Future Uses of Substation Data

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***Abstract*--The trend in today's development of power system monitoring, control and protection solutions is to install more Intelligent Electronic Devices (IEDs) in substations. As a result, variety of data is collected in substations today and much more will be collected in the future. This will change the paradigm of a classical Supervisory Control and Data Acquisition (SCADA) System that may use Remote Terminal Units (RTUs) to collect substation data. This paper presents future developments that will lead to multiple uses of IED data. Examples of new concepts are illustrated by reporting on recent projects that deal with automated analysis of data recorded in substations. For each project, detailed goals and accomplishments so far are be outlined. The uses of data in each of the deployment situations are discussed.**

***Index Terms*--fault location, monitoring, protective relaying, SCADA systems, substation measurements, topology.**

Nomenclature

A - Analog
CBM - Circuit Breaker Monitor
CFL - Centralized Fault Location
DFR - Digital Fault Recorder
DPR - Digital Protective Relay
EMS - Energy Management System
FL - Fault Locator
GOOSE-Generic Object Oriented System Event
GPS - Global Positioning System of Satellites
IED - Intelligent Electronic Device
IS - Integrated System
LMS - Local Master Station
MS - Master Station
PE - Protection Engineer
PMU - Phasor Measurement unit
RTU - Remote Terminal Unit
S - Status
SC (RC) - Substation (Regional) Control
SCADA - Supervisory Control and Data Acquisition
SER - Sequence of Events Recorder
SOE - Sequence of Events Recorder

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I. Introduction

Various types of disturbances in power system are caused by faults, dynamic operations, or nonlinear loads. On the other hand, competition between utilities and increased usage of sensitive electronic circuitry by customers imposed greater demand on the quality of power [1]. Consequently, the solution that monitors, controls and protects power system requires high reliability and versatile functionality. Today many Intelligent Electronic Devices (IEDs) are available. The IEDs typically installed are Digital Protective Relays (DPRs), Digital Fault Recorders (DFRs), Sequence of Events Recorders (SERs), Phasor Measurement Units (PMUs), and other specialized monitors and controllers. IEDs are able to monitor and collect various data, beside their main role to perform control and protection functions.

When one looks at the type and amount of substation data that will be collected by IEDs in the future, it appears that the quality and redundancy of monitoring data will be greatly improved when compared to today's situation where the data is primarily recorded by RTUs and brought to a central EMS location through SCADA. This new quality of data is the key to multiple uses of such data that are expected in the future [2]. The idea is to collect data from all substation IEDs in a substation database, and then have automated analysis packages that will extract the best information for different types of users such as operators, protection engineers, maintenance crews and asset managers, etc [3].

This paper explores different uses of substation data. It first introduces the new concept of data integration and information exchange and describes the transition in the monitoring system infrastructure that will be required to accommodate the new approach. The rest of the paper focuses on the three on-going projects carried out by Texas A&M University where different substation functions are being developed taking advantage of the new type of substation data. The applications of interest are: a) monitoring of faults and fault clearing sequences, b) monitoring of circuit breaker switching sequences and the topology, and c) high accuracy data processing for applications requiring high precision measurements. The paper ends with conclusions and references.

II. Background and Related Work

Power systems sometimes need to bee expanded to meet the growing demand for electrical energy. In order to satisfy increased demand new substations are built and old are upgraded [4]. It is common that arrangements and equipment in substations vary widely from substation to substation. In practice, many different solutions can be found. When it comes to systems for monitoring and control, the legacy infrastructure still dominates although the amount and type of data collected in substations have dramatically increased. A typical architecture of current hardware is given in Fig. 1. It is organized to provide data for traditional power system operating states that are mutually exclusive [5]. In the past, much of the equipment used in power systems was of an electromechanical design, and did not have an ability to communicate with RTUs and SCADA database. Although SCADA was able to provide information related to most equipment in substation, it was not able to track system dynamics [6]. Using synchronized sampling technology and with the development of the substation automation standard IEC 618505 [7], the IEDs can be interconnected to form a substation automation system. With further developments of the standard for Common Information Model (CIM) IEC 61970 [8], the interfacing of the substation automation systems to the EMS will become common practice in the future.

