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Differential Protection of Three Phase Power Transformer Using Wavelet Packet Transform

Jitendra Singh Chandra*, Amit Goswami
*Department of EEE, Disha Institute of Management of Technology Raipur (C.G.) India
Department of EEE, Disha Institute of Management of Technology Raipur (C.G.) India

Abstract

This paper shows the use of a new & innovatory wavelet packet transform (WPT) based method to sensitize the transients resulting from inrush current, CT saturation and fault currents in electric power transformers. This method will efficiently help in the development of differential protective relay to automatically detect and discriminate internal incipient faults from inrush currents, CT saturation condition in electric power transformers. This method can provide very accurate information in each level of the WPT to predict any failures and misrecognition of inrush currents ahead of time so that necessary actions can be taken to prevent outages and reduce down times. It prevents false tripping of differential relay due to inrush current.

Keywords: Wavelet packet transform (WPT), Differential Protection, Inrush current, CT saturation.

Introduction

Transformers are an essential part of the electric power system because it has ability to change voltage and current level, which enables to transmit and distribute electric power at economical and suitable level. Transformer protection is always a challenging problem for protection experts and engineers. The main concern in protecting this particular element of power systems lies in the accurate and rapid discrimination among magnetizing inrush, CT saturation and different internal faults currents. A higher voltage will reduce the energy lost during the transmission process of the electricity. After electricity has been transmitted to various end points to the consumer end, voltage of the electricity will be reduced to usable level by using step-down transformer. Transformers are devices that require special maintenance & protection for their normal operation due to their importance to the electrical system to which they are connected. Generally, differential relays are used for the primary protection of large transformers. In such relays, differential currents are checked considering a percentage differential characteristic with operation and restraining zones, and in the case of an internal fault, the transformer should be disconnected from the rest of the system. However such difference in current also occurs during the normal operating condition because of the Magnetizing inrush current, CT saturation, Transformer Over excitation, CT ratio mismatch, and operation of OLTC etc. which causes false operation of the differential protection relay of transformer. Most of the conventional transformer protection relays employ the harmonic analysis approach to identify the type of the current that flows in the protected transformer. The idea of the harmonic restraint differential relays is to extract the fundamental (1st), the second (2nd) and sometimes the fifth (5th) harmonics and to compare the ratios of the 2nd and 5th harmonics with 1st to a predefined threshold value. Sometimes a time delay method is also employed to protect the unwanted operation of differential relay at the time of switching of transformer.

Transformer is protected using differential protection with restraining coil to maintain the difference in current due to CT ratio error, CT with different combination is used to maintain phase difference between primary & secondary i.e. transformer winding with star side uses Delta connected CT & transformer winding with Delta side uses star connected CT.

In this paper, a new approach is suggested to discriminate inrush and normal operating currents from the fault currents. This new implementation

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method is based on the wavelet packet transform (WPT), in which a one level of WPT is used to accurately differentiate inrush currents and normal operating currents from the all types of the fault currents. Applying the WPT to any signal produces the details (high frequency) and the approximations (low frequency) at each level of resolution of that particular signal. This novel improvement of WPT increases the speed of the digital differential relay in identifying the fault currents from the inrush currents and normal operating currents. The localization of the only first level details of the frequency sub-bands can provide a very strong signature to classify the type of the current.

Wavelet transform

The waveforms associated with fast electromagnetic transients are typically non-periodic signals which contain both high frequency oscillations and localized impulses superimposed on the power frequency and its harmonics. These create a problem for traditional discrete Fourier transform (DFT), because its use assumes a periodic signal and that the representation of a signal by the DFT is best reserved for periodic signals. As power system disturbances are subjected to transient and non-periodic components, the DFT alone is not an adequate technique for signal analysis. If a signal is altered in a localized time instant, the entire frequency spectrum can be affected.

The WT is a powerful signal processing tool used in power system. The WT allows time localization of different frequency components of a given signal. As a result, both frequency and time resolution of the resulting transform will be prior fixed in the WT, the analyzing functions, which are called wavelets, adjust their time-widths to their frequency in such a way that, the high frequency wavelets will be very narrow and low frequency ones will be broader. So WT can separate transient components in the upper frequency isolated in a shorter part of power frequency cycle. The ability of the WT to focus on short time intervals for high-frequency components and long intervals for low-frequency components improves the analysis of signals with localized impulses and oscillations. For this reason, wavelet decomposition is ideal for studying transient signals and obtaining a much better current characterization and a more reliable discrimination

