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Signal Processing Application in Fault Diagnosis of Three Phase Transformers

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***Abstract* - Data acquisition and subsequent fault diagnosis of a three-phase transformer is presented in this paper. A PC with data acquisition card is used for the purpose of storing, monitoring and diagnosis. Spectral analysis algorithms based on FFT as well as Wavelet Transform are used to obtain the signature of currents under various normal and abnormal conditions. The Wavelet Transform is implemented to extract the features from the transient signals simultaneously both in time and frequency domain. Current signatures so obtained serve as input for classifying various faults.**

Keywords—Condition monitoring, Fault diagnosis, Fourier Transform, Discrete Wavelet Transform, Switching inrush current

I. INTRODUCTION

Online monitoring of transformer encompasses detection and diagnosis in order to determine the possibility of breakdown [1, 2]. Current signatures are analyzed to diagnose faults. The basic principle is that faults in the transformer generate harmonics in the line currents. These characteristic harmonics are indication of the type and severity of the fault.

The condition monitoring of a power transformer with on load tap changer (OLTC), which produces a well-defined series of vibration burst as its signature is discussed in [3]. A Wavelet Transform based technique is developed to characterize the OLTC vibration signals and to extract the features in Wavelet domain to provide the realizable indication of the true health of the OLTC of a transformer. Wavelet Transform is applied in [4] for feature extraction of partial discharge pulse signal obtained from a computer aided single acoustic sensor using Neural Network method. Wavelet Transform is proved to be the powerful tool in the analysis of the power transformer transient phenomena [5]. Its ability to extract information from the transient signals simultaneously both in time as well as frequency domain, enables the discrimination between the internal fault and magnetizing inrush current in the power transformer. This is explained in [5] by combining the Wavelet Transform with Neural Network. Iterative FFT algorithm is proposed in [6] for the harmonic distortion analysis with various transformer connections. Concept of sympathetic interaction between transformers connected in the network and the harmonic content of the transient current during switching inrush is explained in [7] considering the saturation characteristic. *Iterative FFT* is proposed in [8] for detection of multiple sinusoids in additive noise, and for spectral estimation based on this algorithm. A scheme based on Parseval's relation and energy concept which defines *group harmonic* identification algorithm for estimation of energy distribution in the harmonics of time-varying waveform is proposed in [9]. Multi-resolution signal decomposition technique is implemented in [10] to detect and localize transformer fault.

This paper presents a method of fault detection from the frequency components of transformer current using the relationship between a definite frequency band and a given fault.

II. EXPERIMENTAL SETUP

The real time behavior of the current signals is analyzed under normal as well as faulty conditions of a transformer with following specifications: 5kVA, 400V/220V, 50Hz, Δ-Y with floating neutral. The experimental set up for study is shown in Fig. 1. Six Hall-Effect current sensors with current ratio 2000:1 are used to monitor the primary and secondary line currents. A RC filter is designed to take care of noise and other interference. A 12-bit A/D converter card, PCL-208 is used for on-line data acquisition to PC. The data acquisition is carried out for switching inrush, single phasing, internal and external faults of the transformer. The sampling time for 6-phase current acquisition is determined to be 44.39 microseconds.

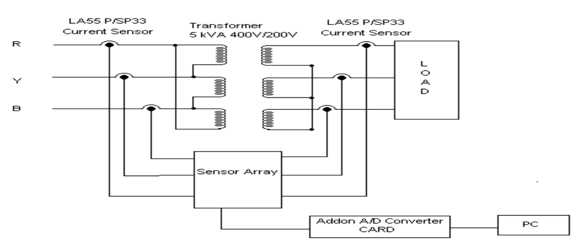

Figure 1 Experimental setup

A. Switching Inrush at No-Load

The waveform of magnetizing inrush current flowing in the primary, during the switching of the primary with secondary open circuited is shown in Fig.2. This current attains 6 times the rated full load value after half-cycles for the extreme saturation of the iron core.

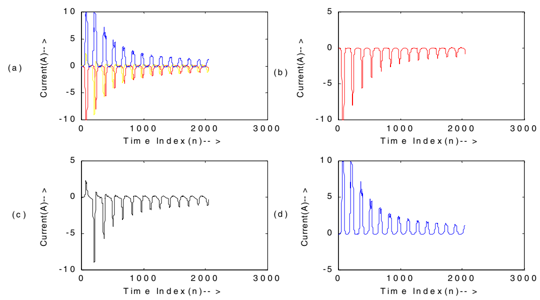

Figure 2 Switching inrush current (a) Three Phases, (b) R-phase, (c) Y-phase, (d) B-phase

B. Creation of Transformer Faults

The internal phase to phase fault is created by shorting the LV terminal of Y and B phases before the current sensor. A fault is also created by shorting R-phase of LV and HV windings. External fault is created by shorting the R, Y, and B at the load end after the current sensors. Current waveform during the fault is shown in Fig.3.

