV bus connected to a 33KV bus through a distribution transformer. A subsystem model contains seven feeders. The sixth feeder acts as a candidate feeder. This model underwent High impedance fault also non-High impedance fault conditions. Non-High impedance fault conditions are analysed as capacitance switching and non-linear load.

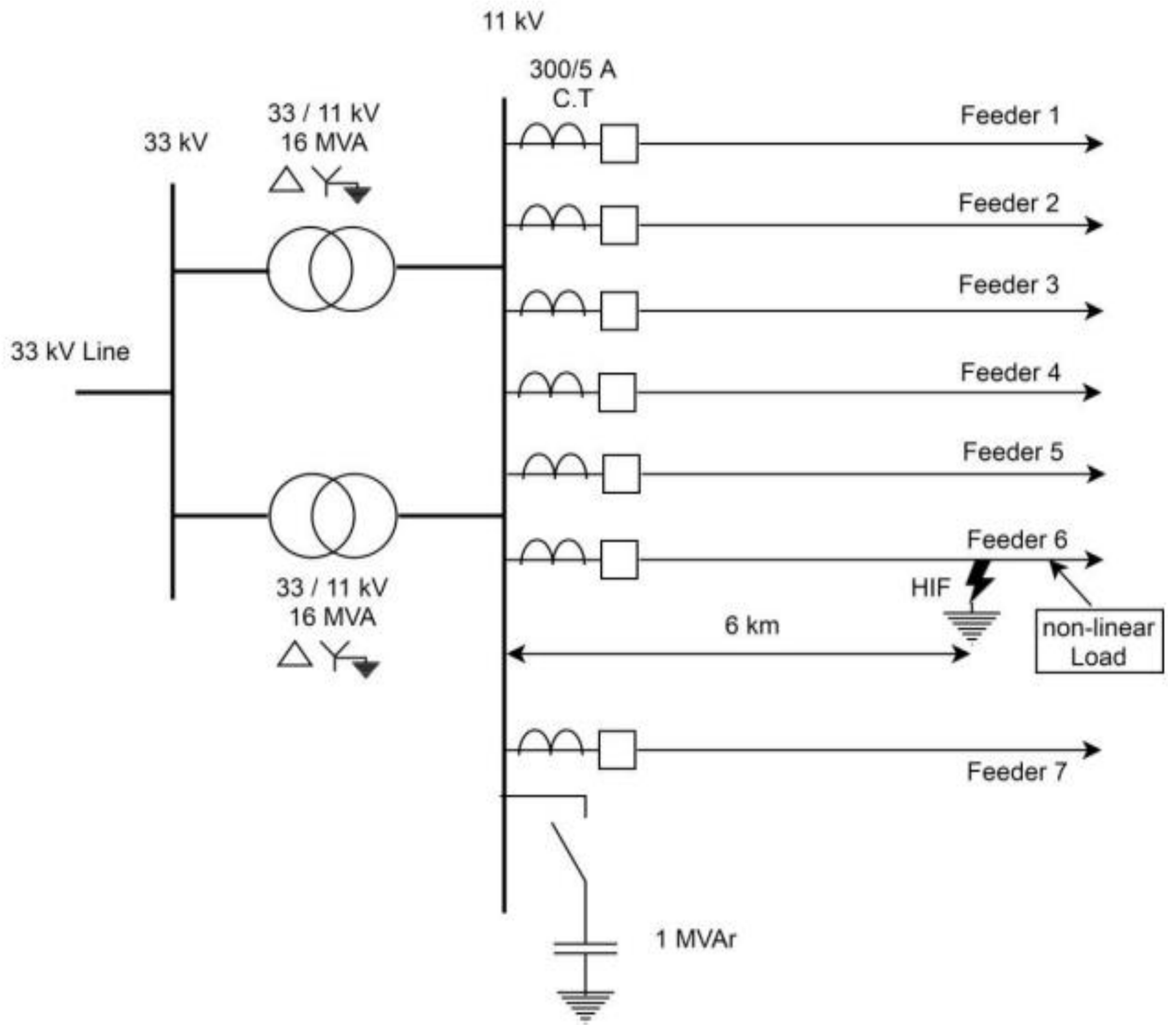

Fig. 1 One-line diagram of the proposed model

2.1. Case 1: Load Switching

In this model, the distribution feeder is connected with RLC load (static or linear load) and three-phase motor loads (dynamic or non-linear load). To analyse the load switching on feeder six, the linear load is injected into the system, so the load level increase from that point due to the current signal being produced at a time of 0.06s. The load-switching current signal is shown in Fig. 2. During the linear load injection, the small distortion is observed, and the load level increases with a change in the current signal. Correspondingly, when the non-linear load is injected, the linear load with 10%, the current signal was produced at a time of 0.06s, shown in Fig.3.

