Automated Analysis Systems for Monitoring, Maintenance and Control of Power Systems

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***Abstract*-Increased demands on power systems reliability lead to more stringent requirements for power system monitoring, maintenance and control. Introduction of Intelligent Electronic Devices (IEDs) in substations allows more elaborate recording of field data that in turn may be used to enhance the analysis for monitoring, maintenance and control purposes. While the additional data recorded by IEDs provides more information than the classical solutions, the overwhelming amount of data makes manual analysis quite impractical. Automating the analysis becomes a crucial approach for improving reliability. The paper also illustrates how the overall solution may be implemented using various software and communication means. Commercial version of the solution is partially implemented at one of the EPRI member utilities and a fully expanded version is being planned at another.**

I. INTRODUCTION

INTRODUCING improved monitoring of substation equipment performance is becoming a focus of utilities due to the aging of the power apparatus and emerging capabilities of new Intelligent Electronic Devices (IEDs). The aging of circuit breakers, power transformers, communication gear, and other substation equipment makes it more prone to performance degradation and failing. With more power system operation scrutiny under deregulated market conditions, it appears that enhancements in equipment monitoring are necessary to make sure that equipment problems are detected immediately and appropriate maintenance actions taken as soon as possible. The emerging need for improved monitoring is well served with new IEDs such as Digital Protection Relays (DPRs), Digital Fault Recorders (DFRs), Circuit Breaker Monitors (CBMs), etc that have powerful recording, processing and reporting capabilities. The remote access to the non-operational data recorded and processed by new IEDs can provide operators, protection engineers, and maintenance staff with timely and detailed information about equipment operation leading to an efficient assessment of the performance degradation and failures.

The IEDs record very detailed data that reflects performance of the substation equipment leading to a wealth of information for different utility groups to make decisions regarding better equipment maintenance and operation. The fact that the amount of recorded data is so overwhelming creates a problem in itself. Manual retrieving and processing of IED monitoring data is time consuming and many utilities do not have the resources to perform this function effectively. As a result, much of the recorded data may not be analyzed in a timely manner and hence the major monitoring advantage of the new IEDs may be underutilized. This not only fails to bring a full benefit of the new investments in the IEDs but also creates a bottleneck for future expansion of the use of such equipment by the utility personnel.

The paper discusses how power system reliability may be affected by a new automated analysis aimed at improved monitoring, maintenance and control. The approach taken in this paper is an R&D work sponsored by the Electric Power Research Institute (EPRI) and several utility members. The approach takes as an example data recorded from Digital Fault Recorders, Digital Protective Relays, and Circuit Breaker Monitors. It is shown how new software that converts automatically recorded data into relevant information needed for enhancement reliability and the overall performance of the power system. The information suitable for improved situational awareness, asset management and operator control is extracted and made available to respective utility staff on line. Web based interface allows the information to be shared with the utility staff on demand as needed. The real time availability of data allows new approaches to identifying faulted equipment, developing just-in-time maintenance strategy, and enabling timely operator actions, all the means for achieving an improved reliability.

II. SUBSTATION EVENT ANALYSIS

The system supports client/server architecture. The client part resides in the substation. It consists of the CBM [1], DPR and DFR devices attached to the substation PC and corresponding Automated Event Analysis (AEA) Client and substation database software, which permanently resides in the substation, as shown in Fig. 1.

The server part of application is running on the server PC installed in the central office. The server application consists of automated analysis applications integrated within the AEA Server software package, server database, web server and web application for company wide dissemination of IED data and analysis reports.

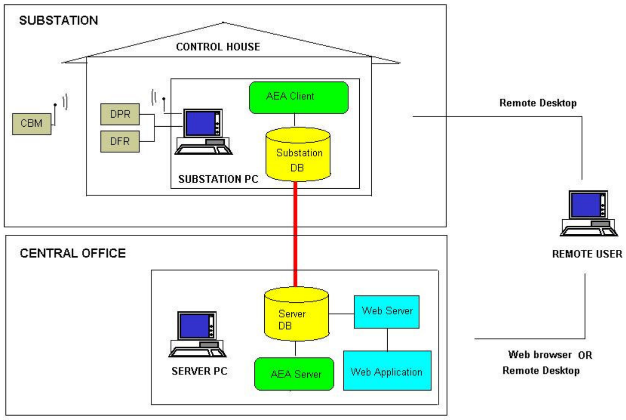

Fig. 1. Architecture of Substation Automation system

In Fig. 2 the architecture and functions of the AEA Client application are shown. The AEA Client application implements functions for Automated Data Acquisition and Conversion, provides interface for users and allows for local IED data preprocessing and analysis.

