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Research Paper

POWER TRANSFORMER PROTECTION USING WAVELETS

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Any power transformer protective scheme has to take into account the effect of magnetizing inrush currents. Since during the energisation of the transformer, inrush current results in 10 times full load currents and can cause maloperation of the relays. The ratio of the second harmonic to the fundamental harmonic of the inrush current is greater than that of the fault current. The second harmonic in these situations might be greater than the second harmonic in inrush currents. This paper describes the protection of power transformer from fault condition, i.e., internal faults from inrush currents by using the Wavelet based differential protection scheme. It is shown that the features extracted by the wavelet transform have a more distinctive property than those extracted by the fast Fourier transform due to the good time and frequency localization characteristics of the wavelet transform.

Keywords: Power transformer, Wavelet transform, Detailed coefficient, Fast fourier transforms

INTRODUCTION

The design of protective relay has to consider various nonlinear effects, which may cause malfunction of the relay equipments. The conventional technique based on second harmonic restrain has complexity in distinguishing between internal fault, inrush current, CT saturation and over excitation thereby effecting transformer stability (Rah Man and Jeyasurya, 1988; Elmore, 1994; and Horowitz and Phadke, 1995). Alternative improved protection techniques based on transient detection were developed for accurate and efficient discrimination. But in these proposed methods the extraction techniques are based on either time or frequency domain signals, but it becomes very important to extract both time and frequency features of the signal for accurate discrimination between an internal fault and other operating conditions (Liu *et al.*, 1992). Moreover to improve system performance an efficient analysis of high frequency and short duration

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events must be done. Hence wavelet transform is chosen for analyzing power transformer transients because of its good ability to extract information from the transient signals in terms of both time and frequency domain (Sidhu *et al.*, 1992).

The technique is to discriminate between an internal fault and the other operating conditions of the power transformer by combining wavelet transform with differential protection scheme. In this proposed method, different fault conditions and inrush condition at no load and no fault conditions are created. After that, a program is written in the M-file of MATLAB and run after each time at different faults, inrush case, without fault Case at different switching instants and checked the sum of detailed coefficient sum over half cycle after the fault has created and compared the differential currents sum with the restraining currents sum based on this which the relay operates for the protection of power transformer.

In this research article the power transformer is simulated in MATLAB/ SIMULINK environment in different operating conditions and the transient differential and restraining signals are analyzed using Daubechies 6 wavelet at level 3. The sum of differential and restraining components (after decomposition) are computed and they are compared for the relay to take action.

WAVELET TRANSFORM

DWT is an ideal way to capture the transient phenomena for transformer. The wavelet transform gives the frequency information of the signal and also the times at which these frequencies occur. Combining, these two properties make the Fast Wavelet Transform (FWT), an alternative to the conventional Fast Fourier Transform (FFT). Wavelet is a waveform of limited duration. Wavelets tend to be irregular, asymmetric, short and oscillatory waveforms. To detect the transformer faults, only dominant transients within the certain bands play the important role. Therefore the wavelet filter banks are designed to extract the required transient currents. DWT is capable of extracting both fast and slow events in a desired resolution. The DWT of a signal x is calculated by passing it through a series of filters. First the original signal $x[n]$ is passed through a half band low pass filter with impulse response $g[n]$, resulting in a convolution of the two.

$$y[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k] \cdot g[n-k] \qquad ...(1)$$

where x is the signal in discrete time function.

The sequence is denoted by $x[n]$, n is an integer, $g[n]$ is the impulse response of the low pass filter and $y[n]$ is the output of the filter. The signal is also decomposed simultaneously using a half band high-pass filter $h[n]$. The outputs from the high pass filter give the detail coefficients and the outputs from the low-pass filter give the approximation coefficients. It is important that the two filters are related to each other and they are known as a quadrature mirror filter. However, since half of the frequencies of the signal have now been removed, half the samples can be discarded according to Nyquist's rule. The filter outputs are then down sampled by 2. Hence the Equation (1) becomes,

$$y[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k] \cdot g[n-k] \quad ...(2)$$

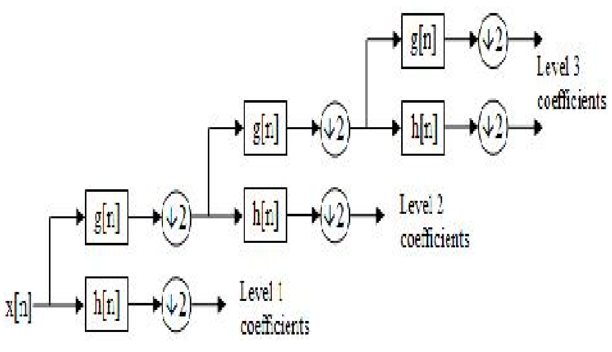
$$y[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k] \cdot g[2n-k] \quad ...(3)$$

This decomposition has halved the time resolution since only half the number of samples now characterizes the entire signal. However, this operation doubles the frequency resolution, since the frequency band of the signal now spans only half the previous frequency band. The Block diagram of filter analysis is shown in Figure 1.

