Research Article / Review Article FUPRE JOURNAL 8(3): 98-104 (2024)

FUPRE Journal

of

Scientific and Industrial Research

ISSN: 2579-1184(Print) ISSN: 2578-1129 (Online)

http://fupre.edu.ng/journal

Multivariate Principal Component Analysis Wavelet for Quick Detection and Isolation of Abnormalities in a Coordinated Protection Scheme

ONAH, J. N. [1,*], ***SHOBO, O. F.*** [2], ***ABAH, O.*** [3], ***EZE, P. E.*** [4]

[1*] *Department of Electrical and Electronics Engineering, Federal University of Petroleum Resources Effurun, Delta State, Nigeria*

[2, 3, 4] *Departments of Electrical Engineering, World Bank Africa Center of Excellence for Sustainable Power and Energy Development, University of Nigeria Nsukka.*

ARTICLE INFO

Received: 23/02/2024
Accepted: 01/05/2024

Keywords

Available Fault Indicator, Faults, Multivariate Principal Component Analysis, Multi-Resolution Signals, Wavelet.

ABSTRACT

Owing to the capital-intensive nature of the power system components and safety of lives, fast response to intolerable conditions of power system networks becomes a growing concern for experts in power system monitoring and protection. To synthesize the noise nature of the signals, the multivariate principal component analysis (MPCA) wavelet method was used to extract and simplify the fault signals. An exploit of Daubechies wavelet (db3) was made and decomposed up to level 7. To have a crack at the composite noise nature, an attempt was made on level-dependent noise size estimation which was down-sampled by two at each succeeding level of 7. The results obtained from details, approximations, and simplified signals show that by far, multi-scale principal component analysis (MPCA) is better than multi-resolution signal analysis (MRSA) wavelet for signal detection and simplification.

1. INTRODUCTION

Although, the recent trend in the development of protective relays gave birth to numerical relays a lot of error accounts for 85% of reliability problems with numerical protection equipment (Beaumont, 2002). According to (Willis and Rashid, 200), one of the challenges of protective devices is the ability to discriminate between the tolerable and intolerable conditions of a power system. Poor selectivity of relay operation arises when relays operate without any traceable cause, no remarkable evidence of a power system fault, and no evidence of equipment failure. The New Haven (Enugu) to Otukpo (Benue) line is one of the critical lines in the South-East that conveys power from Enugu to Benue State in the North Central of Nigeria. The distance of the line is 160km and the voltage is 132kV line. (Sunday, 2022) observed in Transmission Company of Nigeria daily report that a single phase to a ground fault which resulted in the electrocution of a vandal occurred in March 2022 along the line. Every protection system

*Corresponding author, e-mail: onah.jonas@fupre.edu.ng
DIO

ought to possess the basic facets of power systems. Protection devices should have the basic requirements of safety, speed, selectivity, sensitivity, stability, economy, and reliability (Blackburn and Domin, 2006).

(Mishra and Deoghare, 2014) presented fault detection and classification by observing the norm of discreet wavelet transform (DWT) coefficient of the fundamental frequency components of the healthy and faulty line current using Har wavelet. It was observed that if the norm of DWT coefficient for line current is less than a certain threshold, the lines are healthy. But once the norm of one or more current DWT coefficients exceeds the threshold value then disturbance is selected. In (Saini et al., 2014), accurate fault detection and location on a transmission line using a wavelet-based on the Clarke's transformation is presented. The algorithm for fault detection transforms the three-phase currents into two phases using Clarke transformation. There is a handful of rigorous transformations which made the algorithm somewhat computationally intensive. (Borkhade, 2014) proposed an adaptive protection technique for transmission systems using synchronized phasor measurements. According to (Coello, 1991), the application of the Genetic Algorithm to relay coordination has drawn much attention from researchers. Unfortunately, the technique has premature convergence and a long time of processing data. To solve over-current relay coordination, (Ukwueze et al., 2015) used non-linear mixed integer programming to protect the power system. The results are found promising in terms of improvement in the high level of power system over current protection but the approach is time-consuming.

