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<table>
<thead>
<tr>
<th>Year</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>0</td>
</tr>
<tr>
<td>2016</td>
<td>2</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Year</th>
<th>Value</th>
</tr>
</thead>
<tbody>
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<td>0</td>
</tr>
<tr>
<td>2016</td>
<td>0</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Year</th>
<th>Value</th>
</tr>
</thead>
<tbody>
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<td>2016</td>
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Cited documents

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<th>Year</th>
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</tr>
</thead>
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<tr>
<td>2015</td>
<td>0</td>
</tr>
<tr>
<td>2016</td>
<td>2</td>
</tr>
</tbody>
</table>

Uncited documents

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<tr>
<th>Year</th>
<th>Value</th>
</tr>
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<thead>
<tr>
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<th>2009-2015</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SJR</td>
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<td></td>
</tr>
<tr>
<td>Cites per doc</td>
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<tr>
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Algorithm for Fault Location and Classification on Parallel Transmission Line using Wavelet based on Clarke’s Transformation

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## Table of Contents

### Web server-based distributed machine socialization system
Changsu Kim, Hankil Kim, Jongwon Lee, Hoekyung Jung
Total views: 495 times
PDF
631-637

### Automatic Segmentation of Brachial Artery based on Fuzzy C-Means Pixel Clustering from Ultrasound Images
Joonsung Park, Doo Heon Song, Hosung Nho, Hyun-Min Choi, Kyung-Ae Kim, Hyun Jun Park, Kwang Baek Kim
Total views: 183 times
PDF
638-643

### From Agasa Cristie to Group Image Play - Analysis of Horror Survival Game Panic Room: Escaping from the Den on Emotional Elements Development
Doo Heon Song, Hae Kyung Rhe, Ji-eun Kim, Jong Hee Lee
Total views: 41 times
PDF
644-650

### Body information analysis based personal exercise management system
Jongwon Lee, Hyunju Lee, Donggyun Yu, Hoekyung Jung
Total views: 61 times
PDF
651-657

### Utilizing ECG Waveform Features as New Biometric Authentication Method
Ahmed Younes Shdefat, Moon-Il Joo, Sung-Hoon Choi, Hee-Cheol Kim
Total views: 135 times
PDF
658-663

### Intelligent Automatic Extraction of Canine Cataract Object with Dynamic Controlled Fuzzy C-Means based Quantization
Kwang Baek Kim, Doo Heon Song
Total views: 46 times
PDF
666-672

### Centeral Electric Field and Threshold Voltage in Accumulation-mode Junctionless Cylindrical Surrounding Gate MOSFET
Hakke Jung
Total views: 95 times
PDF
673-679

### Model to Evaluate the Performance of Building Integrated Photovoltaic Systems using Matlab/Simulink
Julian Andres Camacho, Andres Julian Aristizabal
Total views: 106 times
PDF
680-688

### Performance Enhancement in Active Power Filter (APF) by FPGA Implementation
Shamala N, C. Lakshminarayana
Total views: 100 times
PDF
689-698

### Algorithm for Fault Location and Classification on Parallel Transmission Line using Wavelet based on Clarke’s Transformation
Makmur Saini, A. A. Mohd Zin, M. W. Mustafa, Ahmad Rizal Sultan, Rusdi Nur
Total views: 488 times
PDF
699-710

### Maximum power extraction method for a doubly-fed induction generator wind turbine
Dinh Chung Phan, Trung Hieu Trinh
Total views: 82 times
PDF
711-722

### Analysis of Inductance Gradient and Current Density Distribution Over Different Cross-section of Rails
M. N. Saravana Kumar, R. Murugan
Total views: 53 times
PDF
723-729

### Design of Hybrid Solar Wind Energy System in a Microgrid with MPPT Techniques
D. Chinnakullay Reddy, S. Satya Narayana, V. Ganesh
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PDF
730-740

### Review of under Frequency Load Shedding Program of Kosovo Power System based on ENTSO-E Requirements
Gazmend Kabashi, Skender Kabashi
Total views: 83 times
PDF
741-748

### A Comprehensive Analysis of Partial Shading Effect on Output Parameters of a Grid-connected PV System
H. Rahimi Mirazizi, M. A. Shafiyi
Total views: 67 times
PDF
749-762

### A Novel Three Phase Multilevel Inverter with Sineol Dc Link For Induction Motor Drive Applications
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PDF
763-770
Algorithm for Fault Location and Classification on Parallel Transmission Line using Wavelet based on Clarke’s Transformation

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ABSTRACT

This paper proposed a new algorithm for fault location and classification using wavelet based on Clarke’s transformation to obtain the fault current. This novel method of fault current approach is studied by comparing the use of the glide path of the fault voltage. The current alpha and beta (Current Mode) were used to transform the signal using discrete wavelet transform (DWT). The fault location was determined by using the Clarke’s transformation, and then turned into a wavelet, which was very precise and thorough. The most accurate was the mother wavelet Db4 which had the fastest time and smallest error detection when compared with the other wavelet mothers. In this study, the Clarke’s transformation is also compared with the Karenbauer’s, which has produced results with similar error percentage. The simulation results using PSCAD / EMTDC software showed that the proposed algorithm could distinguish internal and external faults to get the current signal in the transformation of a signal fault.

