Evaluation of openXDA for Automatic Fault Analysis

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Abstract

The high efficiency of fault location calculation is one of the most crucial techniques which has significant influence on the reliability of power systems. Once an event occurs on a power transmission line, it is followed by a series of automatic device activities: protections triggered, breakers tripped, load outage, etc. The most stringent mission for the utility is to pinpoint the fault location, and then to clear the fault, and restore power. The sooner the power supply recovery, the less power outage, and the better the power system's reliability. Typically, manual analysis is required to calculate a reasonable and acceptable fault location result, including faulted line, fault type, and fault location distance. Based on the result, line crews are targeting to find fault trace in the field. The currently used traditional fault location calculation method is analyzed in this paper, and several problems have been exposed within it. In order to improve fault location analysis efficiency in utility, GPA (Grid Power Alliance Co.) proposed a novel application, openXDA (open-source Extensible Disturbance Analytics) to solve these problems. This project mainly purposes to evaluate openXDA, which targets to realize highly efficient calculations for saving time, and to obtain a reasonable result which could be close enough to the actual event location for line crews' work. It is expected to accomplish a series of analytical processes by automatic calculation, and improve accuracy by using multiple advanced algorithms and plentiful samples for calculating. In this paper, we use several real fault cases on Dominion Virginia Power's transmission network to evaluate openXDA.

Key words: openXDA, power system reliability, automatic fault analysis, fault location

I. Introduction

Power system reliability is one of the most significant indexes needed in order to evaluate the ability of providing reliable and qualified power. For some specific customers, it is strictly required that the outage duration be limited to a certain time period in the contract. The reliability index is closely connected to the profit of a utility. A common target of different utilities is the improvement of power supply and transmission reliability. Most of the time, short circuit events are the primary reason for power outages. However, it is unavoidable in a power system. Any type of fault occurrence on power transmission line is followed by a series of automatic activities: protection operations, breakers tripping and reclosing, and, in some cases, an eventual power outage. Because power outage duration contributes to reliability impairment, the utility should target to eliminate outage duration after any power outage. The most stringent mission is to pinpoint fault location, clean the fault, and recover the power supply. The sooner the power supply recovery, the less power outage, and the higher power system reliability. So the high efficiency of fault location calculation is one of the most crucial techniques, which has a significant influence on the reliability of power system.

In order to accomplish fault analysis after power outage, IEDs (intelligent electric devices) are installed in substations, like PMUs and DFRs. They can be used for system monitoring under steady states and provide disturbance records when faults occur in the system. During a transient process caused by a disturbance, they can store disturbance information, including system voltage and current waveforms during transience, and then they generate records in COMTRADE format for analysis purposes. Currently, analysts do fault analysis based on these records and obtain fault information, including faulted line, fault type, and fault location.

The traditional method to do fault analysis is using vendor specific or third party applications along with system models. However there are several problems with it. The detailed process of this traditional method is introduced in this paper, and drawbacks are displayed. Meanwhile, we are seeking a better way to fulfill higher requirements to improve the efficiency of fault analysis. The openXDA is an advanced application released by GPA for providing an extensible platform for processing event records. Based on the waveform data and transmission line parameters provided by customers, it determines the fault type and calculates the line distance to the fault. The purpose of this project is to evaluate the openXDA application for fault location calculation compared with the traditional method. By using fault cases of Dominion Virginia Power, another target is to verify that openXDA can obtain convincible distance to fault for line crews in utility.

This paper is organized as follows: The traditional fault analysis method is discussed in section II, openXDA application is displayed in section III, real fault cases analysis comparisons are presented in section IV, and the evaluation of novel openXDA application is concluded in section V.

II. The traditional fault analysis method

The traditional fault location method is based on a third party application. By using this application, the transient current and voltage waveforms of faulted line can be visualized. According to the waveforms, the faulted line and fault type can be decided. Meanwhile, it can calculate the fault location on the samples in COMTRADE files. In this section, the process of fault location analysis in the traditional method is introduced as are the problems we have met.

1) Download disturbance record in COMTRADE format from a digital device

The disturbance records are generated once a fault occurs and they are stored on a server. Analyzers download fault records remotely, and then analyze them with the analysis application. COMTRADE is an IEEE standard universal format for disturbance records. The COMTRADE file contains voltage and current data captured during the fault event.

