Protection of power transformer against inrush currents by using DSP techniques

Chilaka.Ranga, Navneet Thakur, Neelam Srinivasulu

***Abstract*- Transmission and distribution networks should be tailored to function smoothly for reliable evacuation of power from generating power plants. Catastrophic failures in the power transformers may lead to capital and human loss. Therefore frequent online monitoring of the same is must. To avoid the needless trip of power system relays by magnetizing inrush current, the second harmonic component is commonly used for blocking differential relay in power transformers. The major drawback of the differential protection of power transformer is the possibility for false tripping caused by the magnetizing inrush current during transformer energization. In this situation, the second harmonic component present in the inrush current is used as a discrimination factor between fault and inrush currents. This paper presents the development of a wavelet based scheme, for distinguishing between transformer inrush currents and power system fault currents, which proved to provide a reliable, fast, and computationally efficient tool.**

Index Terms—: Power system faults, power transformers, inrush currents, wavelet transform, protective relaying, transformers, transforms transient analysis, wavelet transforms (WTs).

I. Introduction

The fault analysis of a power system is required in order to provide information for the selection of switchgear, setting of relays and stability of system operation. A power system is not static but changes during operation and during planning (addition of generators and transmission lines).Thus fault studies need to be routinely performed by utility engineers.

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Faults usually occur in a power system due to insulation failure, flashover, physical damage or human error. These faults may either be three phases in nature involving all three phases in a symmetrical manner, or may be asymmetrical where usually only one or two phases may be involved. Faults may also be caused by either short-circuits to earth or between live conductors, or may be caused by broken conductors in one or more phases. Sometimes simultaneous faults may occur involving both short-circuit and broken conductor faults (also known as open-circuit faults). Balanced three phase faults may be analysed using an equivalent single phase circuit. With asymmetrical three phase faults, the use of symmetrical components help to reduce the complexity of the calculations as transmission lines and components are by and large symmetrical, although the fault may be asymmetrical. Fault analysis is usually carried out in per-unit quantities (similar to percentage quantities) as they give solutions which are somewhat consistent over different voltage and power ratings, and operate on values of the order of unity. In the ensuing sections, we will derive expressions that may be used in computer simulations by the utility engineers.

To avoid the needless trip by magnetizing inrush current, the second harmonic component is commonly used for blocking differential relay in power transformers. The major drawback of the differential protection of power transformer is the possibility for false tripping caused by the magnetizing inrush current during transformer energization. In this situation, the second harmonic component present in the inrush current is used as a discrimination factor between fault and inrush currents. In general, the major sources of harmonics in the inrush currents are

1) Non linearity's of transformer core;
2) Saturation of current transformers;
3) Over excitation of the transformers due to dynamic overvoltage condition;
4) Core residual magnetization;
5) Switching instant.

Previous work on transformer protection includes transformer inductance during saturation flux calculated from the integral of voltage, and the differential current. New methods have been adopted which include ANN, and fuzzy logic. Also, some techniques have been adopted to identify the magnetizing inrush and internal faults. In, a modal analysis in conjunction with a microprocessor-based system was used as a tool for this purpose. In the active power flowing into transformer is used as a discrimination factor, which is almost zero in the case of energization. In a wavelet-based system is used. A wavelet-based signal processing technique, is an effective tool for power system transient analysis and feature

extraction. Some applications of the technique have been reported for power quality assessment, data compression, protection, analysis for power quality problem solution, and fault detection. This paper proposed a new wavelet-based method to identify inrush currents and to distinguish it from power system faults. The second harmonic component is used as the characteristic component of the asymmetrical magnetization peculiar to the inrush. At first, the wavelet transform (WT) concept is introduced. The property of multiresolution in time and frequency provided by wavelets is described, which allows accurate time location of transient components while simultaneously retaining information about the fundamental frequency and its low-order harmonics, which facilitates the detection of transformer inrush currents. The technique detects the inrush currents by extracting the wavelet components contained in the three line currents using data window less than half power frequency
cycle.

