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Development of Mathematical Model for Fault Location Estimation in Power Transmission Lines

E.G.K.C. Gamage*, B.A.U. Dedunu**, M. Warushawithana***, K.A.C. Udayakumar****

**Department of Electrical and Computer Engineering, The Open University of Sri Lanka, Nawala.*
*** Department of Mathematics and Philosophy of Engineering, The Open University of Sri Lanka, Nawala.*
**** Department of Mathematics and Philosophy of Engineering, The Open University of Sri Lanka, Nawala.*
*****Department of Electrical and Computer Engineering, The Open University of Sri Lanka, Nawala.*

ABSTRACT

An identification of fault locations on transmission lines is a critical task in the protection of electric power networks. Since the establishment of distribution and transmission systems, it has become one of the essential tasks of grid operators. The ability to quickly identify the exact position of a fault can aid utility technicians in recovering the damaged section and restoring the line in a timely manner. As a result, while fault detection and locating systems have been created in the past, new methods for doing this task are still being developed.Impedance-based locators, which measure the impedance observed by one or both ends of the transmission line, and traveling wave-based locators, which employ various mathematical models and algorithms for fault location detection, are the most prevalent systems. This research proposed a novel mathematical model for detecting fault location in transmission lines. The proposed mathematical model uses reversed traveling waves and a reversely applied Lagrange Interpolation model to estimate the fault location in transmission lines. Furthermore this model was developed and tested in the MATLAB modeling platform. According to the analyzed results, the proposed model achieved an accuracy of more than 93%. Finally, results verified the precision of the proposed mathematical model.

Keywords-Fault Location, Lagrange Interpolation, Traveling Wave, Wavelet Analysis, Mathematical Modeling

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I. INTRODUCTION

The distribution network is accountable for providing electrical power to target consumers. The transmission network structure and load distribution are complicated areas in the electrical power transmission process [1]. The task of detecting and locating faults on transmission lines is critical for the safety of electric power systems. Since the construction of distribution and transmission systems, it has been one of the key tasks of power system operators. Rapid fault detection can assist protect devices by allowing defective wires to be disconnected before they cause serious harm. Fast and accurate location of a fault can assist electricity technical employees in recovering the faulty piece and restoring the line in a timely manner. Figure 1 shows a simple power transmission system with grounded fault. There are several forms of distribution network faults, approximately 80% of all faults are single-phase grounding problems.

Therefore, studying the fault finding method is important in order to accurately identify the fault, rapidly troubleshoot the defect, and enhance the quality and safety of power consumption. The new sort of smart cities currently use underground cables to supply electricity.

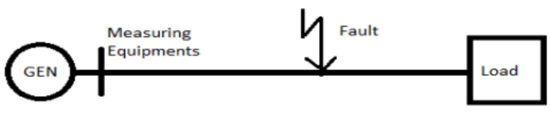

Fig. 1 Simple power transmission system

The system will switch to the backup line if the underground cables fail, ensuring that consumers have consistent electricity. To eliminate the fault, it is important to precisely locate the fault using the fault location method and pull out the cable at the fault location. On the other hand, if the overhead transmission power distribution system fails, the ring network panel will continue to distribute power on the standby sideline. The fault finding method determines the location of the fault by doing offline processing on the faulty line. According to the two scenarios described above, Implementing fault location methods to analyze non-branch distribution networks is essential for solving the problem of underground cables and distribution network systems in practice. As a result, while fault identification and locating systems have been created in the past, this task continues to be performed using a variety of algorithms. Traveling wave-based locators are among the most common systems. The traveling wave technique has difficulty determining the traveling wave's wave head in the distribution network, and the traveling wave method needs that the reflected wave head arrive at an apparent time for precise location. The positioning accuracy is considerably impacted. The method based on transient signal comparison has the disadvantage that the transient signal has a short duration, necessitating the equipment to extract small defect information quickly and precisely.

On the other hand, the traveling wave method needs to calculate the time difference, thus providing the error caused by the time difference under the actual medium and high propagation velocity. Although many intelligent methods have been presented, these methods require a large number of samples to train the neural network and have a high sample data requirement.

