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# Identification of Fault Types for Underground Cable using Discrete Wavelet Transform

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***Abstract*— In this paper, a technique for identifying the phase with fault appearance in underground cable is presented. The Wavelet transform has been employed to extract high frequency components superimposed on fault signals simulated using ATP/EMTP. The coefficients obtained from the Wavelet transform are used in constructing a decision algorithm. Various cases have been investigated so that the algorithm can be implemented. It is found that the proposed method can indicate the fault types with satisfactory accuracy.**

***Index Terms*—Wavelet Transform, Fault Types, Underground Cable, ATP/EMTP.**

## I. Introduction

When faults occur in the transmission and distribution systems, it is important to clear fault from the power system as soon as possible in order that transmission line can reconnect with power system. In previous decade, the development in the algorithm for detecting the faults on the transmission lines has been progressed and results in transient based techniques. In order that the transient based protection can be accurately successful in operation, the application of wavelet transform is employed. In several research papers, the fault classification or the phase with fault appearance can be obtained from employing trial and error method [1-3] or from the artificial intelligent decision algorithms [4-7]. However, most research works have only considered in the fault diagnosis for overhead transmission and distribution systems while research work rarely mention about the fault diagnosis in underground distribution system. The techniques to detect and determine the fault location in underground distribution system are discussed in several research papers [8-9] but the types of fault and the phase with fault appearance are as important as fault location. As a result, it is useful if the fault types in the underground distribution system can be identified using wavelet transform.

Hence, the objective of this paper is to present an application of Wavelet transform and a decision algorithm in order to identify the types of fault in underground cable. The simulations, analysis and diagnosis are performed using ATP/EMTP and MATLAB. It is noted that the discrete wavelet transform is employed in extracting the high frequency component contained in the fault currents and the coefficients of the first scale from the Wavelet transformer are investigated. The comparison of the coefficients is investigated and used in the construction of the decision algorithm.

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## II. Wavelet Transform

Wavelet transform is a mathematical technique used in signal analysis. The advantage of the transform is that the band of analysis can be fine adjusted so that high frequency components and low frequency components can be detected precisely. Results obtained from the wavelet transform are shown on both the time domain and the frequency domain. The wavelet transform which has a change in the analysis scale by the factor of two is called discrete wavelet transform (DWT) as in Equation 1 [5].

$$DWT(m,n) = \frac{1}{\sqrt{2^m}} \sum_k f(k)\psi\left[\frac{n-k2^m}{2^m}\right] \qquad (1)$$

where, $\psi\left[\frac{n-k2^m}{2^m}\right]$ = mother wavelet

## III. Simulation

The ATP/EMTP [5-7] is employed to simulate fault signals, at a sampling rate 200 kHz. The system employed in case studies is chosen based on the underground distribution system as illustrated in Figure 1. In addition, a cross-sectional view of a cable is shown in Figure 2. To avoid complexity the fault resistance is assumed to be 10Ω. Fault patterns in the simulations are performed with various changes of system parameters as follows:

- Fault types are under consideration, namely: single phase to ground (SLG), double-line to ground (DLG), line to line (L-L) and three-phase fault (3-P).
- Fault locations on the underground distribution system are the distance of 1, 8, 27 km measured from the sending end.
- Inception angle on a voltage waveform is varied between 0°-180° , with the increasing step of 30°. Phase A is used as a reference.

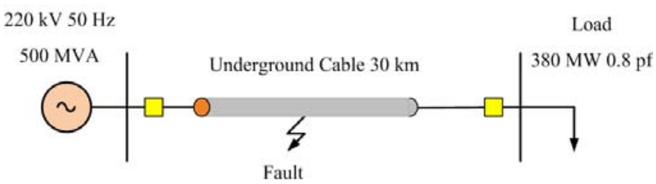


Figure 1. The system used in simulation studies

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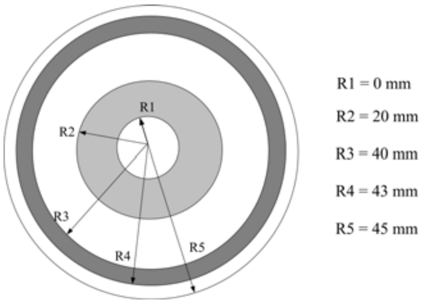


Figure 2. The configuration of cable in simulation studies

The example of ATP/EMTP simulated fault signals is illustrated in Figure 3. This is a fault occurring with phase A to ground fault at 8 km measured from the sending bus as depicted in Figure 1. The fault signals generated using ATP/EMTP are interfaced to the MATLAB for the fault detection algorithm.

