Continuous Wavelet Transform for Discrimination between Inrush and Fault Current Transients in Transformer

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Abstract: This paper presents the characterization of fault transient in transformer using Continuous wavelet transform (CWT). This characterization will add the diagnostic of internal fault in transformer. The detection method can provide information of internal turns to turns fault in winding. CWT analysis provides discrimination of inrush current and fault from terminal parameter. This will add advance concept of on line monitoring of transformer from terminal quantity.

Keywords: Continuous wavelet transform (CWT), inrush, turns to turns fault, transformer.

I. INTRODUCTION

The trends towards a deregulated global electricity market has put the electric utility under severe stress to reduce operating costs, enhance the availability of generation, transmission and distribution equipment, and improve supply of power and service to customers. Using efficient methods of detection and classification of transients will help the utilities to accomplish these objectives.

Transformers are essential and important elements of power systems and whose unexpected outage can cause the total disruption of electrical supply and subsequent major economic loss. Hence, detection and classification of faults through certain intelligent procedure can provide early warning of electrical failure and could prevent catastrophic losses.

Fault detection in transformer has been conducted in several manners. The existing methods can be classified in following major groups like Electrical Based Technique and Oil Based Technique. The electric based methods decide the condition of transformer by means of differential relaying techniques, and oil based technique is mainly represented by Dissolved gas Analysis (DGA). The fault diagnosis with this procedure requires complex and, expensive sensors capable of detecting the different gases dissolved in transformer oil as a consequence of failure.

Several industrial methods exits for online and offline fault diagnosis of transformer, but all of them are expensive, complex and time consuming. To take the diagnostic decisions, transformer fault must be characterized by analyzing quantities of data, which could be generated through computer simulation or field experiments.

The power transformer protection is one of the critical issues in power system. Since minimization of frequency and duration of unwanted outages, is very desirable, this high demand imposed on power transformer protective relays; this includes the requirement of dependability associated with no false tripping and operating speed associated with short fault clearing time.

One of the main concerns in protecting this particular component of power system lies in the accurate and rapid discrimination of magnetizing inrush current from other different faults. This is because the magnetizing inrush current, which occurs during the energizing the transformers, generally results in several times full, load current and therefore can cause mal operation of relay. Such mal operation of a differential relays can affect both reliability and stability of the whole power system.

Traditionally transformer protection methods that use its internal behavior are based on differential protection and the studies for improvement of transformer protection have focused on discrimination between internal short circuit faults and inrush currents in transformer, [4], [5].

But incipient faults in equipment containing insulation material are also very important. Detection of these types of faults can provide information to predict failure ahead of time. The major cause of incipient faults is the deterioration of insulation in the electrical equipment. When the condition of system equipment degrades because of electrical, thermal or chemical effects, intermittent incipient fault begin to persist in the system, leading to more frequent outages degraded the quality of service and eventually longer outages. Until finally a catastrophic failure occurs and service cannot be restored until the source of failure is repaired [6].

The basic philosophy of protective device is different for incipient faults than for short circuits. The classical short circuit methods can not detect incipient faults by using the terminal
behavior of transformer unless a major arcing fault occur that will be detected by protective device such as fuse and relay protection.

Since incipient faults develop slowly there is a time for careful observation and testing. Conventional protective device cannot detect these faults. Supplementary protective system and methods, which may not be based on terminal behavior of transformers, are needed for power system transformer [5].

Over the years various incipient fault detection techniques, such as dissolved gas analysis and partial discharge analysis [15] have been successfully applied to large power transformer fault diagnosis. On line condition monitoring of transformers can give early warning of electrical failure and could prevent catastrophic losses. Hence a powerful method based on signal analysis should be used in monitoring. This method should discriminate between normal and abnormal operating cases that occur in distribution system related to the transformers such as external faults, internal faults, magnetizing inrush, load changes, aging, arcing, etc.

There have been several methods based on time domain and frequency domain techniques. In previous study researchers have used Fourier Transform or Windowed Fourier Transform. Since FT gives only frequency information of signal, time information is lost. In Windowed FT or short time FT has the limitation of a fixed window width, so it does not provide good resolution in both time and frequency. A wide window, for example gives good frequency resolution but poor time resolution, where as a narrow window gives good time resolution but poor frequency resolution. Wavelets on the other hand provide greater resolution in time for high frequency components of a signal and greater resolution in frequency components of signal. In a sense Wavelet have a window that automatically adjusts to give the appropriate resolutions. Therefore in recent studies Wavelet transform based methods have been used for analysis of characteristics of terminal current and voltages, [4], [8].

Traditional Fourier analysis, which deals with periodic signals and has been the main frequency domain analysis tool in many applications, fails to describe the eruptions commonly existing in transient processes such as magnetic in rush and incipient faults.

The Wavelet transform (WT) on the other hand can be useful in analyzing the transient phenomenon associated with the transformer faults.

