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WAVELET TRANSFORM APPLICATION FOR THE CALCULATION OF THE CIRCUIT BREAKER OPERATING TIMES

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ABSTRACT - This article describes the proposal of a new method for the determination of the circuit breaker operation times (opening, closing) through the application of the Wavelets Transform mathematical tool (WT), in the currents and voltages presents in the circuit breaker. This method makes use of the instantaneous measurements (samples) of voltages and currents stored by digital oscillographs or data acquisition units. The basic principle of the algorithm is presented through simulations in Matlab, which will be compared later with the information collected by the monitoring system directly of the current transducers (hall effect) installed in the opening and closing circuit of circuit breaker coil current.

KEY WORDS- Wavelet Transform, Multiresolution Analysis, circuit breaker operating time.

I. INTRODUCTION

Different methods for the evaluation of the circuit breaker based in its performance were studied, among them the measurement of the travel contacts time, vibration analyses, noise analyses, etc. These methods in general are intrusive, because it is force the installation of sensors that in some cases are the origin of future mechanical fault. It is for that reason that is necessary the search of new diagnosis alternatives through the use of the proportionate information for equipments already installed such as the relays, oscillographies, etc., or through devices non-intrusive.

The signal processing technique based on the use of Wavelet Transform (WT) is a very useful strategy applied in energy quality area especially to the phenomenon detection like sags and swells and now it is a tool being applied in the analysis of the current and voltages behavior at the moment of CB operation.

One of the most important properties of Wavelets is its capacity to identify particularities of a signal in time and in frequency. This property is of extreme usefulness in the analysis of signals that possess the following characteristics: non-stationary, transitory components of short duration and singularities in different scales.

So the Wavelet transform is capable to reveal aspects in a signal that was impossible obtained through other processing techniques, such as: tendencies, discontinuity points, discontinuities in derived superiors and self-similarity.

WT decomposes a given signal in different frequency levels through the dilation and translation operations of a Wavelet Mother (Base), conserving the pertinent and relevant information in the time and frequency domain simultaneously. In this way, it is possible to locate disturbances in the time domain and state, which is its frequency level [3].

In this way, this article presents a study with behavior analysis of several families of Wavelet functions, applied to the analysis of the variations of currents with the objective of identifying the Wavelets mother's best behavior in the study in subject. To verify the operation time determination algorithm, it will be used a circuit breaker monitoring system that possesses Hall effect current transducers, installed in the cables corresponding to the feeding circuits of the circuit breaker opening and closing coils in the three phases, being the samples collected in a same time base.

II. CIRCUIT BREAKER MONITORING

The circuit breakers together with the transformers are the most important equipment of a substation. Considering its maneuvering function it can be said that a circuit breaker is usually in an inactive state, considering that it usually stays open or closed for long periods of time, until some alteration occurs in the normal condition operation of the system, moment in which it should operate to change of state. However, when a circuit breaker has to work, an incomplete operation or a fault in the interruption can create a severe disturbance in the system, reason for which it should have a well projected system with an operating mechanism reliable and highly safe.

The CB is an equipment designed to operate in very short interval times (ms) accomplishing two functions basically to open and close circuits, the opening operation is approximately 1/3 faster than the closing operation, as time passes by and due the ageing of the mechanical components these times are altered compromising the correct operation, which is very important for the operation times' monitoring.

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A circuit breaker monitoring system makes in real time the acquisition and supervision of circuit breaker main parameters' data (coil and motor currents, voltages, pressures, temperatures, contacts, etc.). This supervision is made through digital equipment and specific sensors installed close to the circuit breaker. The data are collected and processed in a data acquisition and control unit (UAC), to thereafter through a communication network, using a desirable protocol standardized internationally, they will sent to a central computer located in the control building substation and after to the maintenance centers and so allowing a remote supervision.

The kind and the amount of sensors used in the monitoring system depend on the technology used in each circuit breaker for the arc extinction (mineral oil, compressed air, SF6, among other); as well as the operating mechanism system (spring, hydraulic, pneumatic, among other). Although the circuit breaker manufacturers have already developed monitoring systems for the new current models in the market. The largest challenge is to transform the data obtained in useful information that could permit to grow new applications [13].