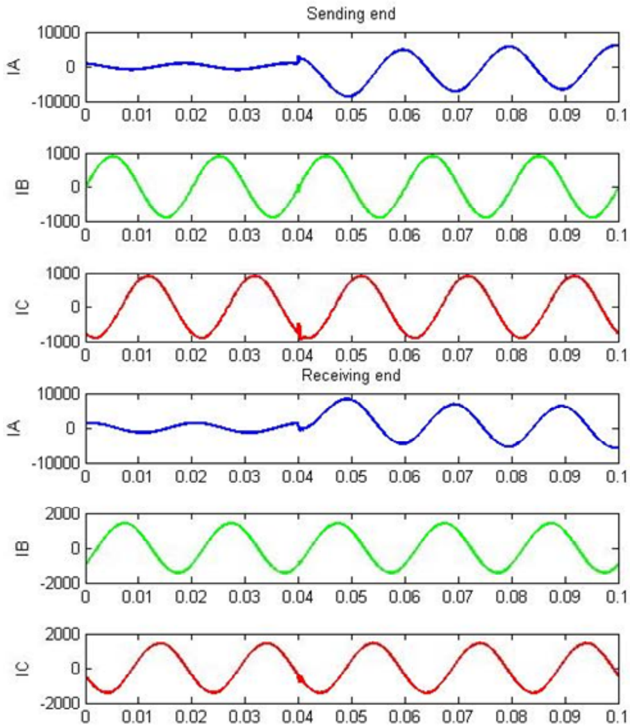


Figure 3. Example of ATP/EMTP simulated fault signals for AG fault at sending end.

## IV. Decision Algorithm

Fault detection decision algorithm is processed using positive sequence current signal. Fault signals generated using PSCAD/EMTDC are imported to the MATLAB/Simulink in order to analyse the high frequency transient components, which are superimposed in the fault current signals, by DWT using the wavelet toolbox. The Clark's transformation matrix is employed for calculating the positive sequence and zero sequence of currents. With several trial and error processes, the fault detection decision algorithm on the basis of computer programming technique is constructed as shown in Figure 4. The mother wavelet daubechies4 (db4) [3, 5-7] is employed to decompose high frequency components from the positive sequence current signals.

