Automatic Identification of Power Quality Variations in the Power Quality Diagnostic System

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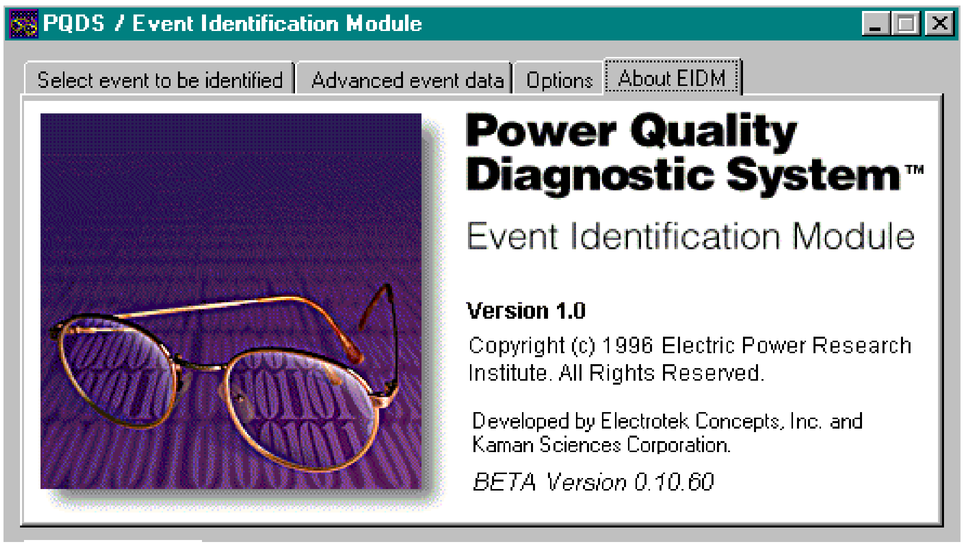

Figure 1
The About Event Identification Module Screen

Abstract

The Power Quality Diagnostic System (PQDS) is a general purpose tool being funded by the Electric Power Research Institute (EPRI) that will help a utility organize the data collection, processing, and analysis tasks associated with a power quality investigation. It should result in much more efficient power quality investigations, allowing utilities to provide better customer support with less manpower. A user will be able to use various modules to help conduct the case study with the results being stored in an Investigation PQ Database. Two modules were recently completed this year including a Measurement Module and an Event Identification Module. This paper will describe the Event Identification Module. The Event Identification Module (EIDM) is a software subsystem that accepts information in Power Quality Data Interchange Format (PQDIF)

and processes it to determine the cause and type of power quality events with three different intelligent processors. A companion paper scheduled for the European PQA conference will describe the Measurement Module. In this paper an overview of the Power Quality Diagnostic System will be given, and the Power Quality Data Interchange Format will be explained as well as the different event categories that the system will identify. Also, the Artificial Neural Network technology used in this module will be outlined along with the user interface.

Introduction to the Power Quality Diagnostic System

Power quality problems experienced by utility customers can be caused by events and conditions on the power system or within the customer facilities. The great majority of problems are related to wiring practices, grounding, and operating procedures within the customer plant. However, the utility is often called on to help solve these problems and, as a minimum, has the burden of showing that the problems are not caused by the supply system.

As the utility industry increasingly moves into a competitive environment, the issue of customer service and responsiveness is growing in importance. Electric utilities are reorganizing and new groups with names like *Customer Engineering*, *Energy Engineering*, *Customer Service*, and *Power Quality* are very important in the new organizations. These groups have the responsibility for keeping customers happy by helping them solve problems and helping to increase their productivity through the use of electricity.

While the customer service functions in the utility organizations are very important, they are also very lean. Utilities are reducing manpower to operate as efficiently as possible. Power quality investigations will continue to be very important but there will be significant emphasis on utilizing tools that improve the efficiency of the people performing the investigations. Tools that provide training, help automate the investigations, and assist with the reporting functions will be in demand.

The *Power Quality Diagnostic System* is a complete system of tools designed to help engineers and technicians develop optimum solutions to power quality problems. It incorporates capabilities for data collection from measurement equipment, data processing, database management, waveform recognition technology to identify disturbance causes, libraries of example cases to identify previous cases that are similar, analytical tools to verify causes and to develop possible technical solutions, economic analysis to identify optimum solutions, and report writing capability to document the results.

The system is built in a modular fashion for expandability and flexibility. The basic concept is illustrated in Figure 2. Individual modules are available for the major functions required in the diagnostic system and a *Power Quality Case Study Investigation Processor* directs the user to the modules that are required for a particular problem or investigation. Both the *Case Study Investigation Processor* and the analysis modules use a variety of databases to store and retrieve the information needed to analyze and solve problems.