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1. INTRODUCTION

Currently, the parallel transmission networks are widely used in the electrical power systems. Therefore, a fast and reliable protection is very much needed in such aspects as rapid fault detection and accurate estimation of the location fault will reduce errors, and assist in the maintenance and restoration services to improve the continuity and reliability of electric supply. Therefore, parallel transmission lines require more special consideration in comparison with a single transmission line, due to the effect of mutual coupling on the parallel transmission line. It also must conform to the standard IEEE.STD.114 2004 [1]. One main advantage of parallel transmission is the availability of the transmission lines during and after the fault.

Fault location problems in the parallel transmission lines have been widely researched. Many diagnostic approaches have been proposed in the literature, including fault location based on the amount of electricity, which includes one-terminal method [2], [3], two-terminal method [4], [5], traveling wave analysis method [6], [7], resistance measurement method [8], and the determination of fault location estimation using wavelet transform [9].

This paper proposed discrete wavelet transformation using the Clarke’s transformation to determine the fault location estimation and classification on the parallel transmission lines. This study presents a different approach, which is based on the Clarke’s transformation known as alpha-beta transformation, which

is a transformation of a three-phase system into a two-phase system [10], [11], where after the result, the Clarke’s transformation is then transformed into discrete wavelet transform.

Wavelet transform is an effective tool in analyzing the transient current and signal associated with faults, both in frequency and in the time-domain [12], [13] and is ideal for dealing with non-stationary signal. This can improve the accuracy, reliability of the detection and classification of power quality disturbance [14], and features can be applied to determine the fault location estimation [15].

The proposed approach combines the decomposition of electromagnetic wave propagation modes, using the Clarke’s transformation of signal processing, given by the discrete wavelet transformation based on the maximum signal amplitude (WTC) to determine the intrusion time. This work made extensive use of the simulation software PSCAD/EMTDC [16] which resulted in the fault of the simulation of the transient signal transmission line parallel to the number of data points (10^5). For one kind of fault, these data were then transferred to MATLAB with the help of Clarke’s transformation to convert the three-phase signal into alpha and beta signals. The signals were then transformed into several mother wavelets [17] such as Db4, Sym4, Coif4 and Db8 which were manipulated for comparison in terms of time and the distance estimation fault in the parallel transmission line.

2. BASIC PRINCIPLE OF CLARKE’S AND WAVELET TRANSFORMATION

2.1. Clarke’s Transformation

Clarke’s Transformation (αβ0) is a useful analytical approach to complement symmetry components (0, 1, 2). Clarke’s transformation can overcome some symmetry component drawbacks such as the calculation of the circuit transient phenomena. Clarke’s Transformation (αβ0) is the transformation method that contains the elements of a 3 x 3 matrix, containing matrix element in the form of real, whereas the symmetry component contains matrix components in the form of real and complex numbers. A three-phase current which has a digital representation is assumed to have the form [18], [19]. Therefore, the above components can be formed into a matrix [20]

\[ i_{\text{mode}} = i_{\alpha\beta\delta} = C \begin{bmatrix} \frac{1}{2} & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_A(n) \\ i_B(n) \\ i_C(n) \end{bmatrix} \]  

(1)

where C is the well-known transformation introduced by Edith Clarke [21].

2.2. Fault Characterization in Clarke’s Transformation

2.2.1. Single Line of Ground Fault Phase A to G

A suppose for a line to ground fault (AG), assuming the grounding resistance is zero, then the instantaneous boundary conditions will be:

\[ I_B = I_C = 0 \text{ and } V_A = 0 \]  

(2)

Then, the boundary condition instantaneous will be:

\[ \begin{bmatrix} I_A \\ I_B \\ I_0 \\ I_Y \end{bmatrix} = \begin{bmatrix} -2/3 I_A \\ 0 \\ -1/3 I_A \\ -2/3 I_A \end{bmatrix} \]  

(3)

2.2.2. Line to Line Fault in Phase A-B

A suppose for the line to line fault (AB), assuming the grounding resistance is zero, then the instantaneous boundary conditions will be:

\[ I_C = 0 \text{ , } I_A = -I_B \text{ and } V_A = V_B \]  

(4)

Then, the boundary condition instantaneous will be:
Algorithm for Fault Location and Classification on Parallel Transmission Line .... (Makmur Saini)

\[
\begin{bmatrix}
I_a \\
I_b \\
I_0 \\
I_y
\end{bmatrix} =
\begin{bmatrix}
I_a \\
-1/3 \sqrt{3} I_b \\
0 \\
-I_a - 1/3 \sqrt{3} I_b
\end{bmatrix}
\]  
(5)

2.2.3. Line to Line to ground Fault in Phase AB to G

A suppose line to line to ground fault (ABG), assuming the grounding resistance is zero, then the instantaneous boundary conditions will be:

\[
I_c = 0 \text{, } I_A = I_B \text{ and } V_A = V_B = 0
\]  
(6)

Then, the boundary condition instantaneous will be:

\[
\begin{bmatrix}
I_a \\
I_b \\
I_0 \\
I_y
\end{bmatrix} =
\begin{bmatrix}
2/3 I_a - 1/3 I_b \\
1/3 \sqrt{3} I_b \\
1/3 I_a + 1/3 I_b \\
-2/3 I_a + 1/3 I_b + 1/3 \sqrt{3} I_b
\end{bmatrix}
\]  
(7)

