Electrical Power and Energy Systems 32 (2010) 788–793

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A wavelet-based method to discriminate internal faults from inrush currents using correlation coefficient

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ARTICLE INFO

Article history:
Received 17 September 2007
Received in revised form 7 July 2009
Accepted 28 January 2010

Keywords:
Inrush current
Internal fault
Transformer
Correlation coefficient
Discrete wavelet transform

ABSTRACT

In this paper a new method based on discrete wavelet transform and correlation coefficient is presented for digital differential protection. The algorithm includes offline and online operations. In offline operation, discrete wavelet transform is used to decompose typical three-phase differential currents for inrush current. Then an index is defined and computed. The index is based on the sum of the energy of detail coefficients at level 5 of three-phase differential currents at each half cycle. The online operation consists of capturing the three-phase differential currents using 10 kHz sampling rate, decomposing it by db1. Finally, the inrush current and internal fault is detected based on correlation coefficients of the computed index of pre-stored typical inrush current and a recorded indistinct signal. The effectiveness of the approach is tested using numerous inrush and internal fault currents. Simulations are used to confirm the aptness and the capability of the proposed method to discriminate inrush current from internal fault.

1. Introduction

The effectiveness of the differential relay used for protecting transformers against internal faults is undisputed [1]. However, the major drawback of the differential relay stems from its potential for false tripping caused by the transient magnetizing inrush current, which flows when the transformer is energized. The most common technique used to prevent false trips during the initial energization is harmonic restraint relays. The principle of the harmonic restraint relays is based on that the second harmonic (sometimes the fifth) component of the inrush current is considerably larger than in a typical fault current [2,3]. If the second harmonic content of the differential current exceeds a pre-defined percentage of the fundamental, the inrush current is assumed and the protection system is prevented from tripping, one of the main drawbacks of these techniques is low speed of the relay operation [2,4–6]. However, the 2nd order harmonic component may also be generated during internal faults in the power transformer. This may be due to current transformer saturation or the presence of a shunt capacitor or the distribution capacitance in a long extra high voltage (EHV) transmission line to which the transformer may be connected [2,7]. The previous work on power transformer protection has included other approaches, among these approaches; transformer inductance during saturation, artificial neural networks, flux and voltage restraints and fuzzy logic can be mentioned [8–11]. These approaches have high dependence on parameters of the protected transformer. In addition, they require complex algorithms to carry out the required computations [12].

The wavelet analysis and wavelet transforms have emerged recently as a powerful tool for signal processing in different applications, in particular now for power system applications. The transient characteristics of wavelets can be employed to carry out accurate and effective analysis of signals with complex frequency-time structure [12].

This paper introduces a simple method based on discrete wavelet transform (DWT) and correlation coefficient is used for discriminating internal faults from inrush currents.

2. Wavelet transform

The wavelet transform represents the signal as a sum of wavelets at different locations (position) and scales (duration). The wavelet coefficients work as weights of the wavelets to represent the signal at these locations and scales [13].

Application of WT in power are reported for

1. power system transient [14]
2. power quality [15]
3. modeling system components in the wavelet domain [16]
4. power system protection [17].

The wavelet transform can be accomplished in three different ways

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doi:10.1016/j.ijepes.2010.01.015

– The continuous wavelet transform (CWT).
– Wavelet series (WS).
– Discrete wavelet transform (DWT).

The DWT has been proven to be very efficient in transient analysis.

The DWT can be implemented with a specially designed pair of finite-impulse response (FIR) filters called a quadrature mirror filters (QMFs) pair.

The outputs of the QMF filter pair are decimated (or desampled) by a factor of two. The low-frequency (low-pass) filter output is fed into another identical QMF filter pair. This operation can be repeated recursively as a tree or pyramid algorithm, yielding a group of signals that divides the spectrum of the original signal into octave bands with successively coarser measurements in time as the width of each spectral band narrows and decreases in frequency. Fig. 1 shows the tree algorithm of a multi resolution DWT for a discrete signal.

The particular structure of the filters is determined by the mother wavelet used for data analysis and by the conditions imposed for a perfect reconstruction of the original signal [18,19].