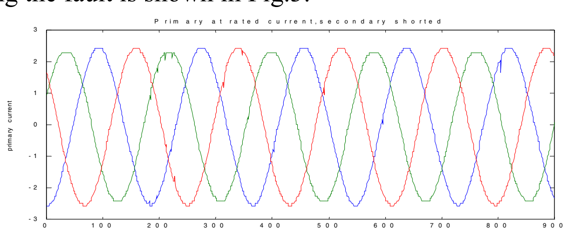

Figure 3 Primary current under External Short circuit

III. CURRENT SIGNATURE ANALYSIS USING FFT

The waveforms associated with the fast electromagnetic transients are typically non-periodic and non-stationary, which contain both high frequency oscillations and localized impulses superimposed on the power frequency and its harmonics. This poses a problem for traditional Fourier Transform (FT) as it does not consider non-stationary signals, which have changing frequency. FT of a signal which contains several different frequencies occurring at different times, is almost identical to the FT of a signal that consists of the same set of the frequencies occurring simultaneously. Moreover, a wide band signal requires denser sampling and longer time periods to maintain good resolution in the low frequencies.

A. FFT of Transformer Currents at Normal Condition

FFT of primary and secondary currents under normal condition are shown in Fig.4. Fundamental component is dominant in the frequency spectrum. Third, fifth, seventh harmonics are also present. This is the characteristic of normal running condition of a transformer from the viewpoints of diagnosis.

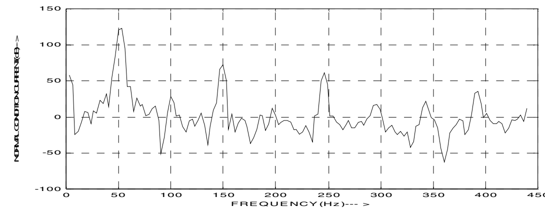

Figure 4 FFT of primary current under normal condition

B. FFT of Switching Inrush Current at No-Load

The magnetizing inrush current spectrum from FFT is shown in Fig.5. The dominancy of second harmonic over other harmonics is the characteristic of switching inrush. The magnitude of second harmonic component is a function of the residual magnetism and the voltage-switching angle.

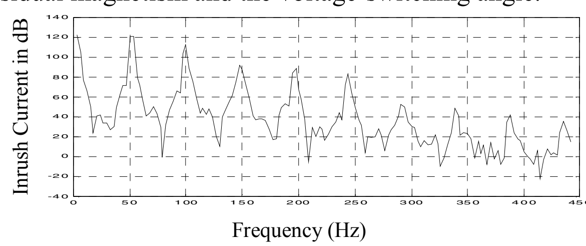

Figure 5 FFT of switching Inrush current at no load

C. FFT under Internal Fault

It is apparent from Fig.6 that the occurrence of an internal fault creates a high frequency distortion in the current waveforms. Though the third harmonic component is second dominant during internal fault, second harmonic component is also developed.

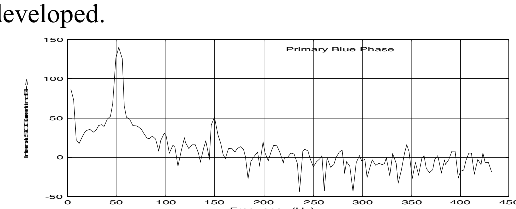

Figure 6 FFT of Primary current under internal LV phase to phase fault

D. FFT under S.C. of HV and LV of Same Phase

FFT of current during fault due to shorting of the HV and LV winding of the same phase is shown in Fig.7. It shows dominancy of fundamental component. Classical FFT analysis could not reveal other high frequency component.

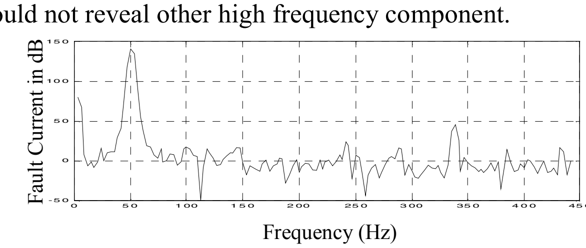

Figure 7 FFT of Primary current under short circuit of R-phase of HV and LV winding

E. FFT of Current under External Fault

Similar to the other internal faults, fundamental component is also dominant in the external fault of a transformer, as seen from current FFT in Fig.8. However the FFT analysis is insufficient to differentiate the external and internal faults.