2.2.4. Three Phase Fault in Phase ABC

A suppose for three phase fault (ABC), assuming the grounding resistance is zero, then the instantaneous boundary conditions will be:

\[
I_a + I_b + I_c = 0 \text{ and } V_a + V_b + V_c = 0
\]  
(8)

Then, the boundary condition instantaneous will be:

\[
\begin{bmatrix}
I_a \\
I_b \\
I_0 \\
I_y
\end{bmatrix} =
\begin{bmatrix}
\frac{2}{3} I_a - \frac{1}{3} I_b - \frac{1}{3} I_c \\
\frac{1}{3} \sqrt{3} I_b - \frac{1}{3} \sqrt{3} I_c \\
\frac{1}{3} I_a + \frac{1}{3} I_b + \frac{1}{3} \sqrt{3} I_c
\end{bmatrix}
\]  
(9)

Based on the above analysis, the characteristics of various faults based on Clarke’s transformation $\alpha$- Modal, $\beta$- Modal and modal $\gamma$ can be proposed.

2.3. Wavelet Transformation

Wavelet transformation is the decomposition of a signal by a function $\varphi_{a,t}(t)$ which is deleted and translated by the so-called mother wavelet. The function of the mother wavelet can be written as follows [22], [23]:

$$\varphi_{a,t}(t) = \frac{1}{\sqrt{a}} \varphi \left( \frac{t-b}{a} \right)$$  
(10)

Where $a$ is the dilation parameter ($a \in \text{Real}$) and $b$ is a translation parameter ($b \in \text{Real}$), parameter $a$ indicates the width of the wavelet curve, when the value of a wider magnified wavelet curve is diminished as the curve gets smaller, while the wavelet parameter curve $b$ shows the localization of wavelet centered at $t = b$. The detection of the discrete wavelet transformed (DWT) fault is required so that the equation becomes [24], [25]

\[
\varphi_{a,b}(t) = 2^{j/2} \varphi \left( 2^j (a - b) \right), j, k \in \mathbb{Z}
\]  
(11)

Variables $j$ and $k$ are integers that scale the shifts of the mother wavelet function, to produce types of mother wavelet such as Sym and Haar wavelets. The width of a wavelet is shown by the scale $a$, and the position is indicated by the wavelet scale $b$. 
Discrete Wavelet Transformations (DWT) are methods used to decompose the input signal, and the signal is analyzed by giving treatment to the wavelet coefficients. The decomposition process involves two filters, which are low-pass filter and a high-pass filter [26]. This is achieved by successive high pass and low pass filtering of the time domain signal and is defined by the following equation:

\[
\delta_{\text{high}} [k] = \sum_n x[n]. g[2k - n] \\
\delta_{\text{low}} [k] = \sum_n x[n]. h[2k - n]
\]

(12) (13)

where \( \delta_{\text{high}} [k] \) = output high-pass filter and \( \delta_{\text{low}} [k] \) = output low-pass filter.

The signal is first passed through the high-pass filter and low pass filter, and then half of each output is taken as sampling, down through the sampling operation, the signal of desired frequency component can be obtained from the recurring decompositions as shown by Figure 1 [27].

![Figure 1. The process decomposition of discrete wavelet transform](image)

This is called a decomposition first level process in the frequency range of 250-500 kHz. The output from the low-pass filter is used as the input of the next decomposition second level, with a frequency range of 125-250 kHz. This process is repeated again until it reaches the third level of decomposition with a frequency of 62.5-125 kHz, and so forth, according to the level desired. In this study, it is chosen to reach level 4, with a frequency range of 31.25-62.5 kHz and a level 8 with frequency range of 7.8125-15.625 kHz [28].

The combination of the output from the high-pass filter and low-pass filter output is called Coefficient Wavelet transformed (CWT), which contains information on the results that have been compressed and transformed. In this study, the high pass filter and low-pass filter are coupled and becoming a Quadrature Mirror Filter (QMF), in which the couples meet the following [29] equation:

\[
h[n] = (-1)^n g [L + 1 - n] \]

(14)

where \( h[n] \) = high-pass filter, \( g[n] \) = low-pass filter, \( L \) = length of each filter. Successful to the down sampling operation that removes redundant information signal, wavelet transform has become one of the most reliable and accurate composition methods [30].

### 3. THE PROPOSED ALGORITHM

In this study, the simulations were performed using PSCAD, and the simulation results were obtained from the fault current signal.

The steps performed in this study were:

- Finding the input to the Clarke’s transformation and wavelet transform. The signal flow of PSCAD was then converted into m. files (*. M) and then converted into mat. Files (*.mat) with a sampling rate of \((10^5)\) and frequency dependent of 0.5 Hz-1 MHz.
b. Determining the data stream interference, where the signal was transformed by using the Clarke’s transformation to convert the transient signals into the basic current mode signal in using Equation (1).

c. Transforming the mode current signals again by using DWT and WTC, which were the generated coefficients, and then squared to be \((WTC)^2\) in order to obtain the maximum signal amplitude to determine the time of the interruption [31], [32].

d. Processing the ground mode and aerial mode and \((WTC)^2\) using the Bewley Lattice diagram [32], [33] of the initial wave to determine the fault location and detection.