SINGLE LINE DIAGRAM OF THE SYSTEM UNDER STUDY

The single line diagram of a three phase power transformer is as shown in Figure 2 given below. It consists of circuit breakers, current transformers, and a Y-Y connected three phase power transformer. Simulation is carried out by using MATLAB/SIMULINK.

Figure 1: Block Diagram of Filter Analysis



SIMULATION DIAGRAM

The parameters of the simulation model are tabulated in Table 1.

The data of transient signals is exported to MATLAB workspace. The data in the workspace is decomposed to Detail coefficients and Approximation coefficients using the wavelet tool box. The decomposition is done by applying wavelets of mother wavelet 'bior5.5' wavelet with at level 2. The approximation and detail levels are observed such that inrush is seen at d1 in which initially a small spike occurs and next large spike

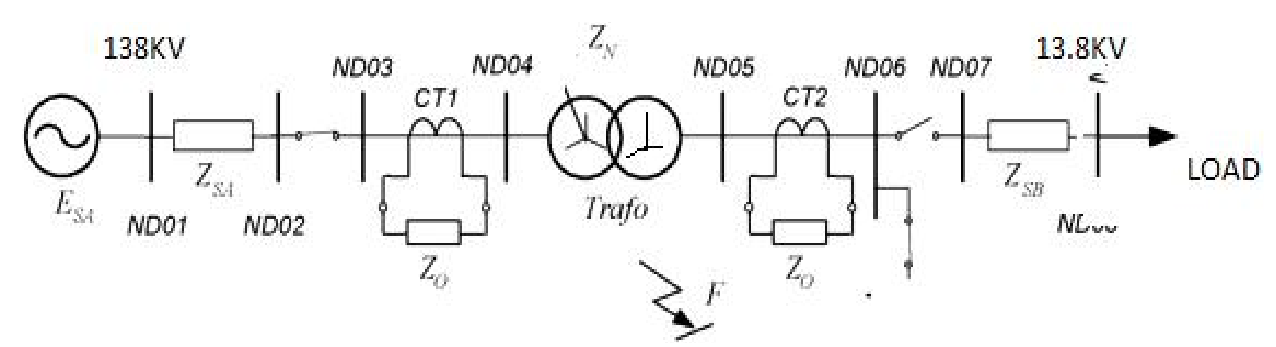
Table 1: Three Phase Voltage Source Parameters

Phase-Phase RMS Voltage	138 KV
Frequency	50 Hz
Phase Angle of Phase a	0°

Table 2: Three Phase Transformer Block Parameters

Three Phase Power	15 MVA
Nominal Power	1 MVA
Frequency	50 Hz

Figure 2: Single Line Diagram



occurred. The circuit breakers are opened at the switching time of 2/50 and proceeds up to 15/50 in which the switching times are taken the frequency of cycles taken as 10/50 so that, that much frequency of samples occur in the simulation. The same procedure is repeated for the next phases. And also for different phase angles, at different switching times.

SIMULATION RESULTS

Because of the facility to allow the use of variable window length, WT is useful in analyzing transient phenomena such as those associated with line faults and/or switching operations. Unlike FT, wavelet analysis has the ability to analyze a localized area of a signal and can reveal aspects of data like break points, discontinuities, etc. WT is thus useful in detecting onset of a fault and in realizing non stationary signals comprising both low and high frequency components.

Figure 4 shows the three phase currents on secondary side of the power transformer under full-load condition.

Figure 5 shows three phase current waveforms during A-G fault at a fault incidence of 90 degrees.

Figure 6 shows three phase current waveforms during A-B fault at a fault incidence of 135 degrees.

The power transformer is operated under different operating conditions such as under no-load, different loading conditions, during energization, and different fault cases at different fault incidents. At each case the sum of the differential currents and restraining currents over a half cycle are computed in each phase and they are tabulated as shown in the appendix. From the results it is clear that during magnetizing inrush, the sum of differential components over a half cycle is less than those of restraining components and it is quite opposite in the case of internal fault case. This in how inrush current can be distinguished from internal fault current and hence the power transformer can be protected.

