AUTOMATED MONITORING OF SUBSTATION EQUIPMENT PERFORMANCE AND MAINTENANCE NEEDS USING SYNCHRONIZED SAMPLING

M. Kezunovic	A. Edris	D. Sevcik	J. Ciufo, A. Sabouba
Texas A&M University	EPRI	CenterPoint Energy	Hydro One

Abstract

Monitoring of substation equipment performance and maintenance needs is typically met with test devices that are brought to a substation and data is collected manually. This paper introduces a new concept where this process is performed through an on-line data acquisition and processing solution. This is accomplished by utilizing substation automation systems for diagnostics and maintenance purposes in addition to their original task of monitoring, control and protection. This paper illustrates how the automation of data processing and analysis can be utilized to monitor equipment performance and indicated abnormalities. The use of Global Positioning System (GPS) synchronization enables very precise determination of various equipment actions leading to improved performance assessment capabilities. This solution is presently being developed and a staged field deployment plan at CenterPoint Energy (CNP) in Houston is underway.

Introduction

Introducing improved monitoring of substation equipment performance and maintenance needs 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 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 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 this 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 IEDs but also creates a bottleneck for future expansion of the use of such equipment by utility personnel.

The paper discuses two major improvements in the mentioned process: automation and synchronized sampling. Automating the monitoring and maintenance analysis process are essential since it, not only, saves time but also enables the expertise of the most experienced staff to be embedded in the software for automated analysis. This way, the expertise of experienced utility staff is captured for future use. Another major improvement in this process is the use of synchronized sampling capabilities of the new IEDs. If all the IEDs can sample the input data synchronously using, GPS receivers, the data can be integrated, processed and relevant information extracted and time stamped in a much more efficient way. Besides efficiency, the accuracy of the monitoring is improved leading to better maintenance decisions.

This paper reports on the results of an on-going EPRI R&D project that is aimed at demonstrating the above mentioned benefits in an actual substation field installation.

Substation Automation

The system supports client/server architecture. The client part resides in the substation. It consists of the CBM , 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 Figure 1.

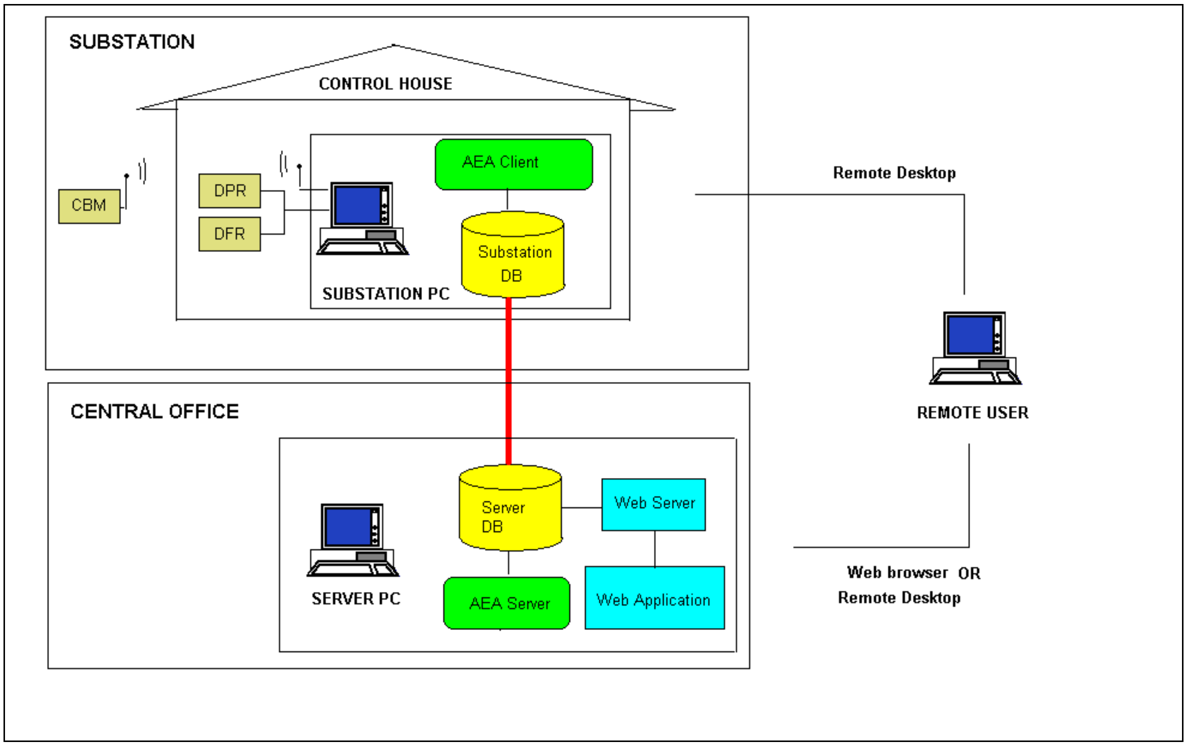

Figure 1 Architecture of Substation Automation system

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.