e. Adding the magnitude of the current gamma to make the fault classification algorithm which then became modal \(I_p\) that can be proposed. While the magnitude of the current gamma of each different types of fault can be seen in Table 1.

\[ I_y = -\frac{2}{3} I_a + \frac{1}{3} (1 + \sqrt{3}) I_b + \frac{1}{3}(1 - \sqrt{3}) I_c \] (15)

f. Determining whether the internal fault in both Circuit 1 or Circuit 2 and external fault using the following equation:

If \(\left|\frac{I_{a1}}{I_{a2}}\right| > 1\) or \(\left|\frac{I_{b1}}{I_{b2}}\right| > 1\) Fault Internal Circuit 1

(16)

If \(\left|\frac{I_{a2}}{I_{a1}}\right| > 1\) or \(\left|\frac{I_{b2}}{I_{b1}}\right| > 1\) Fault Internal Circuit 2

(17)

If \(\left|\frac{I_{a1}}{I_{a2}}\right| = 1\) or \(\left|\frac{I_{b1}}{I_{b2}}\right| = 1\) Fault External

(18)

g. The protection technique should be able to classify the faulted phase for single-phase-to-ground faults. In the case of single-phase-to-ground faults, two of the modal components that include the faulted phase should have almost the same amplitude and the other modal component should be zero, as follows:

\[ \left|\frac{I_{a1}}{I_y}\right| - 1 < \varepsilon \Rightarrow AG \text{ fault} \] (19)

\[ \left|\frac{I_{a1}+I_b}{I_y}\right| - 1 < \varepsilon \Rightarrow BG \text{ fault} \] (20)

\[ \left|\frac{I_{a1}+I_c}{I_y}\right| - 1 < \varepsilon \Rightarrow CG \text{ fault} \] (21)

The algorithm will continue to determine the faulted phases involved in a multiple-phase fault. In the case of line to line faults, the criteria are as given in (22)-(24):

\[ \left|I_a\right| + \left|I_b\right| - \left|I_y\right| < \sigma \Rightarrow AB \text{ fault} \] (22)

\[ \left|I_b\right| + \left|I_c\right| - \left|I_a\right| < \sigma \Rightarrow AC \text{ fault} \] (23)

\[ \left|I_c\right| - \left|I_y\right| < \sigma \Rightarrow BC \text{ fault} \] (24)

In the case of double line to ground faults, the criteria are as given in (25)-(27):

\[ \left|I_y\right| - (\left|I_a\right| + \left|I_b\right|) < \delta \Rightarrow ABG \text{ fault} \] (25)

\[ \left|\left(I_a\right| + \left|I_c\right|) - \left|I_y\right| + \left|I_b\right|) < \delta \Rightarrow ACG \text{ fault} \] (26)

\[ \left|\left(I_y\right| + \left|I_c\right|) - (\left|I_a\right| + \left|I_b\right|) < \delta \Rightarrow BCG \text{ fault} \] (27)

h. Determining the fault Classification where the fault classification was divided into 2 categories
ground and unground. The current approach had zero given threshold or less equal to zero than the
disruption of unground fault, otherwise if the current $I_g$ is greater than the specified threshold limit,
it would be the ground fault.

The unground fault was the line to line fault, while the threshold limit was given for termination
criteria $\sigma = 0.02$, while the ground was divided into 2, which were line to ground fault with the given
threshold $\varepsilon = 0.03$ and the line to line to ground fault with the given threshold $\delta = 0.05$ for the termination
criteria [34], as shown in Figure 2 that illustrates the proposed fault-type classification algorithm that uses the
modal components of the current signals.

4. SIMULATION RESULTS AND DISCUSSIONS

The system was connected with the sources at each end, as shown in Figure 2. This system was
simulated using PSCAD/EMTD. For the case study, the simulation was modelled on a 230 kV double circuit
transmission line, which was 200 km in length.

![Figure 2. One line diagram of the simulated transmission system](image)

Transmission data:
Sequence Impedance ohm/km.
Transmission Line $Z_l = Z_2 = 0.03574 + j 0.5776 Z_0 = 0.36315 + j 1.32.647$
Fault Starting = 0.22 second Duration in fault = 0.15 Second
Fault resistance ($R_f$) = 0.001, 25, 50, 75 and 100 ohm
Fault Inception Angle = 0, 15, 30, 45, 60, 90, 120 and 150 degree
Source A and B $Z_l = Z_2 = Z_0 = 9.1859 + j 52.093$ Ohm
Type Conductor = Chukar, diameter = 1.602 inch,
$D_s = 0.0524$ ft = 0.0162763 m

The results of the calculations took into account the position of the tower and distance between the
conductors. The conductor types used for this simulation were obtained using the propagation
velocity = $\frac{1}{\sqrt{\mu\varepsilon}} = 299863.4379$ km/second.

4.1. Internal Fault

Table 1 shows the results of various internal fault variations with fault resistance = 0.001 Ohm and
the fault inception angle of 0 degrees at various distances of errors. The biggest fault currentoccurred on the
line to ground fault (AG) at a distance of 25 km with a current of 2.8953 kA. The selected threshold line to
ground for fault $\varepsilon = 0.03$ from the simulation results showed that the fault threshold line to ground (AG) was
$\varepsilon = 0.0237$ which is smaller than the threshold ($\varepsilon$) set.