Consequently, the classical paradigm for collecting substation data is changed with the new architecture of the substation automation systems. Future architecture will be based on integration of the data coming from different IEDs, instead of the data previously coming from RTUs. In the future, all substation IEDs will be supplying data that may be utilized by number of software functions and utility staff [5]. This approach is significantly different from today's approach and it is shown in Fig. 2. The limited SCADA view may be enhanced with a view available from other IEDs. This way data is redundantly collected which makes system for monitoring and control more robust. New functions and applications could be developed and old functions could be maintained with greater accuracy. From Fig. 2 it can be noticed that at the substation level there is automatic substation analysis and control application, which is capable of processing data collected from all IEDs in substation. This application is capable of making conclusions and sending them directly to different users. Automatic processing of data eliminates possibility of human mistake and enables access to all substation data synchronously. When comparing the infrastructures shown in Fig. 1 and 2, one can note the following major differences: a) the data collected by different IEDs in Fig. 1 is channeled through different communications and interfacing systems to different users while in Fig. 2 the IED data is collected in a common substation database, b) The data processing to extract information in Fig. 1 is not available at the substation level, while in Fig. 2 automated applications for such a purpose are located in substations, c) The data seen by different user groups in Fig. 1 is conveys different information depending on the type of IED used to collected data while in Fig. 2 the source of data is transparent since the entire substation database can be used to extract the best possible information for each of the user groups.

In next few sections, the new concepts will be demonstrated by reporting on recent Electric Power Research Institute (EPRI), Department of Energy (DOE), Power System Engineering Research Center (PSerc) and other utility sponsored projects that are presently being pursued. Each project represents a deployment of a portion of the overall concept shown in Fig. 2.

