ISSN: 2583-5637 (Onlin
International Journal of Inventive Research in Science andTechnology Volume (2), Issue (4), May 2023

EVALUATION OF SINGLE ENDED TRAVELLING WAVE BASEDFAULT LOCATION WITH DWT THEORY

Aman Pranami[1], , Anula Khare[2]

1. Research Scholar, Department of Electrical & Electronics Engineering, TIT, Bhopal, M.P, India
2. .Professor & Head, Department of Electrical & Electronics Engineering, TIT, Bhopal, M.P, India

Abstract: In the deregulated environment of smart grids, pinpointing the precise location of transmission line faults, removing the resulting defects, and quickly restoring the network are of utmost importance for increasing system availability and reliability, improving the quality of power delivered to consumers, and lowering system costs. In general, there are three methods for locating faults in transmission lines: impedance-based fault location (TWFL), which uses high-frequency transient components of voltages and currents, traveling wave-based fault location (TWFL), and artificial intelligence-based methods, which employ soft computing. Since the first approach, also known as the single-ended method, does not require a communication path between the terminals, data synchronization is cheaper and more dependable. Impedance-based techniques might not hold up well to changes in system factors like resource impedance, power swing, fault impedance, CT saturation, transmission line power flow, etc. In comparison, the TWFL techniques are more dependable and unaffected by the aforementioned issues in addition to being faster and more accurate. Using traveling waves produced by fault conditions and the discrete wavelet transform employed for time-frequency analysis, this thesis investigates the issue of fault localization. On a single circuit of a 500kV system that was modelled using MATLAB SIMULINK, the single-ended traveling wave approaches are shown and assessed. The wavelet, sample rate, and fault resistance employed for analysis are contrasted with the results.

Keywords: Fault Location, TWFL, CT, Impedance, DWT, Single Ended, Arriving Time, LL, LG, LLG etc.

I. INTRODUCTION

Faults in an electric power system are disruptions that disrupt the usual flow of current. Natural occurrences such as lightning strikes can create them, as can short circuited equipment within a substation triggered by local fauna. Long-lasting faults, such as a failing cross arm on a transmission pole that takes a lengthy outage to repair, can also be transitory, such as a tree making contact with an electrified wire before falling to the ground. All failures have one thing in common: they impair transmission service and may be hazardous to nearby persons and equipment. To reduce the impact of defects on transmission lines and customer service, it is becoming increasingly vital to locate a fault promptly and precisely for isolation and repair.

Determining the exact location of transmission line faults, eliminating the resulting defects, and restoring the network in the shortest possible time to increase reliability and system availability, improve the quality of power delivered to consumers, and reduce system costs is especially important in the deregulated environment of smart grids. In general, transmission line fault location can be accomplished in three ways: impedance-based using power frequency components of voltages and currents [1, 2], traveling wave-based fault location (TWFL) using high-frequency transient components [3-6], and artificial intelligence-based methods using soft computing [7]. To locate the defect, each of these approaches can employ measured signals at one terminal or information from both terminals of the transmission line.

The first way, known as the single-ended method, does not require a communication connection between terminals, making data synchronization less expensive and more dependable. Impedance-based approaches may not perform well when system characteristics vary, such as resource impedance, transmission line power flow, fault impedance, CT saturation, power swing, and so on. TWFL techniques, on the other hand, are more trustworthy and unaffected by the aforementioned issues, in addition to being more accurate and faster. Although TWFL methods require high sampling rates, advances in signal processing and the ability to sample signals at high frequencies, using optical sensors instead of conventional CTs and CVTs, have solved these problems in recent decades, allowing TWFL methods to gain popularity.

In this paper discuss the travelling wave based fault location estimation with the help of discreet wavelet transform approach. In the next section discuss the background of the research followed by the problem associated in finding fault location in the overhead transmission line. The proposed method is simulated in MATLAB environment to find out the estimation of the fault location. Here in this paper also used three different wavelets to estimating the fault location.

II. RELATED WORK

The key issues in TWFL in Overhead Transmission Line (OHL) are establishing whether the fault occurred in the OHL and extracting the traveling wave arrival timings (TWATs) with an accurate approach that is less sensitive to system characteristics. There are many researchers work in the finding the fault location to rectify the error of estimation in fault location. In this section discuss the main researchers work in the field of fault location estimation with the help of TWFL.