Also shown in Table 2 $I_{a1}/I_{a2}$ and $I_{p1}/I_{p2}$ on all types of faults that are greater than 1, which indicate that the fault was an internal fault in circuit 1, WTC of the aerial mode and ground mode are shown in
Figure 3 The Clarke's transformation and the mother wavelet Db8 obtained the biggest percentage error in
fault location, about 0.4649 %, at the three phase disorder (AB) which had a distance of 75 km and the WTC
of the aerial mode and ground mode are shown in Figure 4 while the smallest percentage error in fault
location was about 0.0750 %, in line to line (AC) at a distance of 100 km. This indicates that the proposed
algorithm for fault classification is accurate and precise.
Table 1. The obtained result for different faults using the Clarke’s Transformation and mother wavelet Db8

<table>
<thead>
<tr>
<th>Fault Inception Angle</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (km)</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td>125</td>
<td>150</td>
<td>175</td>
<td></td>
</tr>
<tr>
<td>$R_f$ (Ohm)</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Fault</td>
<td>AG</td>
<td>BG</td>
<td>AB</td>
<td>AC</td>
<td>ABG</td>
<td>ACG</td>
<td>ABC</td>
<td></td>
</tr>
<tr>
<td>$I_2$ (kA)</td>
<td>-2.3266</td>
<td>2.3941</td>
<td>-1.6213</td>
<td>1.5088</td>
<td>1.3156</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_1$ (kA)</td>
<td>0.5543</td>
<td>3.3782</td>
<td>-0.4809</td>
<td>2.3185</td>
<td>-0.5580</td>
<td>1.7432</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_{f1}$ (kA)</td>
<td>1.9146</td>
<td>-0.8914</td>
<td>-2.3264</td>
<td>2.3938</td>
<td>-1.6364</td>
<td>1.6941</td>
<td>1.3141</td>
<td></td>
</tr>
<tr>
<td>$I_{f2}$ (kA)</td>
<td>0.4722</td>
<td>2.0446</td>
<td>1.6739</td>
<td>1.0421</td>
<td>1.4762</td>
<td>0.9851</td>
<td>1.8197</td>
<td></td>
</tr>
<tr>
<td>$I_{f3}$ (kA)</td>
<td>1.9612</td>
<td>2.9020</td>
<td>4.0132</td>
<td>-1.3441</td>
<td>3.0248</td>
<td>1.2014</td>
<td>2.3410</td>
<td></td>
</tr>
<tr>
<td>$I_{f4}$ (kA)</td>
<td>1.0492</td>
<td>1.1841</td>
<td>0.00178</td>
<td>0.00198</td>
<td>0.5472</td>
<td>-0.4538</td>
<td>0.0321</td>
<td></td>
</tr>
<tr>
<td>$I_{f5}$ (kA)</td>
<td>-0.5674</td>
<td>0.4403</td>
<td>0.6615</td>
<td>-0.5065</td>
<td>-0.6707</td>
<td>0.7786</td>
<td>-0.8424</td>
<td></td>
</tr>
<tr>
<td>$I_{f6}$ (kA)</td>
<td>-0.3011</td>
<td>-0.4040</td>
<td>0.4453</td>
<td>0.5377</td>
<td>0.6624</td>
<td>0.4012</td>
<td>0.9667</td>
<td></td>
</tr>
<tr>
<td>$I_{f7}$ (kA)</td>
<td>-3.3743</td>
<td>-2.0245</td>
<td>-3.5168</td>
<td>-4.7267</td>
<td>-2.4391</td>
<td>2.1758</td>
<td>-1.5599</td>
<td></td>
</tr>
<tr>
<td>$I_{f8}$ (kA)</td>
<td>-1.5682</td>
<td>-5.0609</td>
<td>-3.5212</td>
<td>1.9381</td>
<td>-1.9417</td>
<td>2.1708</td>
<td>1.8823</td>
<td></td>
</tr>
<tr>
<td>Calculate point of Fault (km)</td>
<td>25.765</td>
<td>49.103</td>
<td>75.930</td>
<td>99.850</td>
<td>123.995</td>
<td>150.98</td>
<td>174.235</td>
<td></td>
</tr>
<tr>
<td>% Error</td>
<td>0.3825</td>
<td>-0.4994</td>
<td>0.4649</td>
<td>-0.0750</td>
<td>-0.5024</td>
<td>0.4994</td>
<td>0.3825</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Line to line fault (AG) circuit 1 from 25 from bus A, (a) Aerial mode for wavelet mother Db8, (b) For ground mode for wavelet mother Db8.

Figure 4. Line to ground fault (AB) circuit 1 from 75 from bus A, (a) Aerial mode for wavelet Mother Db8, (b) For ground mode for wavelet mother Db8.

4.2. Influence of Fault Resistance

Table 2 shows the effects of variations in the resistance of 25 ohms and 50 ohms with fault inception angle at 15 and 45 degrees with varying distances. The simulation showed that when the resistance was increased, the fault current would drop, where the biggest fault current occurred in line to ground (BG) at a distance of 50 km with a fault resistance of 25 ohms.
Table 2 shows the effects of variations in the resistance of 25 ohms and 50 ohms with fault inception angle at 15 and 45 degrees with varying distances. The simulation showed that when the resistance was increased, the fault current would drop, where the biggest fault current occurred in line to ground (BG) at a distance of 50 km with a fault resistance of 25 ohms. The fault inception at the angle of 15 degrees was \( I_b = 2.2829 \) kA and the threshold obtained at \( \varepsilon = 0.00056 \) was smaller than the threshold set \( \varepsilon = 0.03 \). When using the mother wavelet Db8, the percentage error in the fault location was obtained around 0.2%.