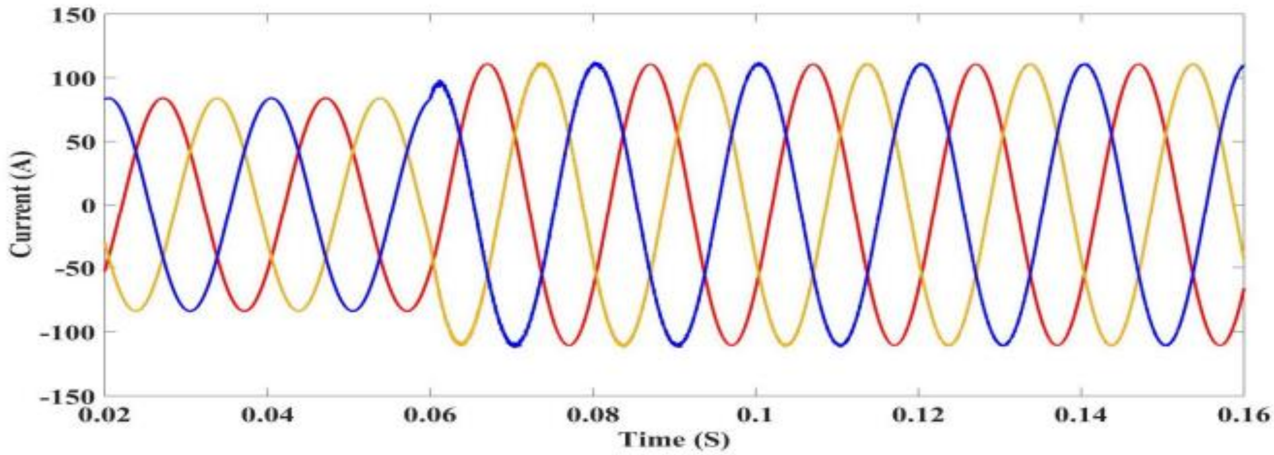

Fig. 2 Linear load switching current signal

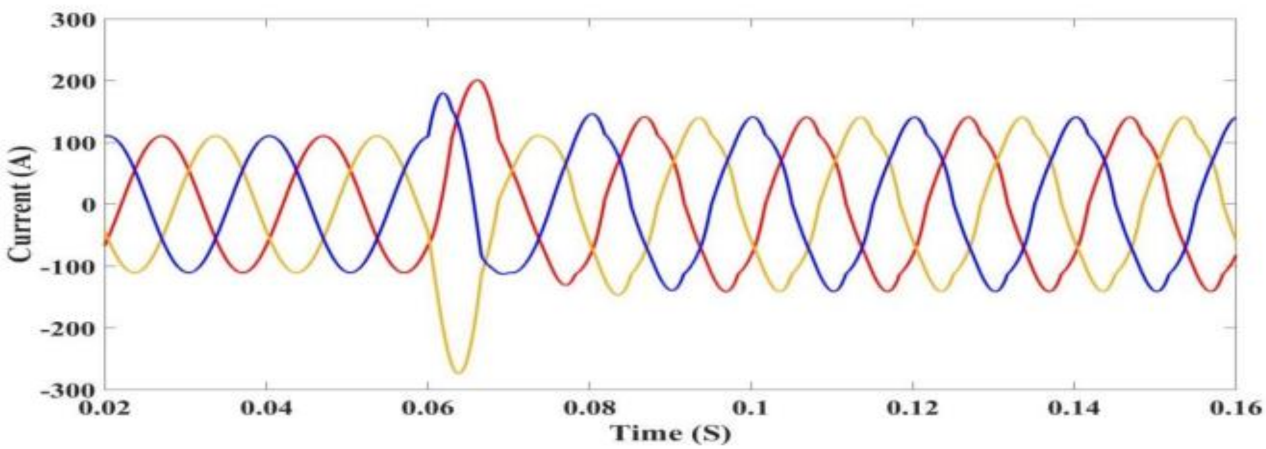

Fig. 3 Non-Linear load switching current signal

2.2. Case 2: Capacitance Switching

In the power system, injection of shunt capacitor banks supplies capacitive reactive current to increase the power quality. During capacitance switching, the transient current signal was produced at a time of 0.06s and sustained around 0.5 to 3 cycles, as shown in Fig. 4.

