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Power Quality Data Interchange Format (PQIF) Software Verification and Demonstration Test Bed for Power Quality and Advanced Revenue Meters

Technical Report

Power Quality Data Interchange Format (PQDIF) Software Verification and Demonstration Test Bed for Power Quality Monitors and Advanced Revenue Meters

1005935

Technical Progress, November 2001

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This report was prepared by

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Knoxville, Tennessee 37932

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This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Power Quality Data Interchange Format (PQDIF) Software Verification and Demonstration Test Bed for Power Quality Monitors and Advanced Revenue Meters, EPRI, Palo Alto, CA: 2001. 1005935.

REPORT SUMMARY

The power quality data interchange format (PQDIF) is a digital file format developed to provide a standard for exchanging power quality data, independent of manufacturer. PQDIF is a proposed IEEE standard (P1159.3). Manufacturers of power quality monitors and other metering devices are working to conform to this standard by providing PQDIF data export capability in their equipment. Both manufacturers and potential users of PQDIF have expressed interest in a test procedure that could verify and validate the ability of the power quality monitoring system suppliers' software and/or hardware to produce valid PQDIF files. This EPRI project provides a test procedure and an independent test facility for verifying and validating PQDIF files.

Background

The need for an open data interchange format such as PQDIF is best understood by considering the growth in the amount of power quality data that is being collected and the diverse sources of this data. The sheer volume of data that many utilities are collecting makes it difficult for personnel to examine each power quality event individually; to further complicate analysis of the data, they often reside in various incompatible file formats. Moreover, many devices exist in utility and industrial power systems—relays, recloser controls, regulator controls, capacitor controls, and energy automation systems, for example—that also could provide valuable data on the quality of power being supplied to the system. A major impediment to using this data is the incompatibility of its various file formats with a powerful power quality analysis tool.

Objectives

- To build a test stand capable of concurrently testing multiple power quality monitors.
- To develop a hardware test protocol for testing the response of power quality monitors to various power quality events.
- To develop a software test protocol for verifying and validating PQDIF files created by various power quality monitoring systems.

Approach

The project was divided into two main tasks: developing hardware and software test protocols and constructing a power quality monitor test facility. The project team developed test protocols using experience gained from many years of testing power quality monitoring devices, then reviewed existing software tools related to PQDIF verification and validation. The team designed and constructed a test stand that allows maximum flexibility in the types of equipment that can be tested and in the sources supplying test signals.

Results

A power quality monitor test stand was constructed that allows up to six power quality monitoring devices to be supplied the same voltage and current signals. These signals can be supplied by various sources such as building service instrument transformers, arbitrary waveform generators, and EPRI PEAC's sag generation equipment. Test protocols were written for evaluating both the hardware response to power quality events and the resulting PQDIF files.

EPRI Perspective

There is a need for an open power quality data interchange format for modern power quality instruments. PQDIF is an open and well-defined standard for exchanging power quality measurements data that is independent of power quality monitoring system manufacturer. The PQDIF open standard allows utilities and end users to easily integrate power quality data to cost effectively manage their electric power systems. This project helped create a technical basis for developing and demonstrating PQDIF technology.

Keywords

Power quality
PQDIF
Power quality monitoring

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The Power Quality Data Interchange Format (PQDIF) is digital file format developed to provide a standard for the exchange of power quality data, independent of manufacturer. At the time of this writing, PQDIF is a proposed IEEE standard (P1159.3), a status which has not prevented many manufacturers of power quality monitors and other metering devices from working toward some form of PQDIF data export from their equipment. Both these manufacturers and the potential users of PQDIF have expressed interest in a test procedure that could validate the ability of software and/or hardware to produce PQDIF files. EPRI created the project described in this report to provide not only a procedure for but also a facility in which to perform this testing.

Background

The need for PQDIF is best understood by a consideration of the growth in the amount of power quality data that is being collected and the diverse sources of this data. The sheer volume of data that many utilities are collecting makes it impossible for personnel to examine each power quality event individually; to further complicate analysis of the data, it often resides in various incompatible file formats. Moreover, many devices exist in the average utility or industrial system—relays, recloser controls, regulator controls, capacitor controls, and energy automation systems, for example—that could also provide valuable data on the quality of power being supplied to the system. A major impediment to the use of this data is the incompatibility of its various file formats with a powerful power quality analysis tool.

Such a powerful tool is EPRI's Power Quality Diagnostic System Measurement Module called PQView®, which was developed to automate the analysis of power quality data for utilities and industrial customers. Originally this application could only accommodate data for which custom data translators had been written, but in its current version it can analyze PQDIF files as well. Other software products have been developed, or are under development, that make use of PQDIF files. All these applications perform the important process of taking large quantities of power quality data about a particular system and automatically turning it into information that can be used by power quality engineers to assess the health of the power system.

Testing

The PQDIF file structure is very flexible in the types of data that can be characterized. Its very flexibility creates concerns about the ability of a particular piece of analysis software such as PQView, to read the data stored in the PQDIF file. Currently, manufacturers of power quality monitoring hardware must work with developers of analysis software to be able to ensure the compatibility of the PQDIF files they produce, a situation open to complications, since in some cases the analysis software vendor is also a competitor in the power quality monitor business. For this reason, manufacturers and power quality data users alike would like to see a certification process developed that could be administered by a third party, such as EPRI using the EPRI PEAC lab.

The project described in this report is the first step toward the development of such a process. Any PQDIF certification process will require two types of testing, which this report will refer to as hardware and software testing. Hardware testing involves characterizing the response of a particular power quality monitor or other monitoring device, to known power quality phenomena as defined by IEEE 1159.1. Software testing involves verifying that the PQDIF file created from the results of the hardware testing meets the proposed IEEE standard's definition of PQDIF, contains accurate information as collected by the monitor, and is compatible with available analysis software (in this instance, PQView).

Hardware Testing

Hardware testing is an important first step in the process of validating the ability of a manufacturer to produce an accurate, compatible PQDIF file. A perfectly compliant PQDIF file is worthless if it does not contain data that accurately represents the power quality events to which the power quality monitor was exposed. In the tests, therefore, monitoring equipment will be exposed to predetermined power quality phenomena and the response of the monitors will be recorded, as this data will be necessary when analyzing the accuracy of the PQDIF file. The monitors will be subjected to all types of power quality phenomena, including those outside of the specifications for the equipment. For example, if a monitoring device is capable of capturing voltage sags and swells only, it will still be subjected to capacitor switching transients as well as other power quality disturbances, because it is important to understand how the device will react to any power quality events to which it is likely to be exposed in real-world situations.

A power quality test stand specially built for this project will facilitate the hardware testing. The test stand provides parallel connections to voltage signals and series connections to current signals for up to six power quality monitors or other devices with monitoring capabilities. These signals are supplied by either instrument transformers connected to the 120/208 V building service or an arbitrary waveform generation rack producing independently controlled, synchronized voltage and current waveforms. This test array provides the flexibility of monitoring the building service for long-duration trending tests or supplying custom waveforms to the instruments for event testing.

Software Testing

Validation of PQDIF files is not as straightforward as simply attempting to read the files using a particular software. The test procedure described in this report will ascertain the following:

- Was the hardware and its associated software able to produce a PQDIF file?
- Is the file format consistent with the proposed PQDIF standard?
- Does the file contain the information recorded during the hardware testing?

- Is the file compatible with currently available analysis software?

The results of the testing will therefore be more than a simple pass or fail. For example, a tested PQDIF file might prove to be compliant with the standard and contain accurate information, but be incompatible with available analysis software, such as PQView. It would then be up to the manufacturer to decide if the PQDIF file's compatibility with a particular analysis package is important. On the other hand, the analysis software currently available does not make use of all of the types of data that can be stored in a PQDIF file as defined by the proposed standard. Proving that the hardware manufacturer's PQDIF file is compliant with the standard even if it is not compatible with the analysis software, may incline the software vendor to expand the capabilities of its product for interpreting the data in the PQDIF file.

2
PQDIF OVERVIEW

Many utilities are monitoring the quality of the power they deliver to their customers, while some have plans to monitor the quality of power on every feeder in their system. Utility customers are also beginning to monitor the quality of the power delivered to them as well as the quality of power at key points inside their facilities. The many sources of power quality data rely primarily on proprietary data formats and analysis software. As the number of monitored points increases, the need for a universal software tool to analyze the data becomes critical, and a common data exchange format is therefore essential.

Overview

While utilities and their customers are increasingly monitoring the quality of the power they provide or use, the number of points that are monitored is driven by both need and cost. Often a utility or customer would like to monitor more points than they can justify financially. The proprietary nature of power quality monitors means that once a brand is selected, it must be used for all future expansion or the user is stuck with incompatible systems. This greatly increases the cost and difficulty of managing power quality monitoring.

Another concern is that although some level of power quality data is available from nontraditional sources such as relays and revenue meters, these devices often have very limited tools for analyzing the data in a way useful to a power quality engineer. Protection relays and revenue meters are already required in the power system, so any power quality data they provide is inherently low-cost. The development and use of a standard power quality data interchange format will make this data accessible for analysis, and the utility or customer can increase the number of monitored points without large capital outlays for equipment. The standard exchange format will also enable the user to change equipment vendors without concern about incompatibilities with existing equipment. Thus a power quality monitoring system originally commissioned with all brand X equipment may subsequently be expanded using brand Y.

The power quality data interchange format (PQDIF) provides vendors with a common format for the export and import of data, allowing the end user maximum flexibility in choice of tool and vendor. Power quality data is a broad category—many forms of data are collected, processed and stored, from basic information like raw voltage waveforms to highly processed statistical information on derived quantities such as total harmonic distortion (THD). Because of the wide range of data that may be measured or calculated, a highly flexible, standard method of data exchange is required. PQDIF was initially developed to allow for the transfer of *most* power quality data – measurements, simulation results, calculated index values, etc. – in a high-fidelity form and in a predictable, standardized way. The PQDIF file structure is therefore very open and flexible.

There are several side effects from this level of flexibility, the most obvious of which is its complexity. PQDIF is indeed a fairly complex format when compared to the simple ASCII files of COMTRADE™ or other proprietary formats. Also, PQDIF's flexibility leads to occasional ambiguities in modeling a particular type of data. Without the proper guidance, this flexibility can be confusing. For example, vendors may develop PQDIF files that appear to be structurally accurate with regard to allowable PQDIF element tags, but are not structured such that the data importer of the analysis tool, in this case PQView IEEE P1159.3 Draft 5 importer expects the data. Many of the instrument manufacturers who have begun to implement a PQDIF export function to allow integration of their instruments with the PQView system have realized this possible confusion and have requested a test tool to verify the validity of their export functions and a means for a third party to validate their files. Tools now available to validate PQDIF files will be discussed in the Chapter 4 of this report, Software Testing.

PQDIF Structure

There are two "layers" to the PQDIF file format: the *physical* layer and the *logical* layer. The physical layer describes the physical structure of the file without regard to what will actually be stored in it. It uses tags to identify particular elements of the file, similar in concept to the tagged image file format (TIFF) used for storing images. The logical layer uses the structure defined by the physical layer and specifies the tags to use when building up elements in the file.

The physical layer of the PQDIF file is based on the following:

- Specific "physical" data types (e.g. INT1, INT2, INT4, REAL4, REAL8, etc.) for portability and a specific list of IDs for physical representation (e.g. ID_SERIES_PHYS_TYPE_INTEGER1, etc.).
- 4-byte alignment for efficient processing.
- Tags—using GUIDs (globally unique identifiers, or "tags")—for unique identification of elements. A GUID is a 16-byte integer which is defined by a standard algorithm. The length of the integer and the algorithm used to calculate it virtually guarantee that every tag created will be unique.

At the highest level, the physical format of the PQDIF file is a series of linked records. Each record is made up of a header and a body as shown in Figure 2-1.

