Integration of Substation Data

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***Abstract* — The paper introduces a concept for integration of substation IED data, primarily coming from digital protective relays (DPRs) and digital fault recorders (DFRs) . Modern substations are equipped with different types of IEDs. DFRs are traditionally used to capture data from various events and disturbances in the power system that may need to be analyzed. Most of the modern IEDs such as digital relays, power quality meters, and sequence of event recorders can offer data recording function that is quite similar to that of DFRs. In some recent substation designs there are cases where DFR function is replaced by an equivalent function provided by DPRs. There are also cases when both DFRs and DPRs are used and configured to record the same events. In this case records from DPRs are used as a redundant source for event analysis.**

The paper addresses main requirements for integration of substation data: communication and automated IED data retrieval, unifying event data file formats, verification of event data content, and proper handling of the system configuration parameters.

Examples of substation data integration using the proposed concept are discussed through expansion of an existing DFR data integration and analysis system and through introduction of data coming from different substation IEDs. Digital simulator was used to evaluate the concept in the example with multiple IED types.

***Index Terms*— protective relaying, 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. The main data integration issues are: use of different type of IEDs, different vendors, different software support tools, different communication channels, different data formats, different methods for time synchronization, etc. If the application is handling only the data coming from a single IED type but using different IED brands or IEDs from different vendors, this still can pose a problem. This paper focuses on how to integrate data from recordings made by DPRs and DFRs. The paper identifies and specifies the requirements and broader framework for integration of substation IED data.

The discussion in the paper is supported by an implementation example that presents solution for integration of DPR and DFR 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 adopted file naming convention (modified IEEE recommendation PC37.232/D8.0 [4]). Special attention is given to the proper use of data retrieval methods, file naming conventions, data format standards, and file copying functions to achieve fully automated setup. Issues related to proper time synchronization of the files captured by substation IEDs is addressed as well. Processed event files are stored into a file repository structure and are available for use by other functions. This is demonstrated using as examples automated event analysis functions and universal tools for data access and data view. Several tools for data management are added and can work with the same database. The file search, data view, and disturbance analysis functions are transparently used on the data coming from different IEDs (DPRs and DFRs in this example), as well as within the same IED type but from different device brands. The presented approach can easily be extended to applications that use other IEDs.

One of the main benefits of the presented solution is that the use of the integrated data is not limited to the existing applications. The integrated data is readily available for use not only with existing third-party software but also with future applications. This issue is tightly related to the data structures and formats used in the file repository and database, and their relationship. Examples of additional applications that could use the data are data viewers, testing tools, two-ended fault location calculations, system-wide protection analysis, transient simulations, etc. Further benefits of the presented solution are the speed of data retrieval and analysis, simplicity of the file repository structure that enables solution to be expanded in the future , and universal method for data access and data view, which all contribute to an improved efficiency.

II. Background

Utilities 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 are uploaded to a dedicated computer, using vendor specific software. The viewing, analysis and classification of IED records are typically performed manually. This section discusses main issues in existing IED data collection systems and necessary steps needed to move towards more integrated solutions.

A. Problems in existing IED data collection systems

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Main problems related to data integration in existing IED systems are summarized:

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.
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.
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.
7. Inefficient data archival and retrieval due to rather primitive means of time-stamping, storing and retrieving the captured data.

B. Moving toward integrated solutions

A big step towards integration of substation data was the introduction of standardized data formats such as COMTRADE [5]. 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. Unfortunately, this export-to-COMTRADE feature, in most cases, is not configurable for automated operation. Additional issue is that the COMTRADE format specification allows freedom, to some extent, on how to provide information inside the files. This leads to situations where different software packages supporting COMTRADE file format cannot 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 [5], there are the latest IEEE revision [3] and IEC version [6]. 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 should contain 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.

There is still a lack of a standardized approach to defining universal data formats for IEDs and a convention for providing information on parameters that describe system objects (signals and associated equipment) monitored by IEDs in substations.

Having a standardized communication protocols [7] facilitates easier integration of IEDs into systems and enables interchangeability of IEDs, but does not solve the problem of inconsistent and/or incomplete data formats. Future IED systems may utilize standards like the one recently proposed by IEC [8] enhanced with further necessary details, but unfortunately, at present, we may still be far from that possibility. Currently, a common approach 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.