When using the mother wavelet Db8, the percentage error in fault location was obtained around 0.2%. Meanwhile, the percentage error in fault location was obtained around 0.4-0.5%, as shown in Table 3. \( I_{a2}/I_{a2} \) and \( I_{g1}/I_{g2} \) varied from 2.5-8, indicating that the fault was internal to circuit 1.

### Table 2. Result for different resistance faults based on mother wavelet Db8

<table>
<thead>
<tr>
<th>Fault Distance (km)</th>
<th>BG</th>
<th>AB</th>
<th>ACG</th>
<th>ABC</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

\( \delta \) (km) 0.05, as it was faulted to the ground. The fault line to line (AC) at a fault distance of 125 km, fault resistance of 25 ohms and fault inception angle 30 degrees obtained a threshold of \( \zeta = 0.0017 \), smaller than the threshold set of \( \zeta = 0.02 \).

### Table 3. The obtained result for different Fault Inception Angle based on mother wavelet

<table>
<thead>
<tr>
<th>Fault Distance (km)</th>
<th>150</th>
<th>125</th>
<th>75</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault Resistance (Ohm)</td>
<td>75</td>
<td>100</td>
<td>75</td>
<td>100</td>
</tr>
</tbody>
</table>

#### 4.3. Influence of Fault Inception.

As shown in Table 3, the simulations showed the effect on the variation of fault inception angle, ranging from 30 degrees to 150 degrees, with variations in fault resistance of 50 ohms and 100 ohms in the various types of fault and fault distance. Meanwhile, the threshold obtained in line to line ground disturbance (BCG) at a fault distance of 75 km, fault resistance 75 ohm and fault inception angle 75 degrees was \( \delta = 0.0851 \); greater than the threshold set on the fault line to line to the ground of \( \delta = 0.05 \), as it was faulted to the ground. The fault line to line (AC) at a fault distance of 125 km, fault resistance of 100 ohms and fault inception angle of 30 degrees obtained a threshold of \( \sigma = 0.0017 \), smaller than the threshold set of \( \sigma = 0.02 \).

Table 3 also shows that if the fault inception angle was enlarged, then the fault current would increase, except for fault three-phase (ABC), which resulted with \( I_{a2}/I_{a2} \) and \( I_{g1}/I_{g2} \), between 1.2-3, indicating that the fault was internal fault circuit 1. Meanwhile, the percentage error in fault location was obtained around 0.2-0.5% when using the mother wavelet Db4. The fault classification algorithms show that the proposed algorithm is correct and responsive.
4.4. Percentage Error in Fault Location for different Types of Mother Wavelet

Table 4 shows the simulation error in determining the fault location when using various types of mother wavelet on the interference resistance of 100 ohms, fault inception angle of 0 degrees and a distance of interference, varied from 25 km-190 km. The fault location estimation error was formulated as follows:

\[
\text{Error} \% = \frac{\text{Fault Simulated Distance} - \text{Real fault Distance}}{\text{Total length of line}} \times 100\%
\]  

From Table 4 it can be seen that the smallest average error was shown by the mother wavelet DB4, while mother wavelets Sym 4, Coif 4 and Db8 have a variation around 0.2-0.5%

Table 4. Percentage error in fault location for different types of Mother Wavelet from Circuit 1,