This paper proposed a new mathematical model combined with a backward traveling wave to estimate grounded fault location in power transmission lines. Firstly, the time taken to reach the first peak of the backward traveling wave from source point to fault point, estimated by wavelet analysis. Then the estimated backward traveling wave time applied to the developed mathematical model to determine the fault location. The mathematical model is modeled based on the Lagrange interpolation method. The Lagrange interpolation method is one of the interpolation methods which can rearrange to estimate the fault locations of the given line with irregular interval sizes. The possibility of using the Irregular intervals is an advantage of using the Lagrange interpolation formula for estimating the fault locations. This paper uses the reverse Lagrange Interpolation formula.

II. RELATED WORKS

YelavarthiSrinivasarao et al. [2] proposed an algorithm to determine a single ended method of traveling wave fault location to locate the fault point when fault occurs in a power line. When the wave reaches both ends of the transmission line, the single-ended traveling wave approach is used to recognize it. To investigate the traveling wave signal, they use the Karrenbauer transformation approach, which is sensitive to frequency when dealing with discrete signals. They used the MATLAB simulation to test and simulate this single-ended technique. The current signals are captured throughout the testing, and then the Karrenbauer transformation is applied to the recorded current signal.

Anamika Yadav et al. [3] have developed an Artificial Neural Network (ANN) for fault distance and direction estimation in power transmission lines. In this research three phase voltage and current signal fundamental components are used as input variables for the ANN model. According to their simulation results they obtained the developed ANN model accuracy up to 90%. Furthermore, in this research the power system line was modeled and simulated in a MATLAB simulation environment. The simulations were tested for different kinds of ANN architectures to achieve more accurate results.

Xing, Z et al. [4] based on the time difference method, suggested a new traveling wave fault location technique for hybrid power lines. To determine the faults in any segment, the technique used the absolute time difference of moving waves. Then, the hybrid connection of a multi-section cable and overhead line was expanded using the standard wave velocity normalization procedure, this was estimated using a set wave velocity and a difference in time Sizu Hou and Xiaoyi Guo. [5] Proposed fault location identification method based on the standing wave principle. They developed a mathematical model for calculating fault distance in transmission power systems due to line to ground faults. The connection between the voltage amplitude value at x position on the transmission line and the distance x from the point to the fault point is theoretically determined using their methodology. Secondly, a certain way of action of two points of detection for the position of the fault is determined. Finally, the proposed method is subjected to simulation and experimental testing.

Qi, Z et al. [6] presented a bus disturbance signal-based, single-ended fault traveling wave locating technique. Following the occurrence of a permanent single-phase grounding fault, the non-fault phase bus was grounded through resistance, according to the traveling wave transmission concept, an effective line mode component was chosen, and the fault distance was computed by measuring the time difference between the arrival and reflected traveling wave time of the line mode component and the arrival time of the reflected traveling wave of the line mode component.

Peng, H et al. [7] in this research, all phase fast Fourier transform (apFFT) spectrum correction and limit gradient lifting (XGBoost) methods were used to develop and measure the single-phase grounding fault location. To generate the original feature set, the apFFT spectrum correction approach was used to obtain the basic phasors of fault voltage and current. The XGBoost method was used to create a prediction model for single-ended fault location, and the significance and order of fault features were determined. According to the existing model, the XGBoost fault locator was employed to determine the new input mode, and the precise location of the fault point was discovered.

Liang, J et al. [8] this research suggested a fault line classification algorithm for a distribution network based on an adaptive convolutional neural network (ACNN). By upgrading the pooling structure, this strategy increased the network's feature extraction capability. According to this method, the position of the secondary fault was discovered utilizing the two-terminal method.

Lan, S et al. [9] by studying the double-end unsynchronized transmission lines, a novel fault location approach for HVDC transmission lines was proposed in this research. The proposed methodology makes use of the Hilbert–Huang transformation and convolutional neural network techniques. The high-frequency elements of the double-terminal fault signals were joined in series after the fault signal was gathered at both ends to create a characteristic waveform. This CNN model was able to learn the properties of different fault kinds and distances from the fault location.

According to the literature, there are numerous methods for locating the location of a fault in a transmission line. These methods are mostly based on the traveling wave method and impedance methods; however, due to advances in Artificial Intelligence (AI) algorithms, various AI methodologies for locating faults in power transmission lines are now available. Ground to phase faults in power transmission lines have a limited number of direct unique mathematical functions for measuring fault location.

III. PROPOSED METHODOLOGY

The proposed methodology consists of two stages. In the first stage we calculate the timethat takes the backward travelling wave head to travel from the fault location to the line end. In the second step, the proposed mathematical model applied to the calculated backward travelling wave time for estimate the fault location. The figure 2 shows the flow of proposed methodology.

