DESIGN OF INTEGRATED ANALYSIS REPORTS USING DATA FROM SUBSTATION IEDs

M. Kezunovic*, P. Myrda**, B. Matic-Cuka*
* Texas A&M University, ** Electric Power Research Institute

Abstract

Full advantage of data recorded in substation may be taken if the process of extracting and merging information suitable for various utility groups is done automatically. This paper shows how substation data are utilized in an on-going EPRI project funded by several utilities, as well as by DOE, ERCOT and the Center for the Commercialization of Electrical Technologies. The project developed an approach where substation data is automatically collected and processed at substation and control center levels. As a first step, several automated analysis applications that process data from different Intelligent Electronic Devices (IEDs) have been implemented. As a result of processing the data, information of interest per an IED is extracted. In the next step this information is integrated in comprehensive reports tailored for specific utility personnel, such as, protection, maintenance and operations groups. In addition recorded data and extracted information are sent to Control Center level to enhance Supervisory Control and Data Acquisition (SCADA) capability and improve existing application such as fault location and alarm processing. New Energy Management System (EMS) solutions, namely Optimized Fault Location and Intelligent Alarm Processor are developed as a result.

New system architecture for data and information integration dealing with the data format and model standardization is proposed. In this way the solution supports open system design for easy expansions in the future. The issues regarding conversion of non-operational data to operational data are also addressed. Those issues involve data acquisition synchronization, data stamping, as well as conversion of data formats and definition of data model extensions. The implementation stage of the overall solution is discussed as well.

Introduction

Substation automation and data integration enhance real time data availability and improve decision making procedures in a utility. Those are promising and challenging processes in terms of design, implementation and usage. The process gets rather involved since the substations are not implemented using fully standardized design characteristics. Most of the substations have devices and applications from different manufactures, which presents distinct variety of characteristics regarding communications, event reporting, data recording, etc. The good news is that the same physical measurements are available from several IEDs and that the data redundancy may be used to verify data quality. The bad news is that each manufacture has their own nomenclature and tools for data integration and operator displays, which works only for their IEDs. As a result, IED data cannot be fully utilized by power system enterprise management system because there is no uniform integration platform for those kinds of data. Current substations are designed to integrate only Remote Terminal Unit (RTU) data through Supervisory Control and Data Acquisition (SCADA) systems. Most of the substations are equipped with RTUs that transmit analog and status signal to an EMS for further processing. With variety of substation IEDs introduced over the last 15-20 years. A need to integrate the data and present the results of automated processing to different utility groups has become acute. It can be easily recognized that IED data volume has impact in the area of communications, databases, data integration, displaying principles, and processing of events and alarms.

Aim of our on-going project is to fully utilize substation data coming from legacy or modern IEDs by making slight adjustments to the basic substation design for data acquisition. The goal is to monitor and remotely diagnose real-time and if there is a need isolate the power fault, so that personnel know basic fault and device behavior characteristics and what needs to be done before they visit the substation site. The data from each device is analyzed and reports are merged into customized reports and transferred to Control Center level to fulfill the needs of the Optimized Fault Location and Intelligent Alarm Processing applications. This project involves integration of 5 IEDs from three manufactures within substation and integration with SCADA data at the Control Center level.

Overview of automated analysis applications for selected types of IEDs

Three types of IEDs were considered and per-device analyses have been developed. All devices are synchronized to the Global Positioning System (GPS) reference clock and knowledge of precise time of sampling allows easier integration of data from different IEDs. Since files generated by IEDs do not have standardized naming format, it is difficult to integrate those data directly without further processing. Developed applications rename all files to standardized File Naming Convection [1] format.

a. Digital Protective Relay *(DPR) and* Digital Protective Relay Data Analysis (*DPRA)*

Modern digital protective relays (DPRs) are capable of generating various files and reports, each of which may contain a specific category of data. These data include samples of analog currents and voltages, statuses of protection elements and control elements of relay logic, statuses of contacts of relays, communication channels and circuit breakers. Generally, DPR outputs a few types of data files: oscillography, fault, setting and event data. Oscillography data contains the records of external signals that a relay sees during disturbance and they are typically stored in COMTRADE [2-4] file format. Secondary voltages and currents coming into the relay are recorded as analog channels while statuses of both external contacts and internal states of the relay can be recorded as digital channels by users' selection. COMTRADE file format consists of three types of the files: header file (.HDR), configuration (.CFG) and high resolution raw data file (.DAT). Header file contains summary information about the event in ASCII format. The

.CFG file is an ASCII configuration file that describes the layout of the .DAT file. The .DAT file is in binary format and contains the values for each sample in the record. Setting data specifies how the relay is configured. Usually setting data configures the relay at three levels: selecting protection and control elements, deciding how the selected elements are logically combined, and setting operating parameters of each selected element. Fault data contained in a fault report include fault type, fault location and voltage and current phasors during pre-fault and fault periods. They are calculated by a relay and used for its decision making. Sequential Event Data contained in an event report are time stamped logic operands in chronological order. It contains most of the information through which the external behavior of a relay and its associated protection system components and the internal states of the relay may be observed.

The Digital Protective Relay Analysis (DPRA) is an expert system which automates validation and diagnosis of relay operation [5]. It takes various relay files as inputs and using embedded expert system generates a report on the results of analysis. If some abnormalities are detected in the event report the process of determining of the reasons will be utilized. The report consists of section that summarizes general fault information such as fault inception/clearance time, fault type and location. The subsequent report section lists logic operands and notifies their status and operating speed. In case that some operand failed to operate the verifying action will be suggested. The next report section lists expected and actual logic operands status. The DPRA is developed for two types of relays: SEL 421 [6] and GE D 60 [7] and it can be extended to another relay variety.

b. **Digital Fault Recorder (*DFR) and* Digital Fault Recorder Analysis (*DFRA)***

DFR is a device with an ability to capture and store huge amounts of data without possibility for automated data processing. It captures transient events, longer-term disturbances and trends of input quantities such as RMS, frequency, harmonics, power and power factor and stores it vendor's file format. This device records large amount of data after being triggered by a pre-set trigger value.

