Automated Analysis of Lightning Caused Faults on the TVA Transmission System

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TVA Overview

The Tennessee Valley Authority (TVA) is the largest public power company in the United States, with 33,000 megawatts of dependable generating capacity serving power to 156 locally owned distributors and to about 9 million residents of the Tennessee Valley. Developing advanced power quality monitoring system capabilities has been a high priority for TVA, particularly given the extent of the company's transmission systems.

Background

When a fault occurs on the transmission system, the scope of impact can be very large. It is important to understand the scope of impact. In addition, quickly finding the location of faults when they occur is important to dispatching field personnel thereby returning equipment to service.

Naturally, we have produced reports and SCADA systems that tell us when equipment has failed. However, we still find ourselves asking the questions “Who did this affect?”, “Where was the event?”, “What caused the event?” and “When exactly did this occur?”. In order to restore service, engineers use a myriad of software and tools to manually produce the answers to these questions.

The process for performing fault analysis is time consuming. First, the SCADA system or Dispatcher notices an event has occurred. Once the maintenance area has been identified, field engineers are notified by phone or email that a component has failed. Next, the field engineer begins analyzing data. After analysis, the engineer reports the suspected location to field crews to begin repair. Finally, the field personnel perform the repair and return the asset to service.

There are numerous manual handoffs to return a failed asset to service. Each handoff adds time to return the asset to service. In addition, there are a number of tools required to return the asset to service. For example, every Digital Fault Recorder (DFR) manufacturer has proprietary software to analyze records. So, if there are multiple DFR types, then there are multiple software packages that must be used to analyze the records. There are at least 17 different software tools and packages that a typical field engineer must know in order to perform a single fault location!

Device Integration

Many types of intelligent electronic devices (IEDs) such as relays, digital fault recorders, and power quality monitors can capture disturbance waveforms and characteristics; however, most monitoring system implementations are designed to manage data from a specific set of hardware. Applications that can process these disturbance characteristics from all these devices and develop conclusions about the disturbances themselves or the impacts of the disturbances can therefore significantly increase the value of the monitoring systems. In order to maximize the value of monitoring applications, the data from these many different types of monitors must be integrated into a common database for analysis.

The concept TVA uses is illustrated in Figure 1. It is beneficial if the monitors comply with IEC Standard 61000-4-30 to assure that disturbances are being recorded in a consistent manner. The means of integration is through industry standard data file formats. The IEEE Power Quality

Data Interchange Format (PQDIF) provides the most flexible means of sharing data between applications. For some devices like digital fault recorders and relays that basically only record waveform information, the interface can be based on the IEEE COMTRADE format.

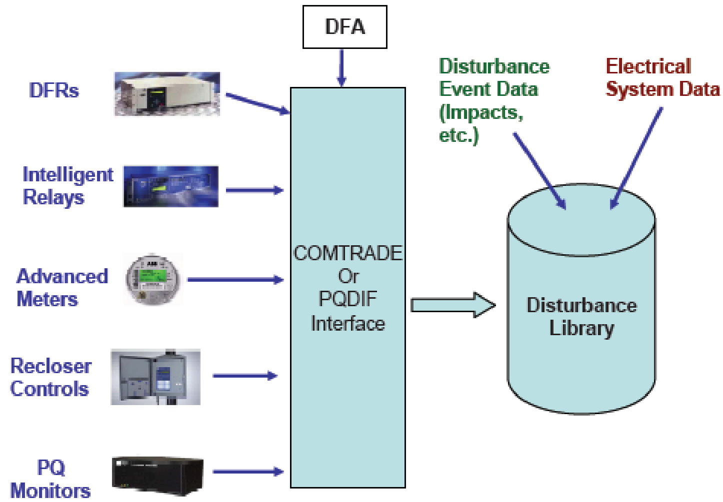


Figure 1 - Integration of monitoring data from different types of monitoring systems for use in data analysis and advanced applications like fault location.

Once the infrastructure is developed to maintain a common database of disturbance monitoring data, many different advanced applications can be implemented. Figure 2 illustrates the general concept of an integrated monitoring system for TVA that uses PQView for implementation of advanced applications.