- Record 1
  - Header
    - Signature
    - Record type tag
    - Size of the body
    - Link to next record
  - Body
    - Self-contained block of data
- Record 2

Figure 2-1
PQDIF Physical File Format

The body of the record contains a set of elements that contain data. There are three element types:

- Scalar – represents a single data value
- Vector – represents an array of data values
- Collection – contains other elements

A scalar or a vector element can contain values of the following types:

- Signed integer (1, 2, or 4 bytes in length)
- Unsigned integer (1,2, or 4 bytes in length)
- Complex (8-byte single precision, or 16-byte double precision)
- Boolean (1, 2, or 4 bytes in length)
- Real (4-byte single precision, or 16-byte double precision)
- Character (1-byte ASCII or 2-byte Unicode)
- Date stamp (12 bytes in length)
- GUID (16 bytes in length)

The logical layer of the PQDIF file is based on:

- Specific lists of tags to identify elements of a file
- A 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

To keep things simple, many elements in the logical layer are based on an explicit list of enumerated Ids, such as:

- Phase (ID_PHASE_AN, ID_PHASE_BN, etc.)
- IEEE 1159 disturbance category (ID_1159_TRANSIENT, ID_1159_SHORTDUR, etc.)
- High-level quantity type (ID_QT_WAVEFORM, ID_QT_RMS, etc.)
- Series quantity units (ID_QU_TIMESTAMP, ID_QU_VOLTS, ID_QU_AMPS, etc.)
- Series value type (ID_SERIES_VALUE_TYPE_MIN, ID_SERIES_VALUE_TYPE_MAX, etc.)

A fragment of a PQDIF file is shown below in Figure 2-2 to illustrate the hierarchy. This fragment was created using a PQDIF-to-ASCII tool available from the IEEE P1159.3 website at *http://grouper.ieee.org/groups/1159/3/index.html*.

```
+-Collection -- tag: tagOneChannelDefn (level 2)
|   +-Vector -- tag: tagChannelName (type: CHAR1) [ 13 ]
|   |  value: 'Waveform VCA'
|   +-Scalar -- tag: tagPhaseID (type: UNS_INTEGER4)
|   |  value: 7 - ID_PHASE_CA
|   +-Scalar -- tag: tagQuantityMeasuredID (type: UNS_INTEGER4)
|   |  value: 1 - ID_QM_VOLTAGE
|   +-Scalar -- tag: tagQuantityTypeID (type: GUID)
|   |  value: {67f6af80-f753-11cf-9d890080} - ID_QT_WAVEFORM
|   +-Collection -- tag: tagSeriesDefns (level 3)
|   |   +-Collection -- tag: tagOneSeriesDefn (level 4)
|   |   |   +-Scalar -- tag: tagQuantityUnitsID (type: UNS_INTEGER4)
|   |   |   |  value: 2 - ID_QU_SECONDS
|   |   |   +-Scalar -- tag: tagQuantityCharacteristicID (type: GUID)
|   |   |   |  value: {a6b31ae5-b451-11d1-ae170060} - ID_QC_RMS
|   |   |   +-Scalar -- tag: tagValueTypeID (type: GUID)
|   |   |   |  value: {c690e862-f755-11cf-9d890080} - ID_SERIES_VALUE_TYPE_TIME
|   |   |   +-Scalar -- tag: tagStorageMethodID (type: UNS_INTEGER4)
|   |   |   |  value: 4 - ID_SERIES_METHOD_INCREMENT
|   |   |   +-(End of collection)
|   |   +-Collection -- tag: tagOneSeriesDefn (level 4)
|   |   |   +-Scalar -- tag: tagQuantityUnitsID (type: UNS_INTEGER4)
|   |   |   |  value: 6 - ID_QU_VOLTS
|   |   |   +-Scalar -- tag: tagQuantityCharacteristicID (type: GUID)
|   |   |   |  value: {a6b31add-b451-11d1-ae170060} - ID_QC_INSTANTANEOUS
|   |   |   +-Scalar -- tag: tagValueTypeID (type: GUID)
|   |   |   |  value: {67f6af97-f753-11cf-9d890080} - ID_SERIES_VALUE_TYPE_VAL
|   |   |   +-Scalar -- tag: tagStorageMethodID (type: UNS_INTEGER4)
|   |   |   |  value: 3 - ID_SERIES_METHOD_VALUES | ID_SERIES_METHOD_SCALED
|   |   |   +-Scalar -- tag: tagSeriesNominalQuantity (type: REAL8)
|   |   |   |  value: 48083.261121
|   |   |   +-(End of collection)
|   |   +-(End of collection)
|   +-(End of collection)
```

Figure 2-2
Fragment of PQDIF File

Other Recommended Reading

This chapter is not meant to be an in-depth coverage of PQDIF files, but rather an overview. Detailed information on the proposed PQDIF standard is available at *http://grouper.ieee.org/groups/1159/3/index.html.* The reader is referred to this document for more than a casual understanding of the requirements for a PQDIF file.

Conclusion

A common data format for the exchange of power quality data is close to a reality with the proposed IEEE Standard P1549.3. However, the flexibility built into the PQDIF file format can create problems when manufacturers try to generate files compatible with existing readers such as EPRI's PQView, and when software vendors endeavor to fashion their own viewers. For this reason, hardware manufacturers, software vendors, and end users have all expressed a desire for a testing process by which PQDIF files can be validated. Chapter 3 of this report discusses the physical requirements for such a hardware test procedure, while Chapter 4 offers a detailed explanation of the software tests that will be required to validate PQDIF files.

3
HARDWARE TESTING

Proper testing of the PQDIF capabilities of power quality monitors requires testing the response of the monitors to power quality events. This is required to obtain data of known characteristics that can then be converted to PQDIF files according to manufacturer specifications. This chapter will discuss the types of power quality events of interest to utility engineers; a test stand that has been developed to test the response of power quality monitors to those events; and a test protocol for use during the testing.

Range of Power Quality Variations in Distribution Circuits

Proper application and testing of power quality monitoring equipment requires a good understanding of the electrical environment in which the monitoring device will be installed. This requires an understanding of the characteristics of the power quality events and the range of expected variation of these events in a typical distribution circuit. Understanding the electrical environment is critical not only to properly specify the performance requirements for monitoring devices but also to ensure that such devices have the proper immunity to survive the electrical environment of the distribution system.

In this section, we review the definition of power quality events as described in IEEE Standard 1159-1995, *Recommended Practice for Monitoring Electric Power Quality,* and review the expected ranges based on the EPRI Distribution Power Quality Project. The material in this section of the report has been compiled from several EPRI reports that have been published over the last decade and represent a vast body of knowledge about the range of power quality variations in distribution circuits. For a more detailed treatment of power quality variations, refer to the sources referenced in the Bibliography.

Categories of Power Quality Variations

The recent proliferation of electronic equipment and microprocessor-based controls has caused electric utilities to redefine power quality in terms of the quality of voltage supply rather than availability of power. In this regard, IEEE Standard 1159-1995, *Recommended Practice for Monitoring Electric Power Quality,* has created categories of power quality disturbances based upon duration, magnitude, and spectral content. Table 3-1 shows the categories of power quality disturbances with spectral content, typical duration, and typical magnitude.

Table 3-1
Categories of Power Quality Variation – IEEE 1159-1995

Categories	Spectral Content	Typical Duration	Typical Magnitudes
1.0 Transients			
1.1 Impulsive			
1.1.1 Voltage	> 5 kHz	< 200 µs	
1.1.2 Current	> 5 kHz	< 200 µs	
1.2 Oscillatory			
1.2.1 Low Frequency	< 500 kHz	< 30 cycles	
1.2.2 Medium Frequency	300–2 kHz	< 3 cycles	
1.2.3 High Frequency	> 2 kHz	< 0.5 cycle	
2.0 Short-Duration Variations			
2.1 Sags			
2.1.1 Instantaneous		0.5–30 cycles	0.1–1.0 pu
2.1.2 Momentary		30–120 cycles	0.1–1.0 pu
2.1.3 Temporary		2 sec–2 min	0.1–1.0 pu
2.2 Swells			
2.1.1 Instantaneous		0.5–30 cycles	0.1–1.8 pu
2.1.2 Momentary		30–120 cycles	0.1–1.8 pu
2.1.3 Temporary		2 sec–2 min	0.1–1.8 pu
3.0 Long-Duration Variations			
3.1 Overvoltages		> 2 min	0.1–1.2 pu
3.2 Undervoltages		> 2 min	0.8–1.0 pu
4.0 Interruptions			
4.1 Momentary		< 2 sec	0
4.2 Temporary		2 sec–2 min	0
4.3 Long-Term		> 2 min	0
5.0 Waveform Distortion			
5.2 Voltage	0–100th Harmonic	steady-state	0–20%
5.3 Current	0–100th Harmonic	steady-state	0–100%
6.0 Waveform Notching	0–200 kHz	steady-state	
7.0 Flicker	< 30 Hz	intermittent	0.1–7%
8.0 Noise	0–200 kHz	intermittent	

Voltage Sags, Swells, and Interruptions

Figure 3-1 shows a typical voltage sag, swell, and interruption. A *voltage sag* is a short-duration decrease of the RMS voltage value, lasting from 0.5 cycles to 120 seconds. Sags are caused by faults on the power system or by the starting of a relatively large motor or other large load. A voltage swell may accompany a voltage sag.

A *voltage swell* occurs when a single line-to-ground fault on the system results in a temporary voltage rise on the unfaulted phases. Removing a large load or adding a large capacitor bank can also cause voltage swells, but these events tend to cause longer-duration changes in the voltage magnitude and will usually be classified as long-duration variations.

A *voltage interruption* is the complete loss of voltage. A disconnection of electricity causes an interruption, usually by the opening of a circuit breaker, line recloser, or fuse. For example, if a tree comes into contact with an overhead electricity line, a circuit breaker will clear the fault (short circuit), and the customers who receive their power from the faulted line will experience an interruption.

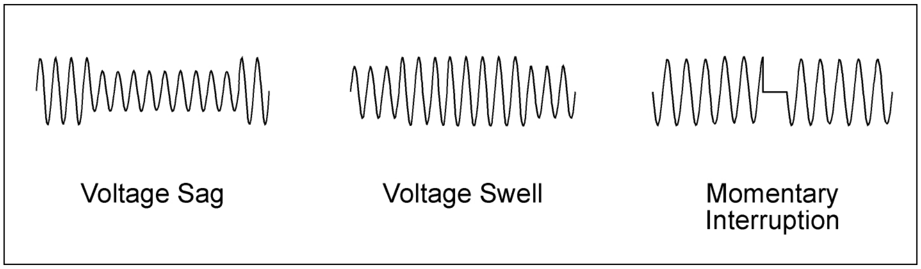

Figure 3-1
Typical Short-Duration RMS Voltage Variations

System Faults

Customers located on a faulted feeder will experience one or more interruptions, depending on the type of fault and the reclosing practices of the utility. For a temporary fault, one or two reclosing operations may be required before normal power is restored. For a permanent fault, a number of reclosing operations (usually no more than three) will occur before the breaker "locks out." In this case, the customers will experience a sustained interruption. Note that the interruptions associated with successive operations of the breaker may be of varying duration depending on relay characteristics. This gives the fault multiple opportunities to clear. The multiple operations also give sectionalizers the opportunity to operate. These devices typically open during the dead time after counting a certain number of consecutive incidents of fault current within a short time period. The number of fault-current incidents is typically two, although it could be one if the sectionalizer is at the head of an underground cable, where all faults are assumed to be permanent.

Reclosing practices vary from utility to utility and perhaps from circuit to circuit. Feeders that are mostly underground will typically not have any reclosing operations because most faults on underground feeders are permanent. Some utilities are experimenting with faster reclosing times (0.3 to 0.5 seconds) for the first reclosing operation in order to solve residential customer problems with momentary interruptions. Residential electronic equipment such as clock radios, VCRs, microwaves, and televisions can often ride through a 0.5-second interruption but cannot ride through longer-duration interruptions. At medium-voltage levels, it usually takes a minimum of 10 to 12 cycles of dead time to ensure that the ionized gases from faults are dispersed.

Customers located on parallel feeders (that is, feeders that are supplied from the same bus as the faulted feeder) will experience a voltage sag for as long as the fault remains on the line. On medium-voltage systems, nearly all faults are cleared within one second and can be cleared in as short as three cycles, depending on the magnitude of the fault current and the relay settings. This means that customers on parallel feeders will experience at least one voltage sag lasting from three cycles to about one second and possibly additional voltage sags if reclosing operations are required. Voltage sags are much less severe than interruptions, and the duration of interest is only the period of time that the fault is on the line.

If there are more than two feeders supplied from a common distribution bus, then voltage sags will occur more frequently than actual interruptions, because a fault on any one feeder will cause voltage sags on all the other feeders.

Customers that are fed directly from the high-voltage system (that is, transmission-fed or large industrial customers) usually have more than one line supplying the facility. Therefore, interruptions should be very infrequent for these customers. However, these customers will experience voltage sags during fault conditions over a wide range of the transmission system. Voltage sags caused by faults in a high-voltage system generally have more consistent characteristics. The faults that originate in the medium- and low-voltage systems tend to have more variation.