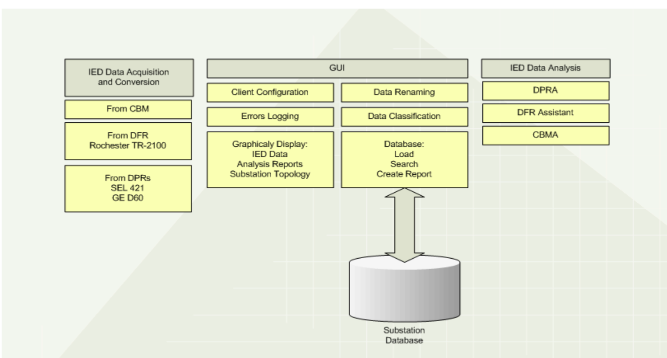

Fig. 2. Functions of AEA Client module

Data Acquisition and Conversion functions are implemented by vendor provided or custom made software modules. Once the IED data are recorded, they are automatically sent to the substation PC via different communication links and related protocols.

User interface functions provide means to configure operation of the substation automation system in different ways, based on the specifics of the installed equipment and available software. This provides for greater flexibility and customization of the whole system.

In case of problems, messages identifying the errors and related data are stored into local log files, but the application tries to recover from them and continue processing un-interrupted.

Based on the IED data source and processing status, automated classification and renaming of data is performed. To allow for more efficient processing and IED data manipulation, customized IEEE file naming convention is implemented [2].

The graphical user interface (GUI) allows users to select and display acquired IED data and analysis reports using internal and external (3rd party) software packages. Preferred data format is COMTRADE [3], [4] , but native vendor formats are supported as well.

Advanced database functions are implemented providing for automated database archival, searching and report generation through dedicated and customized forms.

The IED data flow in the substation consists of three phases: preparation, processing and report generation. The data flow is displayed in Fig. 3.

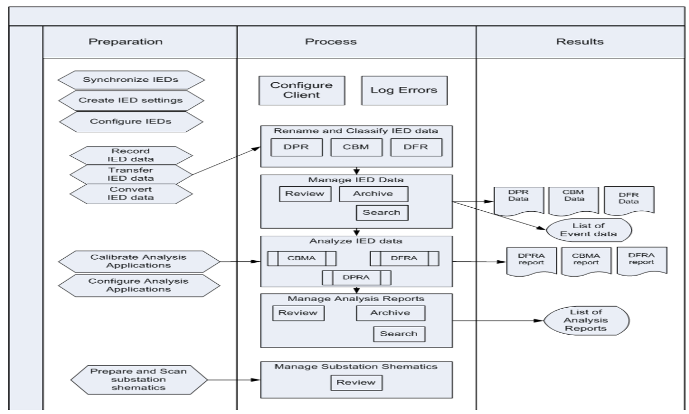

Fig. 3. Substation IED Data Flow

The substation AEA Client application contains many views allowing the user to see the real-time IED acquisition data status details about recorded data, as illustrated in the application screenshot shown in Fig. 4.