A new approach for FL based on impedance method is discussed in [8]. Single ended travelling waves based FL approaches in [9]. For improving the fault location estimation frequency modification technique is also used for the accuracy [10]. For estimation of the fault a finite difference time domain (FDTD) approach is developed in [11]. This is very useful for high sampling rate of data. To improve the resilience of the constructed network a deep learning based approach is suggested in [12]. With the help of resistive sensor, a non-contact technique is used for estimation of fault location in [13]. In this method Kalman filter and travelling wave both approaches is used for estimation of fault location.

A distributed parameter based technique with the help of partial differential equation with boundary condition is discussed in [14]. A strategy based distribution network's impedance matrix based fault location estimation technique is discussed in [15]. A damage localization approach is developed in [16]. Here in this approach a unique signature extraction technology is used for direct coupled mechanical impedance with modified probability weighted function.

A double ended travelling wave based fault location estimation technique is developed in [17]. In [18] an accurate single ended travelling wave based fault location method is developed. In [19] a unique phasor domain method based fault location estimation technique is discussed. For distributed network an adaptive convolutional network approach is developed in [20]. An improved impedance based fault location estimation technique is developed in [21]. A distance difference matrix with travelling wave based fault location estimation is developed in [22].

III. PROBLEM STATEMENT

The impedance calculation approach is far simpler to implement than the traveling wave method. It is also significantly less expensive than the traveling wave approach due to its modest hardware investment. Yet, various variables such as transition resistance, nonlinear voltage transformers, and asymmetrical transmission lines might impair the accuracy of the power-frequency technique. The transient signal used by the traveling wave approach is less impacted by these issues. As a result, the inaccuracy of the traveling wave approach is substantially smaller than that of the impedance calculation method.

The traveling wave approach is more dependable and accurate than the impedance calculation method since it is unaffected by fault resistance, transmission line types, and two-end systems. The propagation time and velocity of the fault travelling wave are the two most important parameters in the accuracy of the travelling wave fault location technique. There are still some issues with the traveling wave approach. The first issue is distinguishing between moving waves reflected from the fault site and those reflected from the far end of the line. Second, the uncertainty of the traveling wave, such as the randomization of fault kinds and fault transition time, might impair accuracy. The third point is that the velocity of a moving wave is modified by various climates and settings. Fourth, the sample rate of recorded signals is an important component that can impact the accuracy of the traveling wave approach

IV. TRAVELLING WAVE THEORY

One of the shortest system transients is the traveling wave phenomena in high voltage lines. It happens in microseconds to milliseconds. Traveling waves are linked with the propagation of electromagnetic waves caused by transmission line short circuits and lightning or switching activities in power systems. A quick and large change in voltage in at least one location along the high voltage line (Figure 1) causes the commencement of an electromagnetic

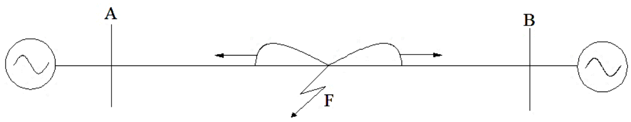

Fig. 1: Schematic Structure of Travelling Wave in transmission line

A voltage wave connected with events occurring in the electric field and a current wave linked with phenomena occurring in the magnetic field are the two types of electromagnetic waves. The movement of particular voltage and current values down the lines with limited speed is a crucial property of such a wave. The application of wave phenomena in fault finding necessitates an investigation of several theoretical difficulties, including:

- Transmission line wave velocity
- Transmission line model with dispersed parameters
- Wave attenuation and distortion
- Wave transition and reflection
- Modal transformation
- Wavelets are used to manipulate data.

The precision of traveling wave fault location is dependent on determining the wave velocity in the transmission line correctly. Wave propagation speed is determined by transmission line characteristics, which alter with variations in ambient temperature, ice, and debris on phase conductors.

V. SIGNAL PROCESSONG METHOD FOR TWFL

High frequency signal components are used by traveling wave fault locators (TWFL) to pinpoint the fault's location. Frequency domain analysis of time domain signals is frequently performed using the Fourier Transform (FT) and the Discrete Fourier Transform (DFT). Nevertheless, frequency domain analysis is unable to reveal information regarding changes in frequency with respect to time. With the use of a time windowing function, the Short Time Fourier Transform (STFT) and the Wavelet Transform were developed to represent a signal in both the time and frequency domains.