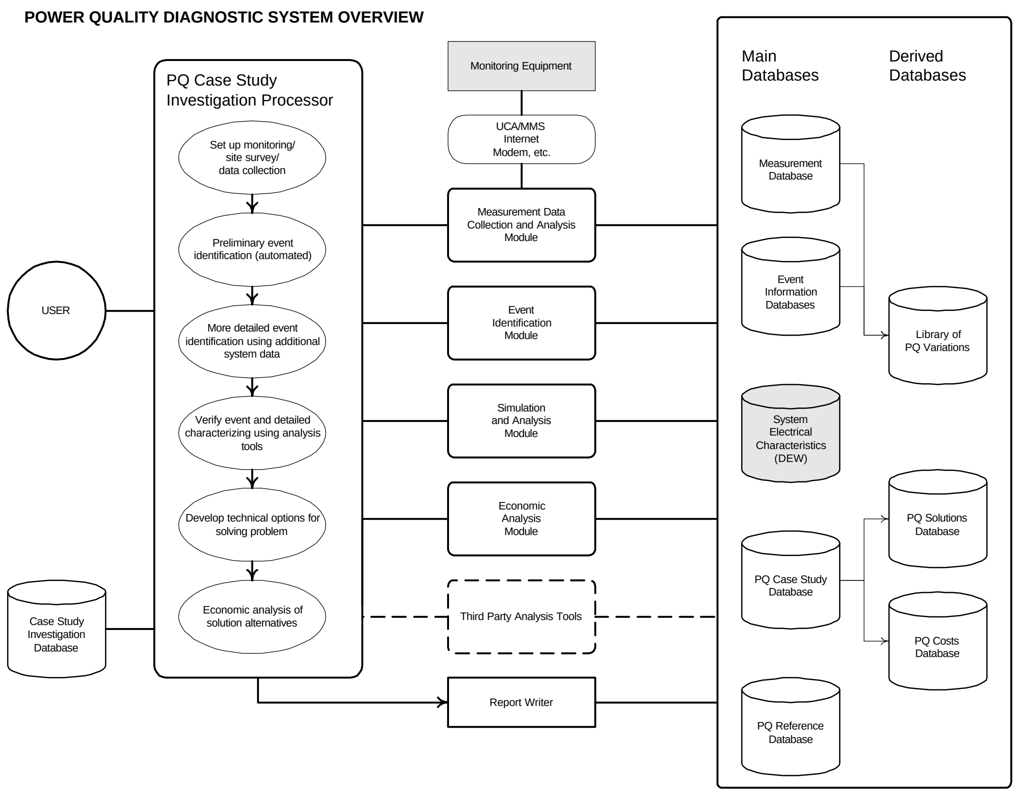

Figure 2
Overview of Power Quality Diagnostic System.

Features of the Power Quality Diagnostic System

PQDS provides:

1. System of tools to help power quality engineers analyze and solve customer power quality problems in the most efficient manner possible.
2. Modular system with an open architecture so that additional capabilities and third party modules can be conveniently interfaced with the system.
3. Stand-alone *Measurement Module* that integrates data collection from various types of monitoring equipment. It includes modules for putting the data in a standard format (PQDIF) and maintaining the data in a complete measurements database. A variety of different modules can be used directly to automate the entire data collection and data processing task.
4. Stand-alone *Event Identification Module* that includes automated procedures for providing an initial assessment of the probable cause and impact of a power quality variation. The module incorporates advanced waveform recognition technology based on neural networks. This module will help the user interpret ongoing monitoring results to identify possible problems and determine the type of investigation that may be required.

5. Stand-alone *Analysis and Simulation Module* that includes a library of basic applications for analyzing specific PQ concerns and also includes interfaces to more advanced analysis tools that may be required while performing a specific power quality investigation..
6. Stand-alone *Economic Assessment Module* that evaluates the economics of different power quality improvement options using a system perspective. It interfaces with more extensive databases of power quality costs by customer and equipment type and databases of power quality solutions costs and effectiveness.
7. *Power Quality Case Study Investigation Processor Module* that integrates all of the modules into a complete package and directs the user through the various steps involved in a power quality investigation. This module includes integration with all the required databases. This module also includes a complete report-writer capability to document the investigation results.
8. Complete network implementation of the Diagnostic System.
9. World Wide Web access to important functions of the Diagnostic System.
10. Documentation and an on-line help system.

Advantages of the Power Quality Diagnostic System

The *Power Quality Diagnostic System* is a key tool for electric utilities in dealing with customer power quality problems. It provides the following benefits to utilities as a stand-alone product:

- It is a training tool for new engineers dealing with power quality problems.
- Investigation time for power quality problems is minimized by automatically collecting and processing measurement results, using analytical tools to verify the cause of disturbances, using a database of previous research to identify possible solutions, determining the optimum solution based on overall system economics, and then automatically generating a report.
- Utilities are able respond faster and more effectively to customers when a power quality problem occurs and they will prevent problems by identifying and solving them before they occur.
- Utilities provide better and more focused customer service by understanding the problems and optimizing the solutions using a system perspective.
- Power quality problems and solutions are quantified, allowing utilities to offer differentiated services in a competitive environment.
- All power quality investigations are documented in a consistent manner and are available for future reference.