The Digital Fault Recorder Analysis (DFRA) (also called DFR Assistant by the vendor that offers this solution [8]) provides automated analysis and data integration of DFR event records. It provides conversion from different DFR native file formats to COMTRADE file format. Moreover, DFRA performs signal processing to identify pre- and post-fault analog values, statuses of the digital channels (corresponding to relay trip, breaker auxiliary, communication signals), fault type, faulted phases. It also checks and evaluates system protection, fault location, etc.

c. **Circuit Breaker Recorder Analysis (*CBR) and* Circuit Breaker Recorder Analysis (*CBRA)***

CBR design is developed to monitor circuit breaker condition on-line [9]. It monitors signals in the control circuit during the opening/closing process and records it in the COMTRADE file format.

The Circuit Breaker Recorder Analysis (CBRA) performs analysis of waveform records taken from the circuit breaker control circuit using a CBR and generates report that explains event and suggests repair actions [10]. Based on detected status of circuit breaker contacts, CBR is providing information on final status of the circuit breakers such as "OPEN" or "CLOSE". The timing of transitions of control signals, such as Trip or Close Initiate, X and Y coil currents, Control and Yard DC voltages, Closing Coil and others is monitored. This enables protection engineers, maintenance crews and operators to quickly and consistently evaluate circuit breaker performance identify performance deficiencies and trace possible reasons for malfunctioning.

The new CBRA system for real-time monitoring and assessment of circuit breaker operations provides for better understanding of condition and operating performance of each individual breaker by monitoring and analyzing expanded set of analog and digital signals from circuit breaker control circuitry. Permanently monitoring and automatically analyzing the circuit breaker data recorded for each operation enables real time monitoring of integrity and topology of the entire power network. This solution facilitates the analysis process by providing timely results that are consistent, irrespective of who runs the analysis. Enhanced reasoning, consistency and speed are achieved by using advanced signal processing and expert system techniques.

Comprehensive report generation for protection and maintenance groups

a. Integration of IED data

Per-device analysis reports provide information about disturbance and/or particular device operation. To analyze event user has to check and compare content of the report for each device. Comparing to the manual analyzing of raw IED data this is tremendous improvement in efficiency, but still it requires additional time and skill before final conclusion is made. To meet the requirement, of further automation in the analysis comprehensive reports are generated. One report combining results of analysis of data from each IED type is generated instantaneously after fault occurrence and consists of all relevant information concerning the event from the user's perspective. Any utility is divided into departments responsible for various tasks related to the system operation. In this paper we are mainly concerned with protection, maintenance and operation personnel and generation of the reports for those users. The information should be well organized and translated to the terminology used by a given utility group.

Benefits of data integration from the several substation IEDs are many. First, IEDs used in this study record some of the same signals, creating an opportunity to utilize data redundancy for data performing consistency checks. Also, certain IEDs record signals not recorded by other IEDs. The applications, such as DPRA and DFRA, can perform detailed disturbance event analysis. However, DFRA analysis cannot perform full analysis of protective relay operation because the DFR device cannot record internal states of a protective relay. On the other hand, the DPRA can validate and diagnose the relay operations in great details, but disturbance information may not be comprehensive since DPR records data from one transmission line only. DFRA cannot perform analysis of the CB tripping operations because DFR device is not used to monitor large number of CB control circuit signals, but CBMA provides this information in details. To achieve full IED data utilization there is need for data integration across the entire substation. Then, the data validity may be checked due to redundant measurements and comprehensive reports may be generated due to completeness of integrated data. For instance, different fault locations may be calculated for the same event due to the use of dissimilar calculation techniques in different IEDs. For this case the comprehensive reports will show the fault location range which is determined based on data from all per–devices analysis applications. In the current stage of the project mechanism for acknowledging which device provides the most accurate fault location has not been implemented yet but the work is underway.

The goal is to automatically collect and integrate data from all substation IEDs, analyze it and extract and integrate information of interest for various types of users such as operators, protection engineers and maintenance group. Data may be analyzed at substation level and conclusion may be sent directly to the protection and maintenance group. Generated file reports have standardized name format what make those reports easy to manipulate. Those reports have multilayer structure and each following layer describes the event in more details.

b. *Report for protection engineers*

Protection engineers are responsible for the final assessment of the correctness of any system response to a given fault condition. They have to check operation of each protection related IED and in case of misoperation to find the cause for device failure or misoperation. Mostly they are interested in DPR operation during the event.

Fig. 1. and Fig. 2. show first and second level of reports for protection engineers in case where one relay on the line has not tripped. Summary section in Fig. 1 shows major information of interest to protection engineers, such as substation name, affected circuit, triggered time and date, fault type, duration and range, event outcome and devices operation with main focus on relay operation. In the case the fault was cleared in a reasonable time and all devices operated correctly, there is no need for additional data and generating the second level report that contains further details may not be of interest. In the presented case the fault is cleared by the second relay, and because of relay misoperation protection engineers require further details leading to the second level report being generated. Second layer of the report describes relay internal logic operation and displays signal waveforms. It lists sequence of the relay logic state and suggests remedial actions. In scenario for this case wrong relay phase distance settings has been set during tests. The analysis suggests that phase distance settings should be checked.

```
==================== EVENT SUMMARY ====================
 Substation :              TAMU
 Affected Circuit:         T 98
 Trigger Date and Time:    08-30-2006 22:08:53.457

 Fault Type   :            AB_FAULT
 Fault Duration:           3 cycles

 Fault Range:              [16.41-16.50] miles from TAMU

 Event Outcome            : CLEARANCE_LOCAL
 Relay Operation (SEL)    : NO_TRIP
 Relay Operation (GE)     : TRIP_OK
 Breakers Operation       : OK
```

