

Integration and Use of Substation Data

M. Kezunovic, *Fellow, IEEE*, D.R. Sevcik, *Member, IEEE*, R. Lunsford,
and T. Popovic, *Senior Member, IEEE*

Abstract — The paper discusses issues related to integration of substation IED data. The approach to discussion is based on the purpose of integrating substation data and how the integrated data can be used. Main reasons for substation data integration can be categorized into following groups: 1) data archival and exchange purposes, 2) easy access and viewing, and 3) data analysis.

The paper identifies issues important for proper substation data integration: 1) handling system configuration information, 2) automated and straightforward communication, and 3) data file formats. Modern substations may be equipped with different types of intelligent electronic devices (IEDs) such as digital protective relays (DPRs), digital fault recorders (DFRs), phasor measurement units (PMUs), power quality monitors (PQMs), digital revenue meters (DRMs), etc. It is an engineering challenge to design and implement automated data integration and analysis systems today since most of the above mentioned issues are addressed through use of vendor-specific solutions, which are quite different from one vendor to another.

The paper gives an overview of the options how existing vendor solutions may be combined with standards and recommendations to enable feasible means for easy and proper use of substation data. The discussion is followed by an example of an existing substation data integration system.

Index Terms — substation measurements, substation automation, data interchange, power system faults, power system monitoring.

I. INTRODUCTION

Integrating data where a substation contains several IEDs of different type may be a challenge [1,2]. A single occurrence of an event can initiate recordings of signals from the same events captured by different IEDs. One approach to the IED data integration is to solve the main issues such as how to handle use of different types of IEDs, different vendors, different software support tools, different communication channels, different data formats, different methods for time synchronization, etc. Even in the cases when dealing with only the data coming from a single IED type but using different IED brands or IEDs from different vendors can pose a problem. This approach usually brings out the issues related to communication protocols and data file formats. To some extent handling of the configuration information is also

identified as an issue, but primarily when handling IED specific functions.

Another approach to integration of substation data is to consider how the integrated data will be used. Main difference in this approach is not only to consider the issues related to the substation equipment, but also to anticipate how the information gathered from substations would be utilized. This approach is broader and helps to better understand the requirements such as what substation data needs to be available to support as many different applications as possible. Different uses of the integrated data generally fall into the following categories:

- Data archival and exchange purposes,
- Easy access and viewing (usually for manual analysis),
- Different data analysis functions (automated).

The paper identifies and specifies the requirements of broader framework for substation data integration. The discussion in the paper is supported by an implementation example that presents a solution for integration of IED data into a single database. The data is collected from the devices utilizing IED vendor specific protocols and software. Next, the downloaded data files are automatically processed before being stored into the database. The main processing functions are: a) unifying the data formats (IEEE Std C37.111-1999 [3]) and b) applying standardized file naming convention (modified IEEE recommendation PC37.232/D8.0 [4]).

The discussion is followed by defining a framework for substation data integration. Two examples that utilize the defined framework are presented.

II. BACKGROUND

Power utilities can employ different IEDs to monitor and control the state of the electric power system and its elements. Typically, IED data records are kept in IED's memory in the field and downloaded manually when needed. The data may also be automatically uploaded to a dedicated computer using vendor specific software. The viewing, analysis and classification of IED records are typically performed manually. When attempting to integrate substation data the majority of the problems can be grouped as follows:

- Handling system configuration information,
- Enabling data communication,
- Introducing standard data file formats.

Handling system configuration information is critical when trying to automatically collect and interpret data collected from different substation IEDs. One needs to know how each

M. Kezunovic is with Texas A&M University, College Station, TX 77843-3128 USA (e-mail: kezunov@ece.tamu.edu).

D. Sevcik is with CenterPoint Energy, PO Box 1700, Houston, TX 77251 USA (e-mail: don.sevcik@centerpointenergy).

R. Lunsford is with CenterPoint Energy, PO Box 1700, Houston, TX 77251 USA (e-mail: bob.lunsford@centerpointenergy.com).

T. Popovic is with Test Laboratories International, Inc., 1701 SW Parkway, Suite 99, College Station, TX 77840 USA (e-mail: tomo@tli-inc.com).