Morales et al., 2014, developed and compared Multi-resolution analysis (MRA) with machine learning as artificial neural network (ANN), K-Nearest neighbours, and Support Vector Machine and concluded that MRA is the most reliable approach but MRA does not give a simplified signal

Anyaka et al., 2015 made use of a Multi-signal analysis (MSA)wavelet to decompose three-phase fault signal to level 7 wavelet signals but signals obtained through the approach were not simplified and are likely to have white noise. This work obtained simplified wavelet signals using a multivariate principal component analysis (MPCA) wavelet.

In (Lioh et al., 2022), the impedance-based algorithm was used to locate a fault in the New Haven -Otukpo transmission line. Although the authors located the faults at various distances of the line there is a feeling of misgiving to the capability of the approach to detect and simplify the intolerable signals

To provide the missing link, an attempt was made on level-dependent noise size estimation to obtain and simplify the faulty signals using MPCA wavelet. Therefore, this study is aimed at ascertaining simplified signals that will enable the protective components of the network to detect and isolate the intolerable fault signals from the power system.

2. MODEL FORMULATION

The data exploited in this work was collated from Enugu Electricity Distribution Company with special consideration given to 132kV, 160km New-Haven to Otukpo transmission line. The model is shown in Figure 2. It contains a three-phase source, three-phase transmission line, three-phase breaker, three phases V-I measurement, distributed line parameters, and three-phase RLC load. First, simulation was done on the no-fault condition of the transmission line as can be shown in Figure 3. Then, a single-line-to-ground fault was considered on account of the fact that it has frequent occurrence as can be seen in Figure 4. The parameters of the components were modeled in MATLAB SIMULINK and the associated fault signal was uploaded in Wavelet script format. A discrete solver with sampling time set at 800µs and 0.2s was called up. The flow chart for fault current detection and discrimination is described in Figure 1.

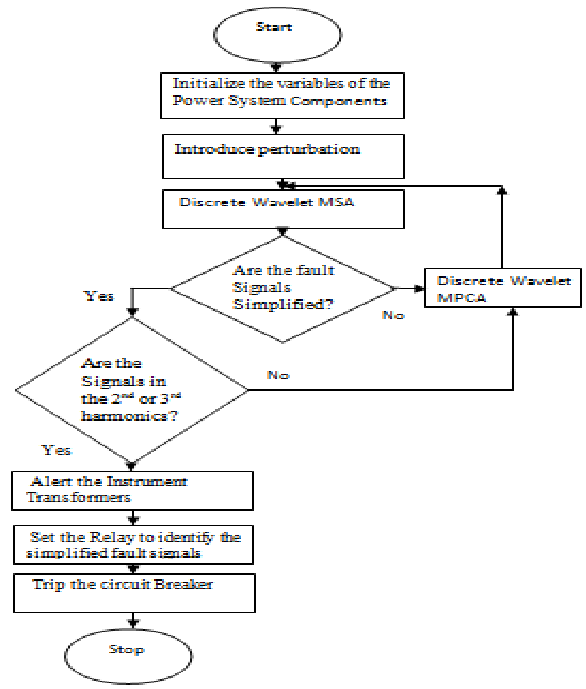

Figure 1: Flow Chart for Fault Current Detection and Discrimination in the Network