In recent years, Discrete Wavelet Transform (DWT) has emerged as a popular method for TW-based fault location. In this blog, we will discuss the basics of DWT-based TW fault location, its advantages over other methods, and some of the commonly used algorithms for DWT-based TW fault location.

DWT is a mathematical technique used to analyze signals and extract information from them. It decomposes a signal into a series of wavelets of different frequencies and scales. DWT-based TW fault location involves analyzing the wavelet coefficients of the travelling wave that is generated by the fault.

The DWT-based TW fault location algorithm consists of the following steps:

- **Data Acquisition:** The voltage and current signals at both ends of the transmission line are recorded.

- **Preprocessing:** The recorded signals are preprocessed to remove noise and other unwanted components.
- **Wavelet Decomposition:** The preprocessed signals are decomposed into a series of wavelets using the DWT technique.
- **Feature Extraction:** The wavelet coefficients are analyzed to extract features that are indicative of the fault location.
- **Fault Location:** The distance to the fault is calculated based on the extracted features

A. Discrete Wavelet Transform

Wavelets are functions that may be used to localize time and frequency. Wavelets have three properties: they are oscillatory, they must decay swiftly to zero, and they have an average value of zero. “Daubechies” wavelets are frequently employed for traveling wave analysis because they are more confined in time, making them helpful for transient study [12]. There are many other forms of wavelets, but this thesis concentrates on the usage of “Daubechies”, “Coiflets”, and “Symlets” for fault finding, especially their versions with four vanishing moments ('db4', 'coif4', and 'sym4').

Although the Discrete Wavelet Transform (DWT) is more often utilized, the Continuous Wavelet Transform (CWT) may also be a valuable tool for signal analysis. The DWT's function is given by:

$$DWT(k,n,m) = \frac{1}{\sqrt{a_0^m}} \sum_n x[n] \psi\left(\frac{k - nb_0 a_0^m}{a_0^m}\right) \qquad [1]$$

Where, ψ is mother wavelet, a_0^m is scaling parameter and $nb_0 a_0^m$ is translation parameter.

When a signal is translated using the DWT, it is divided into its detail coefficients and approximation coefficients by convolving using high pass and low pass filters, respectively. The detail coefficients resemble spikes that indicate discontinuities, but the approximation coefficients resemble a "smoothed out" version of the original signal. A signal will ultimately turn into a DC signal if it undergoes enough processing with a dyadic wavelet transform

B. Clark Transformation

For a completely transposed line, the Clarke Transformation [13] is a handy tool for modal analysis. It operates by converting a three-phase a-b-c reference frame to a α-β-0 reference frame. This eliminates the mathematical complexities associated with electromagnetic coupling between conductors. The Clarke Transformation, as implemented by the MATLAB SIMULINK block, is reflected in Equation (2).

$$\begin{bmatrix} I_\alpha \\ I_\beta \\ I_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \qquad [2]$$

After the Clark Transformation, the traditional three-phase a-b-c reference frame changes from three phases that are each 120^0 desynchronized to two phases that are each 90^0 desynchronized (aerial modes) and a null signal (ground mode). The examination of the aerial modes can then be done using the discrete wavelet transform for fault investigation. In this thesis, the alpha and beta aerial modes are used for fault analysis.

C. MATLAB Function

Several functions from MATLAB's Wavelet Toolbox are required to perform discrete wavelet analysis on current signals [14]. The “wavedec” function computes the wavelet decomposition of a signal x at a level n using the wavelet supplied by “wname”, as shown in Equation (3).

$$[c,l] = wavedec(x,n,'wname') \qquad [3]$$

The decomposition vector and the bookkeeping vector are contained in the outputs *c* and *l*, respectively. The “detcoef” function may then be used to derive the detail coefficients from the “wavedec” function's *c* and *l* decomposition values at level n, as shown in Equation (4).

$$D = \det coef\,(c,l,n) \qquad [4]$$

The time-frequency indices of the signal peaks modulus maxima may then be utilized to compute the fault location using the detail coefficients.