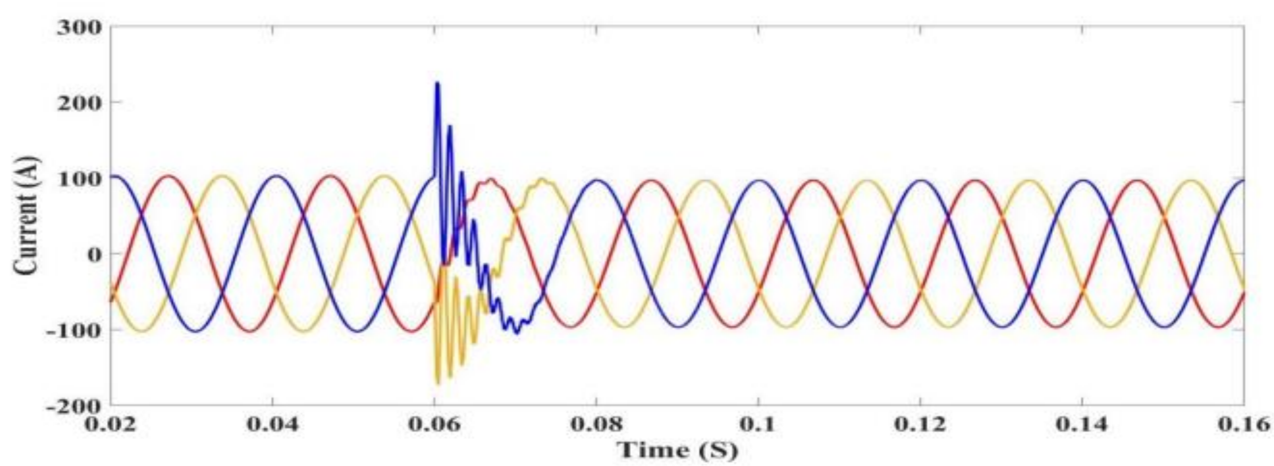

Fig. 4 Capacitance switching current signal

2.3. Case 3: High Impedance Fault

High impedance faults are created when the linear load is injected on feeder six, which was unloaded up to time 0.06s. This high impedance fault current signal has a low magnitude, and it will not be clear as previous case current signals, as shown in Fig. 5. The candidate feeder current is increased slightly, which fails to determine from the actual feeder current signal.

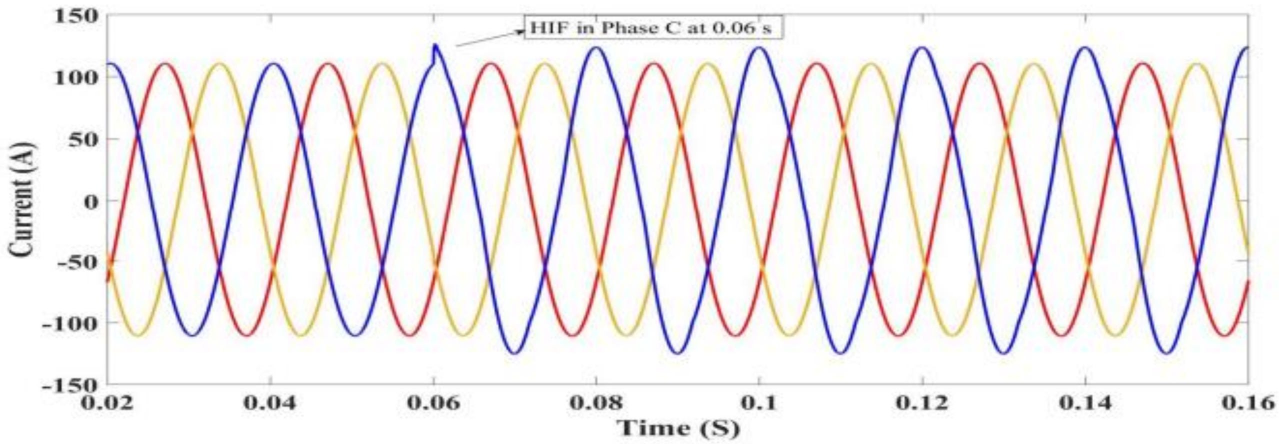

Fig. 5 High Impedance Fault current signal

2.4. Problem Identified from the System

The currents are identified during load switching and capacitive switching on feeder Six at time 0.06s. At the same time, the High impedance fault current is not identified on feeder six at a time of 0.06s due to reduced current magnitude. If the high impedance fault current is unattended, it damages the feeder and the system types of equipment. To detect and correct high impedance faults current in this feeder, signal processing techniques can be adopted. The wavelet transform could be utilised to identify high impedance switching current signals.

