

DPQ Report: Monitoring Power Quality Levels on Distribution Systems

Keywords:

Capacitor Energizing
Harmonic
Lightning Fault
Lightning Transient
Momentary Interruption
Other Faults
Report
Sag/Swell
Transient
Voltage Regulation

Introduction and Approach

This report describes a monitoring program designed to characterize power quality levels on electric distribution systems. The monitoring program is being sponsored by the Electric Power Research Institute. Initial stages of the project resulted in the development of a new power quality monitoring instrument - the BMI 8010 PQNode. This instrument permits simultaneous monitoring of steady-state quantities (rms voltage and current, harmonic distortion levels, power factor, etc.) and disturbances (voltage sags, overvoltages, transients, etc.).

Approximately 200 PQNodes have been installed on distribution systems of 25 different utility companies. This report describes the monitoring system and presents preliminary results of the monitoring effort.

Power quality is a term that is directed at a wide variety of variations in the electric power supplied to utility customers. These variations can originate and/or manifest themselves at various places in the network. Many of the power quality concerns are associated with the operation and design of customer facilities; concerns associated with wiring and grounding problems, switching transients, load variations, and harmonic generation are examples of these. Others are attributed to the design and operation of the supply network.

In response to the concerns expressed by utility companies and their customers over the power quality issue, the Electric Power Research Institute (EPRI) began in 1990 to conduct a study of the state of power quality on distribution feeders in the US. The Distribution Power Quality (DPQ) project involves the monitoring and simulation of power quality phenomena on distribution systems.

The monitoring portion of the project has been designed to provide a statistically valid set of data of the various conducted electromagnetic phenomena related to power quality. The resulting sample design will allow statistically valid and defensible conclusions to be reached about how various system attributes correlate to the incidence rates of power

quality-related electromagnetic phenomena. This is accomplished through the use of sophisticated statistical analysis and modeling techniques appropriate for the sample design used for this project. The survey will be performed over a two year period starting in June of 1992. In 1993 an additional 100 PQNodes will be added for a total of 300 monitoring points. The results of the new survey will be compared to those of earlier power quality surveys such as the one discussed in reference [1].

The project takes advantage of the participation of 25 host utilities across the continental US to provide geographic and operating practice diversity in the study. Figure 1 illustrates the locations of the host utilities. The statistical sampling process resulted in the selection of sites within the service territories of the illustrated host utilities. Table 1 lists the host utilities involved.

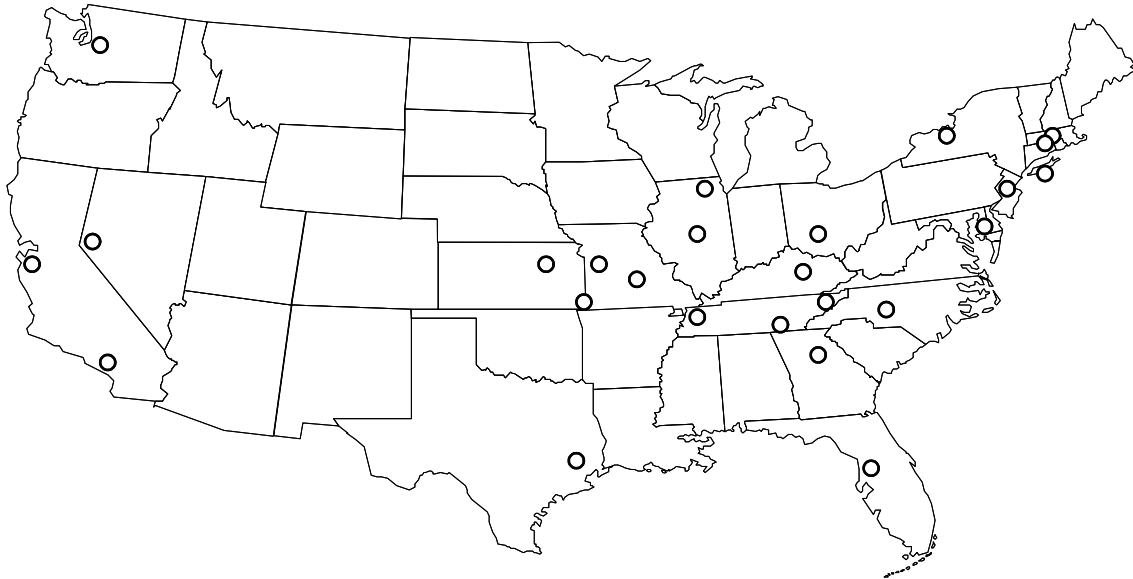


Figure 1: Host Utility Company Locations

Host Utility Companies	
Cincinnati Gas & Electric	Northeast Utilities
L.A. Dept. of Water & Power	Rochester Gas & Electric
East Kentucky Power	Pacific Gas & Electric
Elizabethan Electric - TVA	KPL Gas Service - KEURP
Delmarva Power	Commonwealth Edison
Florida Power Corp.	Georgia Power
Snohomish Public Utility District	Sierra Pacific
Houston Lighting	Illinois Power
Long Island Lighting	Massachusetts Electric
Boone Electric	Duke Power
Gibson EMC - TVA	Empire District - KEURP
Public Service Gas & Electric	Chattanooga Power - TVA
Kansas City Power. & Light - KEURP	

Table 1: Host Utility Companies

Although the number of utilities represented in the western part of the US are few, their service territories are quite large and encompass many states. The resulting geographical representation of the sample design is more than adequate to represent power quality attributes related to geography.

Several key milestones need to be met to accomplish the monitoring objectives:

- Identify the electromagnetic phenomena to be monitored.
- Design and build a new measuring instrument to measure the desired phenomena.
- Implement the sample design and choose monitoring sites.
- Install the instrumentation.
- Develop a software system to automate the data gathering and reporting process.
- Develop a statistical model.

All of these key milestones have been met except for the development of the statistical model. This task needs at least one year of data to be collected before it can begin.

Implementation

One of the first tasks in designing the measurement system, was to specify precisely the electromagnetic phenomena to be monitored. First the scope was limited to conducted electromagnetic phenomena (phase and neutral voltages and currents) only. The measurements were further limited to waveshape acquisition of data to a spectral resolution of around 7 kHz and impulsive transient peak/area detection to 5 kHz - 1 MHz. These limits were designed to allow the acquisition of the most common types of disturbances found on distribution systems that are likely to propagate onto customer systems, and allow an economical instrument design.

Given the above specifications, the PQNode instrument was designed to capture the following types of conducted electromagnetic phenomena:

- Impulsive and Oscillatory Transients
- Short Duration RMS Variations and Interruptions
- Long Duration RMS Variations and Interruptions
- Waveform Distortion

The definitions used for these phenomena are defined in the current draft of IEEE Project 1159 [2], a recommended practice for monitoring power quality. In addition, the PQNode performs periodic steady-state measurements to evaluate steady-state variations and also captures cold load pickup coming out of an outage (current inrush and load diversity recovery). The PQNode uses several different triggering technologies to capture the desired range of phenomena:

- Waveshape Fault Detection
- RMS Threshold Triggering
- Impulse Peak Detection
- Periodic Waveform Sampling
- Periodic RMS Sampling

The waveshape fault detection algorithm [3] illustrated in Figure 2 continuously compares each data point on the waveform with the previous 60 Hz cycle. If the new point is outside the limits of a floating window, a trigger occurs. This algorithm is very sensitive to small deviations and allows triggering on waveform deviations that might not cause peak detection-based algorithms to trigger. This sub-system is principally used to detect low frequency transients.