II. METHODOLOGY/METHODS IN DETAILS

A case study on custom built transformer will be presented in this paper. The laboratory experimental works will focuses mainly on the inter turn short circuits in the transformer and inrush currents. The acquired data will be analyzed as per the fundamentals of signal processing. The probable and possible methods are briefly discussed below.

A. Fourier Transform

It is well known from Fourier theory that a signal can be expressed as the sum of a, possibly infinite, series of sines and cosines. This sum is also referred to as a Fourier expansion. The main disadvantage of a Fourier expansion is that it has only frequency resolution and no time resolution. This means that although we might be able to determine all the frequencies present in a signal, we do not know when they are present. To overcome this problem in the past decades several solutions have been developed which are more or less able to represent a signal in the time and frequency domain at the same time.

The idea behind these time-frequency joint representations is to cut the signal of interest into several parts and then analyze the parts separately. It is clear that analyzing a signal this way will give more information about the when and where of different frequency components, but it leads to a fundamental problem as well: how to cut the signal? Suppose that we want to know exactly all the frequency components present at a certain moment in time. We cut out only this very short time window using a Dirac pulse [2], transform it to the frequency domain and ... something is very wrong. The problem here is that cutting the signal corresponds to a convolution between the signal and the cutting window. Since convolution in the time domain is identical to multiplication in the frequency domain and since the Fourier transform of a Dirac pulse contains all possible frequencies the frequency components of the signal will be smeared out all over the frequency axis. (Please note that we are talking about a two-dimensional time-frequency transform and not a one-dimensional transform.) In fact this situation is the opposite of the standard Fourier transform since we now have time resolution but no frequency resolution whatsoever. The underlying principle of the phenomena just described is due to Heisenberg’s uncertainty principle, which, in signal processing terms, states that it is impossible to know the exact frequency and the exact time of occurrence of this frequency in a signal. In other words, a signal can simply not
be represented as a point in the time-frequency space. The uncertainty principle shows that it is very important how one cuts the signal. The wavelet transform or wavelet analysis is probably the most recent solution to overcome the shortcomings of the Fourier transform. In wavelet analysis the use of a fully scalable modulated window solves the signal-cutting problem. The window is shifted along the signal and for every position the spectrum is calculated. Then this process is repeated many times with a slightly shorter (or longer) window for every new cycle. In the end the result will be a collection of time-frequency representations of the signal, all with different resolutions. Because of this collection of representations we can speak of a multiresolution analysis.

In the case of wavelets we normally do not speak about time-frequency representations but about time-scale representations, scale being in a way the opposite of frequency, because the term frequency is reserved for the Fourier transform. Since from literature it is not always clear what is meant by small and large scales, I will define it here as follows: the large scale is the big picture, while the small scales show the details. Thus, going from large scale to small scale is in this context equal to zooming in.

Following sections presents the wavelet transform and develop a scheme that will allow us to implement the wavelet transform in an efficient way on a digital computer.

B. The continuous Wavelet Transform

The continuous wavelet transform was developed as an alternative approach to the short time Fourier transforms to overcome the resolution problem. The wavelet analysis described in the introduction is known as the continuous wavelet transform or CWT. More formally it is written as:

$$\gamma(s, \tau) = \int f(t)\psi^*_s,\tau(t)dt$$  \hspace{1cm} (1)

Where * denotes complex conjugation. This equation shows how a function $f(t)$ is decomposed into a set of basis functions, called the wavelets. The variables $s$ and, scale and translation, are the new dimensions after the wavelet transform. For completeness sake (2) gives the inverse wavelet transform.

$$f(t) = \int \int \gamma(s, \tau)\psi_{s,\tau}(t)d\tau ds$$  \hspace{1cm} (2)

The wavelets are generated from a single basic wavelet $\psi(t)$, the so-called mother wavelet, by scaling and translation:

$$\psi_{s,\tau}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right)$$  \hspace{1cm} (3)

In (3) $s$ is the scale factor, $\tau$ is the translation factor and the factor $s^{-1/2}$ is for energy normalization across the different scales. It is important to note that in (1), (2) and (3) the wavelet basis functions are not specified. This is a difference between the wavelet transform and the Fourier transform, or other transforms. The theory of wavelet transforms deals with the general properties of the wavelets and wavelet transforms only. It defines a framework within one can design wavelets to taste and wishes.

C. Wavelet Properties

The most important properties of wavelets are the admissibility and the regularity conditions and these are the properties which gave wavelets their name. Functions $\psi(t)$ satisfying the admissibility condition

$$\int \left| \frac{\Psi'(\omega)}{\omega} \right|^2 d\omega < +\infty$$  \hspace{1cm} (4)

can be used to first analyze and then reconstruct a signal without loss of information. In (4) $\psi(\omega)$ stands for the Fourier transform of $\psi(t)$. The admissibility condition implies that the Fourier transform of $\psi(t)$ vanishes at the zero frequency, i.e.

$$\left| \frac{\Psi(\omega)}{\omega} \right|_{\omega=0} = 0$$  \hspace{1cm} (5)

This means that wavelets must have a band-pass like spectrum. This is a very important observation, which we will use later on to build an efficient wavelet transform.