Figure 3: Simulation Results for Inrush Currents at a Fault Incidence Angle of 0°

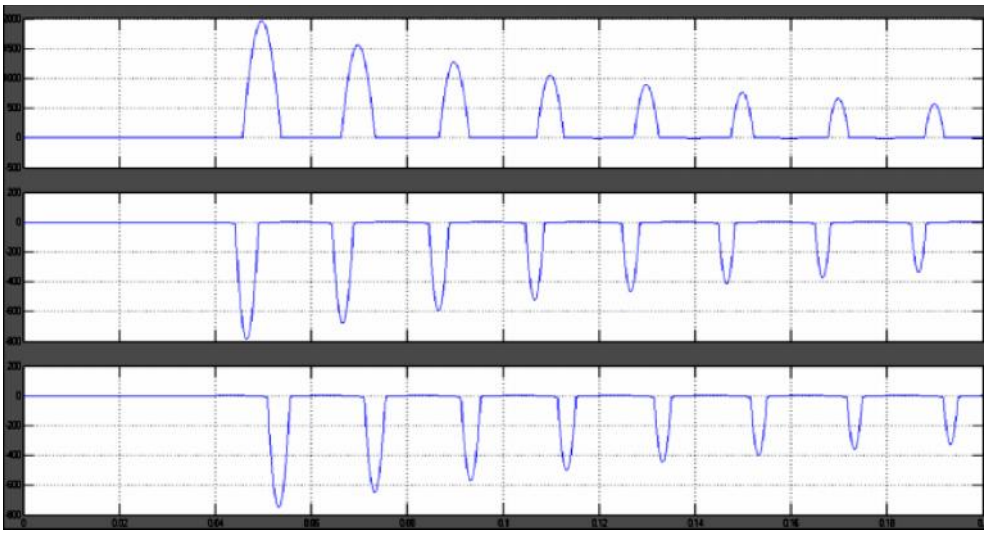


Figure 4: Three Phase Currents on Secondary When the Transformer is Fully Loaded at a Fault Incidence of 45 degrees