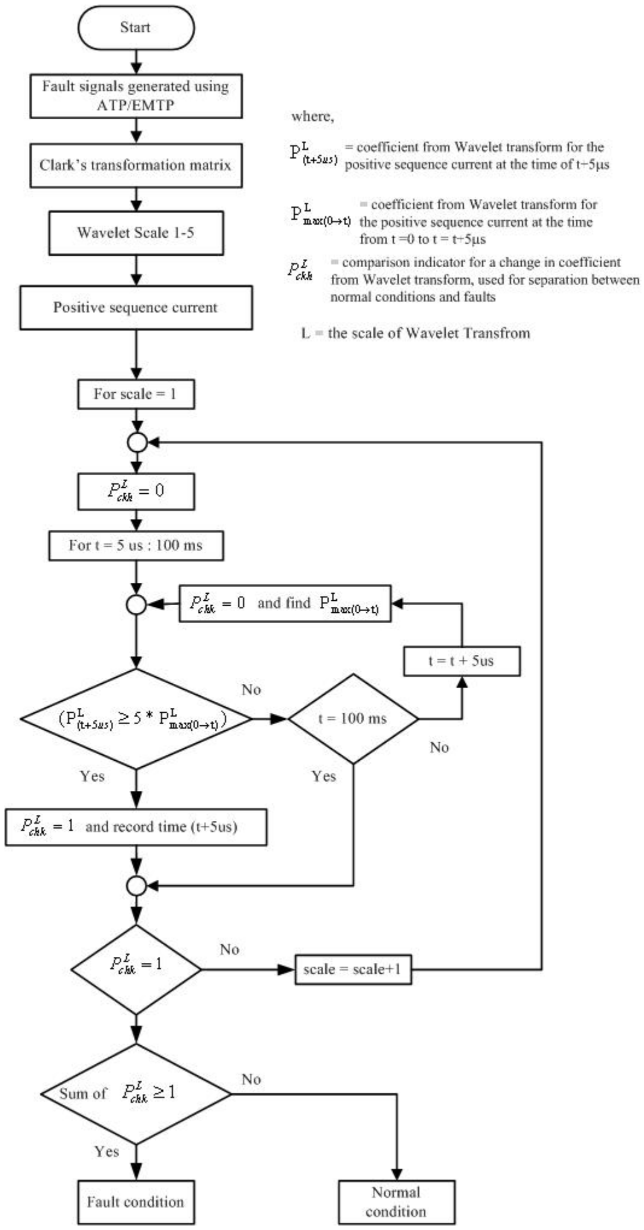


Figure 4. Flowchart for fault detection.

After applying the Wavelet transform to the positive sequence currents, the comparison of the coefficients from each scale is under investigation. Coefficients obtained using DWT of signals are squared so that the abrupt change in the spectra can be clearly found, and it is clearly seen that the coefficients of high frequency components, when fault occurs, have a sudden change compared with those before an occurrence of the faults as illustrated in Figure 5. This sudden change is used as an index for the occurrence of faults. The fault detection decision algorithm has been proposed that if coefficients of any scales are change around five times before an occurrence of the faults, there are faults occurring in underground cable.

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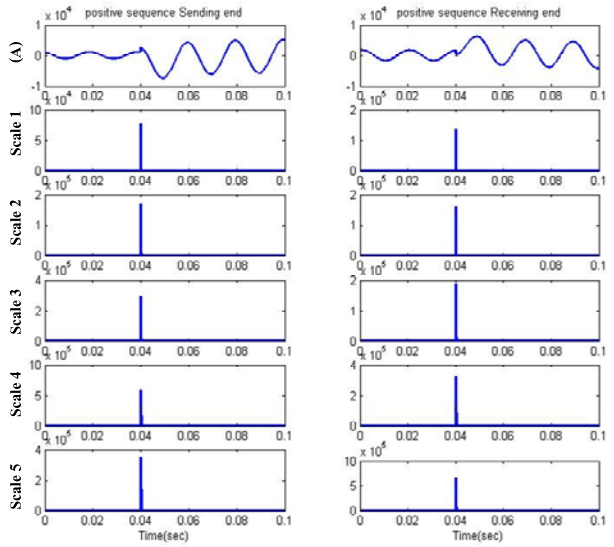



Figure 5 Wavelet transform from scale 1 to 5 for the positive sequence of current signal shown in Figure 3.

From Figure 5, the coefficients in all scale of the wavelet transform are clearly changed then it presumes that these signals are fault condition. After the fault detection process, the comparison of the coefficients from first scale that can detect fault is considered so that the types of fault can be analysed. The most appropriate algorithm for the decision algorithm can be concluded as follows:

The division algorithm between the maximum coefficients of DWT at ¼ cycle of phase A, B, C are performed as shown in Equation 2-4.

$$I^{L}_{AZ,\max(post)} = \frac{I^{L}_{A,\max(post)}}{I^{L}_{zero,\max(post)}} \quad (2)$$

$$I^{L}_{BZ,\max(post)} = \frac{I^{L}_{B,\max(post)}}{I^{L}_{zero,\max(post)}} \quad (3)$$

$$I^{L}_{CZ,\max(post)} = \frac{I^{L}_{C,\max(post)}}{I^{L}_{zero,\max(post)}} \quad (4)$$

where, L = the scale of wavelet transform that can detect fault.