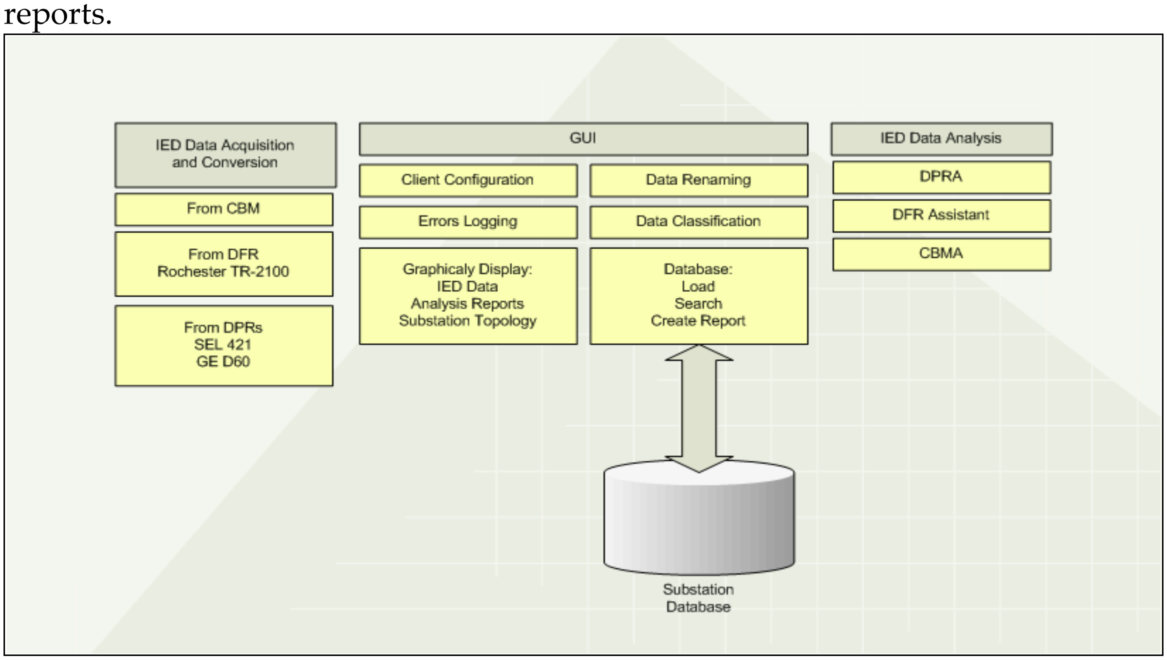

Figure 2 Functions of AEA Client module

In Figure 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.

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. For DPRs, Modbus and YModem protocols are used, while custom protocols are implemented for DFRs and CBMs. Physically, transmission is performed by RS232, RS485, wireless or Ethernet connection.

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 . Format of the file names is given in Table 1.

Table 1 Specification and examples of used IEEE file naming convention

yymmdd	hhmmssmmm	xyz	ssss	dddd	cccc	Xxxx
Fixed length (6)	Fixed length (9)	Fixed length (3)	Variable length	Variable length	Variable length	Variable length
Start date	Start time	Time code	Station identifier	Device identifier	Company name	Category

Input file name:
020828,122632909,-5D,OBR,DR01,CNP,WAVE.CFG
Analysis report file name:
020828,122632909,-5D,OBR,DR01,CNP,DPRA.TXT

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 , 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 Figure 3.