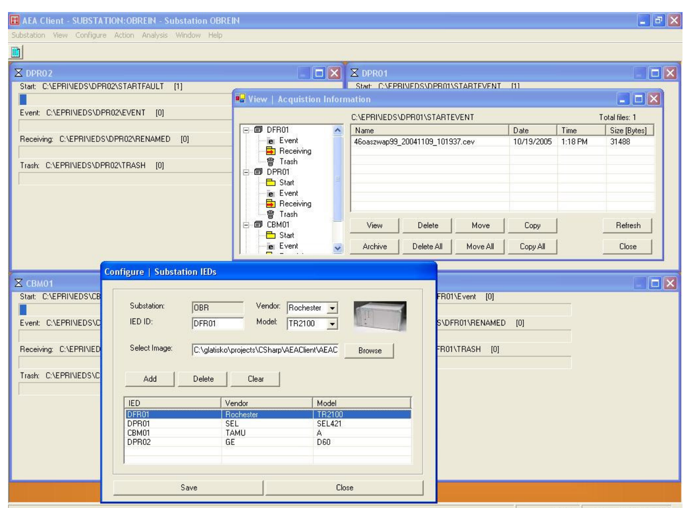

Fig. 4. Substation AEA Client application

III. AUTOMATED ANALYSIS APPLICATIONS

Three advanced automated analysis applications are integrated within GUI. These applications perform the automated processing of IED data, based on the knowledge rules defined by maintenance and protection experts. The knowledge rules are embedded in individual software packages. Those applications are:

(1) DFRA (Digital Fault Recorder Analysis) [5] - provides automated analysis of DFR event records. The analysis looks at all the monitored circuits and identifies the one with the most significant disturbance. For that selected circuit, DFRA performs signal processing to identify pre- and post-fault analog values, statuses of the digital channels corresponding to relay trip, breaker auxiliary, communication signals, etc. The expert system determines fault type, faulted phases, checks and evaluates system protection. At the end, the analysis program calculates the fault location. Fig. 5 displays the architecture of DFRA application.

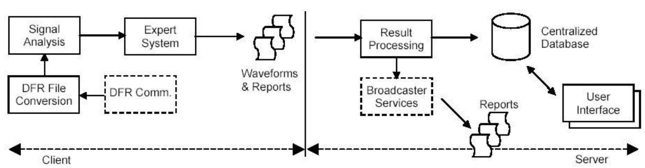

Fig. 5. Architecture of DFRA application

(2) DPRA (Digital Protective Relay Analysis) [6] - is an expert system based analysis application which automates validation and diagnosis of relay operation. Validation and diagnosis of relay operation is based on comparison of expected and actual relay behavior in terms of the status and timing of logic operands. If expected and actual status and timing of an operand is consistent, the correctness of the status and timing of that operand is validated. If not, certain failure or misoperation is identified and diagnosis will be initiated to trace the reasons by the logic and cause-effect chain. Fig. 6 shows architecture of DPRA application.

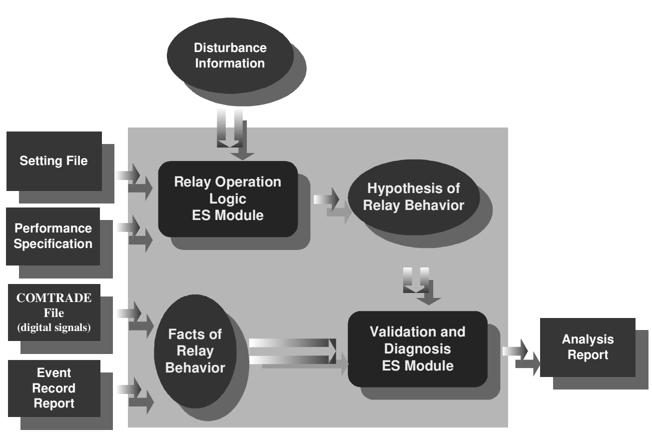

Fig. 6. Architecture of DPRA application

(3) CBMA (Circuit Breaker Monitor Analysis) [7] - is an application based on analysis of records of waveforms taken from the circuit breaker control circuit using a Circuit Breaker Monitor (CBM) device. It enables protection engineers, maintenance crews and operators to quickly and consistently evaluate circuit breaker performance identify deficiencies and trace possible reasons for malfunctioning. It can automatically analyze switching operations of large number of circuit breakers under complex switching conditions. Fig. 7 displays the architecture of the CBMA application.