Because voltage sags can be much more frequent than interruptions, it is important to consider the impacts and possible remedies for voltage sags separately from the required solutions for complete interruptions.

Overvoltages and Undervoltages

Long-duration voltage variations that are outside the normal magnitude limits are most often caused by unusual conditions on the power system. For example, out-of-service lines or transformers sometimes cause *undervoltages,* as shown in Figure 3-2. These types of RMS voltage variations are normally short-term, lasting less than one or two days. Voltage variations lasting for longer periods of time are normally corrected by adjusting the tap on a step-voltage regulating transformer.

The root cause of most voltage-regulation problems is that there is too much impedance in the power system to properly supply the load. The load draws the current that gives a voltage drop across the system impedance. The resistive drop is in phase with the current, and the reactive drop is 90 degrees out of phase. Therefore, the load voltage drops low under heavy load. High voltages can come about when the source voltage has been boosted to overcome the impedance drop and the load suddenly diminishes.

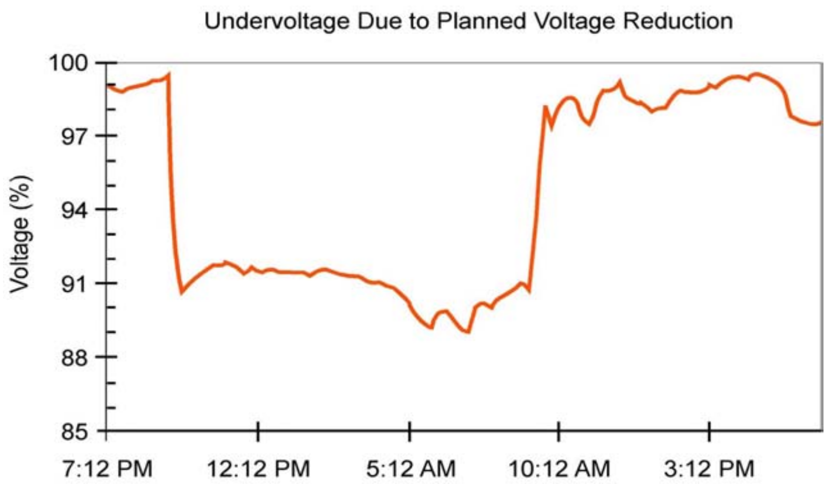

Figure 3-2
Example RMS Measurement of Undervoltage

Voltage Flicker

Voltage flicker is an amplitude modulation of voltage at frequencies less than 25 Hz, which the human eye can detect as a variation in the light intensity of a lamp. Voltage flicker, as shown in Figure 3-3, is caused by an arcing condition on the power system. The arcing condition may be a normal part of a production process, such as a resistance welder or an electric arc furnace. Voltage step changes greater than 3%, usually caused by the starting of large motors, may also cause light flicker, but these events are better classified as sags. Flicker problems can be corrected with the installation of filters, static VAR systems, or distribution static compensators.

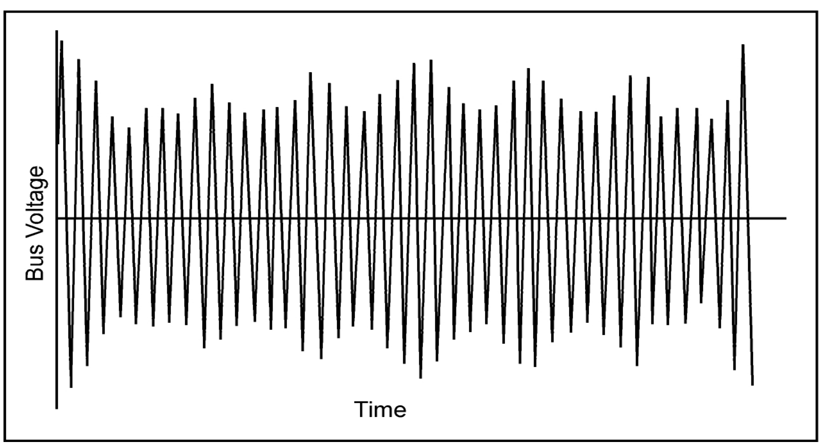

Figure 3-3
Example of Voltage Flicker Caused by an Arc Furnace

Harmonic Distortion

The phenomenon known as *harmonic distortion* is the presence of frequencies in the voltage that are integer multiples of the fundamental system frequency, which is 60 Hz for the North

American system. Electronic loads and saturable devices generate harmonic distortion. Computers, lighting, and electronic office equipment generate harmonic distortion in commercial facilities. In industrial facilities, adjustable-speed motor drives and other power electronic loads can generate significant amounts of harmonics.

It is generally safe to assume that the sine wave voltage generated in central power stations is very good. In most areas, the voltage found on transmission systems typically has much less than 1% percent distortion. However, the distortion may reach 5% to 8% as we move closer to the load. At some loads, the current waveforms will barely resemble a sine wave. Figure 3-4, for example, shows a waveform with over 17% harmonic distortion.

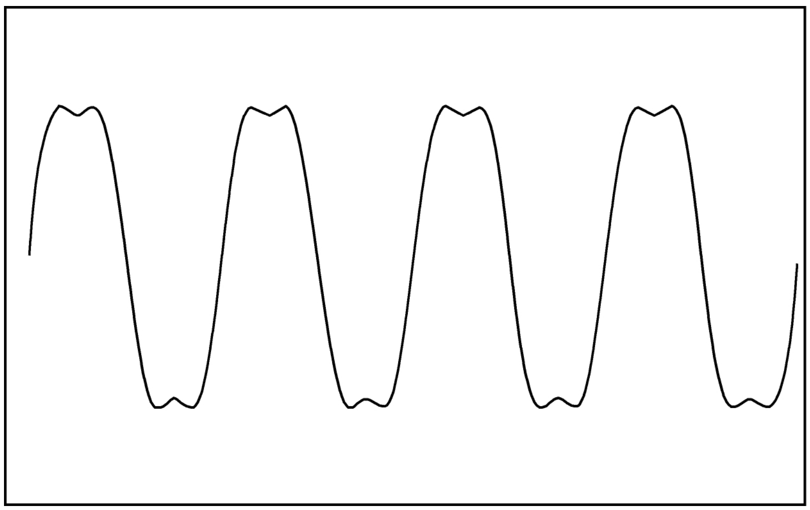

Figure 3-4
Example Voltage Waveform with 3rd Harmonics and 17.42% Total Harmonic Distortion

Electronic power converters can chop the current into a variety of waveforms. Most distortion is periodic, or harmonic. That is, it repeats cycle after cycle, changing very slowly, if at all. This has given rise to the widespread use of the term “harmonics” to describe perturbations in the waveform. However, this term must be carefully qualified to make sense.

Solutions to problems caused by harmonic distortion include the installation of active or passive filters at the load or bus, or taking advantage of transformer connections that enable cancellation of zero-sequence components.

Voltage Notching

Voltage notching is caused by the commutation of power electronic rectifiers. It is an effect that can cause concern over power quality in any installation where converter equipment such as variable-speed drives are connected. The effect is caused by the switching action of a drive’s input rectifier. When the DC-link current in a drive is commutated from one rectifier thyristor to the next, there is an instant during which a line-to-line short circuit occurs at the input terminals of the rectifier. The result is a phase voltage with four notches per cycle caused by a six-pulse electronic rectifier, as shown in Figure 3-5.

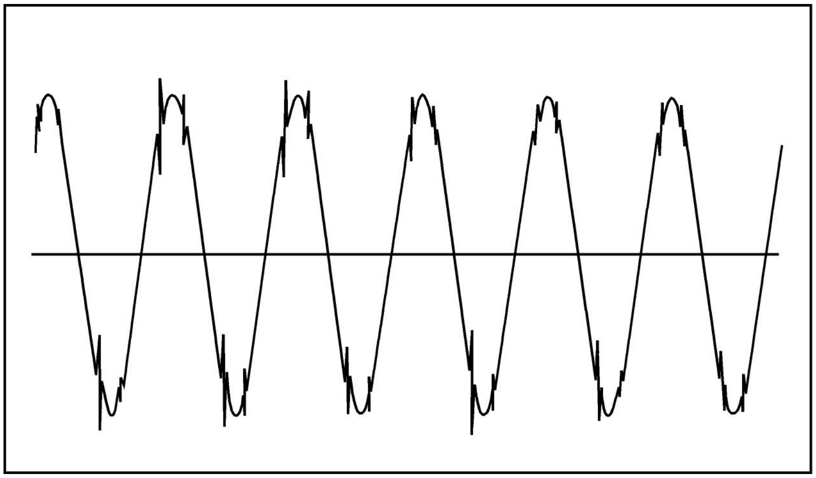

Figure 3-5
Example Waveform with Notching

Transient Disturbances

Transient disturbances are caused by the injection of energy by switching or by lightning. The disturbance may either be *unidirectional* or *oscillatory*. Lightning, electrostatic discharge, load switching, or capacitor switching may cause a unidirectional transient, as shown in Figure 3-6, which is characterized by its peak value and rise time. On the other hand, an oscillatory transient, as shown in Figure 3-7, is characterized by its frequency content. It can be caused by a switching operation such as the energization of a capacitor bank, distribution line, or cable, or the opening of an inductive current. Low- and medium-frequency oscillations, with principle frequencies less than 2 kHz, are normally caused by power system switching. The switching of a load close in proximity to the point of interest may cause high-frequency oscillations with principle frequencies above 2 kHz. Common solutions to problems caused by transients include the application of surge arresters, passive and active filters, and isolation transformers.

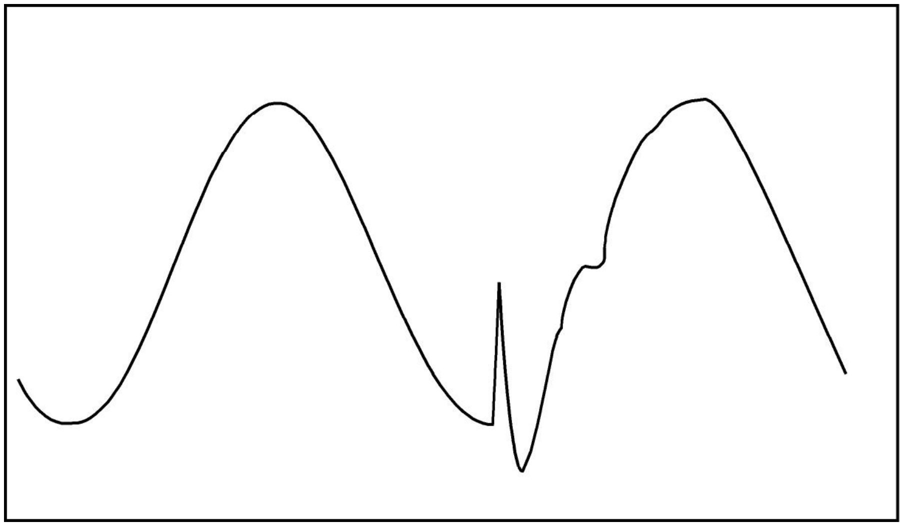

Figure 3-6
Impulsive Transient Waveform

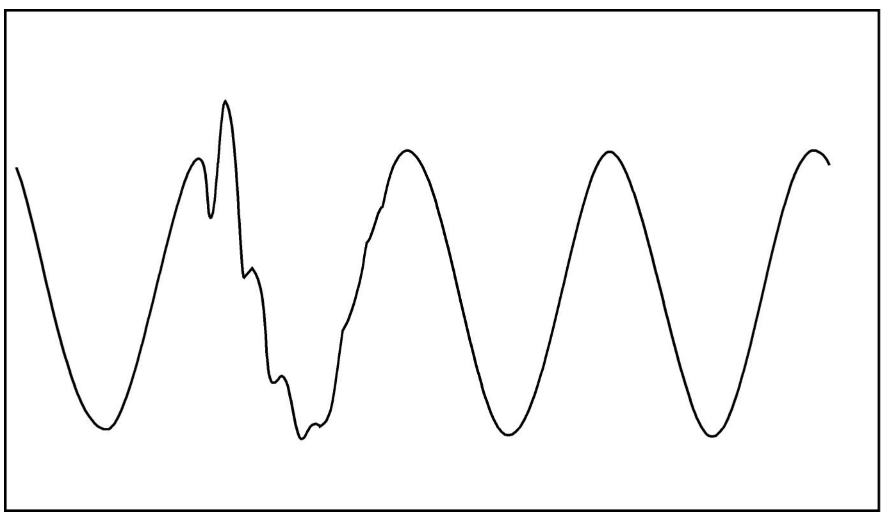

Figure 3-7
Oscillatory Transient Waveform Caused by a Capacitor Energizing

Ranges of Power Quality Variations from the EPRI DPQ Project

EPRI project RP3098, commonly known as the EPRI Distribution System Power Quality Monitoring Project, or EPRI DPQ Project, consisted of a power quality monitoring survey of 277 measurement locations on the primary distribution feeder of 24 electric utilities across the continental United States, which provided geographical and operating-practice diversity. The result of the site-selection process was a set of 100 distribution feeders in the voltage range of 4 kV to 33 kV.