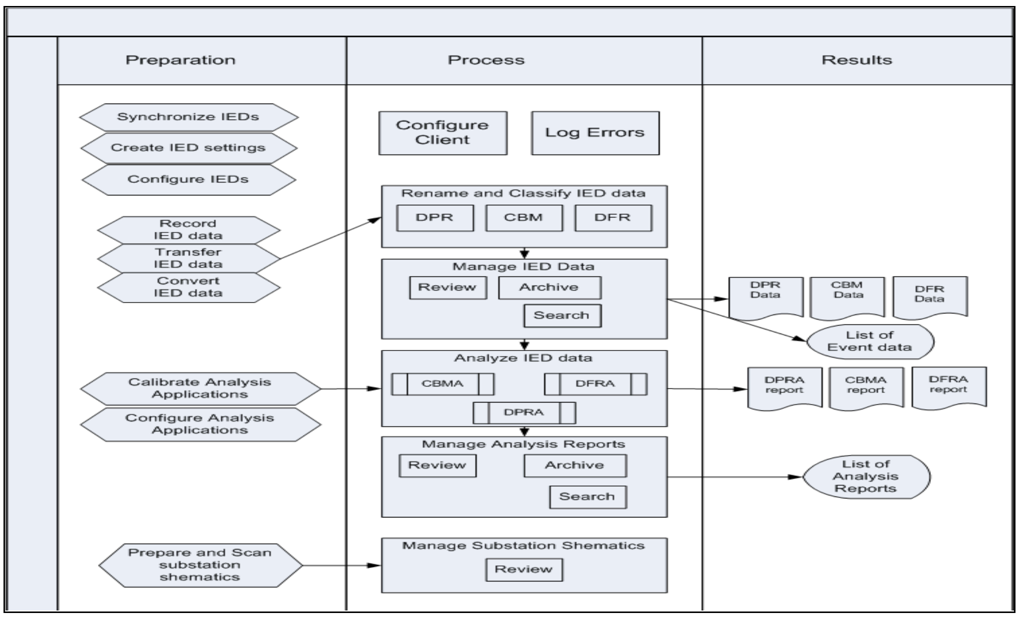

Figure 3 Substation IED Data Flow

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 Figure 4.

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 packages are:

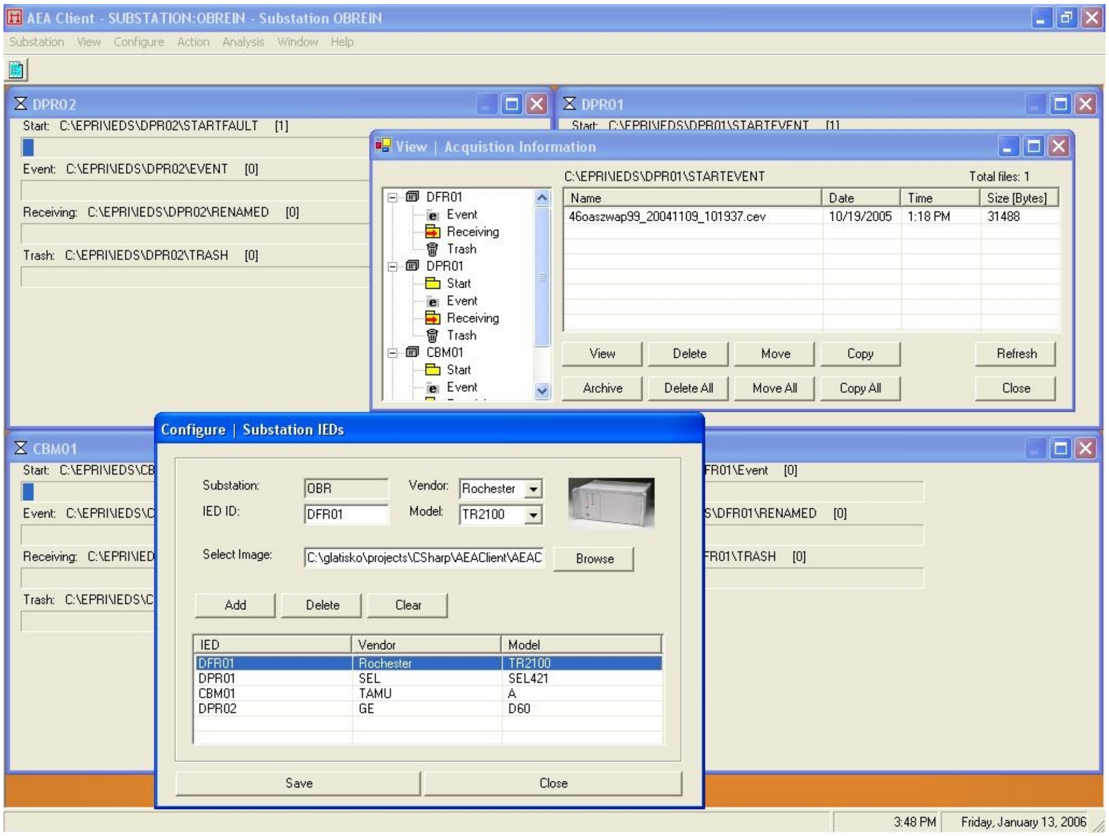

Figure 4 Substation AEA Client application

- DFRA (Digital Fault Recorder Analysis) - 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. Figure 5 displays the architecture of DFRA application.

