A New Fault Recognition of High Impedance Arcing Faults on Transmission Lines Using Wavelet and Fourier Technique

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ABSTRACT: The paper presents the application of the wavelet technique as a fault-recognition to high impedance faults (HIFs). The third and fifth harmonics current components are extracted from the fault current using Fast Fourier Transform (FFT). The current sum of the harmonic components is used as a feature extracted signals for fault discrimination. The ability to differentiate between a linear and non-linear high fault impedance is obtained using the continuous wavelet transform (CWT). The Meyer wavelet function was served as the wavelet basis function. It is more efficient in discriminating fault signals as time varies. No voltage signal is required to determine the high fault impedance. The MATLAB/SIMULINK unified block functional model for a 138kV transmission line with linear and nonlinear arc impedance models is used. A variety of faults and system conditions have been simulated to evaluate the reliability and sensitivity of the proposed technique.

KEYWORDS: *EHV Transmission line, Non linear ARC model, Matlab/Simulink, Protective Relaying, Wavelet Technique.*

1- INTRODUCTION

The High fault impedance reorganization is one of the most critical problems. Some relays fail to detect HIFs and the protection zone of relays shows different boundaries when compared with the setting zone. This miss-operation of the relay under HIFs can lead to large scale failure of the power system [1]. However, the detection of low level ground currents using any conventional over-current or ground fault type relays is both difficult and sometimes inaccurate [2].

In the last few years, a number of proposed schemes are proposed. The schemes explained in two categories. The first category is using the harmonic components caused by arcing faults. The second category is using the unbalance current caused by HIFs. Both categories are explained in [3-11].

Another techniques proposed by [1-2,13-15] encompass natural residual harmonics, excursion harmonic-vector, frequency-based nonlinear transformations and artificial neural network.

The arc natural of HIFs, being intermittent in nature, characterized by very low level fault current is also rich in low harmonic content and high frequency noise spectra that identify the HIFs.

The papers presents a novel technique for HIFs identification based on low harmonic featured signals extracted from measured currents using Fast Fourier Transform (FFT). The technique is based on the concept of CWT based basis function. The Meyer wavelet is used as a basis function. The Meyer wavelet basis function is embedded within a wavelet transform scheme to detect and discriminate faults.

2- WAVELET AND FOURIER TRANSFORM

The main problem with the windowed Fourier transform WFT is the inconsistent treatment of different frequencies: at low frequencies there so few oscillations within the window that the frequency localization is lost, while at high frequencies there are so many oscillations that the time localization is lost. Finally, the WFT relies on the assumption that the signal can be decomposed into sinusoidal components. Wavelet Transform (WT) has been introduced rather recently in mathematics, even though the essential ideas to this development have been around for a longer period 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. WFT 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 WT, 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 is very useful for analyzing fault transients during CT saturation.

The wavelet transform of a time dependent signal, $f(t)$, consists in finding a set of coefficients $\mathrm{WT}_{a,b}$. These coefficients measure the similarity between the signal $f(t)$ and a functional set $\psi_{a,b}(t)$. All the functions, $\psi_{a,b}(t)$, are derived from a chosen mother wavelet $\psi(t)$ as follows [16]:

$$\psi_{a,b}(t) = |a|^{-1/2}\psi\left(\frac{t-b}{a}\right) \quad (1)$$

Where, coefficients a and b are the scaling (dilation) and translation (time shift) constants respectively. The wavelet Transform WT can defined as:

$$WT_{a,b} = \left\langle \psi_{a,b}(t), f(t) \right\rangle = \int_{\infty}^{\infty} f(t)\overline{\psi}_{a,b}(t)dt \quad (2)$$

The signal $f(t)$ can be expressed as a linear superposition of $\psi_{a,b}(t)$ called wavelets:

$$f(t) = \frac{1}{C_{\psi}} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} WT_{a,b} \psi_{a,b} \frac{dadb}{a^2} \qquad (3)$$

$\psi(t)$ must be chosen to satisfy the following conditions:

$$C_{\psi} = \int_{-\infty}^{\infty} \frac{\left|\hat{\psi}(\omega)\right|^2}{|\omega|} \langle \infty \qquad (4a)$$

$$or \ \hat{\psi}(0) = \int_{-\infty}^{\infty} f(t)dt = 0 \qquad (4b)$$

Meyer Wavelet Basis Function

The paper introduces a method of applying the Meyer wavelet transform to discriminate the linear and non-linear high fault impedance. A Meyer wavelet basis function is embedded within a wavelet transform scheme to detect various events of faults. Fig. 1 depicts the scaling and wavelet Meyer function.