3. Discrete wavelet transform

For recognizing low magnitude, short duration, quick fading, and oscillating signals during fault or abnormal conditions, the wavelet transform is one of the power system's most widely used signal processing technologies [17-19]. The wavelet transform divides data, functions, or operators into many frequency components, which are subsequently evaluated with a resolution equal to their scale. The discrete wavelet transform decomposes the input signal into time scales, scales, and wavelet coefficients (DWT). The DWT technique separates signals into low and high-frequency components [20,25]. When the original signals (OS) are filtered with a low pass filter, the low-frequency components, often known as the approximation signal, are obtained (scaling function). Filtering the original signal with a high pass filter produces the high-frequency components or detail signal (wavelet transform), shown in Fig. 6.

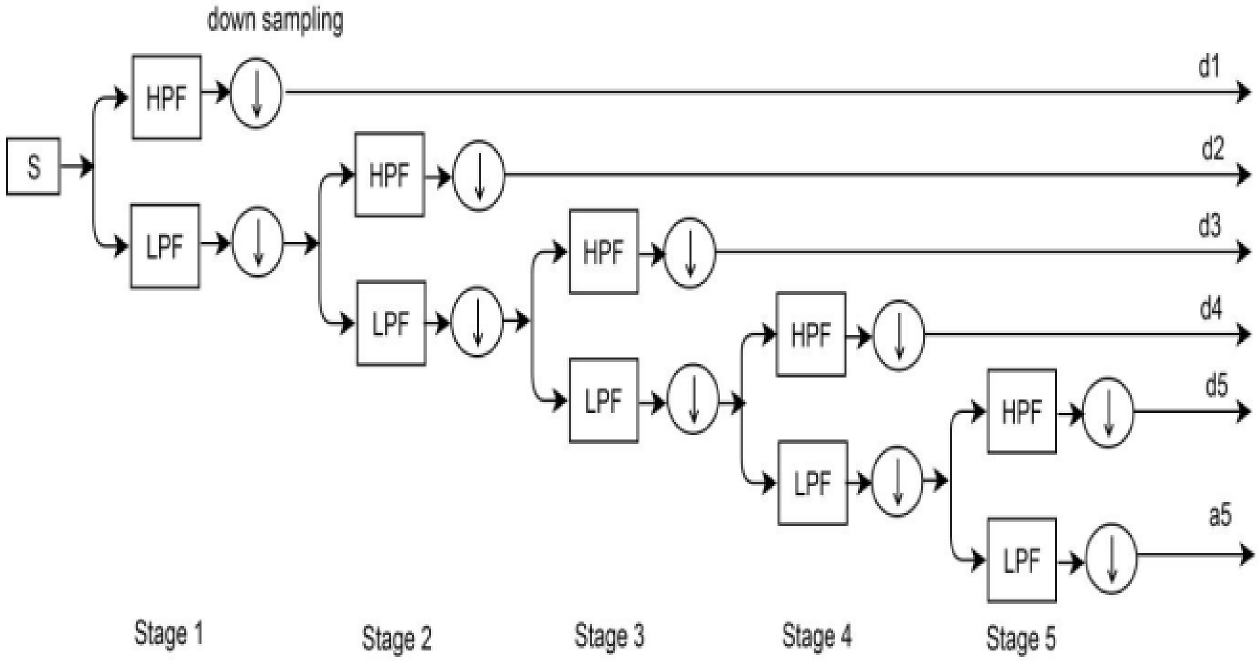

Fig. 6 Discrete Wavelet Transform - Five Level

This wavelet and scaling function can be stated as follows: An energy value (Ev) is generated from these detail coefficients (d_K)in this paper. Also, (a_k) approximations level of wavelet coefficients was mentioned as

$$\text{Ev} = \sum_{i=1}^{k} [Di]^2 + [Ak]^2 \qquad (1)$$

K is the number of levels set to 5, d_1, d_2, d_3, d_4, d_5 is the detailed coefficient levels displayed in Fig 7, and ak is the signal's final level estimates. In this technique, db5 is utilised to break down the present signal. The authors' earlier work describes mother wavelet selection, sampling frequency selection, number of levels, and bandwidth for each level. [21].