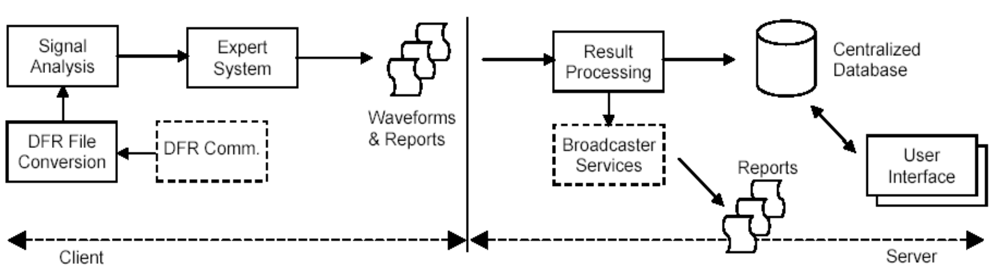

Figure 5 Architecture of DFRA application

- DPRA (Digital Protective Relay Analysis) - 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. Figure 6 shows architecture of DPRA application.

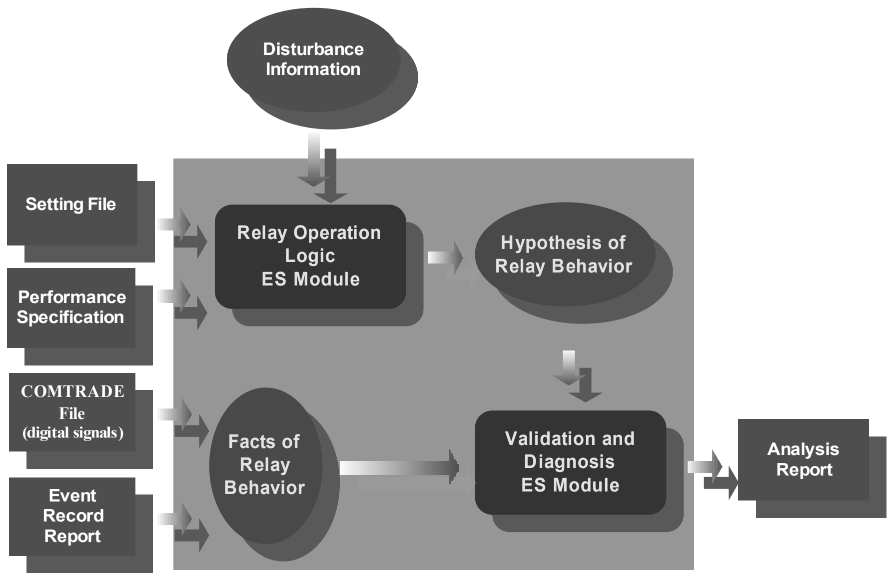

Figure 6 Architecture of DPRA application

- CBMA (Circuit Breaker Monitor Analysis) – 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. Figure 7 displays the architecture of the CBMA application.

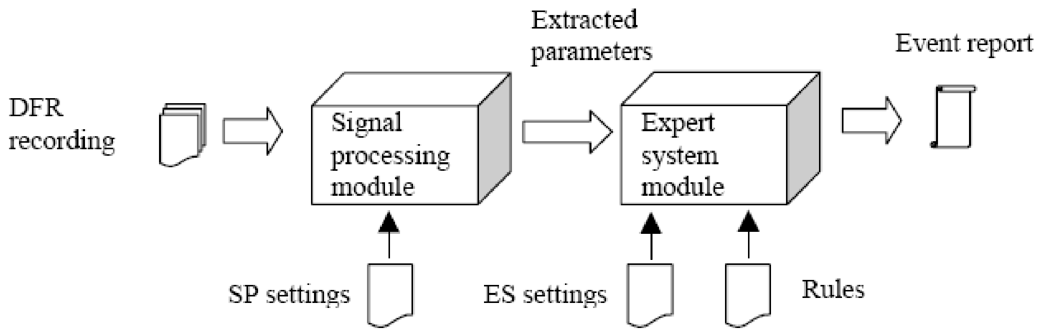

Figure 7 Basic Architecture of the CBMA application

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 (UTC). From the choice of several different systems for reference time transfer, new IEDs typically use GPS . 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 : 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 (Figure 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.