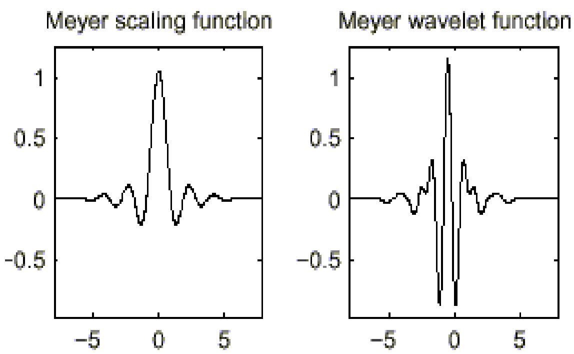

Fig. 1 the scaling and wavelet of Meyer function.

The fault discrimination process is based on proper selection of mother wavelet. This is very important to extract the useful information rapidly. The Meyer wavelet function leads to an accurate discrimination between the linear and non-linear impedance. The main features of the method its effective in monitoring faults, which generated signals as time varies.

3- THE TECHNIQUE PROCEDURE

The technique is based on applying the Meyer wavelet function on the sum of the harmonic components. The harmonic components are transformed into frequency domain using one cycle Fast Fourier Transform FFT from the line current, see Fig. 2. The unified sample Mesh Distribution System was subjected to an ARC type fault at different locations (x=0 to full feeder length) measured from the substation bus. The current signals are only captured from the feeder. The Matlab/Simulink unified functional model is used with linear and non-linear arc impedance models, see Fig. 3.

4- DETECTION METHOD

The analysis of non-stationary signals measured by the protection devices using the conventional techniques is very limited. The proposed technique is based on extracting the windowed wavelet transform of fault generated transients so as to distinguish between linear and non-linear faults. The faults generated transients are extracted from the *SUM* of the third and fifth current harmonics as the operating quantity. The values of wavelet transform based on Meyer basis function are applied on the sum signal.

Equation (5) measures the degree of similarity between the linear and non-linear high impedance. A distinct value in the *CWT* function in (5) indicates that the fault is non-linear. And hence, a significant value can be seen. In case of linear HIF arc conditions, the degree of similarity is decreased and the *CWT* value is consequently decreased.

$$CWT(kT,a) = \sum_{n} SUM(nT).\frac{1}{\sqrt{a}}.T.\psi\left[\frac{(nT-kT)}{a}\right] (5)$$

In (5) the value of CWT is a spike value, to give reliable accurate value the accumulation sum of (5) *(SCWT)* is calculated. If the value of the *(SCWT)* goes lower than some **THRESHOLD** value, the technique will identify that the fault is linear HIF. On the other hand, if the value of *(SCWT)* goes higher than a **THRESHOLD** value, HIF is identified as a non-linear arc fault.

5- POWER SYSTEM CONFIGURATION

The model shown in Fig. 2 has been simulated. The system includes a 138 kV meshed power system. X is taken in per unit length. Data for verifying the proposed technique was generated by modeling the selected system using the Matlab/Simulink model given in 3. The non-linear arc model and the transmission line parameters are given in APPENDIX. The relays are located at the sending and receiving ends (**S** and **R**), respectively. Results of relay responses at **S** are only displayed. Same results are obtained for relay **R**.

6- DYNAMIC RESULTS

The system shown in Fig. 2 was subjected to various types of faults using Matlab/Simulink program to generate data to test the performance of the proposed technique. The proposed approach was tested by computing the Meyer Wavelet function "**CWT**" described in (5). The threshold boundaries for "**SCWT**" were set to identify the linear and non-linear impedance faults. The performance of the proposed technique has been evaluated for different types of internal faults. A wide variation of fault locations, source impedances, close in fault and fault resistances were investigated.

1- *Effect of Internal Linear Fault*

Performance of the relay for a phase-a-to ground fault on the transmission line, Fig. 2, is shown in Fig. 4. The source capacities at **S** and **R** are changed. The fault is located at 30% of transmission line length from **R1**, as the point **F1** shown in Fig. 2. The computed sum of two harmonic components is shown in Fig. 4(a). The corresponding computed “**CWT**“ for **R1** is also shown in Fig. 4(b). For the selected threshold boundary **THRESHOLD**, the “**SCWT**“ value is lower than this boundary, see Fig. 4(c). This indicates that the fault is a linear fault. Many cases of fault locations as linear faults are simulated and successfully resulted are obtained.