PQDS System Overview

The PQDS consists of the following components:

- Databases with information used by analysis and application modules

- Modules to perform specific analytical functions
- Module to help engineers perform power quality investigations (integrates individual modules)
- User interfaces for workstation applications, network applications, or WWW application
- Documentation

The structure is a group of stand-alone modules for different functions of the Diagnostic System that all work from a set of databases with an open architecture that permits development and interface of additional modules from third parties. In addition to the individual modules, the *PQ Case Study Investigation Processor* integrates the group of modules to guide the investigating engineer through an entire PQ case study process, from identification of the problem to developing an optimum solution.

Introduction to the Event Identification Module

The purpose of the Event Identification Module is to identify specific waveforms and predict the power quality event cause. There are two versions of the Event Identification Module: the stand-alone version and that version which is integrated into the Power Quality Diagnostic System (PQDS). It uses artificial neural network (ANN) techniques to identify the cause of a power quality variation. The pre-processors and ANNs were designed and developed by Kaman Sciences Corporation. It contains three parallel sets of ANN processors where each may contain more than one ANN. The Event Identification Module is designed to process three different types of data:

- Actual disturbance waveforms (transients)
- RMS variations (RMS magnitudes vs. time, e.g. sags, swells, interruptions)
- Steady-state waveforms (harmonics, non-linear loads)

The system has five major components as shown in Figure 3:

1. Data Source – The EIDM processes event data files in the PQDIF format.
2. Data Input Interface - It selects an event data file from the data source and prepares it in the form that will be accepted and processed by the ANN systems.
3. Artificial Neural Network System - Three sub-systems were designed to identify one of the three event types: waveform, RMS, and steady-state. Each sub-system has a pre-processor, a main search unit, and a post-processor. The pre-processor prepares the input data by extracting key features that may be related to a specific type of event. The key features are analyzed and processed to match with a specific type of event. The output will be an identified event type with an associated confidence level. The post-processor will validate the output results and prepare the data to be sent to the output data manager.
4. Output Data Manager – This section takes the result from the post-processor and accesses a database that contains detailed information explaining each event category.
5. Output Display Interface – It displays or prints the output keyword, confidence level and description for an identified event.