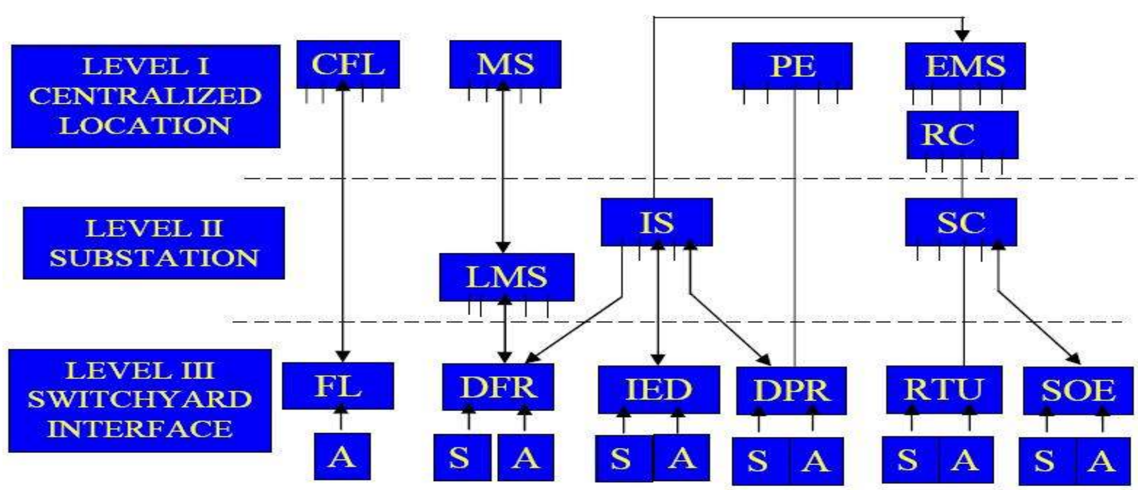

Fig. 1. Old Paradigm – Current hardware architecture

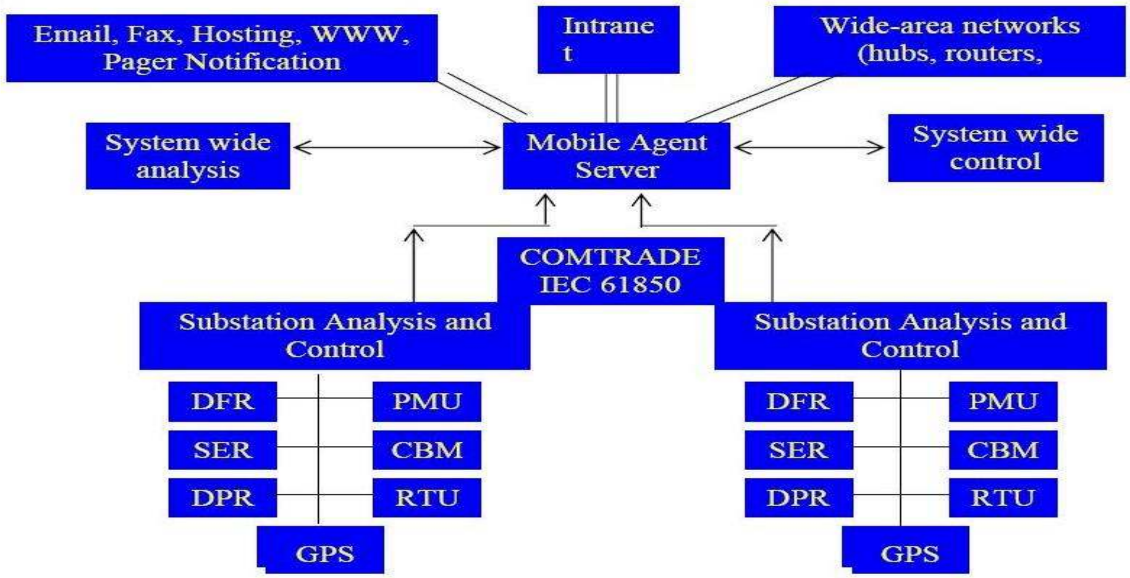

Fig. 2. New Paradigm – Future hardware architecture

A. *Automated Monitoring and Analysis*

The future concept for automated monitoring and analysis has been under development in an on-going project funded by EPRI and its members. New automated data analysis application collects and processes data from three different types of substation IEDs: DFRs, DPRs and CBMs. Fig. 3 shows architecture of substation automation software. Goal of this project is to modify and integrate existing device specific analysis applications for DFR, CBM and DPR into single application environment running on a substation PC.

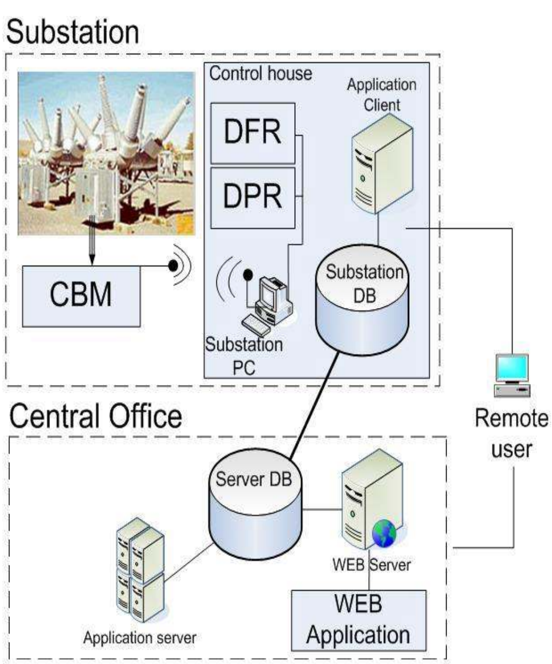

Fig. 3. Architecture of substation automation software

The device specific data analysis applications that should be merged into one are described in Table I. At present the client application automatically collects data from three types of IEDs and separate applications for each IED are automatically executed when new records are present. In the next development phase the client application will be enhanced with new analysis that uses data from all three types of devices.