$I^{L}_{A,\max(post)}$ = maximum coefficient from Wavelet transform at ¼ cycles of phase A for post-fault current

$I^{L}_{B,\max(post)}$ = maximum coefficient from Wavelet transform at ¼ cycles of phase B for post-fault current

$I^{L}_{C,\max(post)}$ = maximum coefficient from Wavelet transform at ¼ cycles of phase C for post-fault current

$I^{L}_{zero,\max(post)}$ = maximum coefficient from Wavelet transform of zero sequence current at the time of ¼ cycles after detecting faults

$I^{L}_{AZ,\max(post)}$ = maximum ratio obtained from division algorithm between $I^{L}_{A,\max(post)}$ and $I^{L}_{zero,\max(post)}$

$I^{L}_{BZ,\max(post)}$ = maximum ratio obtained from division algorithm between $I^{L}_{B,\max(post)}$ and $I^{L}_{zero,\max(post)}$

$I^{L}_{CZ,\max(post)}$ = maximum ratio obtained from division algorithm between $I^{L}_{C,\max(post)}$ and $I^{L}_{zero,\max(post)}$

From Figure 6, it is shown that maximum ratio obtained from division algorithm is calculated. For identifying the phase with fault appearance, the comparisons of the maximum ratio obtained from division algorithm have been performed as follows:

For detecting the phase with a fault condition

if [( $I^{L}_{X,\max(post)}$ > 1) and ( $I^{L}_{X,\max(post)}$ > 5x $Ph^{L}_{\min}$ )] or
( $I^{L}_{X,\max(post)}$ >1000) or ( $I^{L}_{X,\max(post)}$ > 0.4x $Ph^{L}_{\max}$ )

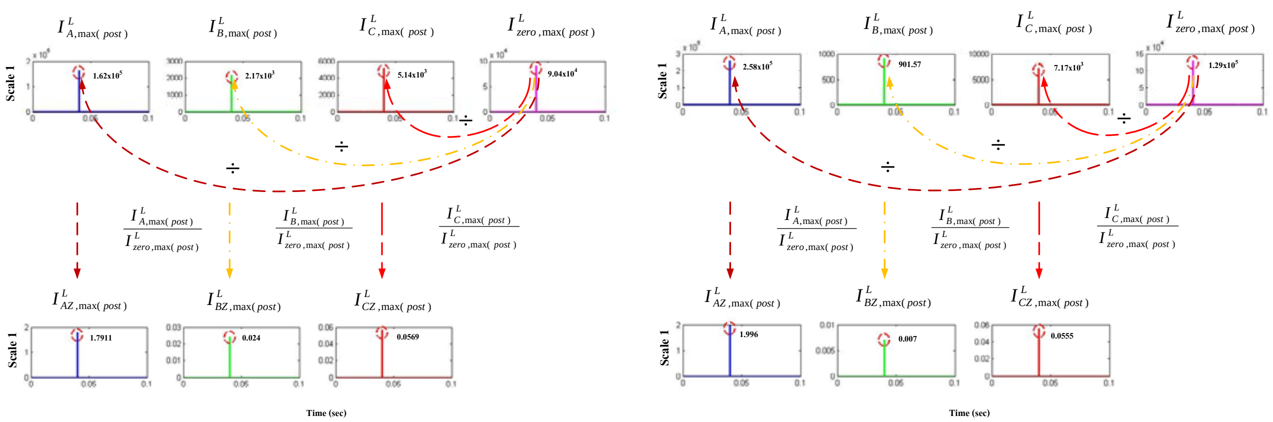
then

Phase X fault

else

Phase X unfault

end




(a) Sending end (b) Receiving end

Figure 6 Result of maximum ratio from the division algorithm proposed in this paper.