3. RESULTS AND DISCUSSION

There are ten cases of current fault signals but for ease of analysis, single line to ground fault, double line to ground fault and three phase fault were considered. Single line to ground fault was chosen because of its frequent occurrence. The work made an exploit of coefficient energy for fault classification. The 3- phase current signals (A, B, C) were decomposed up to level 7 and their energies were calculated to be 0.1257x10-5, 0.1428 x10-5, and 0.1937 x10-5 for no fault condition. The single-line-
A sampling frequency of 12,500Hz and a corresponding sampling time of 80µs yielded a total number of 7 wavelet levels. Again, 1st level detail output corresponded to a frequency band of 62500-12500 Hz. Down-

ground fault, double-line-to-ground fault and three phase faults coefficient energies were found to be 0.00001666, 0.00003730, and 0.000084200, respectively. Although, their coefficient energies were found to be increasing as the severity of the faults increase, with small contributions from the original signal, as can be observed by careful inspection of the detail coefficients. But, special focus was given to the single line to ground fault owing to its frequency of occurrence. .
sampling by two at each succeeding level leads to a 7th level output corresponding to a frequency band of 98-196 Hz. This implies that it includes 2nd and 3rd Harmonics components which are commonly found in

transmission line faults. Therefore, 7th-level decomposition is used for analysis even though the first decomposition level of the DWT contains the highest frequency components. The wavelet toolbox in MATLAB has been used for DWT operation. Daubechies wavelet (Db3) is used as the mother wavelet since it has excellent filtering performance ability in power system analysis. Figure 5 shows wavelet decomposition with details and approximations up to level seven. The results of the original signals in the first column of Figure 6 can be improved by There was a need to suppress the noise because the details at levels 1 to 3 comprise essentially the noise. Removing the noise leads to a crude, but large, de-noising effect. From Figure 6, the MPCA was exploited to reconstruct a multivariate signal using a simple representation at each resolution level, to obtain a simplified multivariate signal in column 3 of Figure 6. The multi-scale principal components generalize the normal MPCA of a multivariate signal represented as a matrix by performing an MPCA on the matrices of details of different levels simultaneously. An MPCA was also performed on the coarser approximation coefficients matrix in the wavelet domain as well as on the final reconstructed matrix to obtain the results in the second column of Figure 6. By selecting the numbers of retained principal components, interesting simplified signals were reconstructed in column 3.

