MANAGING THE RETRIEVAL and ANALYSIS of EVENT and FAULT RECORDS at NATIONAL GRID

LESSONS LEARNED

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Introduction

The August 14, 2003 Blackout increased awareness as to the value of non-operational data. Non-operational data provides information that aids the Protection Engineer in analyzing power system operations. This same data may also provide valuable fault type and distance to fault information to the System Control Center allowing a dispatcher to make decisions on sectionalizing and restoring transmission lines to service. National Grid initiated a project in October of 2001 to automatically retrieve event and transient records from digital relays and fault recorders, regardless of manufacture. The integrated application also includes a common viewer for display and analysis of various types of transient records.

National Grid's increased use of digital relays and digital disturbance recorders provide many sources of event and fault information for disturbance analysis. As recent as ten years ago this information was retrieved only when the engineer required detailed information to better analyze a disturbance. Often the retrieval of these records required field operating personnel to visit the substation and collect the fault information, sometimes several days later. As a result of this method of retrieval, transient records were often overwritten. Advances in technology and more reliable communications allow for the automated remote retrieval of these records. Collecting the fault information automatically reduces the risk of losing fault data that an engineer needs to analyze a power system operation.

Each manufacturer's digital relay or disturbance recorder typically requires the use of vendor specific software program to retrieve and display the proprietary records. This can be frustrating to the engineer, who has to use several, sometimes confusing, programs to display the records, switching between screens to analyze a disturbance. National Grid's data retrieval program includes the use of a universal analysis tool to display for analysis the many different types of transient records in a common viewer. This paper outlines National Grid's data retrieval and analysis program. It discusses the benefits, lessons learned and identifies potential uses for the retrieved records.

Architecture of System

In October of 2001 National Grid began a project to retrieve fault and event records as a result of a major operation that occurred in March of 2001. During the investigation a need for additional records to complete the analysis was identified. Many of the records had been overwritten because of the time that had lapsed. The records are now retrieved daily and upon request from the fault recorders and microprocessor relays in eighty transmission substations using a desktop computer as the master station, and a universal data retrieval and display software package. The project incorporated existing communication processors installations, and for stations that need a communication processor a pc-104 computer is installed running software that can locally retrieve and store the records for later retrieval. The intention of the poll by request was to provide the System Control Center, with a fault summary record listing distance to fault and fault type from the relays within fifteen minutes of an event. This would enable a dispatcher to make decisions about transmission line restoration.

The retrieved records are transferred to a networked server and can be accessed by client computers running the same universal retrieval and display software.

Included in the project was development of a driver to allow a poll to be initiated by request along with development of drivers for each type of fault recorder and relay in National Grid's system. These drivers were to be made portable, meaning that they would be used by the master station and the pc-104 computers installed in the substations.

Master Station

The master station uses two standard desktop computers for dial-up access to the transmission substations. The main computer has four modems with dial-out access only phone lines (Figure 1). The second computer is acting as a bridge to the network. The role of the bridge computer is to monitor the master computers hard drive and transfer any new records retrieved to the server. The master station is located in a secured room that requires key card access for security.

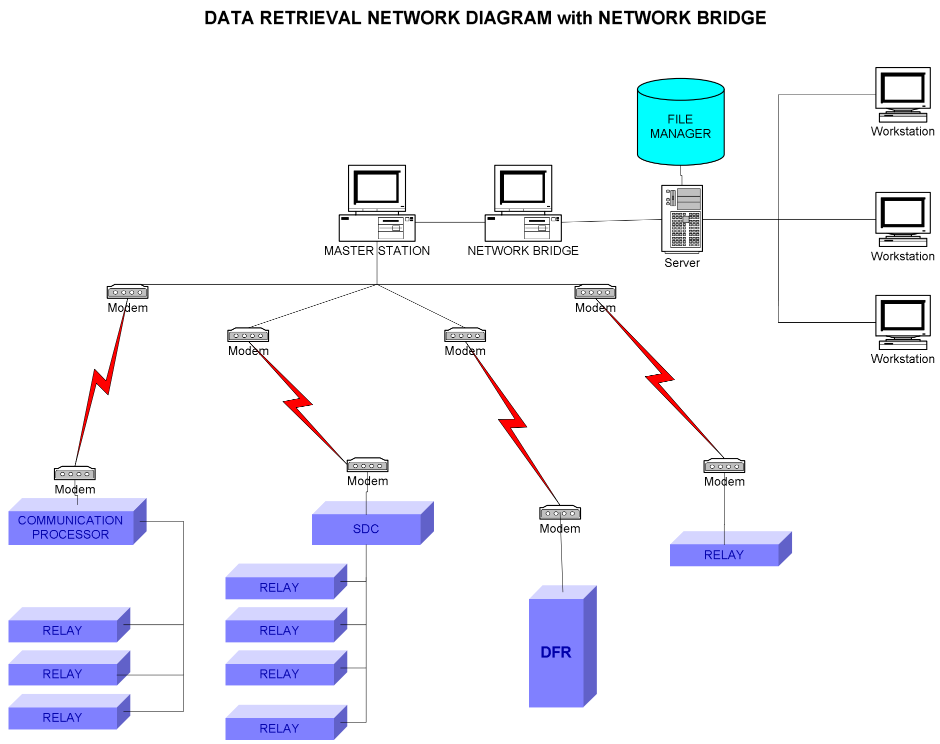


Figure 1 – System Architecture

The client computers have direct access to the event and fault records stored on the server, utilizing the software, which is launched as a National Grid business application over the corporate intranet. An engineer can search the records stored on the server using the file folder window in the software.

The relays and fault recorders are polled on a daily schedule that is controlled by the software's device manager. If an event occurs after the normal polling schedule the engineer may request a poll. When a poll is requested by the engineer a message is placed in a folder on the server that is monitored by the master station.

Substation IED Connections

There are three different substation networks that are part of the polling system. The first is a direct modem connection to the individual relays accessed through a telephone port switch. The second is a modem connection to a communication processor that can have up to sixteen ports. The third is the pc-104 computer (Figure 2), to be referred to as the Substation Data Concentrator (SDC) from this point forward.

The SDC has the data retrieval software installed and is set to poll the fault recorders and relays at fifteen minute intervals. The SDC stores the retrieved records on a flash drive. These records are then transferred when the master station calls during the scheduled polling time.