Floating Window

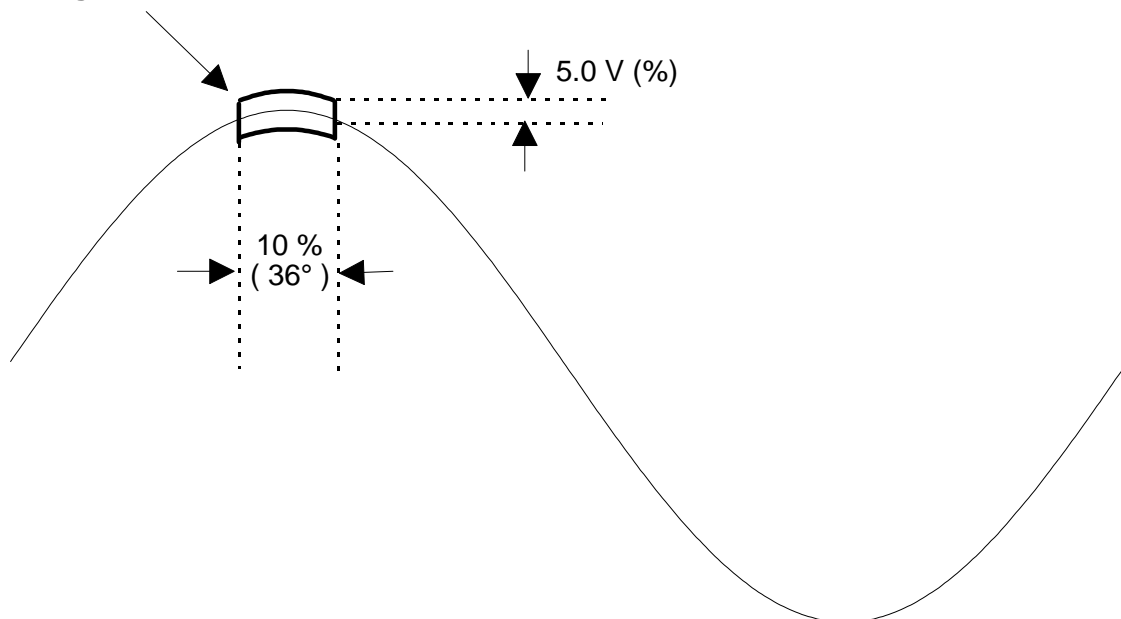


Figure 2: Waveshape Fault Detection

The rms threshold triggering mechanism is utilized to look for deviations of rms voltage magnitude outside of ANSI C84.1 or tighter limits, and trigger a recording of the ensuing phenomena. Since fault induced voltage sags appear to be one of the most important power quality phenomena, considerable effort was put into the design of this part of the PQNode instrument. This sub-system is also responsible for the detection and recording of interruptions and cold load pickup. Figure 3 illustrates the rms triggering parameters for the low threshold. The low and high rms thresholds are set to 95% and 105% respectively for this project.

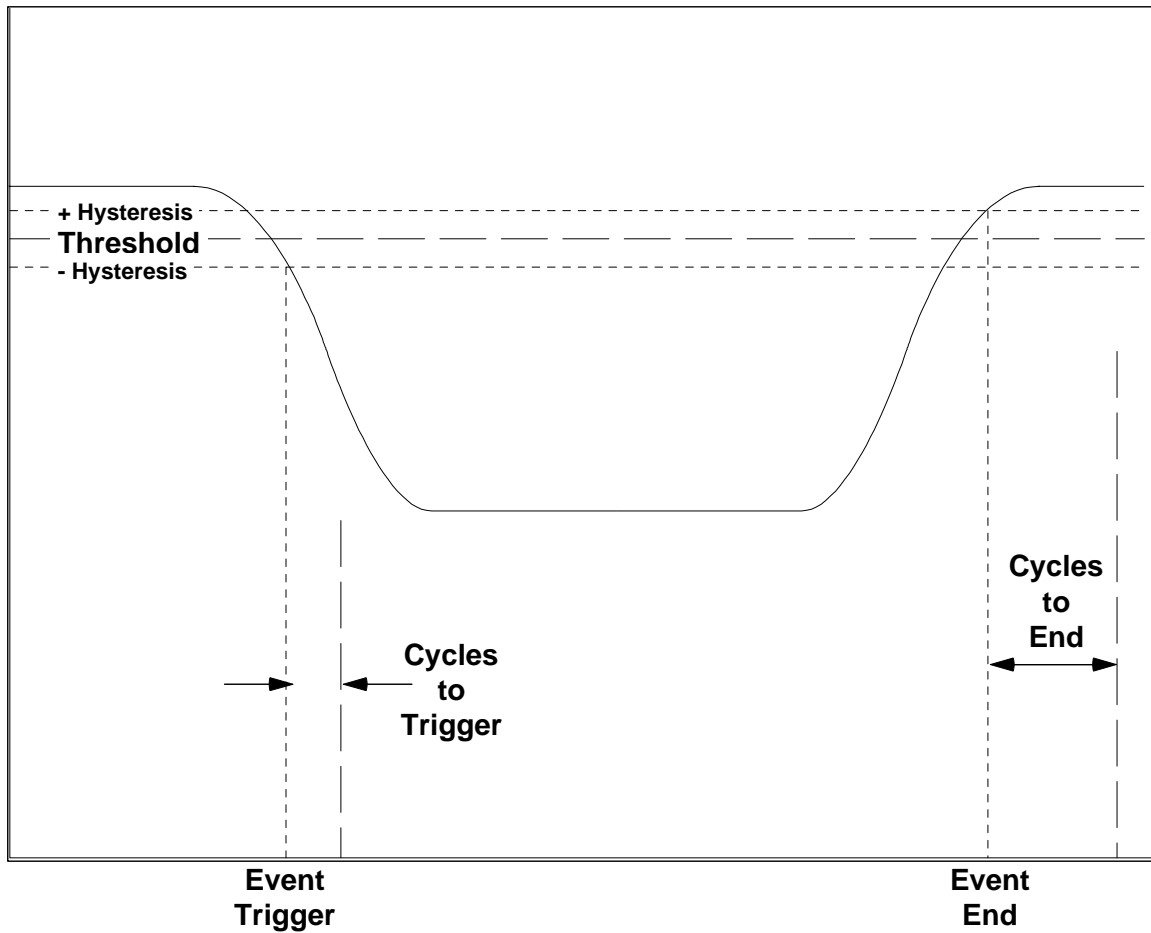


Figure 3: RMS Triggering on Low Voltage

The rms triggering capability is also used to detect outages and initiate cold load pickup monitoring. Most of the PQNodes in the DPQ project have been equipped with batteries capable of keeping the PQNode operating for 8 hours. This ensures that for outages of 8 hours or less, the PQNode can detect the restoration of voltage and start recording the characteristics of the load pickup. For the DPQ project, the PQNode is configured to record several cycles of the voltage and current waveforms during the initial inrush, as well as rms recordings of all channels for 2.5 hours. This information is useful in the design of overcurrent protection systems and equipment.

The impulse peak detection system was designed to provide positive- and negative-going peak voltage measurements as well as impulse area (volt-second) information for high-frequency impulses (5 kHz - 1 MHz). This method allows for the detection of higher frequency electromagnetic phenomena without the complexity and prohibitive cost of actual high frequency waveform digitization.

A periodic sampling sub-system is also provided in the PQNode to obtain long duration variation information, steady-state monitoring, and waveform distortion data. For this project, sampled waveforms are obtained every thirty minutes for harmonic analysis, and steady-state rms data are sampled every fifteen minutes for steady-state variation information.

The instrument includes eight channels, four voltage and four current. This allows all phase voltages and currents to be monitored, as well as neutral voltage and current. Triggering can be initiated only by the voltage channels, any one of which starts the recording process. Table 2 shows all of the thresholds used for the DPQ project for each PQNode sub-system.

Table 2: PQNode Thresholds

Impulse Setup	
	Phases A, B and C active
	Threshold set to 200 volts
	Before set to 1 cycle
	After set to 4 cycles
Waveshape Fault Setup	
	Phases A, B, and C active
	Threshold Tolerance set to 5%
	Threshold Window set to 10%
	Before set to 1 cycle
	After set to 4 cycles
RMS Triggers	
	Phases A, B, and C active
	Threshold high set to 105%
	Threshold low set to 95%
	Hysteresis set to 1.0%
	Cycles to Trigger set to 1
	Cycles to End set to 5
	Instantaneous RMS Before set to 10 cycles
	Instantaneous RMS After set to 120 cycles
	RMS Waveform Before set to 1 cycle
	RMS Waveform After set to 9 cycles
	Min./Avg./Max. 1 Cycles set to 6 cycles
	Min./Avg/Max 1 Duration set to 8 seconds

	Min./Avg/Max 2 Cycles set to 30 cycles
	Min./Avg/Max 2 Duration set to 20 seconds
	Min./Avg/Max 3 Cycles set to 60 cycles
	Min./Avg/Max 3 Duration set to 90 seconds
Outages	
	Phases A, B, and C active
	Threshold set to 8%
	Initiate set to 120 seconds
	Restore set to 120 seconds
Cold Load Pickup	
	Phases A, B, and C active
	Threshold set to 8%
	Trigger set to 120 seconds
	Reset Time set to 120 seconds
	Instantaneous RMS Before set to 10 cycles
	Instantaneous RMS After set to 120 cycles
	RMS Waveform Before set to 1 cycle
	RMS Waveform After set to 9 cycles
	Min./Avg/Max 1 Cycles set to 60 cycles
	Min./Avg/Max 1 Duration set to 118 seconds
	Min./Avg/Max 2 Cycles set to 3600 cycles
	Min./Avg/Max 2 Duration set to 1680 seconds
	Min./Avg/Max 3 Cycles set to 7200 cycles
	Min./Avg/Max 3 Duration set to 5400 seconds
Sampled	
	Sampled Waveform Every set to 30 minutes
	Sampled Waveform Sample set to 1 cycles
	Sampled steady-state Every set to 15 minutes

An additional requirement placed on the instrument design was that of recording all channel information when a trigger occurs, instead of only the triggered channel. This had been a frustrating drawback in earlier studies since the missing channel information could have helped identify the cause, and better predict the consequences, of a particular event.

An analog to digital converter (ADC) resolution of 14 bits was chosen to permit accurate measurement of higher order harmonics than a traditional 12 bit ADC would allow. Also, simultaneous sampling and phase locking techniques were employed to improve harmonic phase angle accuracy (necessary for harmonic power flow measurements).