<table>
<thead>
<tr>
<th>Type Of Fault</th>
<th>Actual Fault Point (km)</th>
<th>Db4</th>
<th>Coif4</th>
<th>Sym4</th>
<th>DB8</th>
</tr>
</thead>
<tbody>
<tr>
<td>LG (AG)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>25.0151</td>
<td>0.0076</td>
<td>25.7650</td>
<td>0.3825</td>
<td>25.3150</td>
</tr>
<tr>
<td>50</td>
<td>49.7601</td>
<td>-0.1949</td>
<td>49.6110</td>
<td>-0.4949</td>
<td>49.0103</td>
</tr>
<tr>
<td>75</td>
<td>75.2550</td>
<td>0.1275</td>
<td>75.8549</td>
<td>0.4274</td>
<td>76.0080</td>
</tr>
<tr>
<td>125</td>
<td>124.745</td>
<td>-0.1275</td>
<td>124.142</td>
<td>-0.4274</td>
<td>123.995</td>
</tr>
<tr>
<td>150</td>
<td>150.239</td>
<td>0.1249</td>
<td>150.389</td>
<td>-0.4949</td>
<td>150.988</td>
</tr>
<tr>
<td>175</td>
<td>174.985</td>
<td>-0.0076</td>
<td>174.350</td>
<td>-0.3825</td>
<td>174.695</td>
</tr>
<tr>
<td>190</td>
<td>198.981</td>
<td>0.0091</td>
<td>198.082</td>
<td>-0.4590</td>
<td>197.750</td>
</tr>
<tr>
<td>25</td>
<td>24.5650</td>
<td>-0.2174</td>
<td>24.1153</td>
<td>-0.4423</td>
<td>25.4651</td>
</tr>
<tr>
<td>50</td>
<td>49.7601</td>
<td>-0.1199</td>
<td>49.1603</td>
<td>-0.4199</td>
<td>48.8603</td>
</tr>
<tr>
<td>75</td>
<td>75.4050</td>
<td>0.2204</td>
<td>75.8549</td>
<td>0.4274</td>
<td>76.0080</td>
</tr>
<tr>
<td>LL (AB)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>125</td>
<td>124.590</td>
<td>-0.2204</td>
<td>124.142</td>
<td>-0.4274</td>
<td>123.995</td>
</tr>
<tr>
<td>150</td>
<td>150.239</td>
<td>0.1199</td>
<td>150.841</td>
<td>0.4199</td>
<td>151.139</td>
</tr>
<tr>
<td>175</td>
<td>175.435</td>
<td>0.2174</td>
<td>175.885</td>
<td>0.4423</td>
<td>174.535</td>
</tr>
<tr>
<td>190</td>
<td>190.432</td>
<td>0.2159</td>
<td>190.232</td>
<td>-0.3840</td>
<td>189.680</td>
</tr>
<tr>
<td>25</td>
<td>25.0151</td>
<td>0.0076</td>
<td>25.0151</td>
<td>0.0076</td>
<td>25.0151</td>
</tr>
<tr>
<td>50</td>
<td>49.7520</td>
<td>-0.1237</td>
<td>49.3120</td>
<td>-0.3449</td>
<td>49.1610</td>
</tr>
<tr>
<td>75</td>
<td>75.6290</td>
<td>0.3150</td>
<td>75.8849</td>
<td>0.4424</td>
<td>75.8540</td>
</tr>
<tr>
<td>LLG (BCG)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>125</td>
<td>124.371</td>
<td>-0.3150</td>
<td>124.161</td>
<td>-0.4224</td>
<td>124.145</td>
</tr>
<tr>
<td>150</td>
<td>150.241</td>
<td>0.1237</td>
<td>150.691</td>
<td>0.3449</td>
<td>150.839</td>
</tr>
<tr>
<td>175</td>
<td>174.985</td>
<td>-0.0076</td>
<td>174.985</td>
<td>0.0076</td>
<td>174.985</td>
</tr>
<tr>
<td>190</td>
<td>190.282</td>
<td>0.1409</td>
<td>189.682</td>
<td>-0.1591</td>
<td>189.982</td>
</tr>
<tr>
<td>25</td>
<td>25.0151</td>
<td>0.0076</td>
<td>25.3150</td>
<td>0.1575</td>
<td>25.6150</td>
</tr>
<tr>
<td>50</td>
<td>49.4600</td>
<td>-0.2699</td>
<td>49.0103</td>
<td>-0.4949</td>
<td>48.8310</td>
</tr>
<tr>
<td>75</td>
<td>75.4050</td>
<td>0.2025</td>
<td>76.0048</td>
<td>0.5024</td>
<td>76.0080</td>
</tr>
<tr>
<td>LLL (ABC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>125</td>
<td>124.595</td>
<td>-0.2025</td>
<td>123.995</td>
<td>-0.5024</td>
<td>123.995</td>
</tr>
<tr>
<td>150</td>
<td>150.540</td>
<td>0.2699</td>
<td>150.989</td>
<td>0.4949</td>
<td>151.169</td>
</tr>
<tr>
<td>175</td>
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<td>-0.0076</td>
<td>174.685</td>
<td>0.1575</td>
<td>174.395</td>
</tr>
<tr>
<td>190</td>
<td>190.582</td>
<td>0.2909</td>
<td>189.532</td>
<td>-0.2340</td>
<td>189.530</td>
</tr>
</tbody>
</table>

4.5. External Fault

Table 5 shows that \( I_{a1} / I_{a2} = 1 \) and \( I_{g1} / I_{g2} = 1 \) in various types of fault, with a fault resistance of 100 and 0.001 Ohms, and fault inception angle of 0 and 60 degrees, which shows that the disturbance was an external fault. The largest fault current was found in the type of fault Bus B Line to line (AB) with fault resistance 0.0001 Ohm, fault inception angle at 60 degrees, and at 1.4344 kA.

4.6. Determining Fault Location using Karenbauer’s Transformation

Table 6 shows the percentage error in the calculation of fault location by using another method, which is Karenbauer’s Transformation, for comparison when using Clarke’s transformation (Table 1). It turned out that the results obtained by both methods in determining the fault location percentage error were similar. The only difference between \( I_{a1} / I_{a2} \) and \( I_{g1} / I_{g2} \) in Table 1 was that the transformations achieved \( I_{a1} / I_{a2} = -3.3743 \) and \( I_{g1} / I_{g2} = -1.5682 \) respectively, in the type of line to ground disturbance (AG) at fault distance 25 km, fault inception angle 0 degrees and fault resistance 0.001 ohm, whereas Table 6 shows type of fault at \( I_{a1} / I_{a2} = 3.6515 \) and \( I_{g1} / I_{g2} = 2.4853 \).
Table 5. The obtained result for different external fault