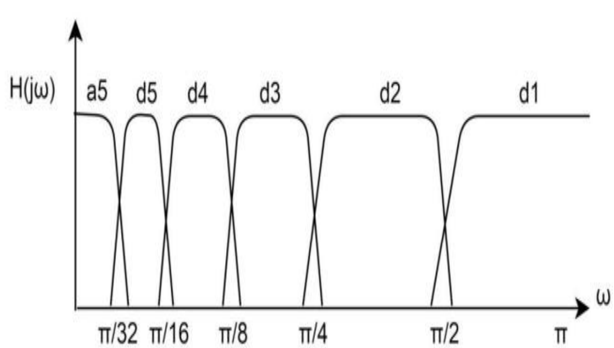

Fig. 7 Five Level Frequency Band of DWT

4. Result and Interpretations

In this model, the phase C current signal is decomposed using Discrete Wavelet Transform in feeder six. This work considers a total of distribution signals—fault and non-fault signal data—. The non-fault signal data represents normal switching, load switching, and capacitance switching, while the fault signal data represents the high impedance fault. The data set, obtained from various simulation cases taken into account and shown in table 1, is used in the proposed fault and non-fault signal detection method.

Table 1. Fault and Non-fault Signal data

Event	Simulation conditions	Total
HIF	HIF model resistance (100 Ω to 12 kΩ). DC voltage in HIF Model (1 kV to 11 kV)Fault inception angle (0°, 30° 45°, 60° 90°) Source voltage phase angle (0°, 30° 45°, 60° 90°)	1500 (60 x 5 x 5)
Load switching	Changes in load level (10 cases) Switching angle in a cycle (0°, 30° 45°, 60° 90°) Source voltage phase angle (0°, 30° 45°, 60° 90°)	250 (10 x 5 x 5)

NLL switching	Changes in NLL level (24 cases) Switching angle in a cycle (0°, 30° 45°, 60° 90°) Source voltage phase angle (0°, 30° 45°, 60° 90°)	600 (24 x 5 x 5)
Capacitance Switching	Switching 1 MVAr (both ON and OFF) at different load levels. Switching angle in a cycle (0°, 30° 45°, 60° 90°) Source voltage phase angle (0°, 30° 45°, 60° 90°)	250 (5 x 2 x 5 x 5)

4.1. Case 1: Non-linear load switching

In Fig. 8, the non-linear load switching current in phase C is decomposed using Discrete Wavelet Transform. From wavelet details d2 to d5 that high and low frequency transient signals are clearly visible from the instant of Non-linear load switching. In detail $d_{1,}$ no remarkable frequency variation of the signal is observed.