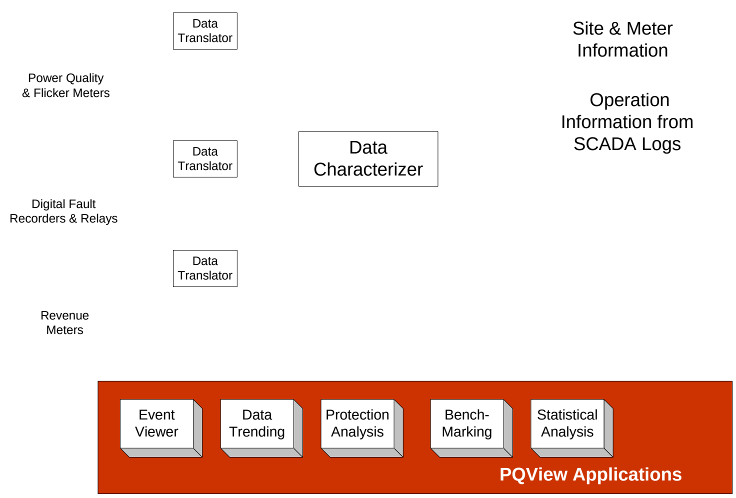


Figure 2 - Integrated monitoring system for implementation of advanced applications like fault location

After the data has been normalized and stored into a disturbance database, the most basic of applications is a data visualization tool. Being able to display basic waveform and phasor data is essential for performing root cause analysis on an event. Figure 3 shows the event viewer.

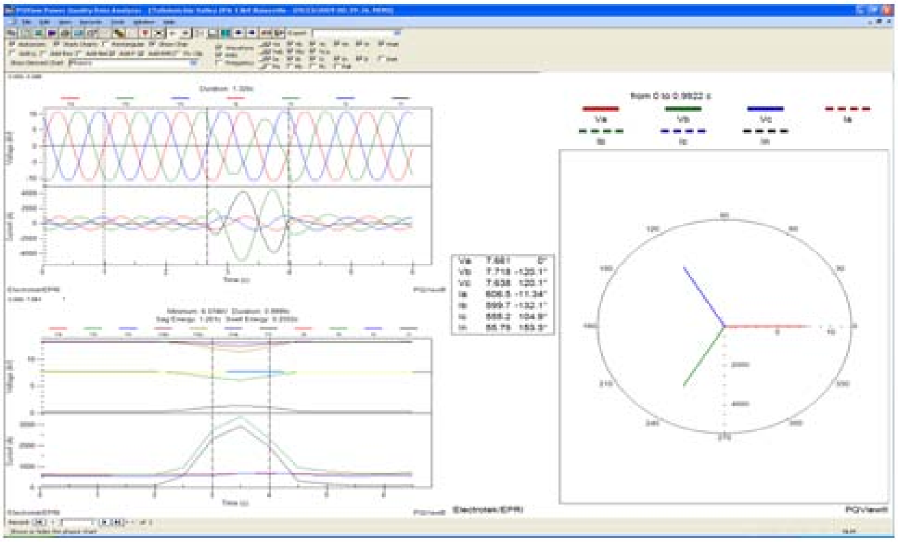


Figure 3 - PQView Event Viewer

Geographic Information Systems (GIS)

While device integration is a key component of an automated analysis system, just as critical is a means to view the results of the analysis. An early realization for the project was that every asset studied is located somewhere physically. As a result, maps became a very effective way to communicate the location of assets. As can be seen in figure 4, below, the location of our transmission lines is stored in a GIS.

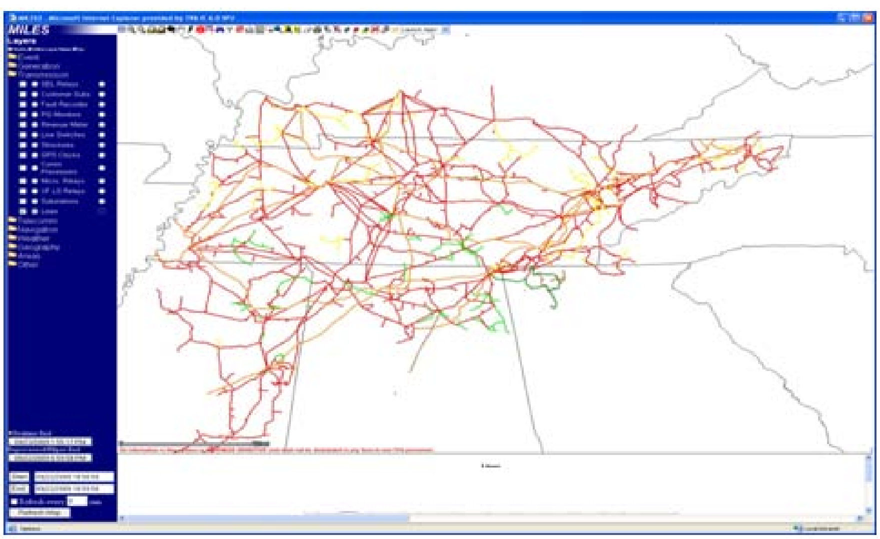


Figure 4 - Transmission Lines in GIS

Moreover, GIS provides a mechanism to not only display where assets are but provides a platform to correlate information that has no other logical relationship. Lightning, for example, has no attributes that match our assets, but it does occur in geographically coincident locations. The lightning data also is stored in our GIS as can be seen in Figure 5, below.

