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# Wind Integrated Line Protection using Local Mean Decomposition of Current Information

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**Abstract**- In this paper, local mean decomposition (LMD) technique is applied to detect distribution line faults. A 25 KV distribution system connected with 9 MW of wind farm is used to test the performance of the LMD fault detection scheme. To achieve the fault detection task, 3-phase instantaneous current signals are processed through LMD and corresponding product functions, instantaneous amplitudes (IA's) of the product functions along with the frequency modulation information is extracted. Further, IA of dominated product function is used to detect the abnormalities in the input signal by using a pre-defined threshold value. The performance of the proposed scheme is tested on different faults by varying the fault parameters like location, inception and fault resistance. Simulation studies are extended to test the efficacy of the protection algorithm during non-fault events, typical remote end, and high-resistive faults. The proposed scheme is able to classify the faults along with detection is an additional advantage in this work.

**Keywords:** Fault detection; Wind farm; Local mean decomposition.

## 1. Introduction

When bounded number of renewable units (wind or solar) generating 1-10 MW of power transmits to grid through distribution system detection of fault will be a strenuous task. Generation of power by renewable in power systems is increased these days due to rise in power demand and reduction of the coal availability [1]-[2]. Consequently, to intensify the power system performance and security at the time of disturbances and faults, improved protection schemes are required [3]. In presence of renewable, the protection scheme adopted should be able to find all types of faults in both islanding mode and grid connected. Distribution networks incorporated with distribution generation will have dynamic performance including magnitude and direction changes of both current and voltage bring out notable problem in the fault detection process [4]. Thus, to improve the detection process, different techniques were proposed to mitigate these issues. In distribution system with distributed generation (DG), classical magnitude and phase comparison techniques are handy in the literature of the protection schemes [5]-[7].

Few examples for regular algorithms in distribution systems/ microgrid protection are current phase angle comparison scheme [5], impedance angle-based approach [6] and energy-based scheme [7]. Signal processing techniques are mostly applied in the fault detection algorithms, to improve the protection aspects. A comprehensive analysis of the application of the different signal processing were applied to detect islanding condition of the DG connected to a distribution network to transmit the power to grid in [8]. In [9], fault detection in a DG penetrated electrical power system, wavelet transform is applied. To differentiate and to locate faults from islanding events, the characteristics of either direct measuring quantities or outputs of various monotonic components of the signal processing are applied for machine learning models like support vector machine [10]. To protect the microgrid in presence of wind speed frequency, in [11], extreme learning machine is adopted. Aside these smart tools, statistical approaches are applied on characteristics obtained using signal processing techniques. Hilbert-Huang transform-based differential algorithm is presented to protect the microgrid, in [12]. For detecting normal faults due to their notable change in signal parameters most of these methods are effective. In [13], in distribution system, empirical wavelet transform is employed to detect high impedance faults (HIFs). To detect the HIFs in an inverter interfaced distribution system a new time-frequency transform is used in [14]. In [15], to detect faults with high impedance with Teager-Kaiser energy operator, variational mode decomposition (VMD) technique is applied. In power systems to detect faults, Mathematical morphology (MM) is one more influential technique. For adaptive over current protection in [16] MM fault detector is used in distribution network in presence of photovoltaic (PV) generation. In different interpretation of the distribution system protection, related works are available in literature. The importance of improving the input characteristics in both quantity and quality, application of signal processing tools strengthened the protection aspects. Smart meters are employed for HIF detection in [17]. In [18], in distribution network, power spectral density (PSD) is used for HIF detection. This PSD scheme is elongated for fault classification also in the work presented in [18]. These signal processing methods are also inspected in DC microgrids including PV and wind. Optimized VMD is applied to detect faults in DC microgrid, in [19]. These techniques are also beneficial to categorize the power quality events of wind integrated system [20]. Overall, renewable integral systems challenges and solutions are provided in [12]-[30] with the help of intelligent tools, signal processing methods and optimization approaches.

In this paper, local mean decomposition (LMD) technique is employed to detect the faults in wind farm integrated power system. The 3-phase currents are measured at the bus are processed through LMD technique to extract the required features to make the decisions during the operation. The LMD technique break up the signal into a linear combination of the product functions comprising of both amplitude and frequency modulation information. From the obtained product functions dominant component is used to detect the faults in the distribution system. To detect the faults, instantaneous amplitude of the dominant product function is taken and compared with the pre-defined threshold. Faulty phase categorization is also spotted using the IA's. By varying resistance, location and inception values of the faults, the functionality of the proposed scheme is tested for different faults. Remote end faults and transients are examined to confirm the merits of the method. Furthermore, the particulars of the proposed method are presented in section 2. Test system particulars in section 3. Simulation results and comparisons are presented in section 4 & 5 respectively. And ultimately in section 6 conclusions are listed.

## 2. LMD-based Fault Detection

LMD is a motile signal processing method used to break a signal comprising of multiple components into a set of product functions (PFs). Additionally, each PF consist of amplitude and frequency information. Suitable components are extracted and used for analysis based on application. Amplitude information of first PF is used for combined fault detection and classification task in this method.