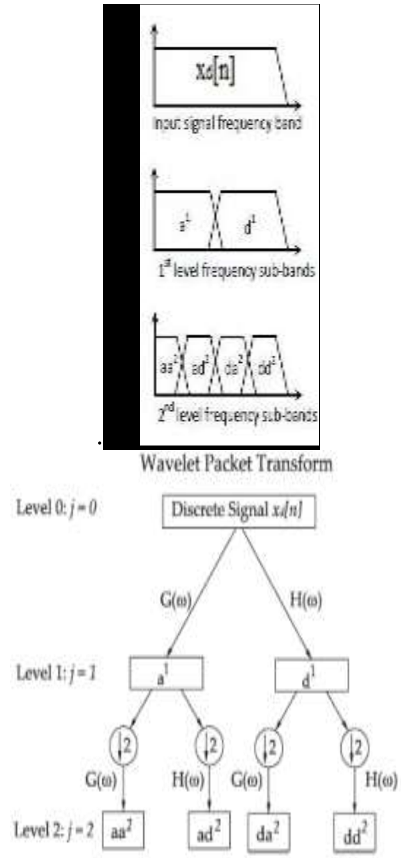

Fig 1: Decomposing a discrete signal $x_d[n]$ using a two-level WPT [1] [3]

Wavelet Packet Transform (WPT) is generated by analyzing the input current signal to a tree of low pass and high pass filtering operations as shown in figure 1. Down-sampling by 2 is taking place between any two successive levels. It is clear from the figure that the frequency bandwidth of the levels band decreases with the growing of the level number, which means that the frequency resolution becomes higher by the increase of the level number. However, the higher the number of the levels the higher the processing time of the signal. The increase of the processing time is a problem when the number of the levels needed is high.

It is obvious from the figure that by decomposing the signal $f(n)$ the low and high frequencies, the low frequency of the first level is the approximation $a^1[n]$ of the signal and the high frequency is the details $d^1[n]$ of the input signal. Where the superfix 1 and 2 refers to the 1st and 2nd level of the wavelet decomposition respectively. Each part in the first level is also decomposed in the same manner into two

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parts of approximations and details. Therefore, it will produce four sub-bands by using the same filters used in the first level of decomposition. These basis functions are generated from one base function called the mother wavelet. The first and second level sub-bands are obtained using two filters (low and high).

WPT-Based disturbance detection and classification

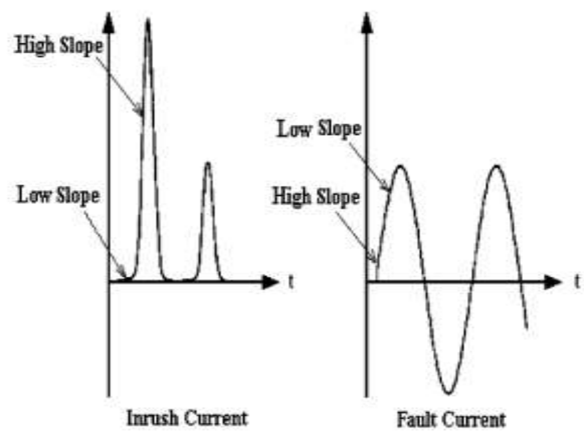

Fig 2: Different behavior of fault and inrush current [2]

The new method of discriminating inrush current from internal fault is based on the different behavior of these waveforms following the disturbance. Since the magnetizing inrush current corresponds to the transformer core saturation, the inrush current has a conical shape (non-sinusoidal); in other words inrush current at the switching time increases very slowly; as time passes its slope increases. Shape of waveform due to inrush current is generally unidirectional. However, when a fault occurs, the differential current has higher slope compared with the starting of the inrush current, and its slope decreases as time passes. Shape of waveform for fault current is generally sinusoidal. Fig. 2 illustrates the above-mentioned features. Since these features occur from the different nature of the currents and parameters of transformer and the connected power system has no influence on it, so these features may be used as the basis of discriminating the fault from the inrush current.

WPT is one type of wavelet-based signal processing that offers a detailed localized frequency–time analysis of discrete time (DT) signals. This analysis is obtained as a result of successive time localization of frequency sub bands generated by a tree of low-pass and high-pass filtering operations. As a result, the frequency resolution becomes higher, while the time resolution reduces with increase in the number of used filter banks. Starting with the DT signal xd[n] of length N, the first level $j = 1$ decomposition produces two sub band DT signals as

$$a^1[n] = \sum_{k=0}^{N-1} g[k]x_d[n-k] \tag{1}$$

$$d^1[n] = \sum_{k=0}^{N-1} h[k]x_d[n-k] \tag{2}$$

where $a^1[n]$ is the first-level approximations, $d^1[n]$ is the first level details, k is an integer, and $g[n]$ and $h[n]$ are the low-pass filter (LPF) and the high-pass filter (HPF) associated with the used wavelet function, respectively. In order to increase the frequency resolution and ensure the time localization of each frequency subband, the outputs of both the Low Pass Filter (LPF) and High Pass Filter (HPF) are downsampled by two at the end of each filtering stage. The second-level decomposition (j = 2) produces four subbands as