Figure 1. Event Summary

```
==================== CONCLUSIONS=============================

Description of Misoperation/Failure:

SEL Relay failed to trip contact to bus breaker
SEL Relay failed to trip contact to middle breaker

Investigation Results:

Trip contact for bus breaker (OUT102) failed to assert
Trip contact for middle breaker (OUT106) failed to assert
Relay trip failed to assert
Phase Distance Zone 4 Element (M4P) failed to assert
Phase Distance Zone 2 Element(M2P) failed to assert
Zone 2 Delay Timer Element (Z2PGS) failed to assert
Stopping Element Pickup failed to assert

Phase distance Zone 1 Element Operation (M1PT) asserted as expected
Level 1 Phase Directional  Overcurrent Element (67P1) asserted as expected
Level 1 Instantaneous Phase Overcurrent Element(50P1) asserted as expected
Phase Distance Zone 1 Element  asserted as expected

Corrective Actions:

Check Phase Distance Zone 4 Element (M4P) setting
Check Phase Distance Zone 2 Element (M4P) setting
```

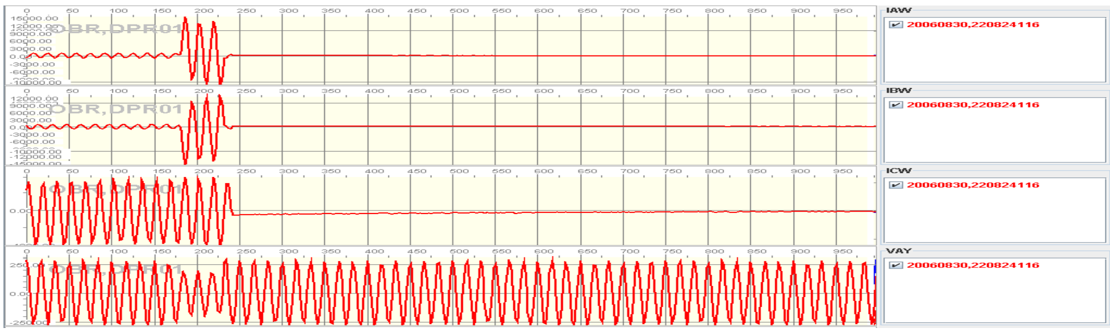


Figure 2. Event Conclusions

c. Report for maintenance staff

Maintenance group is responsible for system repair and restoration. This group is interested in monitoring circuit breaker operation. Fig. 3. shows summary report for maintenance staff in the case the breaker got stuck. Summary report display data of high priority for maintenance group, such as substation name, effected circuit, trip time and date, fault type and duration , event outcome and devices operation with main focus on CB operation. Fig. 4. shows report conclusions aimed at the maintenance staff for the same case. Report conclusion consists of information about signals affected by tripping operation, suggestion for remedial actions, pre-, during and post- fault analog signals values and waveforms display.

```
====================== EVENT SUMMARY ========================
 Substation :              TAMU
 Affected Circuit:         T 98
 Trigger Date and Time:    08-30-2006 16:27:27.6505

 Event Type  :             ABC_FAULT
 Fault Duration:           There is no clearance!|

 Event Outcome               : NO_CLEARANCE
 Relay Operation(SEL)        : TRIP_OK
 Relay Operation(GE)         : TRIP_OK
 Bus Breaker Operation       : OK
 Middle Breaker Operation:     FAILED
```

Figure 3. Event summary

```
================== REPORT CONCLUSION =====================

*** Middle breaker expert system log ***

 'A' contact flat!
 'B' contact flat!
 Phase A Current did not drop!
 Phase B Current did not drop!
 Phase C Current did not drop!
 Stuck breaker while opening!

*** Middle breaker expert maintenance and repair information ***

 Check auxiliary assembly, contacts, and linkage.
 Check Phase currents connections. There may be a bad interrupter.

*** Analog signal values from DFR***

     Prefault Values:             Fault Values:            Postfault Values:
   IO   =    0.0010 [kA]     IO   =    0.0005 [kA]     IO   =    0.0013 [kA]
   Ia   =    0.7653 [kA]     Ia   =   12.2826 [kA]     Ia   =   12.2881 [kA]
   Ib   =    0.7559 [kA]     Ib   =   11.9846 [kA]     Ib   =   11.9844 [kA]
   Ic   =    0.7609 [kA]     Ic   =   12.3566 [kA]     Ic   =   12.3566 [kA]
```