TABLE I
DESCRIPTION OF IED-SPECIFIC ANALYSIS APPLICATIONS

Application	Description
DFRA	Automated analysis of fault records captured by DFRs
CBMA	Automated analysis of data taken from the control circuit of a CB
DPRA	Validation and diagnosis of relay operation

This approach presents new paradigm demonstrated on a small sample of IEDs. Once fully implemented, this solution will serve both local and remote users, allowing further benefits to be drawn from the concept of substation data integration and information exchange [9]. In this project, the users of the extracted information are multiple groups ranging from protection engineers and operators to maintenance crews and asset managers. The server application has access to the data coming from substations, so the entire system data collected by all the IEDs and results from the analysis are stored in the server database. The automated analysis applications, which are embedded in the client software, are used to extract the required information from the raw recorded data.

B. Topology monitoring improvements

Power system topology describes connectivity of various components such as generators, power transformers, transmission lines, loads, etc. In order for operators to react properly when needed, it is very important to know correct topology of the system all the time. Circuit breakers (CBs) have the purpose to connect or disconnect different parts of the power system in order to isolate the faults and/or re-route the power flow. By inspection of behavior and status of circuit breakers in an area of interest we can determine exact topology. Device, which is developed to monitor signals from control circuit of CB, is the CBM. Table II lists signals that are monitored.

TABLE II
CONTROL SIGNALS MONITORED BY CBM

Signal Name
Control DC Yard DC
a Contact b Contact
Trip Current 1 Trip Current 2 Close Current
Trip Initiate Close Initiate
X Coil Y Coil
Phase A Current Phase B Current Phase C Current

The CBM application developed earlier analyses performance and determines current status and behavior of a CB [10]. An extension of the previous application is related to the automated analysis of data collected from multiple CBs. This enables one to determine precise topology of an area and sequence of events. This enhanced system has been under development in an on-going project funded by the Department of Energy (DOE). Fig. 4 presents system architecture for this solution. All CBs in substation should be equipped with CBM device. By using wireless communication CBM devices are sending event files to client application. Since signals from these distributed sources are analyzed together, they must refer to a common time.

All CBM devices should be synchronized with the same time reference. In this project synchronization is accomplished using Global Positioning System (GPS) of Satellites. This architecture with field synchronization of CBMs is one of the innovations of the proposed paradigm.

Besides knowing a momentary state of the topology it is important to understand the time sequence between incident, the relay action and breaker operation. This solution makes possible to track sequence of events not only on a single breaker, but also on a group of breakers. In case a fault is present on the line, corresponding CBs should be activated by a relay in order to de-energize the line and get rid off temporary fault. Fig. 5 shows possible sequence of operations caused by a temporary fault.