### *2.1. Overview of LMD*

Let $x(t)$ is the time domain signal decomposed by LMD technique into finite number of linearly combined PF's and residual component [24]. The generalized expression of LMD is given by

$$x(t) = \sum_{i=1}^{n} PF_i(t) + r_n(t) \quad (1)$$

In Equation (1), $r_n$(t) is the residual component obtained after removing all PFs from the original signal, and n is the total number of monotonic functions. Each PF is picked up with the help of the two successive local extrema from local means and local envelopes. The spotting of envelopes and local extremums, to find product functions are presented in [24]. By the earlier researchers, LMD method is mostly employed for mechanical bearing fault analysis [25]-[26]. In this paper, in the distribution system of the power network LMD technique is used to detect faults.

### *2.2. Application of LMD for Fault Detection*

At grid connected point, 3-phase instantaneous current signals are measured, and these currents are processed through LMD to break up each phase current into number of PFs for fault detection task in distribution system connected with DG. For fault detection, from all PF's first monotonic function IA is used. The flow chart of the proposed fault detection scheme is shown in Fig. 1.

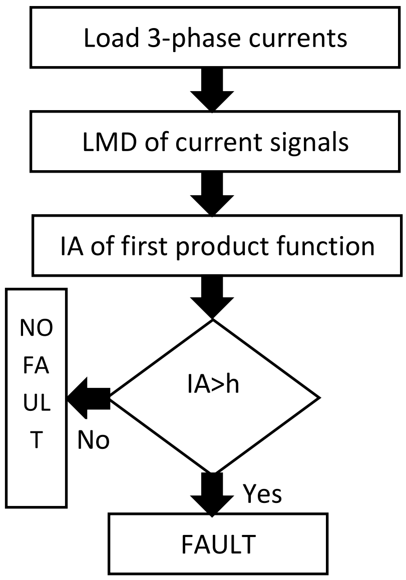


**Fig. 1**. Algorithm of proposed fault detection mechanism.

It also provided the schematic procedure of the algorithm. The magnitude of the current varies significantly during faults, and it is figured by first product function of the LMD. Therefore, for fault detection task, instantaneous amplitude modulation of the first product function is opted as prerequisite attribute. To create trip command as displayed in flowchart, this amplitude value is compared with the pre-defined threshold. Further, the faulty phases are figured from the LMD indices as the signal discrepancy takes place in the fault involving phase.

## 3. Test System

To evaluate the functionality of the proposed LMD-based protection scheme, 9 MW of wind farm is connected to 25 KV distribution system that generates and transmits electrical power to grid operated at 120 KV. The length of the distribution line is 30 km. Doubly fed induction generator (DFIG) used by wind turbines comprising of a wound rotor induction generator and an AC-DC-AC based pulse width modulation converter with IGBT's with a total number of 6 units each of 1.5 MW capacity is used. The test system operated at 60 Hz is modelled in SIMULINK and signals are sampled at 1 kHz and algorithm is tested using MATLAB R2016a software. All other parameters of the test system are available in [27].

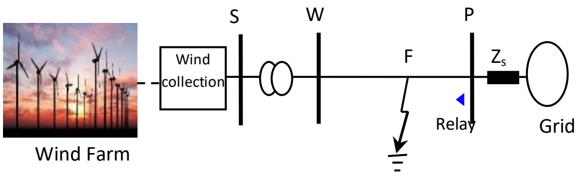


**Fig. 2.** Single line diagram of the test system [27]

## 4. Simulation Results

To examine the results of the proposed scheme under different faults of the distribution system, a test system shown in Fig. 2 is taken. By varying the resistance of the fault, location of the fault and inception of the fault all 11-types of faults are simulated on test system. After that, few typical cases are examined to test the effectiveness of the proposed scheme.

### *4.1. Single Line-ground Faults*

With a fault resistance of 1Ω at 15 Km from the grid connected point, a phase A-ground fault is initiated at inception time of 1.7 sec. Figure 3 shows the combined plots of the LMD outputs and currents. Fault is detected by the scheme along with A-phase classification. In Figure 3.a, it is observed that, due to the inception of A-g fault, the magnitude of the A-phase current raised at 1.7 sec. The amplitude of the LMD product functions of the signal also increased by following the current magnitude as shown in Fig. 3.b. With a fault resistance of 20Ω at 15 Km from the relay point, a phase B-ground fault is initiated with inception time of 1.72 sec. Fig. 4 shows the combined plots of the LMD outputs and currents. It is observed that the magnitude rise in the currents is low, as the fault resistance is comparatively higher. Still, such changes are spotted by the proposed scheme and able to detect the simulated B-g fault in 5m.sec. Faulty phase identification task is also accomplished by the algorithm along with the fault detection, as shown in Fig. 4.b. Lastly, a phase C-ground fault with inception time of 1.56 sec and fault resistance of 10Ω and located at 10 Km from the relay point is simulated and results are plotted in Fig. 5. The proposed LMD scheme functionality is good in terms of the detection and fault phase categorization in all cases. As 85% of faults are single line-to-grounds faults as per to the earlier research reports and are detected within 4-8 m.sec using the proposed scheme is added advantage.