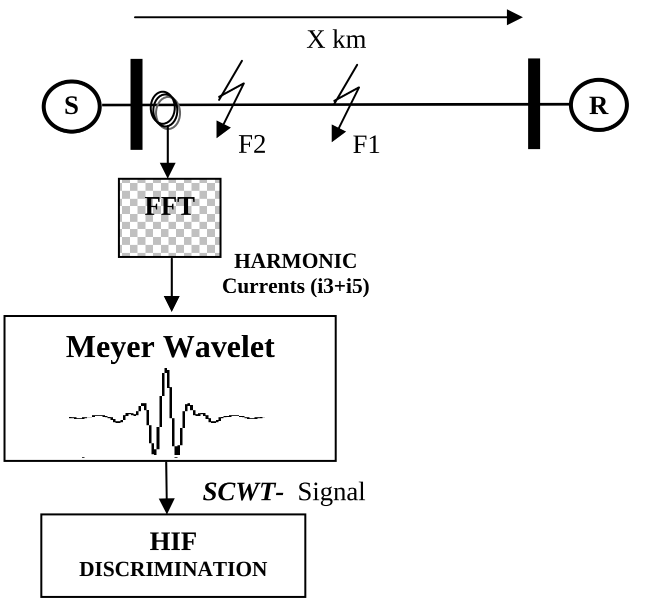

Fig. 2: Studied simulated model and procedure of the technique.

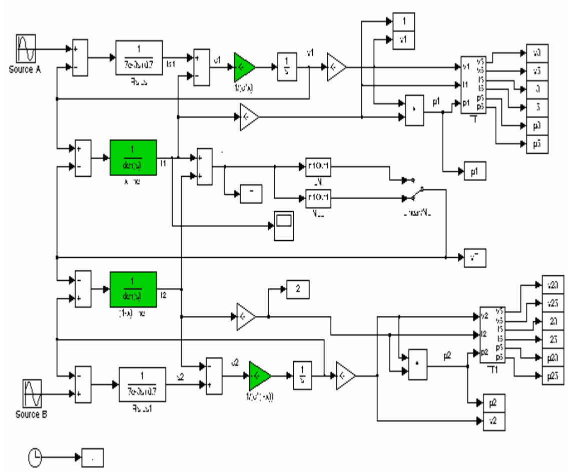

Fig. 3 Matlab/Simulink unified block functional model.

2- *Effect of Internal Non-Linear Fault*

Performance of the relay for a phase-a-to ground fault on the transmission line, Fig. 2, is shown in Fig. 5. The fault is located at 30% of transmission line length from **R1**, as the point **F1** shown in Fig. 2. The computed sum of the harmonic current is shown in Fig. 5(a). The corresponding computed "**CWT**" for **R1** is shown in Fig 5(b). For the selected threshold boundary, the "**SCWT**" does cross the selected threshold boundary. As seen in Figure, the relay operates successfully to identify a nonlinear fault, see Fig. 5(c). Many cases of non-linear faults are simulated due to changing the fault location and short circuit impedances and successfully results are recorded.

CONCLUSIONS

The paper presented a new technique for transmission line fault discrimination due to high impedance faults using the continuous wavelet transform. The Meyer mother wavelet function has proved that it is very effective for fault discrimination. The Fourier transform and wavelet are combined to detect and discriminate between linear and non-linear faults. The current harmonics are features extracted for fault discrimination. No voltage signal is used. Studies also show that the proposed technique is able to offer a very high accuracy and a very fast action in all cases of fault conditions.