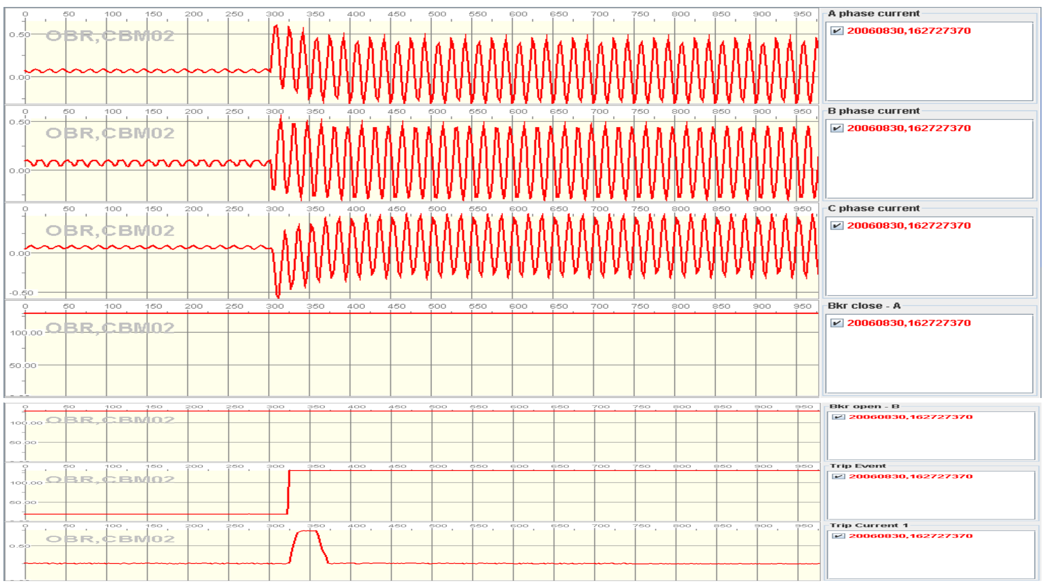


Figure 4. Event conclusion

Comprehensive reports for operators

a. Integration of operational and non-operational data

Operators are responsible for making decision about system operation and restoration. In the case of an event occurring on the system they are interested in knowing if the fault is permanent, where the fault location is, and whether relays and circuit breakers operated correctly (reclosing sequence). Since IED devices can measure more data than RTUs the additional data can be used to verify and supplement SCADA reading. Often right conclusion may only be made using IED data. As an example, if consequences of relay operations are to be assessed, the pickup and operation information of protection elements usually presented in the form of logic operands that can be extracted from relays will be more informative than SCADA data collected by RTUs that only captures relay trip signals and circuit breaker status signals. In this case, combining data from digital relays with SCADA data can be utilized to improve the accuracy of analysis applications that will in turn provide better results for the operator.

Per-device reports may be used as additional source of information for Control Center applications. Most applications at the Control Center level require real time data and are based primarily on the use of SCADA systems that are fed with data collected by Remote Terminal Units (RTUs) located in substations. There may be errors in the SCADA measurements because of some malfunction occurring in the CB contacts, transducers, SCADA communication equipment or RTUs. Also, the SCADA systems are not capable of tracking dynamic changes occurring in the intervals shorter than the SCADA scan time. Another performance issue with SCADA is its relatively slow scanning rate for measurements. The limited SCADA capabilities can be extended with the view obtained from the data captured by IEDs. However, it takes time to transfer raw IED data files to higher level or to upload/retrieve it to database. IED row files have size of several Mb and in the case of multiple disturbances taking place sequentially communication resources may not be able to transfer such a huge amount without time delay. Per-device analysis reports capture all information relevant to device and event. Also they are much smaller in size than raw IED data thus may be easily transferred. Those files are time stamped and may easily be upload/retrieved into databases and integrated with other data.

The IED and SCADA data may be matched together based on the file name stamp. The whole process is triggered by the fault inception time from the DFRA report. This time is used as a reference for the data matching with DPRA, CBMA information and SCADA data. In case that there is no SCADA data for this event information from reports and IED raw data that contain the same measurement as SCADA will be sent to the applications. In case of SCADA data availability, the system topology also may be verified using information from CBMA reports.

Due to substation IED data ”explosion” integration became complex and databases that store substation data drastically increase in size and to maintain and build them becomes an issue. Without standardization in data model, format and naming, application in attempt to communicate and access to the data has to have custom interface to other applications and data source. Also, adding new data source or applications requires developing new interfaces for old applications, which is difficult due to proprietary data formats and database designs. Several standards for data modeling, data format and naming have been proposed. Some of the existing standards are under revision and already have more than a few versions which make the platform for data integration complex.

b. System architecture

The proposed approach is to convert all substation IED data to standardizes CIM 61970 [11] data model. Since legacy SCADA systems have different data format it is necessary to build interfaces to existing databases. This allows integrating the information distributed among different databases or creating enterprise data warehouse where information from many legacy databases is copied after an appropriate translation to a central database. By standardizing database structure the system become open for integration of new applications that will process those data. The interface to the data is predefined and communication between applications is simplified. In achieving the integration goal it needs to be recognized that different IEDs or SCADA have different terminology for the same data values and it is necessary to translate all the values into the same terminology. Database must be maintained to keep up with changes in the power system. The methods have been developed for automatically updating data. Generally, at Control Center level only operational data from SCADA are accessible and non operational data generated by IEDs is not accessible to the operators. The CIM 61970 standard is defined to model only operational data and it is not easy to define how non operational data may be modeled. The data entities those standard models are in the Object Oriented Structure, which can be extended to the non operational quantities.

Fig. 5. displays a simplified example of the system architecture for integration of operational and non-operational data sing proposed standards. Data is collected from IEDs in COMTRADE file format. Than the data is processed at the substation level and populated into the database together with the automated analysis reports and recording system configuration information. Integrated IED data and analysis reports can be accessed and visually inspected using individual graphical user interfaces (GUIs) that display results from each of the automated analysis applications. The changes in the database containing integrated and processed IED data are monitored by Control Center Adapter that merges those data with SCADA information and translates SCADA and IED data into the CIM data format. The analysis and processing applications at control center level, in this case Optimal Fault Location and Intelligent Alarm Processing, use the translated data in CIM format for further processing.