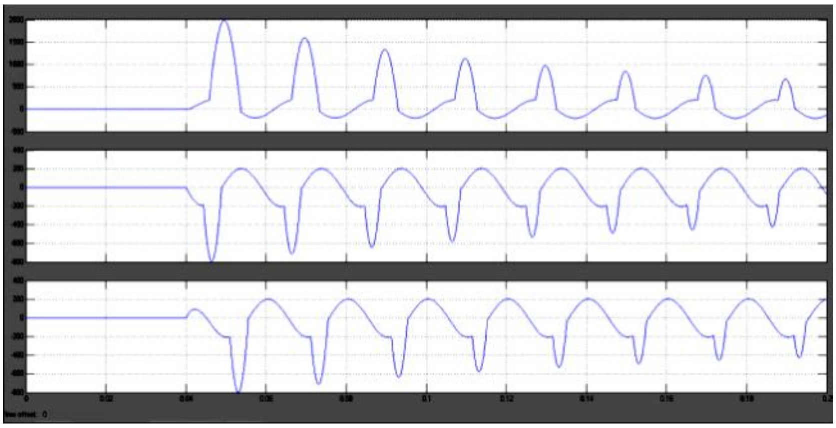


Figure 5: Phase A-G Fault

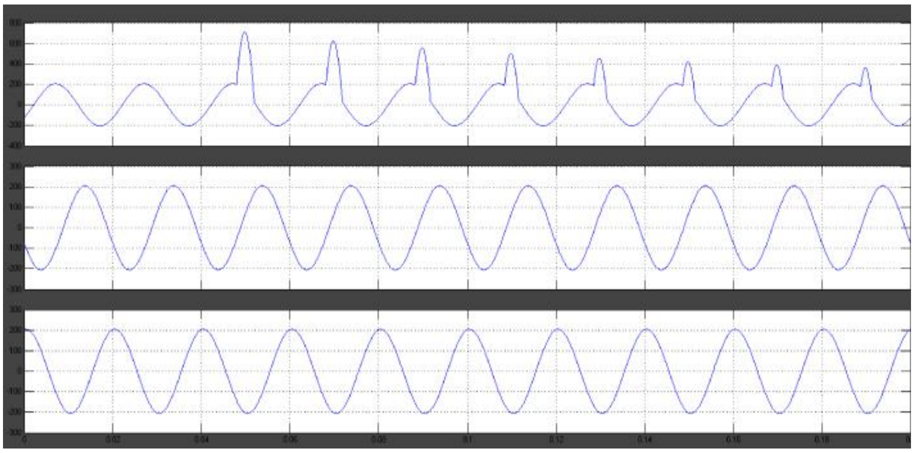
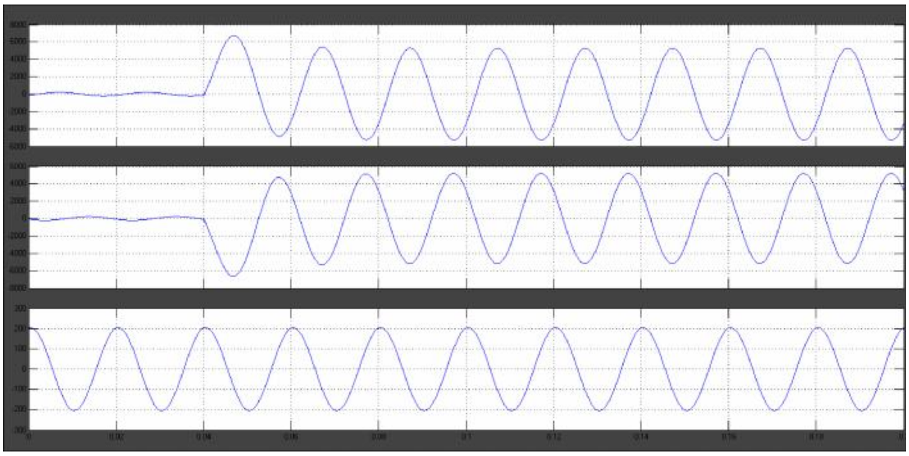


Figure 6: Line A-B at a Fault Incidence Angle of 270 degrees



CONCLUSION

Extensive simulation studies have shown that the wavelet transforms of magnetizing inrush currents and internal fault currents have the following different features. For fault cases shown in Figs above, we can clearly see that the sum of the detailed coefficients of the operating quantities over half cycle is greater than the sum of the detailed coefficients of the restraining currents at level 2. However, in case of inrush currents and no fault conditions sum of the operating quantities is less than the restraining quantities.

REFERENCES

1. Bastard P, Meunier M and Regal H (1995), "Neural Network-Based Algorithm for Power Transformer Differential Relays", *IEEE Proc., Generation, Transmission Distribution*, Vol. 142, No. 4, pp. 386-392.
2. Elmore W A (1994), *Protective Relaying Theory and Applications*, ABB Power T&D Company Inc., Relay Division, Coral Springs, FL.
3. Horowitz S H and Phadke A G (1995), *Power System Relaying*, 2nd Edition, Research Studies Press Ltd., Somerset, UK.
4. Liu P, Malik O P, Chen D, Hope G S and Guo Y (1992), "Improved Operation of the Differential Protection of Power Transformers for Internal Faults", *IEEE Trans. Power Delivery*, Vol. 7, No. 4, pp. 1912-1919.
5. Perez LG, Flechsig A J, Meador J L and Obradovic Z (1994), "Training an Artificial Neural Network to Discriminate Between Magnetizing Inrush and Internal Fault", *IEEE Trans. Power Delivery*, Vol. 9, No. 1, pp. 434-441.
6. Rahman M A and Jeyasurya B (1988), "A State-of-the-Art Review of Transformer Protection Algorithms", *IEEE Trans. Power Delivery*, Vol. 3, No. 2, pp. 534-544.
7. Sidhu T S, Sachdev M S, Wood H C and Nag Pal M (1992), "Design, Mplementation and Testing of a Microprocessor-Based High-Speed Relay for Detecting Transformer Winding Faults", *IEEE Trans. Power Delivery*, Vol. 7, No. 1, pp. 108-117.