$$aa^2[n] = \sum_{k=0}^{\frac{N}{2}-1} g[k]a^1\left[\frac{N}{2}-k\right] \tag{3}$$

$$ad^2[n] = \sum_{k=0}^{\frac{N}{2}-1} h[k]a^1\left[\frac{N}{2}-k\right] \tag{4}$$

$$da^2[n] = \sum_{k=0}^{\frac{N}{2}-1} g[k]d^1\left[\frac{N}{2}-k\right] \tag{5}$$

$$dd^2[n] = \sum_{k=0}^{\frac{N}{2}-1} h[k]d^1\left[\frac{N}{2}-k\right] \tag{6}$$

where $dd^2[n]$ represents the highest frequency subband of the second level of the WPT decomposition. Below Fig. 1 shows the successive LPF and HPF stages that implement the WPT decomposition.

The WPT algorithm for power-transformer protection can be realized by evaluating the coefficients of the WPT details and comparing their values in the second-level highest frequency subband to zero. The evaluation of the WPT coefficients can be achieved by extracting the second-level highest frequency subband $dd^2[n]$ component of the transformer differential currents. The required digital HPFs for

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extracting the second-level highest frequency subband $dd^2[n]$ component are separated by a downsampling stage to increase the frequency resolution. The WPT-based transformer differential protection can be implemented using the following steps

• ***Step 1***: Initialize the samples' counter $n = 0$.
• ***Step 2***: Read one sample from each of the three-phase differential currents Ia, Ib, and Ic and store these samples in three vectors of length N as $I_{da}[N]$, $I_{db}[N]$, and $I_{dc}[N]$.
• **Step 3**: Perform the first-level high-pass filtering for $I_{da}[N]$, $I_{db}[N]$, and $I_{dc}[N]$ (disturbance detection) as

$$d_a^1[n] = \sum_{k=0}^{N-1} h[k] I_{da}[N-k]$$

$$d_b^1[n] = \sum_{k=0}^{N-1} h[k] I_{db}[N-k]$$

$$d_c^1[n] = \sum_{k=0}^{N-1} h[k] I_{dc}[N-k].$$

• ***Step 4***: Downsample $d^1{}_a[n]$, $d^1{}_b[n]$, and $d^1{}_c[n]$ by two.
• ***Step 5***: Perform the second-level high-pass filtering for the downsampled by two versions of $d^1{}_a[n]$, $d^1{}_b[n]$, and $d^1{}_c[n]$ (disturbance classification) to determine $dd^2{}_a[n]$, $dd^2{}_b[n]$, and $dd^2{}_c[n]$ using equation (6)
• ***Step 6***: Declare FAULT and initiate a trip signal
IF

$$\left|\sum_{k=0}^{\frac{N}{2}-1} dd_a^2[k]\right| > 0 \text{ or } \left|\sum_{k=0}^{\frac{N}{2}-1} dd_b^2[k]\right| > 0 \text{ or } \left|\sum_{k=0}^{\frac{N}{2}-1} dd_c^2[k]\right| > 0$$

ELSE: n = n + 1.
• **Step 7**: If $n \geq N$, then $n = 0$.
• **Step 8**: Go To Step 2.

Fig. 3 shows the schematic diagram for the WPT-based transformer differential protective relay. The WPT-based differential relay is supplied by three-phase differential currents in order to detect and classify disturbances that may result from load changes, inrush currents, through faults, and internal faults. These detection and classification functions are carried through the successive high-pass filtering of the sampled versions of the three-phase differential currents. These DFs require digital circuitry for their implementation, which is supplied from the power-system line voltage. As a result, disturbances that affect the line voltage can cause severe impacts on the overall functionality of the WPT-based transformer protective relays.

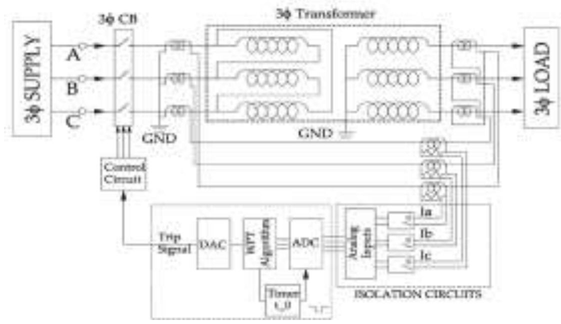

Fig 3: Schematic diagram for the WPT based transformer differential protective relay[1]

Conclusion

In this paper, a novel algorithm for transformer differential protection is presented. This method is based on the different behaviors of differential currents. A criterion function was defined using the difference of the amplitude of the WT over a particular frequency spectrum due to a fault and inrush current, internal fault conditions can be detected by evaluation of the criterion functions of the three phases. This proposed method is very accurate, it can differentiate fault from inrush current & CT saturation quickly and easily in less than a quarter a cycle after the disturbance so response time is very fast.

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