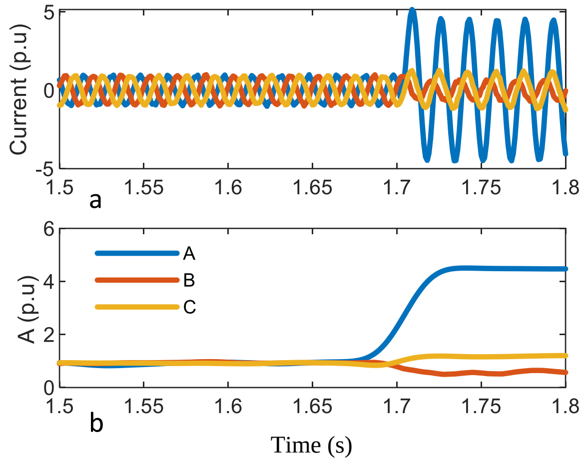


**Fig. 3.** Output of LMD scheme during A-g Fault, a. currents, b. IA of LMD

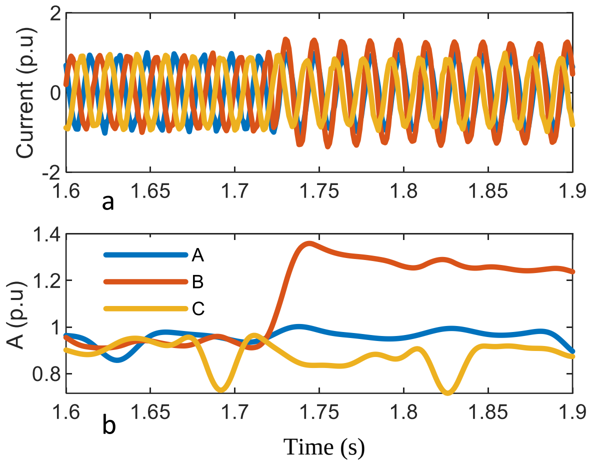


**Fig. 4.** Output of LMD scheme during B-g Fault, a. currents, b. IA of LMD.

### *4.2 Double Line and Double Line-ground Faults*

To examine the functionality of the proposed scheme during multi-phase faults like double line and double line-to-ground faults, 6 faults are simulated in the test system and the data is processed though the LMD. The 6 cases are phase A- phase B (Fig. 6), phase B- phase C (Fig. 7), phase A-phase C (Fig. 8), phase A- phase B-ground (Fig. 9), phase B-phase C-ground (Fig. 10) and phase A- phase C-ground (Fig. 11) faults. In Table 1, the fault parameters and outputs of all these 6 faults are tabulated. It can be observed from Table 2, that all the line-to-line, line-to-line-ground faults are detected by the proposed LMD scheme within 4msec from their inception time and correct faulty phases are figured by same algorithm without any add-on decision-making units.

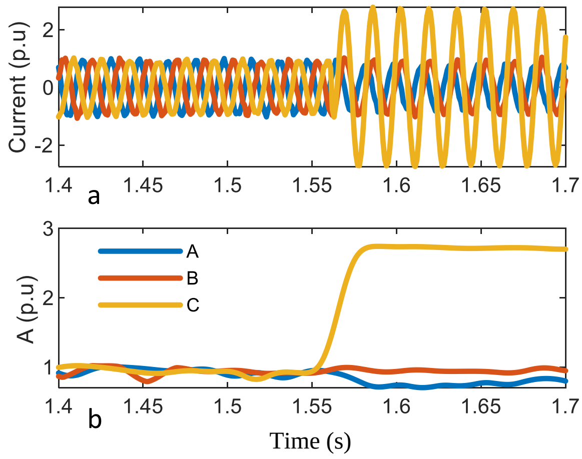


**Fig. 5.** Output of LMD scheme during C-g Fault, a. currents, b. IA of LMD.

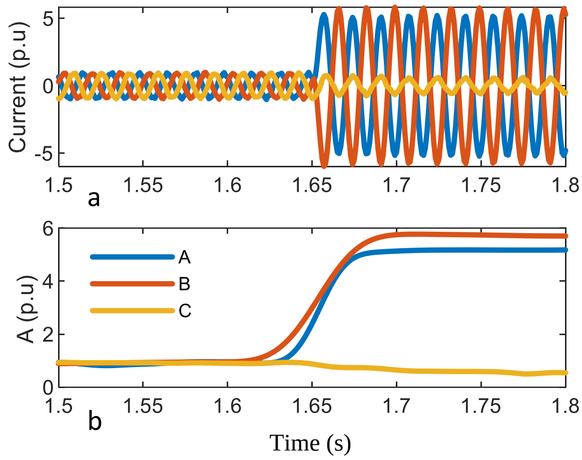


**Fig. 6.** Output of LMD scheme during A-B Fault, a. currents, b. IA of LMD.

**Table 1.** Detection times and faulty phase identification outputs of the LMD approach for different L-g faults.

| Type of fault | Fault resistance (Ω) | Inception time (s) | Fault location (km) | Outputs | |
|---|---|---|---|---|---|
| | | | | Detection time (msec) | Faulty phases |
| A-g | 20 | 1.65 | 20 | 4 | A |
| B-g | 25 | 1.45 | 10 | 3 | B |
| C-g | 15 | 1.55 | 15 | 4 | C |
| A-g | 10 | 1.62 | 05 | 3 | A |
| B-g | 15 | 1.53 | 08 | 3 | B |
| C-g | 18 | 1.42 | 10 | 4 | C |
| A-g | 05 | 1.34 | 10 | 4 | A |
| B-g | 08 | 1.56 | 14 | 4 | B |
| C-g | 10 | 1.72 | 18 | 5 | C |
| A-g | 08 | 1.57 | 15 | 4 | A |
| B-g | 07 | 1.40 | 22 | 5 | B |
| C-g | 05 | 1.50 | 30 | 5 | C |