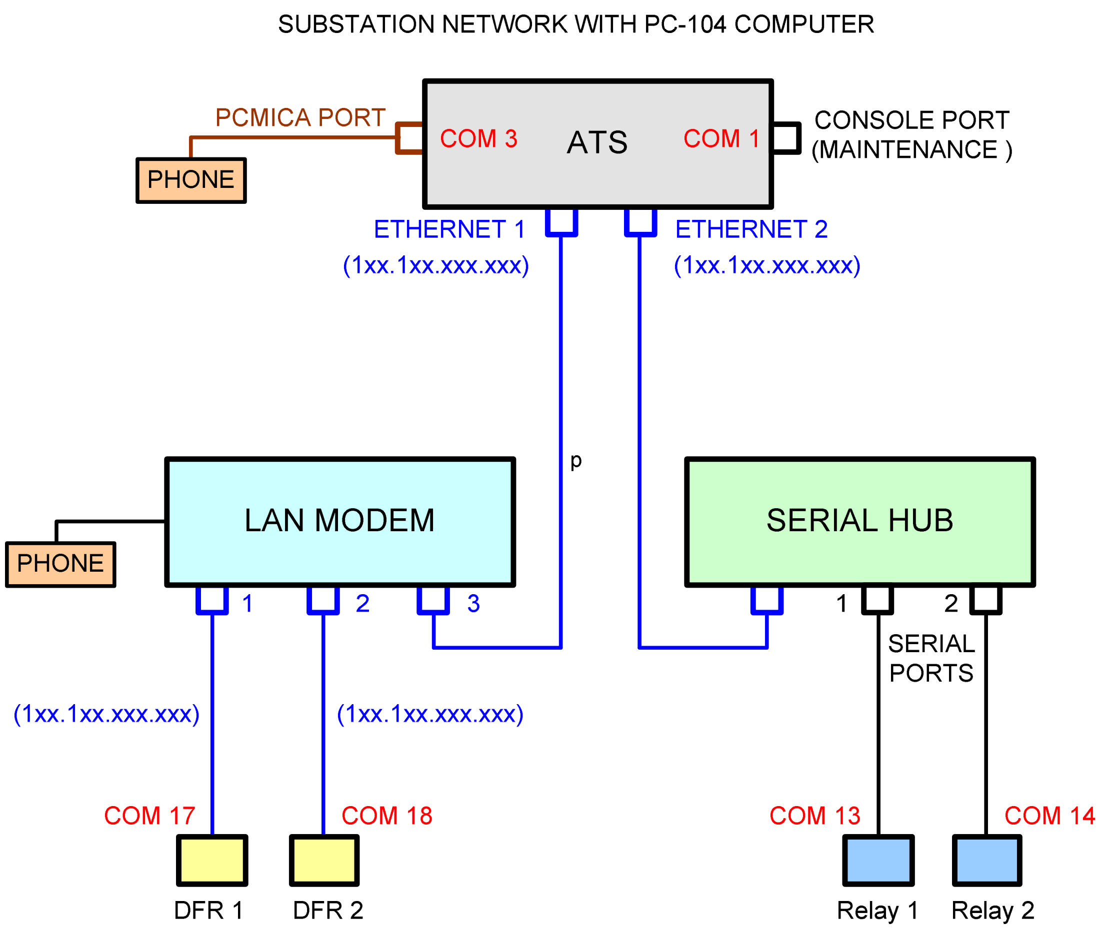


Figure 2 – Substation Network

Communications

The most common communication link for fault recorders and relays at present is a RS232 serial connection. These devices are typically connected directly to a modem or a communication processor with multiple serial connections. Serial connection speed range from 2400 bps to 115200 bps and the retrieval of a record can take from several seconds to minutes to retrieve.

New generation fault recorders and relays offer Ethernet connectivity that allows the use of Telnet or FTP (File Transfer Protocol) for retrieval of the records. This connection method is much faster for the retrieval of records. For example, a 1 MB record that could take greater than a minute to retrieve at 28.8k bps only takes twenty seconds via FTP. If the Ethernet connection is a TCP/IP connection, multiple sessions can be operating simultaneously, such as the SCADA data and the fault record retrieval data using two different TCP ports for communications.

Remote access to the substations is primarily done via a dial-up modem connection. Some fault recorders and communications processor offer dial-up networking through a PPP (Point-to-Point Protocol).

The Universal Software

The software is designed as a device independent universal data retrieval and analysis solution for fault and event records. The software has a library of device interfaces (drivers) that are continually updated as new relays are added to the system. Today, most manufacturers records can be displayed in a common viewer for analysis and about sixty-percent of these are able to be retrieved remotely.

The software is comprised of four main components, the Device Manager, which is a table where the communication parameters and drivers for each device to be polled are entered. The Multiple Interrogation Display (MID) is the part of the package that initiates the polling based on the schedule or a request placed on the master station. The File Manager, which is a simple file folder, with extended features that simplify searching and sorting of the retrieved records. The last is the Display, which copies the selected files for display and opens them for viewing.

Fault and Event Record Retrieval

The Device Manager (Figure 3), MID, and drivers are integral for polling the remote devices. The devices are entered into the device manager and the drivers are logically assigned to the modems, communication processors, relays and DFRs, to be polled. The drivers are then assigned to initiate the modems, dial, log into the communication processor, switch to the relays, retrieve the records, and then hang-up. The drivers are written in a script language that is designed to be universal for each device and can be used by the master station or the SDC. Once the Device Manager is configured the MID (Figure 4) is launched and the scheduled polling of the devices is initiated.