2) Analyze the COMTRADE data to determine the fault type and the faulted line

According to visualization of voltage and current waveforms in the analysis application, the faulted line and the fault type can be decided. For example, Fig 2.1 shows a group of voltage and current waveforms during a fault.

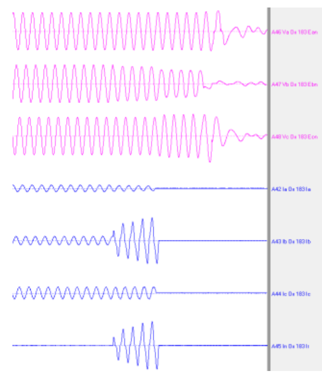


Fig 2.1 transient voltage and current waveforms

In Fig 2.1, the upper three curves are the phase voltages of line 183, and the lower four curves are the phase current and the ground current of line 183. When a short circuit fault occurs on line 183, both voltage and current waveforms change correspondingly. In this case, the phase B and ground current change abruptly at the same time, and the magnitude of phase B voltage decreases gradually. It represents a phase B to ground fault. After a period of oscillation, these current waveforms change to zero, which indicates the breakers on line 183 tripped the circuit. The fault is isolated.

Through the display of the transient waveforms in Fig. 2.1, we can conclude that it is a phase B to ground fault occurrence on line 183.

3) Calculate the fault location with one picked sample during the fault

There are three algorithms for fault location calculation which are fixed in the analysis application. For each time, one sample during the fault is selected, which contains a completed period, and one fault location result can be calculated by the application. Based on the information of a faulted transmission line and a specific algorithm, the fault location result can be shown as circled in percentage term. Then analyzers need to look up the total distance of the transmission line to calculate fault location from the substation in miles. For each sample, there are three fault location results at most with three algorithms available.

4) Repeat fault location calculations at different timestamps

Typically, at least four samples at different timestamps are needed to conclude a credible result. The same calculations must be repeated at least 4 times, and 12 different results obtained.

5) Conclude a best fault location based on all results

Generally, the best result is the average value of all results. Then analyzers report this fault location result to help the line crews find it in the field.

Through the process of the traditional fault analysis method, we can find several drawbacks which apparently impact the efficiency of analysis. Firstly, the whole process of traditional fault location calculation is manual. Sequentially, analysis would take a lot time using this process. When a fault occurs in transmission, saving time means saving the economic loss of utility. However this manual calculation would cost us a lot of time. Second, it calculates the result with only three algorithms. For now, there are available more advanced algorithms which can be useful to provide more comprehensive results. Third, the result is based on countable randomly selected samples during the fault, which means it would result in a significant amount of information loss within the other thousands of samples which are not selected. Mainly on account of these three issues, the traditional method is not able to meet the requirement of providing credible fault location result in a reasonable time.

III. openXDA for fault analysis

openXDA is an extensible platform for processing event files from disturbance records. Based on transient waveform data and transmission line parameters provided by customers, it determines the fault type, faulted line and calculates the line distance to the fault. The most attractive attribute of openXDA is the ability of automatic fault analysis, for saving much time. It solves every problem of the traditional method with advance techniques.

Compared with the traditional method, openXDA presents a more powerful ability on fault analysis. First, openXDA is able to read COMTRADE event files in a user-specified folder, and parse these files into timestamp-value sets. With transmission network parameters, it calculates fault location automatically and produces a complete fault analysis result in a few seconds. It has an advantage on calculation efficiency comparing with manual process of traditional method. Secondly, the performance of calculation can be extended with new algorithms. For now, all five currently available algorithms are used. Compared with only three or fewer algorithms in traditional analysis applications, the result of openXDA is more comprehensive. Thirdly, openXDA calculates frequency domain values for each cycle of measured data, which means the result of each algorithm is computed for every sample in a COMTRADE file. In contrast with the traditional method, which uses a much smaller amount of samples selected manually for calculation, openXDA utilizes the complete information of fault records.

openXDA is expected to help overcome the weaknesses of traditional methods, improve the fault analysis process, and provide a significant contribution to power system reliability. As we can see from the analysis of the traditional method, the most time consuming part is the process of fault location calculation. Improvement on this point would prompt work efficiency of the whole fault analysis process most obviously. So in section IV, we mainly focus on the comparison of fault location calculations.