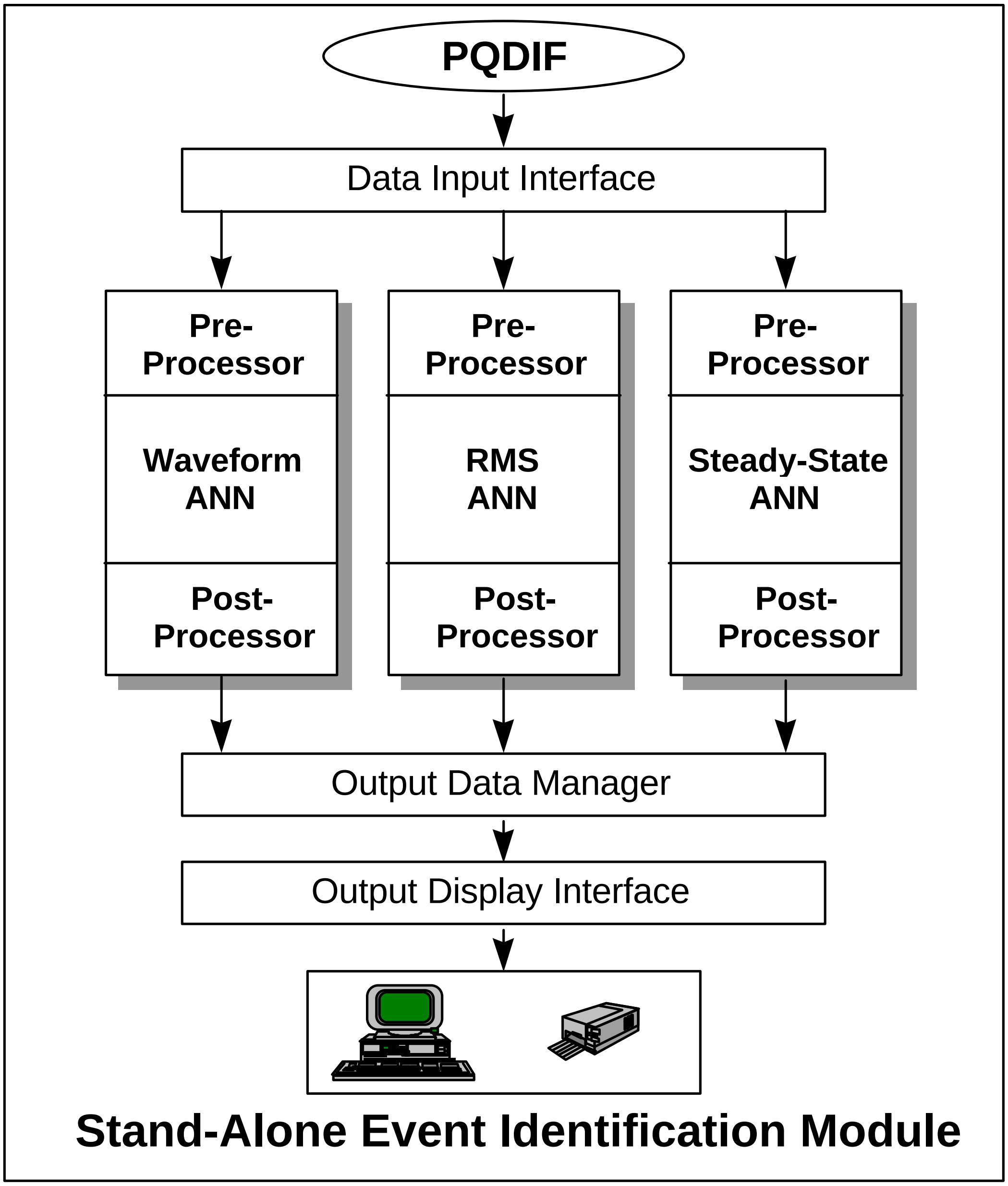

Figure 3
Stand-Alone Version of the Event Identification Module

The waveform sub-system uses single-phase voltage waveform data only when making a determination. If a measurement contains three-phase data, each waveform can be sent through the identifier separately. The RMS variation sub-system uses all three phases of an RMS voltage event to make a determination. Current information is presently ignored for both of these sub-systems. The steady-state waveform sub-system uses single-phase current snapshots to determine a load type. Voltage information is currently ignored in this sub-system.

Power Quality Data Interchange Format

The Power Quality Data Interchange Format (PQDIF) is the primary mechanism used by the EIDM to import raw waveform data. There are two layers to the PQDIF format: the physical layer and the logical layer. The physical layer describes the physical structure of the file without regard to the stored content. It uses tags to identify particular elements of the file. This is similar to the Tagged Image File Format (TIFF) used for storing images. The physical layer is based on:

- Specific “physical” data types for portability
- Specific list of IDs for physical representation
- 4-byte alignment for efficient processing
- Tags using Globally Unique Identifiers (GUIDs) for unique identification of elements

The logical layer uses the structure defined by the physical layer. It specifies tags to use when building up elements in the file. The logical layer is based on:

- Specific list of tags to identify elements of a file
- Hierarchy of tags and expected physical types
- Extensibility using user-defined tags for private data
- Extensibility of the standard format using tags defined in the future

The structure of an example PQDIF file is shown in Figure 4 for illustrative purposes.

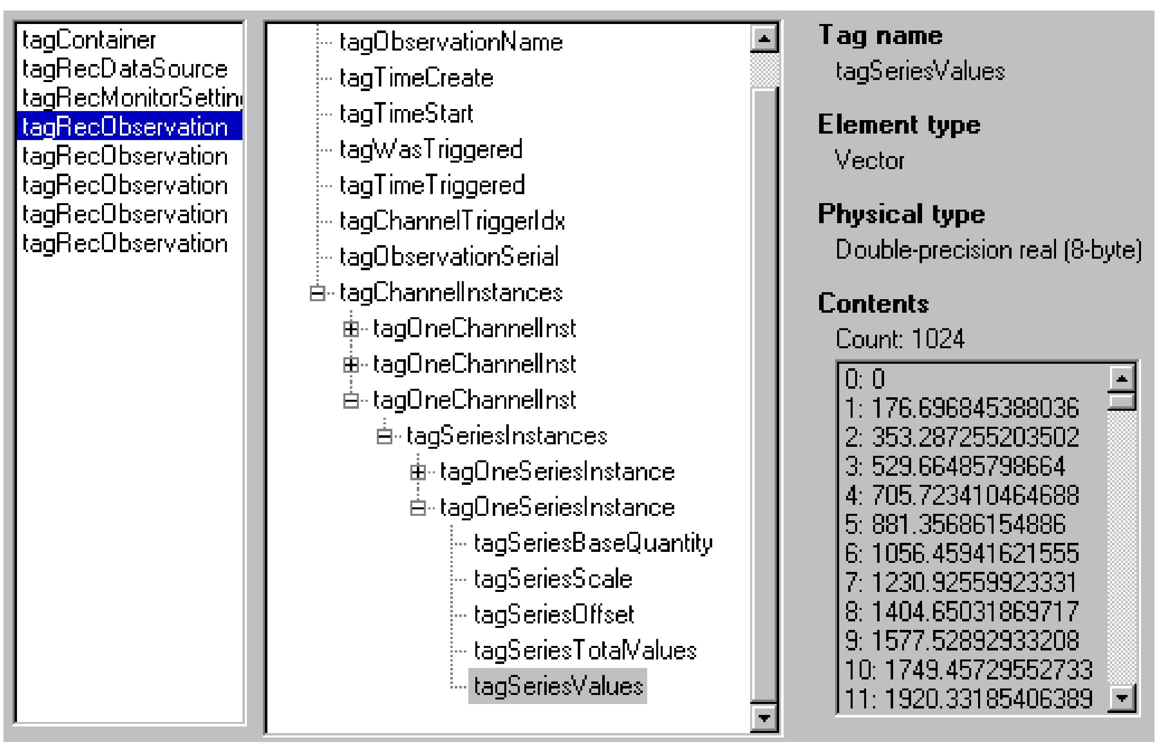

Figure 4
Example PQDIF File

PQDIF files are generated from the Disturbance Viewer of the PQDS Measurement Module that was described earlier. This module was also recently released by EPRI.