Figure 1, shows the general architecture of the monitoring system with their principal parameters installed in the prototype.

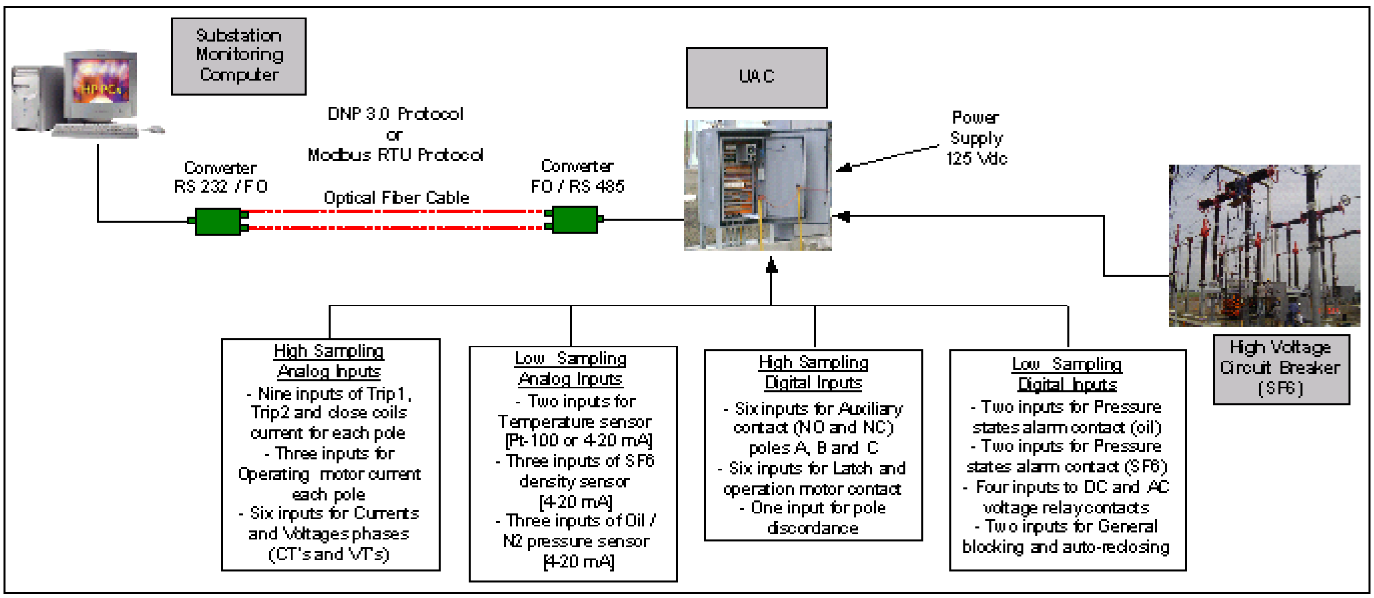

Figure 1. Monitoring System General Architecture.

To verify the determination algorithm of the CB operation times through the WT use the information provided by the monitoring system prototype implemented in the CB, were used specifically the coils current transducer data installed in the opening and closing circuits as illustrated in Figure 2, this method is non-intrusive.

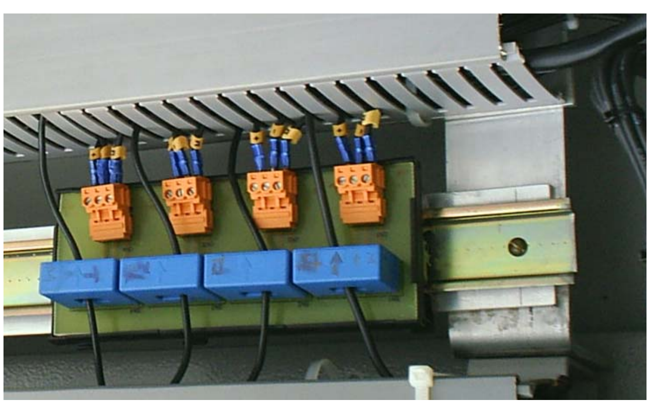

Figure 2. Current transducer coil current monitoring**.**

III. WAVELET TRANSFORM

The main objective of this paper is to show the possibility to use Wavelet Transform (WT), for the determination of the circuit breaker operation times (opening and closing) using the oscillography of the currents and voltages present in the CB operation moment.

