PQSoft Case Study

Customer Data Analysis Case Study

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Abstract:

Monitoring is often used to characterize power quality levels at various locations on utility and customer power systems. Field measurements provide a convenient means to characterize power quality problems. This case study summarizes a commercial customer power quality measurement data evaluation.

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RELATED STANDARDS

IEEE Std. 1159, IEEE Std. 519

GLOSSARY AND ACRONYMS

ASD	Adjustable-Speed Drive
DPF	Displacement Power Factor
PF	Power Factor
PWM	Pulse Width Modulation
THD	Total Harmonic Distortion
TPF	True Power Factor

CUSTOMER DATA ANALYSIS CASE STUDY

A commercial customer power quality measurement data analysis case study was completed for the system shown in Figure 1. The utility substation included a 10 MVA, 161 kV/12.47 kV step-down transformer and two 12.47 kV distribution feeders that supplied a mix of residential and commercial customers. One of the feeders had a switched 300 kVAr capacitor bank that was being used for power factor correction and voltage control. The monitoring location is identified as Commercial Customer #1. The customer, which was supplied from 150 kVA transformers with 120/208 V and 480 V secondary buses, was a small office building.

The twelve-month monitoring period was from January 1, 2003 thru December 31, 2003. The power quality instrument used to complete the power quality measurements was the Dranetz-BMI 8010 PQNode.™ The instrument samples voltage at 256 points-per-cycle, current at 128 point-per-cycle, and follows the IEC 61000-4-3 method for characterizing harmonic measurement data. The sampling rate also allows characterization of low-to-medium frequency oscillatory transients. The measurement and statistical analysis was completed using the PQView® program.

Figure 2 shows the rms voltage histogram for the twelve-month monitoring period. Statistical analysis of the 37,463 individual steady-state measurements yielded a minimum voltage of 264.1 V, an average voltage of 294.4 V, and a maximum voltage of 306.3 V. In addition, the CP95 value was 299.7 V (108% of nominal). CP95 refers to the cumulative probability, 95th percentile of a value.

Figure 3 shows the measured customer voltage distortion (V_{THD}) trend during the twelve-month monitoring period. The minimum harmonic distortion was 0.79%, the average distortion was 2.56%, and the maximum distortion 21.18%. The CP95 value was 3.83%. The measured voltage distortion value was below the assumed 5% limit a vast majority of the time.