IED is configured to be able to interpret the following: what are the channel assignments, what parameters are used (such as scaling or sampling rates), what communication channels are used and how are they configured, etc. While also very relevant, the configuration of the actual power system and its components being monitored is usually not a part of the consideration or at least it is not considered in full. There is still a lack of a fully standardized approach to defining universal conventions for describing power system objects monitored by IEDs and making these descriptions part of the event data files. One possible approach to solving this problem is to use the Substation Control Language (SCL) defined in IEC 61850 [5], but such approach still does not provide full compatibility with the SCADA database model as described in IEC61970 [6].

Enabling Data Communication - having a standardized communication protocol [5] facilitates easier integration of IEDs into systems and enables interchangeability of IEDs. This effort partially solves the problem of handling the system configuration data, but mainly for the communication and IED interchangeability purposes. The problem of inconsistent and/or incomplete data formats should be transparent to the user when it comes to the actual use of the information. Currently, a common approach to communication is to use software provided by vendors that needs to be configured to automatically collect IED data files and make them accessible through corporate network. Each IED vendor typically provides software support such as DFR master station software or digital relay file viewing programs. All the configuration and communication typically go through these vendor specific software packages.

Introducing Standard Data File Formats - A big step towards standardization of data formats was the introduction of COMTRADE [7]. IED vendors are accepting the use of COMTRADE thus opening a door for easier data integration. Most of the vendors are still keeping their own native IED file formats, developing new ones and just providing additional utility programs or commands for exporting data in COMTRADE. This export-to-COMTRADE feature, in most cases, is not configurable for automated operation because COMTRADE format specification allows some freedom on how to provide information inside the files. Different software packages supporting COMTRADE file format may not be able to exchange data among themselves due to the lack of standardized descriptions of the files and signals inside. In addition to the original COMTRADE standard specification [6], there are the latest IEEE revision [3] and IEC version [8]. Having three versions currently being used increases a possibility not to be able to exchange IED data among different types of software packages due to inconsistencies between different versions. One step further was the introduction of the standardized IEEE file naming convention for the time sequence data [4]. The proposed convention defines coded schema for naming the data files captured at different times. Such file names can enable easier handling of large volume of files as well as unique file identification since

the file name contains unique information about the event: date, time, station, company, duration, location etc. Benefits of using this standardized file naming schema should encourage IED and related software vendors to provide the standard support, which is not a common feature today.

As seen, several issues need to be resolved to implement automated substation data integration. Communications and handling of system configuration required for proper data integration is expected to be covered by IEC 61850 [5] and can be handled using vendor specific software packages requiring additional adjustment effort depending on the IED setup. The main problem is still in the data formats, even the COMTRADE format itself, which sometimes limits the usability of integrated data. It is important to note that the data format issues have been recognized and the changes in the standards are being discussed and expected [9].

III. USE OF SUBSTATION DATA AND NEED FOR INTEGRATION

Another approach to substation data integration is to look at it through the prism of a user of the data. First, it is interesting to look at the common problems users experience with their IED systems. Second, one needs to understand the actual need for monitoring and recording information in substations and how can the integrated data coming from substations can be used by end users.

A. Common problems with existing IED systems

It is important to note that a lot of power utilities are in some transitional states and are currently introducing new IEDs to their substations. This section identifies common problems users experience with their existing substation IED systems. Some of the problems related to user experiences with existing IED systems are:

1. IED data records cannot be efficiently analyzed manually due to an overwhelming number of records captured in a moderately sized system.
2. Use of different vendor specific programs increases personnel training costs due to distinctively different features as well as the look and feel of different packages.
3. Slow response (for example, manual analysis of IED data takes time) is an impediment if several records supplied by different IEDs for the same event must be uploaded and analyzed. Slow response can also be a result of the communication issues or the fact that different types of IEDs are used, or that the used devices are coming from different vendors.
4. Lack of ability to integrate data coming from different IED types and models is evident when one attempts to integrate the different IED systems and services. Sometimes different IED subsystems require different communication channels and interfaces, different protocols, and almost on a regular bases use different data formats.
5. Highly-skilled people devote a lot of time to routine tasks because most of the records may just confirm the proper operation of the equipment being monitored.

6. Non-selectivity (for example, IED data records are not event prioritized) is an issue if the operator must sort out the records for the analysis purposes. This generally depends on the type of the IED and its functions, but when dealing with multiple devices it is a common problem.
7. Inefficient data archival and retrieval due to rather primitive means of time-stamping, storing and retrieving the captured data. Some of the devices are being installed for their main functions and these problems occur when one wants to use them as recording devices. For example, a process of replacing electromechanical relays with digital relays does not always include considerations regarding the possible use of digital relays as recording devices. It is common that providing communication resources to connect to these substations as well as to interconnect the IEDs inside the substations comes after the relays have been installed.