II. Wavelet transforms

Wavelet transform has been introduced rather recently in mathematics, even though the essential ideas that lead to this development have been around for a longer periodic of time. It is a linear transformation much like the Fourier transform, however with one important difference: it allows time localization of different frequency components of a given signal. Windowed Fourier transform also partially achieves this same goal, but with a limitation of using a fixed width windowing function. As a result, both frequency and time resolution of the resulting transform will be fixed. In the case of the wavelet transform, the analyzing functions, which are called wavelets, will adjust their time-widths to their frequency in such a way that, higher frequency wavelets will be very narrow and lower frequency ones will be broader. This property of multi resolution is particularly useful for analyzing fault transients which contain localized high frequency components superposed on power frequency signals. Thus, wavelet transform is better suited for analysis of signals containing short lived high frequency disturbances superposed on lower frequency continuous waveforms by virtue of this zoom-in capability. Given a function $f(t)$, its continuous wavelet transform (WT) will be calculated as follows:

$$DWT(f,m,n)=\frac{1}{\sqrt{a0m}}\ \sum_k f(k)\varphi * (\frac{n-ka0m}{a0m})$$

where, the parameters *a* and *b* in Eq.(1) are replaced by *a;* and *ka?*, *k* and *m* being integer variables. In a standard discrete wavelet transform, the coefficients are sampled from the continuous WT on a dyadic grid, *a0* = 2 and *bo* = **1,** yielding *a:* = 1, *U;'* = i, etc. *b* = *k* x 2-', i being an integer variable. Actual implementation of the discrete wavelet transform, involves successive pairs of high-pass and low-pass filters at each scaling stage of the wavelet transform. This can be thought of as successive approximations of the same function, each approximation providing the incremental information related to a particular scale (frequency range), the first scale covering a broad frequency range at the high frequency end of the spectrum and the higher scales covering the lower end of the frequency spectrum however with progressively shorter bandwidths. Conversely, the first scale will have the highest time resolution, higher scales will cover increasingly longer time intervals. While, in principle any admissible wavelet can be used in the wavelet analysis, we have chosen to use the Daubechies4 wavelet as the mother wavelet in all the transformations.

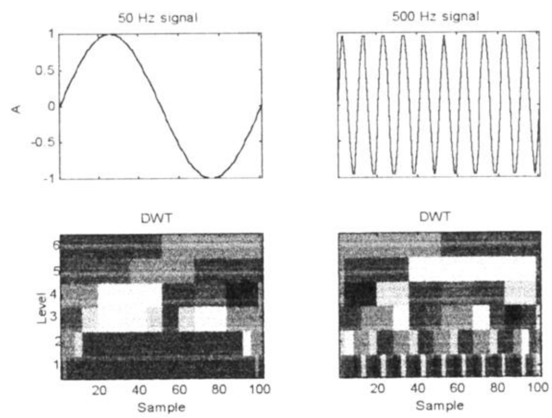


Fig. 1 Time-frequency tiles in DWT of two sinusoids.

A WT expands a signal not in terms of a trigonometric polynomial, but by wavelet, generated using the translation (shift in time) and dilation (compression in time) of a fixed wavelet function called the mother wavelet. The wavelet function is localized in time and frequency yielding wavelet coefficients at different scales (levels). This gives the WT much greater compact support for the analysis of signals with localized transient components. The discrete wavelet transform (DWT) output can be represented in a two-dimensional (2-D) grid in a similar manner as the STFT, but with very different divisions in time and frequency, such that the windows are narrow at high frequencies and wide at low frequencies. In contrast with the STFT, the WT can isolate transient components in the upper frequency isolated in a shorter part of power frequency cycle. In discrete wavelet analysis of a signal, a time–frequency picture of the analyzed signal is set up. The time–frequency plane is a 2-D space useful for idealizing a two properties of transient signals,
localization in time of transient phenomena, and presence of specific frequencies. The signal is decomposed into segments called time–frequency tiles plotted on the plane. The position of the tiles indicates the nominal time, while the amplitude is indicated by shading. As shown in Fig. 1, two sinusoids with 50 Hz, 500 Hz frequency, and a sampling rate 5 kHz, are plotted on the top trace. The DWT is represented by the time–frequency tiles, and the mother wavelet function (db4) is dilated at low frequencies (level-6) and compressed at high frequencies (level-1) so that large windows are used to obtain the low frequency components of the signal, while small windows reflect discontinuities. The ability of WT to focus on short time intervals for high-frequency components and long intervals for low-frequency components improves the analysis