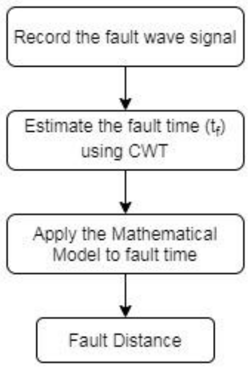

Fig. 2 Proposed methodology

3.1 Identification of Backward Travelling Wave Arrival Time.

In this methodology, precise determination of the backward travelling wave head arrival time is critical for high accuracy. The proposed methodology used Continues Wavelet Transform (CWT) for identify the surge arrival time because of its simultaneous time and frequency localization capabilities [10].Previously there were several researchers used CWT for analyze faulty wave forms [11]-[15]. In the CWT, parent wavelets are the analysis functions, and they are defined as (1).

$$\varphi_{p,\tau}(t) = \frac{1}{\sqrt{p}} \varphi * \frac{(t-\tau)}{p} \qquad (1)$$

Where, φ is the provided mother wavelet, τ is the time shift and p is the scale or duration. These shift and scale values can be changed in the CWT. This is known as multi resolution analysis, and it is important for fault transient analysis [16]. In this research we used Daubenchie(db) mother wavelet types. According to the research db4 mother wavelet were used berceuse it provides more information about frequency changes. The figure 3 shows the form of used mother wavelet.

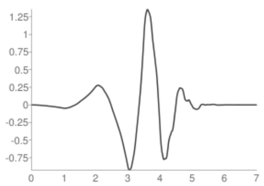

Fig. 3Daubenchie (db) mother wavelet type db4

The CWT still employs discretely sampled data, but the shifting process is smooth across the length of the sampled voltage data, and the scaling can be determined from a minimum to a maximum desired value. As a result, CWT has a finer resolution. In this research we apply CWT for recorded voltage signal of the faulty line to extract the extract backward weave head arrival time.

3.2 Methodology for Fault Location Estimation.

The proposed mathematical algorithm shows in figure 4. Mainly this method consists of nine steps, these steps briefly explained in below. The Lagrange Interpolation is the main concept of this methodology.The Lagrange interpolation method is one of interpolation methods which can rearrange to estimate the fault locations of the given line with irregular interval sizes. The possibility of using the Irregular intervals is an advantage of using the Lagrange interpolation formula for estimating the fault locations. This paper uses reversely the Lagrange interpolation formula [17]. When operating the Lagrange interpolation formula in reverse way, the roots of the constructed polynomial be either complex or real. Existing of the real roots for the constructed polynomial is trivial. Hence the mode of the real roots will be considered to choose the exact answer from the real roots. By following the suggested method, estimation of the fault location is not trivial. That task will be done by tracking the fault time.

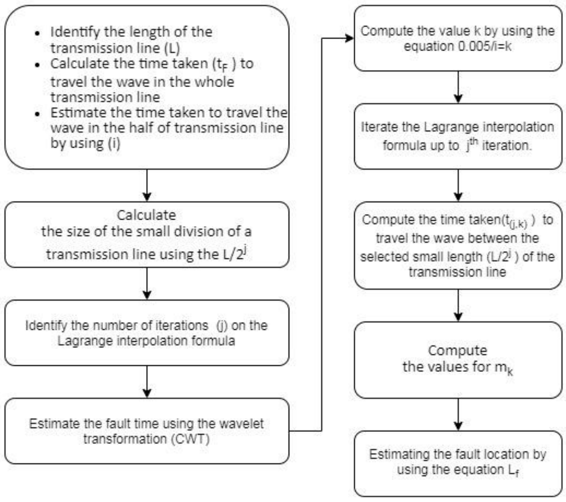

Fig. 4Proposed mathematical algorithm

The fault time and the fault location are not proportionally varying quantities. This research identified that there is no linear relationship in between fault time and the fault location. Hence, the Lagrange interpolation method governed to build a relationship in between the arbitrary locations and time travel from a one end to the arbitrary chosen location. The suggested method chooses the arbitrary locations by descending order. The research identified that handling of the Lagrange interpolation formula is difficult when the size of a two consecutive chosen location become very small when comparing with the length of the transmission line.A transmission line could be mapped into the positive part of the real number line such that one end should be placed on the origin of the real line. This line segment can divide infinitely many parts. In this paper, transmission line is divided for countable parts because of the reliability of the research work.The Lagrange interpolation formula is given by (2).

