DISCRETE WAVELET TRANSFORM BASED ANALYSIS OF TRANSFORMER DIFFERENTIAL CURRENT

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Abstract

Abstract The conventional differential relay has been used to detect the internal faults within the transformer. But, in field certain mal-functioning of differential relay has been reported which results in unnecessary tripping of differential relay. This leads to the need for development of improved classifier technique. But, for that all possible operating conditions of transformer has to be studied. In this paper, the Authors have used discrete wavelet transform to analyze the transformer differential current during various operating conditions, since wavelet transform gives good information about frequency and time domain simultaneously. Certain statistical features have been extracted from the decomposed signals and they can be used as an input to the improved classifier algorithm Daubechies 6 is used as mother wavelet for the analysis using DWT and signal has been decomposed up to level 4

Key Words: *Differential Relay, Discrete Wavelet Transform, Magnetizing Inrush Current, and Internal Fault*

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1. INTRODUCTION

For detecting internal faults in transformer, differential protection is used. The differential relay should detect the faults inside the transformer protection zone correctly and also with a high degree of immunity to operating conditions for which tripping is not required [1], [2]. There are certain conditions which cause needless operation of over-current relay in differential circuit such as switching inrush condition, recovery inrush condition, sympathetic inrush condition, over-fluxing.

Conventionally, harmonic restrain feature is used in percentage bias differential relay to give stability to delay operation during charging condition or over-fluxing condition. But, due to the improvement in modern day core material used in transformer and due to parallel distributed capacitance of EHV transmission line, the conventional harmonic restrain based differential relay causes mal-operation [3], [4].

This paper presents the application of discrete wavelet transform for the analysis of differential currents for various operating conditions, since magnetizing inrush and fault currents are non-periodic fast electro-magnetic transients and are not stationary signals i.e. they have different frequency components at different intervals of time. In this paper, the physical model of a two winding, 2 kVA, 50 Hz, 230 V/ 230 V single phase transformer is simulated in MATLAB Simulink environment for various operating conditions. From the various decomposition levels of wavelet coefficients of differential current, certain statistical parameters are obtained.

1.1 Case Study

Fig. 1 illustrates the studied system.

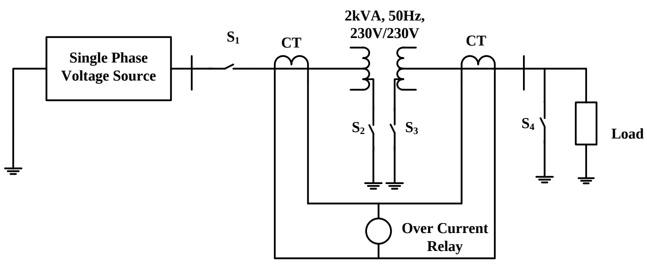

Fig.1: System configuration of simulated differential protection scheme

The system shown in Fig. 1 has been simulated in MATLAB Simulink environment using SimPower System (SPS) toolbox. It consist of,

[1]. **Single Phase Supply from Grid:** The voltage source represents the supply from grid. The values of voltage and frequency of source is set equal to 230V, 50 Hz respectively
[2]. **Two winding Transformer:** A 2 kVA, 50 Hz, 230V /230 V transformer is used in simulation. Appendix 1 gives the parameters of two winding transformer.
[3]. **Current Transformer (CT):** Many of the previous researchers have used constant block to simulate current transformer [5]-[8]. In this paper, Authors have used saturable transformer of SPS to simulate the CT. Since the voltage rating on two sides of transformer is same, two identical CTs of rating 25VA, 10/1 A are

used to scale down the currents on two sides of transformer so that the differential current during normal operating condition is near to zero.

[4]. **Load:** The parallel RLC load block is used to implement a linear load whose voltage and frequency is set equal to 230 V and 50 Hz respectively. The real and reactive power can be specified for load.

[5]. **Switch S_1:** It is used to simulate the energization operation of transformer at the time of switching.

[6]. **Switches S_2 and S_3:** These are used to simulate the internal faults (inter-turn faults on winding 1 and 2) i.e. faults inside the CT locations. The percentage of shorted turns can be varied.

[7]. **Switch S_4:** It is used to simulate external fault i.e. fault outside the CT location.

In this paper, Authors have simulated different relay model for small sized transformer but, can also be extended to large power transformers.