**Table 2:** Detection times and faulty phase identification outputs of the LMD approach for different L-L and L-L-g faults.

| Type of fault | Fault resistance (Ω) | Inception time (s) | Fault location (km) | Outputs | |
|---|---|---|---|---|---|
| | | | | Detection time (msec) | Faulty phases |
| A-B | 5 | 1.65 | 10 | 4 | A, B |
| B-C | 1 | 1.68 | 22 | 3 | B, C |
| A-C | 3 | 1.60 | 03 | 3 | A, C |
| A-B-g | 1 | 1.54 | 27 | 4 | A, B |
| B-C-g | 5 | 1.64 | 18 | 4 | B, C |
| A-C-g | 3 | 1.62 | 8 | 3 | A, C |
| A-B-g | 10 | 1.77 | 20 | 4 | A, B |
| B-C-g | 15 | 1.43 | 15 | 4 | B, C |
| A-C-g | 29 | 1.56 | 08 | 4 | A, C |

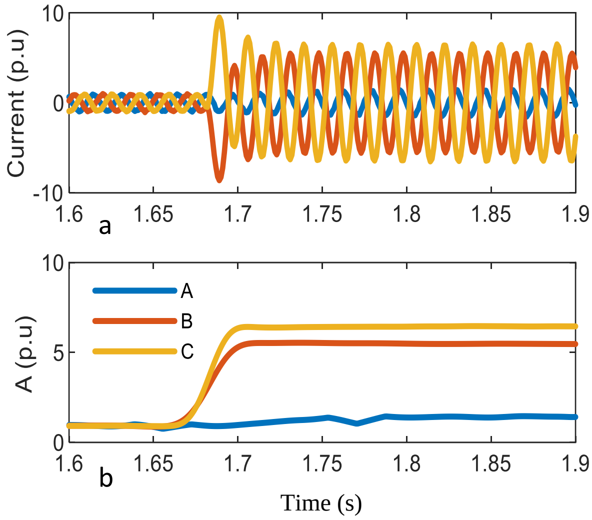


**Fig. 7.** Output of LMD scheme during B-C Fault, a. currents, b. IA of LMD.

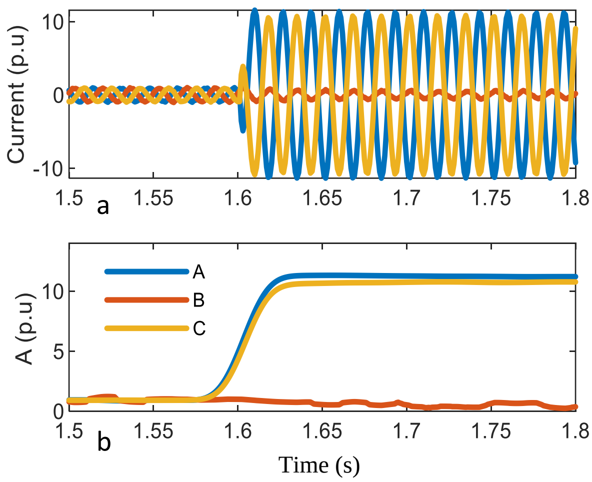


**Fig. 8.** Output of LMD scheme during A-C Fault, a. currents, b. IA of LMD

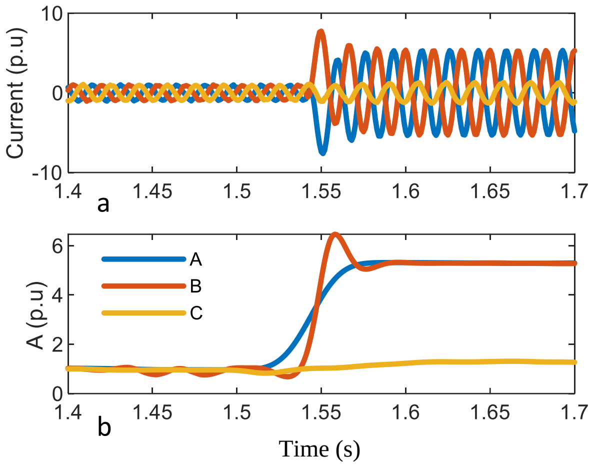


**Fig. 9.** Output of LMD scheme during A-B-g Fault, a. currents, b. IA of LMD.

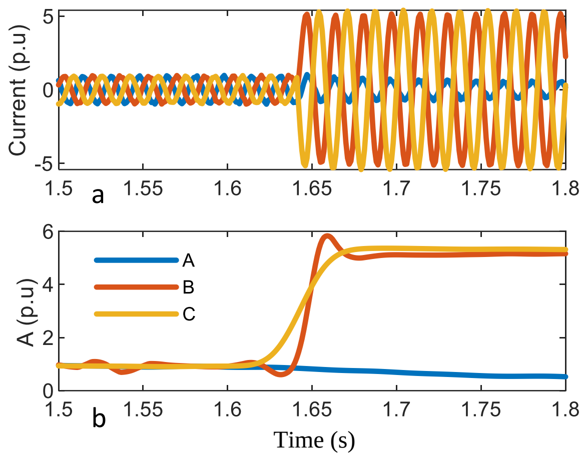


**Fig. 10.** Output of LMD scheme during B-C--g Fault, a. currents, b. IA of LMD

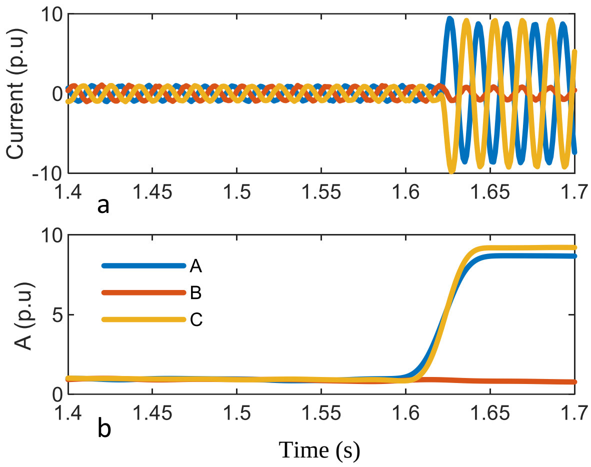


**Fig. 11.** Output of LMD scheme during A-C-g Fault, a. currents, b. IA of LMD

*4.3 Symmetrical faults*

In Fig. 12 the results of the proposed scheme against 3-phase faults are simulated and furnished. In this, a three-phase symmetrical A-B-C-g fault is simulated with inception time of 1.6 sec, fault location of 13 km, and fault resistance of 5 Ω. It is observed that the proposed method detects symmetrical faults quickly and also give correct faulty phase categorization. The detection indices are higher in this case comparatively due to involvement of the 3-phases in the short circuit.

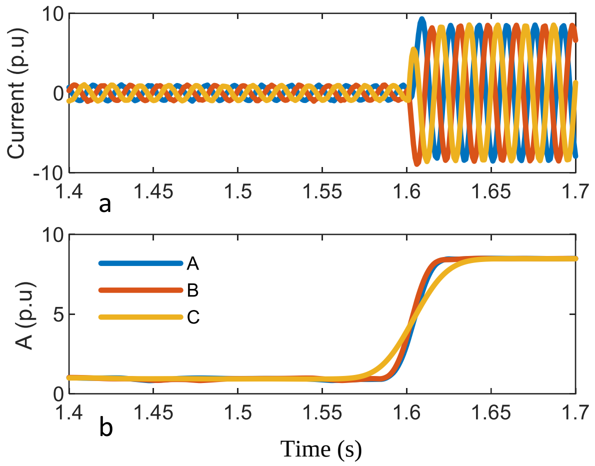