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>Bus A</th>
<th>Bus B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AG</td>
<td>AB</td>
</tr>
<tr>
<td>Fault Inception Angle</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>Rf (Ohm)</td>
<td>0.001</td>
<td>100</td>
</tr>
<tr>
<td>Ia (kA)</td>
<td>-1.1360</td>
<td>-1.2477</td>
</tr>
<tr>
<td>Ib (kA)</td>
<td>0.3369</td>
<td>-1.5471</td>
</tr>
<tr>
<td>Ic (kA)</td>
<td>0.4560</td>
<td>0.3269</td>
</tr>
<tr>
<td>Ia (kA)</td>
<td>-0.9213</td>
<td>1.2477</td>
</tr>
<tr>
<td>If1 (kA)</td>
<td>0.3047</td>
<td>-1.0665</td>
</tr>
<tr>
<td>Id (kA)</td>
<td>-0.9213</td>
<td>1.2478</td>
</tr>
<tr>
<td>If2 (kA)</td>
<td>0.3051</td>
<td>-1.0661</td>
</tr>
<tr>
<td>Ia / If2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Id / If2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Ia (kA)</td>
<td>-0.2151</td>
<td>0</td>
</tr>
<tr>
<td>Ia (kA)</td>
<td>-1.1360</td>
<td>1.2477</td>
</tr>
</tbody>
</table>

Table 6. The obtained result for different faults based on Karenbauer transformation and mother wavelet Db8

<table>
<thead>
<tr>
<th>Fault</th>
<th>AG</th>
<th>BG</th>
<th>AB</th>
<th>AC</th>
<th>ABG</th>
<th>ACG</th>
<th>ABC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (km)</td>
<td>25</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td>125</td>
<td>150</td>
<td>175</td>
</tr>
<tr>
<td>Rf (Ohm)</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Fault Inception Angle</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ia (kA)</td>
<td>2.8953</td>
<td>0.5330</td>
<td>-2.3266</td>
<td>2.3941</td>
<td>-1.6213</td>
<td>1.5088</td>
<td>1.3156</td>
</tr>
<tr>
<td>Ib (kA)</td>
<td>0.5543</td>
<td>3.3782</td>
<td>2.6240</td>
<td>-0.4809</td>
<td>2.3185</td>
<td>-0.5580</td>
<td>1.7432</td>
</tr>
<tr>
<td>Ic (kA)</td>
<td>0.5950</td>
<td>-0.5358</td>
<td>0.4682</td>
<td>2.1064</td>
<td>-0.5121</td>
<td>-1.9317</td>
<td>-1.8289</td>
</tr>
<tr>
<td>Ia (kA)</td>
<td>-1.0664</td>
<td>-1.0156</td>
<td>-1.6500</td>
<td>0.8938</td>
<td>-1.2098</td>
<td>0.6492</td>
<td>-0.9158</td>
</tr>
<tr>
<td>Ic (kA)</td>
<td>0.8711</td>
<td>-0.2779</td>
<td>-0.6763</td>
<td>1.5000</td>
<td>-0.4432</td>
<td>1.1054</td>
<td>0.9397</td>
</tr>
<tr>
<td>Ia (kA)</td>
<td>-0.2904</td>
<td>0.2989</td>
<td>-0.3918</td>
<td>-0.2586</td>
<td>0.2967</td>
<td>0.3248</td>
<td>0.5674</td>
</tr>
<tr>
<td>Ia (kA)</td>
<td>0.3505</td>
<td>0.1752</td>
<td>-0.2992</td>
<td>-0.3757</td>
<td>0.3797</td>
<td>0.4649</td>
<td>0.5864</td>
</tr>
<tr>
<td>Ia / If2</td>
<td>3.6515</td>
<td>-3.3978</td>
<td>4.2133</td>
<td>-3.4563</td>
<td>-4.0776</td>
<td>1.9988</td>
<td>-1.6140</td>
</tr>
<tr>
<td>Ic / Ia</td>
<td>2.4853</td>
<td>1.5862</td>
<td>2.2603</td>
<td>-3.9925</td>
<td>-1.1673</td>
<td>2.3778</td>
<td>1.6025</td>
</tr>
<tr>
<td>Io (kA)</td>
<td>1.0422</td>
<td>1.1841</td>
<td>0.0179</td>
<td>0.0198</td>
<td>0.5472</td>
<td>-0.4538</td>
<td>0.0321</td>
</tr>
<tr>
<td>Calculate point of</td>
<td>25.765</td>
<td>49.103</td>
<td>75.930</td>
<td>99.850</td>
<td>123.995</td>
<td>150.98</td>
<td>174.235</td>
</tr>
<tr>
<td>% Error</td>
<td>0.3825</td>
<td>-0.4994</td>
<td>0.4649</td>
<td>-0.0750</td>
<td>-0.5024</td>
<td>0.4994</td>
<td>0.3825</td>
</tr>
</tbody>
</table>

5. CONCLUSION

The application of parallel transmission lines requires a more special consideration in comparison with the single transmission line, due to the effect of mutual coupling method. To overcome this problem, a new method was proposed, by using the Current alpha and beta (Current mode) from the Clarke’s transformation to convert the signal. Then, discrete wavelet transform (DWT) is used to obtain wavelet transform coefficients (WTC)², to determine the current time when the fault amplitude values (WTC)² would reach a maximum point, to determine the fault location distance. This paper also proposed algorithm fault classification by using Clarke’s transformation. The simulation results showed that the results were accurate, which were also compared against the results obtained by using the Karenbauer’s transformation.

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REFERENCES


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