D. Filter Bank

By decomposing the signal into approximation and detail information using scaling and wavelet functions, the DWT can evaluate a signal at multiple frequency bands with varying resolutions. The DWT MATLAB technique works by first convolutionally filtering the original signal using a high-pass and low-pass filter, then down sampling the signal while maintaining the even indexed components to produce the level one approximation and detail coefficients. If additional decomposition is necessary, the level one approximation coefficients will be down sampled again and processed through the same high-pass and low-pass filters to generate the level two approximate and detail coefficients.

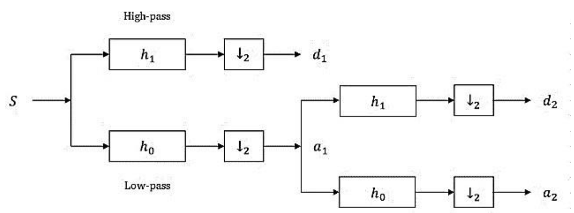

Fig. 2: Filter Bank using the MATLAB “wavedec” Function

Figure 2 depicts a filter bank with two decomposition stages. This thesis focuses on level one detail coefficients since they are the most time-localized.

E. Sampling Rate

When employing the traveling wave approach, the sampling rate of the signal might affect the accuracy of the fault location estimation. Smaller sample rates need less processing resources but result in more mistakes in fault location estimation as compared to higher sampling rates. By comparing sampling rates of 10kHz, 100kHz, 300kHz, 500kHz, and 1MHz, this paper will investigate the effect of sampling rate on the accuracy of the fault location estimate for the single-ended methods. Where feasible, the sample frequency required for location accuracy will be supplied to within 1000m, 100m, and 10m. Figure 3 depicts the Clarke Transformation implementation circuit and sampling of alpha/beta aerial mode current signals utilized in the assessment tests. The current signals are converted to aerial modes and sampled before being delivered to the workspace for wavelet analysis.

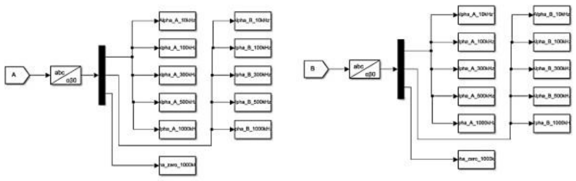

Fig. 3: SIMULINK Model of Sampling Circuit

The flowchart of the signal processing approach employed in the assessment experiments is shown in figure 4.

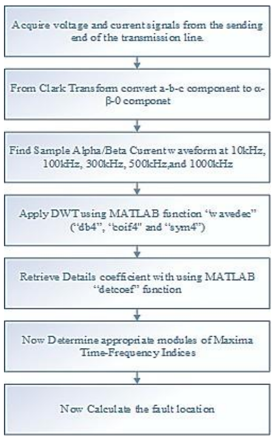

Fig. 4: Flow chart of signal processing in DWT based TWFL

VI. SIMULATION & RESULT

Using traveling waves and the discrete wavelet transform, a single circuit three-phase power system was simulated in MATLAB SIMULINK for fault localization testing. Two 500kV busses, Bus A and Bus B, with associated generators, are part of the system, along with a transmission line that was modeled using distributed parameters. With the exception of line length, which was employed to shift the fault's position, line properties on both ends of the fault were kept constant. Figure 5 depicts the 500kV single circuit setup.

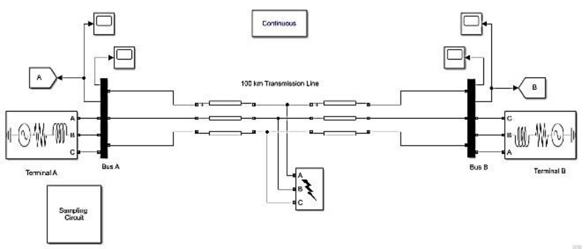

Fig. 5: SIMULINK Model of Proposed System

Single phase to ground, double line ungrounded, double line to ground, and three phase to ground are the fault types employed in the assessment studies. In order to evaluate the traveling, wave approaches several fault levels in addition to diverse fault kinds were explored in this paper.