The instrument was also designed to be highly programmable to allow not only the thresholds to be changed, but also a change in its basic functionality (the "firmware") if desired. This is accomplished by uploading setups or new firmware to the instrument via serial port or modem. This feature was deemed important due to the natural evolution of

a new instrument, and the likelihood of the monitoring objectives to change over the life of the project.

Since the scope of the measurement project involves the measurement of power quality-related electromagnetic phenomena on distribution systems, the instrument was designed to be pole-mounted. This necessitated the use of a NEMA 4 outdoor enclosure and measurement electronics that can maintain operation and accuracy over an extreme temperature range.

To accommodate the rigors of pole mounting such a device, the PQNode is divided into two major components - the enclosure and input module assembly, and the measurement module. The enclosure and input module assembly is very rugged and is installed by a line crew along with the necessary CTs and PTs.

When the line crew is finished with its installation, utility metering personnel visit the site and snap in the measurement module, connect the phone line, and check for monitor activity. All further diagnostics and setup are performed remotely over the phone line.

To obtain the data needed for the statistical analysis, approximately 200 monitoring sites were selected, with another 100 to be added during the second year of the project. The siting criteria results in three PQNodes being placed on each randomly selected feeder. One PQNode is placed at the substation, the other two are placed in randomly selected zones out on the feeder. This results in each host utility having between 3 and 12 PQNodes for the first year of the project.

Total installation cost for each site including transducers and labor, ranges from \$10,000 to \$50,000 depending on the utility and physical location.

Field testing of the PQNodes took place over a one year period before the actual monitoring program began in June of 1992. This testing resulted in the final selection of the triggering thresholds to be used for the project. The general philosophy used was to set the thresholds as tight as possible to gather as much data as possible without saturating the instrument. Other thresholds can then be simulated in software to evaluate the impact of the settings on the number and type of events captured.

The thresholds and steady-state sampling rates shown in Table 2 result in a significant amount of data being recorded. On a per PQNode basis, the steady-state sampling results in about 160 kB of data per day with another 40 kB per day average for triggered events. This translates to 40 MB per day or about 15 GB per year for 200 PQNodes. In order to deal with this much data, an automated system for gathering the data and generating reports was developed.

To allow each host utility to more directly participate in the project, and to distribute computational and communications chores, each host utility has a computer at its premises dedicated to controlling the PQNodes in its service territory.

The software systems developed to control the PQNodes all utilize the Microsoft Windows 3.1 operating system. This software was developed using advanced techniques for the visualization of power system data in personal computer environments [4], [5].

The software provides for PQNode setup, automated downloading of data, data archiving, generates simple reports, and allows general visualization of the data. Figure 4 illustrates the relationship between the PQNode and the host PC.

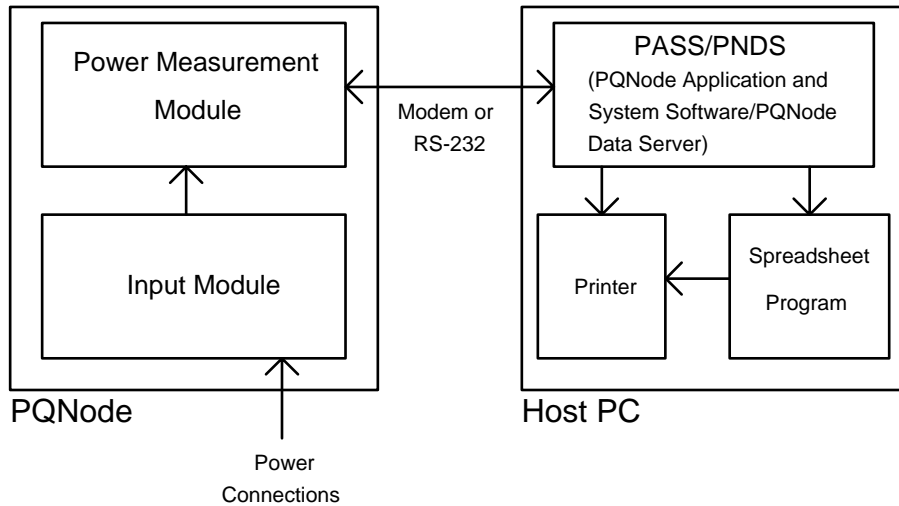


Figure 4: PQNode - Host PC Relationship

Additional analysis can be performed on the database through the use of third party software. Some specialized statistical reports and displays needed for the DPQ project are generated in this way. Figure 5 illustrates how the data acquisition system accommodates third party interfaces.

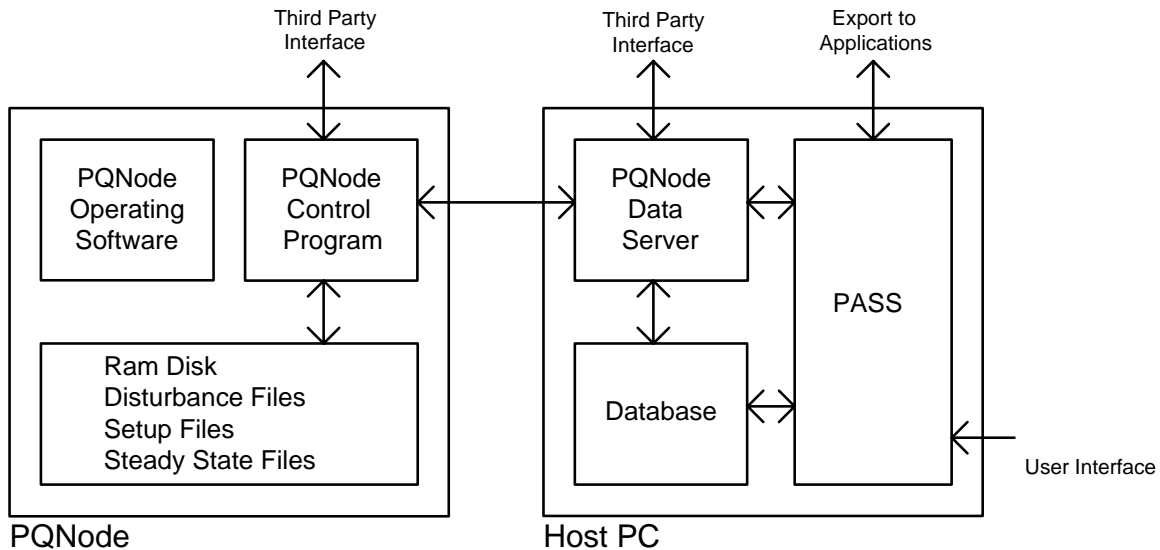


Figure 5: Third Party PQNode Data Interface

A necessary set of procedures are implemented to gather the data from the host utility computers spread around the country into the main database. The complete data flow is as follows:

1. The utility host computer automatically downloads PQNode data daily.
2. The contractor's computer automatically calls the host utility computer daily, reads error log, polls operator if trouble.
3. The utility operator archives the previous eight days of data each Monday morning and sends it via express mail to the contractor.
4. Contractor loads data from each host utility into the master database.
5. Contractor engineers perform a sanity check on the data and look for interesting events.
6. Contractor uses an automatic report generator to produce monthly reports.
7. Contractor advises utilities to delete data that are three weeks old or older (unless they have the storage to retain more than three weeks of data).
8. The utility archives and deletes data older than three weeks, if desired, ensuring that enough disk space remains for the next weeks data.
9. Contractor ships three week old archive media back to utility.

The data acquisition system could be made more robust by eliminating the host utility participants and computers from the data path, but it was more desirable to have the experienced eyes of utility power engineers exposed to the data on at least a weekly basis. This results in problems being found earlier, and the host utility engineers get better feedback concerning disturbances occurring on their system.

The master database is also maintained on a personal computer based system. There is 2.7 GB of hard disk storage on-line for holding a few weeks of raw PQNode data and the primary characterized event database. The characterized event database contains information that efficiently describes each event. This includes information like magnitude, duration and area for rms variations. The resulting database is very efficient and compact. This database is used by statistical analysis and spreadsheet programs for most statistical analysis. The original raw data (waveforms, rms traces) are stored on a read/write optical disk "jukebox" style storage system.

Preliminary Results

Although the monitoring program for the EPRI DPQ project has just begun, some very interesting data has already been obtained.

A common operation that occurs daily on many distribution systems is capacitor switching. This is done to provide voltage/var support on the system as the load increases. This type of switching operation causes an oscillatory transient that is readily captured by the PQNode. Figure 6 is an example of just such an event.