B. Multiple Uses of Substation Data

In answering the question how the substation data can be used one can categorize the possible uses into following main groups:

- Data archival and exchange purposes,
- Easy access and viewing,
- Different data analysis functions.

Data Archival and Exchange Purposes – a common goal for almost all end users is to provide a safe and secure data archival system and to be able to exchange the data with other users within the same group or company or with others. Having the substation data coming from a variety of IED types and vendors it is very important to utilize unified data formats and system configuration descriptions. The data archival system should provide for easy access, search through, and retrieval of the data whenever needed. The data formats and configuration descriptions should provide sufficient information related to each event recognized and recorded by the network of available IEDs in the system.

Easy Access and Viewing is commonly lacking in the existing IED systems and is a cause of lots of the problems discussed above. End users want to be able to access and view substation data. In some cases there is a need even to combine the data coming from different IEDs that pertain to same event or group of events. Typically, users want to be able to quickly locate and display event data in order to visually inspect and manually analyze the event information. Additional tools that support this process can be used here. Examples are: reading RMS values, Fourier analysis and viewing of harmonics, scaling, zooming, etc. An important issue for an end user here is to be able to use same viewing tools for all event data regardless of the source (IED type or vendor or configuration).

Different Data Analysis Functions – having substation IED data retrieved and integrated opens endless possibilities for utilization of all kinds of automated data analysis functions. Some examples are determining the fault type, verifying system protection operation, calculating fault location (single-

or two-end), performing redundancy checks, etc. Most of these functions can be implemented automatically as the data become available. Automated analysis can provide user with a variety of additional information based on the partially or fully processed IED data hence significantly affecting the decision making process and system restoration. The main challenge is proper handling of system configuration information and data formats. Having event data available without being able to map the data to the actual power system components being monitored and without knowing the system component parameters makes the automated analysis impossible.

IV. SUBSTATION DATA INTEGRATION EXAMPLE

Moving toward integrated solutions in this example is done by providing a substation data integration framework based on the following requirements:

1. Providing communication and automated data retrieval. The solution should use either vendor's software or custom built communication modules to provide for automated retrieving of newly recorded event files.
2. Unifying event data file format by converting to widely accepted standard format. All IED event data files should be automatically converted into same file format (for example IEEE 1999 COMTRADE [3]) and all the files should utilize file naming convention.
3. Making sure that content of the files is correct and all the fields are utilized properly (for example: substation information, time stamps, channel assignment, phase information, scaling, etc.).
4. Making all the power system components descriptions available and easily mapped to the event data collected from substation IEDs.

A. Substation Data Integration Framework

Several IEDs may be used to collect data measurements in today's substations: digital fault recorders (DFRs), digital protective relays (DPRs), PQ meters, circuit breaker monitors (CBMs), remote terminal units (RTUs), sequence of event recorders (SERs), programmable logic controllers (PLCs), etc. Originally, most of these devices were designed and made with a very specific, often limited, data collection function in mind. With the technological progress, the IEDs evolved into more and more sophisticated devices with new capabilities. The crucial improvements include: more memory, better communication interfaces, and higher quality of data recording. These improvements enable adding new functionality, primarily related to automated processing and analysis of IED-recorded data.

Substation data integration concept is depicted in Figure 1. Each IED type requires communication and data format conversion modules in order to import data to the IED data file repository. Automated collection of the IED data can be done utilizing IED vendor legacy software packages or by direct access to IED's communication resources. The first approach is less involved and it is recommended since the standard

communication protocols have not been widely accepted and/or implemented yet. All the IED-recorded data is meant to be converted to an existing standard data format such as COMTRADE [3,8].

The file repository in the database should utilize standardized file naming convention [4]. Some modifications to the file naming recommendation include: 4-digit year information, use of additional time stamp that corresponds to time when the event files are downloaded, time stamp featuring microseconds resolution (in order to achieve equal length of the file names). It is most likely that the actual file repository integration will require combination of vendor-based and custom developed software modules in order to make sure that the records comply with the selected data format and naming standards.

