2003년도 대한전기학회 전력기술부문회 추계학술대회 논문집(2003.11.13~15)

A Current Compensation Algorithm for a CT Saturation

*Xiao-Li Yi, *Sang-Hee Kang, *Dong-Gyu Lee, **Yong-Cheol Kang
*Myongji University Next-Generation Power Technology Center, **Chunbuk University

CT 포화 복원 알고리즘

*이효력, 강상희, 이동규 **강용철
*명지대학교 차세대전력기술연구센터 **전북대학교

Abstract - In this paper, an algorithm to compensate the distorted signals due to CT(Current Transformer) saturation is suggested. Firstly, WT(Wavelet Transform) is used to detect a start point and an end point of saturation. Filter banks which can be easily realized in real-time applications are employed in detecting CT saturation. Secondly, least- square curve fitting method is used to restore the distorted section of the secondary current. Fault simulations are performed on a power system model using EMTP(Electromagnetic Transient Program). A series of test results indicate that WT has superior detection accuracy and the proposed algorithm which shows very stable features under various levels of remanent flux is also satisfactory.

Keywords : Wavelet Transform, CT Saturation,
Least-Square Fitting

1.INTRODUCTION

As power systems have grown from the viewpoint of complexity and size, the level of fault currents has been increased. Therefore, protective relays play a more important role than before. For these relays, it is essential to provide accurate information of current signals in undesirable conditions. Ideally, the secondary current of a CT(Current Transformer) should have the same wave-shape to its corresponding primary current with a scaled-down magnitude for correct relay operations. But since a CT is a kind of transformer, saturation of magnetic flux in the core may occur when a large primary current flows. This saturation makes the secondary current distorted, thus CT could not feed correct information into relays and measuring instruments and then mal-operation may happen.

In this paper, to detect the start and end points of distorted current signal, wavelet transform is implemented by way of the multi-resolution filter banks , which can be easily realized in real-time application. The reference [1] also used wavelet analysis to detect the onset of distortion due to CT saturation. But it could not meet real-time demands.

Much effort has been put into the development of effective and efficient compensation methods for CT saturation[1-3]. A least-square curve fitting algorithm is used to restore the signal by the feature extracted from the healthy section.

A series of test results indicate that WT has superior detection accuracy and the proposed algorithm which shows very stable features under various levels of remanent flux is also satisfactory.

2. CT SATURATION WITH REMANENT FLUX

2.1 CT saturation

It's well known that above the knee-point of the magnetization curve, the exciting current drawn by the core saturation increases far more rapidly than under the knee-point. Thus, the ratio error of CTs becomes more severe rapidly, and this is called CT saturation.

Fig. 1 Model system

The general experience with conventional static or electromagnetic relays does not indicate that remanence is a serious problem in a certain point of view, but it can cause serious problems with digital relays. Distorted secondary currents can threaten dependability and security of relays, especially current differential relays, and this kind of influence may have a detrimental effect on relay operation.

Table 1 Effect of Remanent Flux

Parameter	Range	Test Time
Remanent Flux	-50%~ 80%	14

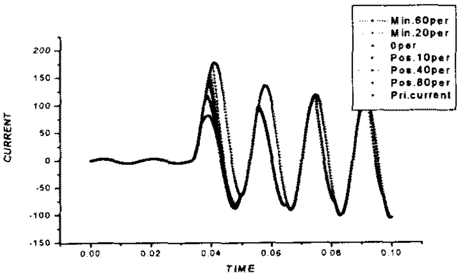


Fig. 2 Various cases of CT saturation

Various conditions having different remanent flux in a CT core were simulated in a model system shown in Fig. 1. Table 1 shows the conditions of the remanence in the CT. EMTP simulation is done with the model system. Fig.2 shows the significant effect of the remanence on the secondary currents. The extent of the distortion becomes gradually more severe as the remanence increases.

2.2 CT characteristics

The pseudo nonlinear reactor component (type 96 Unit)is used in this simulation. A support routine, HYSTERESIS exists within the EMTP for calculating the characteristics. A 2000:5(a turns ratio of 400) CT was selected, and its hysteresis characteristic is shown in Fig. 3.

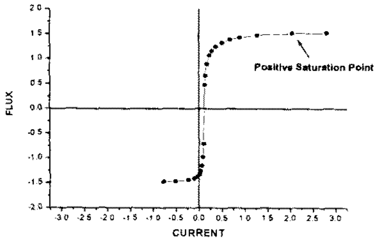


Fig. 3 Hysterisis characteristic of CT

3. SATURATION DETECTION

3.1 introduction of DWT

A "wavelet" is described as a "little" wave, little in the sense of being short duration with finite energy which integrates to zero, and hence its suitability for transients.

