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A reliable setting-free technique for power transformer protection based on wavelet transform

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ABSTRACT

This paper presents a new methodology based on the analysis and monitoring of the discrete wavelet transform (DWT) detail coefficients (DetC) for internal fault conditions identification and discrimination in power transformers. The method extracts the characteristics and calculates the DetC signals levels variation through DWT decomposition for identification of transients. During internal faults the DetC present a sudden and high variation, different from what happens in other transients, allowing their discrimination. The proposed method was able to correctly identify the different types of internal faults in power transformers and additionally transient as inrush currents. The main novelty of the method are: (1) Intelligent data analysis and monitoring, without a threshold adjustment; (2) Fast identification of an internal fault conditions and high coverage of turn-to-turn faults; (3) Secutity during transients such as inrush currents, external faults and overexcitation; (4) Simplicity. The results show that the proposed method has potential for real application in power transformers protection.

1. Introduction

Power transformers are extremely important equipment for the electric power system (EPS) operation. Due to their importance and high financial cost they need a reliable, safe and fast protection system to avoid damages during fault condition or abnormal operation.

The differential function (ANSI 87) provides the best overall protection for phase and ground internal faults in power transformers. In order to avoid a false trip during power transformers energization, the differential protection normally is filtered through a fundamental frequency band-pass filter. The second harmonic restriction is still the main technique used to avoid unwanted trip of the protection during power transformer energization [1,2]. In this way, many efforts have been made to ensure a correct protection system performance during inrush currents and internal faults.

The differential protection is also used to detect the inter-turn fault in the power transformer. However, this protection scheme may detect the fault only when a large number of windings are involved [3]. Some internal fault conditions are difficult to identify, especially when it involves a small percentage of windings or when this fault occurs simultaneously with another transient, such as the inrush current, which may lead the protection scheme to not identify the fault condition.

In the last years several methods have been proposed to improve power transformers protection, being the main focus the distinction between inrush currents and internal faults conditions. Some papers have proposed a protection scheme using artificial neural networks (ANN) [4–6]. However, a large number of sample data training is required and it leads to a tendency for data over-adjustment, which is a limitation of ANN-based schemes. A method that uses differential current gradient is proposed by Alencar et al. [7] to identify inrush currents in power transformers. The method was tested under various operating conditions and proved to be robust in identifying inrush currents and internal faults. However, the method requires setting a threshold for discrimination between operating conditions. Refs. [8] and [9] used the mathematical morphology for transients identification in power transformers. Ref. [8] analyzed the differential currents peaks and valleys characteristics for each transient condition. To identify the operating situations, the method requires two thresholds, and in Ref. [9] three thresholds are required, which makes it difficult to apply these methods to systems using different transformers. In [10–18] the wavelet transform (WT) has been developed to be applied in power transformer protection, but in all proposed methods it is necessary to determine a threshold. Ref. [19] proposed an adaptive method using the spectral energy analysis extracted from the differential currents by DWT. The method developed proved to be robust in the internal fault conditions discrimination and other simulated transients, but it needs to set an adaptive threshold, and it has not been tested in internal faults conditions, which are difficult to identify, such as the inter-turn fault in power transformers.

In this paper, a new methodology based on detail coefficients (DetC)

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analysis and monitoring through DWT is proposed to identify and discriminate different internal fault conditions in power transformers, as well as the discrimination between transient operating conditions that may affect the differential protection. The proposed method intelligently monitors the detail coefficients levels behavior by DWT decomposition, and with a simple comparison between the DetC signals, identifies the operating conditions without the need to set a decision threshold. Such identification is possible because of DetC present characteristic behaviors during internal fault conditions. The methodology was tested in several operating conditions, including turn-to-turn fault up to 5% of winding, and was promising in the transients identification in power transformers. The proposed method presents the following contributions:

- Intelligent operating conditions analysis and discrimination, without the need to set a threshold;
- Fast identification of internal fault conditions;
- Security during the transient, such as inrush currents, external faults and overexcitation condition;
- Simple implementation process.

2. Differential protection

Currently, the percentage differential protection is the main method used for power transformers protection [20]. Under normal operating conditions, the currents circulating in the secondary of current transformers (CTs) installed on the high voltage and low voltage power transformer sides are approximately equal. However, if an internal fault condition exists, the differential current becomes larger, causing the relay to operate. Fig. 1 shows a schematic of the differential protection.