To accomplish the objective before mentioned, it was needed to obtain data from real situations previous to the construction of the prototype, in other words, disturbances that caused the circuit breaker trigger (short current). Therefore, the information provided by the oscillograph was used, along with a program for the manipulation of the Comtrade format files, regarding the data related to the operation of a circuit breaker (440kV) installed in a transmission substation system of the Sao Paulo state (Brazil). In the oscillographies collected a sampling rate of 15.4 kHz was used, in other words, 256 samples/cycle to 60Hz with possibility of choosing a variable number of cycles pre and post trigger.

The question that immediately sprang up was: Which will be the Base function (Wavelet mother) to be used for the analysis of the oscillographies. To answer such question, studies were developed with several base functions, aiming to choose a Wavelet mother capable to extract pertinent characteristics from the different disturbances involved in the period of the circuit breaker operation. So, a Daubechies Wavelet mother was chosen and the Multiresolution Analysis (MRA) to determine the involved times, was used. For such analyses, algorithms were used, developed in the Matlab software that explored the different waveforms (current and voltage) and they allowed calculate the opening and closing times of the circuit breaker studied.

3.1 Multi-resolution analysis (MRA)

The Multiresolution technique decomposes a given signal in different resolution levels, so as to supply important information in the time and frequency domain.

The technique of MRA consists in the decomposition of the signal to be analyzed in two other signals, one version contain the details and another attenuated (or the approximation) of the signal, through high pass (D) and low pass (A) filters respectively. The attenuated signal (originating in the low pass filter) is decomposed again resulting in two other new signals, detailed and approximated, in levels of different frequency, these supply direct information on the frequency and time domain that are represented mathematically by Wavelets functions [5].

After a certain number of decompositions, it is obtained an approximate version of the signal and their respective details in an amount as much as the number of decompositions is performed.

It is possible through the approximation (A) and detail information (D), recomposes the original signal. It can also be made the recomposition removing some detail, and in this way, filtering and compacting the information, which is useful in the storage and data communications.

Figure 3, shows the described technique, where it is represented the filter process generating the approximation (cA) and detail (cD) coefficients, for each of the levels.

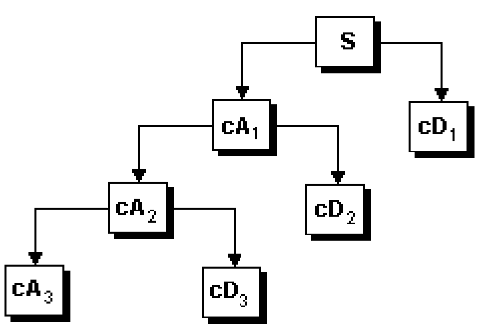

Figure 3. Signal decomposition through filters processing.

The decomposition can continue until that the individual detail consists in only one sample. In practice, a satisfactory number of levels are selected based on the nature of the signal.

In the MRA, the approximation is described using the concept resolution or levels, where better resolutions (initial levels) possess more samples for unit of time. The passing for a higher level implicates in a larger freqüêncial resolution, though at the expense of a smaller temporary resolution. For this reason the use of this tool becomes useful in signal classification systems.

IV. DETERMINATION OF THE CIRCUIT BREAKER OPERATING TIMES

The input signals that will be submitted to the time calculation algorithm consist of "vectors" that contain the sampling points of the current and voltage oscillographies for each phase.

Figure 4, illustrates the oscillography of the currents in phases A, B and C, after a fault in phase C, in the previously mentioned substation.