**Fig. 12.** Output of LMD scheme during A-B-C-g Fault, a. currents, b. IA of LMD.

*4.4 Faults Nearer to Wind Farm*

Fault detection can be done easily when the fault location is nearer to relay point because of notable changes of the measured data. Detection becomes difficult when remote ends faults occur. Thus, to present the merits of the proposed scheme it is required to evaluate the functionality of the method for faults located at wind farms. For this, a phase A-g fault is initiated at 1.6 sec with a fault resistance of 10Ω at 0.9 km from the wind farm (i.e., 29.1 km from the relay point) is simulated. Fig. 13 shows the instantaneous 3-phase currents along with the detection and categorization results of the proposed method. From the initiation of the fault, this typical fault is detected within 3msec. In case of these remote end faults the reliability of the conventional detection methods are not high unlike the proposed method.

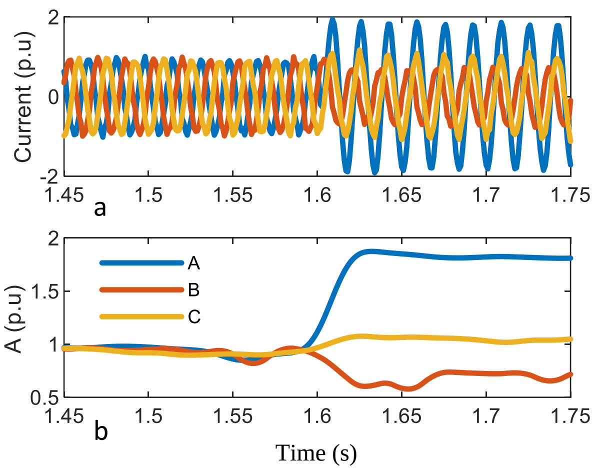


**Fig. 13.** Remote end A-g faults, a. currents, b. IAs of LMD.

### *4.5 Performance During Transients*

For all types of faults at different inception times, locations and resistances, the functionality of the proposed scheme is examined and verified. To evaluate the dependability of the protection scheme, it is required to analyse the transients. Thus, on test system, a transient event is simulated with noise, spikes, and signal amplitude disturbance. Fig.14 shows both current and IA's information of transient event, these disturbed signal data is processed through the LMD, and IA's primary product functions are obtained. It is observed that the rise in index is not exceeding the thresholds as it is less than non-fault index and trip is not generated. Thus, the certainty of the algorithm is also justifiable.