$$I(x) = y_o L_o(x) + y_1 L_1(x) + \cdots + y_n L_n(x) \quad (2)$$

Here the polynomial $L_j(x)$ is given by

$$L_j(x) = \frac{(x - x_o) \cdots (x - x_{j-1})(x - x_{j+1}) \cdots (x - x_n)}{(x_j - x_o) \cdots (x_j - x_{j-1})(x_j - x_{j+1}) \cdots (x_j - x_n)} \quad (3)$$

Formula (3) is known as Lagrange's interpolation coefficients.The following steps show the methodology of this research.

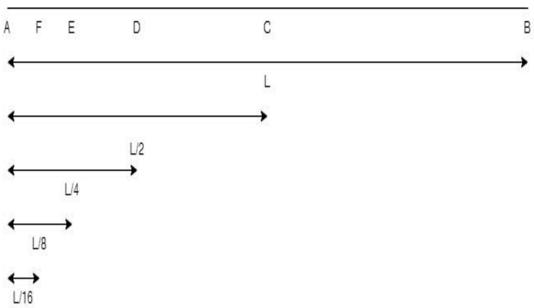

Fig. 5Transmission line (length L)

Figure 5 shows that how the transmission line is divided. Let a length of a transmission line AB=L. Observe that,

Where,

$$AB = L$$

$$AC = \frac{AB}{2} = \frac{L}{2}$$

$$AD = \frac{AB}{4} = \frac{L}{4}$$

$$AE = \frac{AB}{8} = \frac{L}{8}$$

$$AE = \frac{AB}{16} = \frac{L}{16}$$

Then we can get x is an arbitrary point such that AC>AD>AE>⋯>Ax. In this research choose the divisions of a transmission line is 2^n such that,

$$Ax = \frac{AB}{2^n} = \frac{L}{2^n} \quad (4)$$

Using this Lagrange interpolation method, this research could be able to find the time taken to travel the wave between each divided part of the transmission line. For that work, this research assumed that the time taken to travel a wave through the transmission line from the point A to point B of the figure 6 is t. Let consider a sample wave representation on a transmission lime.

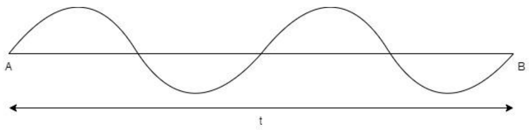

Fig. 6Transmission line (time t)

Observe that, the maximum time taken should be t/2 if the wave characteristics are similar. But considering the practical situation, this paper considers that time taken is $t/(2 + i)$. Here the variable i is a very small value such that -0.005< i<0. This variable i is always negative because if the variable i is positive, then the time taken will be greater than t/2. In practical situations that cannot be happened. See the figure 7.

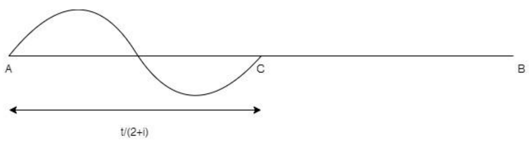

Fig. 7Transmission line (time t/2)

Starting this point, this research could be able to find all the time taken to travel the wave between each divided part of the transmission line. This research calculated four time taken by varying the variable i in the assumed region. Then iterate those four values up to the end results and finally take the average of the fault point of the transmission line. This research manipulates the Lagrange interpolation formula in another way. Normally the Lagrange interpolation method use in the following way. Let use a simple example. In the following data set parameter $y(t)$ is measured against the time. Notice that, time measured is arbitrarily, difference between any two of time measured is different.Let the data is given in table 1,

Table 1 Time and distance values

$Time$	t_1	t_2	t_3	t_4
$y(t)$	y_1	y_2	y_3	y_4

$$y = \pi(t).s \qquad (5)$$

$$s = \frac{y_1}{D_1} + \frac{y_2}{D_2} + \frac{y_3}{D_3} + \frac{y_4}{D_4} \qquad (6)$$

Let consider the difference of the time as table 2. Take t' be the time between $t_1$and t_4. Hence y be the value against the time t'. See the equation 7.