The monitoring sites were determined by using a systematic and controlled selection process to provide a wide diversity of distribution system conditions. The monitored feeders ranged in voltage level from 4.16 kV to 34.5 kV and in length from 1 to 80 km. The 27 months of monitoring resulted in a staggering collection of data that was statistically summarized in a three-volume EPRI report[1]. The data collected during the measurement period provides a statistically valid sample of the range of power quality events in a distribution system, although not necessarily valid at any given site.

Figures 3-8 through 3-12 provide some results from the DPQ study to quantify the electrical environment based on the monitoring results. The data shows the sag and interruption rate, average magnitude and duration of sags and interruptions, oscillatory transient rate, average magnitude of oscillatory transients, voltage THD, and individual harmonics from all monitoring sites.

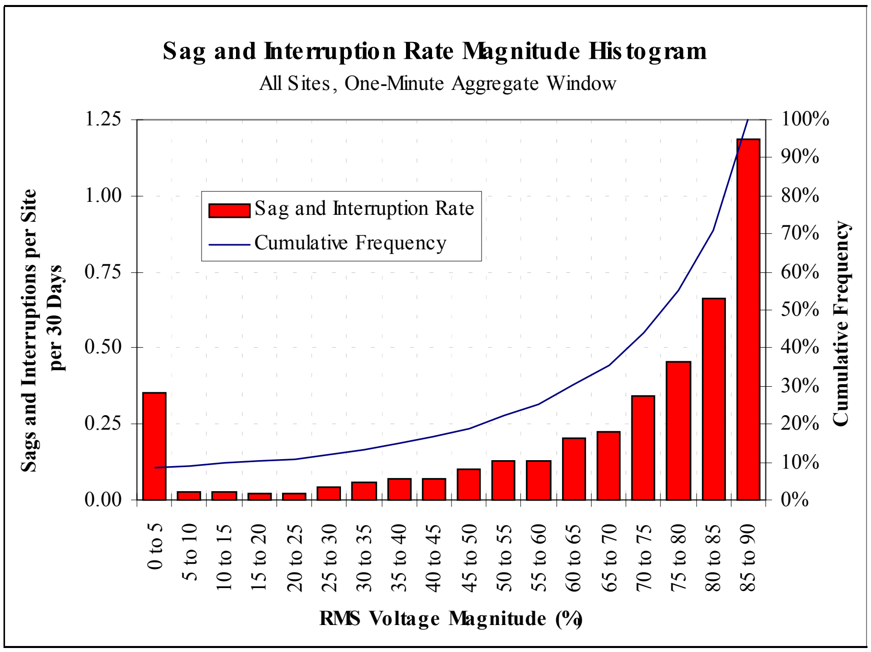

Figure 3-8
Sag and Interruption-Rate Magnitude Histogram, One-Minute Aggregation, 6/1/93 to 6/1/95, Treated by Sampling Weights, All Sites

[1] An Assessment of Distribution System Power Quality : Volumes 1-3; TR-106294-V1, TR-106294-V2, TR106294-V3.

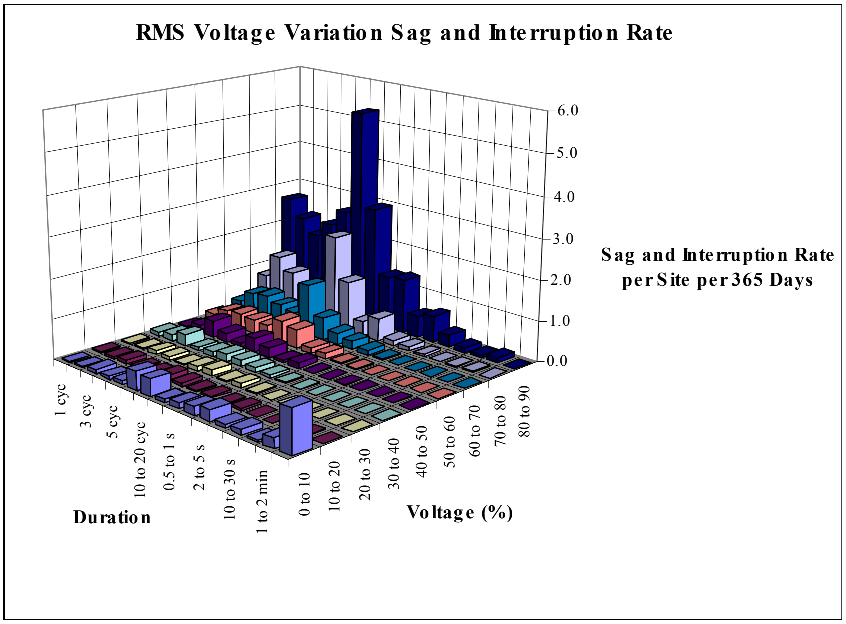

Figure 3-9
Sag and Interruption Rate Magnitude Duration Histogram, One-Min Aggregation 6/1/93 to 6/1/95, Treated by Sampling Weights, All Sites

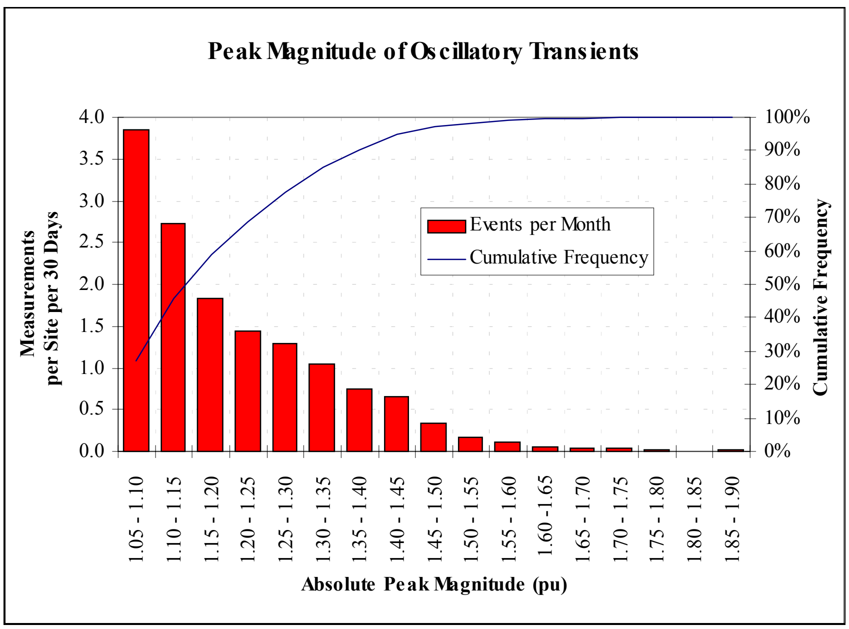

Figure 3-10
Histogram for Magnitude of Oscillatory Transients Measurement Events, 3/1/95 to 9/1/95, Treated by Sampling Weights, All Sites

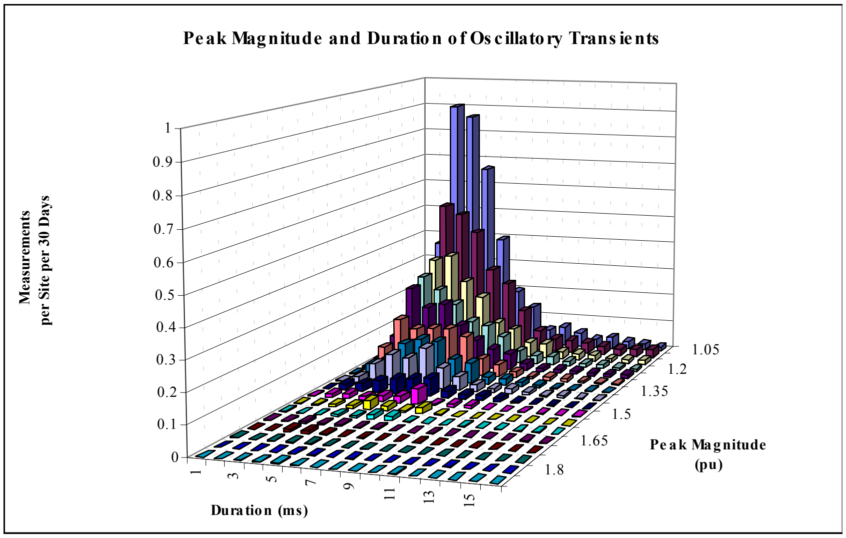

Figure 3-11
Magnitude and Duration of Oscillatory Transients Measurement Events, 3/1/95 to 9/1/95, Treated by Sampling Weights, All Sites

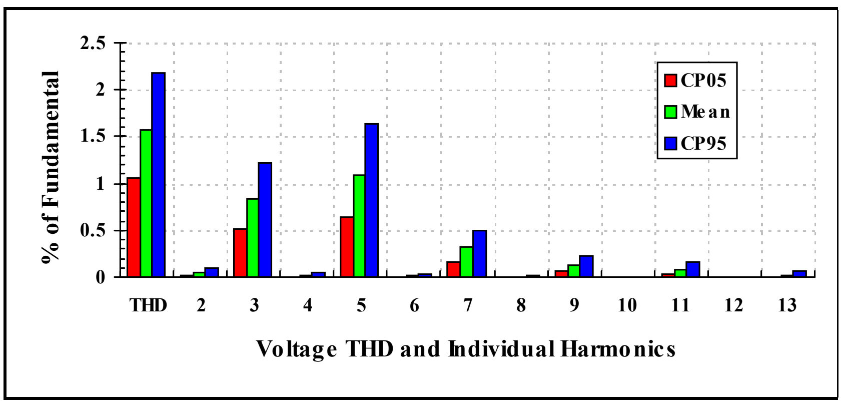

Figure 3-12
Voltage THD and Individual Harmonics, 6/1/93 to 3/1/95, All Sites

These definitions of power quality events and their probability characteristics are important for both specifying monitoring equipment and for developing test procedures for evaluating the performance of the equipment. This data will be used in developing a test protocol for evaluating both the instruments' power quality monitoring capabilities and the PQDIF files produced by the interface software.

Power Quality Monitor Test Stand

To facilitate the testing of power quality monitors, and other devices with power quality monitoring capabilities, under controlled situations, a power quality monitor test stand was designed and built. The stand was built with flexibility in testing as a key design consideration.

The test stand (Figure 3-13) allows up to 6 power quality monitors to be tested at the same time using the same input signals. Figure 3-14 illustrates the configuration of the test stand.

Figure 3-13
Power Quality Monitor Test Stand

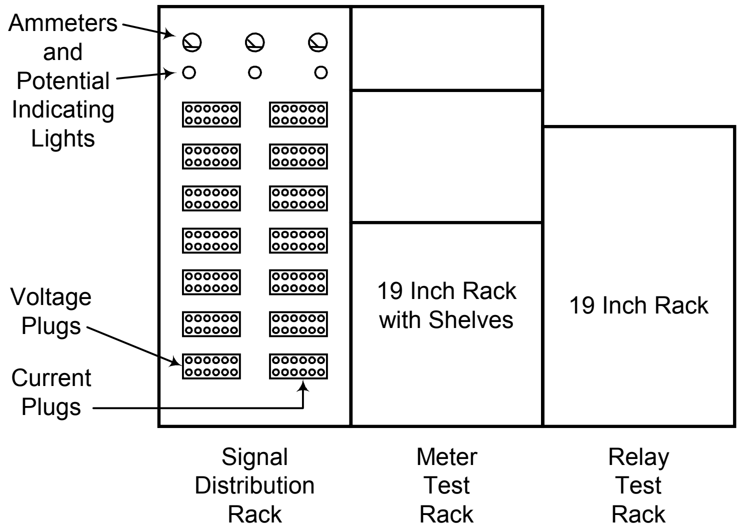

Figure 3-14
Power Quality Monitor Test Stand Layout

The source of the voltage and current signals can be either the 120/208 V supply to EPRI PEAC's main building or an arbitrary waveform generation rack with synchronized, separately controllable voltage and current sources, as shown in Figure 3-15. Current transformers with a ratio of 250:5 amps were installed in the main 120/208 panel of the building. Signals from these current transformers were wired to two separate test plugs in the wall behind the test stand, while the arbitrary waveform generation rack was wired with two similar plugs. This makes it possible to simply unplug the test stand from one source and plug it into the other.