IV. Comparison of multiple fault analysis tools

In order to verify the capability of openXDA to calculate fault location efficiently with a certain error limit, six real fault cases that happened on Dominion's transmission network are analyzed in this section. With use of fault records generated by IEDs, openXDA produces fault location results. Based on the comparison with actual fault location found in the field, we verify its calculation capability. Generally in utility, the error of calculation result less than 1 mile is acceptable. On the other hand, we also use the traditional method to calculate the fault location as well. By comparison of two of these results, we verify the improvement of openXDA application.

The first case is a phase C to ground fault that occurred on transmission line 126. The line crews found the actual fault location is 18.50 miles from Earleys Substation. With the traditional fault location method, we can get a result, 17.70 miles from Earleys substation. However by use of openXDA to calculate fault location is about 17.75 miles from Earleys substation, which is close to the traditional method result and matches the actual fault location found. We can conclude that the result of openXDA in this case is effective. More details about the result of openXDA are shown in Fig 4.1.

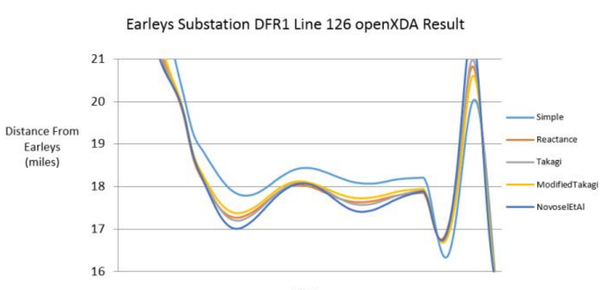
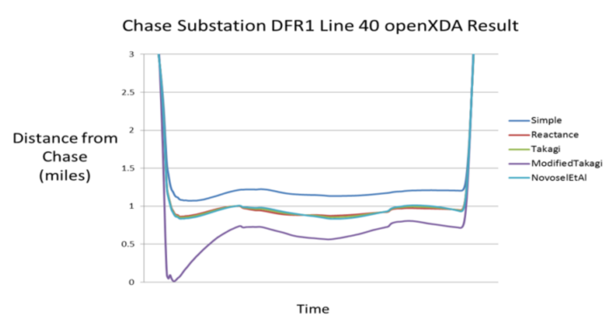


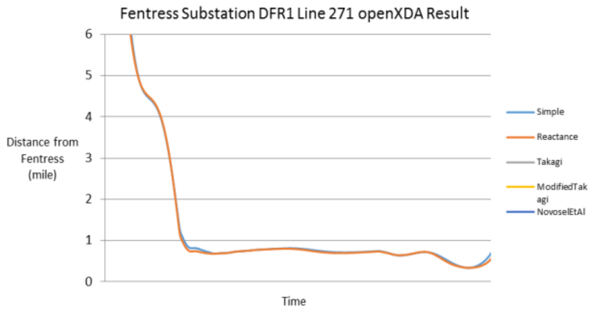
Fig. 4.1 openXDA Result for the Fault on Line 126

In Fig 4.1, the x-axis represents time, and y-axis represents the distance of the fault from the substation. openXDA confirms the fault location based on results of all five currently available algorithms. Five results are displayed in the plot with different colors. For each curved line, when the trend goes down, and then keeps a relatively flat period for a while, it signifies a fault occurrence during this period (x-axis) around this area (flat area in y-axis). Through the plot, we can see that the results of different algorithms are very close. They have similar change trends, and some of them overlap with each other, which indicates that these five algorithms correlate very well. They can be evidence for each other to prove the results are credible. Based on five credible results calculated by five available algorithms, openXDA concludes a comprehensive result, which is closer to the actual location compared with the traditional fault location result which uses only three algorithms. In this case, the fault occurred on line 126. The location can be estimated at approximately 17.75 miles from Earleys Substation through the corresponding average y-axis value of a relatively flat period when the fault endures. Comparing to the actual fault location and result of traditional methods provided, we can see that openXDA can calculate the fault location effectively, with only 0.75 miles difference.

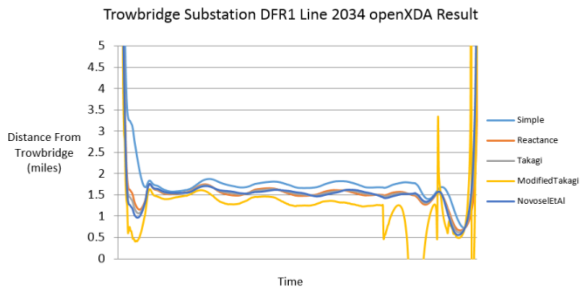
There are five other fault cases used for calculating the fault location results with openXDA. In order to display the results compared with the traditional method results and the actual fault locations, the openXDA results of each case is displayed in Fig 4.2, and the corresponding comparison is shown in Table 4.1.