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TABLE 1 Result for detecting types of faults at sending end

| Phase A | | Phase B | | Phase C | | Zero sequence | | $Ph^L_{\max}$ | $Ph^L_{\min}$ | Result |
|---|---|---|---|---|---|---|---|---|---|---|
| Max (post) | $I^L_{AZ,\max(post)}$ | Max (post) | $I^L_{BZ,\max(post)}$ | Max (post) | $I^L_{CZ,\max(post)}$ | Max (pre) | Max (post) | | | Sending end |
| $1.62\mathrm{x}10^5$ | 1.7911 | $2.17\mathrm{x}10^3$ | 0.024 | $5.14\mathrm{x}10^3$ | 0.0569 | $3.2\mathrm{x}10^{-5}$ | $9.0\mathrm{x}10^4$ | $1.62\mathrm{x}10^5$ | $2.17\mathrm{x}10^3$ | AG |

TABLE 2 Result for detecting types of faults at receiving end

| Phase A | | Phase B | | Phase C | | Zero sequence | | $Ph^L_{\max}$ | $Ph^L_{\min}$ | Result |
|---|---|---|---|---|---|---|---|---|---|---|
| Max (post) | $I^L_{AZ,\max(post)}$ | Max (post) | $I^L_{BZ,\max(post)}$ | Max (post) | $I^L_{CZ,\max(post)}$ | Max (pre) | Max (post) | | | Receiving end |
| $2.58\mathrm{x}10^5$ | 1.196 | 901.57 | 0.007 | $7.17\mathrm{x}10^3$ | 0.0555 | $8.5\mathrm{x}10^{-4}$ | $1.3\mathrm{x}10^5$ | $2.58\mathrm{x}10^5$ | 901.57 | AG |

Table 3 Percentage average accuracy for fault types

| Fault Location (Distance measured from the sending end) | Number of case studies | Fault type | | | |
|---|---|---|---|---|---|
| | | SLG | DLG | LL | 3-P |
| 1 km | 28 | 100% | 71.4% | 85.7% | 85.7% |
| 8 km | 28 | 100% | 71.4% | 100% | 100% |
| 27 km | 28 | 100% | 71.4% | 100% | 100% |
| Average | | 100% | 71.4% | 95.2% | 95.2% |

where,

$I^L_{X,\max(post)}$ = maximum value obtained from division algorithm ($I^L_X = I^L_{AZ}, I^L_{BZ}$ and $I^L_{CZ}$ respectively)

$Ph^L_{\max}$ = the maximum value obtained form comparing among $I^L_{AZ,\max(post)}$, $I^L_{BZ,\max(post)}$ and $I^L_{CZ,\max(post)}$

$Ph^L_{\min}$ = the minimum value obtained form comparing among $I^L_{AZ,\max(post)}$, $I^L_{BZ,\max(post)}$ and $I^L_{CZ,\max(post)}$

In addition, for detecting the zero sequence current with a fault condition

If $\left(I^L_{\text{zero, max (post)}} \geq 5 \times I^L_{\text{zero, max (pre)}}\right)$
then
Ground fault
else
Unground fault
end

where,
$I^L_{\text{zero, max (pre)}}$ = maximum coefficient from Wavelet transform of zero sequence current at the time of ¼ cycles before the inception of faults

Results illustrated from Tables 1 to 2 are obtained from one case of phase A to ground fault. Case studies are varied so that the decision algorithm capability can be verified. Various case studies are performed with various types of faults at each location in the underground cable including the variation of fault inception angles. The results are shown that the average accuracy of fault type from the decision algorithm proposed in this paper is highly satisfactory as shown in Table 3.

## V. Conclusion

The applications of the discrete wavelet transform (DWT) for identifying the phase with fault appearance along the underground cable distribution system have been investigated in this paper. Daubechies4 (db4) is employed as mother wavelet in order to decompose high frequency components from fault signals. Coefficients of positive sequence current signals are calculated and employed in fault detection decision algorithm. By performing many simulations, the result is found that the fault detection decision algorithm can detect fault with the accuracy of 100% using scale 1 only. The maximum coefficients details (cD1) in scale 1 at ¼ cycle of phase A, B, C and zero sequence for post-fault currents waveforms are used in constructing a decision algorithm. Various case studies have been studied including the variation of fault inception angles, different locations in cable and various types of faults. The results are shown that the proposed algorithm can indicate fault types with the accuracy higher than 90%. The further work will be improvement the overall accuracy so that the higher precision can be achieved.

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