Substation data integration solution should provide the framework based on the following requirements:

1. 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. All the power system components descriptions should be available and easily mapped to the event data collected from substation IEDs.

The solution described in this paper utilizes such a framework for data integration that allows easy access and data analysis.

III. Integrating Data

Several IEDs may be used to collect the 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 [9,10].

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 [3,6].

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 features microseconds resolution (in order to achieve equal length of the file names).

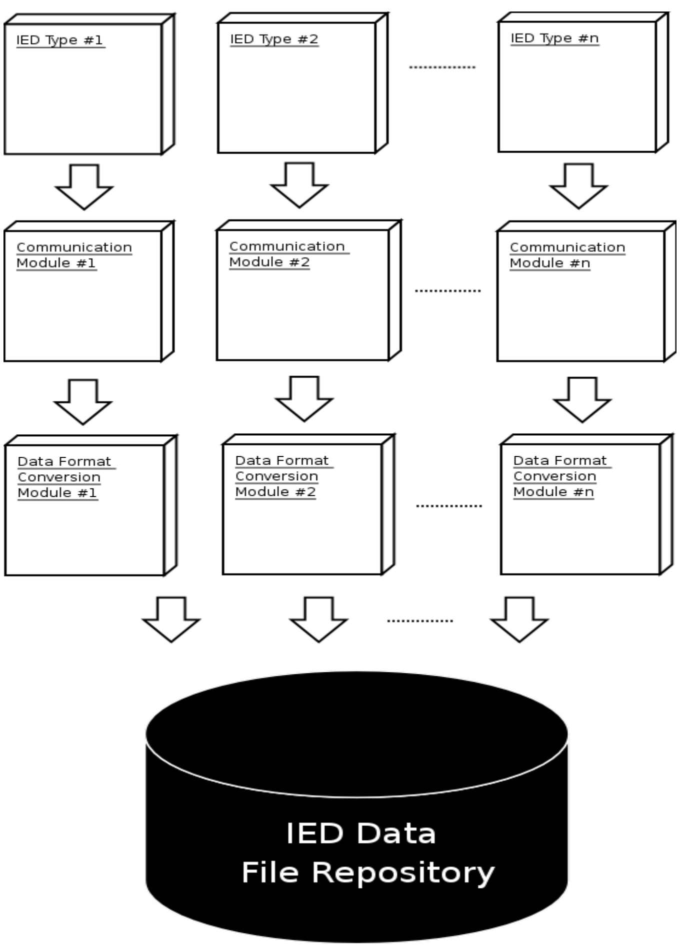

Fig. 1. Substation IED data integration concept

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.

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) [7]. 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.

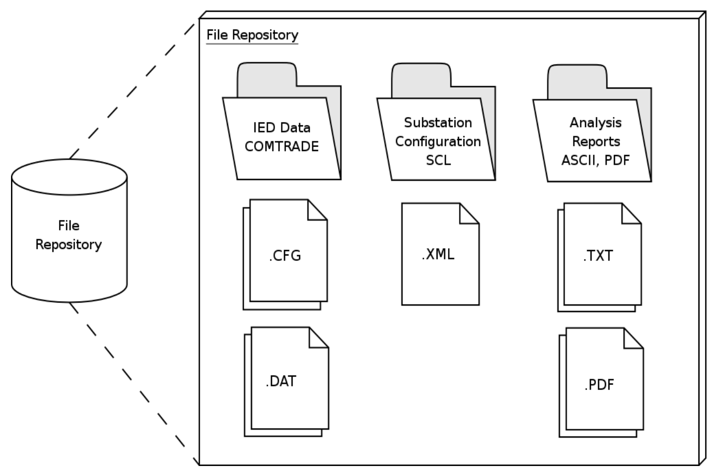

Fig. 2. File repository example

IV. Examples of Data Integration

The following examples demonstrate how the presented approach to substation integration data may be implemented.

A. Upgrading DFR Data Integration and Analysis

Existing DFR data integration and analysis system in this example has been upgraded to conform to the requirements for substation data repository and database [11].

