Automated monitoring functions for improved power system operation and control

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***Abstract*—This paper describes how new functions for automated analysis of data collected in substations of an electric power system can be developed. The new functions are first defined and architecture of the integrated substation solution is proposed. Database and user interfacing needs are also presented. Once fully implemented, this solution will serve both local and remote operators allowing further benefits to be drawn from the concept of substation data integration and information exchange.**

I. INTRODUCTION

Development of substation automation systems was taking place for the last decade but the lack of enabling technologies and adequate standards were preventing such applications from becoming widespread. In the last few years the required technology became readily available and various standardization efforts were either completed or are close to a completion.

The technology area of interest for substation automation is associated with communication interfacing that is specified in the new substation automation standard IEC 61850 [1]. This standard enables interoperability among different Intelligent Electronic Devices (IEDs) that perform various local substation functions. Once all the IEDs can communicate, which the new standard makes possible, one can then start developing new functions that will take advantage of this provision. As a results, a new concept, namely data integration and information exchange (DIIE) can be implemented allowing data from different IEDs to be integrated, information relevant to different users both locally in substations and at remote locations to be extracted, and eventually to be presented to various groups of users.

One of the main requirements for such an implementation to take place is the compatibility of IEC 61850 with other IEC standards that define applications at the Energy Management System (EMS) and Distribution Management System (DMS). This compatibility is assured through the harmonization process that is currently taking place between IEC 61850, IEC 61970 [2] and IEC 61968 [3].

This paper addresses the new trends in substation automation by first providing a specification of the new functions and related implementation architecture. Database and user interface requirements are discussed next. Conclusions and references are given at the end.

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II. NEW AUTOMATED ANALYSIS FUNCTIONS

In this section, new automated analysis functions are elaborated. Their goal is to enhance existing automation practices through a new concept of data integration and information exchange (DIIE).

The Table I lists new automated analysis functions, together with their input/output data and brief description of each function. Most of the functionalities listed are performed locally in the substation, but it is important to note that some of the applications offer system-wide functionalities.

Applications can be categorized per two main purposes:

- Status tracking
- Automated analysis.

The status tracking function provides additional level in the process of data integration that enables verification of data being collected in the substation. There are currently two functions aimed at status tracking: Two-stage State Estimation (TSSE) [4,5] and Substation Switching Sequence Verification (SSSV) [6]. Later one is primarily of local character, while the first one serves both the local and system-wide functions.

Some of automated functions can be identified as device specific applications that provide automated analysis of data collected by specific IEDs in substation such as Digital Fault Recorder (DFR) [7], Digital Protection Relay (DPR), Power Quality Meter (PQM) [8], Remote Terminal Unit (RTU), Sequence of Events Recorder (SER), Programmable Logic Controllers (PLC), Circuit Breaker Monitors (CBM) [9], and Operator Meter (OPM). Other functions may be identified as substation-wide or even system-wide automated analysis applications. Examples are Fault Analysis including Fault location (FAFL) [10] and Two-stage State Estimation (partially executed as a local function as well) [4,5].

Currently, four device-specific and two system-wide automated data analysis applications are already developed: Circuit Breaker Monitor Data Analysis (CBMA) [9], Digital Fault Recorder Data Analysis (DFRA) [7], Power Quality Monitor Data Analysis (PQMA) [8], Fault Analysis including Fault Location (FAFL) [10] and two Stage State Estimation [4,5].

Input data are usually in the COMTRADE [11] file format, while the outputs are reports in an ASCII text file format containing the results of analysis. The developed applications are implemented using both a stand alone approach as well as an approach were they may be incorporated in an EMS solution.

TABLE I.
NEW AUTOMATED ANALYSIS FUNCTIONS

Function name	Inputs	Outputs	Description
Circuit breaker monitor data analysis (CBMA) [9]	Digital samples of signals from circuit breaker control circuitry in COMTRADE [10] file format	Report in an ASCII text file format containing list of circuit breaker operating problems as well as recommendations how the detected problems can be solved	Evaluates performance of the circuit breaker based on the analysis of data taken from the control circuitry
DFR data analysis (DFRA) [7]	DFR records in COMTRADE file format	Report in an ASCII text file format containing results of detection and classification of faults and disturbances, verification of the correctness of the protection system operation and fault location calculation	Conducts automated analysis of fault records captured by digital fault recorders (DFRs) and disseminates event reports
Power quality meter data analysis (PQMA) [8]	PQ measurements	Report in an ASCII text file format containing results of event detection and classification, waveform characterization, equipment sensitivity study and fault location calculation	Power quality analysis and modeling
Two-Stage State Estimation (TSSE) [4,5]	Substation topology and measurements data	Report in an ASCII text file format containing the results of three estimation phases: First Stage State Estimator, Suspect Substations Identification, Second Stage State Estimation and Correction of Topology Errors	Detection and identification of the topology errors
Digital Protective Relay (DPRA)	Digital Relay files in COMTRADE file format	Report in an ASCII text file format containing estimation of relay performances	Consistency checking of the data of various relay files. Correctness verification of the data of various relay files
Verification of switching sequences (VSSS) [6]	Statuses of switching devices and substation topology	Report in an ASCII text file format containing the results of the analysis and verification	Determination of optimal switching sequence for each type of fault condition or load transfer operation. Verification of the switching sequences
Fault analysis including fault location (FAFL) [10]	Analysis results from CBMA and DPRA applications	Report in an ASCII text file format containing the results of the system wide fault analysis	It performs local as well as system wide analysis of the faults