of signals with localized impulses and oscillations. For this reason, wavelet decomposition is ideal for studying transient signals and obtaining a much better current characterization and a more reliable discrimination. It has been shown in a previous paper [18] that the single-level decomposition process in wavelet analysis of a signal simply consists of passing through two complementary filters, i.e., convolving the signal with filter coefficients, called low-pass decomposition (LD) and high-pass decomposition (HD) filters, and by down-sampling the result they emerge as two components called low-frequency and high-frequency coefficients. Taking the appropriate length, up-sampling them and passing the result through two filters, called low-pass and high-pass reconstruction filters, they emerge as the two main components of (called the low-frequency and the high-frequency components of the original signal). This is illustrated in Fig. The composition and reconstruction filters form quadrature mirror filters and are related to what is called the scaling filter. In multilevel wavelet analysis, the composition process can be iterated, with successive low-frequency components being decomposed in turn, so that one signal is broken down into many lower-resolution components. This is shown in Fig. 3, while Fig. 4 shows a typical four-level wavelet analysis of line currents during simultaneous transformer inrush and BCG fault.

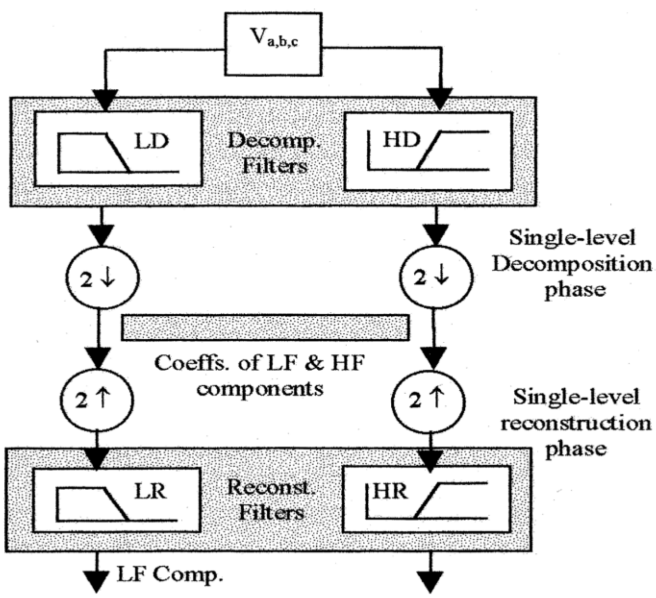


Fig. 2 Single level wavelet decomposition and reconstruction procedure.

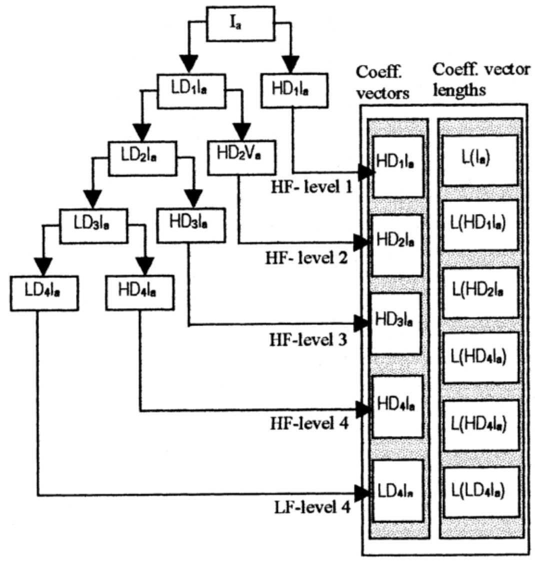


Fig 3 Four-Level wavelet decomposition of line current I . HD; LD: HF, and LF decomposition coefficients respectively L (HD I) length of the HF decomposition coefficients.