Table I: Parameter Used for SIMULINK of Proposed System

System Parameter	Parameter Value
System Base Voltage	500 kV
System Base Power	100 MVA
System Frequency	50 Hz
Number of Phase	3
Source 'A' Internal Resistance	0.8929 Ohm
Source 'A' Internal Inductance	16.58 mH
Source 'B' Internal Resistance	0.9375 Ohm
Source 'B' Internal Inductance	17.41 mH
Positive Sequence Line Resistance	0.01273 Ohm/km
Zero Sequence Line Resistance	0.3864 Ohm/km
Positive Sequence Line Inductance	0.9337 mH/km
Zero Sequence Line Inductance	4.1264 mH/km
Positive Sequence Line Capacitance	12.74 nF/km
Zero Sequence Line Capacitance	7.751 nF/km
Total Length of Transmission Line	500 km

Table I shows the parameter used in the simulation of the transmission line fault diagnostic. Single phase to ground fault resistances of 10, 50, 100, 500, were examined. For double line ungrounded and grounded faults as well as three phase to ground faults, fault resistances of 1, 5, and 10 were evaluated. The following are instances of the single circuit system employing on single-ended approach.

Table II shows the different result generated by the experiments at different location of the single line to ground (A-G) fault. Here in this table three wavelets ('db4', 'coif4' and 'sym4') are compared at 1 MHz sampling frequency.

Table II: Single Phase to Ground (A-G) Fault Location Result for 100 km Line

Actual (km)	'db4'		'coif4'		'sym4'	
	Estimated (km)	Error (%)	Estimated (km)	Error (%)	Estimated (km)	Error (%)
10	10.15	0.15	9.86	0.14	10.44	0.44
20	20.30	0.30	19.72	0.28	20.30	0.30
30	30.44	0.44	30.44	0.44	30.44	0.44
40	40.30	0.30	40.30	0.30	40.30	0.30
50	49.87	0.13	49.58	0.42	50.16	0.16
60	59.99	0.01	59.99	0.01	60.28	0.28
70	69.85	0.15	69.85	0.15	70.14	0.14
80	79.99	0.01	79.99	0.01	79.99	0.01
90	90.14	0.14	90.43	0.43	89.85	0.15
Average		0.18		0.24		0.25

Here it is observed that average error in 'db4' is 0.18% and 'coif4' is 0.24% and 'sysm4' is 0.25%. maximum error of the proposed system is never exceeding 0.44%.

Table III shows the different result generated by the experiments at different location of the line to line (A-B) fault. Here in this table three wavelets ('db4', 'coif4' and 'sym4') are compared at 1 MHz sampling frequency.

Table III: Line to Line (A-B) Fault Location Result for 100 km Line

Actual (km)	'db4'		'coif4'		'sym4'	
	Estimated (km)	Error (%)	Estimated (km)	Error (%)	Estimated (km)	Error (%)
10	10.15	0.15	10.15	0.15	10.15	0.15
20	19.72	0.28	19.72	0.28	19.72	0.28
30	29.57	0.43	29.28	0.72	29357	0.43
40	40.30	0.30	39.72	0.28	39.72	0.28
50	50.16	0.16	50.16	0.16	50.16	0.16
60	60.28	0.28	59.70	0.30	59.70	0.30
70	70.43	0.43	70.72	0.72	70.43	0.43
80	79.70	0.30	80.28	0.28	80.28	0.28
90	89.85	0.15	89.85	0.15	89.85	0.15
Average		0.28		0.34		0.27

Here it is observed that average error in 'db4' is 0.28% and 'coif4' is 0.34% and 'sysm4' is 0.27%. maximum error of the proposed system is never exceeding 0.72%.

Table IV shows the different result generated by the experiments at different location of the line-line-ground (A-B-G) fault. Here in this table three wavelets ('db4', 'coif4' and 'sym4') are compared at 1 MHz sampling frequency.

Table IV: Line-Line-Ground (A-B-G) Fault Location Result for 100 km Line

Actual (km)	'db4'		'coif4'		'sym4'	
	Estimated (km)	Error (%)	Estimated (km)	Error (%)	Estimated (km)	Error (%)
10	10.15	0.15	1015	0.15	10.15	0.15
20	19.72	0.28	19.72	0.28	19.72	0.28
30	29357	0.43	29.28	0.72	29.57	0.43
40	40.30	0.30	39.72	0.28	39.72	0.28
50	50.16	0.16	50.16	0.16	50.16	0.16
60	60.28	0.28	59.70	0.30	59.70	0.30
70	70.43	0.43	70.72	0.72	70.43	0.43
80	79.70	0.30	80.28	0.28	80.28	0.28
90	89.85	0.15	89.85	0.15	89.85	0.15
Average		0.28		0.34		0.27

Here it is observed that average error in 'db4' is 0.28% and 'coif4' is 0.34% and 'sysm4' is 0.27%. maximum error of the proposed system is never exceeding 0.72%.