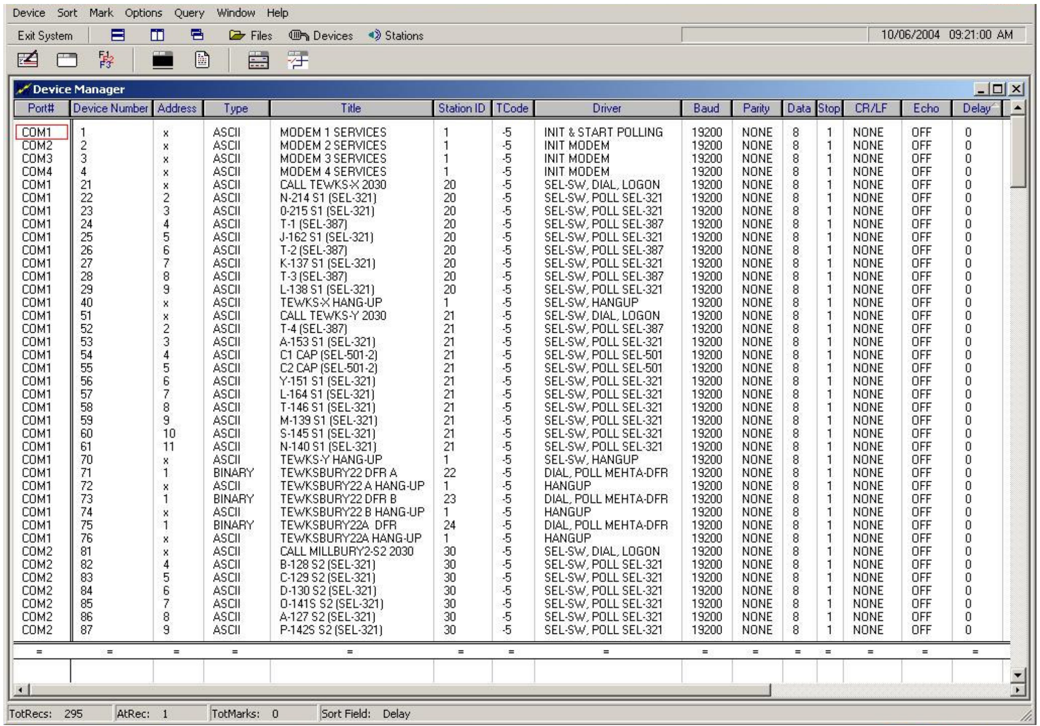


Figure 3 - DEVICE MANAGER

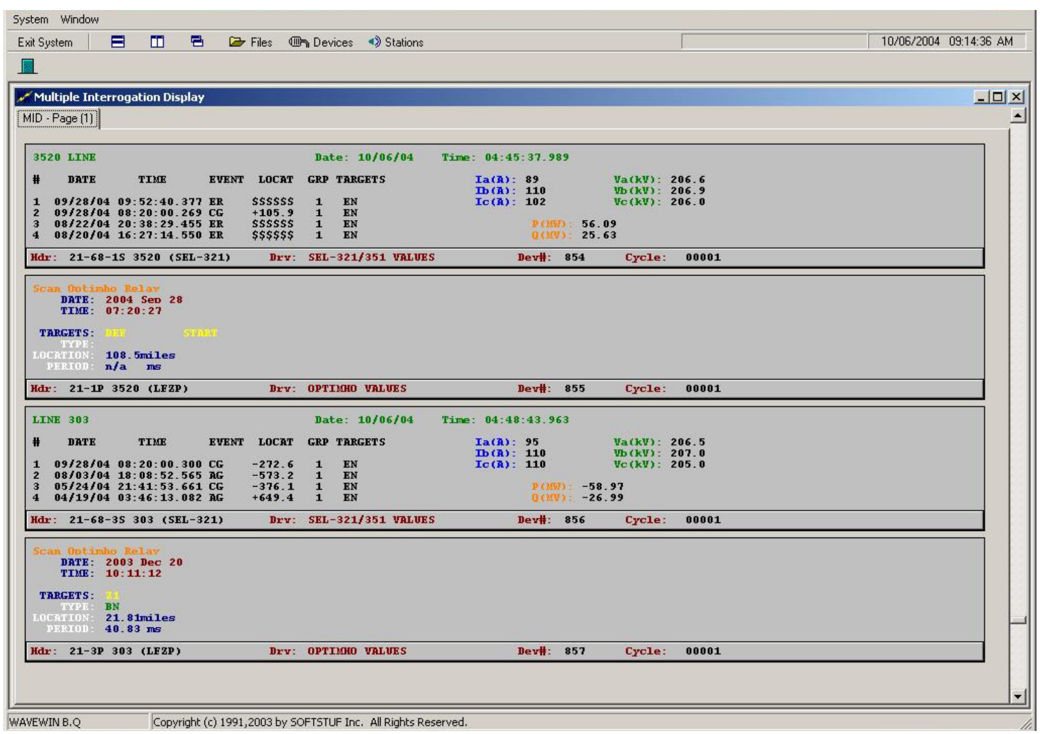


Figure 4 - MULTIPLE INTERROGATION DISPLAY (MID)

The client interface (Figure 5) and assigned drivers enable the poll-on-demand functionality. The user interface was created using a conventional drawing program. The drawing displays the outline of a communication processor or SDC to which the attached devices logically mapped. To initiate a poll, the user selects a station then strikes the Enter key to bring up the station polling list. The user then selects the “Request Data” button in the pop-up menu to initiate a poll. This places a message in the station folder on the server, which is continually scanned by the master station software. Once a poll is initiated a message pops up stating that “A poll is in progress please wait approximately three to ten minutes for the records to be retrieved.” An identifier is placed next to the station name to indicate to all users a poll is in progress (Figure 6). A user must manually refresh the information on the station screen to determine when a poll is completed. When complete, the identifier is removed from the station tab. When a device is polled, a meter reading is taken and displayed in the station diagram along with the date of the last successful communication with the device. This is done to provide the user with an indication of general relay health.