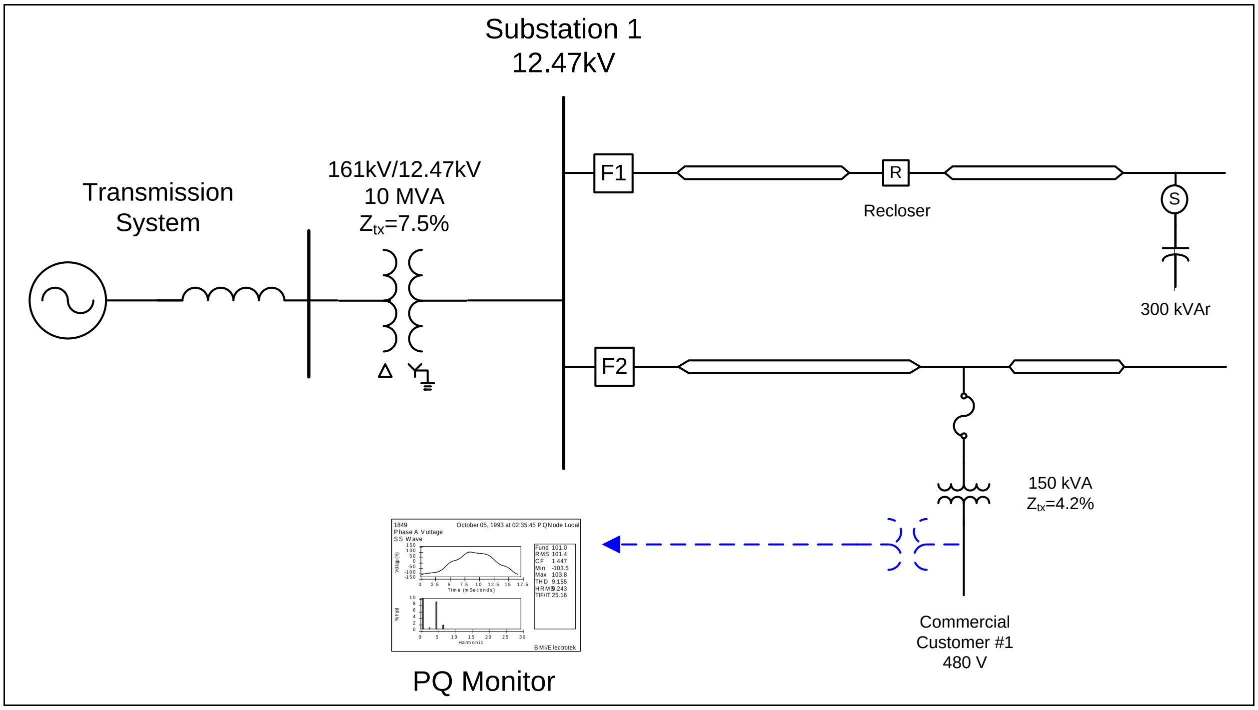
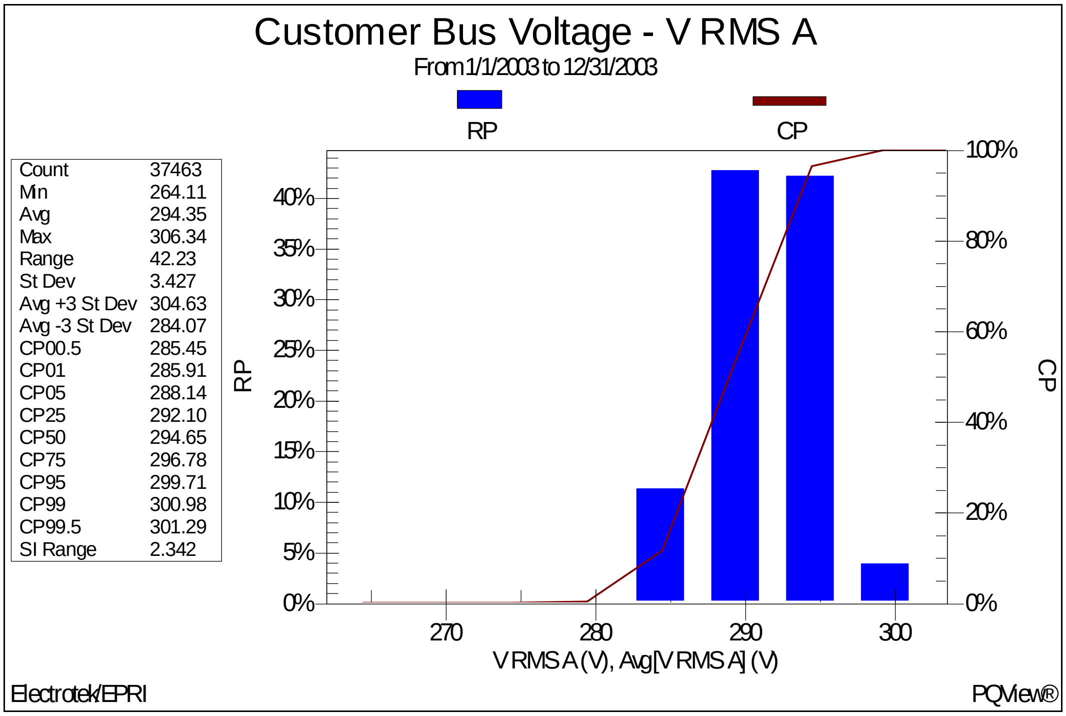