Table V shows the different result generated by the experiments at different location of the line-line-line-ground (A-B-C-G) fault. Here in this table three wavelets ('db4', 'coif4' and 'sym4') are compared at 1 MHz sampling frequency.

Table V: Line-Line-Line-Ground (A-B-C-G) Fault Location Result for 100 km Line

Actual (km)	'db4'		'coif4'		'sym4'	
	Estimated (km)	Error (%)	Estimated (km)	Error (%)	Estimated (km)	Error (%)
10	10.15	0.15	9.86	0.14	10.44	0.44
20	20.30	0.30	19.72	0.28	20.30	0.30
30	30.44	0.44	30.15	0.15	30.15	0.15
40	39.72	0.28	39.72	0.28	40.30	0.30
50	50.16	0.16	49.87	0.13	50.45	0.45
60	59.99	0.01	59.99	0.01	60.28	0.28
70	69.85	0.15	69.85	0.15	70.14	0.14
80	80.57	0.57	80.57	0.57	79.99	0.01
90	90.14	0.14	90.43	0.43	89.85	0.15

Here it is observed that average error in 'db4' is 0.24% and 'coif4' is 0.24% and 'sysm4' is 0.25%. maximum error of the proposed system is never exceeding 0.57%.

VII. CONCLUSION

The goal of this paper is to discuss fault location approaches that use the traveling wave method and the discrete wavelet transform. Traveling wave concepts and single-ended and double-ended fault location methods are investigated. Signal processing approaches for traveling wave analysis in MATLAB SIMULINK employing the discrete wavelet transform are also addressed. A single circuit 500kV line is evaluated, and fault location findings utilizing three distinct wavelets, as well as sampling rate and fault resistance analysis, are compared.

The wavelet comparison analysis employing the 'db4', 'coif4', and 'sym4' wavelets with a similar sampling rate of 1 MHz yielded unclear results since no wavelet consistently offered reduced average errors across all evaluated circumstances. The sample rate may have had a considerably greater influence than the wavelet utilized for analysis in this section of the study.

References

[1]. K. Kalita, S. Anand, S.K. Parida, A novel non-iterative fault location algorithm for transmission line with unsynchronized terminal, IEEE Trans. Power Delivery 36 (3) (2021) 1917–1920. June.

[2]. S.M. Hashemian, S.N. Hashemian, M. Gholipour, Unsynchronized parameter free fault location scheme for hybrid transmission line, Electric Power Syst. Res. 192 (2021), 106982.

[3]. R. Liang, et al., Fault location method in power network by applying accurate information of arrival time differences of modal traveling waves, IEEE Trans. Ind. Inf. 16 (5) (2020) 3124–3132. May.

[4]. H.A. Abd el-Ghany, A.M. Azmy, A.M. Abeid, A general travelling-wave-based scheme for locating simultaneous faults in transmission lines, IEEE Trans. Power Delivery 35 (1) (2020) 130–139. Feb.

[5]. D. Rezaei, M. Gholipour, F. Parvaresh, A novel traveling wave arrival time detection method in power system, IET Gener. Transm. Distrib. 00 (2021) 1–15.

[6]. S. Sawai, A.K. Pradhan, Travelling-wave-based protection of transmission line using single-end data, IET Gener. Transm. Distrib. 13 (2019) 4659–4666.

[7]. M. Farshad, J. Sadeh, Transmission line fault location using hybrid wavelet-prony method and relief algorithm, Int. J. Electrical Power & Energy Syst. 61 (2014) 127–136.