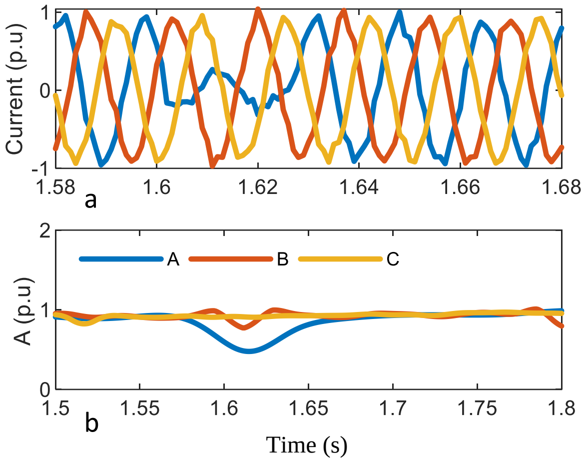


**Fig. 14.** Response of the proposed scheme during disturbances

### *4.6 Performance During Diverse Fault Parameters*

The functionality of the proposed scheme is evaluated for all types of faults and outputs are presented from Fig. 3 to Fig. 11, and the efficacy of the scheme against variations of fault parameters can be observed. The faults are simulated by varying the inception time, fault location and resistance of the fault randomly and obtained signals are processed through the proposed LMD scheme. It can be observed from the results that all types of faults are detected by the algorithm irrespective of the inception and location. However, when large fault resistance is used faults are not detected. Additionally, three separate cases are incorporated in this section to examine the proposed approach during variations in this parameter. In Fig. 15, for a phase A-ground fault initiated at 1.6 sec with a fault resistance of 10Ω, the effect of variation of the fault location on LMD assisted fault detector indices are shown. In Fig. 16, for a phase B-ground fault located at 10 km with a fault resistance of 20Ω, the effect of variation of the fault inception on LMD assisted fault detector indices are shown. In Fig. 17 the variation of the fault detection indices with fault resistance is shown. To evaluate the dependability of the proposed scheme at different fault resistances, a phase C-ground fault is considered with fault inception time of 1.5 sec at 5 km location. The response of the proposed method is reliable in all three cases irrespective of the location, inception and resistance of fault. For checking the reliability of the scheme, the single-line-to-ground fault is considered as its probability of occurrence is high. Further, from Fig. 15 to Fig. 17, fault detection indices of the other non-fault phases are shown to show the extension activity of the proposed scheme to categorize the faulty phases.

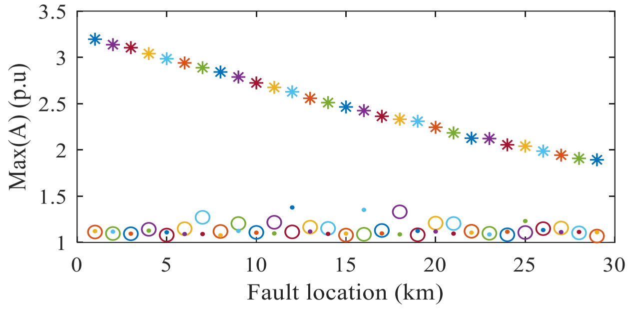


**Fig. 15.** Response of the proposed scheme at different fault locations.

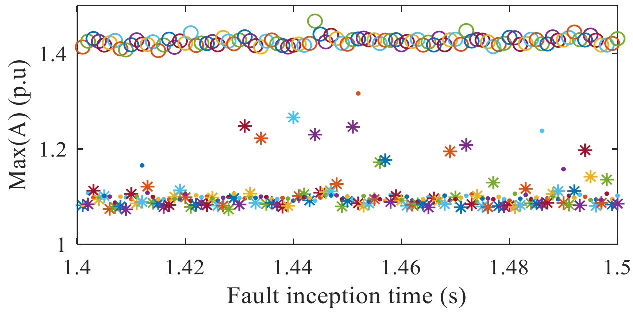


**Fig. 16.** Response of the proposed scheme at different fault inceptions.

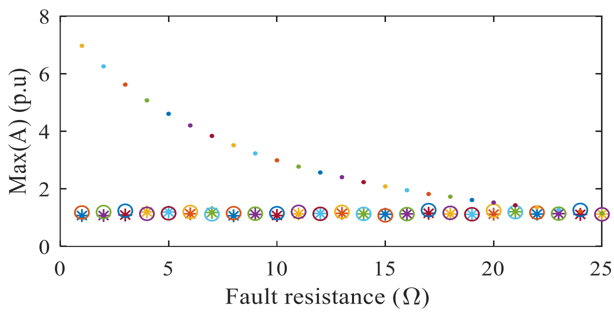


**Fig. 17.** Response of the proposed scheme at different fault resistances.

## 5. Comparisons

A comparative assessment is provided with sample-to-sample approach, cycle to cycle approach, mean estimation approach and WT method to show the merits of the proposed detection approach. With a high resistive fault condition, Fig. 18 shows the responses of all these four approaches on the test system. These methods are not able to give sensible decisions as the index variations are not clearly separated from pre fault indices, with proper threshold setting. Due to inclusion of the nonlinear power electronic components and unstable nature of the wind speed, the input signals of the detection algorithms comprises of distortions which leads to notable increase in the detection indices. From fig. 18 these variations during pre-event period are observed. To show the comparisons, the response of simulation case of phase C-ground fault initiated at 1.5 sec with a fault resistance of 100 Ω and located at 5 km from relay end is considered. For the sample-to-sample approach, cycle to cycle approach, mean estimation approach and WT methods, it is not possible to provide reliable decisions during faults and the indices during fault instant are similar to pre-fault indices. Thus, during typical fault events these methods failed to operate. In the Fig. 19, the response of the proposed method is furnished. Reliable outputs are guaranteed from the proposed method unlike other methods and the change in the indices during high resistive faults is clearly differentiated from the pre-fault condition. The approach is more loyal and assured for application of absolute sum, cumulative sum etc. To detect the faults this additional mechanism adjusts all the indices in positive direction.