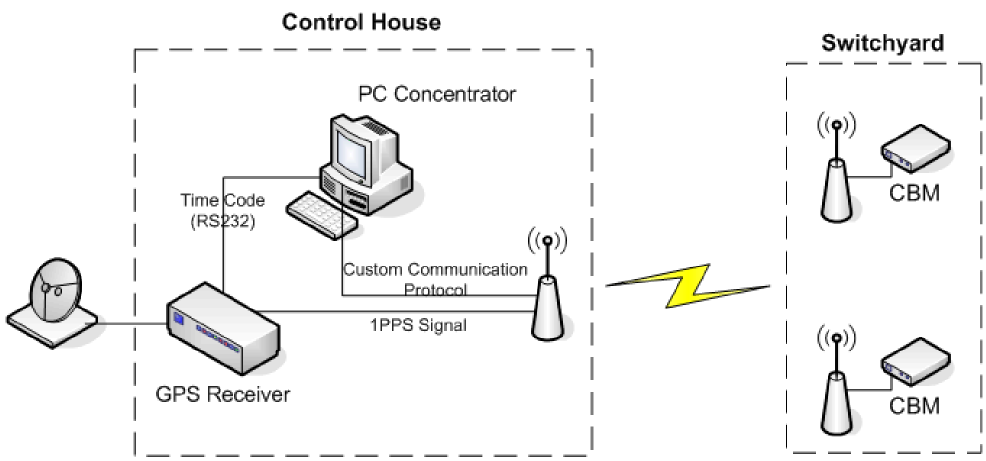

Figure 8 CBM substation setup

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 a 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 (Figure 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.

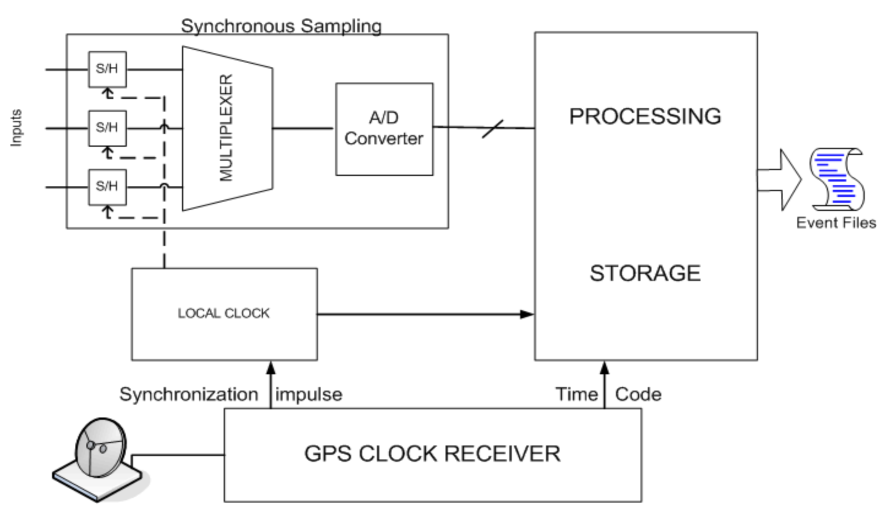

Figure 9 CBM synchronization circuits

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 specifc 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 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 [13]. 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.