[8] Power distributed networks: Impedance-based and machine learning technique", Electric Power Systems Research Volume 210, September 2022, 108073

[9]. Narges Rezaee Ravesh, Nabiollah Ramezani, Iraj Ahmadi, Hassan Nouri, (2022), "A hybrid artificial neural network and wavelet packet transform approach for fault location in hybrid transmission lines", Electric Power Systems Research Volume 204, March 2022, 107721

[10]. Wei Chen, Dong Wang, Donghai Cheng, Feng Qiao, Ximei Liu, Mengqian Hou, (2022), Novel travelling wave fault location principle based on frequency modification algorithm", International Journal of Electrical Power & Energy Systems Volume 141, October 2022, 108155

[11]. J. Sun, Q. Yang, W. Xu and W. He, (2022), “A Distribution Line Fault Location Estimation Algorithm Based on Electromagnetic Time-Reversal Method Calculated in the Finite Difference Time Domain," in IEEE Transactions on Electromagnetic Compatibility, vol. 64, no. 3, pp. 865-873, June 2022, doi: 10.1109/TEMC.2021.3140170.

[12]. S. Afrasiabi, M. Afrasiabi, M. A. Jarrahi and M. Mohammadi, (2022), "Fault Location and Faulty Line Selection in Transmission Networks: Application of Improved Gated Recurrent Unit," in IEEE Systems Journal, vol. 16, no. 3, pp. 5056-5066, Sept. 2022, doi: 10.1109/JSYST.2022.3172406.

[13]. J. A. De Oliveira Neto, C. A. F. Sartori and G. M. Junior, 2021, "Fault Location in Overhead Transmission Lines Based on Magnetic Signatures and on the Extended Kalman Filter," in IEEE Access, vol. 9, pp. 15259-15270, 2021, doi: 10.1109/ACCESS.2021.3050211.

[14]. Abdelhamid Bendjabeur, Abdelmalek Kouadri, Saad Mekhilef, (2021), "Transmission line fault location by solving line differential equations" Electric Power Systems Research Volume 192, March 2021, 106912

[15]. Hosseinimoghadam, S.M.S., Dashtdar, M. & Dashtdar, M. (2021), “Fault Location in Distribution Networks with the Presence of Distributed Generation Units Based on the Impedance Matrix”. J. Inst. Eng. India Ser. B 102, 227–236 (2021). https://doi.org/10.1007/s40031-020-00520-2

[16]. Jianjian Zhu, Xinlin Qing, Xiao Liu, Yishou Wang, (2021), "Electromechanical impedance-based damage localization with novel signatures extraction methodology and modified probability-weighted algorithm", Mechanical Systems and Signal Processin Volume 146, 1 January 2021, 107001

[17]. Mahmood Parsi, Peter Crossley, Pier Luigi Dragotti, David Cole, (2020), "Wavelet based fault location on power transmission lines using real-world travelling wave data", Electric Power Systems Research Volume 186, September 2020, 106261

[18]. O. D. Naidu and A. K. Pradhan, (2020), "Precise Traveling Wave-Based Transmission Line Fault Location Method Using Single-Ended Data," in IEEE Transactions on Industrial Informatics, vol. 17, no. 8, pp. 5197-5207, Aug. 2021, doi: 10.1109/TII.2020.3027584.

[19]. Y. Liu, B. Wang, X. Zheng, D. Lu, M. Fu and N. Tai, (2020), “Fault Location Algorithm for Non-Homogeneous Transmission Lines Considering Line Asymmetry," in IEEE Transactions on Power Delivery, vol. 35, no. 5, pp. 2425-2437, Oct. 2020, doi: 10.1109/TPWRD.2020.2968191.

[20]. J. Liang, T. Jing, H. Niu and J. Wang, "Two-Terminal Fault Location Method of Distribution Network Based on Adaptive Convolution Neural Network," in IEEE Access, vol. 8, pp. 54035-54043, 2020, doi: 10.1109/ACCESS.2020.2980573.

[21]. F.M. Aboshady, D.W.P. Thomas, Mark Sumner, (2019), "A new single end wideband impedance based fault location scheme for distribution systems",Electric Power Systems Research Volume 173, August 2019, Pages 263-270

[22]. L. Xie, L. Luo, Y. Li, Y. Zhang and Y. Cao, (2019), "A Traveling Wave-Based Fault Location Method Employing VMD-TEO for Distribution Network," in IEEE Transactions on Power Delivery, vol. 35, no. 4, pp. 1987-1998, Aug. 2020, doi: 10.1109/TPWRD.2019.2959188.