Figure 1 - Illustration of Oneline Diagram for Commercial Customer Data Evaluation



Count	37463
Min	264.11
Avg	294.35
Max	306.34
Range	42.23
St Dev	3.427
Avg +3 St Dev	304.63
Avg -3 St Dev	284.07
CP00.5	285.45
CP01	285.91
CP05	288.14
CP25	292.10
CP50	294.65
CP75	296.78
CP95	299.71
CP99	300.98
CP99.5	301.29
SI Range	2.342

Figure 2 - Measured Customer Secondary Voltage Histogram

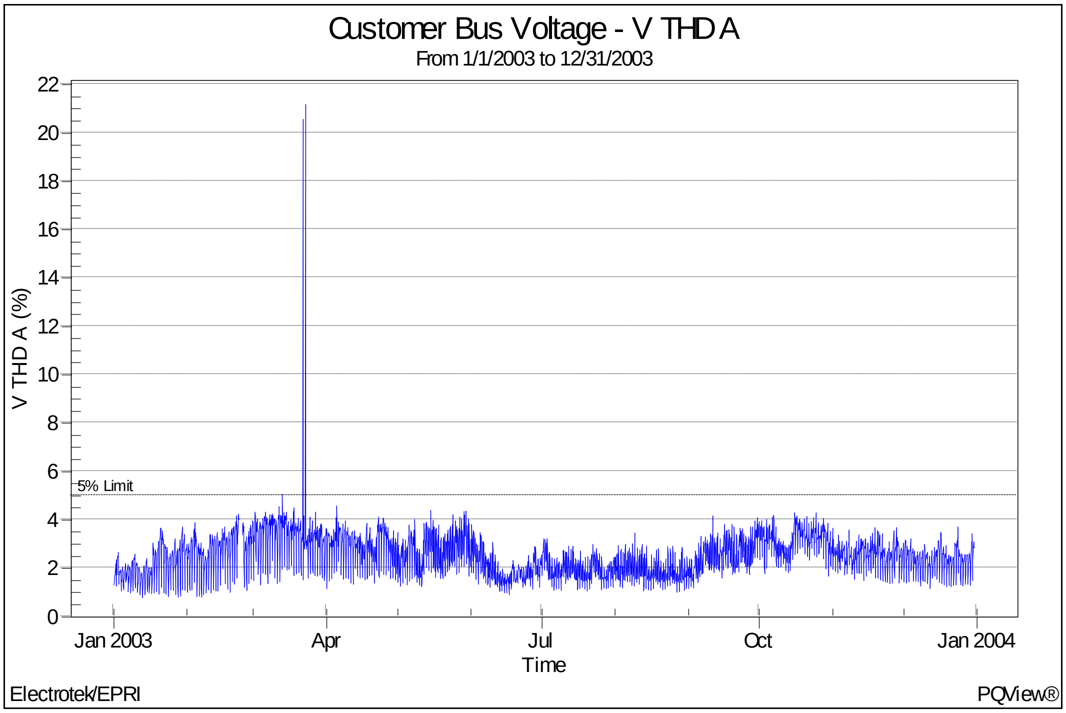


Figure 3 - Measured Customer Secondary Voltage Distortion

Figure 4 shows the statistical summary of total harmonic voltage distortion (V_{THD}) and number of individual harmonics for the twelve-month monitoring period. The analysis showed that the predominate harmonics for the measured customer secondary bus voltages were the 3rd, 5th, and 7th. The measured values were below the assumed 5% voltage distortion limit.