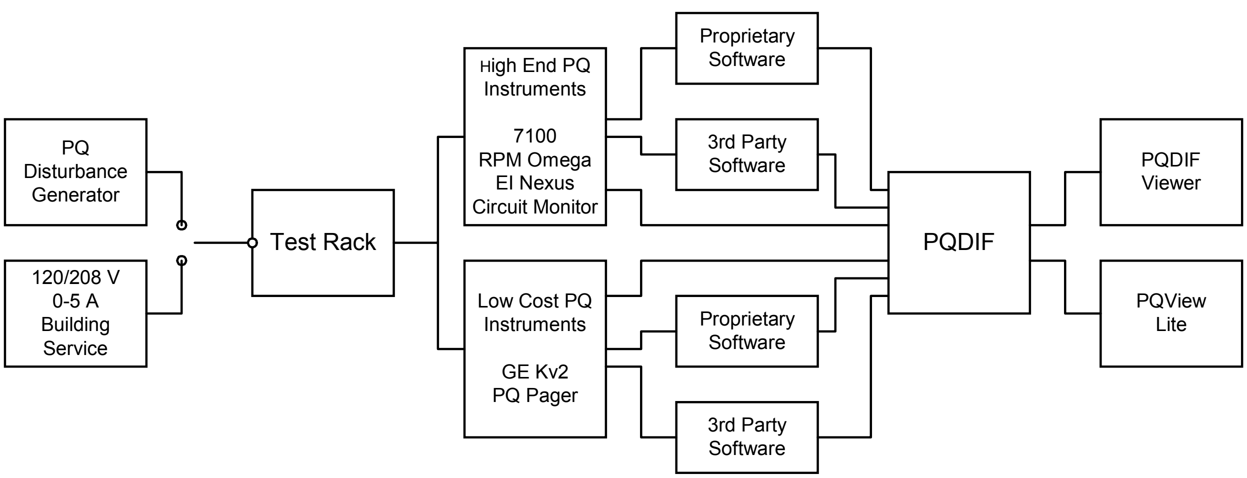

Figure 3-15
Power Quality Monitor Testing Block Diagram

The test stand can accommodate instruments with direct-connected current channels (0 to 5 amps) and instruments that require the use of auxiliary CTs. An instrument can be connected and disconnected from the test stand without affecting the other instruments. The current plugs are self-shorting, eliminating the possibility of accidentally opening a CT circuit.

Testing of Power Quality Monitoring/Reporting Capabilities

The purpose of this project is to develop a system of evaluating the power quality monitoring and reporting capabilities of power quality monitors with PQDIF export capabilities. The project's primary goal is the evaluation of the monitors' PQDIF capabilities with respect to IEEE Standard P1159.3. In order to evaluate the PQDIF files generated by each monitor, it is necessary to subject the monitors to an assortment of known voltage and current variations. In this way, the resulting PQDIF file can be compared to the known disturbance and the data recorded by the monitor. The protocol that will be used for testing the functionality of power quality monitors is described in the section below.

Test Protocol

The purpose of the test is not to perform any verification of absolute accuracy specifications; however, substantial variations in recorded values will be noted. Although most waveforms will be re-creations of actual recorded events, the magnitudes of the recreated wave shapes may be adjusted to challenge either instrument thresholds or over-range capability. In addition, the sequence of and intervals between events will be adjusted to determine the monitors' response to consecutive, related events. In instances where field-recorded events lack high-frequency fidelity to similar known events (possibly due to potential transformer limitations), events will be staged with laboratory equipment and scaled to match nominal conditions.

The performance criteria for each test defined in this protocol is **not intended to be pass/fail**, but shall provide a consistent and repeatable mechanism for evaluation of each power quality monitor. The results of these tests will be tabulated and presented on data sheets for sponsor review. Because there are differences in feature capabilities among the power quality monitors that will be tested, the intent will be to report on the features and performance ability of each monitor individually. While there is a natural tendency to want to compare one monitor brand to another, the emphasis in this test protocol is to compare the individual relay to the rationale behind the actual test and not to the other devices.

Power quality monitors with default threshold values will be initially set to those recommendations. In instances where the default values fail to cause an event trigger, EPRI PEAC will readjust the thresholds accordingly. Similar adjustments will be made if the nominal values are found too sensitive. Should problems arise, EPRI PEAC will communicate the findings to the manufacturer in an attempt to resolve the difficulty. Annotations will be recorded where the necessity to change thresholds to induce current events was required. The following procedures assume a single power quality monitoring device is under test. However, the test stand is designed to test up to 6 different devices at the same time.

Voltage Sags

Rationale: Voltage sags are one of the most common power quality phenomena. Detecting, capturing and recording these events accurately is essential to understanding load equipment susceptibility levels.

Purpose: To characterize the power quality monitor's ability to capture and report voltage sags of varying magnitudes and durations.

Test Guidelines: Connect the power quality monitor and apply the following test sequence to the device under test.

1. Connect the units under test into the configuration shown in Figure 3-16 (single phase connection).
2. Set the relay thresholds for voltage sags to 90 percent of the applied input nominal voltage.
3. Induce a voltage sag to 88 percent of V nominal for one-half cycle and record the time that this event was induced. Record the response of the relays under test.
4. Repeat Step 3 for durations of one, two, six, 10, 20 and 30 cycles. Repeat Step 3 for duration's of one second and three seconds.
5. Repeat Steps 3 and 4 for voltage sags to 80, 70, 50 and zero percent of V nominal.
6. Obtain a hard copy of the relay information recorded during the test sequence (including plots and text data if applicable) and attach to the recorded test results.

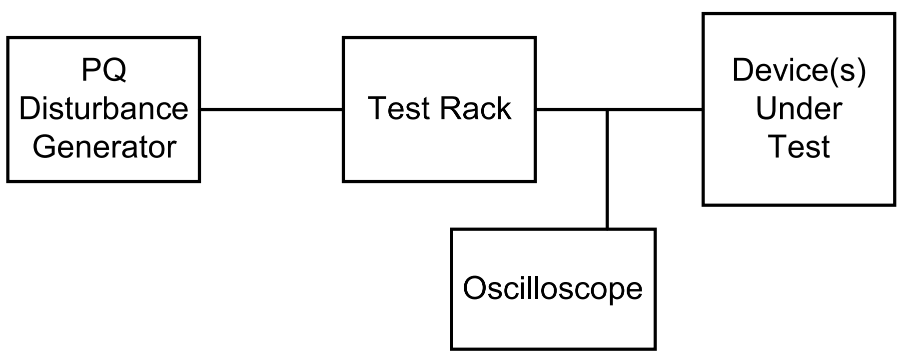

Figure 3-16
Test Setup for Power Quality Disturbance Testing

Voltage Swells

Rationale: Voltage swells occur on the power system occasionally and are observed at locations up to and including the end-use load equipment point. While most load equipment has inherent immunity to limited voltage swell conditions, it is important to accurately capture and report these events to understand equipment upsets and potential damage due to voltage swell events.

Purpose: To characterize the power quality monitor's ability to capture and report voltage swells of varying magnitudes and durations.

Test Guideline: Connect the relays and apply the following test sequence to the device under test.

Step 1. Connect the power quality monitor under test into the configuration shown in Figure 3-16.

Step 2. Set the monitor to record voltage swells above 110 percent of the applied input nominal voltage

Step 3. Induce a voltage swell to 112 percent of V nominal for one-half cycle and record the time that this event was induced. Record the results of the test.

Step 4. Repeat step 3 for durations of one, two, six, 10, 20 and 30 cycles. Repeat Step 3 for durations of one second and three seconds.

Step 5. Repeat Steps 3 and 4 for voltage swells to 120, 140 and 180 percent of V nominal.

Step 6. Obtain a hard copy of the relay information recorded during the test sequence (including plots and text data if applicable) and attach to the results.

Temporary Voltage Interruptions

Rationale: Momentary voltage interruptions are common power quality phenomena occurring on average some ten to twenty times per year at the typical location. Detecting, capturing and recording these events accurately is essential to understanding load equipment susceptibility levels, particularly because power conditioning solutions for momentary interruptions are distinctly different from those for momentary voltage sags. It is therefore very important that the relay be able to distinguish between the two events.

Purpose: To characterize the power quality monitor's ability to capture and report momentary voltage interruptions of varying magnitudes and durations.

Test Guidelines: Connect the power quality monitor and apply the following test sequence to the device under test.

Step 1. Connect the device under test into the configuration shown in Figure 3-16.

Step 2. Set the monitor up to the manufacturer's recommended levels for recording momentary voltage interruptions.

Step 3. Induce a momentary voltage interruption for one-half cycle and record the time that this event was induced. Record the response of the monitor.

Step 4. Repeat step 3 for durations of one, two, six, 10, 20 and 30 cycles. Repeat Step 3 for durations of one second and three seconds.

Step 5. Obtain a hard copy of the monitor information recorded during the test sequence (including plots and text data if applicable) and attach to the recorded results.

Long Duration Interruptions

Rationale: Long-duration interruptions occasionally occur. How a relay responds to these interruption events is of interest.

Purpose: To characterize the power quality monitor's ability to capture and report long-duration interruptions. Some power quality monitors contain built-in battery backup systems and should continue to function during power outages. Others do not have this feature and may shut down during interruptions. It is of interest to determine if the monitor can correctly record the time and duration of these events.

Test Guidelines: Connect the power quality monitor and apply the following test sequence to the devices under test.

Step 1. Connect the device under test into the configuration shown in Figure 3-16.

Step 2. Set the monitor to record low RMS events less than 90 percent of the applied input nominal voltage.

Step 3. Induce a 5-minute interruption event. Note the time of the induced event and the monitor response

Step 4. Obtain a hard copy of the monitor information recorded during the test sequence (including plots and text data if applicable) and attach to the recorded results.

Capacitor Switching Transient

Rationale: Capacitor switching transients are a known cause of upset for many industrial loads such as adjustable speed drives, servo machines and other devices with DC bus rails. It is important for the relay to be able to capture and identify capacitor-switching events that may be correlated to equipment upsets. Regardless of whether a power quality monitor has the ability to capture capacitor switching events or not, it is of interest to understand how these events are captured and classified.

Purpose: To characterize the power quality monitor's ability to capture and report capacitor switching transients and to understand the minimum bandwidth required by a monitoring device to accurately catch the event. Also to understand how the monitor must be set up to capture these events.

Test Guidelines: Connect the power quality monitor and apply the following test sequence to the devices under test.

Step 1. Connect the device under test into the configuration shown in Figure 3-16.

Step 2. Set up the monitor per the manufacturers recommendations to capture capacitor switching type transients. If the device is not capable of capturing capacitor switching transients, default settings for voltage thresholds will be used.

Step 3. Apply a capacitor switching transient having a 2.0 per unit magnitude at the 90 degree peak of the voltage sine wave. Record the time of occurrence of this event and the response of the relay.

Step 4. Repeat the Step 3 procedure for events with magnitude 1.8. 1.6, 1.4, and 1.2 per unit. Then repeat the sequence at the 270 degree peak.

Step 5. If the monitor did not capture and record all of the applied events, and is specified to be able to record these types of events, determine what must be done to the monitor settings to achieve capture of all of the applied capacitor switching transient. Record this information.

Step 6. Obtain a hard copy of the relay information recorded during the test sequence (including plots and text data if applicable) and attach to the recorded data.

ANSI C62.41 100 kHz Ring wave

Rationale: Ring waves are the most frequently observed transient events occurring in low-voltage power systems. Even a unidirectional impulsive surge on overhead lines will induce oscillatory transients at a facility service entrance. The ANSI/IEEE Standard Ring Wave, represented by a 0.5-µs rise time and a 100-kHz frequency, has a shorter transition time than the 1.2/50 µs - 8/20 µs Combination Wave. A short transition time means a fast dv/dt, which can fail or spuriously turn on semiconductors.

Purpose: To characterize the monitor's ability to capture and report different amplitudes for the 100 kHz ring wave.