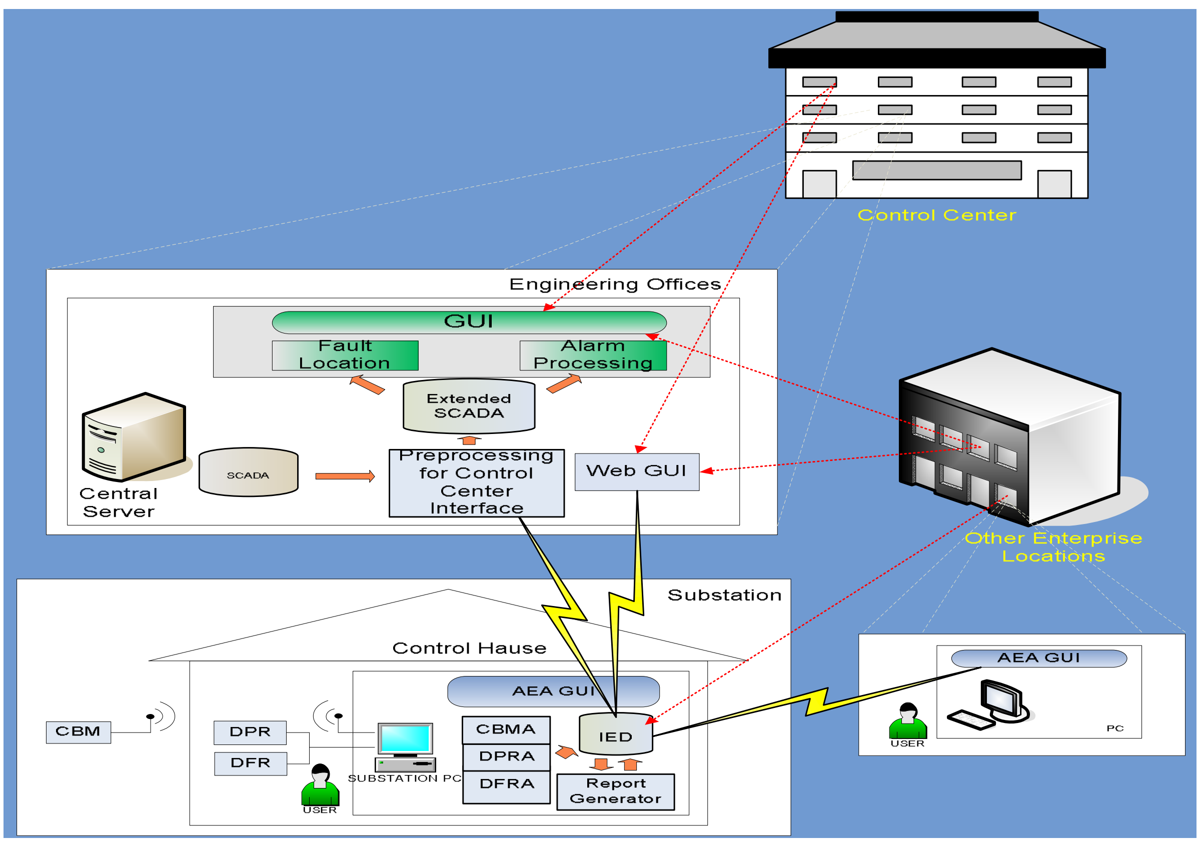


Figure 5. System Architecture

c. Graphical user interfaces

The following section presents an example of GUI developed for the Optimized Fault Location application [12]. This application uses data from SCADA, as well as data from substation IEDs to improve interfaces for various groups including system operators. Fig. 6 shows how different utility group interact today. Operators are monitoring system behavior and creating list of archived data when ever an even occurs. The list of events is typically kept in a spreadsheet that is updated by protection and maintenance group as they complete their part of the work related to event analysis and required repair respectively. Proposed solution for improved interface, called Visual-Interactive Distributed (VID) Spread Sheet uses SCADA and DFR data to automate the event recording, analysis and orders for repair as shown in , Fig 7.