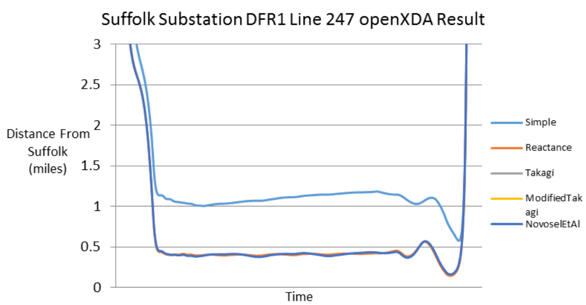
a. openXDA Result for the Fault on Line 40



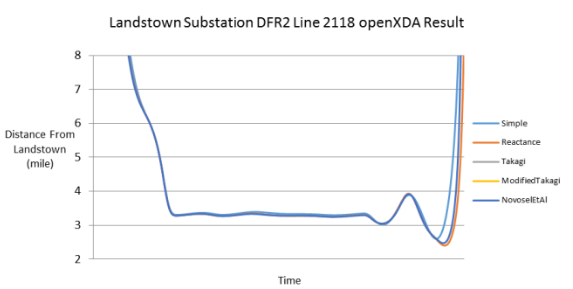
b. openXDA result of fault on Line 271



c. openXDA result of fault on Line 2034



d. openXDA result of fault on Line 247



e. openXDA Result for the Fault on Line 2118

Fig. 4.2 Fault location results of openXDA for different cases

In Fig 4.2, the results of openXDA for each case are shown respectively. The calculated result of each algorithm is displayed in terms of a curve in different colors. In each plot, the curves have obvious descending trends and flat area for a specific time period, which means that these algorithms installed in openXDA are able to calculate fault location for these real cases effectively. The curves in each plot are close to each other with some of them are overlapping. The biggest difference between different curves is about 0.5 miles. This indicates that five algorithms in openXDA correlate with other algorithms very well. Based on those high correlated results, it is convincing that the result of openXDA on fault location calculation is credible.

Faulted Line	Fault type	Actual fault location	Result of Traditional Method	Result of openXDA
40	Phase A-Phase B	0.90	0.91	0.90
271	Phase A-Phase B	0.83	1.00	0.70
2034	Phase B-Phase C	1.39	1.56	1.60
247	Phase A-Ground	0.58	0.40	0.65
2118	Phase C-Ground	4.24	3.37	3.41

Table 4.1 Comparison of Fault location results

These five cases are real faults that occurred in the utility transmission network. The actual location that line crews found can be used as a reference for evaluating the results from openXDA. The result of the traditional manual calculation method is also compared in this paper. The comparison of results between openXDA and the traditional method is shown in Table 4.1. These faults occurred in the 230kV transmission network. Fault records generated by DFRs on one side of each faulted line are used for calculation. The data in Table 4.1 shows for distance between the fault location and the corresponding substation. There are mainly two fault types tested in this paper, phase-to-phase and phase-to-ground. For phase-to-phase fault cases, the largest difference between openXDA results and the actual fault location is 0.21 miles, compared to the largest error of the result of traditional method is 0.17 miles. For phase-to-ground fault cases, the largest error is 0.83 miles versus 0.87 miles for the results of openXDA and traditional method, respectively. The calculation result is less than 1.0 mile different from the actual location. In practical utility work, this calculation error is acceptable. It can prove that openXDA can calculate acceptable fault location effectively. Furthermore, the results of openXDA for some cases are better than that of traditional method. To some extent, it means that openXDA is able to improve the accuracy of fault location calculation.

V. Visualization

In addition to providing multiple fault locations based on different algorithms, this tool allows for visualization of the fault location. Traditional single point locations do not offer as much detail about the nature of the fault as the graphs of the calculations provide. We wanted a simple way to graph these locations without having to import the data in a spreadsheet and create a graph. The simple solution to this was to provide a COMTRADE file of the associated channels and include traces from each fault location calculations. This output COMTRADE file is produced whenever a reasonable location is calculated on a line.