The approximation is the output of the low–pass filter, while the detail is the output of the high-pass filter. In a dyadic multiresolution analysis, the decomposition process is iterated such that the approximations are successively decomposed. The original signal can be reconstructed from its details and approximation at each stage. A three – level decomposition is shown in Fig. 2.

Decomposition proceeds until the individual details consist of a single sample. The nature of the process generates a set of vectors a3, d3, d2, and d1, containing the corresponding coefficients. These vectors are of different lengths, based on powers of two. These coefficients are the projection of the signal onto the wavelet at a given scale; they contain signal information at different frequency bands (a3, d3, d2, and d1) determined by the filter bank frequency response.

A three level discrete DWT frequency band is shown in Fig. 3 [18]. In this paper db1 is chosen for analysis.

3. Correlation coefficient

In practice, the most convenient way to assess the strength dependence between two variables is through their correlation.

The correlation between two variables X and Y is defined as [20]:

$$\mathrm{Corr}(X,Y) = \frac{\mathrm{Cov}(X,Y)}{\sqrt{\mathrm{Var}(X)\mathrm{Var}(Y)}} \tag{1}$$

Variables with a positive correlation are said to be positively correlated, and in such cases there is a tendency for high values of one variable to be associated with high values of the other variable. Variables with a negative correlation are said to be negatively correlated, and in such cases there is a tendency for high values of one variable to be associated with low values of the other variables. The strength of these tendencies increases as the correlation moves further away from 0 to 1 or −1 [20].

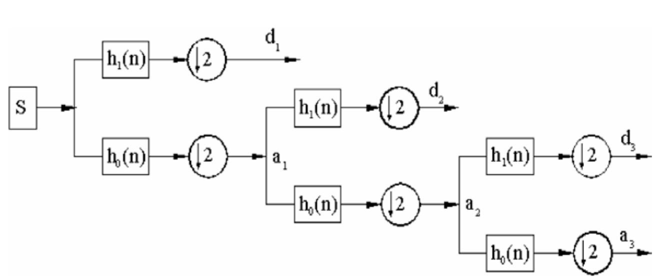

Fig. 1. DWT multiresolution algorithm.

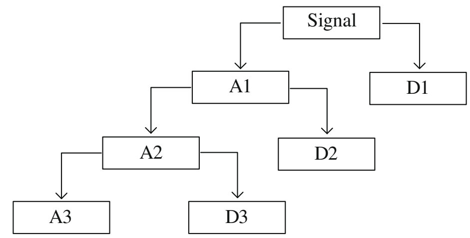

Fig. 2. Three level decomposition signal in DWT.

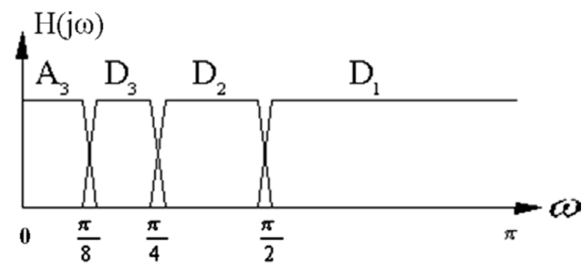

Fig. 3. Three-level DWT frequency band.

4. Proposed algorithm

This section presents a new approach for discriminating internal faults from inrush current based on DWT and correlation coefficient.

4.1. A: proper selection of mother wavelet

Proper choice of the mother wavelet plays a significant role in detecting and localizing different types of signal variations. The choice depends on the nature of the application. Furthermore, the accuracy of disturbance time localization decreases as the scale increases. Also, wideness and smoothness of mother wavelet depends on its number. Therefore, careful considerations are required for the selection of the suitable wavelet family and its number. In this paper, after many examinations, the db1 mother wavelet was selected.

4.2. B: proposed algorithm methodology

This paper proposes a novel internal fault and inrush current detection algorithm based on DWT and correlation coefficients.

4.2.1. Offline operation

In offline operation of the algorithm, DWT is used to decompose the known inrush current signal. For this signal, the index is generated. This Index (Eq. (4)) is the sum of the energy of detail coefficients at level 5 of three-phase differential currents at each half cycle. As mentioned, db1 mother wavelet is used.

Since to compute this index, parseval's theorem is used, first this theorem is introduced.

If the used scaling function and the wavelets form an orthonormal basis, then the parseval's theorem relates the energy in each of the expansion components and their wavelet coefficients. This