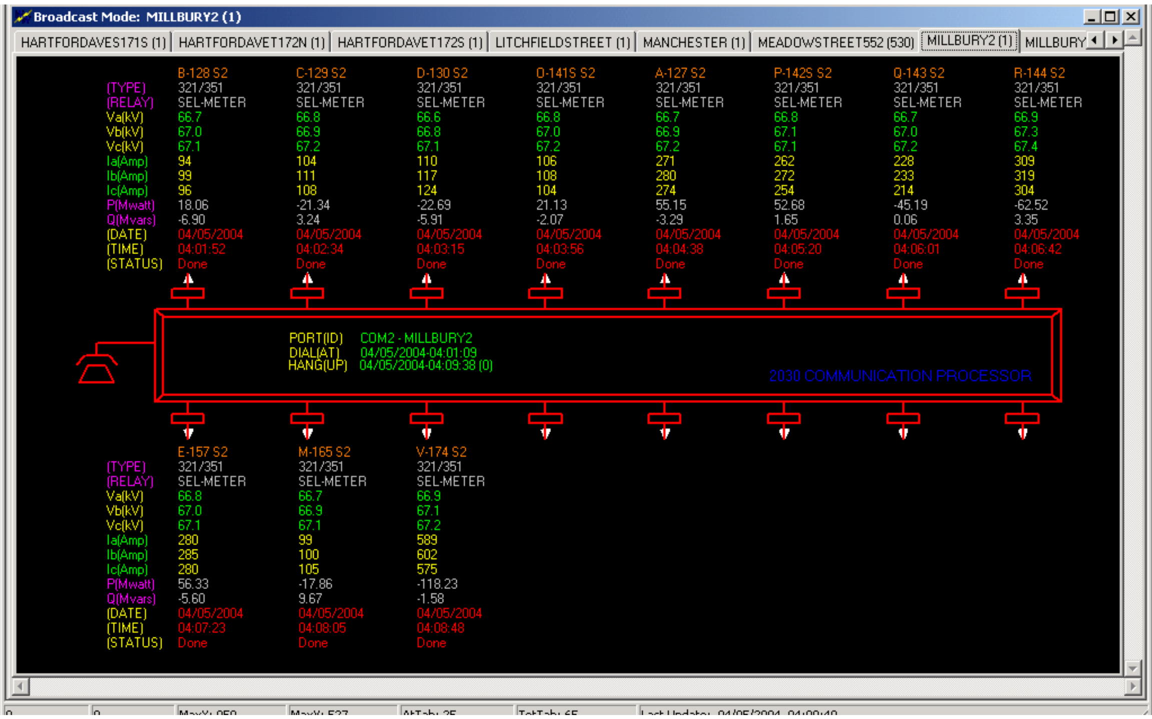


Figure 5 - CLIENT INTERFACE

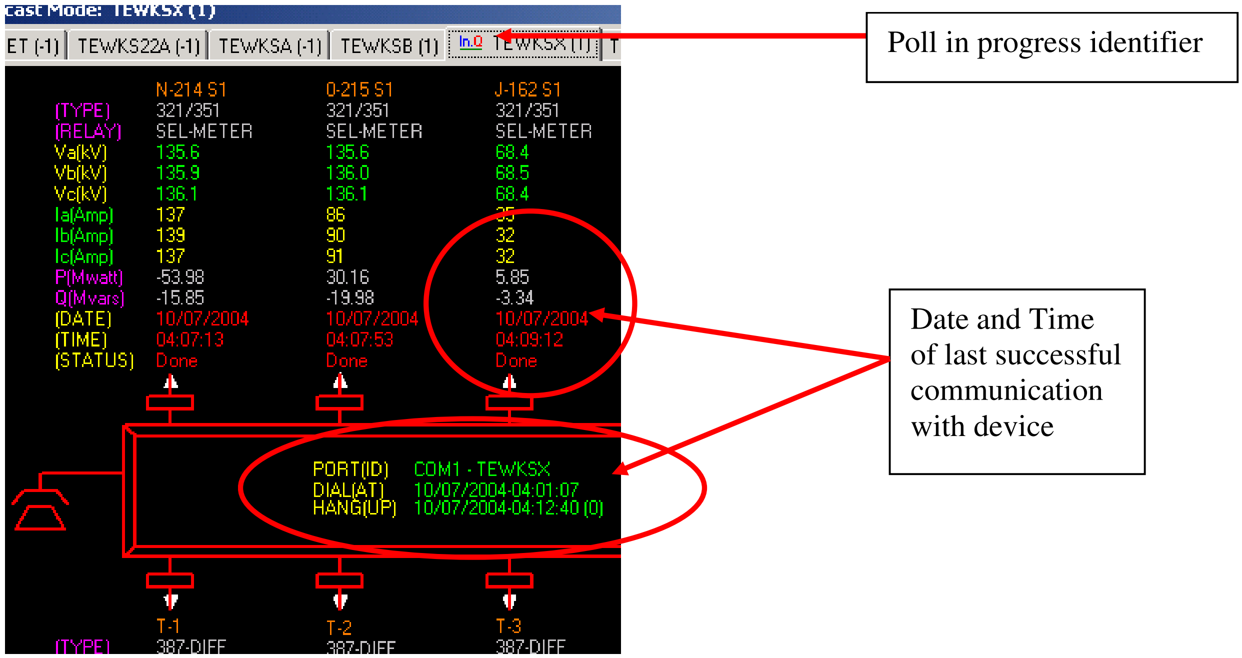
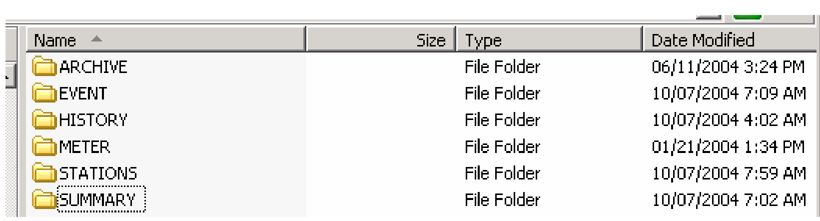


Figure 6 - STATUS INDICATIONS

Transient Record Management

As mentioned above the retrieved records are stored on a server that the client computers can access. To facilitate searching for a record a simple directory structure was created. Separate folders were created to store event data, summary data, metering data, history data and station information including polling request messages (Figure 7). A standard fault summary record format was outlined (Figure 8) in anticipation of creating a reporting application that would send fault information to the System Control Center. This was required as not all models of relay provide a history file that could be used as a summary.



Name	Size	Type	Date Modified
ARCHIVE		File Folder	06/11/2004 3:24 PM
EVENT		File Folder	10/07/2004 7:09 AM
HISTORY		File Folder	10/07/2004 4:02 AM
METER		File Folder	01/21/2004 1:34 PM
STATIONS		File Folder	10/07/2004 7:59 AM
SUMMARY		File Folder	10/07/2004 7:02 AM

Figure 7 - DIRECTORY STRUCTURE

Date: 07/02/04
Time: 02:39:33.35
Station: STATION C
Device: 115kV LINE S1
Event: ABG T
Location: +2.17
LineLen: 8.70
Targets: INST ZONE1 EN A B G 50

Figure 8 - FAULT SUMMARY RECORD

The records stored on the server are renamed following the IEEE Power System Relaying Committee H8 Working Group recommended naming convention. The file name includes the date and time at which the record was triggered, the time zone offset, the station name, the circuit number, and the company name. The naming convention allows for easier searching for records in the directory. An Example of a filename is as follows:

031014,10082069,-5,VERNON#13,B2 S1 PODD-PODG ,NGRID.RLY

The File Manager (Figure 9) is used to search for the files. Users can sort by file name, fault date, fault time, or any other type of information provided in the filename by selecting the name on the upper Title Block of the file manager or they can enter the desired search criteria in the lower search fields.

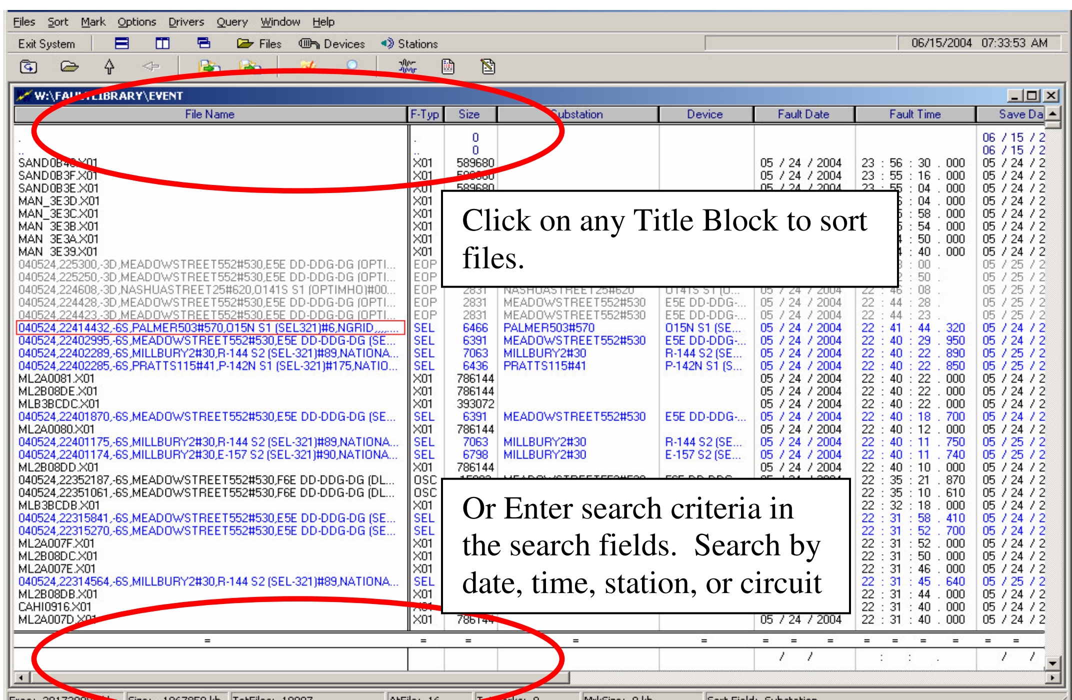


Figure 9 - FILE MANAGER

All retrieved records are stored in their native manufacturer's format. Records can be converted to the COMTRADE for exchanging information by using the program's COMTRADE conversion utility.