2. DISCRETE WAVELET TRANSFORM

Discrete wavelet transform (DWT) is discretization of Continuous wavelet transform along with decomposition of signal. With discretization and decomposition operation carried out by DWT, the coefficients of different magnitudes are obtained at each level. The coefficients obtained from this process are of two types,

[1]. Detail

[2]. Approximate

The levels of decomposition can be changed and can vary among researchers. In this paper, Authors have chosen the decomposition level maximum of 5. The advantage of DWT is its invertibility. The invertibility operation allows the reconstruction of decomposed signal from the magnitudes of both detailed and approximate coefficients. The DWT is given by,

$$\psi_{m,n}(t) = \frac{1}{\sqrt{2^m}}\psi\left(\frac{t-2^m n}{2^m}\right) \quad (1)$$

where,

'ψ' is the mother wavelet.

'm' is the scaling parameter.

'n' is the translation index at each decomposition level.

The Mallat [9] Multi Resolution Analysis (MMR Analysis) is used for study DWT. In this analysis, the firstly signal passed through FIR filter and decomposition signal begins. This decomposed signal is passed through Low pass filter and approximate coefficients will be obtained and remaining signal passed through high pass filter and detail coefficients will be obtained [10]. The DWT also requires the selection of mother wavelet. The mother wavelet can be of any shape and nature. Only requirement is it should periodic in nature. There are so many functions of mother wavelet are available in literature [11]. In this paper, Authors have chosen the mother wavelet as Daubechies.

2.1 Daubechies Wavelet

The Daubechies wavelet is invented by mathematician Daubechies and till day, it is the most popular choice of mother wavelet in application based mathematical study. Daubechies wavelet is represented by db followed by numerical number 'N' (dbN). In dbN, 'N' represents the level of decomposition and has 2^{N-1} possible solutions [12]. In this paper following conditions are analyzed

2.2 Discrete Wavelet Transform of Magnetizing inrush Current

Magnetizing inrush current appears during transformer energization due to saturation of its core. This current may reach 8 to 10 times the full load current. The differential relay may detect it as an fault condition but, this is a non-fault condition. Fig. 2 shows the magnetizing inrush current waveform for one cycle and four successive detail and approximate coefficients of the differential current wave.

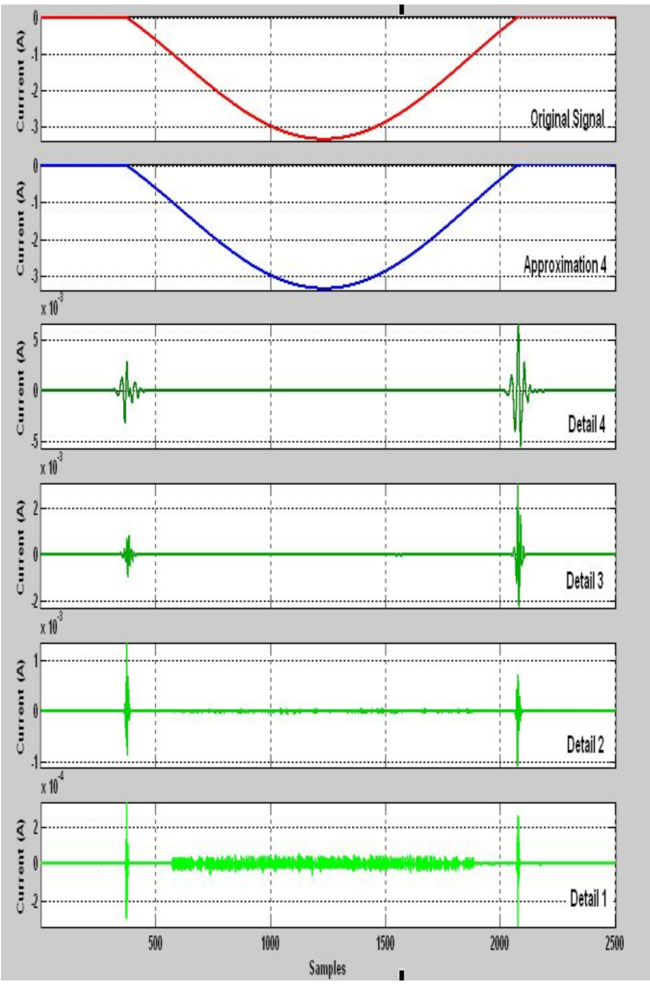

Fig. 2: 5-Succesive details and approximate for magnetizing inrush current

2.3 Discrete Wavelet Transform Of Internal Fault Current

Fig. 3 shows the differential current waveform during internal fault condition (when few of the winding turns are shorted) for one cycle and four successive detail and approximate coefficients of the differential current wave.