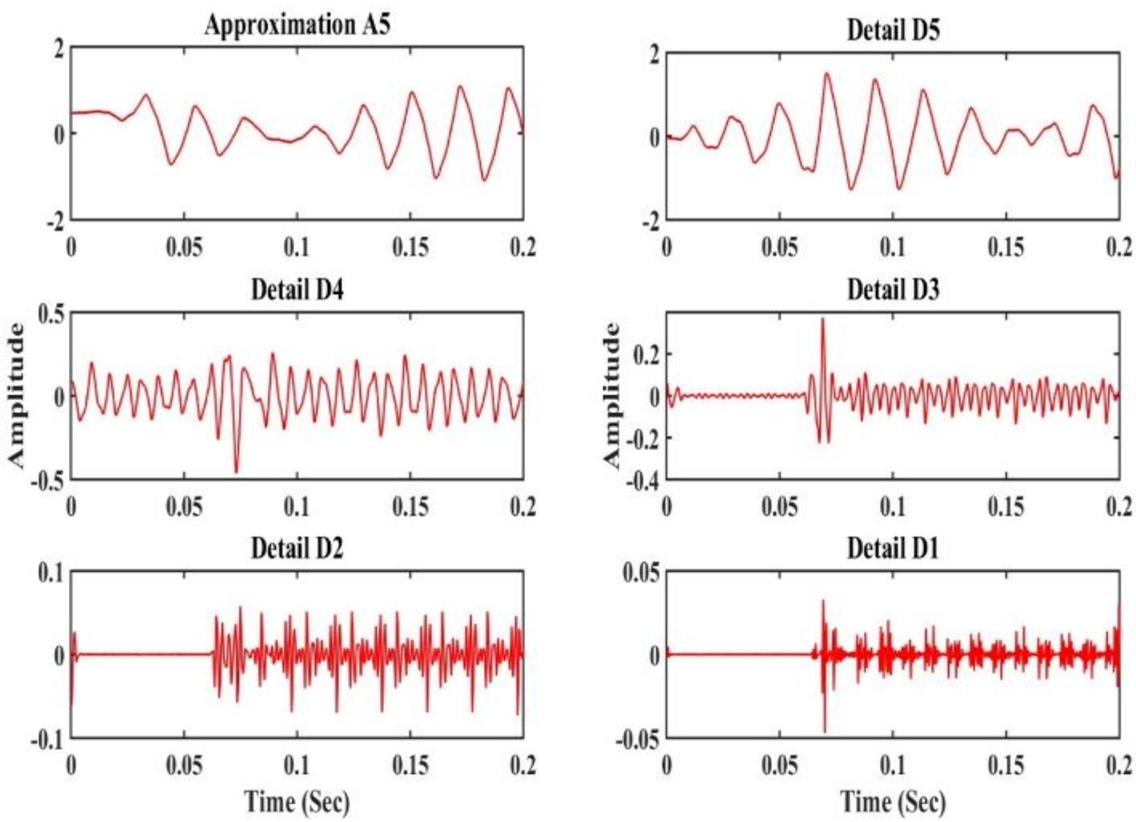

Fig. 8 DWT Output of Non-linear load switching

4.2 Case 2: Capacitance Switching

In Fig. 9, the phase C current signal due to capacitance switching is decomposed using DWT. The high-frequency part of these switching signals is present during the switching point and also prolongs for a very short duration in all wavelet levels. The high and low-frequency component is not visible in the wavelet detail, and approximation after a very short duration is shown in Fig 8. The increase or decrease in current caused due to capacitance switching creates variation in the signal frequency for very few seconds after the switching operations.