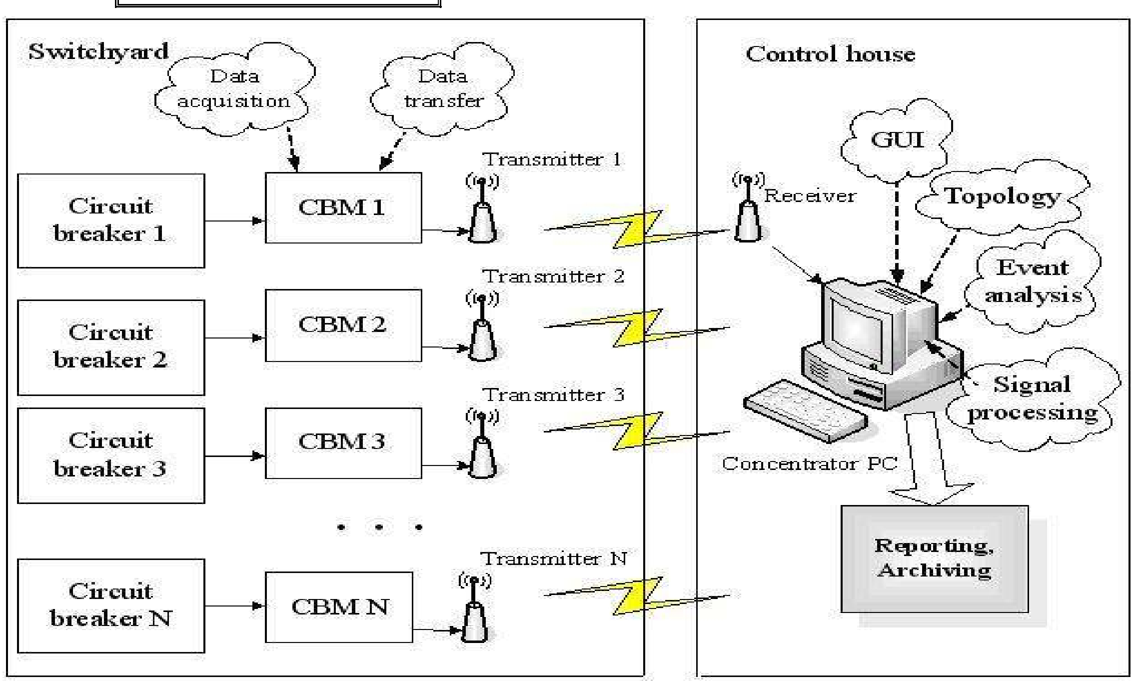

Fig. 4. System architecture of topology monitoring

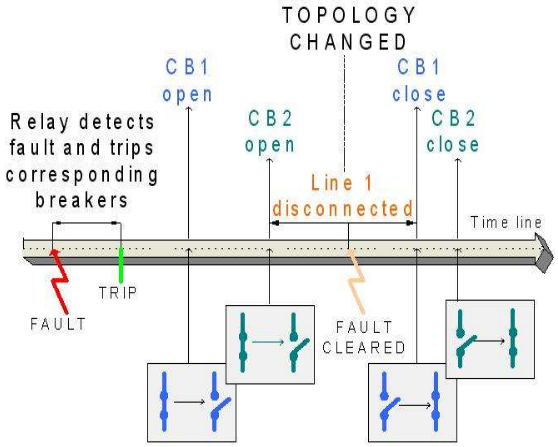

Fig. 5. Sequence of operations caused by fault

Automated analysis of this events enables accurate determination of the topology in real-time. Taking into account data collected from other IEDs beside CBMs would bring redundancy during analysis, leading to more accurate determination of power system topology.

C. All-Digital Substation

In last couple of years, manufacturers of power system devices are trying to make their products compatible and interchangeable. The IEC 61850-9.2 digital process bus permits direct interconnection of the different systems, which assures compatibility of different devices. Some companies already demonstrated interoperability between different devices; however all-digital field systems have not been widely introduced yet. In an on-going project funded by PSerc performance of an all-digital protection system using optical instruments transformers directly connected with digital relays is evaluated. Connection is managed using IEC 61850-9.2 digital process bus. Example of described architecture is shown on Fig.6.

During testing, the simulation computer generates the exposures according to the selected test scenarios, which is fed to the optical transducers. The merging

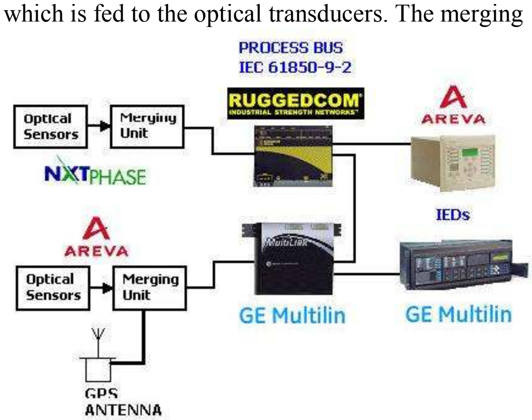

Fig. 6. An all-digital substation protection system

unit is multicasting the sampled values over an IEC 61850-9-2 process bus [9]. After that protective relay operates and sends Generic Object Oriented System Event (GOOSE) messages to test computer. Test computer will capture messages sampled values as Fig, 7 shows.

The importance of IEC 61850 standard for facilitating implementation new paradigm is obvious. Presently such systems are still in a development phase and very important issue that should be considered during its development is the security.