Test Guidelines: This test will not be performed in the power quality monitor test stand. Choose one monitor and apply the following test sequence to the device under test.

Step 1. Connect the device under test into the configuration shown in Figure 3-17.

Step 2. Set up the monitor to capture transient voltage events. If the monitor is not specified to capture such events, default settings for voltage thresholds will be used.

Step 3. Apply a positive polarity (line-to-neutral) ring wave surge with a 500 V peak amplitude at the 90 degree sine wave peak. Repeat the surge with the generator set for negative polarity.

Step 4. Obtain oscilloscope traces of the Step 3 events and attach them to a hard copy of the relay information captured during the applied transients.

Step 5. Repeat Steps 3 and 4 using peak amplitude levels of 1000, 2000, 3000, and 6000 Volts.

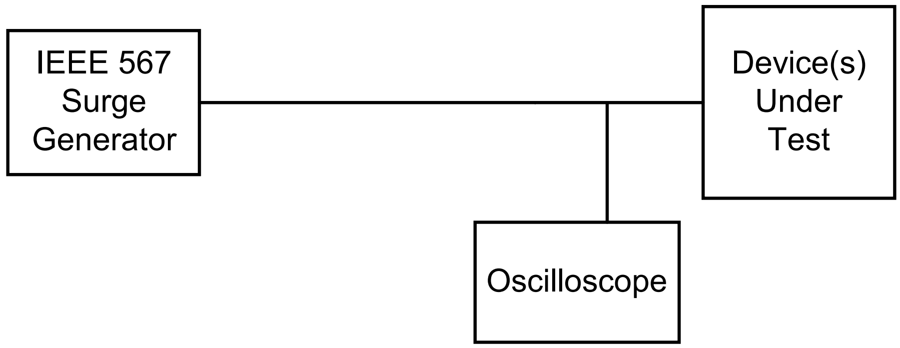

Figure 3-17
Test Setup for Surge Testing

ANSI C62.41 Combination Wave

Rationale: The 1.2/50 µs open-circuit voltage part of the Combination Wave, described in ANSI/IEEE C62.41-1991, has long been used to represent lightning surges on overhead lines. A corresponding 8/20 µs short-circuit current waveform has also been defined with levels appropriate to the location within a building premises. These two waveforms have substantial energy deposition capability and provide representative stresses to the surge protectors and commercial electronics connected to the power system. A power quality monitor may be capable of capturing varying levels of this event.

Purpose: To characterize the monitor's ability to capture, report, and survive a 6KV/3KA-combination wave.

Test Guidelines: This test will not be performed in the power quality monitor test stand. Choose one monitor and apply the following test sequence to the device under test.

Step 1. Connect the device under test into the configuration shown in Figure 3-17.

Step 2. Set up the monitor to capture transient voltage events. If the monitor is not specified to capture such events, default settings for voltage thresholds will be used.

Step 3. Apply a positive polarity (line-to-neutral) combination wave surge with a 1000 V peak amplitude at the 90 degree sine wave peak. Repeat the surge with the generator set for negative polarity.

Step 4. Obtain oscilloscope traces of the Step 3 events and attach them to a hard copy of the relay information captured during the applied transients.

Step 5. Repeat Steps 3 and 4 with the surge generator set to deliver 6000 volts at 3000 amps.

Extraneous Zero Crossings

Rationale: Extraneous voltage zero crossings, while not common, have been reported by many utilities as the cause of fast clock operation, misfiring of SCR control circuitry, and a variety of other equipment malfunctions. It is of interest to understand exactly what effect, if any, a steady state extraneous zero crossing event may have on different monitors.

Purpose: To characterize the monitor's ability to record accurate information in the presence of an unusual voltage waveform.

Test Guidelines: Connect the monitor and apply the following test sequence to the device under test.

Step 1. Connect the device under test into the configuration shown in Figure 3-16.

Step 2. Set up the monitor in the manufacturer's recommended configuration.

Step 3. Program the amplifier to deliver an output waveform similar to the one shown in Figure 3-18 and observe the monitor capture and reporting characteristics.

Step 4. Experiment with the monitor's programmable settings until performance is observed that is neither continual triggering nor some other unusual condition. Record all monitor responses.

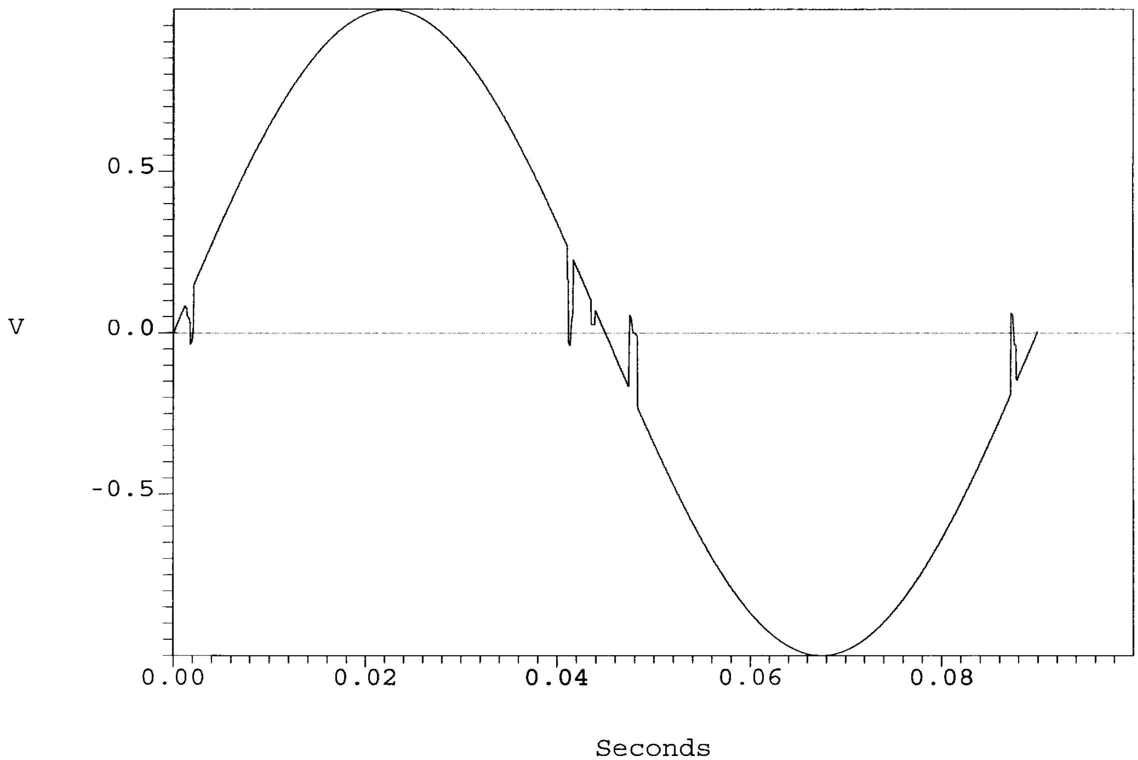

Figure 3-18
Waveform with Extraneous Zero Crossings

Harmonics

Rationale: Some power quality monitors have the ability to perform harmonic analysis of recorded voltage and current waveforms. Regardless of the specified claims of a given monitor regarding harmonic data capture, it is of interest to know how accurately the monitor records data in the presence of harmonics.

Purpose: To characterize the power quality monitor's ability to record harmonic data and/or record RMS voltage and current data in the presence of different levels of harmonic distortion.

Test Guidelines: Connect the monitor and apply the following test sequence to the device under test.

Step 1. Connect the device under test into the configuration shown in Figure 3-19.

Step 2. Set up the monitor with the manufacturer's recommended harmonic voltage capture configuration. If the monitor does not perform harmonic capture, set the device's other thresholds to default levels.

Step 3. Program the amplifier to deliver a steady state voltage waveform similar to the one shown in Figure 3-20.

Step 4. Obtain a voltage harmonic spectrum from the digital harmonics analyzer and attach it to a hard copy of the monitor information captured during the applied condition. Record the actual RMS voltage levels produced by the amplifier as well as the RMS voltage levels reported by the monitor.

Step 5. Repeat the above sequence with the amplifier programmed to deliver a steady state voltage wave shape similar to the one shown in Figure 3-21, Figure 3-22, and then Figure 3-23.

Step 6. Connect the non-linear test load, obtain a harmonic current spectrum from the digital harmonics analyzer and attach it to a hard copy of the monitor information captured during the applied condition. Record the actual RMS current values and those reported by the monitor.