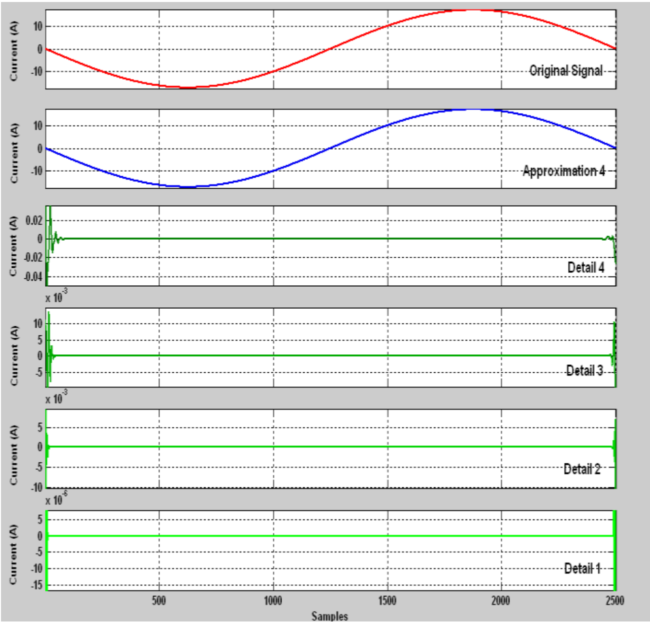

Fig. 3: 5-Succesive details and approximate for internal fault current

2.4 Discrete Wavelet Transform Of Internal Fault Current At The Time Of Switching

Fig. 4 shows the differential current waveform during internal fault condition at the time of switching for one cycle and four successive detail and approximate coefficients of the differential current wave.

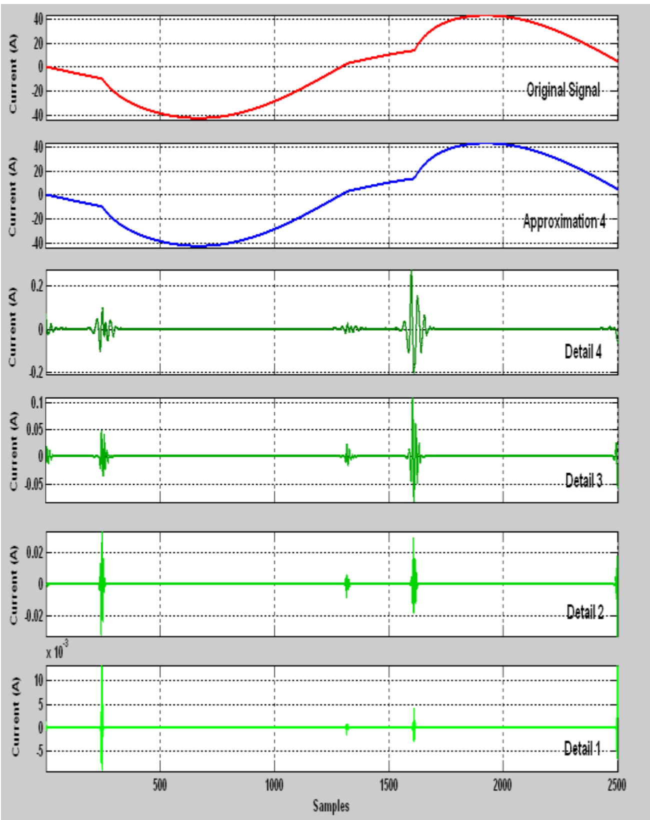

Fig. 4: 5-Succesive details and approximate for internal fault current at time of switching

2.5 Discrete Wavelet Transform of Differential current during Over-Fluxing Condition

A transformer operating under normal design conditions develops a maximum flux density in the core which is directly proportional to applied voltage and is inversely proportional to supply frequency. If either or both of these quantities are varied from the nominal values, transformer core is subjected to over-fluxing condition. Fig. 5 shows the differential current waveform (when supply voltage is increased by 25% and frequency is reduced by 5%) for one cycle and four successive detail and approximate coefficients of the differential current wave.