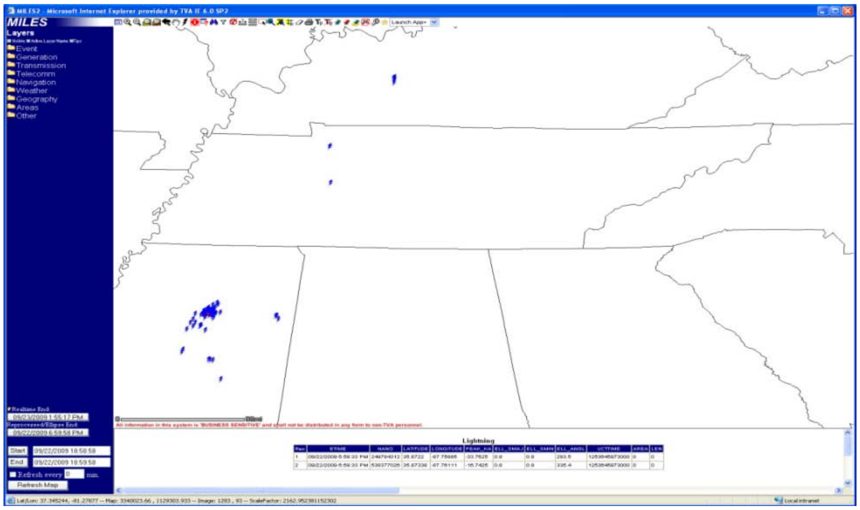


Figure 5 - Lightning in GIS

However, being able to just display items in relation to one another does not tell the whole story. For example, just because lightning occurs near a line, does not necessarily mean that it is the root cause for the failure. Having both types of data in the GIS is good, but optimally, the system should be detecting faults automatically.

Automating the System

With all of the disturbance data in a single repository and all of the GIS information in a repository, it is a relatively simple matter to combine the two for analysis purposes. A new system was built called Event Correlation Manager (or ECM) to watch the systems and perform automated analysis. An overview of the process is shown in Figure 6, below.

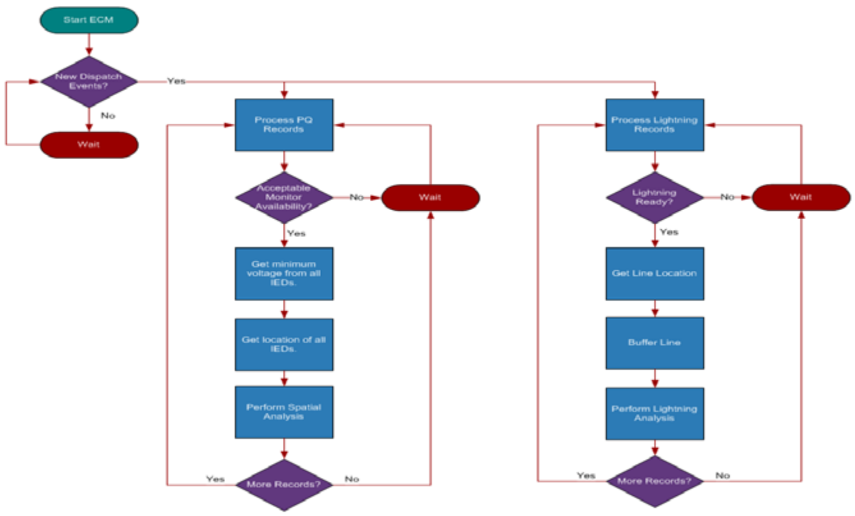
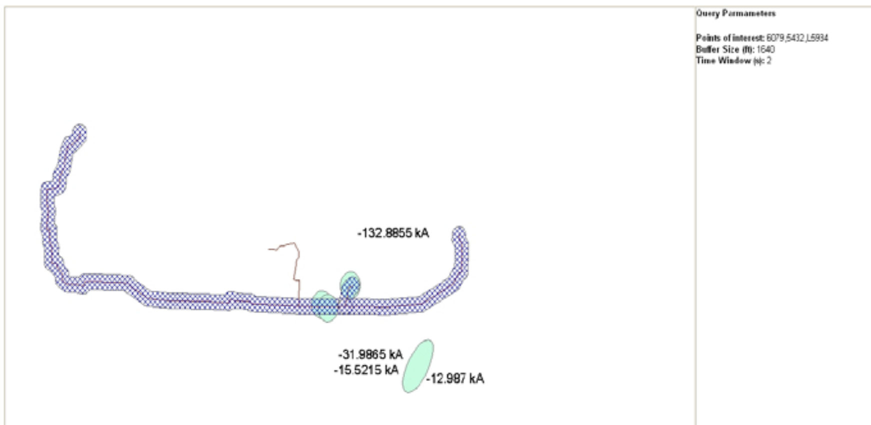


Figure 6 - ECM Process Overview

The system continuously monitors the system operators' database. As operations occur, the disturbance database is checked for any waveform records that were recorded. Next, the GIS system is queried to identify any nearby lightning in the system. The operations database provides the time and the name of the line that operated. Next, the line name is used to query the GIS for the location of the line. The time is used to filter the lightning data in the GIS. A report like the one in Figure 7 is produced by the GIS analysis.