Fault Analysis

The user interface includes a display function that opens the records and offers three main viewing windows for post-fault analysis. The first is the waveform display which presents the user with the transient analog and digital I/O. The second is a tabular format that presents phasor quantities such as magnitude and angle and the third is the phasor display. Figure 10 shows each of these display options.

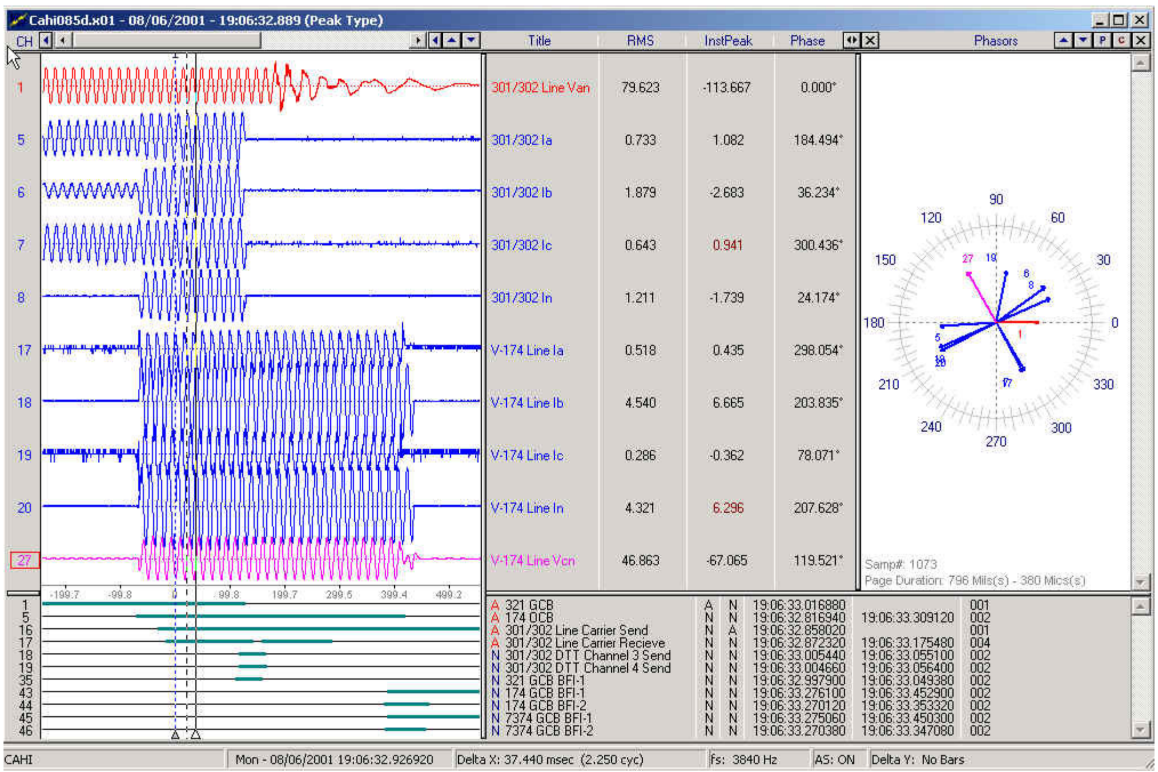


Figure 10 – 345 kV and 115kV record

Two examples follow; where the display feature of the software was used to aid in the investigation of a fault.

Example One:

On August 6, 2001 the 174 line between Millbury 2 station and Carpenter Hill station faulted (Figure 11). Both terminals tripped clearing the fault. The breakers at the Millbury 2 terminal auto-closed back into the faulted line. Figure 10 above displays the fault record captured at Carpenter Hill when the 174 line was re-energized. Before the Millbury 2 terminal opened the 301/302 Carrier Directional Ground (CDG) relay at Carpenter Hill operated sending a transfer trip to the Ludlow and Millbury 3. The 174 Line then tripped and locked out at Millbury 2.

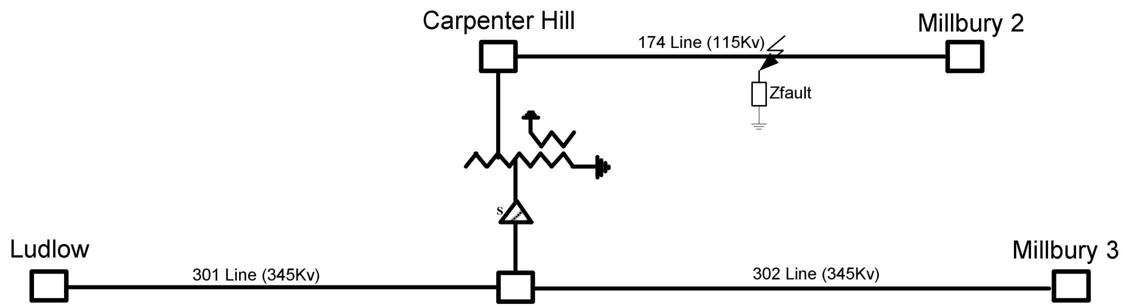


Figure 11 – One line for 174 and 301/302 Lines

The analysis tools in the software were used to calculate the polarizing voltage (Figure 12) showing that the combined neutral current and voltage was high enough to operate the directional element of the relay. A short circuit analysis program was used to verify this and during the analysis it was discovered that mutual coupling between the 174 and 302 lines contributed to the Carpenter Hill 301/302 CDG operation.

Follow up action identified the polarizing source of the CDG relay was from the bushing potential devices on the high side of the transformer. It was discovered that the mutual coupling effect between the two lines was the primary cause of the incorrect directional sensing of the CDG relay which contributed to the operation. However, Engineering decided to relocate the polarizing source for CDG relay to the 115 kV Capacitive Coupling Devices on the low side of the transformer providing a more secure voltage polarization source.