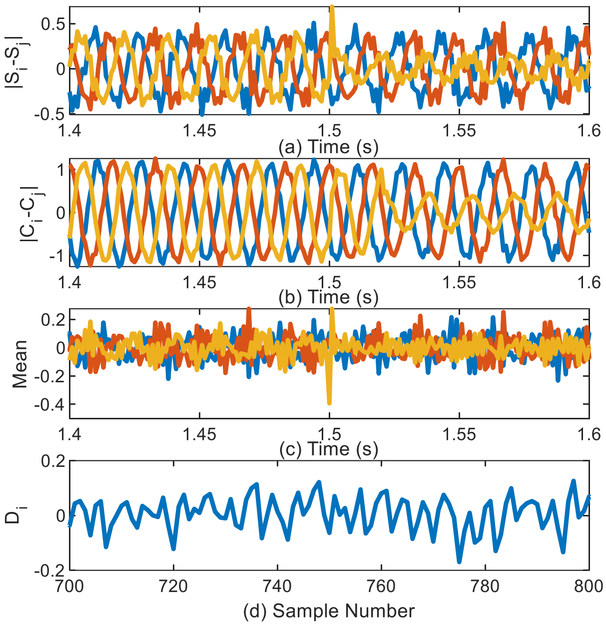


**Fig. 18.** Response of the different algorithms during the high resistive fault.

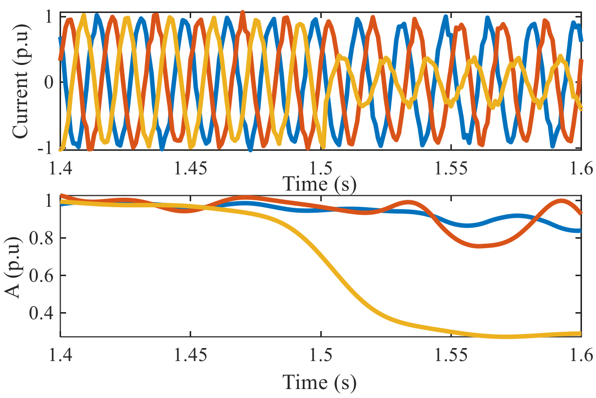


**Fig. 19.** Response of the proposed scheme during high resistive fault.

## 6. Conclusion

Thus, to protect the distribution system connected with wind farm exporting electrical power to main grid LMD based new protection scheme is proposed in this paper. The proposed scheme provides accurate decisions in quick time during faults. An added advantage of the proposed algorithm is along with the detection, faulty phases are also identified. Remote end faults are also detected by the method reliably along with normal faults. The scheme is more secure and avoids unnecessary trip commands during non-fault disturbances.

## References

[1] E. Zonkoly, and M. Amany, "Fault diagnosis in distribution networks with distributed generation", *Electric Power Systems Research*, vol.81, no. 7, pp.1482-1490, 2011.

[2] M. Pooria, H. El-Kishyky, M.A. Akher, and M.A. Salam, "The impacts of distributed generation on fault detection and voltage profile in power distribution networks", In *2014 IEEE International Power Modulator and High Voltage Conference (IPMHVC)*, pp. 191-196. IEEE, 2014.

[3] A. Gonzalez, Daniel, Eva Maria García del Toro, María Isabel Más-López, and Santiago Pindado, "Effect of distributed photovoltaic generation on short-circuit currents and fault detection in distribution networks: A practical case study", Applied Sciences, vol. 11, no. 1, pp.405-420, 2021.

[4] M.Y Nsaif, M.S. Hossain Lipu, A. Ayob, Y. Yusof, and A. Hussain, "Fault Detection and Protection Schemes for Distributed Generation Integrated to Distribution Network: Challenges and Suggestions", *IEEE Access*, vol. 9, pp.142693-142717, 2021.

[5] N. El Halabi, M. García-Gracia, J. Borroy, and J. L. Villa, "Current phase comparison pilot scheme for distributed generation networks protection", *Applied Energy*, vol. 88, no. 12, pp.4563-4569, 2011.

[6] K. Dubey, and P. Jena, "Impedance angle-based differential protection scheme for microgrid feeders", *IEEE Systems Journal*, vol. 15, no. 3, pp. 3291-3300, 2020.

[7] B. Anudeep, and P.K. Nayak, "Transient energy-based combined fault detector and faulted phase selector for distribution networks with distributed generators", *International Transactions on Electrical Energy Systems*, vol. 30, no. 4, pp. e12288, 2020.

[8] S. Raza, H. Mokhlis, H. Arof, J. A. Laghari, and L. Wang, "Application of signal processing techniques for islanding detection of distributed generation in distribution network: A review", *Energy Conversion and Management*, vol. 96, pp.613-624, 2015.

[9] P.K. Ray, B. K. Panigrahi, P.K. Rout, A. Mohanty, and H. Dubey, "Fault detection in an IEEE 14-bus power system with DG penetration using wavelet transform", In *Computer, Communication and Electrical Technology*, pp. 221-225. CRC Press, 2017.

[10] H.R. Baghaee, D. Mlakić, S. Nikolovski, and T. Dragicević, "Support vector machine-based islanding and grid fault detection in active distribution networks", *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 8, no. 3, pp.2385-2403, 2019.