Wavelet analysis employs a prototype function called mother wavelet. This function has a mean of zero and sharply decays in an oscillatory fashion. One of the most widely applied mother wavelets suitable for a wide range of power system applications is the Daubechies wavelet, which is ideally suited for detecting low amplitude, short duration, fast decaying and oscillating type of signals, which are typically encountered in power systems.

Mathematically, the Discrete Wavelet Transform (DWT) of a given signal x(t) with respect to a mother wavelet g(t) is generically defined as Eq. (1):

$$DWT(m,k) = \frac{1}{\sqrt{a_0{}^m}} \sum_n x(n) g\left(\frac{k-nb_0a_0^m}{a_0^m}\right) \qquad (1)$$

where $g(\ )$is the mother wavelet, the scaling and translation parameters a and b are functions of an integer parameter $m(a=a_0{}^m,\ b=nb_0a_0{}^m)$ which gives rise to a family of dilated mother wavelets. k is an integer variable that refers to a particular sample number in an input signal. The scaling parameter gives rise to geometric scaling, 1, $1/a_0$, $1/a_0{}^2$, ···. This scaling gives the DWT a logarithmic frequency coverage.

DWT can be implemented by using a multi-stage filter with the mother wavelet as the high-pass filter *H(n)* and its dual as the low-pass filter *L(n)*. As evident from the example considered, down-sampling the output of the low-pass filter *L(n)* by a factor of 2(↓2) effectively scales the wavelet by a factor of 2 for the next stage.

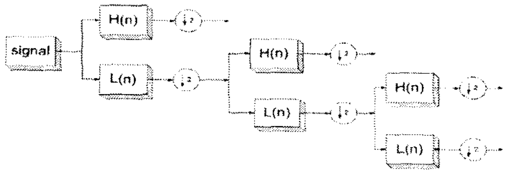
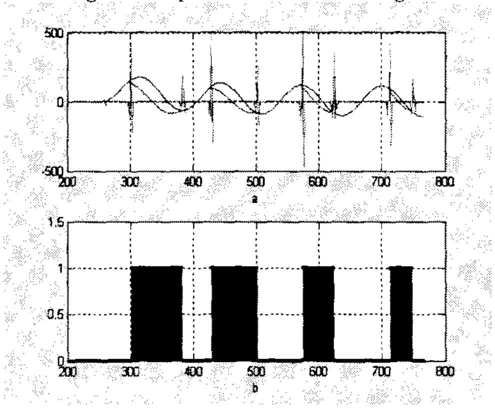


Fig. 4 Filter bank tree of DWT

The implementation of the DWT with a filter bank is computationally efficient. The output of the high-pass filter in Fig. 4 gives the detailed version of the high-frequency component of the signal. The low-frequency component is further split to get the other details of the input signal. By using this technique, any wavelet can be implemented.

Fig. 5 The performance of detecting CT



saturation
(a)Primary & Secondary currents and Output of 2^{nd} High-Pass Filter
(b)Saturated Section

The structure of computations in a DWT and in an octave-band filter bank are identical. In this paper, a two-level filter bank is constructed, and satisfactory results are got from the output of the 2^{nd} high-pass filter.

3.2 simulation and test results

In Fig. 5, we can see that DWT shows the superior detection accuracy in feature extraction. In the (b), shaded region is the distorted section corresponding to the case shown in (a). The saturation detection technique based on the WT shows stable and accurate result.

4. REGRESSION ALGORITHM

4.1 Least-squares method

The method of least-squares is the best known as the one which leads to "regression" formulae used in statistical computation. The estimation by least-square method has the optimum statistic character under some certain conditions.

Suppose the measurement equation is written as Eq. (2):

$$Y = X\Theta + e \qquad (2)$$

where Y(m×1 dimensions) and X(m×n dimensions) are observation vector and matrix, e(m×1 dimensions) is error vector, Θ(n×1 dimensions) is parameter vector to be determined. In power system, it is assumed that a current waveform $i(t)$ consists of a decaying DC component, fundamental component and harmonics. The signal is sampled at preselected times, and the measured samples set up the matrix Y. X is a function of time, related to the time at which the samples are taken. Only Θ is unkown.