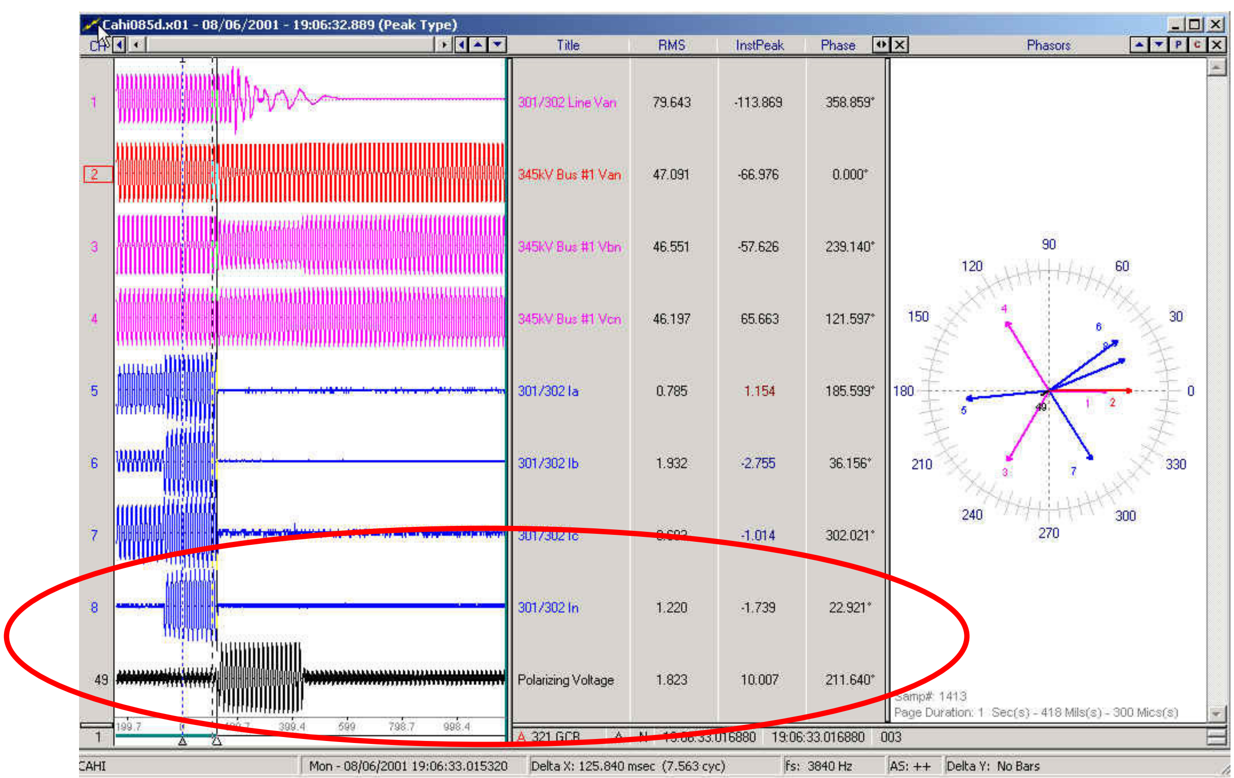


Figure 12 – Calculated Polarizing Voltage

Example 2: On November 20, 2004 the 314 and 343 lines between Sandy Pond substation and Millbury 3 substation operated several times during a heavy rain. Based on fault records captured by Digital Fault Recorders at Sandy Pond and Millbury 3, the 314 Line operated improperly.

As per fault records captured at Sandy Pond and Millbury #3 substations (Figure 13) the sequence of the 343 and 314 operation are as follows:

1. The 343 line at Sandy Pond tripped for the fault (Figure 14a).

2. Immediately after the 343 opened at Sandy Pond a current reversal (Figure 13, item A) on the 314 line occurred. At this moment the 314 Carrier Blocking scheme at Sandy Pond momentarily stopped transmitting a blocking signal to Millbury #3 (Figure 13, item B and Figure 14b).

3. When the current reversal occurred, the 314 carrier trip relay at Sandy Pond sensed high enough fault current in the trip direction. Since it did not receive the blocking signal from Millbury #3 the 314 line at Sandy Pond tripped and sent a direct transfer trip (DTT) to the 314 terminal at Millbury #3 (Figure 14c) before the 343 terminal at Millbury 3 tripped. Figure 13, item C, shows phase relationship of the 314 line at each terminal and indicates normal power flow from Sandy Pond to Millbury 3.

4. Finally, the 343 line at Millbury #3 tripped, isolating the 343 fault.

The determination was that the improper operation of the 314 line was due to the time coordination within the 314 line carrier blocking scheme. Of interest was that when initially placed in service in 1989 the settings were done per the manufacturer's recommended settings in the instruction manual.