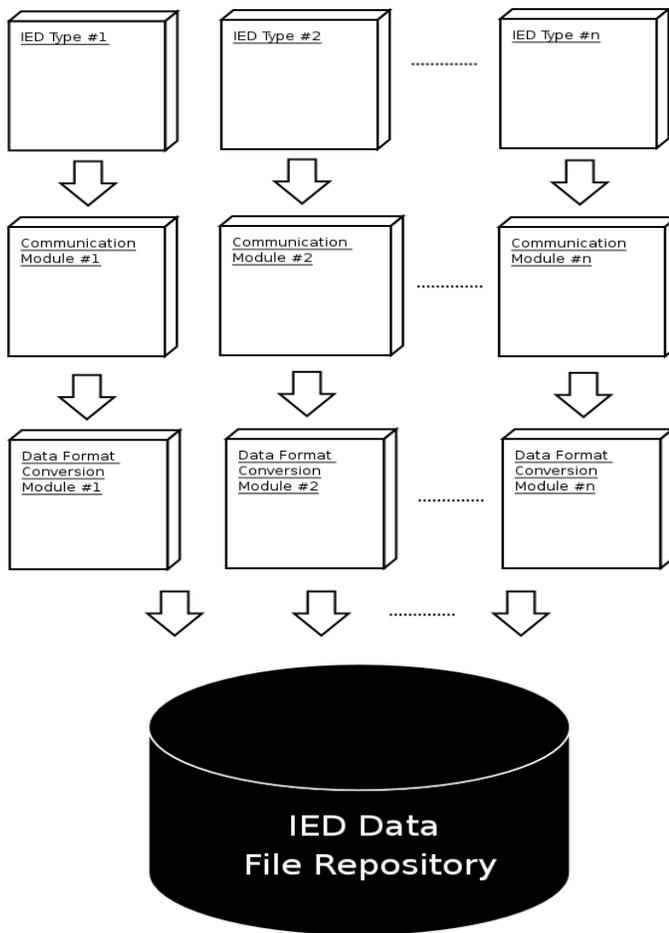


Fig. 1. Substation IED data integration concept

Besides the IED data, the database has to contain system configuration data, which describe: 1) system components and their relationship (i.e. lines, buses, circuit breakers, switches, relays, CTs, VTs, etc.); 2) IED channel assignments and mapping/calibration to specific system components (line/bus voltages, line currents, status signals). The system configuration data enables automated IED data conversion into

standard formats and integration into the database thus making the data available for new functions (software applications).

The result of substation data integration is a database with file repository (Fig. 2.). The file repository should contain:

- IED data in a standard format such as COMTRADE file format (IEEE Std. C37.111-1999) with file names conforming to the file naming convention guidelines.
- Configuration descriptions in a standard format such as Substation Configuration Language (SCL) [5]. The configuration should describe power system components (lines, buses, relays, breakers, transformers, etc.) and how are the components being monitored (IED channel assignments, scaling, etc.).
- Additionally, as the data is aimed for automated analysis, the repository should also contain analysis reports. In general, reports can be produced by different analysis applications that utilize integrated data.

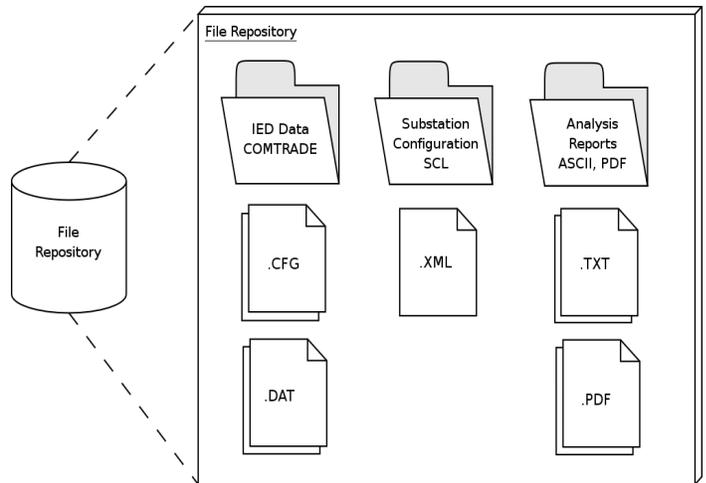


Fig. 2. File repository example

B. Upgrade of Existing DFR Data Analysis System

Existing DFR data integration and analysis system in this example has been upgraded to conform to the requirements for substation data repository and database [10]. Two different types of DFRs have been used in more than 30 substations. DFR data are downloaded utilizing vendor's software with auto-poll option. Two master station computers are used to alternatively cycle through a call list and call each DFR to check if there are new event files. New event files are downloaded automatically. In this case, the communication issue is handled utilizing master station software provided with DFRs (Figure 3).