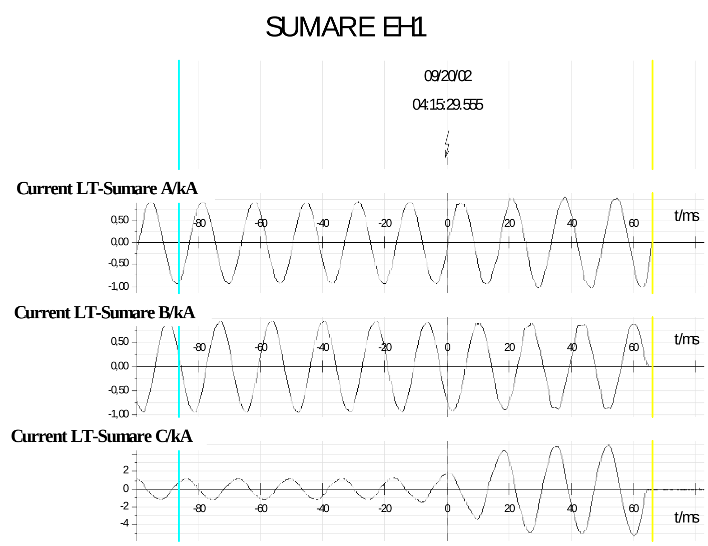

Figure 4. Line current oscillographies representation.

With the objective of selecting a base Wavelet function better conditioned to the analysis of the circuit breaker operation times, tests were realized with several families. Such tests consisted of submitting the oscillography of the current (phase C) shown in Figure 4 utilizing several base functions.

The functions: Haar, Daubechies (dbN, N = 1,2...10), Symlets (symM, M = 2,3...8), Coiflets (coifP, P = 1,2...5), biorthogonal (biorN, N = 1.1,1.3...6.8), reverse biorthogonal (rbioM, M = 1.1,1.3...6.8) and discrete approximation of Mayer (dmey), with different levels (1,2...10), they form a group of forty two orthogonal bases submitted. Be noticed that N, M and P represent the order of such functions.

In Figure 5, it is shown the results obtained with some of the cases tested using Haar (a), Daubechies 4 (b), Daubechies 6 (c), Coiflet 1 (d) and Symlet 2 (e) bases respectively. These tests with the objective of detecting alterations in the current that allows to determine the initial and final instant of circuit breaker opening and closing of the phase current that originated the fault, after making several tests, it was chosen level 1 of decomposition for the detection of the initial time of operation, because Wavelet Transform presents a better response in time and the level 4 for the detection of the final time, where an appropriate response in frequency (moment of arc extinction) is obtained in the circuit breaker opening operation. It is under those decompositions that the circuit breaker time operating methodology, was apply.

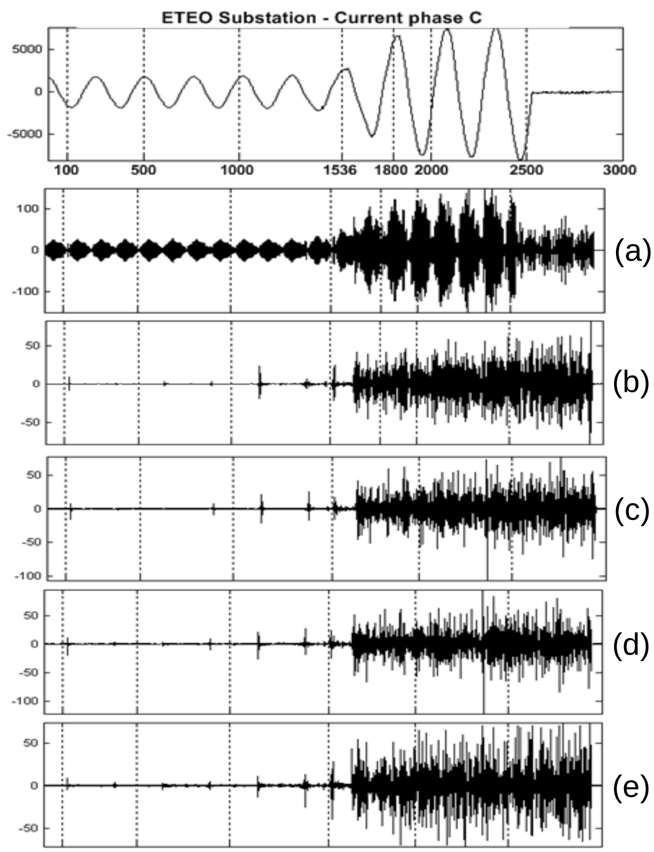

Figure 5. Result of the Phase C analyzes using different Wavelet Base.