Event Date: 09/06/2009 11:17:51 PM



Event Time	Peak kA	Latitude	Longitude
09/06/2009 11:17:49 PM	-15.5215	34.90445	-89.84736
09/06/2009 11:17:49 PM	-31.9865	34.90257	-89.84213
09/06/2009 11:17:49 PM	-132.8855	34.91631	-89.82483
09/06/2009 11:17:49 PM	-132.8855	34.91631	-89.82483

Found: 4

Figure 7 - Lightning Analysis Results

While the lightning analysis is performed, the system begins analyzing the data from IEDs on the system. A list of sites that have recorded events during the time window is created. The minimum voltage from each location is normalized to a percentage basis. The GIS also has the location for each of these IEDs. A shaded relief map based on the minimum voltage is generated by the system. A sample report is shown in Figure 8, below.

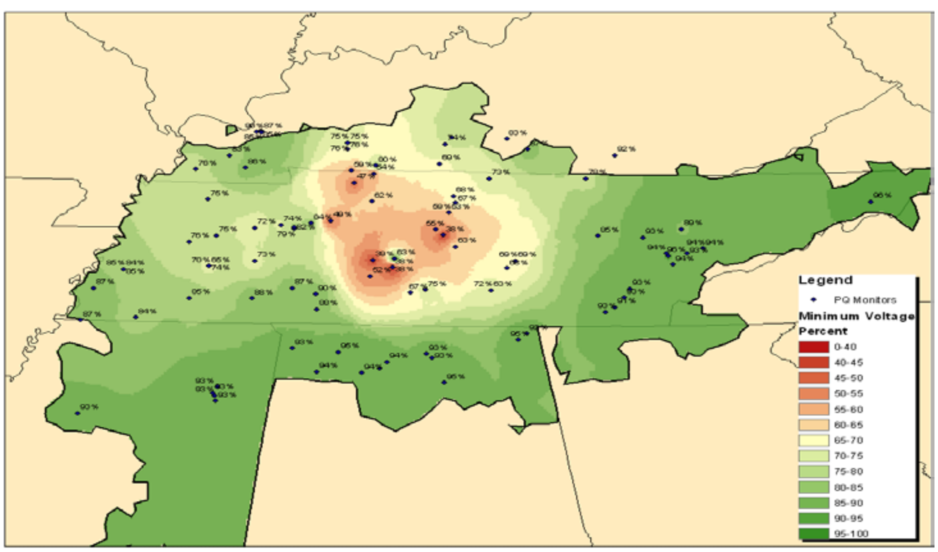


Figure 8 - Minimum Voltage Analysis Report

Both the lightning and minimum voltage reports are available through a web interface. Consequently, they are readily accessible by field staff. Though events that are entered into the dispatch database are automatically analyzed, the web interface allows the user to input an event manually. In addition, several query parameters can be modified from the system results. For example, the default time window for the lightning analysis is 2 seconds. This time can be expanded in cases where there is less certainty in the fault time.

Next Steps

Presently, the system has a number of components integrated: GIS, Lightning, SCADA, IED Data. These components were easily integrated using time and location information. However, a future version of the software should include some kind of fault location algorithm. This would improve the quality of the analysis by seeing if the calculated fault location matched the lightning location. In addition, the system could then provide a location when the fault cause is not lightning.

Additionally, the system should be integrated with the outage reporting process. Currently, the system is completely isolated while it is in a proof-of-concept stage. Integrating the system with an outage reporting system would enable field personnel to add additional information to the event with much of the details already populated. The expected result would be to reduce the work load associated with reporting on field staff.

Some of the technical components of the system could be replaced with web services. The proof of concept is running as a desktop application. There is a web interface that allows personnel to add and view results of the analysis. However, much of the functionality could be available directly to web clients.

Conclusion

Integrating lightning data, SCADA data and IED information is possible. Though the system is automated, users can add case studies manually which provides ultimate flexibility. Since the system continuously monitors SCADA, analyses are completed almost immediately reducing outage duration. Using an automated system also ensures consistent results. The system quickly answers the questions “Who was affected?”, “Where was the event?” and “When did the event occur?”.