Table 2 Time difference values

$t^{'} - t_1$	$t_1 - t_2$	$t_1 - t_3$	$t_1 - t_4$
$t^{'} - t_2$	$t_2 - t_1$	$t_2 - t_3$	$t_2 - t_4$
$t^{'} - t_3$	$t_3 - t_1$	$t_3 - t_2$	$t_3 - t_4$
$t^{'} - t_4$	$t_4 - t_1$	$t_4 - t_2$	$t_4 - t_3$

Then $\pi(t)$is given by,

$$\pi(t) = (t^{'} - t_1).(t^{'} - t_2).(t^{'} - t_3).(t^{'} - t_4) \qquad (7)$$

D_1, D_2, D_3, D_4Appeared in the equation B is given by,

$$D_1 = (t^{'} - t_1).(t_1 - t_2).(t_1 - t_3).(t_1 - t_4)$$

$$D_2 = (t^{'} - t_2).(t_2 - t_1).(t_2 - t_3).(t_2 - t_4)$$

$$D_3 = (t^{'} - t_3).(t_3 - t_1).(t_3 - t_2).(t_3 - t_4)$$

$$D_4 = (t^{'} - t_4).(t_4 - t_1).(t_4 - t_2).(t_4 - t_3)$$

Finally using the equation A, the value ofy(t′)will be calculated. This example illustrated that how the Lagrange interpolation could be used for interpolation.

In this research paper consider the converse of the Lagrange interpolation method. Explain further this using the above illustrated example, notice that from the equation A, the Lagrange interpolation formula is manipulated to computey(t′). In this research compute the possible roots for the polynomial function of t with respect to the provided value ofy(t′). In this approach, the research found the roots satisfied by the constructed polynomial function of t are in the form of real and complex. But the Lagrange interpolation formula guaranteed that the existing of the real root in the given value range for the constructed polynomial function of t with respect to the provided value ofy(t′). The next step explains the calculation of fault distance.

Let the research consider the interpolation process up to the j^{th} iteration. Estimation of the fault point using all the steps above is another iteration process. This research found the fault time and the time taken to travel the wave in $L/2^j$part of the transmission line. This methodology generates few times taken because of the variable i. Notice that, j∈N.Hence, adding continuously the time taken to travel the wave in $L/2^j$part of the transmission line up to the fault time, this research could estimate the fault point.

Let $m_k \in N$ such that,

$$\frac{t_f}{t_j{}^k} = m_k \qquad (8)$$

Where, $t_f$be the fault time and t_j be the time taken to travel the wave in $L/2^j$ part of the transmission line. This research produced few m_k because of the variable i. Letm_1,m_2…,m_k, where $k \in N$ such that

$$\frac{0.005}{i} = k$$

Hence, estimating the fault location is,

$$L_f = \frac{L}{2^j}\frac{(m_1 + m_2 + \cdots + m_k)}{k} \qquad (9)$$

IV. SIMULATION ENVIRONMENT

The simulation environment was developed by using MATLAB Simulink environment [18]. The figure 8 shows the developed power transmission model by using Simulink blocks.

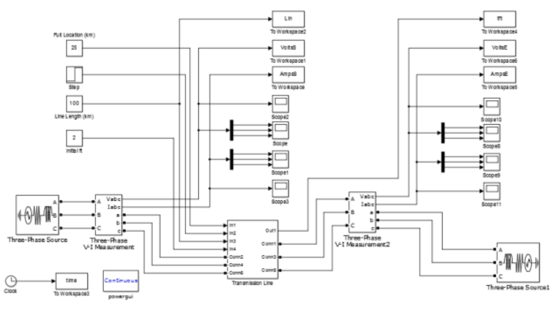

Fig. 8MATLAB simulation model

The modeled transmission line consists two power sources and transmission line model. The table 3 and table 4 shows the selected power source and line parameters for the simulation. The simulation time is 0.2 seconds and the fault generating time is 0.05 seconds, we used three-phase fault generation Simulink block for generate the phase-ground fault in line A. Finally end of the simulation, we recorded the fault voltage single in line A and used to estimate fault time/fault distance.