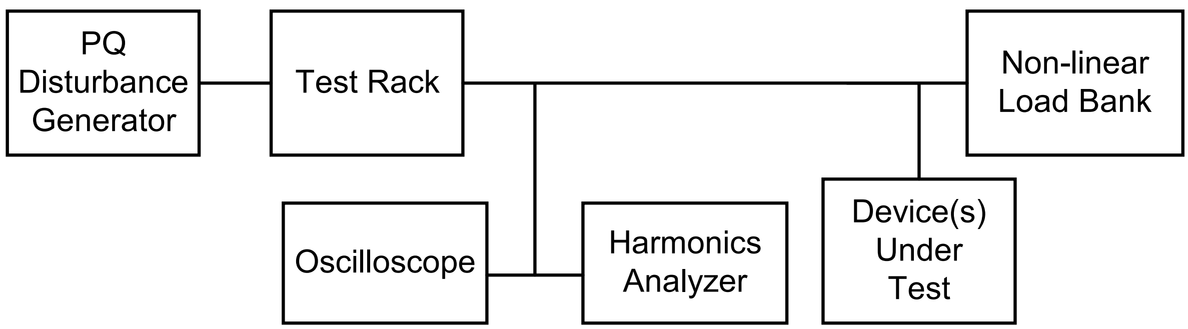

Figure 3-19
Test Setup for Voltage and Current Harmonics Test

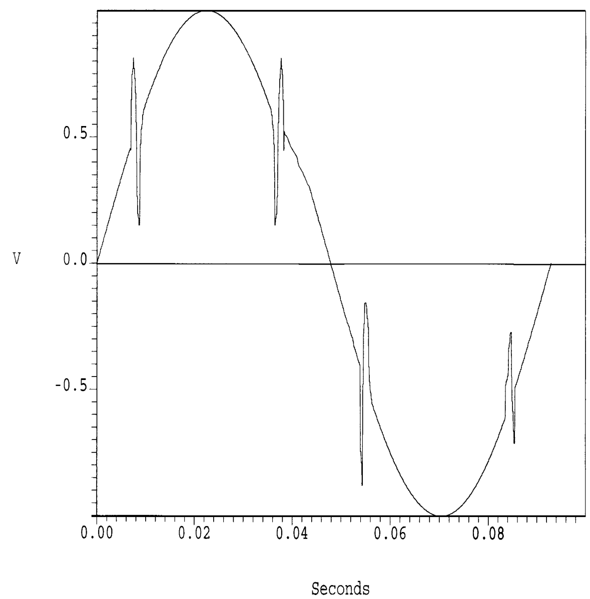

Figure 3-20
Harmonic Voltage Waveform

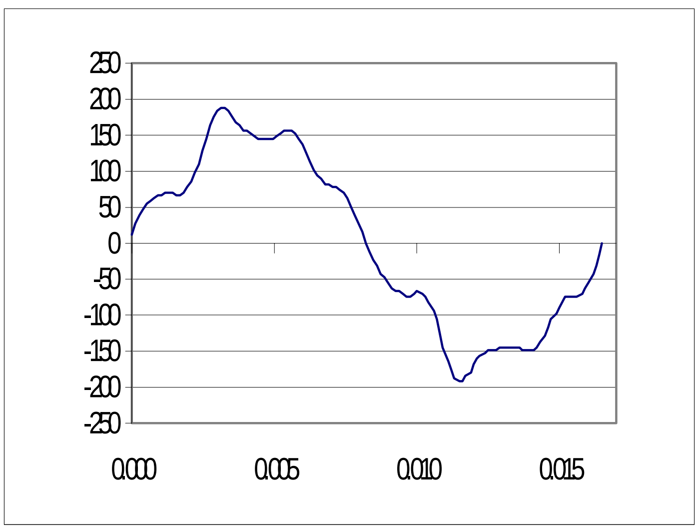

Figure 3-21
Harmonic Voltage Waveform

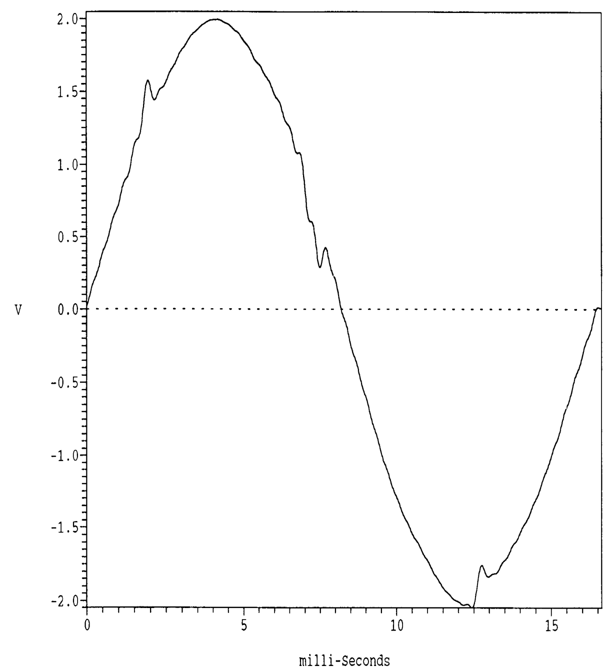

Figure 3-22
Harmonic Voltage Waveform

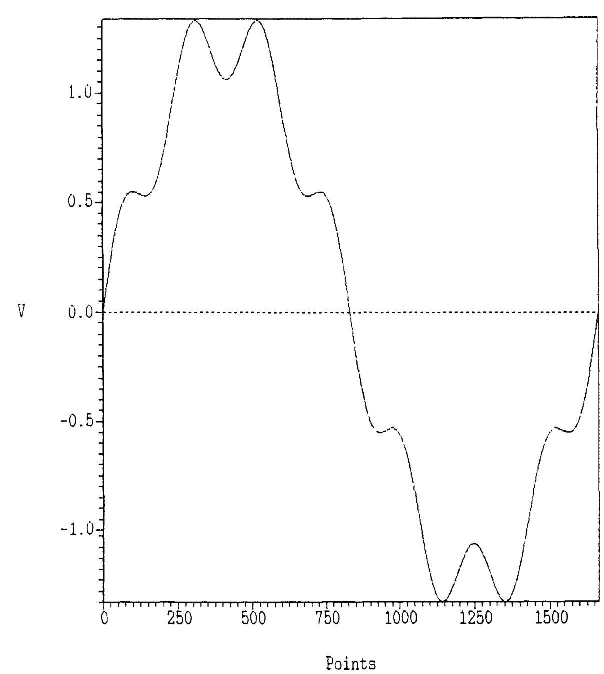

Figure 3-23
Harmonic Voltage Waveform

Conclusion

The data collected in each of the tests described in this section will be used in the creation of PQDIF files. The PQDIF files will be created in one of three ways according to the specifications of the manufacturer: natively by the power quality monitor, using the manufacturers proprietary software, or using available third-party software. Chapter 4 of this report will discuss the software related testing required to validate the PQDIF files.

4
SOFTWARE TESTING

Introduction

The single most important aspect of power monitoring is the data generated by the monitor. This data can be processed so that useful information is created. There are third-party packages that can perform very complex analysis on monitor-generated data. PQView is an example of this type of software. Getting this data, often in a proprietary file format, to these third-party packages without a standard data interchange format can be a difficult if not impossible situation. The PQDIF file format was developed to address this problem.

The PQDIF file format is very flexible, but this flexibility has inherent complexity which can lead to confusion by third party developers, causing poorly generated PQDIF files. If the PQDIF standard is to be used as the standard for power quality data interchange, it is important that the developers of the various monitors or monitoring software packages have the ability to generate an accurate and compliant PQDIF formatted file. The suite of tests outlined in this chapter is an attempt to verify the ability of software packages to generate a valid PQDIF file.

We will be using some EPRI-developed tools as well as some third-party tools to perform validation. Other tests will involve direct comparison to the standard. All of the items in this chapter are derived from IEEE Standard P1159.3: Recommended Practice for the Transfer of Power Quality Data, Draft 5.

Test Descriptions

A set of software from various sources will be tested to answer what should be considered the basis of a PQDIF validation suite.

The validation suite will ask the following questions:

- Does the software create a PQDIF?
- Is the data accurate?
- Is the file generated compliant with the PQDIF file structure?
- Is it portable?

If at the end of the validation sequence, a product responds in the positive to all four questions, it should be deemed a PQDIF file generator.

Tools

Tools that will be used in the software testing will be the tools posted on the IEEE 1159.3 Web Site, http://grouper.ieee.org/groups/1159/3/index.html, except for PQView, which is part of the Power Quality Diagnostic System available from EPRI. See http://www.epri.com for more info.

PQDIF Viewer and Test Utility

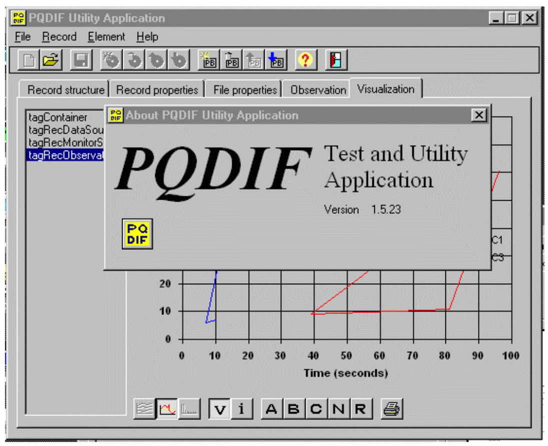

Figure 4-1
PQDIF Viewer and Test Utility

This Windows utility (Figure 4-1) can be used to query a binary PQDIF file and look at the physical and logical structure of the file. The program can show the position of a record within the file as well as query all of the tags and collections within it. Waveform data can be displayed as well.

PQDIFR – Binary to ASCII PQDIF Translator

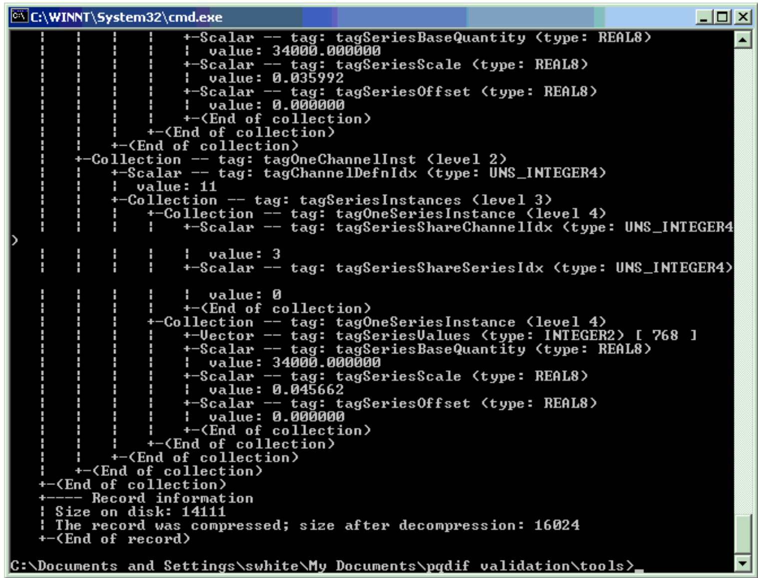

Figure 4-2
PQDIFR Sample Output Screen

The PQDIFR command line program will take the binary PQDIF file outputted from third-party software and generate an ASCII representation of the structure. A sample console output is shown in Figure 4-2. The output from this program will be used to compare the file structure to the standard.

PQView PQDIF Utility

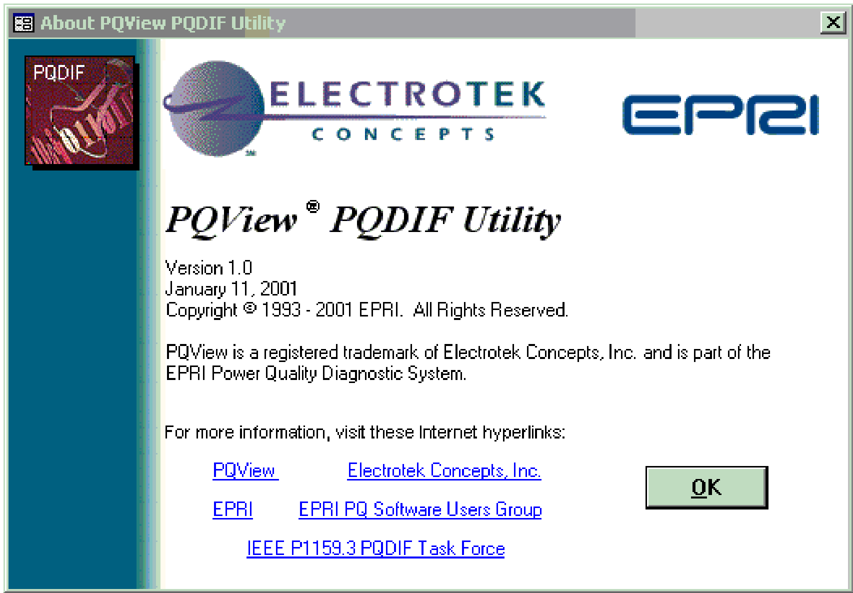

Figure 4-3
PQView PQDIF Utility

This utility (Figure 4-3) was developed to import PQDIF files generated from third parties into PQView. Specifically these PQDIF files, though structurally compatible, may not import correctly into PQView. The utility looks like and runs very similarly to PQView (see Figure 4-4).

PQVIEW

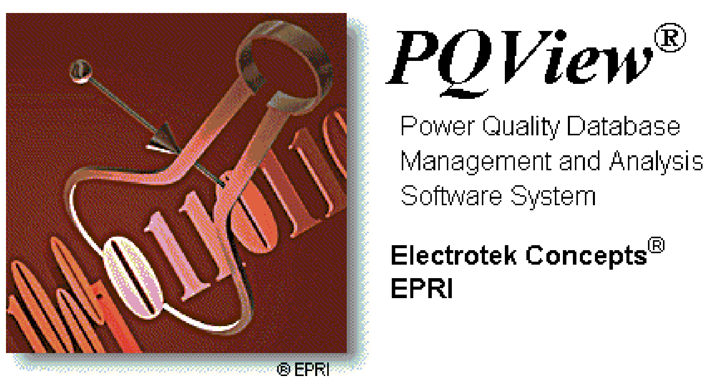

Figure 4-4
PQView Splash Screen

PQView is part of EPRI's Power Quality Diagnostic System. It used to analyze and characterize power quality monitor data. PQView can perform RMS variation analysis, list power quality events, and characterize to over twenty PQ indices, such as SARFI. PQView can generate power quality reports as well as event notification via email or pager.

Test 1: PQDIF Output

This test will determine if a given product can actually output a PQDIF file.

The following items will be recorded:

- Does the package have an option to generate PQDIF output?
- If yes, is it built in?
- If not, is there a third-party tool to translate the data to PQDIF?

Test 2: Data Accuracy

Data accuracy is a very important aspect of PQDIF generation. The test will be comprised of generating a PQDIF file from one of the test subjects and then using the PQDIF Viewer and Test Utility to go through the PQDIF records to view the data and compare it to the original, pre-PQDIF output. See Figure 4-5 for sample.

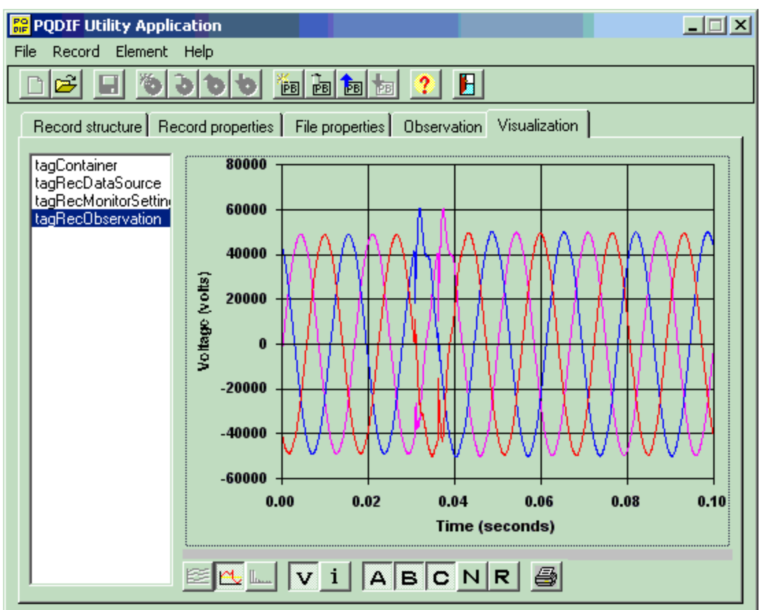

Figure 4-5
Sample Output of a 3-Phase Waveform in a PQDIF-Formatted File

Test 3: Structure Compliancy

Structure compliancy will attempt to analyze the format of the file generated. Two tools will be used to accomplish this: the PQDIF Viewer and Test Utility and the PQDIFR binary-to-ASCII dump utility.