The results obtained with bases Haar and dmey, as well as bases sym1 and coif1, were not appropriate to this type of analysis, as such application demands better resolution in frequency. On the other hand, the dbN, that possesses softer behavior, offers decomposition answers in multiple resolutions that will indicate the location of alterations clearly, as well as the detection of the same, especially the db4.

It is pointed out that bases dbN (N = 4,5...10), symM (M = 6,7 and 8), biorN (N = 4.0...6.8), and coifP (P = 4 and 5) are framed to the same profile analysis to detect alterations obtained with the db4. Contrarily, bases db2, db3, sym2, sym3 and coif2 present results that can indicate mistakes in a detection process of the alterations, showing the presence of inexistent frequencies in the original signal or precision loss in the detection of the involved times.

Figure 6, shows the decomposition process of the current in phase C (S), after the triggering command of the circuit breaker opening in the last four cycles before its total extinction, the Wavelet db4 was used and can be observed the alterations detected and the possible initial (IT1) and final (FT1) instants of the circuit breaker opening operation (arrows).

The starting instant of the opening process (IT1) occurs after 3 to 4 ms of the digital protection relay departure, which is the time that spends the auxiliary relay to close his digital contact for triggering the circuit breaker shown in detail 1 (d1). The final instant (FT1) of interruption of the current when passing through zero is suitable for the beginning of a larger alteration in the decomposition signal shown in detail 4 (d4).

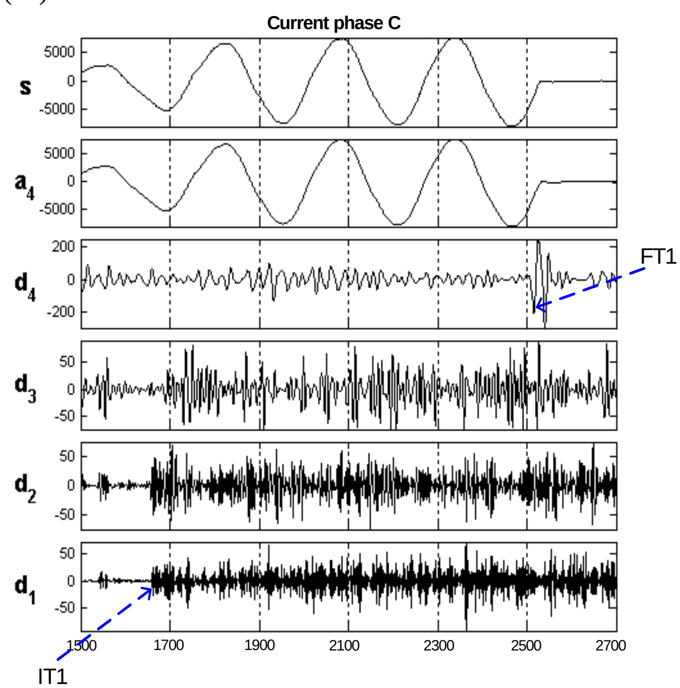

Figure 6. Phase C current decomposition during the circuit breaker opening operation using the db4 WT.

The presence of frequencies different from 60 Hz in the moment of the circuit breaker operation confirm the variations present in detail1 (d1) of db4 Wavelet Transform, indicating the beginning of the main contacts' physical separation, inside the circuit breaker chamber.

V. RESULTS COMPARISON

As commented previously, to do the evaluation of the operation times algorithm calculation was used the information provided by the developed monitoring system. Figure 7, illustrates the coil current opening operation of the three phases collected on 13/07/05 at 07:51:03 hours, where, it can be appreciated that the opening time of each phase is approximately 15 to 16ms.