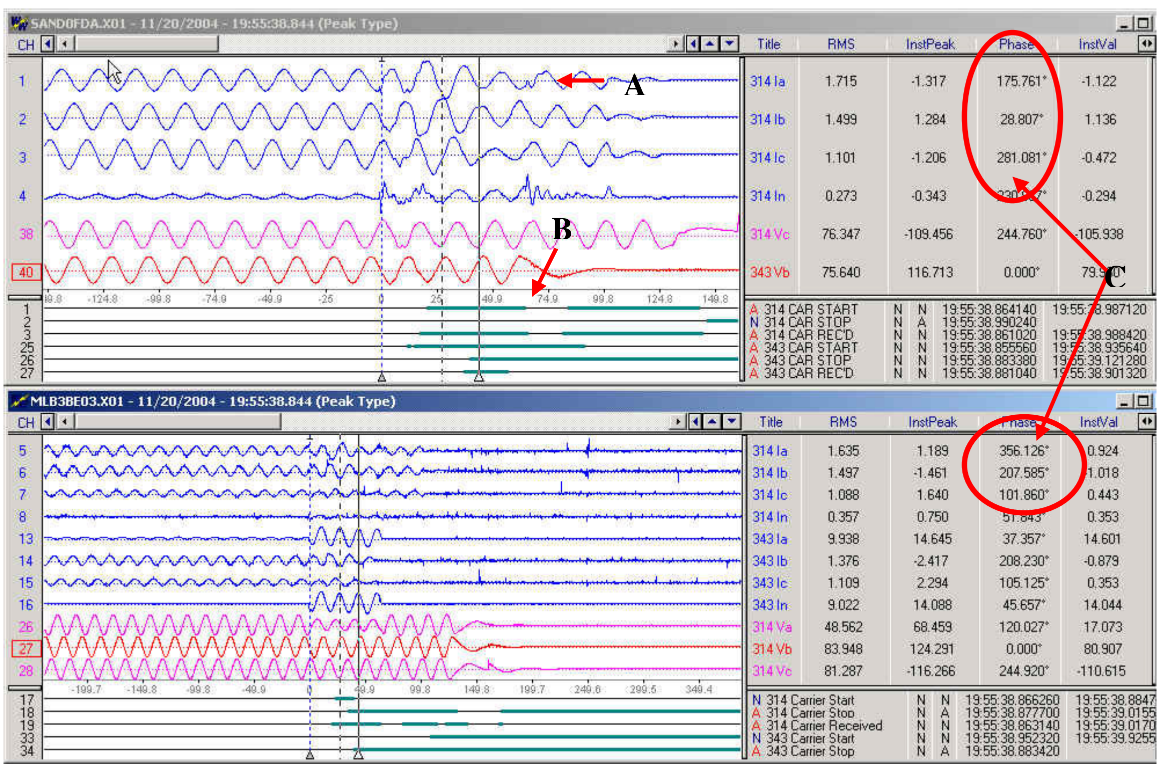


Figure 13 - Sandy Pond and Millbury Fault Records

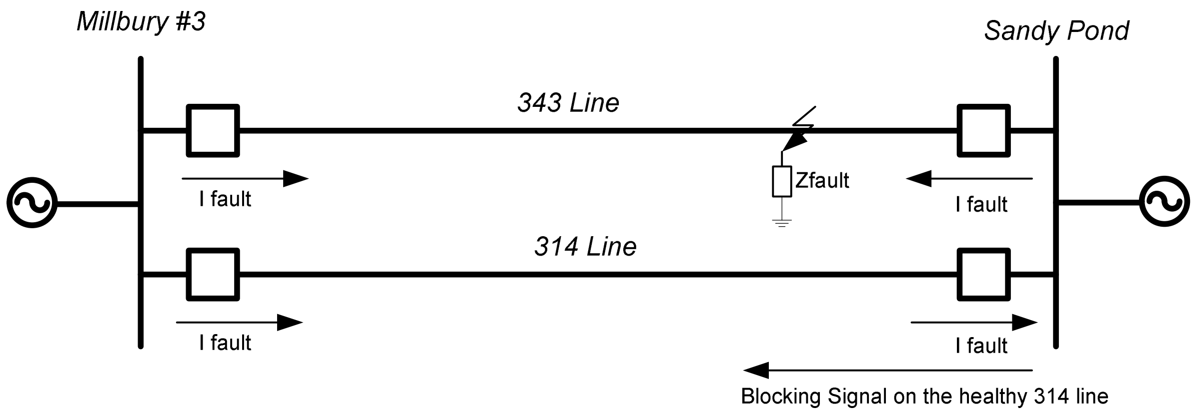


Figure 14a - 343 Fault Occurs

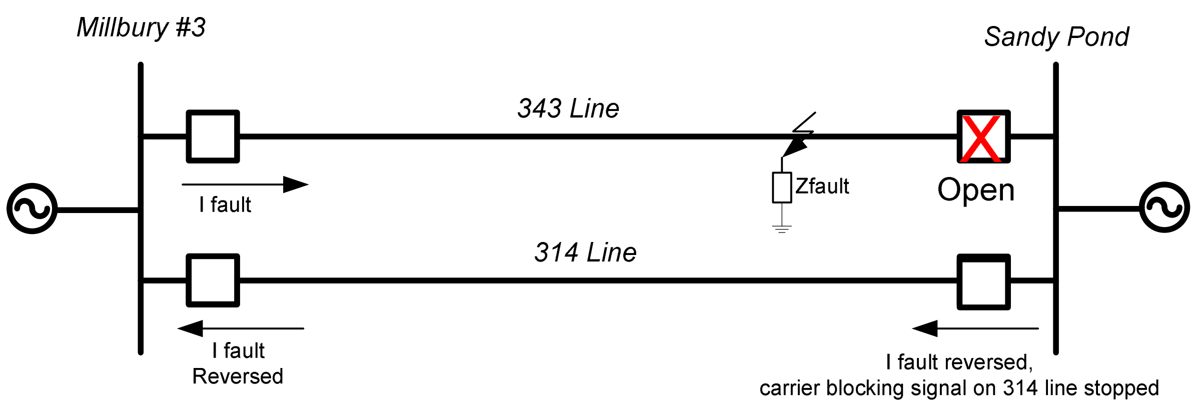


Figure 14b - Sandy Pond End of 343 Line Tripped

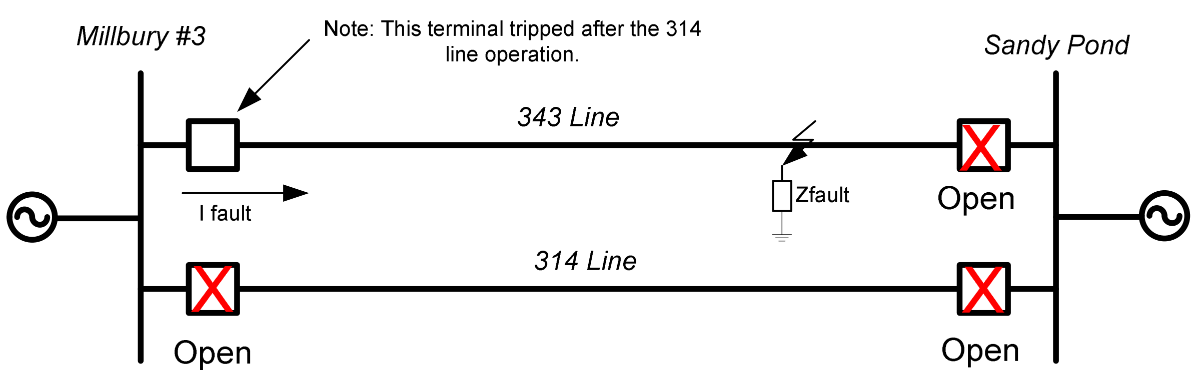


Figure 14c - 314 Line Tripped Due to Current Reversal and loss of block signal

Lessons Learned

Developing and implementing a data retrieval system for event and transient records turned out to be a complex task. Lessons learned about the development and implementation issues that arose are discussed in this section.

Lesson 1: An automated data retrieval system must be available 24/7.

During the first twenty-four hours of operation, the new master station had shut down. An investigation revealed that the building's emergency back-up system had been tested during the off hours. To prevent this from occurring again, an uninterruptible power supply was added so the master station would ride through these tests and other possible power interruptions.

Lesson 2: Phone line connections are slow and often unreliable:

Dial up connections have been problematic. The phone circuits are proving to be an unreliable method of connectivity and data transfer. The phone lines are subject to noise and interruptions causing the modems to sometimes disconnect during record transfer. When this occurs, the record that is being retrieved is often corrupted and must be retrieved again. This is problematic because the software cannot tell if the retrieved file is a partial record or the data becomes corrupt. At present a manual retrieval must be initiated to get this record again.

To relieve the interruptions in retrieval that cause the phone to disconnect, a retry on failure function was added to the application. When the master station fails to make a successful connection to the remote station, the station is placed back in the queue and is redialed once the scheduled polling is complete. The application is set to make two additional connection attempts to a remote station. If these two attempts fail, the application waits until the next scheduled poll and the user interface is not updated.

National Grid is beginning to migrate towards frame relay circuits for the Energy Management System for SCADA. With the available bandwidth of this type of connection the company plans to include access to the fault recorders and relays in the substation over this communication channel.

Lesson 3: Guaranteeing the quality of the fault records is difficult.

As mentioned above, a disconnection in the middle of retrieving a record or a poor quality phone line can cause the record to become corrupt. The quality of this data cannot be controlled over a phone line, as many IEDs do not have a means of compressing the created records for transfer and nor do the IEDs do any form of error checking. The data retrieval application is also unable to verify the integrity of the record, as it relies on the reporting IEDs to provide the error and end of record indications. The data retrieval software may not be the best place for doing a quality check of the data due to the wide variety of record types being retrieved. Until a method of checking the data can be found, the risk that transient data will be lost if the corrupt record is not identified in a timely manner exists.