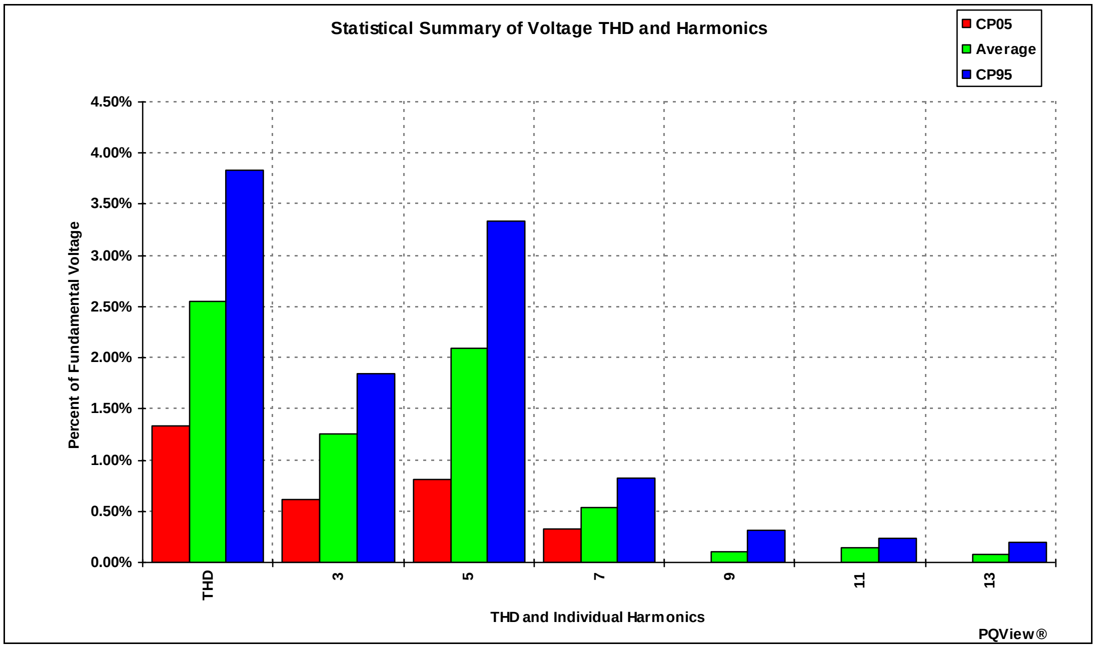


Figure 4 - Measured Statistical Summary of Voltage Distortion and Harmonics

Voltage sags and momentary interruptions are inevitable on the electric power system. Many of these variations occur during faults on the power system, and since it is impossible to eliminate the occurrence of faults, there will always be voltage variations on customer systems. Other sources of voltage variations include unbalance, induction motor starting, and voltage flicker. Table 1 shows an rms variation event summary listing for several of the sixty rms variation events that occurred during the twelve-month monitoring period. The table shows the date-and-time for each event, as well as the phase-to-neutral voltage magnitude in both volts (kV) and per-unit and the event duration in both seconds and cycles.

Figure 5 shows the corresponding waveform and rms characteristic for one of the voltage sag events measured during the monitoring period (Event #3 in Table 1). The magnitude of the voltage sag was 47.9% and the duration was 7.0 cycles. The voltage sag occurred during a storm. It was caused by a short-duration fault and subsequent fuse clearing on a feeder branch circuit.

Table 1 - Event Listing for Measured RMS Variations

Event Number	Event Time	Magnitude ($kV_{\varphi N}$)	Magnitude (per-unit)	Duration (sec)	Duration (cycles)
1	1/10/2003 09:02:33.2520	0.242	0.874	0.017	1.0
2	3/22/2003 08:43:43.1900	0.174	0.628	0.033	2.0
3	4/22/2003 13:39:38.3150	0.133	0.479	0.117	7.0
4	8/20/2003 22:54:15.1900	0.209	0.753	0.083	5.0