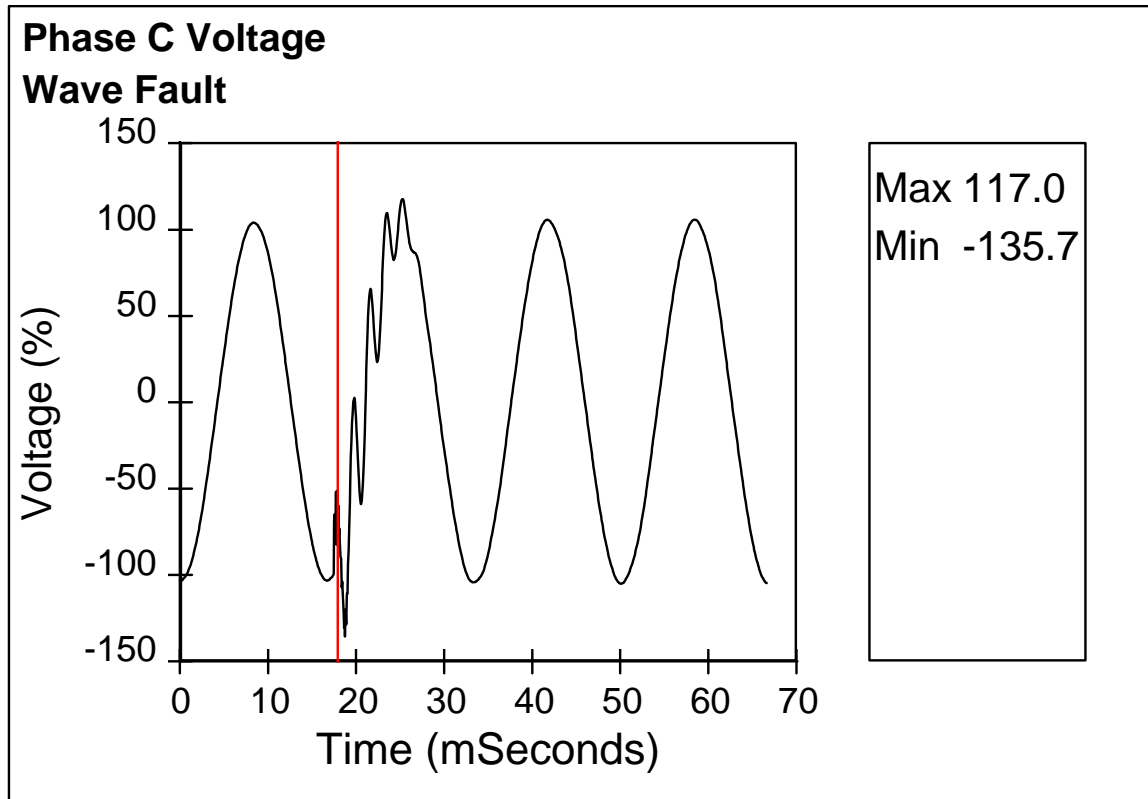


Figure 6: Capacitor Switching Transient

This capacitor switching-induced transient does not normally affect equipment attached to the power system. However, as loads become increasingly more sensitive without regard for the real world operation of a power system, equipment misoperation may become more common. This is particularly true for industrial power systems which have power factor correction capacitors applied at low voltage [6]. A planned extension of the EPRI DPQ project to include customer side monitoring should allow direct observation of this phenomena.

Another event that occurs on the power system with some regularity, although not intentionally, is a fault. Faults have many causes such as lightning, fallen tree branches, animal activity, equipment failure, etc. Most faults are single phase and temporary in nature. The result of such a fault is a depression of the feeder voltage during the fault. This is followed by a complete loss of voltage on the feeder downline from the protective device that operates as a result of the fault. The voltage on parallel feeders returns to normal after the protective device clears the fault. If the fault is temporary, and reclosing breakers are used for protection, the faulted feeder voltage will be restored upon reclosing.

Figure 7 shows a PQNode recording of the rms variation phenomena resulting from of a fault with reclosing. The figure shows the phase which caused the PQNode to trigger a recording. The initial depression of voltage to 18% occurs while the fault is in progress.

This is probably the voltage developed across an arcing fault (note the squared-off waveform). The sag is then followed by a reduction of the voltage to zero. To determine what is causing this event requires more information. Figure 8 shows all three phase voltages and currents for the disturbance.

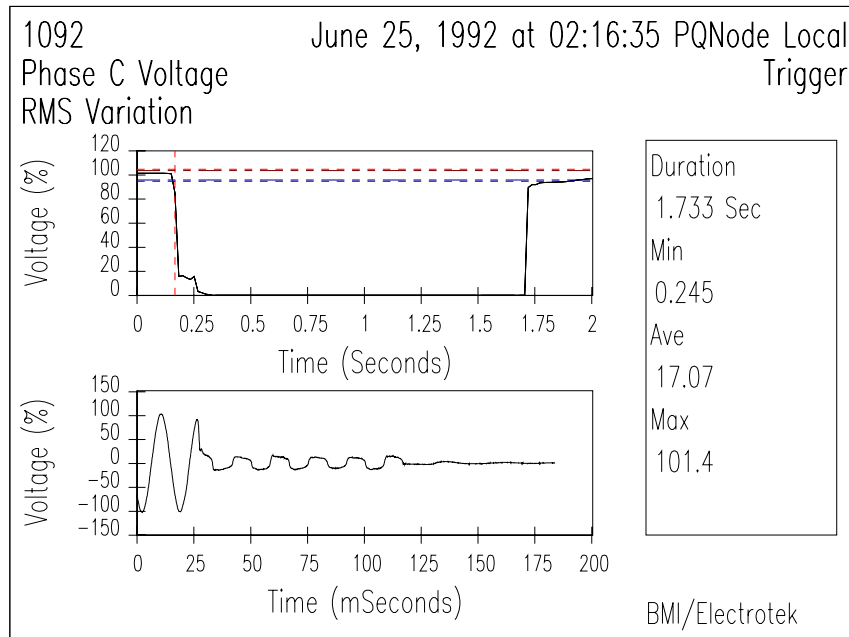


Figure 7: Sag and Interruption on Faulted Feeder

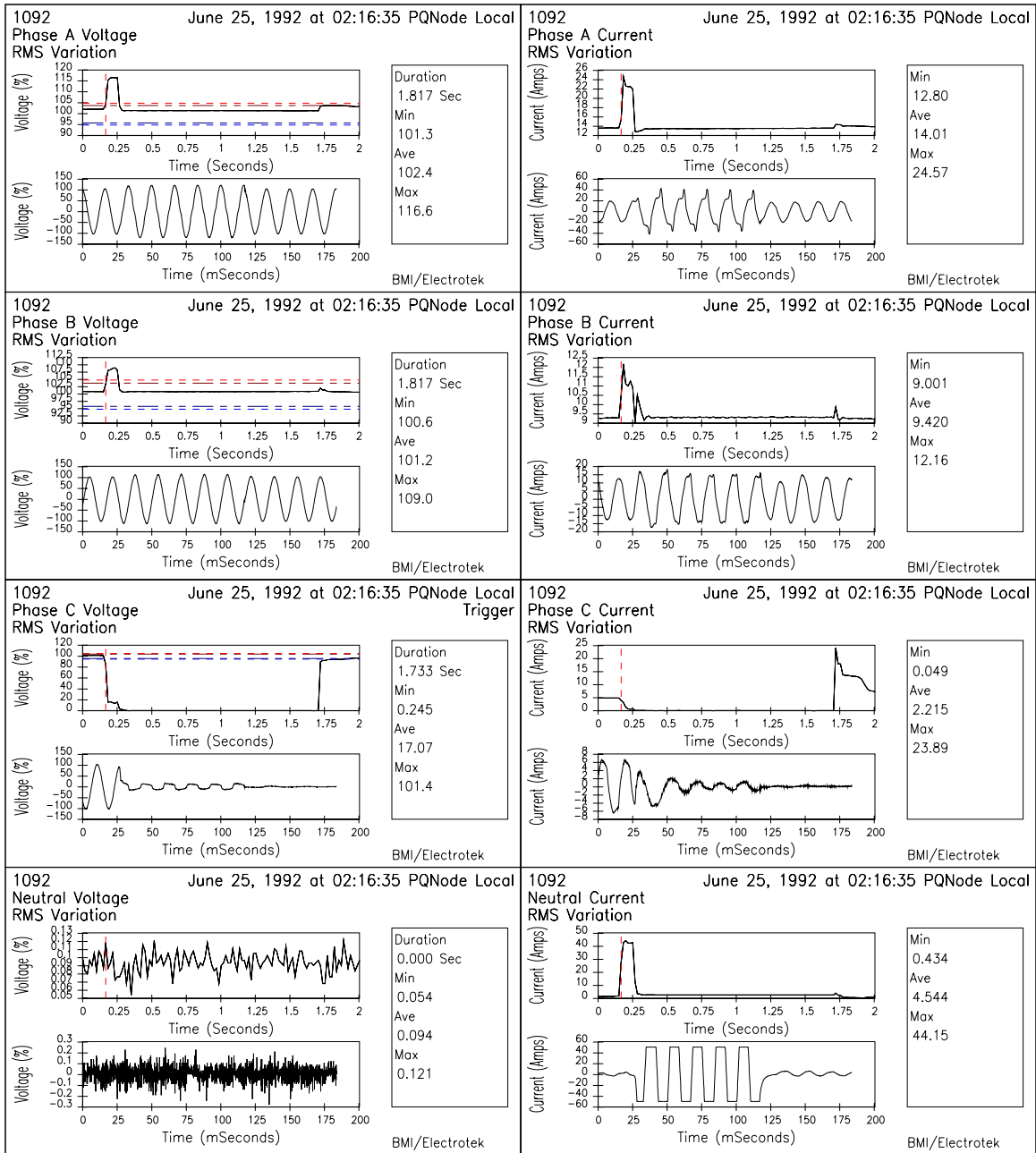


Figure 8: All Phase View of Fault Induced Disturbance

It is interesting to note the voltage rise on the sound phases. This is a typical result of a single line-to-ground fault. In this case, the swell reaches 116% of nominal for 6 cycles on phase A. Swells can be important as they may cause degradation of transient voltage suppressors found in many electronic apparatus in the home and in industry.