A custom made file copying module transfers a copy of each new DFR event file to the incoming folder dedicated for automated data integration. All DFR files are being automatically processed and imported into the new file repository and database. All event files in the database are in IEEE 1999 COMTRADE file format and are properly named. The processing module makes sure that the content of the files

is correctly populated with all the data of interest for later analysis. File naming provides that all the event files are sorted by event date and time and each file uniquely identifies event's origin and time of occurrence. The file repository can be browsed using standard file managers.

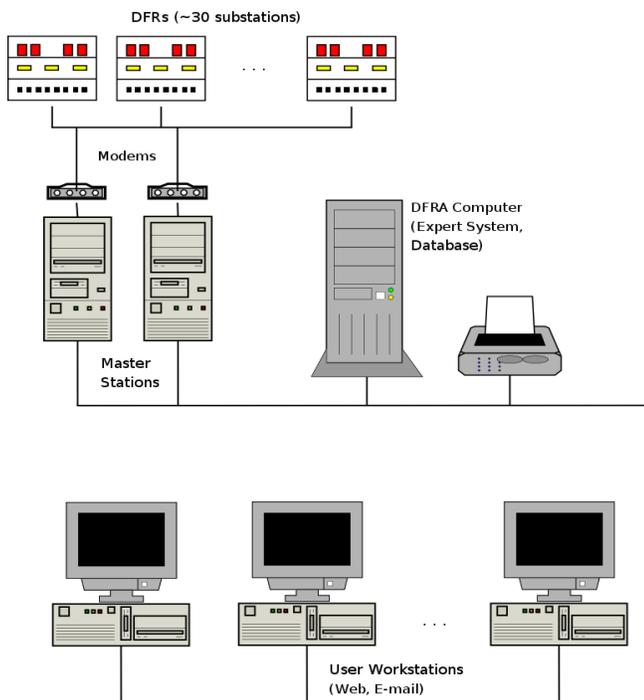


Fig. 3. DFR communication configuration

Data integration and analysis software application implemented in this example to handle integrated substation data is depicted in Figure 4. Thin clients utilize web browsers and corporate network to access and display substation data and file repositories. Web-based server application is developed to allow access and browsing through integrated substation data. The web application and user interface are built with generic assumption that data source can be any type of substation IED that provides event recording functionality (in this case DFR).

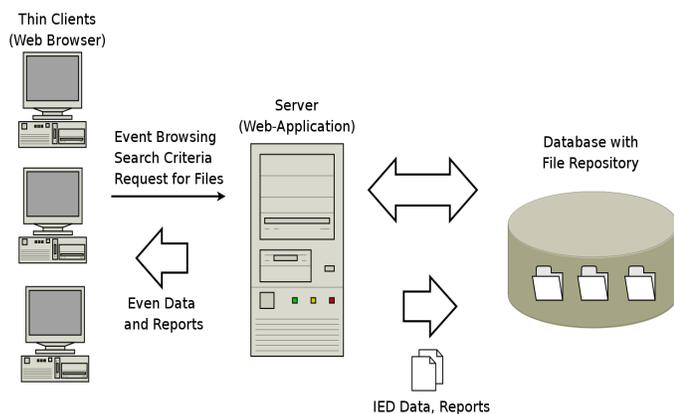


Fig. 4. Software application that handles integrated data

Once available in the file repository, which is now part of the centralized database, the DFR data is made available for automated analysis [10,11]. Analysis function utilizes event data and configuration data to create analysis reports. Additional features provide for automated notifications using email and pager messaging as well as a web-based event browsing and viewing (Figure 5). The system is open for adding new analysis functions. The introduced concept of substation data integration allows easy expansion of the analysis functionality.