A zero at the zero frequency also means that the average value of the wavelet in the time domain must be zero,

$$\int \psi(t)dt = 0$$  \hspace{1cm} (6)

and therefore it must be oscillatory. In other words, $\psi(t)$ must be a wave.
As can be seen from (1) the wavelet transform of a one-dimensional function is two-dimensional; the wavelet transform of a two-dimensional function is four-dimensional. The time-bandwidth product of the wavelet transform is the square of the input signal and for most practical applications this is not a desirable property. Therefore one imposes some additional conditions on the wavelet functions in order to make the wavelet transform decrease quickly with decreasing scale $s$. These are the regularity Conditions and they state that the wavelet function should have some smoothness and concentration in both time and frequency domains. Regularity is a quite complex concept and we will try to explain it a little using the concept of vanishing moments. If we expand the wavelet transform (1) into the Taylor series at $t = 0$ until order $n$ (let $\gamma = 0$ for simplicity) we get:

$$\gamma(s,0) = \frac{1}{\sqrt{s}} \sum_{p=0}^{n} \int \frac{f^{(p)}(t)}{p!} \psi \left( \frac{t}{s} \right) dt + O(n+1)$$

Here $f^{(p)}$ stands for the $p$th derivative of $f$ and $O(n+1)$ means the rest of the expansion. Now, if we define the moments of the wavelet by $M_p$,

$$M_p = \int t^p \psi(t) dt$$

then we can rewrite (7) into the finite development

$$\gamma(s,0) = \frac{1}{\sqrt{s}} \left[ f(0)M_0 s + \frac{f^{(1)}(0)}{1!} M_1 s^2 + \frac{f^{(2)}(0)}{2!} M_2 s^3 + \ldots + \frac{f^{(n)}(0)}{n!} M_n s^{n+1} + O(s^{n+2}) \right]$$

From the admissibility condition we already have that the 0th moment $M_0 = 0$ so that the first term in the right-hand side of (9) is zero. If we now manage to make the other moments up to $M_n$ zero as well, then the wavelet transform coefficients $(s, t)$ will decay as fast as $sn+2$ for a smooth signal $f(t)$. This is known in literature as the vanishing moments or approximation order. If a wavelet has $N$ vanishing moments, then the approximation order of the wavelet transform is also $N$. The moments do not have to be exactly zero, a small value is often good enough. In fact, experimental research suggests that the number of vanishing moments required depends heavily on the application. Summarizing, the admissibility condition gave us the wave, regularity and vanishing moments gave us the fast decay or the let, and put together they give us the wavelet.

III. EXPERIMENT SETUP

The main component of the experiment setup is 230V/230V, 50Hz, 2KVA single phase transformer. The transformer is having 5 tap on primary winding, first four tap after each 10 turns and on secondary having total 27 tap, each of 10 turns. The taps are especially provided for turns to turns fault application. The primary winding was connected across rated voltage at rated frequency. The transformer was loaded at 50% of its full load. The application of fault on primary, secondary and both winding was done with the help of external contactor.

A portable data acquisition system was used to collect the instant of faulted samples. The primary and secondary current and voltage were measured with the help of current transformer (CT) and Potential transformer (PT), suitable for data acquisition system. The current and voltage signal were recorded at sampling rate of 10000 sample/s. The experimental circuit and laboratory set up is as shown in Fig. 2(a) and Fig. 2(b).

![Fig No. 2(a) Experimental Circuit](image)

![Fig No. 2(b) Laboratory Setup](image)
IV. RESULTS AND DISCUSSION

A. Inrush Transients

When a transformer is de-energized, a permanent magnetization of the core remains due to hysteresis of the magnetic material. This “residual flux” is influenced by the transformer core material. When a transformer is energized the instantaneous magnitude of core flux at the instant of energization is the residual flux. The amount of offset of the sinusoidal flux generated by the applied voltage depends upon the point of voltage wave where the transformer is energized. The core flux can therefore reach a value double the normal flux plus residual flux. The most severe case where energization at voltage zero, the peak transient core is more than two time higher than the peak normal core flux. Experimental readings for inrush current are taken accordingly. Fig.3. Shows CWT of Inrush current.

B. Internal Short Circuit Transient

Internal fault are the fault that occurs within protective zone and protective scheme suppose to sense the fault and take action on it. Internal fault is generally turns to turns short circuit fault.

Fig.4. shows the CWT result from turns to turns fault on primary side. The fault was created with help of external contactor. The turns to turns fault was done between 10 to 20 turns of primary winding on rated voltage and loaded condition.

V. CONCLUSION

This paper presents a new approach for discrimination between inrush current and internal faults in power transformer by pattern recognition technique using CWT. The CWT gives the contours for inrush current and internal fault very distinctly. The obtained results clearly show that the scheme can provide accurate discrimination between Inrush and fault condition in transformer. The online implementation of this technique needs to be explored using suitable artificial intelligence method.

REFERENCES