By observing that only the phase C voltage goes to zero, that the phase A and B voltages increase, and that fault current does not appear to flow, we know that a single phase recloser has operated in response to a single line to ground fault upline from the monitoring point. The reclose is observed to be successful since the phase currents return to normal (Phase C current, Figure 8).

This supposition can be reinforced by looking at another point upline on the same feeder. Since there are three monitoring points on each feeder for the DPQ project, we are able to do this.

Figure 9 shows the same disturbance recorded upline on the same feeder. The time stamp is different since the PQNode clocks had not yet been synchronized to National Institute of Science and Technology time (NIST). The sag appears on a different phase since the line crew did not assure that the phases were the same at other monitoring points on the feeder (this problem has been corrected). In this case we observe that fault current flows at the monitoring point. This indicates that the fault is located between the two monitoring points.

Another interesting feature of Figure 9 is the increased current flow on phases B and C during the fault. This is the result of increased transformer magnetization current due to the increase in the system voltage during the fault. This current has a high third harmonic current which is visible in the plot of Phase C current in Figure 9.

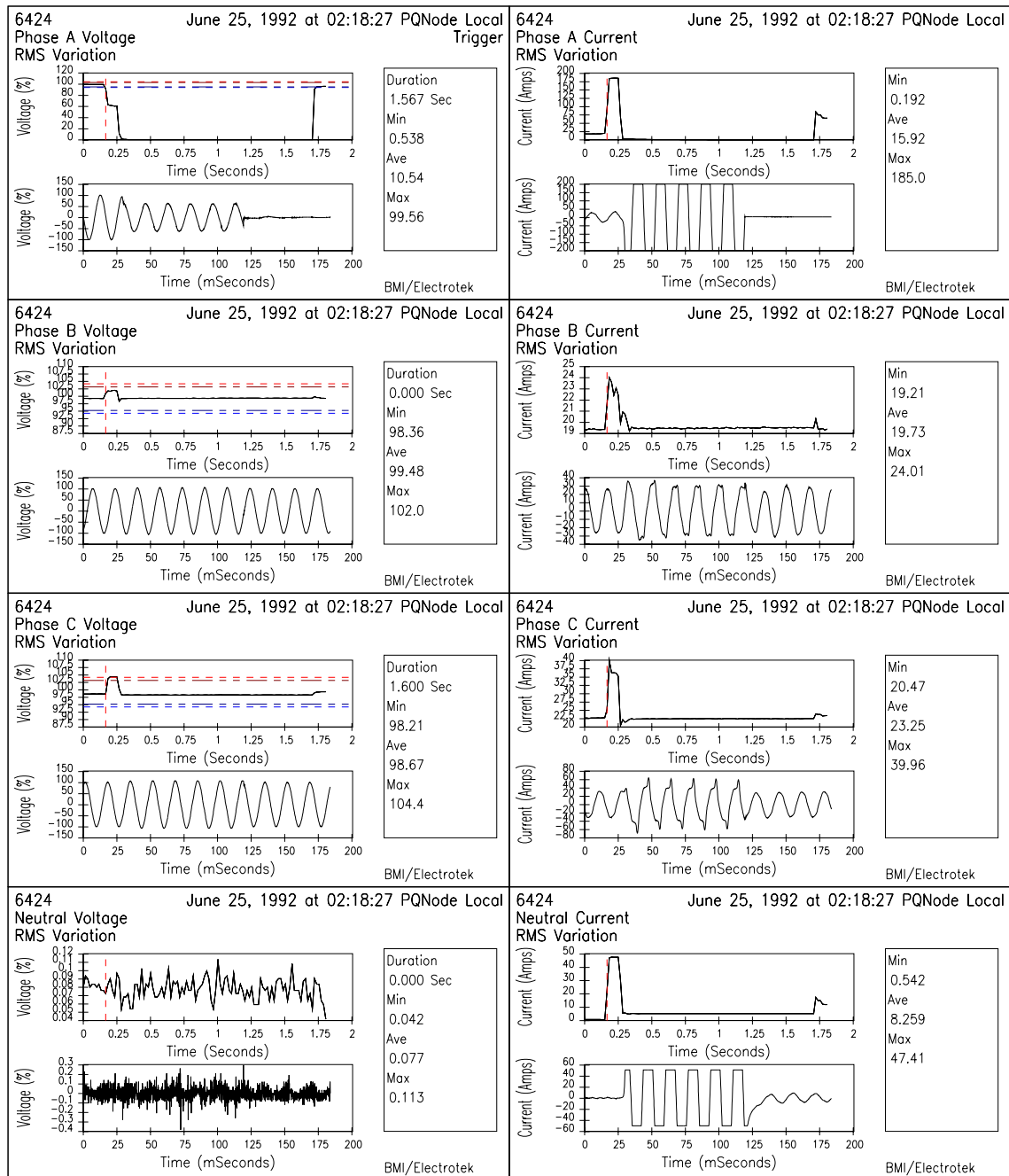


Figure 9: Fault Induced Disturbance Near Substation

Fault induced disturbances are often characterized by profiling the rms voltages and currents as shown in the figure. These profiles can be summarized further by determining the magnitude and duration of the disturbance as is reported in the data blocks of the previous figures. A common way of displaying a large number of rms measurements is to use a scatter plot of each measured disturbance magnitude and duration. Figure 10 shows a plot of this type for a single monitoring point and a period of two weeks.

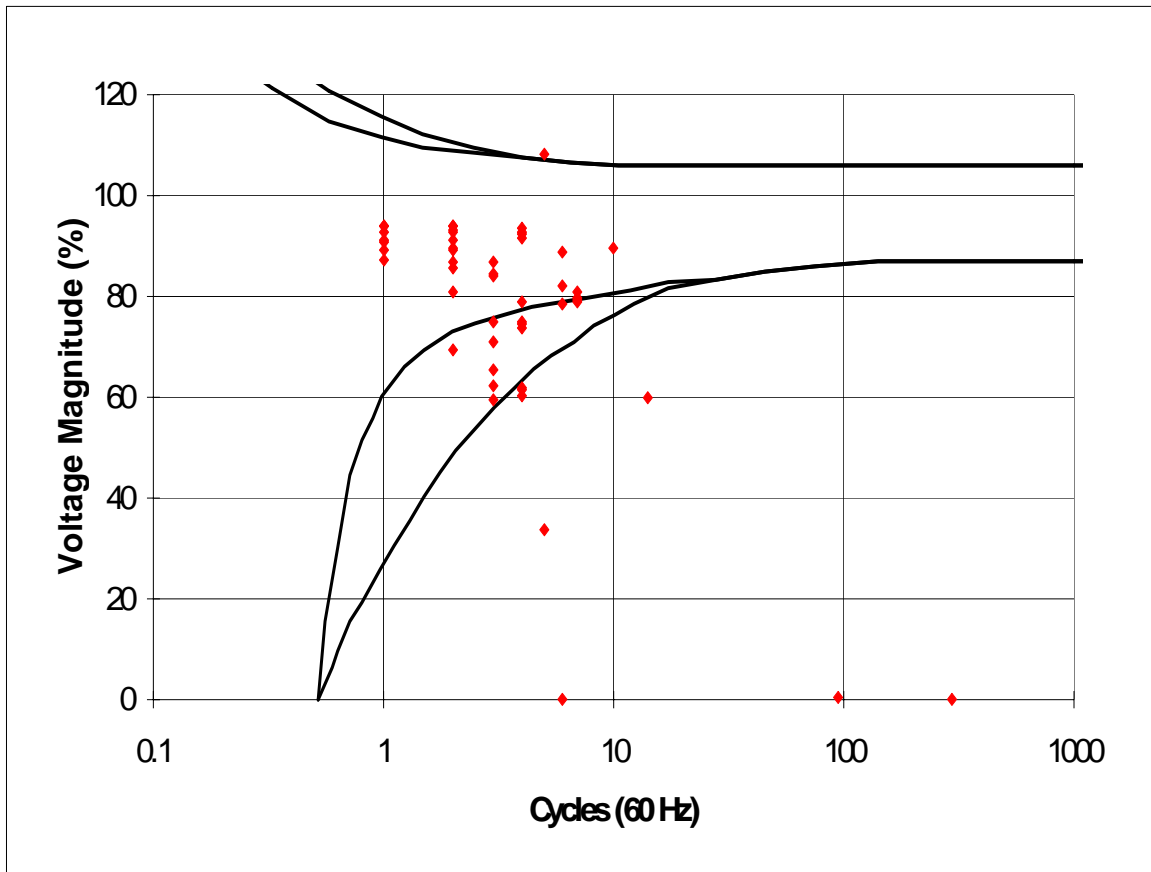


Figure 10: Magnitude vs. Duration Scatter Plot

Figure 10 also contains an overlay of the tolerance envelope used as a design goal for power-conscious computer manufacturers as defined in ANSI/IEEE Standard 446-1987 [7]. This plot can be used to indicate how often a piece of equipment is likely to misoperate if connected to a point at or near the monitoring point. If the exact tolerance profile of a particular piece of equipment is known, a more precise evaluation can be made.