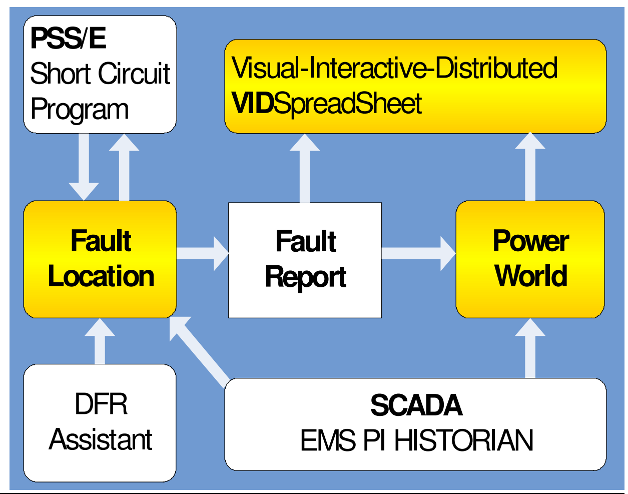


Figure 6. Data Flow

Figure 7. System Architecture

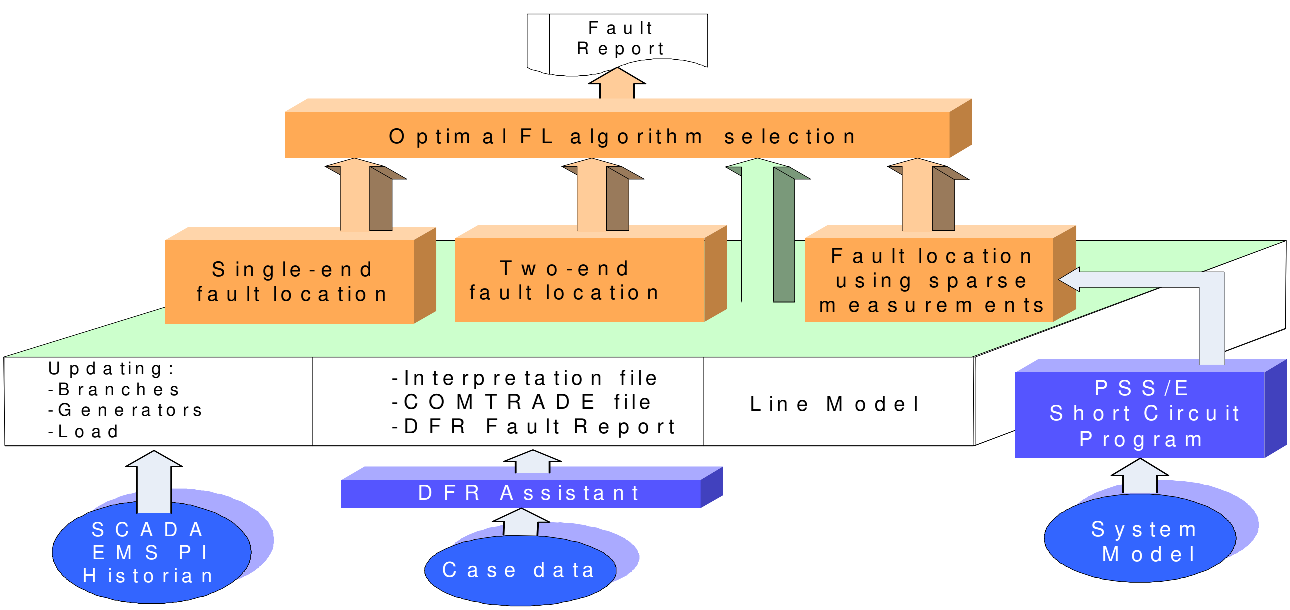


Figure 8. Fault Location Module

The core of the solution is an optimized fault location module shown in Fig. 8. DFR Assistant software is used as a system wide solution for collecting data from substation IEDs [13]. In addition, SCADA data from the PI historian is used to obtain system condition at the time of fault. The short circuit program is used to calculate fault values for the given network condition and estimated fault location. the fault location module selects the best location by moving running short circuit program for different location candidates and each time comparing the results of the short circuit program with the measured values from IEDs. An optimized solution is the one that provides best match between measured and simulated waveforms.

VID spreadsheet provides user critical information about fault event through visualization. This module uses information provided through fault report generated by the FL module. Fig. 9 summarizes graphical user interface views built in the VID Spreadsheet. Several commercial software packages are used in this module for different purposes. Power World [14] software is used to represent power system network and it is enhanced with custom designed software to accurately determine fault location is shown in Figures 10 and 11. The same results for fault location may be overlaid on the earth satellite pictures obtained from Google Earth [15] as shown Figure 12. This way, in case of outage it is easy not only to determine where the fault location may be in the electrical network but also to know what to expect from the physical terrain surrounding actual equipment around fault location. This information is important for the maintenance crews that are supposed to patrol the area, locate the fault, assess possible damage from the fault, and fix the problem. To give even better information about the equipment and area characteristics, a 3D model of the equipment and physical area may be developed as shown in Figures 13. It is possible to interact though these views by rotating them and zooming in and out. This model allows maintenance crews to view the area from different angles allowing better assessment of what may be involved in the repairs.

Besides the fault location view the GUI provides a view for the two types of equipment as shown in Fig 14 and 15: transmission towers and circuit breakers respectively. The tower is a complex structure that holds the transmission lines through insulators. If any fault occurs on particular segment of transmission line, it is likely that the fault occurs on the tower and insulators. The breaker plays an important role in fault clearing. Visualization of these parts could help maintenance crew to take better decisions for diagnostic and maintenance purposes. The time line shown in Fig. 16 demonstrates that the current process requires considerably more time to complete then what the proposed automated process requires.

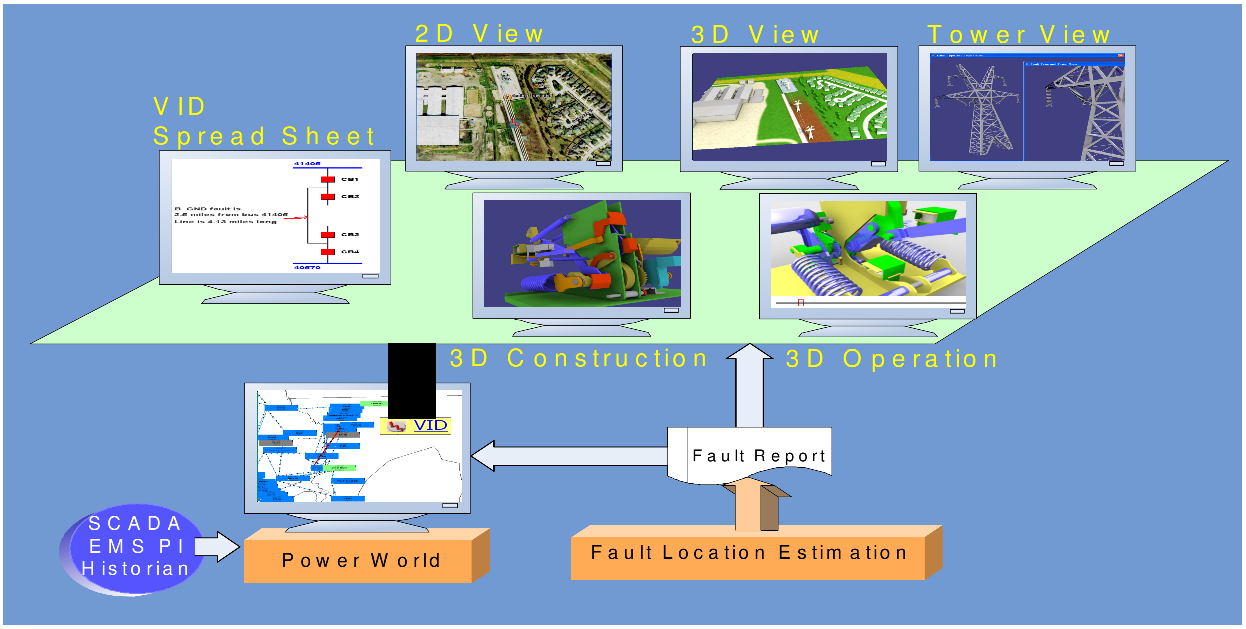
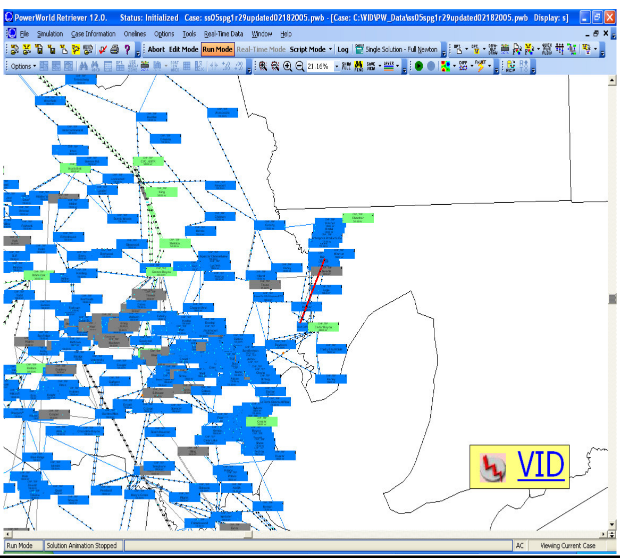