Field deployment

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

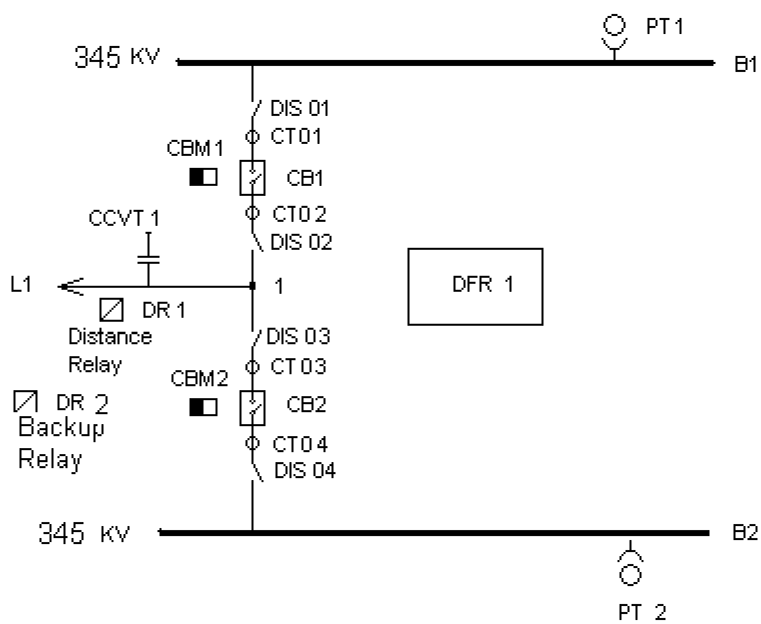

Figure 10 One line diagram of a portion of the substation for field deployment

The field deployment will be implemented in several phases and steps.

- Phase 1- Lab testing and field installation of individual monitoring and control functions:
  - Step 1, testing in the Texas A&M University (TAMU) lab using digital simulator
  - Step 2, testing in CNP substation using field data

- Phase 2- Lab testing and field installation of an integrated monitoring and control functions:
  - Step 1, testing in the TAMU lab using digital simulator
  - Step 2, testing in CNP substation using field data

The project was started in 2005 and all the deployment phases are expected to be completed in 2006. The system will be in service for some time for evaluation of the performance and implementation improverments before further deployment.

Conclusions

Major benefits that this new application will bring are:

- Integration of IED data acquisition functions will allow 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 will allow 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 will enhance 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 will be enhanced through various means of distributing the analysis reports including pagers, company Intranet, and web-based services.
- Automation of the data analysis will reduce the time and provide means for dealing with an overwhelming amount of data being collected by IEDs.
- Improved management of data and analysis reports will allow maintenance crews and asset management staff to keep both

instantaneous and time-correlated account of events and associated equipment performance.

Acknowledgments

This project is funded by EPRI. The reported research on circuit breaker monitoring was coordinated by the Consortium for Electric Reliability Technology Solutions (CERTS), and funded by the Office of Electric Transmission and Distribution, Transmission Reliability Program of the U.S. Department of Energy under Interagency Agreement No.DE-AI-99EE35075 with the National Science Foundation. The support for the project also comes from CNP in Houston, Texas where the hardware and software developments from this project have been installed for field-testing.

Besides the authors, many staff contributed to the developments reported in this paper, particularly CNP staff Christopher Mogannam, John Lucey, Ed Koch and Robert Lunsford, as well as Texas A&M research staff Goran Latisko and graduate students Xu Luo, Zarko Djekic, and Anisha Jonas.

References

[1] "RTR-84 Circuit Breaker Response Recorder", Hathaway Systems Corporation, Belfast, Ireland.

[2] "IEC PAS 62030, Digital data communications for measurement and control - Field bus for use in industrial control systems, Section 1: MODBUS® Application Protocol Specification V1.1a", www.iec.ch

[3] Chuck Forsberg , "XMODEM/YMODEM Protocol Reference", [online]. http://www.commonsoftinc.com/Babylon_Cpp/Documentation/Res/KYModem.htm

[4] Final Report of IEEE Power System Relaying Committee Working Group H8, 2001, "File Naming Convention for Time Sequence Data", *Fault Disturbance Analysis Conference*, Atlanta, Georgia

[5] IEEE Std. C37.111-1991 "*IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems*", IEEE Inc.,1991

[6] IEEE Inc., 1999 "IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems", IEEE Std. C37.111-1999

[7] M. Kezunovic, T. Popovic, "Integration of Data and Exchange of Information in Advanced LAN/Web Based DFR Systems," Fault and Disturbance Analysis Conference, Atlanta, Georgia, April 2002

[8] X. Luo, M. Kezunovic, "An Expert System for Diagnosis of Digital Relay Operation," 13th Conference on Intelligent Systems Application to Power Systems, Washington DC, USA, November 2005.

[9] M. Kezunovic, et. al. "Automated Monitoring and Analysis of Circuit Breaker Operation", IEEE Trans. on PWRD, Vol. 20, No. 3, July 2005.

[10] W. Lewandowski, J. Azoubib, W.J. Klepczinski, "GPS: Primary Tool for Time Transfer" Proceedings of the IEEE, January 1999.

[11] Range Commanders Council, "IRIG Standard 200-04", New Mexico, September 2004.

[12] R.E. Crochiere, L.R. Rabiner, "Interpolation and Decimation of Digital Signals – A tutorial review", Proceedings of the IEEE, March 1981.