Now Θ is calculated based on the principle that makes the sum of error squares be least. According to the criterion of the sum of error squares, so called cost function J is defined as Eq. (3):

$$J = \sum_{i=1}^{m} e_i^2 = (Y - X\Theta)^T (Y - X\Theta) \tag{3}$$

and then the necessary condition that J reaches the minimum value $\widehat{\theta}$ should satisfy the following Eq. (4)

$$\frac{\partial J}{\partial \widehat{\theta}} = 0 \text{ or } 2X^T(Y - X\widehat{\theta}) = 0 \tag{4}$$

then the solution for $\widehat{\theta}$ is:

$$\widehat{\theta} = (X^T X)^{-1} X^T Y \tag{5}$$

this is the solution of the least-square method.

In this paper, this method is applied to recover the distorted section making use of features extracted from the healthy section, essentially to restore the secondary current to a scaled down replica of the primary system current.

4.2 simulation and test results

In case of Fig. 6, 10% remanent flux ,128 samples/cycle, primary current is used to test.

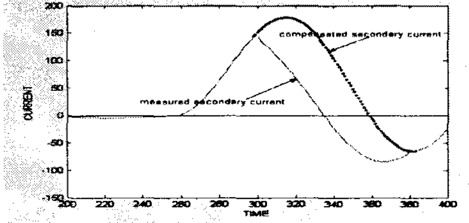


Fig. 6 Compensated & measured secondary current

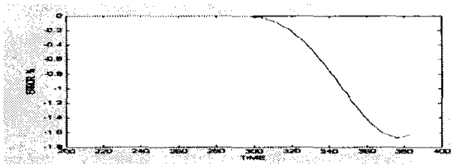


Fig. 7 Effect of the proposed compensation technique

The compensation error is under -2% as shown in Fig. 7. Because of some influence comes from CT, if we choose secondary current to calculate the coefficients, the compensated secondary current curve is distorted as shown in Fig. 8.

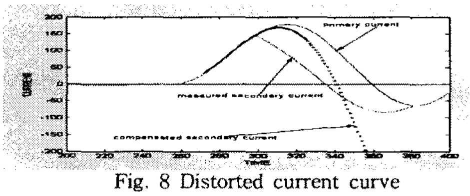


Fig. 8 Distorted current curve

To solve this problem, besides data taken before the start-point of saturation, we add several data right after the end point of the first distorted section. As shown in Fig. 9 and Fig. 10, the proposed algorithm successfully estimates the correct secondary current.

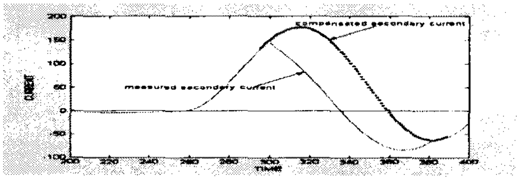


Fig. 9 Compensation using secondary current

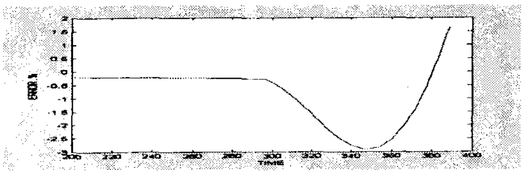


Fig. 10 Effect in case of Fig.9

5. CONCLUSION

The effectiveness of the filter bank has been tested on many cases : different saturation points (current: 0~20%, flux: 0~200%) and remanent flux left in the CT core (-50~80% of the flux at the saturation point). WT performs very well and the structure of filter makes it possible to be used in real-time. Results show that, Least-square method can recover the distorted section of secondary current with very low error level.

ACKNOWLEDGMENT

Author would like to thank Korea Ministry of Science and Technology, Korea Science and Engineering Foundation for their supports on ERC program.

REFERENCES

[1] F.Li, Y.Li and R.K.Aggarwal, "Combined wavelet transform and regression technique for secondary current compensation of current transformers", IEE proc-Gener. Transm. Distrib. Vol. 149, No. 4, pp. 497-503, July 2002

[2] Y.C.Kang, S.H.Kang, R.K.Aggarwal, "An algorithm for compensating secondary current of current transformers", IEEE Transactions, Vol. 12, pp. 116-124, Jan. 1997

[3]Johannes, R.Sveinsson, Jon Atli Benediktsson, "Feature extraction for neural network classifiers using wavelets and tree structured filter banks", IEEE International , Vol. 2, pp. 1026-1028, Aug. 1997