Key Word Output

The Event Identification Module accepts information in the PQDIF format and processes it to determine the type of power quality event, with the output being a key word. A list of key words supported is shown in Table 1. As you can see from this table there is a main category, such as "Steady-state," and then two sub categories, such as "Six pulse switching power supplies" and "DC drives." In this version, only enough data to accurately identify down to sub category number one was obtained. If more raw measurement data is obtained, additional refinements can be made to identify down to sub category number two.

Table 1
Key Words

Category	Sub Category 1	Sub Category 2
Waveform Disturbances	Capacitor energizing	*Capacitor or Harmonic filter*
		Cap with nearby cap in service (back to back switching)
		High voltage cap with monitor at low voltage cap (magnification)
		Capacitor switch restrike on opening
	Motor starting	
	Transformer energizing	
	Line energizing	*Predominately aerial*
		Predominately cable
	Normal waveshape variations	*Capacitor trip*
		LTC/regulator operation
	High frequency transients	*Transients caused by lightning impulses*
		Motor interruption or other load switching
	Converter operation (notching)	
	Fault initiation	*Solid*
		Arcing
	Fault clearing	*Current limiting fuse*
		Other (e.g., breaker, fuse)
	Static switch transfer	
	Ferroresonance	
	Arcing contacts	
RMS Disturbances	Motor starting	
	Transformer energizing	
	Load fluctuation (flicker)	
	Three-phase remote faults	*Transmission fault*
		Distribution fault
	One or two-phase remote faults	*Transmission fault*
		Distribution fault
		Remote fault cleared by CL Fuse
	Fault conditions causing an Interruption	*Three-phase fault*
		One or two-phase fault

		Fault cleared by CL fuse
	Reenergizing after an interruption	
	Static transfer switch operation	
	Ferroresonance	
	Long duration voltage variations	*Load or capacitor switching*
		Transformer or regulator tap Changing
Steady-State (Nonlinear Loads)	Six pulse switching power supplies	*DC drives*
		CSI type ASDs
		VSI type ASDs with choke inductance
		VSI type ASDs without choke inductance
		Other rectifier loads (e.g., induction furnace)
	Twelve pulse power supplies	*ASDs*
		UPS
		DC arc furnace
		Other rectifier loads
	Higher pulse number power supplies	
	Semiconvertors	
	Cycloconvertor	
	Single-phase switching power supplies	*Computers, office equipment*
		Electronic ballast fluorescent lighting
	Phase-controlled device	*Inductive loads (reactor, motor)*
		Resistive loads (lighting, heating)
	Arcing loads	*AC arc furnace*
		Magnetic ballast
		Fluorescent lighting
	Saturable loads	

Training the Neural Networks

Neural networks are a type of artificial intelligence technology that mimics the structure of a biological nervous system. It learns by example to recognize patterns in data. It is the technology of processing information like a person does instead of like a computer. Just as humans apply knowledge gained from past experiences to new problems or situations, ANNs take previously solved examples to build a system of “neurons” that learns to make new decisions, classifications, and forecasts. To train the neural networks used in this module, a significant amount of data was collected from many sources. EMTP simulations were also used to fill holes in the data where not enough measurement data could be collected. For each sub one category, a minimum of twenty events were collected. These waveforms were then stored in a database created using EPRI’s PQ Database program (1). A utility program was then written to extract the data from the database and generate files to be used for training and validating the neural networks. The secret to successful ANNs involves the intelligent pre-processing of the data to extract relevant features and renormalize the data – this is still and art and will be the subject of a future paper.

Starting the Module and Selecting a PQDIF File

After installation, selecting the Event Identification Module from the Program Manager opens EIDM. The program opens with the ***Select event to be identified*** screen displayed. To select a power quality event file, click on the FILE OPEN icon of the ***Select event to be identified*** screen (Figure 5). The ***Select PQ event file*** screen is displayed to allow you to select the power quality event file you wish to view.