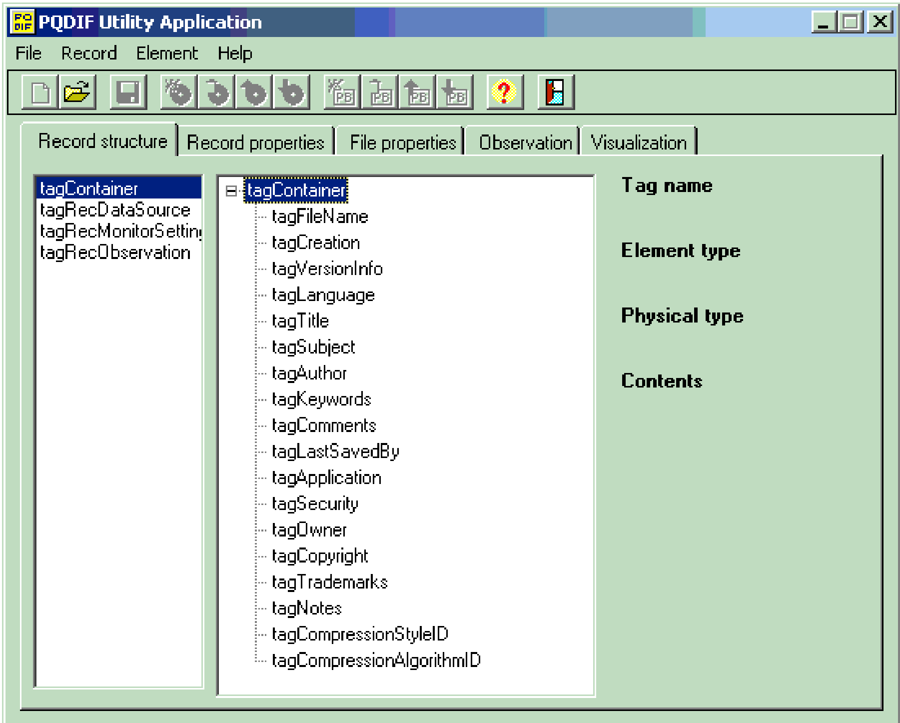

Figure 4-6
Sample PQDIF File Record Structure

We will be ascertaining that the file contains the correct and required tags as defined is IEEE Standard P1159.3 Draft 5. A PQDIF flat file is a linked list of records. Figure 4-6 illustrates the files structure of a PQDIF file. Each record is composed of a record header (see Figure 4-7), which contains a GUID, or tag. that describes what the record is, plus its size and a link to the next record.

<table>
<tr><td>Record header
• Tag: PQDIF Signature
• Tag: Type of record
• Size of record header
• Size of record body</td><td>{ 4a111440-e49f-11cf-9900-505144494600 }
tagContainer
64 bytes
512 bytes</td></tr>
<tr><td rowspan="2">Record body
• Starts with a Collection
• Links are relative file references, and point to elements within the body of the record. They are relative to the first byte of the record header.</td><td>Collection
• Count: 12
Element 0
• Tag: tagFileName
• Type: Vector
• Physical type: CHAR1
• Link
• Size (16 bytes – padded from 13)</td></tr>
<tr><td>Vector
Count: 13 (includes the NULL terminator)
Data: “FILENAME.PQD”</td></tr>
</table>

Figure 4-7
Example Record Header

Besides the header, the PQDIF file has a logical structure which contains a hierarchy of records that consists of a single container followed by one or more data sources. The file should also contain monitor settings and observation records. Tags are used to explain the element structure within the container and other records within the hierarchy (see Figures 4-8 through 4-10). Each data source, monitor setting and observation record has a set of required element tags.

Level	Element Tag	Example Value
0	tagRecDataSource	--NA--
1	tagNominalFrequency	60.0
1	tagChannelDfns	--NA--
2	tagOneChannelDfn	--NA--
3	tagPhaseID	*ID_Phase_AN*
3	tagQuantityTypeID	*ID_QT_Waveform*
3	tagQuantityMeasuredID	*ID_QM_Voltage*
3	tagSeriesDfns	--NA--
4	tagOneSeriesDfn	--NA--
5	tagValueTypeID	*ID_Series_Value_Type_Time*
5	tagQuantityUnitsID	*ID_QU_Seconds*
5	tagQuantityCharacteristicID	*ID_QC_None*
5	tagStorageMethodID	*ID_Series_Method_Values*
4	tagOneSeriesDfn	--NA--
5	tagValueTypeID	*ID_Series_Value_Type_Val*
5	tagQuantityUnitsID	*ID_QU_Volts*
5	tagQuantityCharacteristicID	*ID_QC_Instantaneous*
5	tagStorageMethodID	*ID_Series_Method_Values*

Figure 4-8
Required Element Tag for a Data Source Record

Level	Element Tag	Example Value
0	TagRecMonitorSettings	--NA--
1	TagEffective	Date settings were implemented.
1	TagTimeInstalled	Date monitored installed
1	TagChannelSettingsArray	--NA--
2	TagOneChannelSetting	--NA--
3	TagChannelDefnIdx	57
3	TagTriggerTypeID	--NA--

Figure 4-9
Required Element Tags for the Monitor Setting Record

Level	Element Tag	Example Value
0	TagRecObservation	--NA--
1	TagObservationName	*Phase A Voltage Waveform*
1	TagTimeCreate	*12/9/1998 11:42:24.453813818*
1	TagTimeStart	*2/13/1998 23:17:44.086079597*
1	TagTriggerMethodID	*ID_Trigger_Meth_Channel*
1	(tagTimeTriggered)**	*2/13/1998 23:17:44.086079597*
1	TagChannelInstances	--NA--
2	TagOneChannelInst	--NA--
3	TagChannelDefnIdx	57
3	TagSeriesInstances	--NA--
4	TagOneSeriesInstance	--NA--
5	TagSeriesValues	0,0.00013,0.00026, . . .
4	TagOneSeriesInstance	--NA--
5	TagSeriesValues	-4607.4621, -5030.9689, -5428.9193, . . .

Figure 4-10
Required Element Tags for the Observed Record

The PQDIF format also defines the different types of common power quality data, such as Waveform, RMS Variation, Steady State Values and others. We will be checking that these common types are accurately represented within each product's generated output.

For a further exploration of the PQDIF file format, please consult Chapter 2 in this document or visit the IEEE web site on the Internet at http://grouper.ieee.org/groups/1159/3/index.html

Test 4: Portability

The last phase of the validation suite is to see how portable the generated output is. We will be using PQView as the test bed for this; however, other third-party products may be brought in to augment this stage. Checklist items for the portability testing are:

- Can the PQDIF file be successfully imported into PQView?
- Is the data represented the same as it was before import, i.e., is there any variation or degradation of the data as a result of any import conditions?
- Can a successful data analysis be performed on the data?

Conclusion

We have outlined the various procedures needed to perform a complete validation of a given product's PQDIF file output. Though lacking in detail, we can use this outline to flesh out a more specific test protocol as well as for discussion of additions or deletions from the test suite.

5
CONCLUSION

The Power Quality Data Interchange Format (PQDIF) was created to provide a platform-independent file format that enables the exchange of data between proprietary power quality monitoring systems. For this to work as intended, the PQDIF files created by various manufacturers must meet the proposed IEEE Standard (P1159.3) and be compatible with the selected analysis software. Manufacturers of monitoring hardware, producers of power quality analysis software, and end users are interested in a testing procedure to evaluate the compliance and compatibility of PQDIF files.

Testing

The PQDIF file structure is very flexible in the types of data that can be characterized. However, its very flexibility creates concerns about the ability of a particular piece of analysis software to read the data stored in the PQDIF file. The same data can be stored in different ways while staying within the definition of the standard. The analysis software might not be able to correctly import the data if it is in a location other than where the software expects it. For this reason, testing the compliance and compatibility of PQDIF files is important to end users. This report describes a testing process to assess PQDIF for these important features. The testing process contains two main types of testing: hardware and software.

Hardware testing involves testing the response of power quality monitoring equipment to various power quality events as defined in IEEE 1159. The monitoring equipment can be traditional power quality monitors, revenue meters, power system relays, or other intelligent electronic devices connected to the power system. This report describes a protocol for testing the response of the monitors to predetermined events. As the first group of devices are tested, the protocol will be modified based on the lessons learned.

A power quality test stand specially built for this project will facilitate the hardware testing. The test stand provides parallel connections to voltage signals and series connections to current signals for up to six power quality monitors. These signals are supplied by either instrument transformers connected to the building service or an arbitrary waveform generator that produces independently controlled, synchronized voltage and current waveforms.

Software testing involves three major steps: verifying the structure of the PQDIF file, verifying the data stored in that file, and assessing the compatibility of the file with analysis software. Various tools will be used to evaluate the PQDIF files created by the various hardware manufacturers. These tools include rudimentary file-structure viewers, sophisticated data viewers, and power quality analysis packages. The result of this testing is not a simple pass or fail. A file could be determined to have the correct structure and data but not be compatible with the selected analysis software. In this case, the file would be compliant with the proposed IEEE Standard 1159.3. However, the incompatibility of the file with the analysis package would be documented.

Next Steps

A preliminary protocol for both hardware and software testing related to PQDIF file verification has been written. A test stand specifically designed to aid in the testing of the power quality monitoring capabilities of traditional power quality monitors, revenue meters, and power-system relays has been constructed. The next step is to choose several devices with PQDIF capabilities and perform the tests outlined in this report. The lessons learned from this testing can then be used to identify additions and/or modifications needed in the test procedures.

Many manufacturers and end users have indicated a desire to have a PQDIF certification system created by an independent third party. Such a certification would help end users when evaluating monitoring equipment for use in system- wide power quality monitoring systems. The certification system would also eliminate the need for hardware manufacturers to work with competitors in both the software and hardware industries when developing PQDIF capabilities for their equipment. EPRI, using the facilities and expertise of EPRI PEAC Corporation, could administer a PQDIF certification system.

A

PQDIF COMPATIBLE INSTRUMENTS

As mentioned earlier in this report, the fact that the PQDIF standard has not yet been adopted by IEEE has not discouraged manufacturers from adopting it. Many instruments can now produce PQDIF files, either natively, or through the use of post processing software. Below are the instruments known to be capable of PQDIF output at the time of this report. The list is not meant to be comprehensive as the list of vendors supporting PQDIF is rapidly expanding. The PQDIF capabilities of the listed devices have not been verified at this time.

Traditional Power Quality Monitors

The following are the traditional power quality monitors with some form of PQDIF capability. This group of instruments represents the instruments that are designed specifically as power quality monitoring devices.

Manufacturer	**Model(s)**	**PQDIF**
Dranetz-BMI www.dranetz-bmi.com	8010/8020, 7100, 3100	Yes, through third party software (1)
Dranetz-BMI	Signature System	Yes
Reliable Power Meters www.reliablemeters.com	Omega, Insight	Yes
Rochester www.rochester.com	PQR, TR100	Yes, through third party software (2)

(1) PQView, www.pqview.com
(2) Open System, www.kjt.com

Revenue Meters

The following are the revenue meters with some form of power quality monitoring capabilities and a method to obtain PQDIF files. This group of instruments represents devices designed primarily for power metering or measuring.

Manufacturer	Model(s)	PQDIF
Electro Industries www.electroindustries.com	Nexus, Futura	Yes, third party software (2)
GE www.ge.com	KV2	Yes, third party software (1)
Power Measurement www.pml.com	ION series	Yes

(1) Translator developed by EPRI and American Electric Power
(2) Open System, www.kjt.com

Power System Relays

The following are the power system relays with some form of power quality monitoring capabilities and a method to obtain PQDIF files. The primary function of these devices is the protection of power systems.

Manufacturer	Model(s)	PQDIF
GE www.ge.com	Multilin	Yes, third party software (1)
Schweitzer www.selinc.com	351-x	Yes, third party software (1)

(1) Open System, www.kjt.com

Target:
Power Quality Measurements and Testing

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