Figure 9. Visualization Module



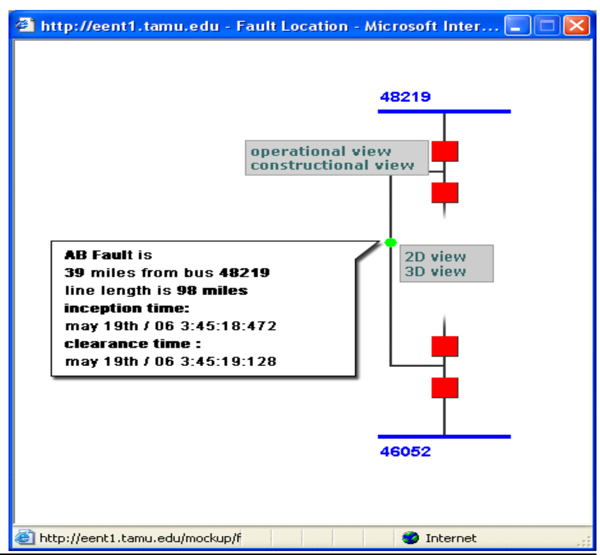


Figure 10. Fault indication in Power World

Figure 11. Summary View in VID Spreadsheet

Figure 12. 2D satellite image

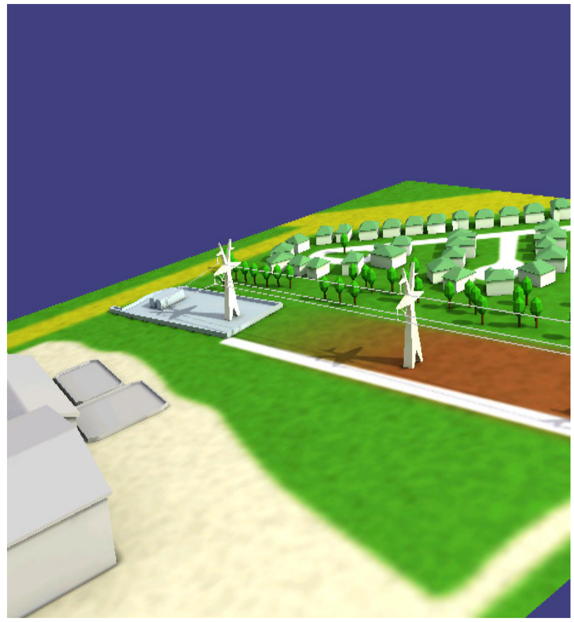


Figure 13. 3D model view

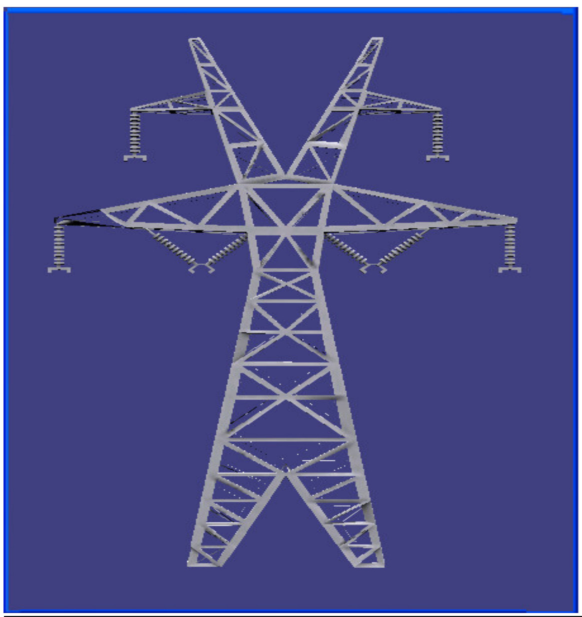


Figure 14. Tower View

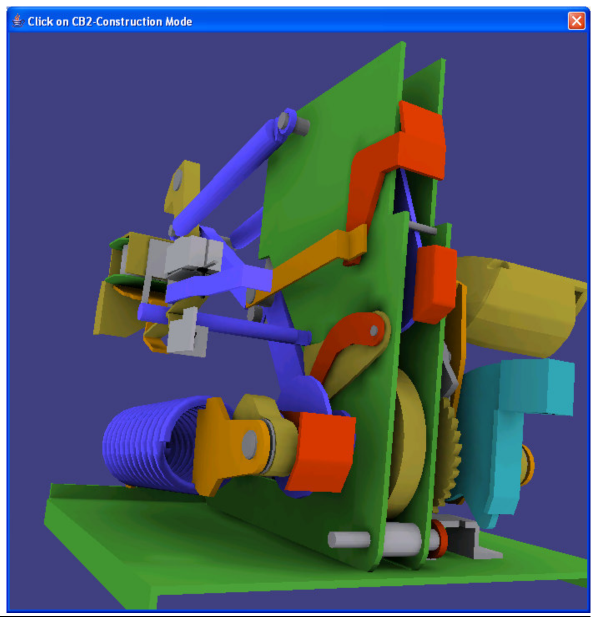


Figure 15. CB Construction View

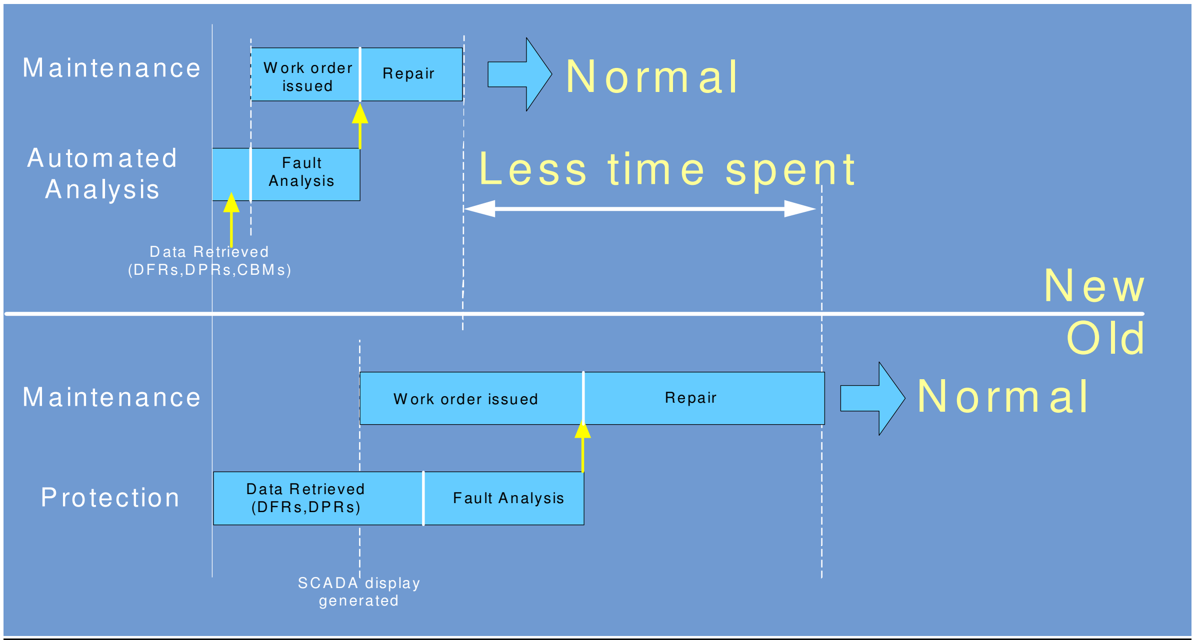


Figure 16. Improved Timeline

Conclusion

Major benefits that proposed solution brings are:

- Easy integration of raw IED data due to standardized file name format.
- Straight forward data extraction and processing due to open database format
- Efficient data handling by utility personnel responsible for analyzing the faults and device operations
- Enhanced SCADA capability and improved Control Center level applications utilizing data from variety of substation IEDs
- Standardized way of storing data for archiving purposes and development of future applications

Acknowledgments

The authors gratefully acknowledge the contribution of Mr. Don Sevcik from CenterPoint Energy, Mr. Scott Sternfeld, from FirstEnergy Ms. Edvina Uzunovic formerly from New York Power Authority (NYPA) in coordinating inputs from many staff at the respective companies, as well as Texas A&M research staff Goran Latisko and Deng Xianda and graduate students Xu Luo, Zarko Djekic, and Noah Badayos for performing various research activities over the years.

References

[1] IEEE PC37.232-2007, Recommended Practice for Naming Time Sequence Data Files, 2007.
[2] IEEE Standard C37.111-1991, Common Format for Transient Data Exchange (COMTRADE) for Power Systems, IEEE,1991

[3] IEEE Standard C37.111-1999, Common Format for Transient Data Exchange (COMTRADE) for Power Systems, IEEE,1999