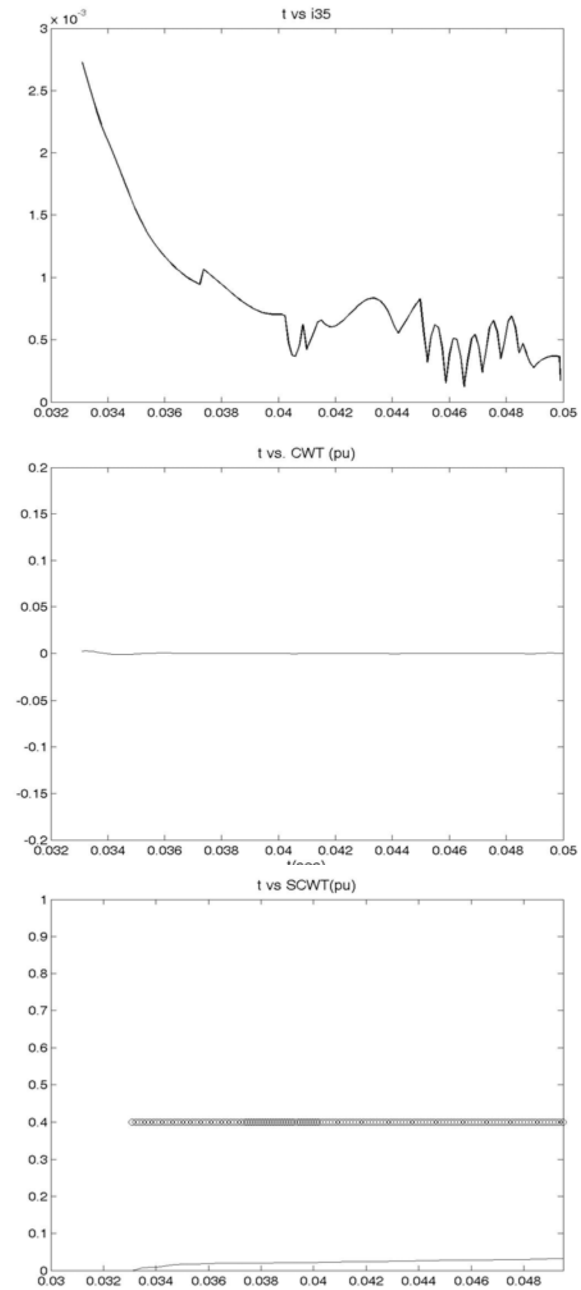

Fig. 4: Response to an internal fault at F1 (phase-a-to-ground), linear fault at x=30%.

APPENDIX

The 138kV transmission line parameters are given as:

Rs	Ls	Cs	ω	V_{LL}	Transformer
0.7 Ω	7mH	0.012 μF	377 rad/sec	25 kV	138/25kV

Linear HIF fault

R_f	L_f
30 Ω	**3mH**

Non-Linear HIF fault model

R_f		L_f
$R_f = R_{fo}(1+\alpha(\frac{i_f}{i_{fo}})^{\beta})$	R_{fo}=20, i_{fo}=70, α=0.6, β=2	**3mH**