Single site statistical summaries are also useful for characterizing short duration rms variations. Figure 11 shows a histogram of the magnitude of the same disturbances plotted in Figure 10.

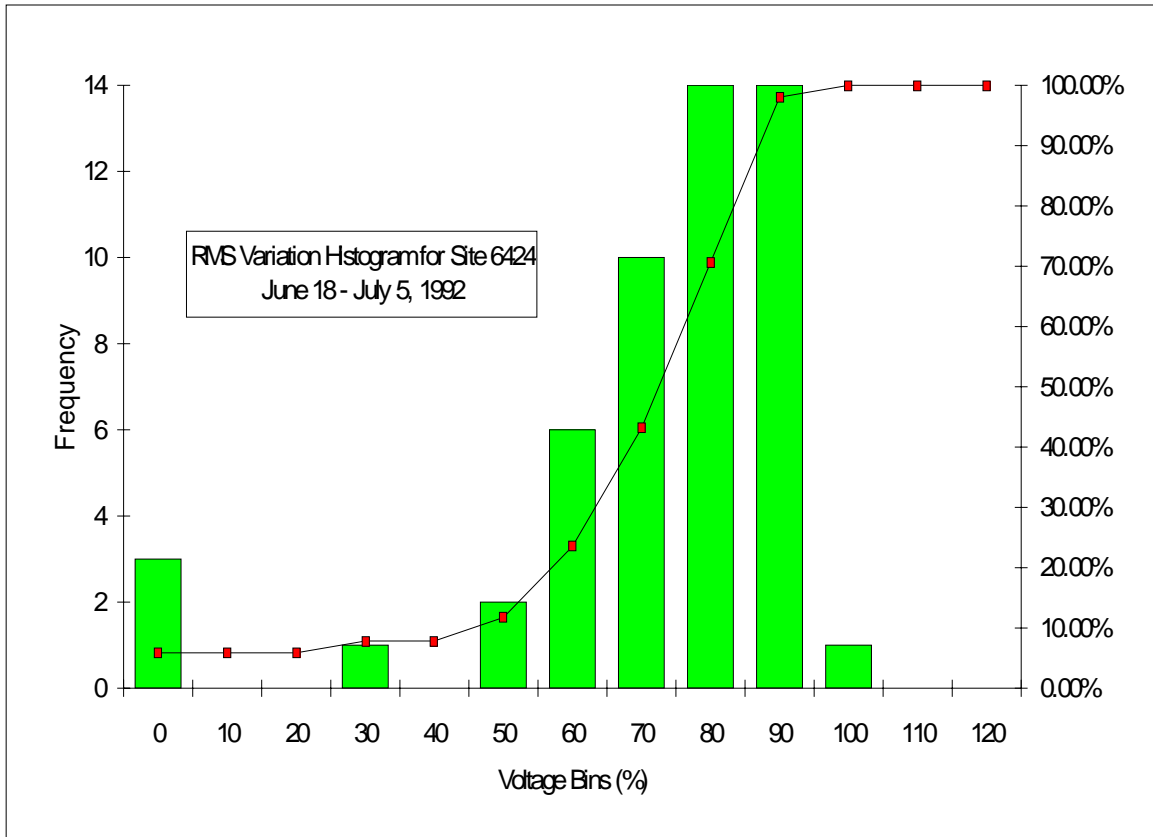


Figure 11: Statistical Analysis of RMS Variations

So far, we have shown examples of relatively low frequency power system phenomena. The PQNode instrument was also designed to capture higher frequency phenomena through the use of analog peak and area detectors. For the EPRI DPQ project, this capability is utilized to help detect lightning induced transients on the distribution system.

The accuracy of the high frequency measurements is suspect due to the characteristics of the transducers used. Enough information is obtained, however, to show that such an event did occur. Figure 12 illustrates a lightning induced transient.

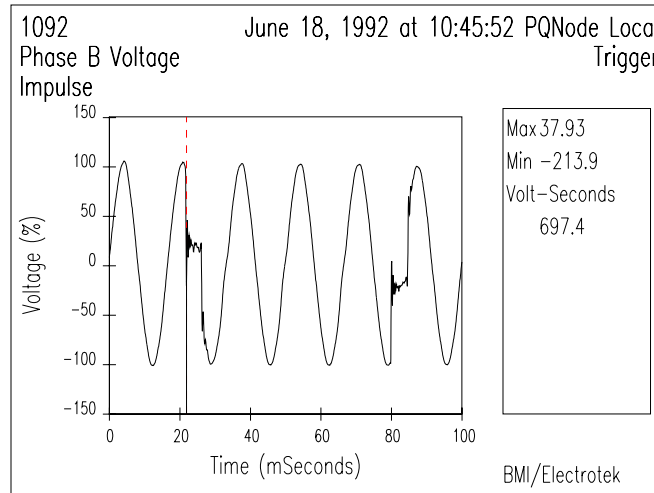


Figure 12: Lightning Induced Transient

This transient is thought to be due to two successive lightning strikes nearby, causing faults on phase B which clear themselves near zero crossings. The three cycle delay between strokes is a common characteristic of following on lightning strokes once the initial path has been established.

The lightning induced transient shown in Figure 12 is one of many disturbances captured over a short period of time by the PQNodes at one of the DPQ project host utilities during a period of intense storm activity. The summary shown in Table 3 illustrates how the storm can be tracked by location and intensity across the power system.

Table 3: Event Summary During Storm

8478	6/18/92 4:48	Wave Fault	1092	6/18/92 9:36	Wave Fault	8478	6/18/92 10:27	Wave Fault
1092	6/18/92 4:48	Wave Fault	1092	6/18/92 9:36	Wave Fault	8478	6/18/92 10:27	Wave Fault
6424	6/18/92 4:50	Wave Fault	1092	6/18/92 9:36	RMS Variation	8478	6/18/92 10:27	RMS Variation
8839	6/18/92 6:04	Wave Fault	8478	6/18/92 9:36	Wave Fault	1092	6/18/92 10:27	Wave Fault
8839	6/18/92 6:04	Wave Fault	8478	6/18/92 9:36	RMS Variation	1092	6/18/92 10:27	Wave Fault
8839	6/18/92 6:04	Wave Fault	8478	6/18/92 9:36	Wave Fault	1092	6/18/92 10:27	RMS Variation
8839	6/18/92 6:04	RMS Variation	1092	6/18/92 9:36	Wave Fault	6424	6/18/92 10:29	Wave Fault
8839	6/18/92 6:04	Wave Fault	1092	6/18/92 9:36	RMS Variation	6424	6/18/92 10:29	Wave Fault
8839	6/18/92 6:05	Wave Fault	1092	6/18/92 9:36	Wave Fault	6424	6/18/92 10:29	RMS Variation