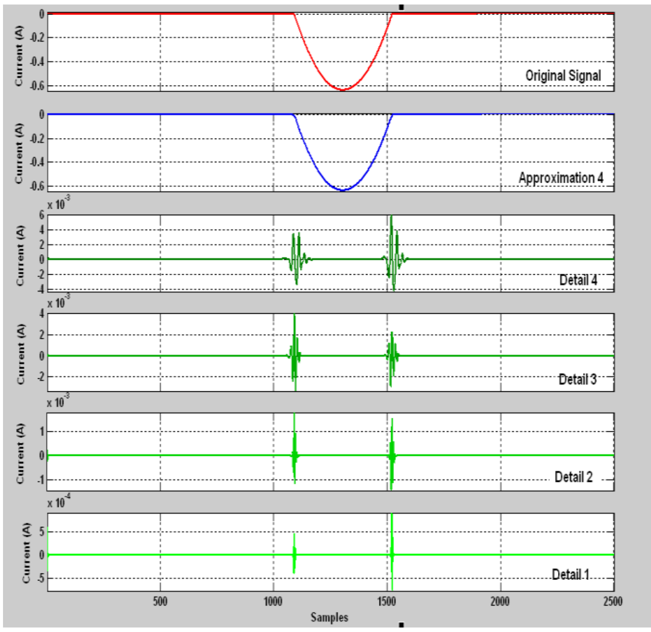

Fig. 5: 5-Succesive details and approximate for Differential current during Over-Fluxing Condition

3. STASTICAL ANALYSIS OF DWT COEFFICENTS

The developed Simulink model in MATLAB is used to capture the data of differential current for 20 msec. for various operating conditions.

Table I shows the data generated during Simulation for analysis

Table I- Type of Conditions generated during Simulation

Type of Conditions	Number of Data
Internal Fault Condition	454
Other Disturbances	222

After rigorous analysis of wavelet coefficient for internal and non internal fault conditions, Authors in this paper have obtained certain statistical features like harmonic mean, Energy, Kurtosis etc. of wavelet coefficients at different levels of decompositions.

Fig. 6-10 shows the distributed plots of these statistical features.