In addition to the analog traces of fault location, there are also digital status traces indicating a fault condition as well as fault type. One example is shown in figure 5.1.

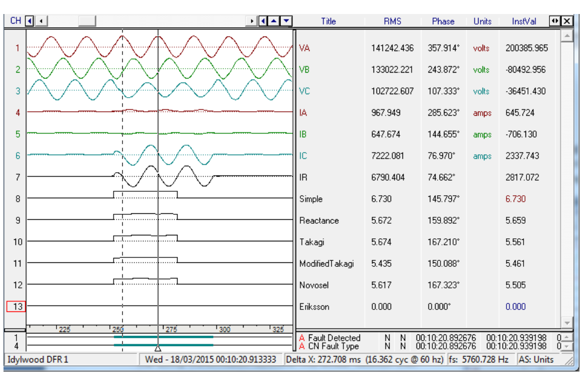


Fig 5.1 Visualization of fault traces in Comtrade

VI. Further research

We plan to use the results of the various fault location methods to further classify which methods perform best for various types of faults. For example, we may find that some algorithms may perform better than others on high impedance ground faults.

Through visualization and statistical analysis we hope to determine which of the many calculated locations is most likely to be accurate.

VII. Conclusion

In this paper, comprehensive analysis and evaluation of openXDA on fault analysis performance is presented. It is an extensible application for processing event records automatically and determining the fault results efficiently. Through an all-sided explanation of the process of the traditional fault analysis method, several problems are revealed. By contrast, openXDA is designed for not only implementation of the fault analysis function, but also targeting to solve these problems, and ultimately to realize better advancement of power system reliability. In order to furnish a convincing comparison between the calculation ability of openXDA, a series of fault cases in Dominion's transmission network are analyzed by both openXDA and the traditional method. Based on the results and comparison with the actual fault locations found in the field, the conclusion of openXDA performance evaluation is exhibited as follows.

The results of openXDA match the actual fault locations very well for both phase to phase and phase to ground fault types. The distance errors are less than one mile. openXDA is capable of calculating fault location correctly with an acceptable error.

Furthermore, five algorithms correlate with each other. For each case, the final fault location result given by openXDA is more credible, because it is based on all five currently available algorithms. It calculates and analyzes every sample during the whole fault period, not just several random samples as the traditional method does. Sequentially, in most of the cases, results of openXDA can be closer than those of the traditional method with less error.

Finally, the calculation abilities of openXDA can improve the analytic efficiency because it is performed automatically. For each case, the process only takes several seconds to give us the result. Compared with the traditional method, which repeats the process manually with just a few selected samples, openXDA can save us much time on fault analysis. Plus it provides a more accurate result, line crews can find the fault, and restore power faster.

About the authors

Ling Wu is currently a Ph.D. student in the Min H. Kao Department of Electrical Engineering and Computer Science at the University of Tennessee, Knoxville. She received her B.S and M.S from Xian Jiaotong University, China, in 2008 and 2011, respectively. Her research interests involve wide-area power system monitoring and power system dynamic analysis. Prior to pursuing her Ph.D., she was a substation engineer in the State Grid Corporation of China.

Stephen Wills began as an intern at the Tennessee Valley Authority in 2009, working on open source software for synchrophasor systems. Since graduating from the University of Colorado at Colorado Springs in 2011, he has continued work on open source software for electric power systems at the Grid Protection Alliance. He has been the primary developer for openXDA since the project began in 2013.

Kyle Thomas received his M.S. degree in Electrical Engineering from Virginia Tech in 2011 and is currently pursuing his Ph.D. while working for Dominion Virginia Power's Electric Transmission Operations Research group. He has technical expertise in power system protection/control, wide-area measurements, fault analysis, cascading analysis/physical security, and system simulations. Kyle is a technical lead of Dominion's synchrophasor installations, applications, and training, and is actively involved in the North American Synchrophasor Initiative (NASPI), IEEE, and Cigre organizations.

Robert Orndorff has worked at Dominion since 1984. He earned an A.A.S degree in Electronics in 1986 and spent 11 years as a field relay technician and in 1997 transferred to the Fault Analysis department where he currently works. His current responsibilities include maintaining and configuring Dominion's Digital fault recorders, event retrieval and analysis from smart relays and DFRs. Robert is an IEEE member and has been a member of the Transient Recorder's User Council (TRUC) since 2002.