Table 3 Line parameters

Parameter	Value
Number of phases	3
Frequency (Hz)	50
Resistance per unit length (Ohms/km) [r1 r0]	[0.01273 0.3864]
Inductance per unit length (H/km) [l1 l0]	[0.9337e-3 4.1264e-3]
Capacitance per unit length (F/km) [c1 c0]	[12.74e-9 7.751e-9]
Line Length (km)	100

Table 4 Source parameters

Parameter	Value
Phase-to-phase rms voltage (V)	11e3
Frequency (Hz)	50
Source resistance (Ohms)	0.8929
Source inductance (H)	16.58e-3

To get the simulation results from suggested algorithm, the research chooses 100 km transmission line. To maintain the accuracy of the estimated fault point location in nearest 100 m, the paper has been set the number of small divisions on the transmission line is $100/2^{10}$. In another way, the Lagrange interpolation formula is iterated to the 10th iteration because of the selection of the length of the small division on the transmission line. Once the experiment selects those parameters, the algorithm is ready to run. The fault time estimated by using MATLAB wavelet and design analysis application [19].

V. RESULTS & DISCUSSION

The table 3 shows that the fault points are placed in unique interval size of 5 km and the estimated fault location.By going through the results in the table 5, the average accuracy of the estimated outcomes is 93%.

Table 5 Estimated fault location & accuracy

Fault Location (km)	Calculated Fault Location (km)	Accuracy (%)
5	4.71	94.22
10	9.35	93.50
15	14.03	93.53
20	18.65	93.26
25	23.32	93.28
30	28.00	93.26
35	32.64	93.26
40	37.30	93.26
45	41.97	93.21
50	46.60	93.22
55	51.27	93.22
60	55.93	93.22
65	60.60	93.19
70	65.23	93.16
75	69.87	93.23
80	74.59	93.20
85	79.22	93.18
90	83.86	93.18
95	88.53	93.18

To differentiate the variation between the exact fault location and the estimated fault location, the paper has plotted the accuracy variation with the fault time.The figure 9 shows the variation of the accuracy of the estimated fault location and the exact fault location. In the figure 9, the blue line indicates the actual fault point and the red line indicates the calculated fault point by the proposed methodology. By analyzing the two curves of the figure xx in the above, the research concluded that the accuracy is deducted gradually in the exact second half of the transmission line. That error could be avoided by applying the same algorithm and the procedure with reference to the opposite end.

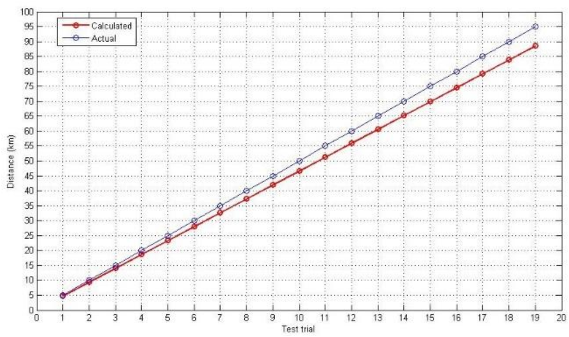

Fig. 9Simulation results – Variation of actual and calculated values

The relation of estimated fault time and the fault location is not trivial. There is no research found in the study of the previous related works to show the validity of the statement ‘the fault time and the fault location is proportional to each other'. This research assumes theoretically the above stated statement is true for a short time and take place the conditions under that true statement be the initial conditions of the Lagrange interpolation formula. Once the 1st iteration is done the validity of the above stated statement is again expired. This work is not trivial. To do so, the research has been taken place a dummy variable i. The role of the dummy variable $i$is to bring that the above stated true statement to false. The research proposed this theoretically, but for the practical adoptions really need the real time data to define the exact values of the variable i.

VI. CONCLUSION

This research identified that there is no linear relationship in between fault time and the fault location. Hence, the Lagrange interpolation method governed to build a relationship in between the arbitrary locations and time travel from a one end to the arbitrary chosen location. The suggested method chooses the arbitrary locations by descending order. The research identified that handling of the Lagrange interpolation formula is difficult when the size of a two consecutive chosen location become very small when comparing with the length of the transmission line. This research focus only for single transmission line, but also this concept could be extended to other cases. The suggest method is fully theoretical work. In the process of converting this suggested method from the theoretical base to practical, the research integrated a variable with the Lagrange interpolation formula. The role of the above-mentioned variable is to avoid the errors due to practical effects. The outcomes of the experiment guaranteed that the accuracy of the fault location computing by the suggested method.

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REFERENCES

[1]. Dong, X.; Wang, J.; Shi, S. Traveling wave based single phase-to-ground protection method for power distribution system. CSEEJ. Power Energy 2015, 1, 75–82.