III. NEW ARCHITECTURE

Figure 1 shows an architecture supporting previously mentioned new automated analysis functions. The DIIE concept is introduced in order to enable implementation of new applications related to substation automation and EMS operation [13].

All the data collected by substation IEDs has to be stored in a Substation Database. This process is called data integration and it serves the purpose of integration of the data coming from different IEDs, in some cases made by different vendors. Besides the data measured by IEDs, new substation database contains consistent, verified, pre-processed data and reports that are readily available for local and system-wide users or other applications that may be connected to the database.

Information Exchange serves as a middle layer between the Substation Database and Applications and User interfaces, as shown in Figure 1. It enables the information that is extracted from the database to be sent to the specific applications at the system layer, which in turn serve various users through customized user interfaces.

Main purpose of the Information Exchange part is to enable:

- Exchange of data, reports and application settings between applications and database
- Exchange of data and reports between application and database on one side and the user on the other side.

This DIIE approach enables full utilization of data since data coming from specific IEDs will serve multitude of functions, which was not the case in the past.

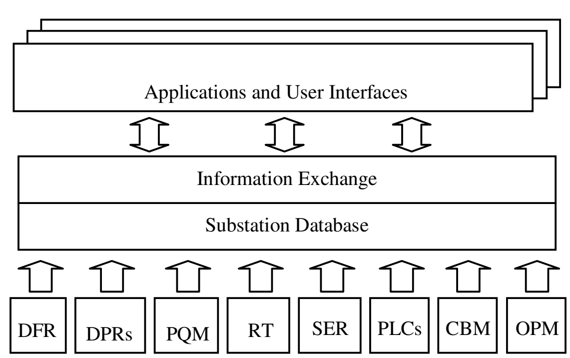

Figure 1 Data Integration and Information Exchange Concept

IV. DATABASE REQUIREMENTS

The general requirements for data integration and database implementation can be summarized as follows:

- Capture all the available data from substation IEDs. Provide accurate measurement of all power system parameters of interest.
- Manage and save the information. Transfer IED data utilizing either automated file format filters for legacy devices or advanced communication protocols such as IEC 61850 for new IEDs.
- Verify the data. There is a dedicated function called Verification of Substation Database (VSDB) [5,6], which performs collecting, processing and data consistency checking at the substation level. The status tracking function provides additional level in the process of data integration that enables verification of the data being collected in the substation and ensures the database consistency.
- Convert data into useful information. Pre-process the measured data to make them readily available for various applications and users. Preferred file format for all measurement data containing digital samples of monitored signals is COMTRADE. Therefore, file conversion functions enabling conversion of data from raw file formats to the COMTRADE are inseparable part of the substation architecture.
- Enable automated processing of measured and pre-processed data.
- Make the information available for local/substation and system-wide use.

Figure 2 displays one implementation approach for data integration in the substation. Measurements data are collected from various IEDs which monitor lines, buses, breakers and disconnect switches installed in the substation.

Three main functions of substation application are:

- Data acquisition. Preferred protocol used for data acquisition and communication is IEC 61850.
- Data display. Event reports, logged files or waveforms of the signals recorded in COMTRADE files are displayed in one unique GUI, which enables comparison of data from various sources.
- Database loader. It automatically loads pre-verified and converted data into the database.

V. USER INTERFACE

User interface in can be divided into two categories:

- Substation application user interface. This interface reports to the user data acquisition status and displays raw measurement data.
- Web application user interface. This interface provides remote access to the data stored in the databases. List of functions supported by the web application user interface is given in Table II. Interface supports several modes of database searches. Based on user inputs and retrieved data, contents of the pages dynamically changes. Figure 3 displays one example of dynamically created web page [9].