Using wavelet function db4 with ten samples, data window, and noting that the filter and its LF decomposition (LD), HF decomposition (HD), LF reconstruction. Using the moving data window approach, and multiplying the row matrix by the 10 samples column matrix of line current, we get a single output sample. Updating the data window by one sample, we get a new output sample, and so on. Based on the 5-kHz sampling rate, it should be noted that the frequency components are confined to wavelet analysis according to the scheme listed in Table I.

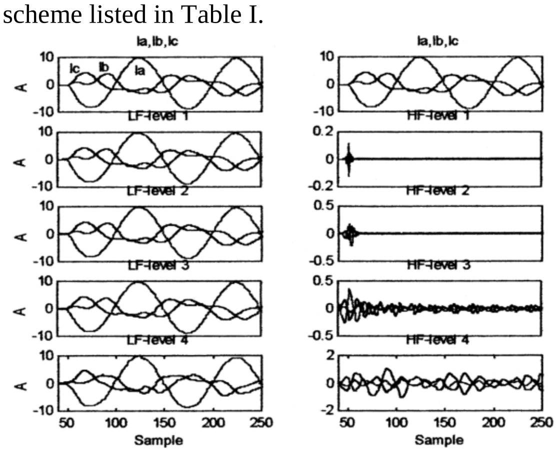


Fig. 4 Four-level wavelet analysis of line current I . Simultaneous transformer inrush and B–C–G fault.

Wavelet Analysis	Frequency components, Hz
Level 1(scale2)	1250-2500
Level 2(scale4)	625-1250
Level 3(scale8)	312.5-625
Level 4(scale16)	156.25-312.5
Level 5(scale32)	78.125-156.25

Table I
FREQUENCY ALLOCATION IN WAVELET ANALYSIS

III. System studied

The system under consideration is the simplified one machine model with a 11/132 kV transformer, with both sides star connected with grounded neutrals. This is shown in Fig. 5.

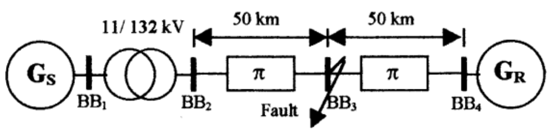


Fig. 5. Model system under consideration.

The transmission line is two 132-kV, 50-km sections. The system is simulated using the MATLAB in which the line was simulated using the lumped parameters model, while the local-end source was simulated using lumped impedance model..

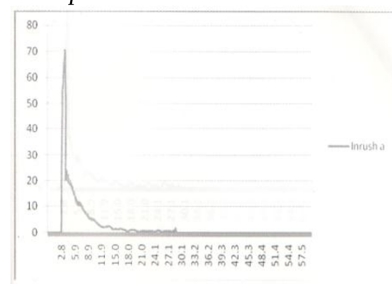
IV. Digital simulations

Digital simulations of the proposed algorithm are carried out using the model system described earlier. The proposed technique is tested using simulated data from the EMTP. The transformer was simulated with 11-kV, Y-connected primary, 132-kV, Y-connected secondary with both neutrals grounded. With the data given in Appendix, subroutine BCTRAN in EMTP is used to obtain transformer parameters. The simulations provide samples of currents in each phase when the transformer is energized or when a fault occurs on the system or when both occur simultaneously. The model transformer exhibited inrush phenomena which produced inrush currents in all three phases. Data from the simulations are used as input to the algorithm to identify its response. A total of 108 fault cases.