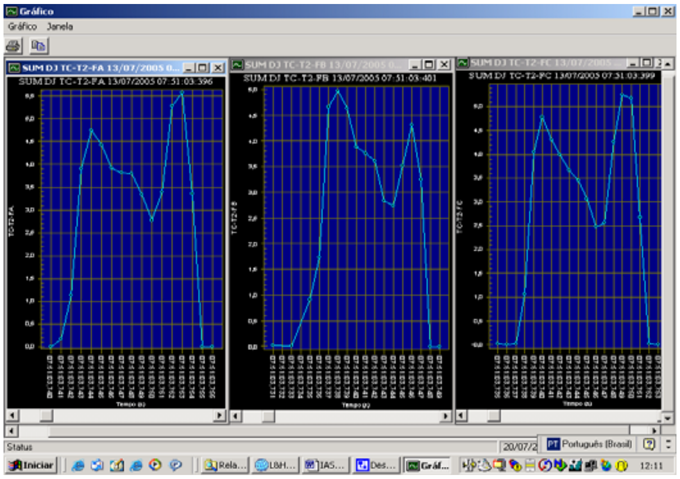

Figure 7. Circuit Breaker opening coil currents.

Figure 8, shows the three phases current oscillographies in the CB opening moment.

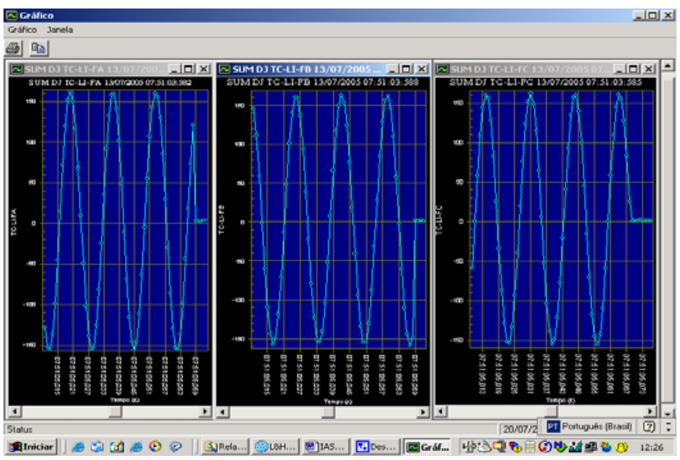

Figure 8. Circuit Breaker current oscillographies.

After the WT Daubechies (db4) was applied with five decomposition levels to each one of the oscillographies shown in Figure 8, it was obtained the results illustrated in Figures 9, 10 and 11 for the phases A, B and C, respectively.

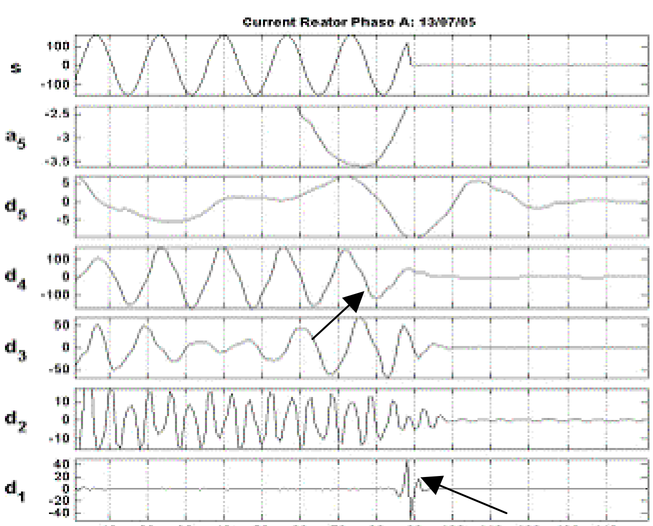

Figure 9. Phase A current decomposition using db4.

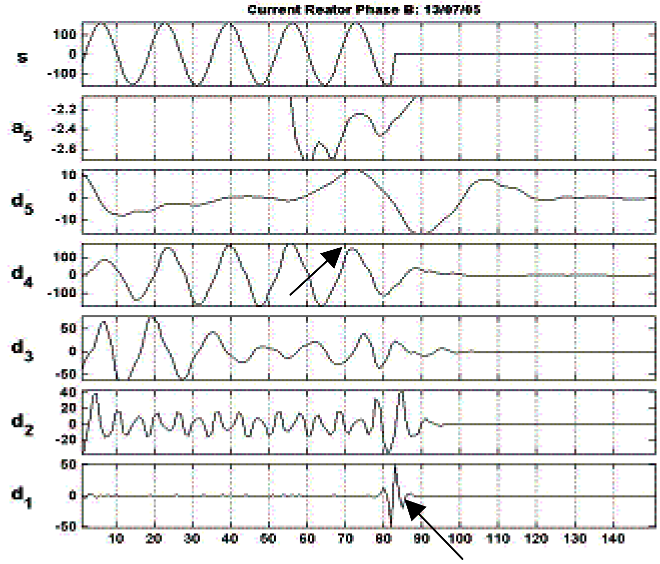

Figure 10. Phase B current decomposition using db4.