The differential current can be obtained by the phasor sum of the currents that run through the protected element [21], a differential current is defined as (1).

$$i_d = |i_{2LV} - i_{2HV}| \tag{1}$$

Where i_{2HV} and i_{2LV} are the CTs secondary currents on high voltage and low voltage power transformer side, respectively.

In order to prevent differential protection from the occurrence of small differential currents due to errors in the CT transform ratio or transformer tap changes, a restriction current is defined as Eq. (2), and a percentage differential protection function is established.

$$i_R = \frac{i_{HV} + i_{LV}}{2} \tag{2}$$

3. Discrete wavelet transform

The fast Fourier transform (FFT) is a tool widely used for finding the signal frequency components. However, the FFT assumes that the signal under analysis is periodic and stationary, but some transients present in the EPS, including the inrush currents, are non-periodic, non-stationary and of short duration [16].

Several studies in the signal processing area have used wavelet transform (WT). This technique emerged as an alternative to the problems encountered by the FFT, in which it is possible to obtain a good representation, both in the time domain and in the frequency domain.

The WT uses low-pass and high-pass filters to eliminate high and low frequency signal components. The signals resulting from the previous filtering are again filtered by splitting the signal. The process of filtering the signal is repeated up to a predetermined number of times. Fig. 2 shows a decomposition of a signal using WT, where ApC means the approximation coefficients and DetC means the detail coefficients of the discrete wavelet transform (DWT) decomposition levels.

The DWT of a discrete signal can be represented by Eq. (3).

$$DWT_{(m,n)} = \frac{1}{\sqrt{a_0^m}} \sum_n x(n) g\left(\frac{k - na_0^m}{a_0^m}\right) \tag{3}$$

Where g(n) is the mother wavelet and the scaling and translational parameters a and b, respectively, are functions of an integer parameter m, $a = a_0^m$ and $b = na_0^m$.

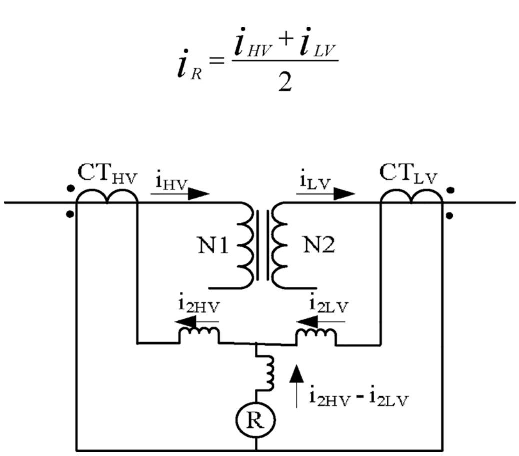

Fig. 1. Scheme of differential protection.

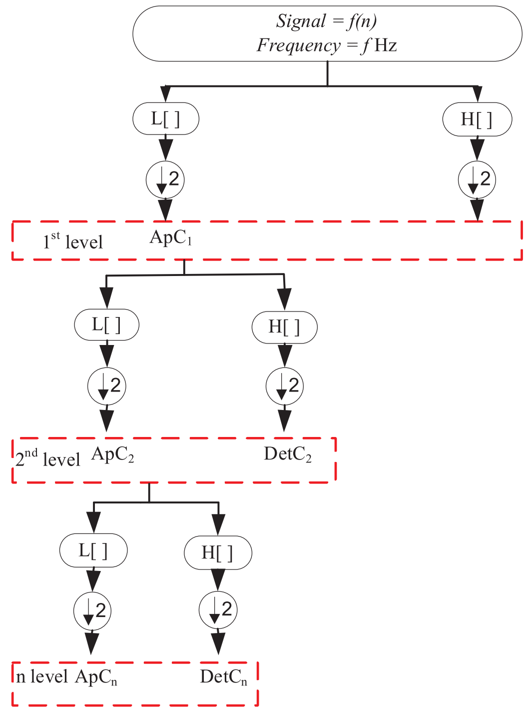

Fig. 2. DWT data decomposition.

4. Proposed method

The methodology proposed in this paper has been developed to identify internal fault conditions in which the power transformers are subjected to. Moreover, to improve the transformer protection reliability, it aims to distinguish transients conditions, such as, inrush currents, from internal fault conditions.

The transients identification is based on the analysis and monitoring of the 1st and 3rd levels detail coefficients (DetC) through DWT decomposition, using mother wavelet Daubechies 4 (db4) [22]. The use of DWT decomposition for different DetC levels is justified because inrush currents and internal fault conditions present a characteristic behavior and signals distinct variation. The 1st and 3rd decomposition level DetC behavior, for the inrush and internal fault conditions are presented in

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