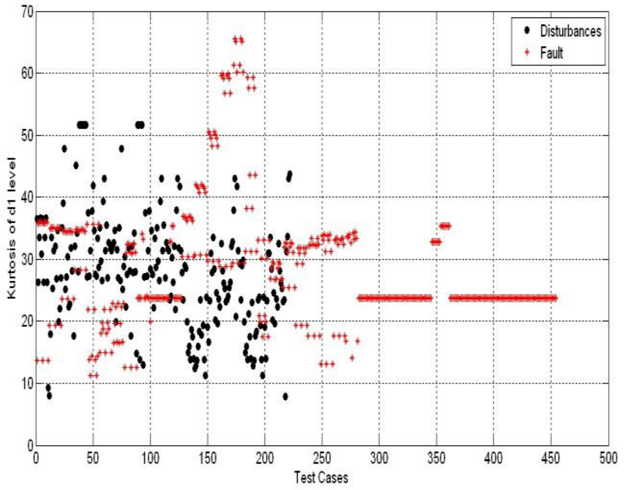

Fig. 6: Kurtosis of Fault and Disturbances at decomposition level 1

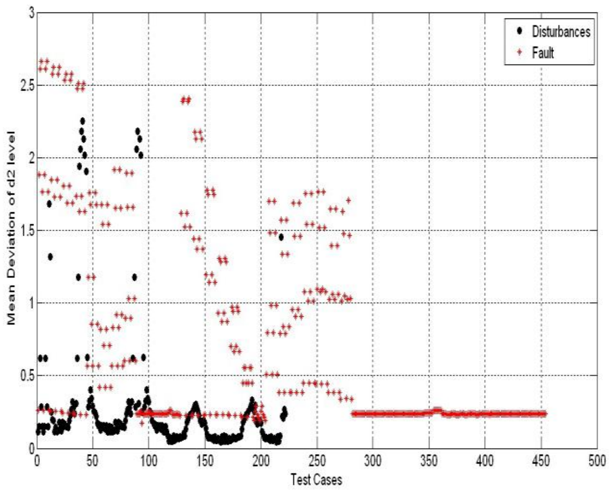

Fig. 7: Mean Deviation of Fault and Disturbances at decomposition level 2

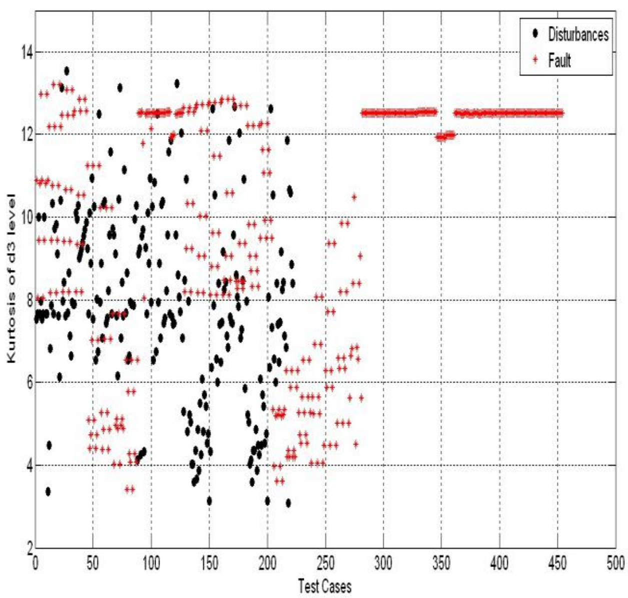

Fig. 8: Kurtosis of Fault and Disturbances at decomposition level 3

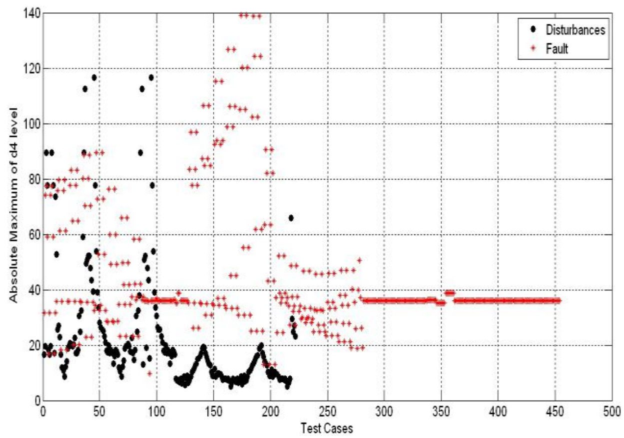

Fig. 9: Absolute Maximum of Fault and Disturbances at decomposition level 4

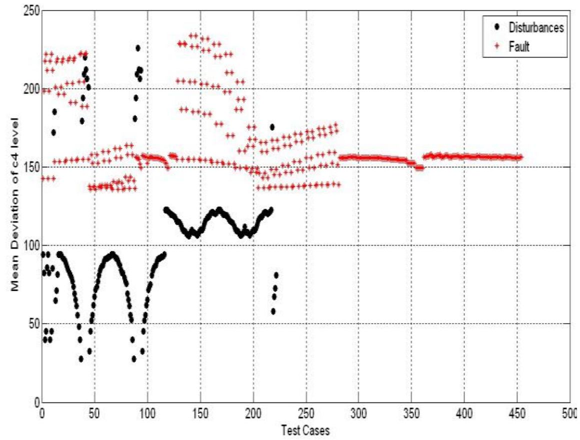

Fig. 10: Mean Deviation of Fault and Disturbances at decomposition level approximate 4

4. CONCLUSIONS

Due to mal-operations of differential protection based on harmonic restrain feature, wavelet transform is used for rectifying the issue. Hence, transformer transients are analyzed using discrete wavelet transform with db6 as mother wavelet and certain statistical features are obtained from these decomposed wavelet coefficients. From distributed plots, we can conclude that the obtained statistical features from various decomposed levels using DWT gives good information about the operating conditions in transformer. Any single parameter is not sufficient for identifying non-fault conditions in transformer and hence, all the five parameters can be used as an input to the classifier algorithm for discrimination between fault and non-fault conditions, since the merit of any classifier algorithm depends on input parameters which it gets for classification.

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Appendix I

1)	Winding resistances	R1= 0.027603946 p.u.
		R2= 0.027603946 p.u.
2)	Winding inductances	L1= 0.022495099/314.5 p.u.
		L2=0.022495099/314.5 p.u.
3)	Magnetizing resistance	Rm= 500 p.u.
4)	Magnetizing inductance	Lm=80 p.u.

BIOGRAPHIES

Pankaj B. Thote has born in Nagpur (India) in 1975. He received the B.E. degree in Electrical Engineering in 1997, the M.E. degree in Electrical Power System in 2010 from Sant Gadge Baba Amravati University, India and currently pursuing the Ph.D. degree in electrical engineering from G.H.R.C.E., R.T.M. Nagpur University, India. His research interests include network analysis and protection. Currently, he is working as Head in Electrical Engineering Department of S. B. Jain Institute of Technology, Management and research, Nagpur, India. He is a Graduate Member of the Institution of Engineers (India) and a Life Member of the Indian Society for Technical Education.

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