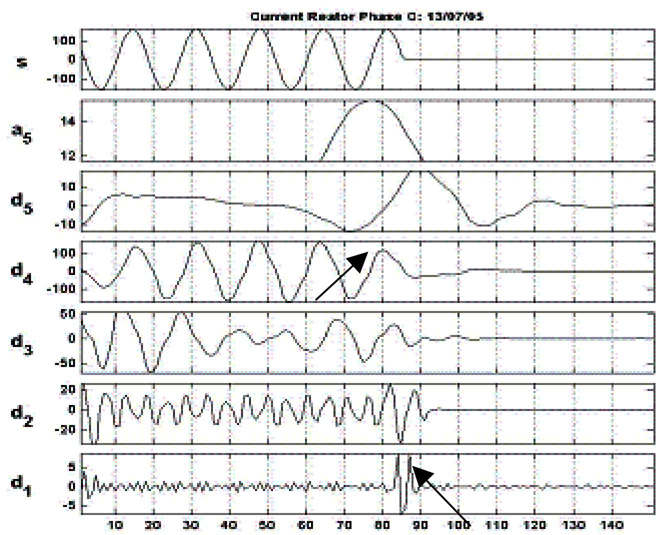

Figure 11. Phase C current decomposition using db4.

It was done the decomposition until the fifth level, because this frequency (960Hz) is smaller than the cutoff frequency of the measuring current transformer, which is 1KHz. In Figures 9, 10 and 11, it can be observed in the detail (d1) and (d4) waves where the opening time established is approximately 15ms which it is similar to that obtained by the coil monitoring system considering the sampling rate of one millisecond.

VI. CONCLUSION

The present work presented a study with behavioral analysis of different families of Wavelet bases with the objective of identifying which of these bases are better adapted to the study in subject.

The MRA technique, using Wavelets allows to determine versions of details (D) and approximations (A) capable to detect any alterations in the current, once the bases used for the analysis possess characteristics that allow to distinguish the levels of frequencies of the normal signal and of the alterations. Thus, this work proposed a study of seven types of Wavelets mothers: Haar, Daubechies, Symlet, Bior, Rbio, Dmey and Coiflet, that form a group of forty two different bases, having restricted only to the orthogonal Bases.

The analysis of such disturbances present in the circuit breaker current was realized using MRA, having identified some base Wavelets as more appropriate for the study of the operation times. The behavior of the Wavelet base function is fundamental in the performance of the analyses, as Wavelets with softer behaviors allow better resolution in the frequency domain, while Wavelets that possess great variations in small time intervals characterize better resolution in the time domain.

It could be observed that by increasing the order of orthogonal Wavelet mothers, their behavior in softness offer better frequency resolution. So, Daubechies and Symlet Wavelets of superior order to four and Coiflets of superior order to three offer better results, this in relation to the orthogonal Wavelet Bases used in this work. Such result, associated to the easiness of calculations involved, justifies the wide use of Daubechies Wavelet of fourth order (db4) for analyses of the circuit breaker operation times. On the other hand, for presenting behaviors with smaller softness, the other bases (dbN, N = 1...3, symM, M = 1...3 and coifP P = 1...3) are unviable for the application in this work.

Another application could be the determination of the wear-out or damage of the main contacts through the comparison between the first detail signatures of the signal collected with the first detail of the reference signal to the normal operation (new circuit breaker). Thus, differences among these waveforms will indicate the presence of alterations (wear or damage). These signals being able to be compared evaluating the ratio between the average of the first detail of the input signal data window and the reference signal, enabling the estimation of different wear-out degrees.

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