DFR communication configuration is shown in Figure 3. 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.

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 the DFR files are being automatically processed and imported into the new file repository and database. All the 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 the 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.

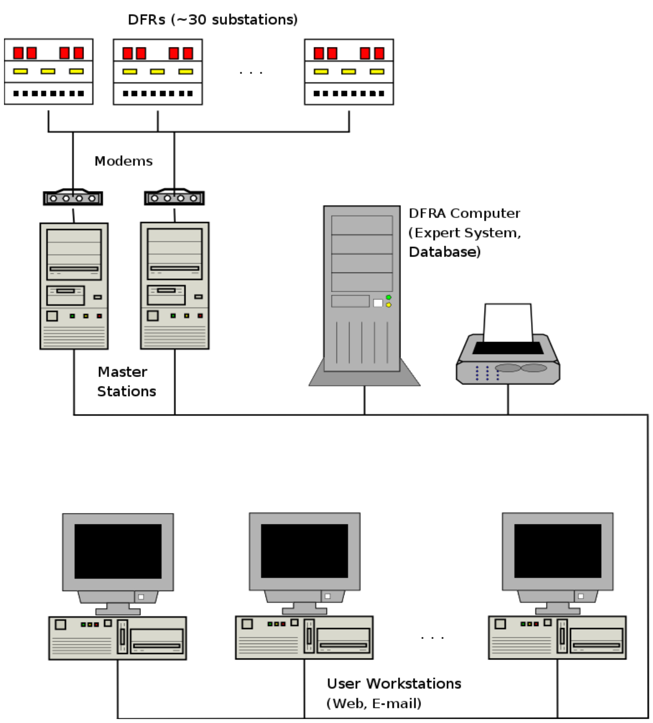

Fig. 3. DFR Communication Configuration

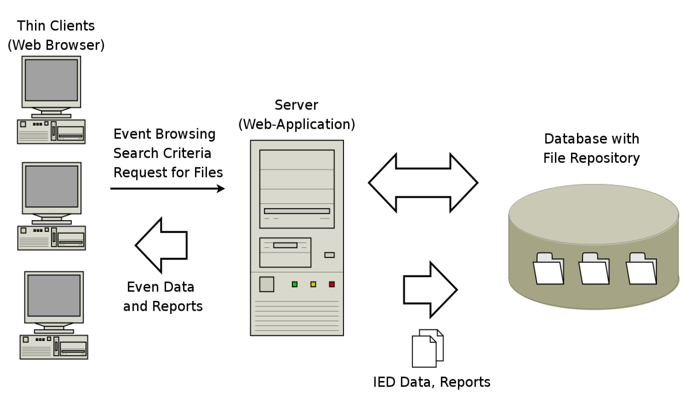

Fig. 4. Software application that handles integrated data

Custom 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 (Figure 5). 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).

Once available in the file repository, which is now part of the centralized database, the DFR data is made available for automated analysis [11,12]. Analysis function utilizes event data and configuration data to create analysis reports. Additional features provide for automated notifications using email and pager messaging. The system is open for adding new analysis functions. The introduced concept of substation data integration allows easy expansion of the analysis functionality.

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.

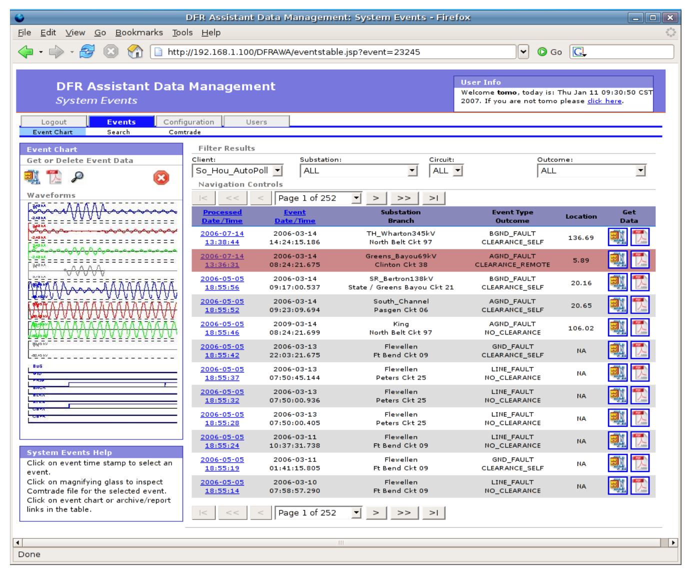

Fig. 5. Accessing substation data using web-based application

B. Integrating Data from Different Substation IEDs

Next step may be integration of event files coming from other types 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. [13]

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.