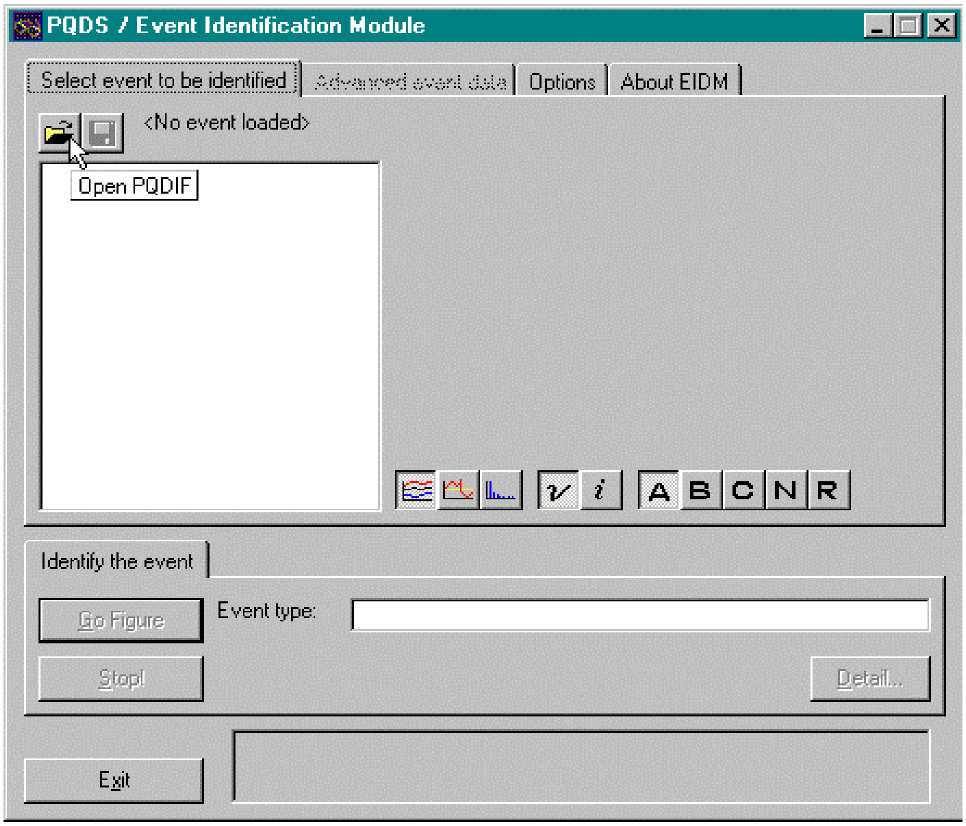

Figure 5
Opening the Select PQ Event Screen

Selecting a Specific File and Event to View

The data sources are displayed in the left side of the ***Select event to be identified*** screen (Figure 6). The plus sign displayed indicates that the single data source in this file is collapsed. The text box at the bottom of the screen shows that the data file was successfully opened.