One possible solution to improve the quality of data is sending it over frame relay networks. The data is being transferred is broken into packets and sent to the remote terminal. The receiving frame relay reassembles the packets and requests any corrupt or missing be resent.

Lesson 4: Developing a universal data retrieval platform is difficult.

When National Grid began this program we assumed that manufacturers would be willing to provide us with the necessary communication protocols and file formats for display. It did not turn out to be as easy as thought. Some manufacturers are reluctant to supply their proprietary communication formats. After continued discussions with the different manufacturers we eventually received the necessary protocol information.

Acceptance of the universal data retrieval program has also been difficult within National Grid as well. Management was supportive, because of the potential benefits improving system reliability because engineers would have quicker access to the data for post fault analysis. However, the field operations groups that are needed to support the installations were not as supportive, because it is another responsibility added on to their already stressed workforce.

National Grid has learned how to effectively communicate with the IED manufacturers and operations group, which has improved our ability to expand the data retrieval program. The manufacturers are able to realize the potential commercial benefits of this type of platform. Acceptance and support within the operations group is growing slowly. To help with the acceptance of the program a user's manual is developed for each installation.

Lesson 5: Pay attention to details.

The first stations polled were ones where a communication processor already existed. The communications processors are connected to the station battery and each modem is modified to run off the internal direct current power of the communication processor port. The SDC was designed as an alternating current powered pc-104 computer. The first SDC installed was connected to a 120 vac power source. When the blackout of August 14, 2003 occurred, it raised awareness that should a similar event happen again, the ac-powered SDCs would not function until power was restored. Immediately following an event it is important to be able to retrieve these IED event records as quickly as possible. The SDCs are now connected to the substation battery for all installations.

Lesson 6: Be prepared for more work than you planned on.

When the pilot program was first implemented it included only event data from protective relays. When fault recorders were added to the polling list the volume of records being retrieved increased greatly. The large volume was impacting the performance of the master station and preventing records from being retrieved in a timely manner.

It was discovered that National Grid needed to evaluate the trigger settings in all fault recorders. An engineer would typically set the fault recorder triggers to be very sensitive to system changes. This caused a typical recorder to trigger several times during a 24-hour period. It was generally thought that too sensitive was better to guarantee a record would be triggered when needed. Fault recorders triggers are now evaluated for each installation. Once a fault recorder is installed, the records are retrieved daily to evaluate the triggers that occurred and the trigger settings are adjusted so that they do not initiate a record for normal system conditions.

The large volume of records also affected the master stations performance. The initial master station configuration did not include the "Network Bridge" shown in Figure 1. Initially a serial port on the master station was used to monitor the folder where the records were stored and when a new record was detected the software application would transfer it to the server. Due to the large volume of records it was taking up to five hours to transfer all of them to the server. The network bridge was added to perform this process instead of the master station. This noticeably improved performance and the records were being transferred at a quicker rate. To improve the file transfer process a file transfer protocol (ftp) driver is being tested to further speed up the transfer.

Lesson 7: Plan for contingencies

The project identified eighty transmission substations, which were to have the event and fault records retrieved for relays and fault recorders over a two year period. At the close of the two years thirty-seven stations were being polled, and records were being retrieved from 234 IEDs. There were several factors that contributed to the project status. The project schedule was developed assuming that it would be a full time effort and that the application was a fully operational commercial software package. In actuality resources worked part-time on the project, as there were many competing projects with limited resources. The application worked well on the installed base of communication processors in the substations. However, when the SDCs were installed, it turned to a development effort.

The vendor had been involved in other projects where the application software was installed on the SDC that was also being used in National Grid's project. The key difference in our project was the requirement that the master station control the polling schedule, pulling the records from the substation. The previous project was installed with the installed SDCs calling the master station on a daily schedule and pushing the records to the master. This one change shifted the project from a production environment to a developmental one. The software had to be modified to meet National Grid's requirements. The impact to the project was significant.

National Grid is still committed to installing the substation data concentrators, but instead of a special project, the SDC is included in new substation designs. The estimates for the installation of the SDCs now include development costs and time.

Summary

The data retrieval project demonstrates that transient and event records can be retrieved from a range of relays and digital fault recorders using a universal application. The universal approach will eliminate the need for learning and having to work with a diverse mixture of applications and operating nuances.

With the records being retrieved daily and stored on a networked server helps ensure that important information relating to system disturbances will be available to the engineer when needed. In fact there was one instance where information relating to a fault that occurred six months prior was needed. If the program had not been initiated the records needed would probably would have no longer been available. At best they would have been located on an engineer's workstation.

In addition the file naming convention and specialized file manager tools have proven useful in managing, accessing and archiving fault records. These tools eliminated the need for having to create and maintain a database system which is normally an expensive adventure but especially in this case because of the complex nature of digital fault records.

The retrieved records have proven useful when analyzing a system disturbance. The information contained in the records helps the engineer to improve the protective relay settings, thereby helping create a more reliable system.

Jeffrey Pond has been an employee of National Grid USA for 25 years. He is a Lead Technician on the Substation Systems Integration Team, where he is responsible for the selection and configuration of disturbance recording equipment and RTUs. He has implemented a program to automatically retrieve transient event data from relays and fault recorders. Previously Jeff worked for the Relay and Telecommunications Operations Group, where he was responsible for commissioning, maintaining, and troubleshooting protection and control systems. He also assists the Protection Engineers in performing post-fault analysis of transmission system operations.

Jeffrey received an Associate degree in Electrical Engineering Technology from Wentworth Institute of Technology, in Boston, MA, and a Bachelor of Science degree in Business Management from Lesley University in Cambridge, MA. He is a member of IEEE and is active in several working groups of the Power System Relaying Committee.

Amir Makki helped establish SoftStuf, Inc. in 1991 where he remains today serving as Chief Engineer. His main experience is in developing tools for management and analysis of digital fault records, and his trademark is the Wavewin Software. Amir is a graduate of Tennessee Technological University (1981 - 1986) and he helped to create a Ph.D. program in Software Engineering at Temple University (1986 – 1991). Amir is a member of the IEEE Standards Association and also a member of the PSRC Main Committee.

References:

"Naming Convention for Time Sequenced Data Files," H8 working group report for the IEEE Protective Systems Relaying Committee (PSRC), PC37.232 Draft 4.7, April, 2005

“A Universal Approach for Retrieving and Analyzing Event & Fault Records,” Jeffrey Pond, Amir Makki; Proceedings of the 2005 Distributec Conference, San Diego, California, January 2005

"IEEE Common Format for Transient Data Exchange for Power Systems (Comtrade Standard)," IEEE Standard C37.111, 1999

"Survey of Event File Naming Schemes," A&M Makki, M. Taylor, Proceeding of the Fault and Disturbance Analysis Conference, Atlanta, Georgia, May 1998