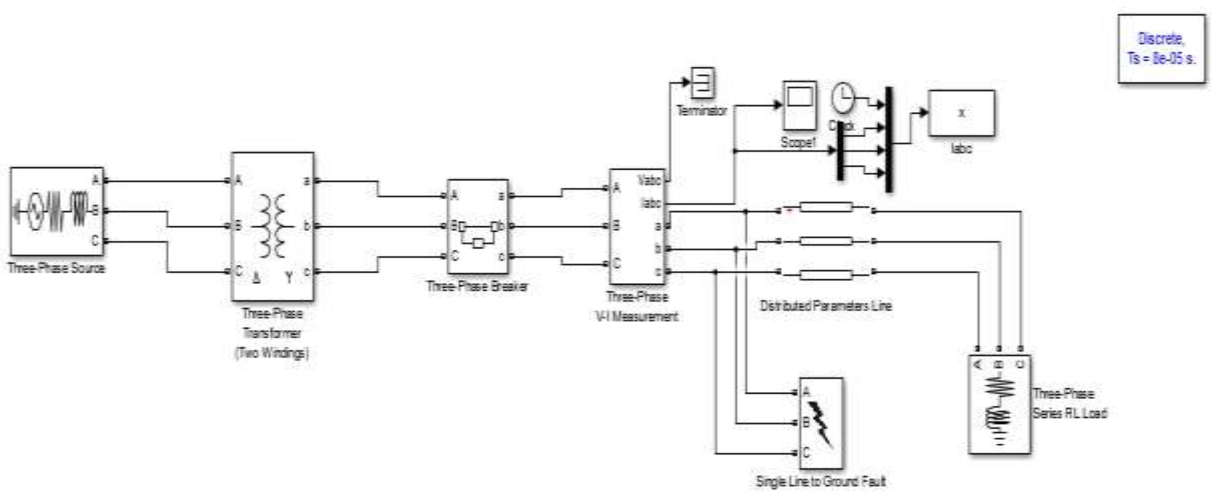

Figure 2: A Model of New Haven-Otukpo Transmission Line

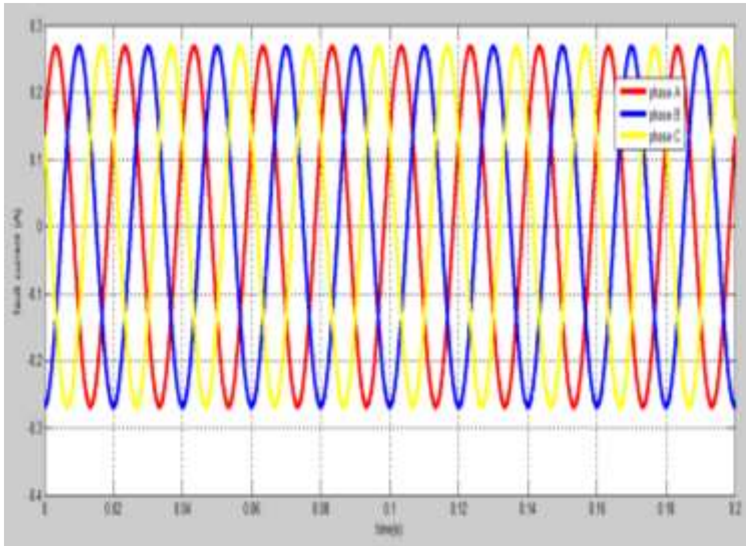

Figure 3: Three Phase Current Signal at no Fault Condition

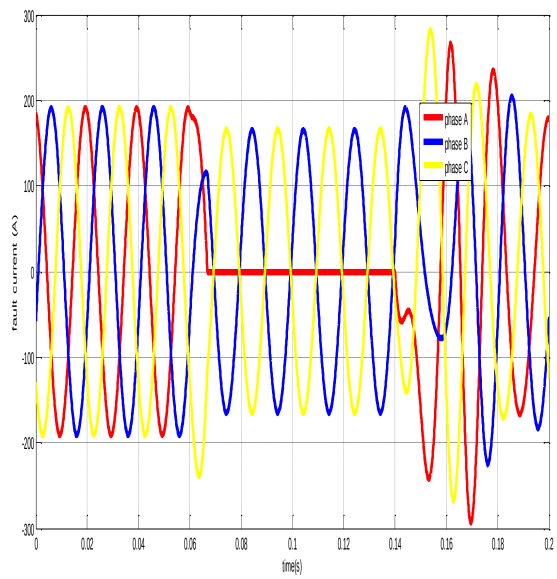

Figure 4: Single Line to Ground Fault

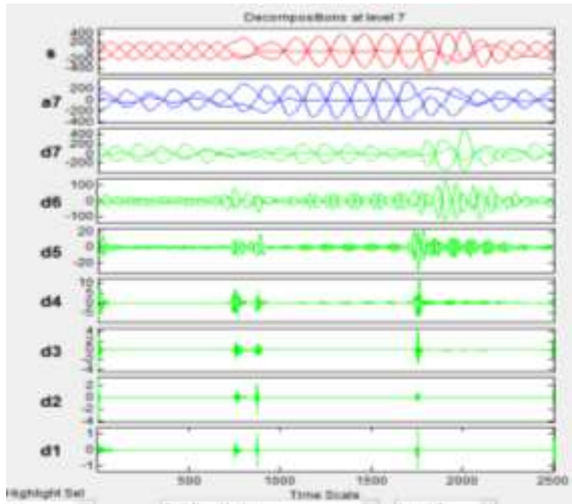

Figure 5: Wavelet Decomposition Showing Details and Approximations

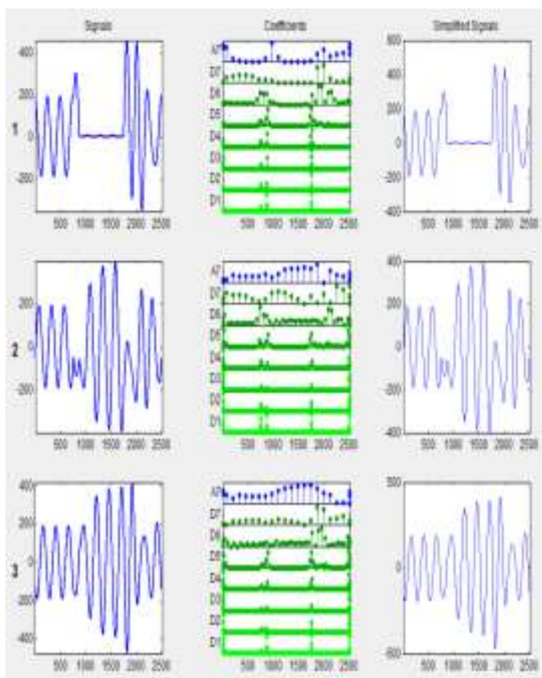

Figure 6: Multi-scale Wavelet Principal Component Analysis Decomposition Showing Details and Approximations

4. CONCLUSION

A Multivariate Principal Component Analysis (MPCA) Wavelet succeeded in simplifying the fault current signals of single line to ground fault for easier detection and isolation. The signals were generated by workspace on MATLAB simulation model and analyzed using Daubechies-3 (d3) mother wavelet at 7th level decomposition. The 2^{nd} and 3^{rd} harmonic components in the range of 98-196Hz were extracted by Multi-signal Discreet Wavelet Transform. They are the intolerable signals that were detected when single line to ground fault occurred. Comparative analysis of the two approaches shows that multi-scale principal component analysis (MPCA) is better than multi-resolution signal analysis (MRSA) wavelet for signal detection and simplification

Reference

Anyaka, B.O., Onah,J.N., Ugwuanyi, N. S and Ozioko., I. O., (2018). A framework for fault current detection and discrimination in a dwindling electric power system NIEEE Journal on Innovative Research and Technology. 1(1):78-85

Beaumont, P. G., (2002) New trends in protection relays and substation automation systems IEEE/PES Transmission and Distribution Conference and Exhibition, Yokohama, Japan. pp. 6-10 Oct.