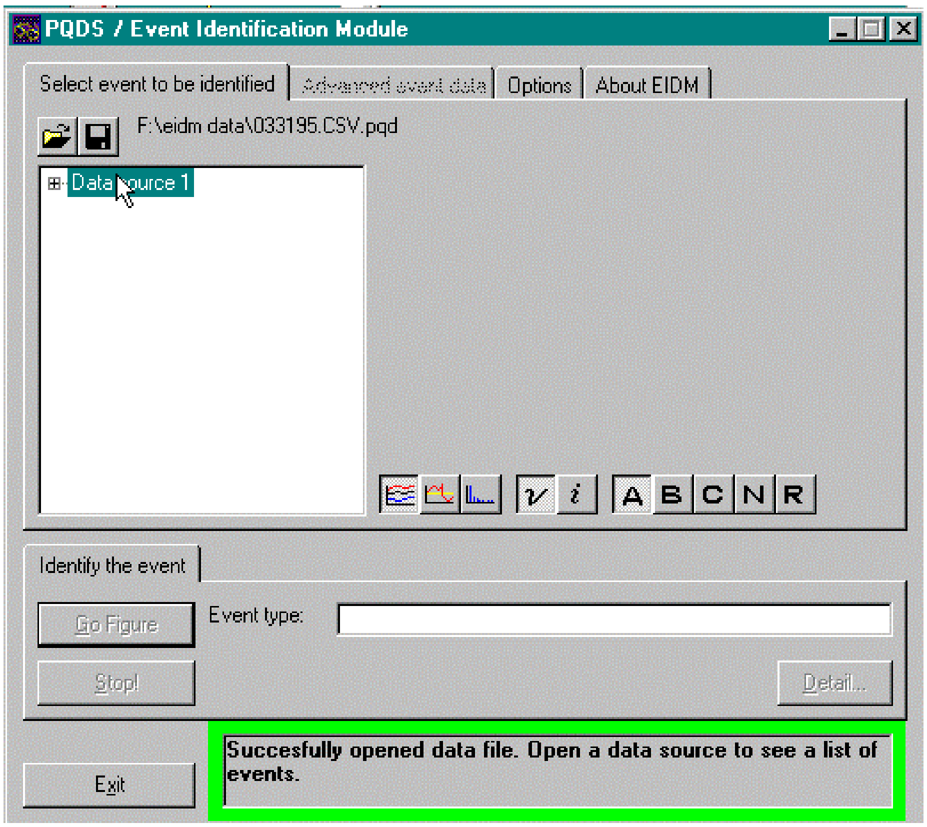

Figure 6
Selecting a File

The data source may be expanded by clicking on the box beside the file name. When the data source is expanded a minus sign is displayed. Clicking upon the event to be identified enables the appropriate icon selection buttons at the bottom of the screen. Either voltage or current may be displayed, but only one can be selected at a time. Any combination of phases may be selected, from one to all. The methods of display are made available by enabling the appropriate icons. There are numerous combinations of event displays available. Clicking on the enabled RMS icon displays the event. Figure 7 shows the RMS variation phase A voltage of the PQDIF file previously opened.

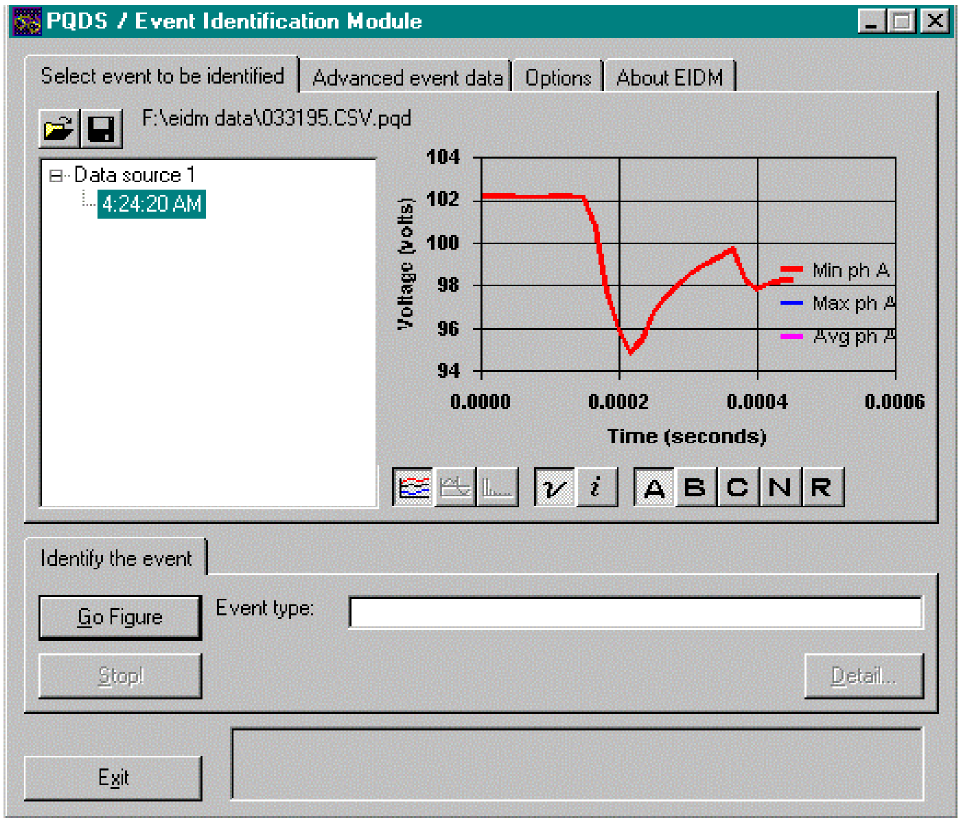

Figure 7
RMS Variation Event Displayed

Event Identification

By clicking the GO FIGURE button, the Event Identification Module estimates the type of event from the data given. The event type is entered into the *Event Type* box (Figure 8). For the PQDIF file opened above, the EIDM correctly determined that it was a one or two phase fault condition. Also displayed, directly below the *Event Type* box is a confidence level. This indicates that the confidence is high that this is a one or two phase fault condition.