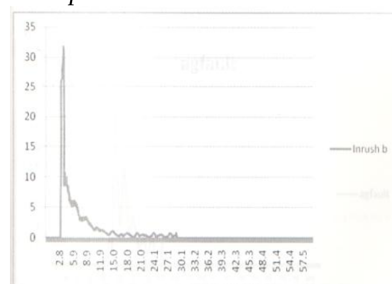
V. Results and analysis

INRUSH CURRENTS:

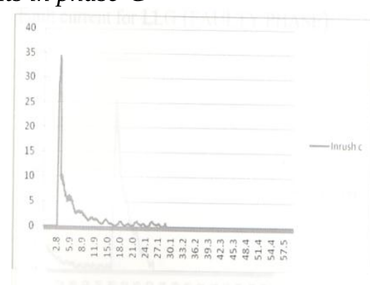
Inrush currents in phase-A



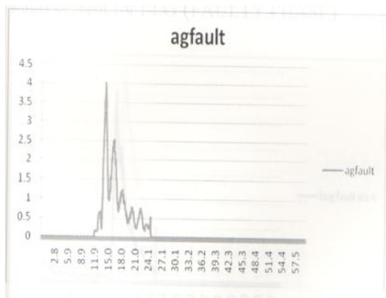
Inrush currents in phase-B



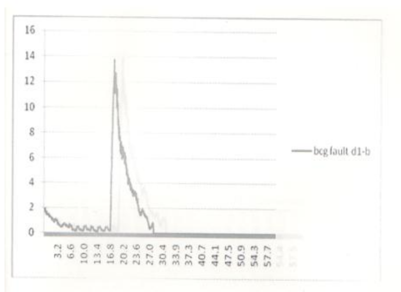
Inrush currents in phase-C



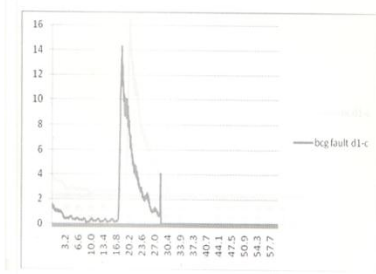
Fault current for LG fault:



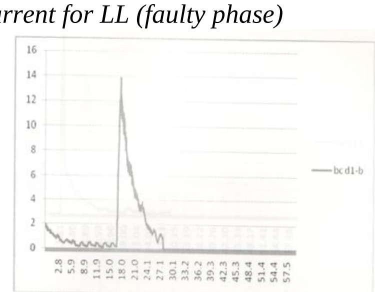
Fault current for LLG (faulty phase)



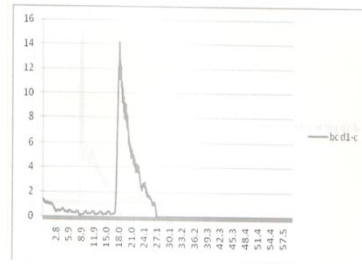
Fault current for LLG (faulty phase)



Fault current for LL (faulty phase)

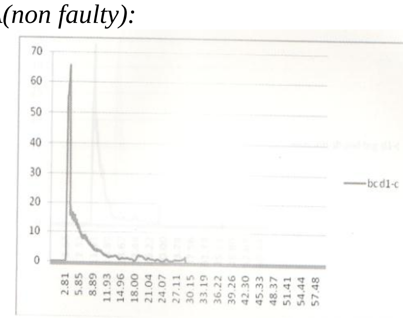


Fault current for LL (faulty phase)

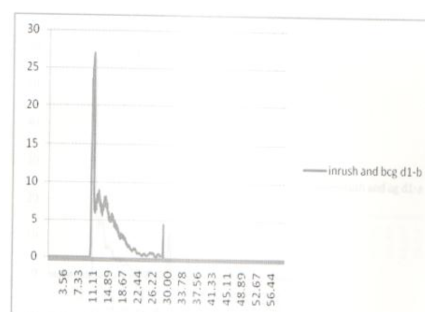


Currents for simultaneous inrush and LLG faults:

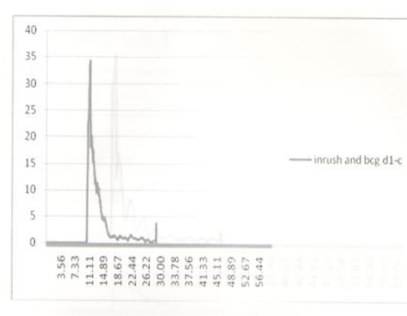
Phase-A(non faulty):



Phase-b(faulty):



Phase C(faulty):



and 12 energization cases were simulated to test the various features of the algorithm. The inrush currents used correspond to energization angles of 90 , 180 , 270 , and 360 from phase-a voltage zero-crossing. The fault resistance, considered to simulate fault currents with the same energization angles, was 0.001, 10.0, and 100.0. A sampling rate of 5.0 kHz has been considered for the algorithm 50 Hz). Simulations have been divided into three main categories: simultaneous fault and inrush conditions, magnetizing inrush conditions only and faulty conditions (LG, LL, and 2LG) only. MATLAB has been used to implement the algorithm using the three line currents derived from the EMTP. In the fault tests, a total of 216 cases were simulated. Those correspond to 108 cases for simultaneous inrush and fault conditions (three different source capacities, three different fault types, three different fault resistance, and four different fault inception angles), and 108 cases for fault conditions without inrush currents. Figs. 6–11 show example test digital simulation results: the three line current waveforms along with their resulting discrete wavelet analysis (absolute coefficients), and their frequency spectrum. In all of the tests, the magnetizing inrush current was characterized by the presence of considerable second harmonic components. Observing DWT trace, the high-frequency impulse components in the line currents of the three phases, if present, appear in level 1[1250–2500 Hz]. In successive scales, the relative amount of energy in each frequency band is shown by the magnitude and duration of the oscillations. The bulk of energy in the transient appears in level-4 (the lower frequency). The transient energy is filtered through successive stages.

VI. Feature extraction scheme

By detecting two successive peak and bottom, or bottom and peak of the three line current, and counting the number of samples between them, the phase subjected to inrush current can be identified. Peak detection is carried out by computing the difference between every two successive current samples. A change in its sign from positive to negative indicates a peak while change from negative to positive indicates a bottom. In case of inrush just after switching on, the second harmonic is predominant (25 samples/half cycle), while faulty or healthy conditions are characterized by 50 samples/half cycle. The algorithm issues a zero output if the number of samples is greater than 30, while it issues the actual computed number of sample if it is less than 30 samples, which is translated to seconds/cycle (25* 2/5000=0.01 s). This is explained in Figs. for different inrush, simultaneous inrush, and fault conditions.

VII. Conclusion

The application of WT reveals that each waveform has distinct features. Using features in the waveform signature, automated recognition can be accomplished. The use of WTs as a feature extraction naturally emphasizes the difference between fault and inrush currents as generated by the MATLAB, since their frequencies are very different. This paper demonstrates that the algorithm successfully differentiates between magnetizing inrush and fault conditions in less than half power frequency cycle. The classification scheme is powerful yet the required calculations are simple (10 multiplications and 10 additions each sampling interval) and that data window required for the algorithm is less than half the power frequency cycle (40 samples based on 5 kHz sampling rate). It can actually be implemented in real time. In general, WTs used in analyzing power system transients provide valuable information for use in feature detection systems. In the above figures shown the inrush current can be discriminated from fault using magnitude and duration as inrush has more magnitude and less duration compared to fault.

	A	B	C
Inrush	3-4ms	3-4.1ms	3-4ms
Fault(LL)	-	18-27.1ms	17.9-27.1ms
Fault(LG)	11.9-24.1ms	-	-
Fault(LLG)	-	16.8-27.4ms	17-29ms

Table-II

VIII. References

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