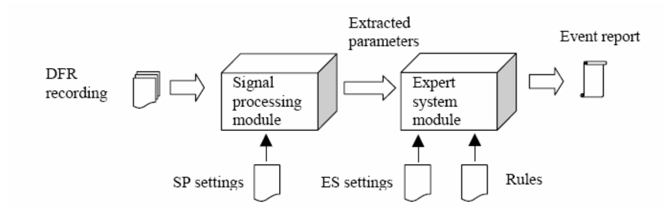

Fig. 7. Basic Architecture of the CBMA application

IV. SYNCHRONIZED SAMPLING

Ideally, the system hardware in a substation consists of circuit breaker monitors located on each breaker in the switchyard, digital fault recorders, digital relays and a concentrator PC used for gathering data that is placed in the control house. This monitoring system performs real-time data acquisition and signal processing. New IEDs introduce capabilities of synchronous data sampling and time stamping. They can sample several input signals synchronously with accurate time stamp measured in Coordinated Universal Time (CUT). From the choice of several different systems for reference time transfer, new IEDs typically use GPS [8]. IEDs such as Digital Fault Recorders and Digital Protective Relays have already implemented time synchronization using either an external or embedded GPS receiver. GPS provides a very accurate time reference independent of location or weather condition. There are several standards, which define the format used for time exchange. The most common used by monitoring devices are Inter-Range Instrumentation Group (IRIG) time codes [9]: IRIG B (100PPS) and IRIG H (1PPS) with different cariers and codes. IEDs use two types of information from the GPS receiver: synchronization pulse and time stamp.

This feature is implemented on the CBMs using a GPS clock receiver and wireless modems for time distribution to devices in switchyard. The GPS Synchronization signal (1PPS) is distributed from the master radio modem located in the control house to the slave units at each CBM device (Fig. 8). In this way only one GPS receiver per substation is needed. Radio modems used for this purpose have implemented the option for 1PPS distribution from master modem to several slave units.

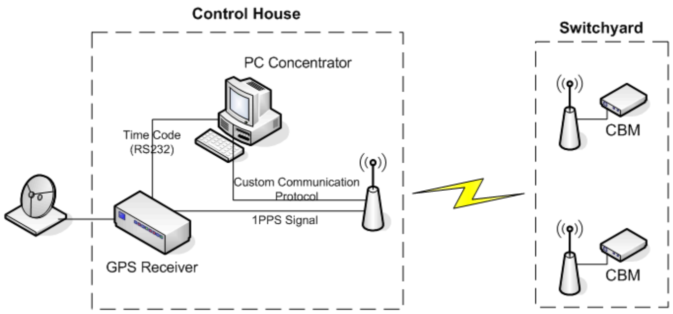

Fig. 8. CBM substation setup

Time stamp transfer from GPS to CBMs has been implemented using a custom communication protocol. Besides time transfer, this protocol enables remote configuration of the CBM and data transfer from CBM to PC concentrator. Using this setup achieves time accuracy better than 10usec, which satisfies the requirements for this application.

The CBM device samples 16 input channels synchronously using sample and hold circuits. The start sampling signal comes from the local clock, which is synchronized by the 1PPS signal from the GPS (Fig. 9). The local clock is necessary for the CBM sampling rate to be implemented because the GPS synchronization signal has a predefined frequency that is different from the CBM sampling rate.