[2]. YelavarthiSrinivasarao, Sarikonda Pavani and GummireddySudharmi,"Detection Of Fault Location In Transmission Lines", International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 1 (2017)

[3]. Yadav, Anamika &Thoke, A.,"Transmission line fault distance and direction estimation using artificial neural network". International Journal of Engineering, Science and Technology. 2012. 10.4314/ijest.v3i8.9.

[4]. Xing, Z.; Tian, X.; Liu, Y.; Li, J.; Gao, Q.; Liu, H. Research on Traveling Wave Fault Location Algorithm for Hybrid Cable-Overhead Lines. Power Syst. Technol. 2020, 44, 3540–3546.

[5]. Zhou, L.; Liang, R.; Peng, N.; Xu, C.; Teng, S.; Chen, X. ARIMA-based fault identification and fault location of transient traveling wave in mine power grid. Electr. Power Autom. Eq. 2020, 40, 177–188.

[6]. Qi, Z.; Zhuang, S.; He, X.; Huang, Z. Traveling wave fault location technology for mixed lines of distribution network based on bus disturbance signal. Autom. Electr. Power Syst. 2019, 43, 124–133.

[7]. Peng, H.; Zhu, Y. Single-phase grounding fault location based on apFFT spectrum correction and XGBoost in wind farm collection line. CES 2020, 35, 4931–4939.

[8]. Liang, J.; Jing, T.; Niu, H.; Wang, J. Two-Terminal Fault Location Method of Distribution Network Based on Adaptive ConvolutionNeural Network. IEEE Access 2020, 8, 54035–54043.

[9]. Lan, S.; Chen, M.; Chen, D. A Novel HVDC Double-Terminal Non-Synchronous Fault Location Method Based on ConvolutionalNeural Network. IEEE Trans. Power Deliver. 2019, 34, 848–857.

[10]. A. Borghetti, S. Corsi, C. Nucci, M. Paolone, L. Peretto, and R. Tinarelli, "On the use of continuous-wavelet transform for fault location in distribution power systems," International Journal of Electrical Power & Energy Systems, vol. 28, Nov. 2006, pp. 608-617.

[11]. R.A. Keswani, "Identification of Fault in HVDC Converters Using Wavelet Based Multi-Resolution Analysis," 2008 First International Conference on Emerging Trends in Engineering and Technology, Nagpur, Maharashtra, India, 2008, pp. 954-959.

[12]. P. Murthy, J. Amarnath, S. Kamakshiah, and B. Singh, "WaveletTransform Approach for Detection and Location of Faults in HVDCSystem," Industrial and Information Systems conference, 2008, pp. 1-6.

[13]. J. Suonan, G. Shuping, S. Guobing, J. Zaibin, and K. Xiaoning, "ANovel Fault-Location Method for HVDC Transmission Lines,"

IEEEtransactions on power delivery, vol. 25, 2010, pp. 1203–1209.

[14]. O.M.K.K. Nanayakkara, A.D. Rajapakse, and R. Wachal, "FaultLocation in HVDC Transmission Lines Using Discrete WaveletTransform", presented at the 2010 Cigre Canada conf. on powersystems, Vancouver, Canada, 2010.

[15]. L. Shang, G. Herold, J. Jaeger, R. Krebs, and A. Kumar, "Analysis andidentification of HVDC system faults using wavelet modulus maxima,"IEE conference publication, 2001, pp. 315–320.

[16]. M.M. Saha, J. Izykowski, and E. Rosolowski, Fault Location on PowerNetworks, Springer Verlag, 2009.

[17]. Biswajit Das, Dhritikesh Chakrabarty "Lagrange's Interpolation Formula: Representation of Numerical Data by a Polynomial curve", International Journal of Mathematics Trends and Technology (IJMTT). V34(2):64-72 June 2016. ISSN:2231-5373.

[18]. Konda, Jamuna. (2016). Modeling and Simulation Methods Using MATLAB Simulink.

[19]. www.mathworks.com. (n.d.). Practical Introduction to Continuous Wavelet Analysis - MATLAB & Simulink Example. [online] Available at: https://www.mathworks.com/help/wavelet

E.G.K.C. Gamage, et. al. "Development of Mathematical Model for Fault Location Estimation in Power Transmission Lines." *International Journal of Engineering Research and Applications (IJERA*), vol.12 (07), 2022, pp 01-09.