8839	6/18/92 6:05	RMS Variation	6424	6/18/92 9:37	Wave Fault	8478	6/18/92 10:44	Wave Fault
8839	6/18/92 6:05	Wave Fault	6424	6/18/92 9:37	Wave Fault	1092	6/18/92 10:44	Wave Fault
8839	6/18/92 6:05	Wave Fault	6424	6/18/92 9:37	RMS Variation	8478	6/18/92 10:45	Wave Fault
8839	6/18/92 6:05	RMS Variation	8478	6/18/92 9:37	Wave Fault	8478	6/18/92 10:45	RMS Variation
8839	6/18/92 6:09	RMS Variation	8478	6/18/92 9:38	RMS Variation	1092	6/18/92 10:45	Wave Fault
8478	6/18/92 7:55	Wave Fault	8478	6/18/92 9:38	Wave Fault	1092	6/18/92 10:45	RMS Variation
1092	6/18/92 7:55	Wave Fault	1092	6/18/92 9:38	Wave Fault	1092	6/18/92 10:45	Impulse
1092	6/18/92 7:55	RMS Variation	1092	6/18/92 9:38	RMS Variation	8478	6/18/92 10:45	Wave Fault
1092	6/18/92 7:55	Wave Fault	1092	6/18/92 9:38	Wave Fault	1092	6/18/92 10:45	RMS Variation
1092	6/18/92 7:55	Wave Fault	6424	6/18/92 9:38	Wave Fault	1092	6/18/92 10:45	Wave Fault
1092	6/18/92 7:55	RMS Variation	6424	6/18/92 9:38	Wave Fault	1092	6/18/92 10:45	Impulse
6424	6/18/92 7:57	RMS Variation	6424	6/18/92 9:38	RMS Variation	1092	6/18/92 10:45	Wave Fault
6424	6/18/92 7:57	Wave Fault	6424	6/18/92 9:38	Wave Fault	8478	6/18/92 10:45	RMS Variation
6424	6/18/92 7:57	Wave Fault	6424	6/18/92 9:38	RMS Variation	8478	6/18/92 10:45	Wave Fault
6424	6/18/92 7:57	RMS Variation	6424	6/18/92 9:38	Wave Fault	1092	6/18/92 10:45	RMS Variation
8478	6/18/92 8:51	Wave Fault	8478	6/18/92 9:39	Wave Fault	8478	6/18/92 10:45	Wave Fault
8478	6/18/92 8:51	RMS Variation	8478	6/18/92 9:39	RMS Variation	1092	6/18/92 10:45	Wave Fault
8478	6/18/92 8:51	Wave Fault	1092	6/18/92 9:39	Wave Fault	1092	6/18/92 10:45	Impulse
1092	6/18/92 8:51	Wave Fault	6424	6/18/92 9:39	Wave Fault	1092	6/18/92 10:45	Wave Fault
6424	6/18/92 8:53	RMS Variation	6424	6/18/92 9:39	RMS Variation	6424	6/18/92 10:46	Impulse
6424	6/18/92 8:53	Wave Fault	6424	6/18/92 9:39	Wave Fault	6424	6/18/92 10:46	Wave Fault
6424	6/18/92 9:05	RMS Variation	6424	6/18/92 9:41	Wave Fault	6424	6/18/92 10:47	Wave Fault
8478	6/18/92 9:14	Wave Fault	6424	6/18/92 9:41	RMS Variation	6424	6/18/92 10:47	RMS Variation

1092	6/18/92 9:14	Wave Fault	8478	6/18/92 10:05	Wave Fault	6424	6/18/92 10:47	Impulse
6424	6/18/92 9:16	Wave Fault	8478	6/18/92 10:05	Wave Fault	6424	6/18/92 10:47	Impulse
8478	6/18/92 9:35	Wave Fault	8478	6/18/92 10:05	RMS Variation	6424	6/18/92 10:47	Wave Fault
8478	6/18/92 9:35	Wave Fault	1092	6/18/92 10:05	Wave Fault	6424	6/18/92 10:47	Impulse
8478	6/18/92 9:35	RMS Variation	1092	6/18/92 10:05	RMS Variation	8478	6/18/92 10:47	Wave Fault
1092	6/18/92 9:35	Wave Fault	1092	6/18/92 10:05	Wave Fault	8478	6/18/92 10:47	RMS Variation
1092	6/18/92 9:35	RMS Variation	6424	6/18/92 10:07	Wave Fault	8478	6/18/92 11:00	Wave Fault
1092	6/18/92 9:35	Wave Fault	6424	6/18/92 10:07	Wave Fault	8478	6/18/92 11:01	Wave Fault
8478	6/18/92 9:36	Wave Fault	6424	6/18/92 10:07	RMS Variation	8478	6/18/92 11:01	Wave Fault
8478	6/18/92 9:36	Wave Fault	1092	6/18/92 10:21	Impulse	6424	6/18/92 11:03	RMS Variation
8478	6/18/92 9:36	RMS Variation	6424	6/18/92 10:23	Impulse			

It is interesting that only the lower frequency event types are observed early in the summary and are then followed by a number of impulse events. This would seem to indicate that an intense area of lightning activity moved into the vicinity of the affected monitoring points.

Another area of power quality being studied in this project is harmonics. For this project, the PQNode has been set up to capture one cycle of all eight channels every thirty minutes. This is not adequate for characterizing the harmonic characteristics of a single process during a single cycle of that process. This rate is more than sufficient, however, for obtaining longer term statistics of the harmonic characteristics of a point in the distribution system. Figure 13 illustrates a typical trend of the Total Harmonic Distortion (THD) of a distribution feeder. This information is better displayed as a histogram/cumulative percentage type plot as in Figure 14.

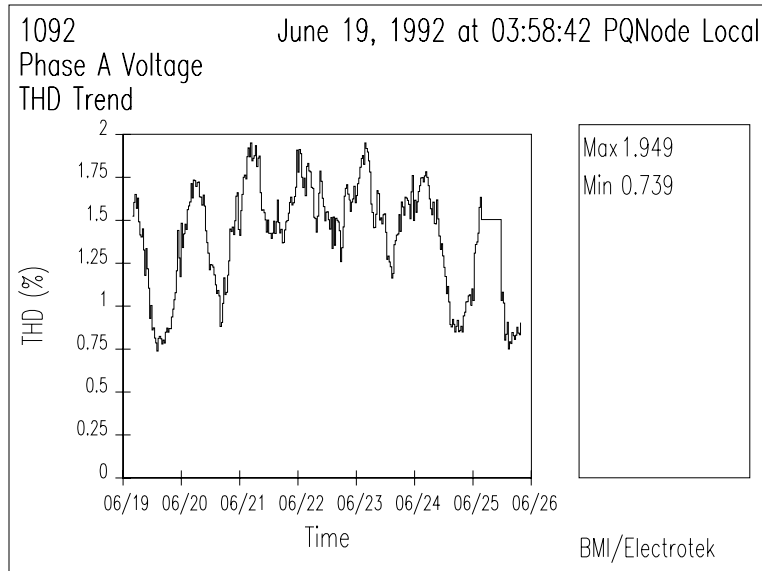


Figure 13: Distribution Feeder THD Trend

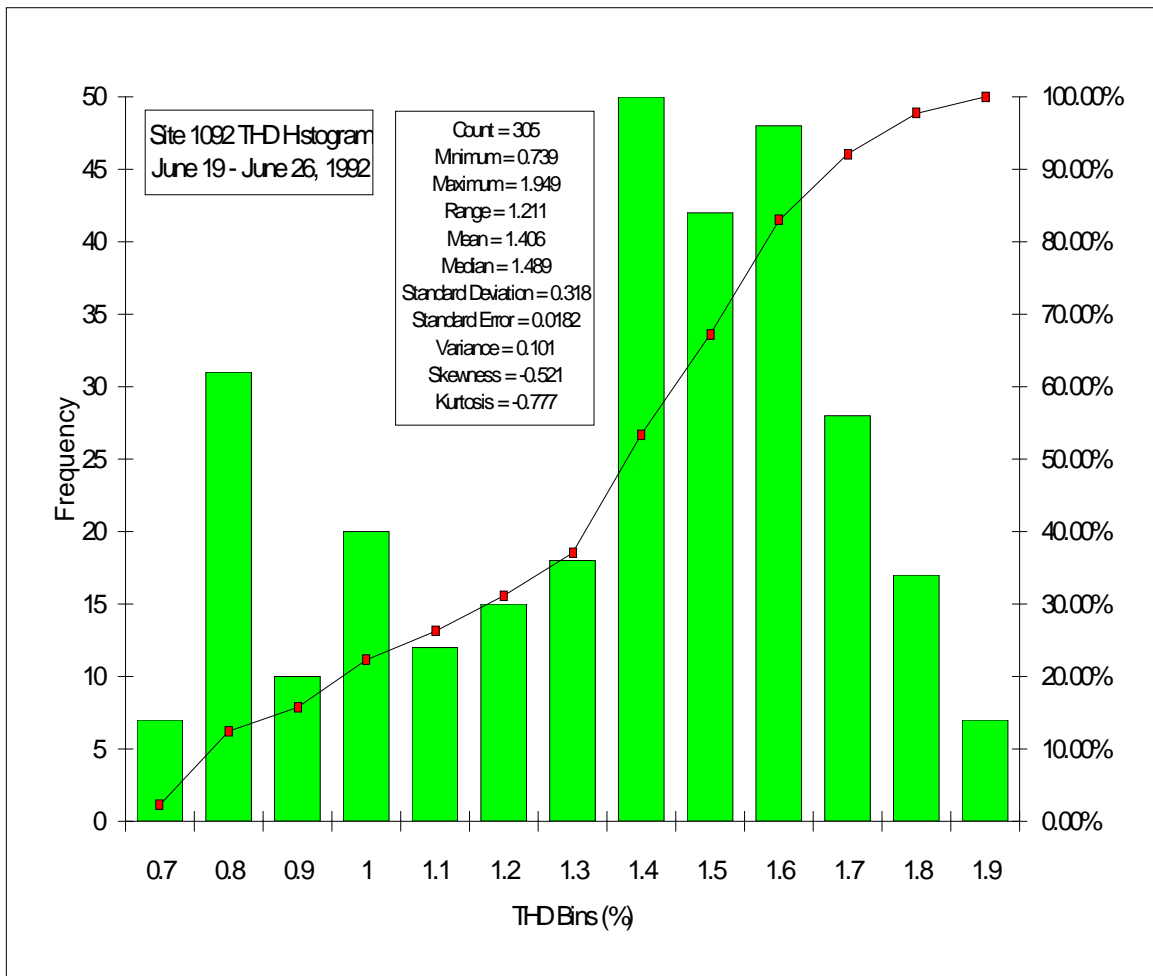


Figure 14: Distribution Feeder THD Histogram

In addition to harmonic trending, the PQNode system is also being used to trend rms voltage and current of all measured quantities including frequency and PQNode internal temperature. For the EPRI DPQ project, the minimum, maximum, and average values of fifteen minute intervals are stored. Figure 15 shows a typical trend for a distribution system feeder. Note how all significant rms events are visible on this display.