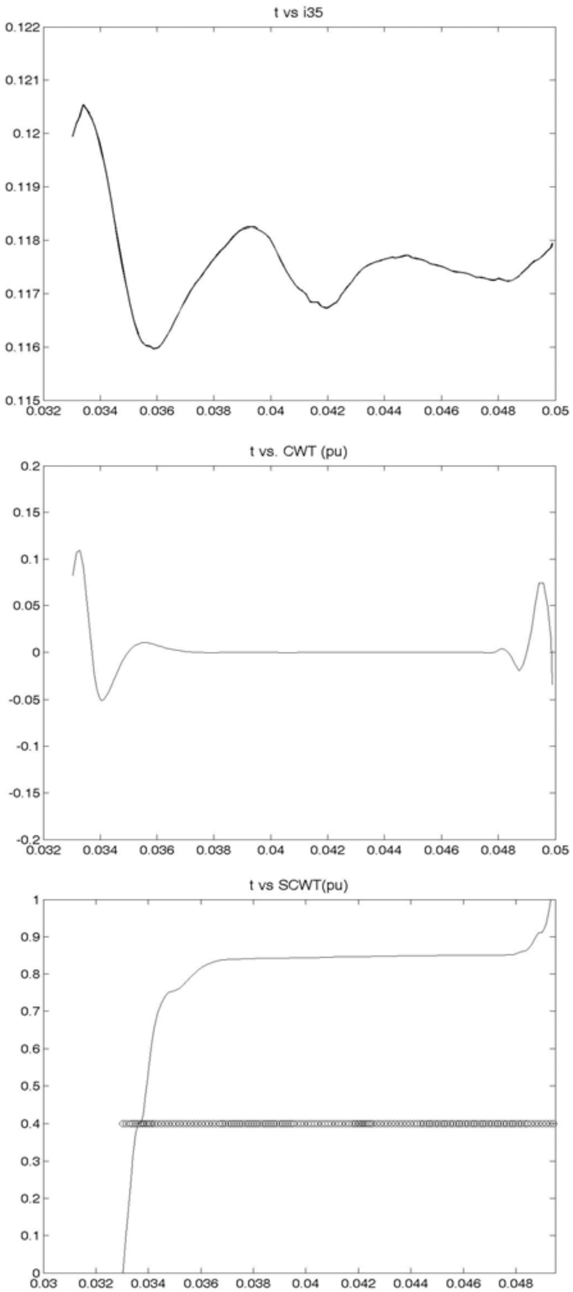

Fig. 5: Response of relay for an internal phase-a-to-ground fault), nonlinear fault at x=30%.

REFERENCES

[1] A. M. Sharaf and S. M. A. Saleem, "Application of Neural Networks and Wavelet Transforms in High Impedance Fault Detection in Electrical Systems", in Proc. MEPCON-2005, Suez Canal University, Port Said, Egypt, Dec 13-15, 2005.

[2] A. M. Sharaf and S. M. A. Saleem, "High impedance fault detection using a neural network based relaying scheme", in Proc. MEPCON-2003, Shebin El-Kom, Egypt, Dec 18-25, 2003.

[3] B. D. Russell and M. Aucoin, "Distribution high impedance fault detection utilizing high frequency current components," IEEE Transaction on Power Apparatus and systems, vol. PAS-101, pp. 1596-1606, June 1982.

[4] Y.Q. Xia, K. K. Li and A.K. David, "High-Resistance Faults on a Multi-Terminal Line: Analysis, Simulated Studies and an Adaptive Distance Relaying Scheme," IEEE Transaction on Power Delivery, vol. 9, No. 1, Jan. 1994.

[5] Q.S. Yang and I.F. Morrison, "Microprocessor-Based Algorithm for High-Resistance Earth-Fault Distance Protection," IEE Proc., vol-130, Nov. 1983.

[6]A. T. Johns, "Correspondence on Microprocessor Based Algorithm for High-Resistance Earth-Fault Distance Protection," Proc. Inst. Elect. Eng., Part C, 132 (1985).

[7]A. Wiszniewski, "Accurate fault Impedance Locating Algorithm," Proc. Inst. Elect. Eng., Part C, 130 (1983).

[8] M. M. Eissa, M. Masoud, "A Novel Digital Distance Relaying Technique for Transmission Line Protection," IEEE Trans on Power Delivery, vol. 16(3), July 2001.

[9] M. M. Eissa and O.P. Malik, "Laboratory Investigation of A Distance Protection Technique for Double Circuit Lines," IEEE Trans on Power Delivery, Vol. 19, no. 4, October 2004, pp 1636-1641.

[10] P.J. Moore and A. T. Johns, "Performance of Adaptive Distance Protection under High Resistance Earth Faults," CIGRE, Sept. 1992.

[11] Q.S. Yang and I.F. Morrison, "Microprocessor-Based Algorithm for High-Resistance Earth-Fault Distance Protection," IEE Proc., vol. 130, No. 6, Nov. 1983.

[12] A. T. Johns, Z. Q. Bo and R. K. Aggarwal, "A Novel Non-unit Protection Scheme Based on Fault Generated High Frequency Noise on Transmission Lines," Proceedings of the Fifth International Conference on Developments in Power System Protection, IEE Pub. No. 368, pp. 21-24.

[13] A. M. Sharaf, L. A. Snider and K. Debnath, "Residual Third Harmonic Detection of High Impedance Fault in Distribution Systems Using Perception Neural Networks," Proceedings of the ISEDEM 93, Singapore, October 1993.

[14] A. M. Sharaf, L. A. Snider and K. Debnath, "Harmonic Based Detection of High Impedance Faults in Distribution Networks Using Neural Networks," Proceedings of IASTED conference 1993, Pittsburgh, PA.

[15] A. M. Sharaf, R. M. El Sharkawy, H. Jalaat and M. A. Badr, "Fault Detection on Mesh and Meshed Transmission Systems," EPSR, vol. 41, pp 185-190, 1997.

[16]An introduction to Wavelet [online]. At: www.amara.com/IEEE-wave.