[11] M. Manohar, E. Koley, and S. Ghosh, "Microgrid protection under wind speed intermittency using extreme learning machine", *Computers & Electrical Engineering*, vol.72, pp.369-382, 2018.

[12] G. Ashika, S. R. Mohanty, and J.C. Mohanta, "Microgrid protection using Hilbert–Huang transform based-differential scheme", *IET Generation, Transmission & Distribution*, vol.10, no. 15, pp. 3707-3716, 2016.

[13] J. Gao, Xiaohua Wang, Xiaowei Wang, A. Yang, H. Yuan, and X. Wei, "A High-Impedance Fault Detection Method for Distribution Systems Based on Empirical Wavelet Transform and Differential Faulty Energy", *IEEE Transactions on Smart Grid*, vol. 13, no. 2,pp. 900-912, 2021.

[14] M. Biswal, S. Ghore, O. P. Malik, and R. C. Bansal, "Development of time-frequency based approach to detect high impedance fault in an inverter interfaced distribution system", *IEEE Transactions on Power Delivery*, vol.36, no. 6, pp.3825-3833, 2021.

[15] X. Wang, J. Gao, X. Wei, G. Song, L. Wu, J. Liu, Z. Zeng, and M. Kheshti, "High impedance fault detection method based on variational mode decomposition and Teager–Kaiser energy operators for distribution network", *IEEE Transactions on Smart Grid*, vol. 10, no. 6, pp. 6041-6054, 2019.

[16] M. Kavi, Y. Mishra, and M. Vilathgamuwa, "Morphological fault detector for adaptive overcurrent protection in distribution networks with increasing photovoltaic penetration", *IEEE Transactions on Sustainable Energy*, vol. 9, no. 3, pp. 1021-1029, 2017.

[17] S. Chakraborty, and S. Das, "Application of smart meters in high impedance fault detection on distribution systems", *IEEE Transactions on Smart Grid*, vol. 10, no. 3,pp. 3465-3473, 2018.

[18] S. Roy, and S. Debnath, "PSD based high impedance fault detection and classification in distribution system", *Measurement*, vol. 169, pp. 108366, 2021.

[19] K. Anjaiah, P. K. Dash, and M. Sahani, "Detection of faults and DG islanding in PV-Wind DC ring bus microgrid by using optimized VMD based improved broad learning system", *ISA Transactions*, 2022.

[20] L. Saihi, Y. Bakou, A. Harrouz, I. Colak, K. Kayisli and R. Bayindir, "A Comparative Study Between Robust Control Sliding Mode and Backstepping of a DFIG Integrated to Wind Power System," *2019 7th International Conference on Smart Grid (icSmartGrid)*, Newcastle, NSW, Australia, 2019, pp. 137-143

[21] M. Biswal, C.D. Prasad, P. Ray, and N. Kishor, "Modified Complete Ensemble Empirical Mode Decomposition based HIF detection approach for microgrid system", *International Journal of Electrical Power & Energy Systems*, vol.141, pp.108254, 2022.

[22] C. D. Prasad, M. Biswal, M. Mishra, J. M. Guerrero and O. P. Malik, "Optimal Threshold-Based High Impedance Arc Fault Detection Approach for Renewable Penetrated Distribution System," in IEEE Systems Journal, vol. 17, no. 2, pp. 2971-2981, 2023

[23] C.D.Prasad, M. Biswal, and P. Ray, "Enhancing fault detection function in wind farm-integrated power network using Teaching Learning-Based Optimization technique", *International Transactions on Electrical Energy Systems*, vol.31, no. 10, pp.e12735, 2021.

[24] J. Yu, and L. Jingxiang, "Weak fault feature extraction of rolling bearings using local mean decomposition-based multilayer hybrid denoising", *IEEE Transactions on Instrumentation and Measurement*, vol. 66, no. 12, pp. 3148-3159, 2017.

[25] W.Y. Liu, W. H. Zhang, J. G. Han, and G. F. Wang, "A new wind turbine fault diagnosis method based on the local mean decomposition", *Renewable Energy*, vol. 48, pp. 411-415, 2012.

[26] Z. Wang, J. Wang, W. Cai, J. Zhou, W. Du, J. Wang, G. He, and H. He, "Application of an improved ensemble local mean decomposition method for gearbox composite fault diagnosis", *Complexity* 2019.

[27] C.D. Prasad, M. Biswal, and A.Y. Almoataz, "Adaptive differential protection scheme for wind farm integrated power network", *Electric Power Systems Research*, vol. 187, pp. 106452, 2020.

[28] A. K. Gangwar and A. G. Shaik, "Wavelet Based Transmission Line Protection Scheme Using Centroid Difference and Support Vector Regression", *2018 7th International Conference on Renewable Energy Research and Applications (ICRERA)*, Paris, France, 2018, pp. 1184-1189.

[29] A. Heidari, V. G. Agelidis, H. Zayandehroodi and M. Hasheminamin, "Prevention of overcurrent relays miscoordination in distribution system due to high penetration of distributed generation", *2013 International Conference on Renewable Energy Research and Applications (ICRERA)*, Madrid, Spain, 2013, pp. 342-346.

[30] O. J. Aworo and A. Kwasinski, "Fault Detection Strategy for Grid-Tie Three-Phase Photovoltaic Inverter", *2018 7th International Conference on Renewable Energy Research and Applications (ICRERA)*, Paris, France, 2018, pp. 655-660.