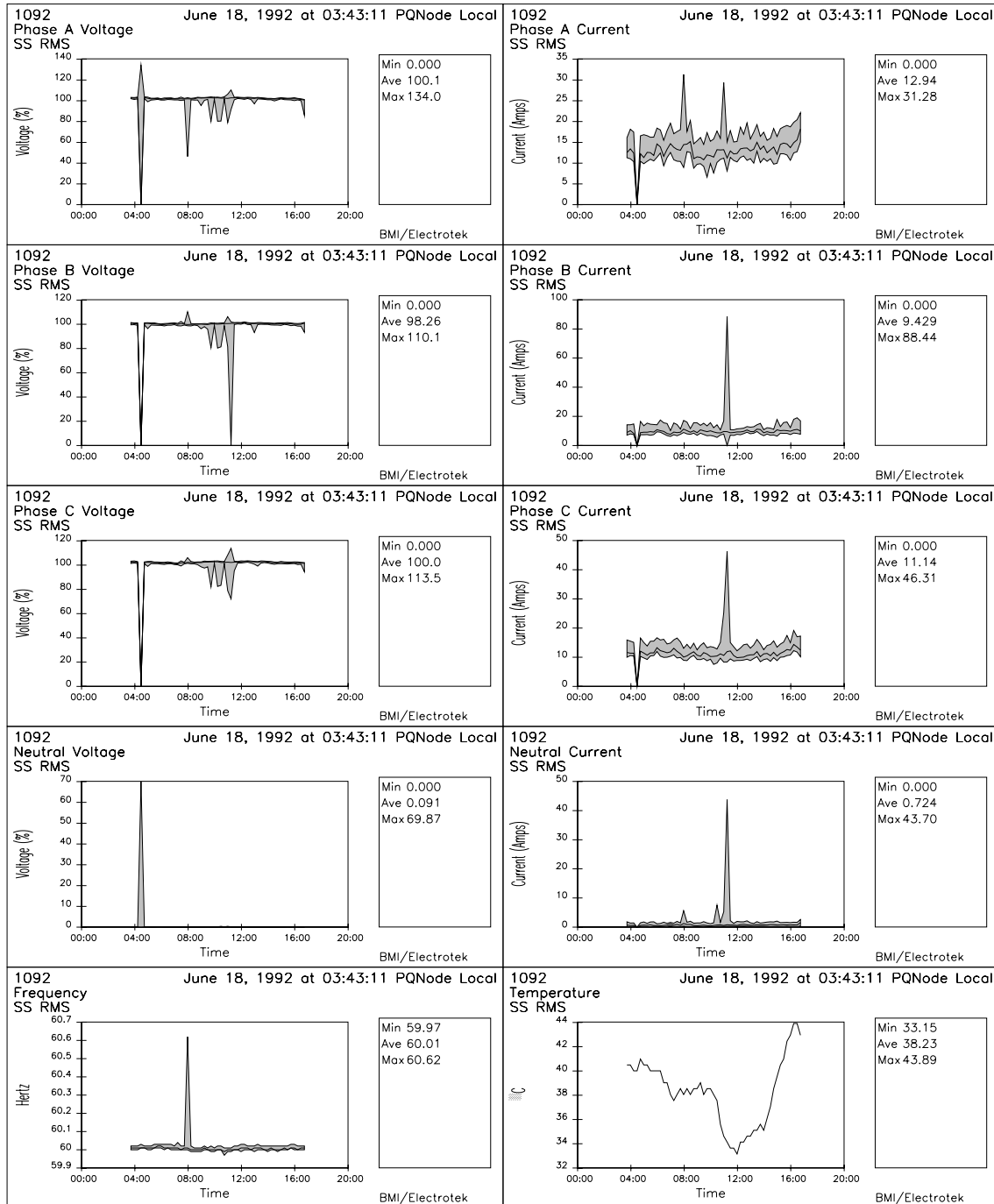


Figure 15: Typical Distribution Feeder RMS Trend

All of the data provided so far in this report have involved single site examples and statistics. As mentioned earlier, however, statistical analysis of the complete data set is also a major goal of the DPQ project. At this time there is not enough data available to provide much information of this kind. One example of the type of data that will be available is the correlation of various electromagnetic phenomena and site description characteristics used by the sample design. Typical interesting correlations include number of feeders out of the substation versus sags per month, feeder length versus sag depth, feeder length vs. sags per month, etc.

Other statistics available include weighted incidence rates of various power quality phenomena. Figure 16 shows an example of this for sag incidence rate. The data represented here is for three weeks with only 21% of the PQNodes reporting.

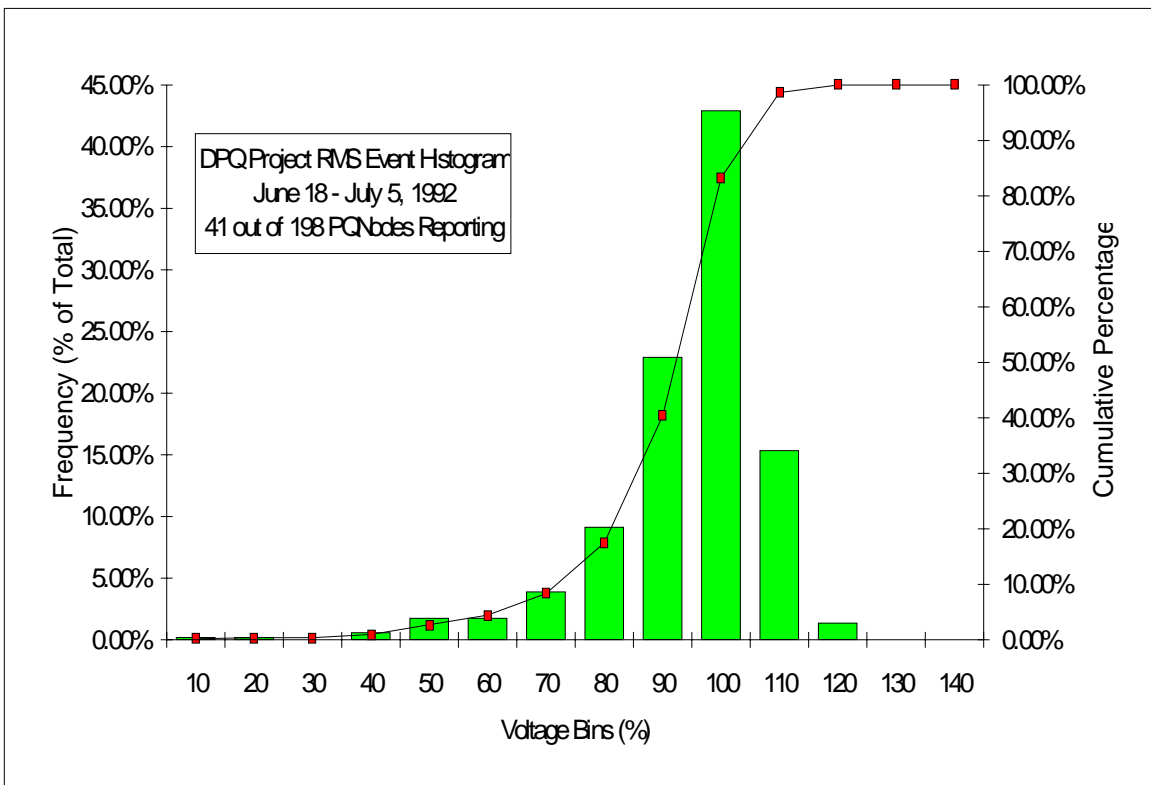


Figure 16: U.S. Utility Sag/Swell Incidence Rate Data

Conclusions

The requirements of the EPRI Distribution Power Quality project have led to the development of a state-of-the-art measurement system for the gathering of comprehensive data on power quality related electromagnetic phenomena.

The statistically valid sample design will allow mathematical models to be created to assist utility power engineers and marketing representatives to better predict the power quality related behavior of the power system.

Capturing all data channels during a disturbance allows insight into the causes and effects of the event.

The data being obtained are voluminous and will continue to be a rich source of information on the fundamental behavior of electric power distribution power systems for years to come.

Future work includes the addition of customer side monitoring sites. These sites will provide additional information in the quest of understanding the relationship between the phenomena measured on the primary distribution feeder and its impact on the customer side of the meter.

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