APPENDIX

0° of Fault Incidence	**Sda**	**Sra**	**Sdb**	**Srb**	**Sdc**	**Src**
inrush	1.2648e-07	7.1801e-05	3.194e-07	2.6629e-05	2.8972e-07	4.1333e-05
Sec is at no load	1.3459e-08	1.6459e-04	2.1832e-08	1.6832e-04	1.1114e-8	1.6914e-04
Phase A-G fault	398.9058e+02	188.9058	3.5699e+02	1.5799	1.7415e+02	1.1915
Line A-B fault	299.4827e+03	99.4827	313.0067e+03	33.007	1.1957e+03	11.1957
45° of Fault Incidence	**Sda**	**Sra**	**Sdb**	**Srb**	**Sdc**	**Src**
inrush	2.2648e-07	8.1801e-05	4.194e-07	3.6629e-05	3.8972e-07	5.1333e-05
Sec is at 1/8th full-load	2.3459e-08	2.6459e-04	3.1832e-08	2.6832e-04	2.1114e-8	2.6914e-04
Phase A-G fault	498.9058e+02	288.9058	4.5699e+02	2.5799	2.7415e+02	2.1915
Line A-B fault	399.4827e+03	100.4827	413.0067e+03	43.007	2.1957e+03	21.1957
90° of Fault Incidence	**Sda**	**Sra**	**Sdb**	**Srb**	**Sdc**	**Src**
inrush	3.2648e-07	9.1801e-05	5.194e-07	4.6629e-05	4.8972e-07	6.1333e-05
Sec is at 1/4th full-load	3.3459e-08	3.6459e-04	4.1832e-08	3.6832e-04	3.1114e-8	3.6914e-04
Phase B-G fault	598.9058e+02	388.9058	5.5699e+02	3.5799	3.7415e+02	3.1915
Line B-C fault	499.4827e+03	101.4827	513.0067e+03	53.007	3.1957e+03	31.1957
135° of Fault Incidence	**Sda**	**Sra**	**Sdb**	**Srb**	**Sdc**	**Src**
inrush	4.2648e-07	7.1801e-05	3.194e-07	2.6629e-05	2.8972e-07	4.1333e-05
Sec is at 3/8th full-load	4.3459e-08	1.6459e-04	2.1832e-08	1.6832e-04	1.1114e-8	1.6914e-04
Phase B-G fault	698.9058e+02	188.9058	3.5699e+02	1.5799	1.7415e+02	1.1915
Line B-C fault	699.4827e+03	99.4827	313.0067e+03	33.007	1.1957e+03	11.1957
180° of Fault Incidence	**Sda**	**Sra**	**Sdb**	**Srb**	**Sdc**	**Src**
inrush	1.2648e-07	7.1801e-05	3.194e-07	2.6629e-05	2.8972e-07	4.1333e-05
Sec is at half full-load	1.3459e-08	1.6459e-04	2.1832e-08	1.6832e-04	1.1114e-8	1.6914e-04
Phase C-G fault	398.9058e+02	188.9058	3.5699e+02	1.5799	1.7415e+02	1.1915
A-C fault	299.4827e+03	99.4827	313.0067e+03	33.007	1.1957e+03	11.1957
225° of Fault Incidence	**Sda**	**Sra**	**Sdb**	**Srb**	**Sdc**	**Src**
inrush	3.2648e-07	8.1801e-05	4.194e-07	2.6629e-05	2.8972e-07	4.1333e-05
Sec is at 5/8th full-load	2.3459e-08	1.6459e-04	2.1832e-08	1.6832e-04	1.1114e-8	1.6914e-04
Phase C-G fault	498.9058e+02	188.9058	3.5699e+02	1.5799	1.7415e+02	1.1915
A-C fault	799.4827e+03	99.4827	313.0067e+03	33.007	1.1957e+03	11.1957
270° of Fault Incidence	**Sda**	**Sra**	**Sdb**	**Srb**	**Sdc**	**Src**
inrush	1.2648e-07	7.1801e-05	3.194e-07	2.6629e-05	2.8972e-07	4.8333e-05
Sec is at 3/4th full-load	1.3459e-08	1.6459e-04	2.1832e-08	1.6432e-04	1.1714e-8	1.9914e-04
Phase C-G fault	398.9058e+02	188.9058	3.5699e+02	1.5799	1.0415e+02	1.1915
A-C fault	299.4827e+03	99.4827	313.0067e+03	33.007	1.1957e+03	11.1957

APPENDIX (CONT.)

315° of Fault Incidence	Sda	Sra	Sdb	Srb	Sdc	Src
inrush	9.2648e-07	17.1801e-05	11.194e-07	10.6629e-05	10.8972e-07	4.1333e-05
Sec is at full-load	9.3459e-08	9.6459e-04	10.1832e-08	9.6832e-04	9.1114e-8	9.6914e-04
Phase C-G fault	407.9058e+02	197.9058	11.5699e+02	9.5799	9.7415e+02	9.1915
A-B-C fault	307.4827e+03	107.4827	320.0067e+03	40.007	9.1957e+03	19.1957

Note: Sda: Sum of the differential components in phase A over a half cycle from the fault incidence.
Sdb: Sum of the differential components in phase B over a half cycle from the fault incidence.
Sdc: Sum of the differential components in phase C over a half cycle from the fault incidence.
Sra: Sum of the restraining components in phase A over a half cycle from the fault incidence.
Srb: Sum of the restraining components in phase B over a half cycle from the fault incidence.
Src: Sum of the restraing components in phase C over a half cycle from the fault incidence.