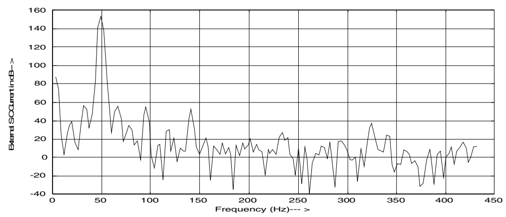

Figure 8 FFT of primary current under external fault

IV. CURRENT SIGNATURE ANALYSIS USING WAVELET TRANSFORM

The time-frequency resolution problem is a problem accounted to physical phenomena and will exist in any transform method. Multi-resolution Analysis (MRA) however, analyzes a signal at different frequencies with different resolutions, thus every spectral component is not resolved equally. The continuous wavelet transform (CWT) was developed as an alternate approach to the Short Time Fourier Transform. The CWT is a natural way to obtain the time-scale (time-frequency) representation.

A family of function is defined as:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left[\frac{t-b}{a}\right]$$

where, ψ is a fixed function, called the 'mother wavelet', localized both in time and frequency. ψ has certain admissibility condition which must be met in order to qualify to be a wavelet. 1. It must be oscillatory. 2. It must integrate to zero (i.e., no dc component). 3. It must decay quickly to zero (i.e., a fast transient). Thus the wavelet is a small (finite length window) wave.

For the above family of functions, the continuous wavelet transform is defined as follows:

$$CWT(a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} x(t)\ \overline{\psi\left[\frac{t-b}{a}\right]}\ dt$$

where, $\overline{\psi\left[\frac{t-b}{a}\right]}$ represents complex conjugate of $\psi\left[\frac{t-b}{a}\right]$.

The Wavelet transform has a digitally implementable counterpart which is called the Discrete Wavelet Transform (DWT). The DWT is defined as

$$DWT[m,k] = \frac{1}{\sqrt{a_0^m}}\sum_n x[n]\psi\left[\frac{k-n\,a_0^m}{a_0^m}\right]$$

where, $\psi[n]$ is the 'mother wavelet', and the scaling and translation parameters 'a' and 'b' are functions of an integer parameter 'm', $a = a_0^m$ and $b = n\,a_0^m$. The result is a geometric scaling by 1, 1/a, 1/a^2, …, and translation by 0, n, 2n,...This scaling gives the DWT logarithmic frequency coverage.

A. Implementation of Wavelets

The implementation procedure of a Discrete Wavelet Transform (DWT) is shown Fig.9, in which x[n] is the original signal, h[n] and g[n] are high-pass and low-pass filters respectively. Down sampling at the output of the low-pass filter g[n] effectively scales the wavelet by two for the next stage. At the first stage, an original signal is divided into halves of the frequency bandwidth, and sent to both high-pass filter and low-pass filter. Then the output of low-pass filter is further cut in half of the frequency bandwidth, and sent to the second stage; this procedure is repeated until the signal is decomposed to a pre-defined level.

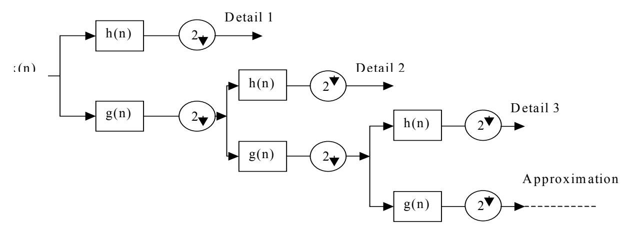

Figure 9 Implementation of DWT

B. Wavelet Transform of No-Load Inrush Current

The magnetizing inrush current waveforms, which correspond to R, Y, B phase's differential-current are shown in Fig.10. The differential current waveforms are distorted quite significantly over the time. The current magnitude changes over a significant range. This is expected due to the fact that sudden changes from on state to other different states produce small ripples.