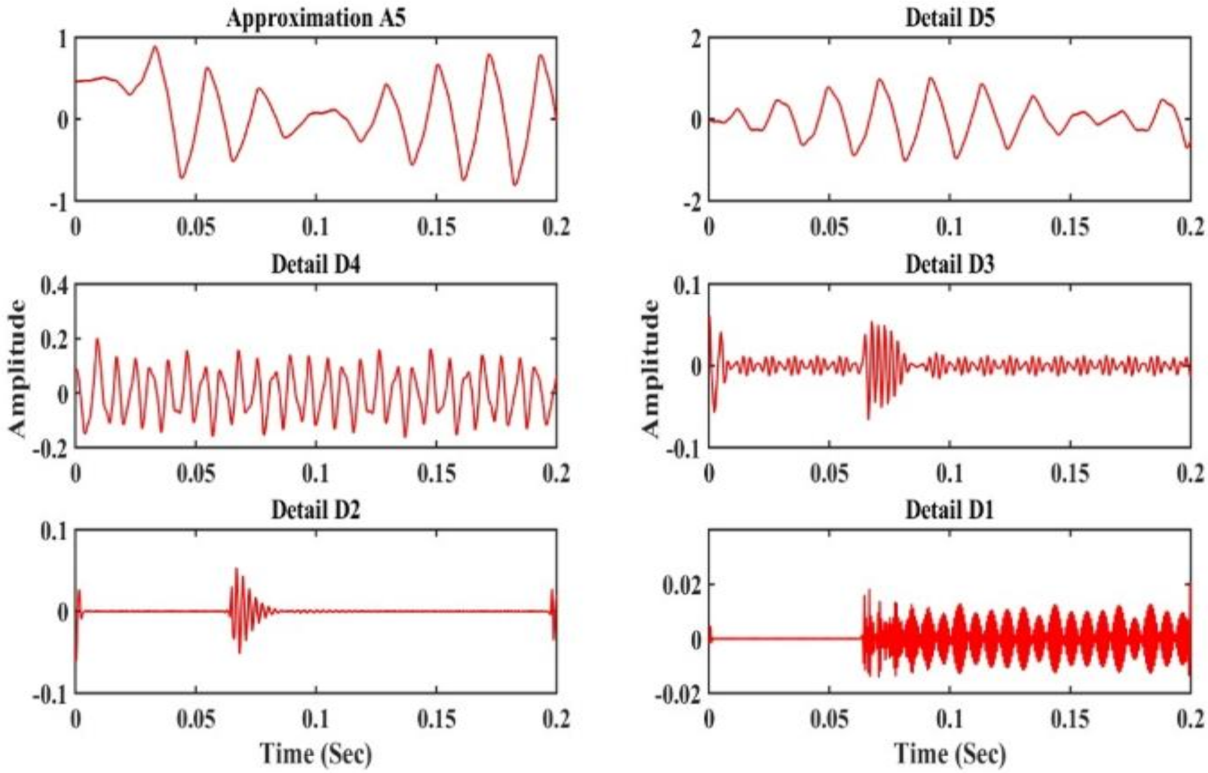

Fig. 9 DWT Output of Capacitance Switching

4.3 Case 3: High Impedance Fault

In Fig 10, the phase C current signal due to high impedance fault is decomposed by DWT, and its behaviour is shown. The sub-harmonic frequency part of the wavelet details d_4 and d_5 are observed, which resembles nearly the non-linear load switching conditions with low magnitude.

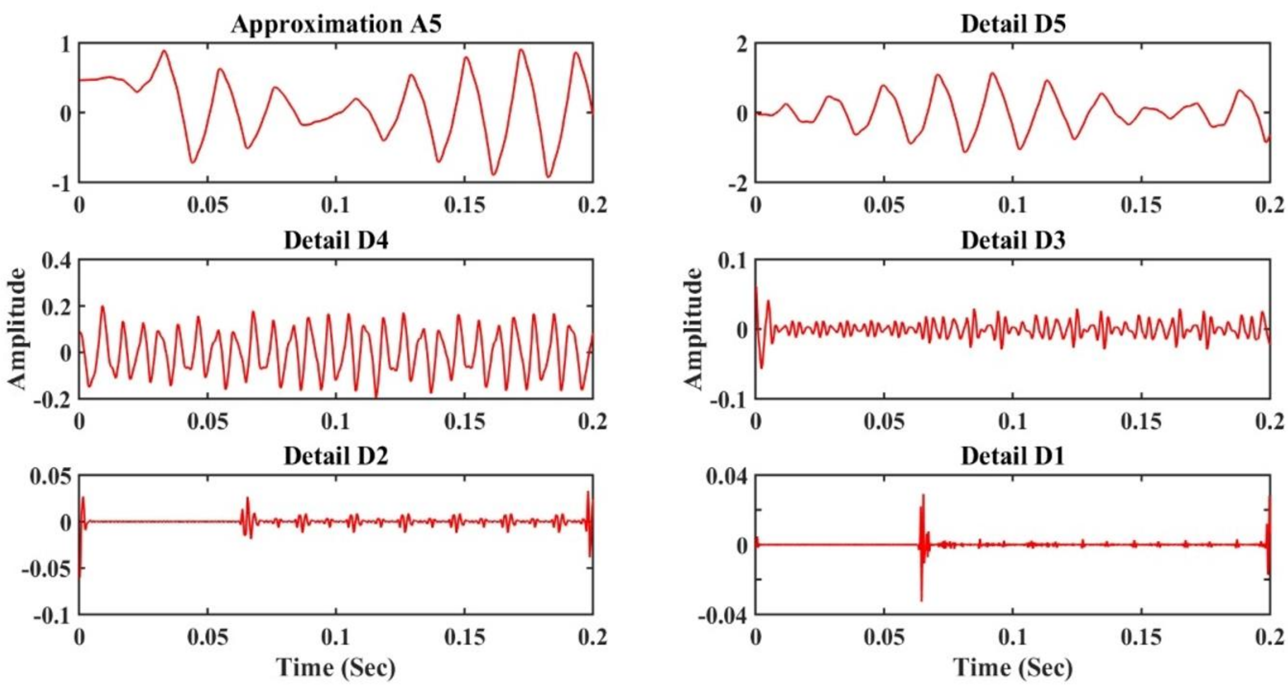

Fig. 10 DWT Output of High Impedance Fault

4.4. Case 4: Normal Feeder current

In Fig 11, the phase C current during normal conditions is decomposed by DWT, and its behaviour is shown. In wavelet details d_1 to d_5, no remarkable change in frequency signal is present. At the same time, the wavelet details d_3 to d_5 signals appear to be sinusoidal.