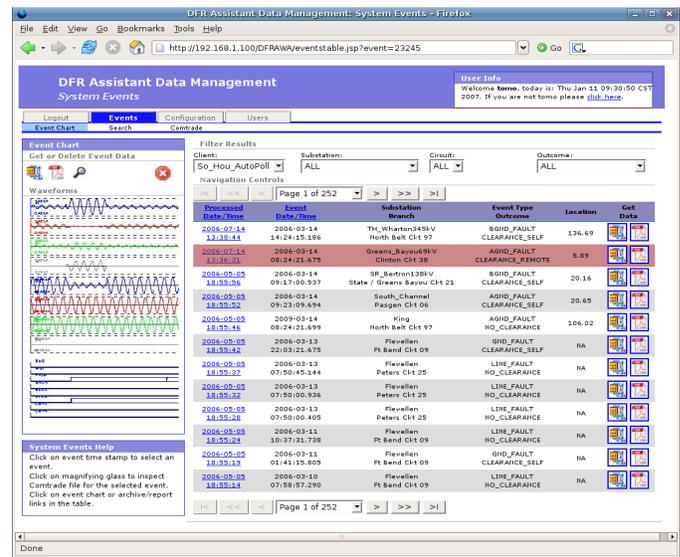


Fig. 5. Accessing substation data using web-based application

This upgraded system has been installed and used in the field for about one year. All new DFR data are automatically downloaded, stored into the centralized database, analyzed, and prioritized. All the automated analysis functions are upgraded to work on the substation data from the file repository as defined in the framework.

C. Integrating Data from a Variety of Substation IEDs

This second example assumes integration of substation data coming from a variety of substation IEDs. The concept is verified in a lab setup. The IED configuration is depicted in Figure 6. The figure represents one end of a transmission line coming from a substation. Power system components involved are a bus, a transmission line, CTs and CCVTs to obtain analog measurements on the line, and a circuit breaker (CB). Following IEDs are used in this scenario:

- DFR, which monitors line voltages and currents as well as contact status signals such as relay trip, breaker auxiliary, and carrier send/receive;
- DPR, which monitors line voltages and currents, contact status signals related to protective relaying function (trip, carrier send/receive), as well as the external/internal status signals of the protective relay (starting elements, targets).

- CBM, which monitors line currents going through the circuit breaker, 52a & b contacts, X & Y coils, DC power supply at the breaker, trip command, trip coil current, etc. [12]

Generally, a DFR would monitor most of these signals for all the lines (or at least the most important ones) and give a comprehensive overview of the signal changes for the whole substation. Each protective relay monitors only signals related to the transmission line where they are installed. A relay does not “see” the signals related to other system components, but the relay recording can provide much more details about its own operation (time-stamped log of all the status changes of internal/external elements, oscillography as seen by the internal logic of the relay). A CBM in this configuration would monitor all the signals related to a selected circuit breaker. Similarly to the DPR monitoring providing additional details about relay operation, CBM would provide further details about each operation of monitored circuit breaker. Each of the devices might operate (and typically would) on different sampling rate and have different recoding length. That is why it is critical to have all the IEDs synchronized to an external time reference (through a GPS for example) to enable waveform alignment and comparison. In this particular example, it is assumed that the IEDs are connected to a substation PC, which allows for the synchronization and time stamping of all the files automatically transferred from the IEDs connected to the PC. In addition, all substation PCs can be connected to a main server located in central offices.

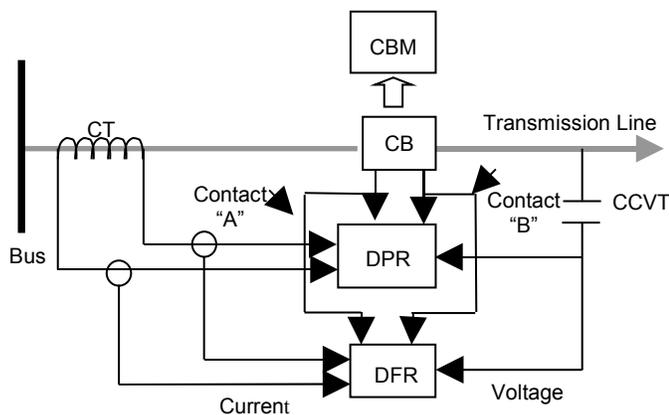


Fig. 6. Example IED configuration on a single line

The lab testing of the concept is done using digital simulator which is typically used for evaluation of relay operations [13]. For this purpose the simulator was used to create inputs for different types of substation IEDs simultaneously.

All the test waveforms are created using simulation of different fault events on the same transmission line. All four IEDs were configured to monitor same transmission line (DFR, two DPRs, and CBM). Two digital distance relays from different vendors were configured as primary and backup

relay. Each simulated occurrence of a fault would result in all four tested IEDs to capture an event recording.