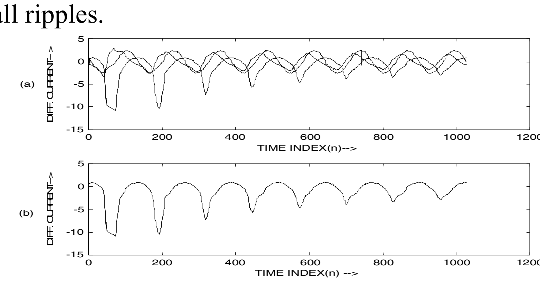

Figure 10 Switching inrush differential current at no load (a) for three phases (b) for Y-phase

In implementing the DWT, the original inrush current signal is sampled at 6.50 kHz and passed through a DWT based on structure shown in Fig.9. Based on the foregoing, 5 detailed signals that contain frequency bands of 3.25 kHz ~ 1.62 kHz at detail 1, 1.62 kHz ~ 812 Hz at detail 2, 812 Hz ~406 Hz at detail 3, 406 Hz ~203 Hz at detail 4, and 203 Hz ~ 101 Hz at detail 5 as well as one approximation signal in the frequency band 101 Hz ~DC level are obtained. The features of the decomposed magnetizing inrush current signals are shown in the Fig.11. Certain high frequency component can be located well in time than a low frequency component. In contrast, a low frequency component can be located well in the frequency domain than the high frequency component. This means all features for a particular signal are obtained.

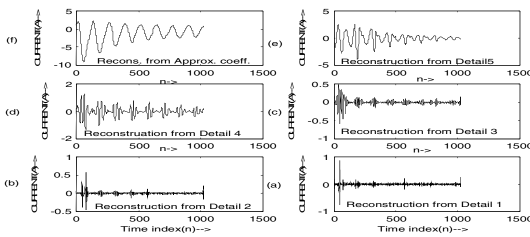

Figure 11 (a)-(e) Reconstruction of five successive details and (f) Approximation for inrush current

C. *Wavelet Transform of Internal Fault Current*

Figure-12 represents the differential current signal of three phases for an internal fault corresponds to Y-B phases internally short-circuited on the LV side of the transformer. It is apparent from Fig.12 that there is a high frequency distortion in the current waveforms. The Discrete Wavelet Transform of R-phase current is shown in Fig. 13.

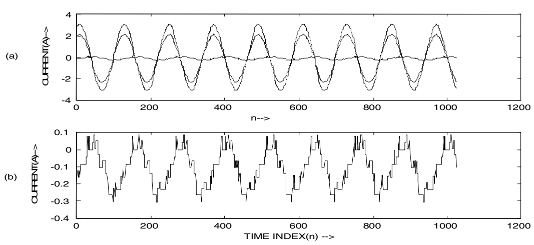

Figure 12 Differential current when Y-B phases internally shorted (a) Three phase, (b) R-phase

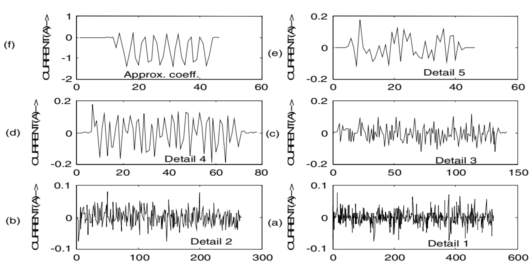

Figure 13 (a-e) Five successive details, (f) Differential current for internal short circuit

Corresponding to the details 1-3 of the DWT, it is observed from Fig.13 (a)-(c) that there are several sharp spikes appearing immediately following the fault inception time. However, in marked contrast to the inrush current case, these sharp spikes rapidly decay to zero within one cycle, whereas those associated with the inrush current suffer from little attenuation during the entire inrush transient period. It is apparent that this difference of density of sharp spikes and their rapid decay can be the effective features for diagnosis, and distinguish between the internal fault and inrush current.

D. *Wavelet Transform of External Fault Current*

Wavelet transform details for external fault current are shown in Fig.14. From Fig. 14 (a)-(c), which corresponds to the details 1-3 of the DWT, it is observed that the bursts comprise of a number of spikes but not so sharp and dense as internal fault. It is the unique features that can be used to distinguish between internal and external faults.

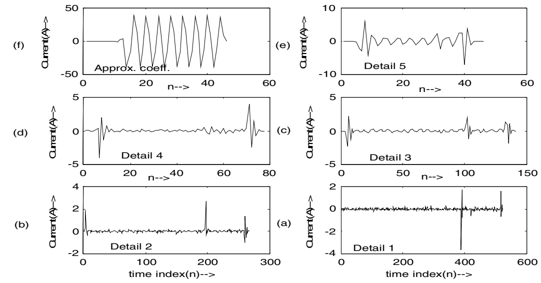

Figure 14 (a-e) Five successive details and (f) Approximation for differential external fault current

V. CONCLUSION

The wavelet transform is a powerful tool in the analysis of transformer transient phenomena for its ability to extract information from the transient signals simultaneously in the time and frequency domain. Fourier transforms can only give the information in frequency domain. The wavelet technique is robust. The performance shown demonstrates that the technique adopted in this paper gives a very high accuracy in the classification of the transient.

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