Blackburn, J.L.and Domin, T. J., (2006). Protective relaying principle and application CRC Press Taylor & Francis Group,

Borkhade, A. D., (2014). Transmission line fault detection using wavelet transform International Journal on Recent and Innovation Trends in Computing and Communication, 2 (10): 3138 – 3142

Coello, C. A., (1991). Theoretical and numerical constraints handling techniques used with evolutionary algorithm-A Survey of the State of Art Computer Methods in Applied Mechanics and Engineering, 3(4):20-25

Lee Willis., H and Rashid. M. H. (2006). Protective relaying principles and applications" Third Edition, Taylor and Francis Group,

Iioh, J.P., Okowoko. I.I., and Anierobi, P.O., (2022). Fault location on transmission line using two ended impedance based algorithm - A Case Study of Otukpo 132kv transmission Lines. Global Scientific Journals. 3(10):159-179

Mishra, R.C., and Deoghare, P.M., (2014). Analysis of transmission line fault by using wavelet International Journal of Engineering Research & Technology, 3(5): 36-40,

Morales, J.A., Orduña,E., Rehtanz, C., (2014).Classification of lightning stroke on transmission line using multi-resolution analysis and machine learning. International Journal of Electrical Power & Energy Systems 6(58):19-31

Saini,M., Bin Mohd zin, A. A., Bin Mustafa, M. W., and Sultan, A.R.,(2014) Accurate fault detection and location on a transmission line using wavelet-based on Clarke's transformation Przegląd Elektrotechniczny, 90(11):156-161

Sunday, S. E., (2022) Vandal damage power transmission tower in Enugu, Transmission Company of Nigeria TCN Daily Report of TCN,

Ukwueze, V. C., Madueme, T.C., and Onah, J. N., (2015). Frame-work for over-current relay protection optimization. International Journal of Engineering Research and Technology. 4(9): 917-922.