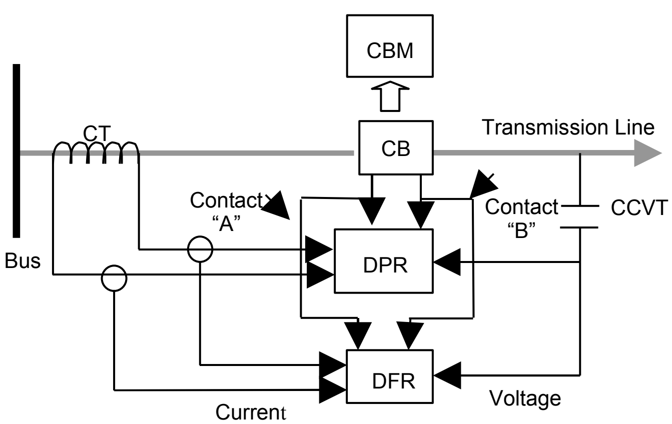

Fig. 6. Example IED configuration on a single line

The lab testing of the concept is done using digital simulator which is typically used for evaluation of relay operations [14]. For this purpose the simulator was used to create inputs for different types of substation IEDs simultaneously (Figure 7.).

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.

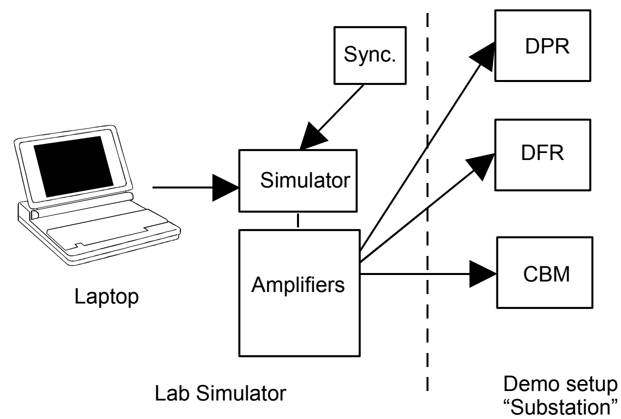

Fig. 7. Digital simulator is used to evaluate integrated solution

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 the database file repository and stores analysis reports back to the database. Additional analysis functions can be added. Examples are: automated analysis of CBM data [13], automated analysis of digital relay data [15], advanced fault location calculation algorithms [16,17], and advanced monitoring applications [18].

V. Conclusions

The paper introduces a concept for integration of substation data. Several issues in existing IED data collection system have been identified. The paper addresses the steps towards an integrated solution and proposes a framework for integration of substation event data.

The framework identifies four main requirements: 1) communication to IEDs and automated data retrieval, 2) use of standardized file formats and file naming convention, 3) verification of the content, 4) handling system configuration.

Examples of utilization of the approach is exercised through two steps:

1. Upgrading an existing system for data integration and automated analysis of DFR event files data to fit into the specified framework. New system has been installed for the past year.

2. Demonstrating an integration of data from different other IED types such as DFRs, DPRs, and CBMs into the new database format. Digital simulator was used to evaluate the setup.

The proposed substation integration framework is open and allows easy access and viewing of the integrated data. It also enables functional expansion and building analysis functions at the top of the database.

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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.

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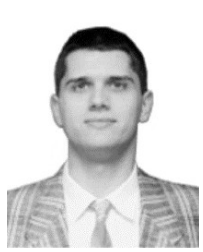

Tomo Popovic (M'99, S'06) received his BS degree in electrical engineering in 1994 from University of Novi Sad, Serbia and his MS degree from Texas A&M University, USA.

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.