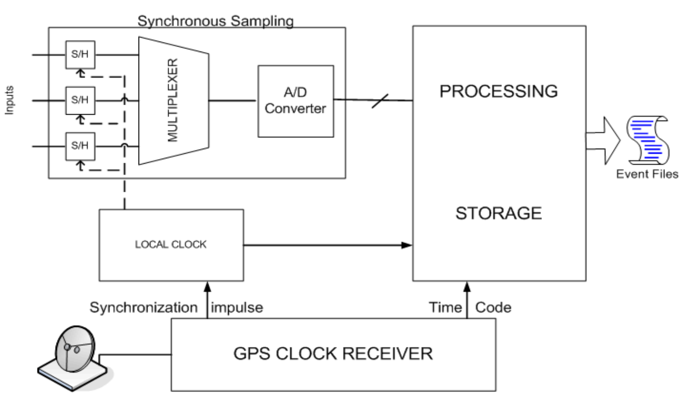

Fig. 9. CBM synchronization circuits

The local clock is used as the time reference for sampling between two synchronization pulses from the GPS. The local clock divides the time interval between pulses is a specific way to get the required sampling rate. The local clock has a very small time drift between the two pulses so that it does not affect sampling accuracy. For every sample, the processor creates a time stamp using the GPS time code and the actual time from the local clock. By using signal values and time stamps, CBM generates event reports in COMTRADE format with time stamp assigned to all samples. Time synchronism enables usage of file naming convention [2] that simplifies data processing and enables efficient database organization. Precise time information enables automated data processing and analysis and enables combining data from different monitoring devices. It is possible to align data when monitoring devices sample at different rates using interpolation and decimation algorithms [10]. Synchronous sampled data enables usage of algorithms for simpler and more accurate fault classification and location and it gives more information about performance and equipment status.

V. Field Deployment

The above described system is currently being implemented at a 345KV substation. The one line diagram of a portion of the substation is shown in Fig. 10.

The field deployment will be implemented in several phases and steps. All the deployment phases are expected to be completed in the first half of 2008.. The system will be in service for some time for evaluation of the performance and implementation improvements before further deployment.

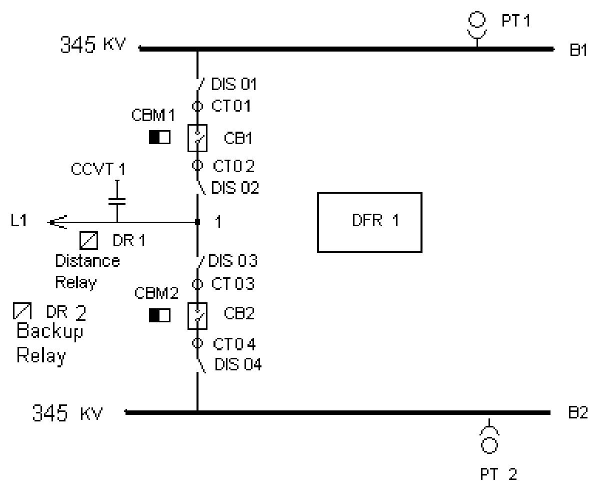

Fig. 10. One line diagram of a portion of the substation for field deployment

VI. Conclusion

Major benefits that this new application will bring are:

- Integration of IED data acquisition functions allows for collection of data from different IEDs so that the data redundancy and data variety are enhanced from data collected by a single type of IED.
- Integration of device specific analysis applications enables conclusions about different events or equipment operations to be enhanced by extracting already processed information rather than reviewing raw data.
- Local and centralized historical data repository enhances the way the data is collected and the results are stored since all the data will be collected with the same time stamp and synchronized sampling.
- Company wide dissemination of data is facilitated through various means of distributing the analysis reports including pagers, company Intranet, and web-based services.

- Automation of the data analysis reduces the time and provides means for dealing with an overwhelming amount of data being collected by IEDs.
- Improved management of data and analysis reports enables maintenance crews and asset management staff to keep both instantaneous and time-correlated account of events and associated equipment performance.

VII. ACKNOWLEDGMENTS

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IX. BIOGRAPHIES

Mladen Kezunovic (S'77, M'80, SM'85, F'99) received his Dipl. Ing. Degree from the University of Sarajevo, the M.S. and Ph.D. 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 Systems Engineering Research Center, and 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 quality monitoring. Dr. Kezunovic is a registered professional engineering in Texas, a member of CIGRE and a Fellow of the IEEE.

Abdel-Aty (Aty) Edris was born in Cairo, Egypt. He received his BS with honors from Cairo University, the MS from Ain-Shams University, Egypt, and the Ph.D. from Chalmers University of Technology, Sweden. Dr. Edris spent 12 years with ABB Company in Sweden and in the USA, in the development and application of Reactive Power Compensators and High Voltage DC Transmission systems. In 1992, Dr. Edris joined EPRI as Manager of Flexible AC Transmission System (FACTS) Technology. Dr. Edris is Technology Manager of EPRI Power Delivery and Markets, and a member of several IEEE and CIGRE Working Groups.Dr. Edris is the recipient of the IEEE 2006 Award for Industry Leadership and Scientific Contribution to FACTS Technology, pioneering transformation of electric transmission system into flexible, controllable, yet secure system operated at thermal capacity.