The mentioned tests performed in this project revealed multiple benefits of such a solution: a) data collected from optical transducers can be shared by multiple IEDs allowing for implementation of new protection and control functions not foreseen earlier [12], b) the fact that the data may be shared opens new possibility for redundant solutions that are much cheaper to implement than before, and c) the fact that the data already comes in a sampled form makes the implementation of signal processing much faster and cheaper than what is possible with traditional systems.

This concept, if widely applied in the future opens up a whole new opportunity not only for intrastation but also for interstation applications. If the process bus becomes available to exchange data between various substations, than new functionalities for fault location and control may be implemented [13].

The final comment about the uses of digitized data relates to the capturing of data for the power system monitoring purposes. With such data being channeled through a database and fast communication links, the entire power system may be monitored in time-domain in real time. This will allow for fast tracking of system dynamic and very accurate determination of the power system switching state.

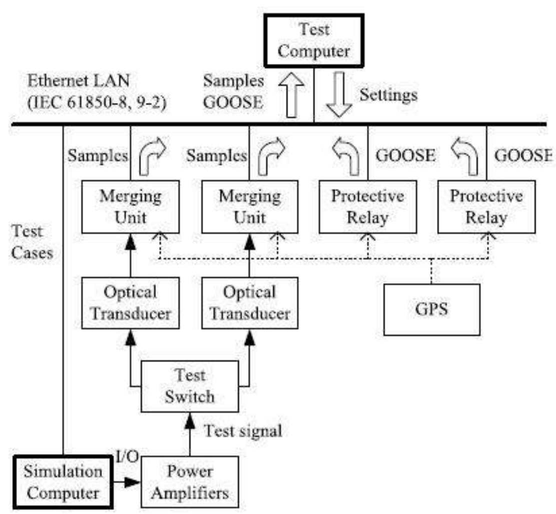

Fig. 7. Hardware architecture of fully networked test system [11]

III. Conclusions

With development of the new IED technology and IEC standard 61850 and 61970, realization of new paradigm is inevitable. This paper presents three on-going projects where each of them demonstrates how new paradigm can be deployed. First project gives example of the new data integration and information exchange concept applied on a subset of IEDs: DFR, CBM and DPR. Second project illustrates how synchronized IED can be used for determining power system topology. Since many fault location and state estimation applications rely on determination of the system topology, more accurate topology determination could enhance those applications. Finally, third project presents how IEC 61850 could be used to improve current infrastructure of monitoring and control systems by readjusting to new paradigm where all data comes in sampled form and may be shared by all the functions in a given substation and among adjacent substations.

All of the mentioned projects lead to one common conclusion: the field data obtained with new solutions is more precise, reliable, and redundant than what is currently available. Such data properties can be utilized to extract much better information than what was possible before. The better information will benefit a variety of different utility groups such as protection, operations, maintenance and asset management, planning and performance compliance.

IV. Acknowledgment

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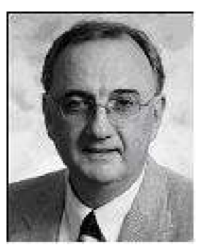
VI. Biographies



Mladen Kezunovic (S'77-M'80–SM'85–F'99) received the Dipl. Ing. Degree in electrical engineering from the University of Sarajevo, Bosnia-Herzegovina, in 1974, and the M.S. and Ph.D. degrees in electrical engineering from the University of Kansas, Lawrence, in 1977 and 1980, respectively. Currently, he is the Eugene E.Webb Professor and Director of Electric Power and Power Electronics Institute at Texas A&M University, College Station. He was with Westinghouse Electric Corporation, Pittsburgh, PA, and the Energoinvest Company, Sarajevo, Bosnia-Herzegovina. He was also with the University of Sarajevo, Bosnia-Herzegovina, and a Visiting Associate Professor at Washington State University, Pullman, from 1986 to 1987. His main research interests are digital simulators and simulation methods for relay testing as well as application of intelligent methods to power system monitoring, control, and protection. Dr. Kezunovic is also a Fellow of IEEE and a member of CIGRE.