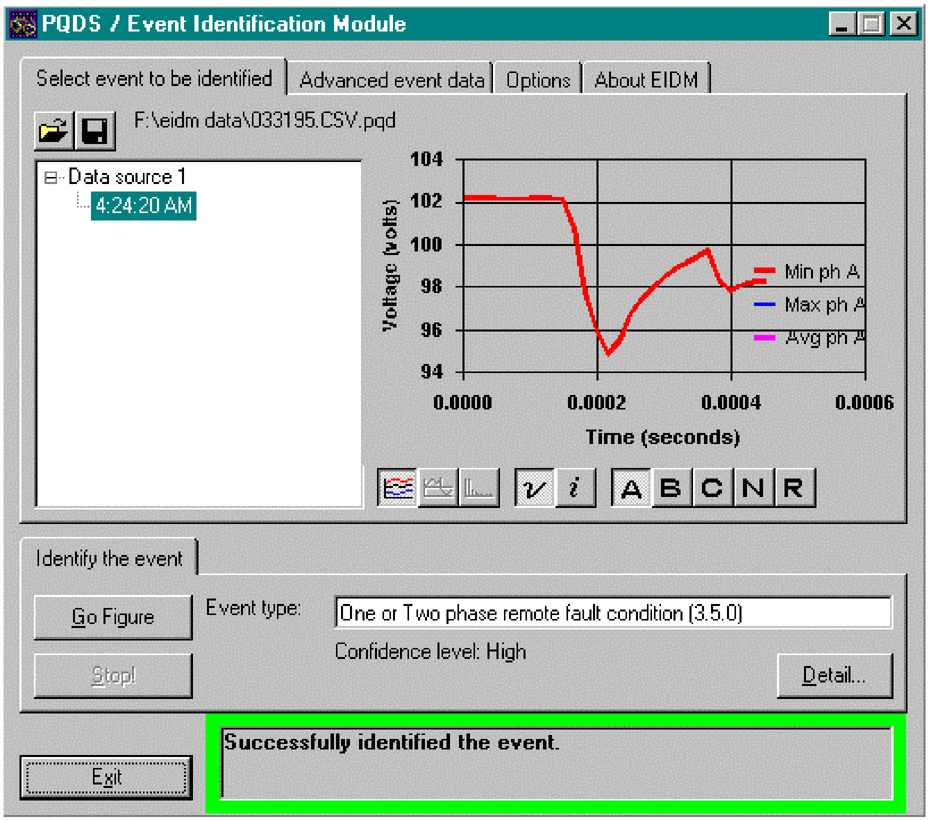

Figure 8
Type of Event and Confidence Level of Identification

In some cases, the confidence level may be "moderate" which means that the EIDM has identified more than one possible event type. A low confidence level means that no event types were identified.

Viewing More Details about the Event

To view the Event Identification Report, click the DETAIL button. The Event Identification Report is created automatically by the information generated by the Event Identification Module (Figure 9). These reports may be printed or saved by being exported to a file.

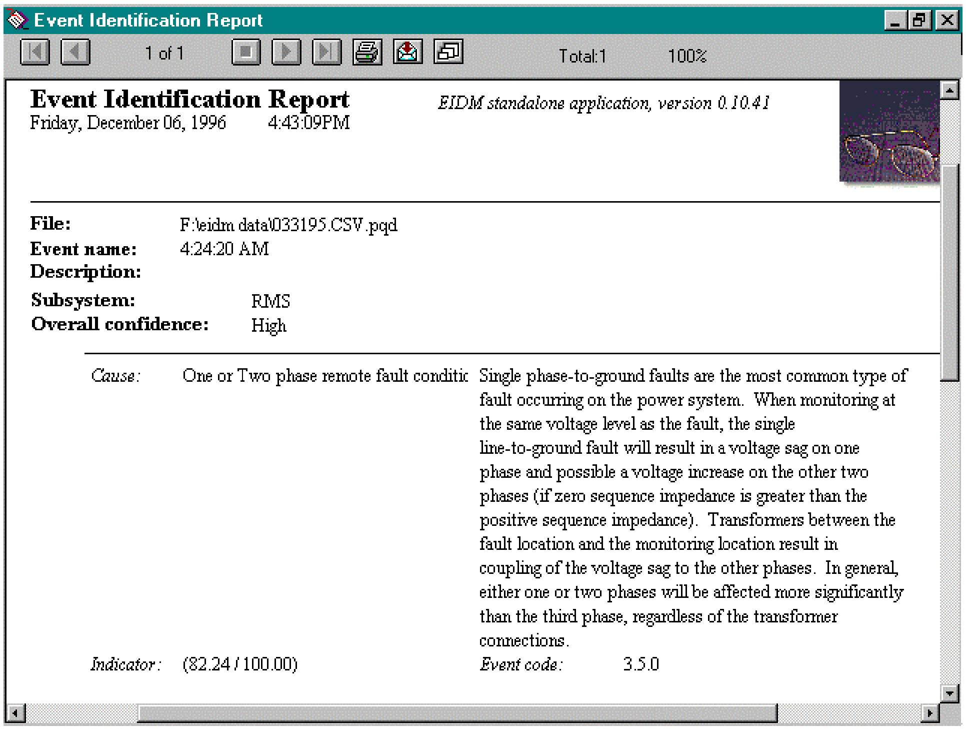

Figure 9
Event Identification Report

Summary

Testing and validation done on this module indicate a very high identification success rate. As more data is collected, retraining of the neural networks can be done so sub category two predictions can be made which will further enhance the value of this module. As it stands now, this module provides a valuable tool to utilities that are performing power quality measurements and trying to troubleshoot or analyze waveforms and/or problems.

Acknowledgments

Special thanks to the PQ Diagnostic System Utility Advisory Group members who provided feedback and raw measurement data used in the training of the neural networks.

References

1. J. Lamoree, B. Dabbs, J. King, C. Patton, M. Samotyj, “The Power Quality Database: A Software Tool for Power Quality Engineers to Solve Problems,” presented at the 1995 PQA Conference, New York, NY (May 1995).