[4] IEC Std. 60255-24,"Common Format for Transient Data Exchange (COMTRADE) for power systems" First Edition 2001-05, International Electrotechnical Commission, 2001
[5] X. Luo, M. Kezunovic, "An Expert System for Diagnosis of Digital Relay Operation", 13th Conference on Intelligent Systems Application to Power Systems, Washington DC, USA, November 2005
[6] Schweitzer Engineering Laboratories, Inc., Pullman, WA, *Instruction Manual for SEL421 High-Speed Line Protection, Automation, and Control System*, 2004.
[7] General Electric Company, *Instruction Manual for D60 Line Distance Relay*, 2004.
[8] T. Popovic, M. Kezunovic, "Data Warehouse and Analysis Agents", Fault and Disturbance Conference, Atlanta, Georgia, May 2008.
[9] M. Kezunovic, Z. Djekic, "CBM Hardware Implementation - Final Report for FY 06", CERTS, DOE, October 2006
[10] M. Kezunovic, Z. Ren, G. Latisko, D.R. Sevcik, J. Lucey, W. Cook, E. Koch, "Automated Monitoring and Analysis of Circuit Breaker Operation," IEEE Transactions on Power Delivery, Vol. 20, No. 3, pp 1910-1918, July 2005.
[11] IEC Std. 61970-301, "Energy Management Systems Application Program Interface-Part 301: Common Information model (CIM) base", International Electrotechnical Commission, 2003.
[12] M. Kezunovic, E. Akleman, M. Knezev, O. Gonen, S. Natti, "Optimized Fault Location," *IREP Symposium 2007*, Charleston, South Carolina, Aug 2007.
[13] Test Laboratories International, Inc.: "DFR Assistant -Software for Automated Analysis and Archival of DFR records with Integrated Fault Location Calculation" [Online]. Available: http://www.tliinc.com
[14] Power World Corporation; [Online]. Available: < http://powerworld.com/downloads/demosoftware.asp>.
[15] Google Earth. [Online]. Available: <http://earth.google.com/>.