The presented approach to substation data integration enables multiple uses of the data. Since all the event data is stored using same file format and file naming convention it is very easy to locate event files of interest, search through the database, and use the same viewing and analysis tools.

Communication with the DFR is done using master station software. Communication with the DPRs and CBM was done using custom made communication modules implemented for the test purpose. All the event files were converted and properly named. Resulting database contains a file repository with all the events ordered and stored following the proposed substation data integration framework.

The integrated solution is fully open and allows for expansion with different viewing, processing, and analysis functions. The first example demonstrated use of upgraded DFR data analysis function that performs analysis on the DFR data from an integrated database file repository and stores analysis reports back to the database. Additional analysis functions can be added. Examples are: automated analysis of CBM data [12], automated analysis of digital relay data [14], advanced fault location calculation algorithms [15,16], and advanced monitoring applications [17].

V. CONCLUSIONS

The paper discusses integration and use of substation IED data. First approach is based on the fact that the utilities are using different types of IEDs often built by different vendors. This approach recognizes the challenges and issues that arise when attempting to integrate the data retrieved from a variety of this variety of IEDs. This approach identifies the following main issues:

- Handling system configuration information,
- Communication,
- Data file formats.

Second approach discusses substation data integration from user's point of view. Possible uses of the substation data are considered in order to define the requirement for the integration. Multiple uses of substation data are grouped into following categories:

- Data Archival and Exchange Purposes,
- Easy Access and Viewing with tools for manual analysis,
- Automated data analysis functions

The discussion in the paper recognizes that the problems related to the main issues are being addressed through the existing and developing standards and software tools. However, there is a lack of the momentum to resolve the issues related to the event data file formats, especially when the possible uses of the integrated data are being considered.

The paper introduces a framework for integration of substation data. Two example solutions utilizing the described framework are presented. The first example is an upgrade of an existing system for automated DFR data integration and

analysis. The second example is a demo setup where a variety of different types of IEDs have been used and tested simultaneously. The second example was evaluated in a lab using digital simulator.

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VII. BIOGRAPHIES



Mladen Kezunovic (S'77, M'80, SM'85, F'99) received his Dipl. Ing. Degree from the University of Sarajevo, the MS and PhD degrees from the University of Kansas, all in electrical engineering, in 1974, 1977 and 1980, respectively.

He has been with Texas A&M University since 1987 where he is the Eugene E. Webb Professor and Site Director of Power Engineering Research Center (PSerc), an NSF I/UCRC.. His main research interests are digital simulators and simulation methods for equipment evaluation and testing as well as application of intelligent methods to control, protection and power system monitoring. Dr. Kezunovic is a registered professional engineer in Texas and a Fellow of the IEEE.



Don Sevcik (M'77) is a Senior Consulting Engineer in the Substation Projects Division of the Substation Operations Department at CenterPoint Energy in Houston, Texas. This department is responsible for engineering, construction, operations and maintenance of the transmission and distribution substation facilities of CenterPoint Energy. Don Sevcik has been employed for thirty-one years at CenterPoint Energy. His previous assignments involved transmission & generator protective relay application, transmission system equipment application, transmission system studies and power plant auxiliary equipment application. Don Sevcik received a B.S. degree in Electrical Engineering from Texas A&M University, is a registered Professional Engineer in Texas and a Member of the IEEE.



Robert Lunsford received his BS degree in Electrical Engineering in 1978 from Texas A&M University. Mr. Lunsford is a registered Professional Engineer in the state of Texas and currently working for CenterPoint Energy Substation Projects. He has been responsible for the administration of the transmission DFR system and fault analysis at CenterPoint Energy for the last 20 years.



Tomo Popovic (M'99, S'06) received his BS degree in electrical engineering in 1994 from University of Novi Sad, Serbia and his MS degree from Texas A&M University, USA.

He has been with Test Laboratories International Inc. since 1998 where he is a development engineer. His prior positions were with NIS-GAS, part of Petroleum Industry of Serbia, and University of Novi Sad, both in Novi Sad, Serbia. His main professional interest is developing and implementing software and hardware solutions for industrial applications, especially in the field of electric power system engineering: analysis of fault records, transient testing of protective relays and digital simulators. Mr. Popovic is Senior Member of the IEEE.