TABLE II
LIST OF WEB APPLICATION USER INTERFACE FUNCTIONS

#	**Function description**
1	Authorization and authentication of the users
2	Basic search (default) of processed data and reports
3	Advanced search of processed data and reports
4	Displaying signal waveforms of processed data and analysis reports
5	Graphical presentation of the system and substations statistics
6	Displaying application specific settings
7	Remote manual classification of the records and analysis reports
8	File transfer of the records between server and workstations connected to the company intranet and vice versa
9	Remote user accounts maintence
10	Exporting search results to the spreadsheet

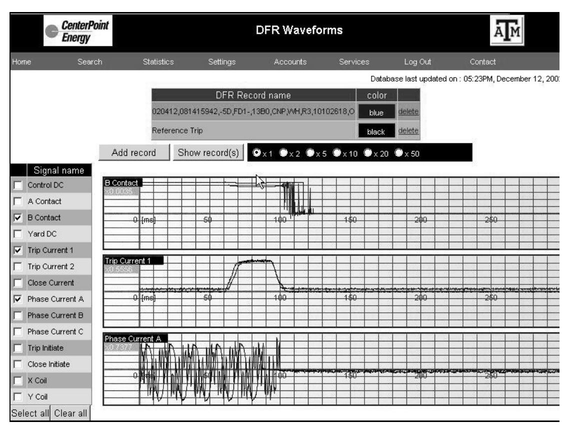

Figure 3 Dynamically created web page

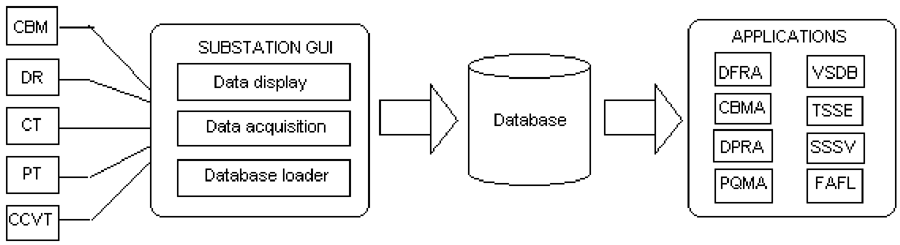

Figure 2 Concept of data integration at substation level

VI. IMPLEMENTATION SCENARIO

At present, development efforts are underway to implement functions discussed in Table I for a specific layout of the substation system. The one-line diagram of the selected substation layout is shown in Figure 4.

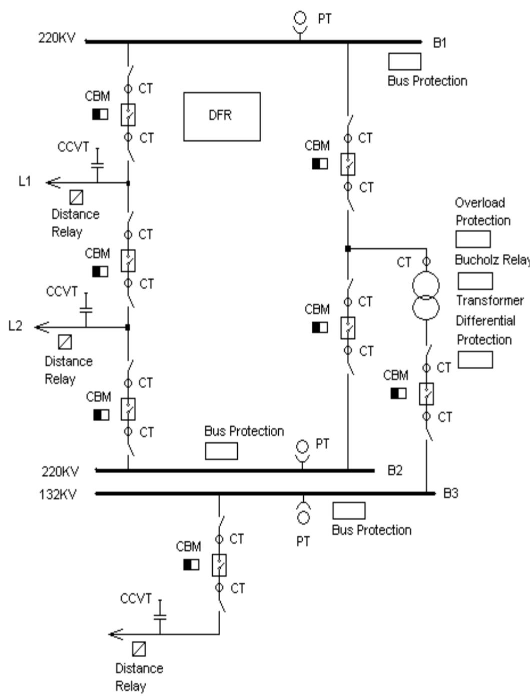

Figure 4 One-line substation diagram

VII. CONCLUSIONS

Based on the discussion given in the paper, several major conclusions can be outlined:

- Substation automation standards and technology enable easy integration of substation data, which offers many new benefits not available before
- In order to explore the new benefits, one has to define new functions that will enhance the capability to analyze system disturbances and monitoring operation of substation equipment.
- The new functions will take advantage of the data integration and information exchange concept that assumes the multiple uses of data from any given IEDs by various groups of utility staff.
- All new functions need to be automated so that the analysis is performed in a timely manner and without operator's intervention.
- Design of appropriate database and user interface is a critical part of the implementation since this determines how well the different utility staff can get access to the data and information.

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BIOGRAPHIES

Mladen Kezunovic (S'77, M'80, SM'85, F'99) has been with Texas A&M University since 1987 where he is the Eugene E. Webb Professor and Director of Electric Power and Power Electronics Institute. His main research interests are digital simulators as well as application of intelligent methods to control, protection and monitoring. Dr. Kezunovic is a registered professional engineer in Texas, and a Fellow of the IEEE.

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