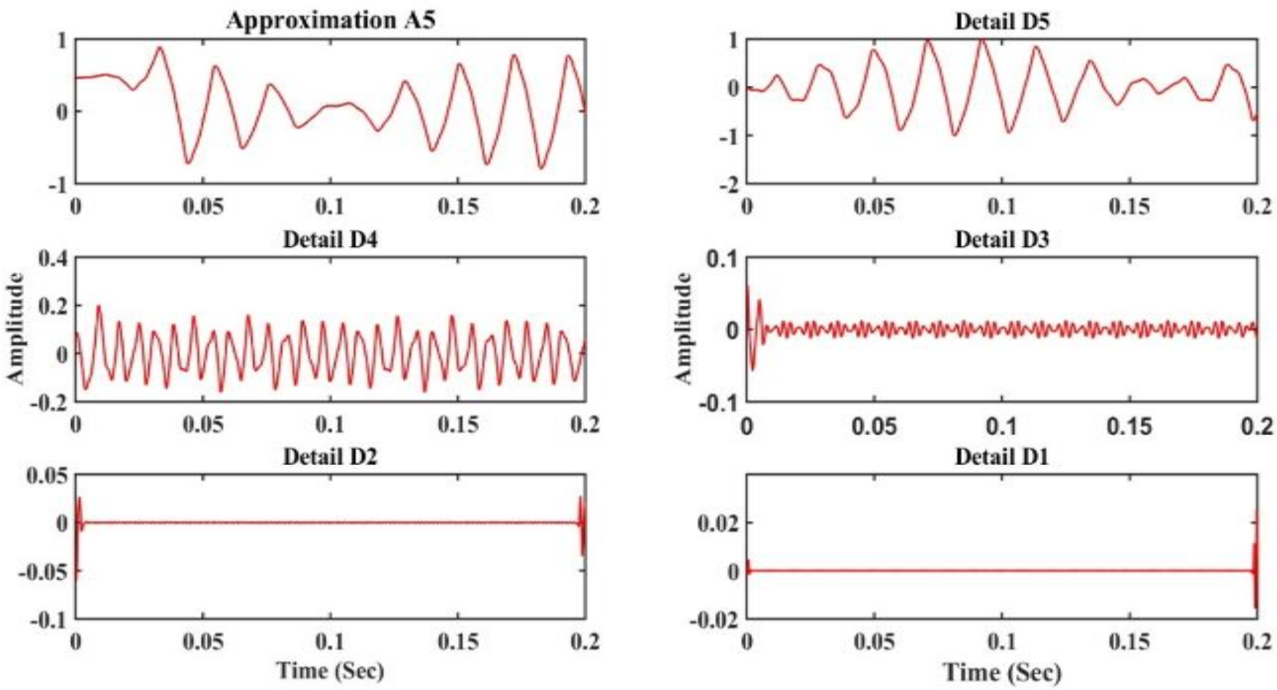

Fig. 11 DWT Output of Normal Feeder current

From the above results, a high impedance fault was produced with a low magnitude current when feeder six was connected to a non-linear load at a time of 0.06s. The conventional relay fails to predict this high impedance fault as the current signal is invisible and acts under normal conditions. But in load switching and capacitance switching, the switching current signal is visible on feeder six at a time of 0.06s. Hence, the relay will operate when the switching current signal extends on the distribution line. But in high impedance faults (HIFs) conditions, switching current is invisible, also shown as a normal condition. Hence, these signals are not sensed by the relay. To determine such an invisible, low magnitude current signal, the DWT technique decomposes the current signal and identifies the fault at time 0.06s. DWT technique is applied to decompose up to db5.

5. Conclusion

From the above research work, a discrete wavelet transform (DWT) technique is implemented under - normal condition, High impedance fault, and non-High impedance fault conditions like capacitance switching and non-linear load. The DWT technique decomposes the current signal and identifies the fault at time 0.06s. DWT technique is applied to decompose up to db5. This paper shows five levels of decomposition db15(d_1 to d_5) are high-frequency decomposition and A_5 is low-frequency decomposition. Decomposition is the fifth stage d_5 shows the appropriate detection of normal conditions, High impedance fault also non-High impedance fault conditions in each phase of the system. This result shows the exact identification of faults even at low magnitude current appropriately under assumed fault conditions. In future work, the energy values exact by DWT are applied to intelligent techniques [23,24,26,27] to identify and improve the system's protection mechanism.

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