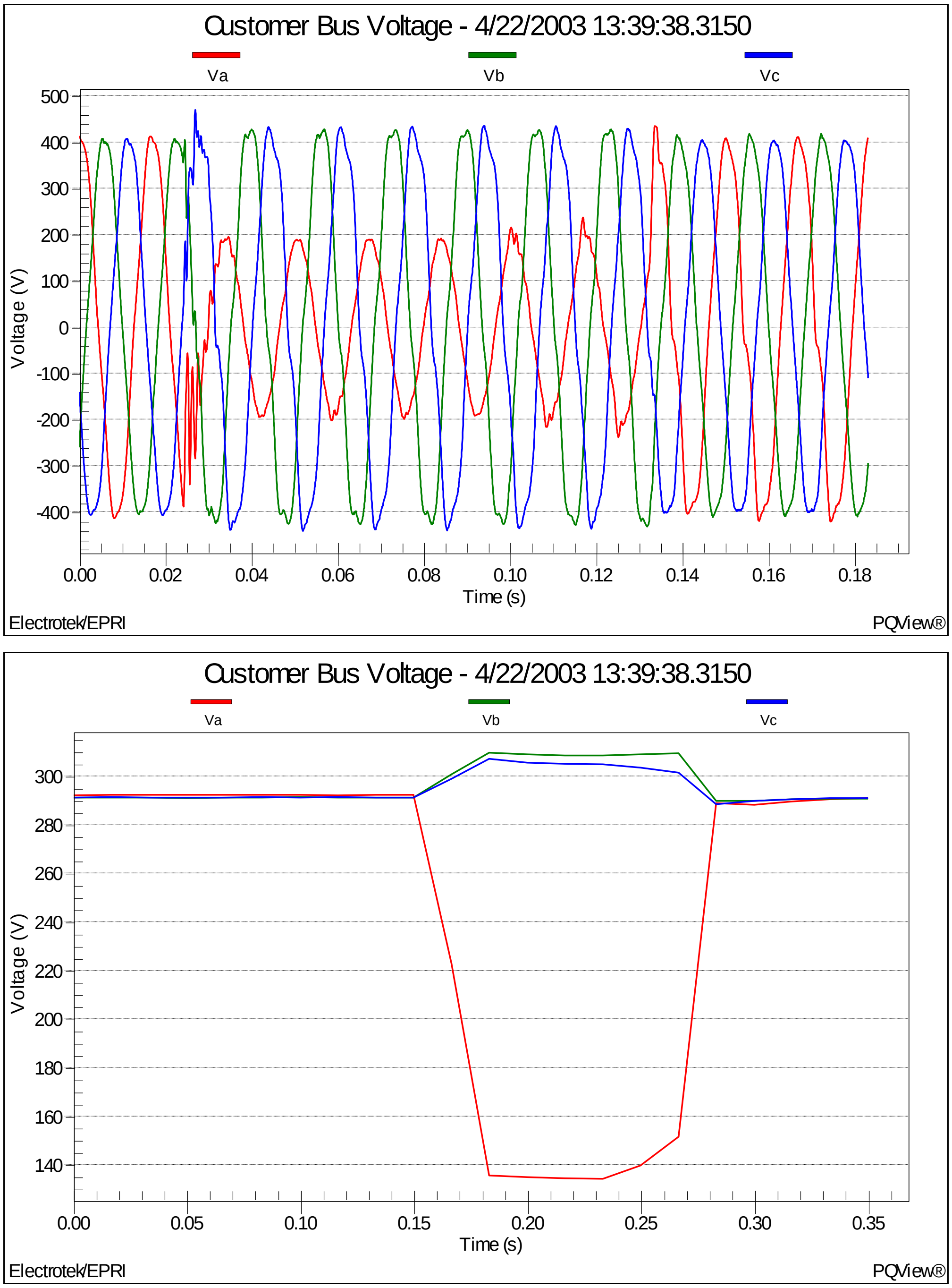


Figure 5 - Measured Customer Secondary Voltage Sag Event

When there are a significant number of events, it is generally not desirable to show the results for each individual measurement. One method for summarizing rms variation event data is to graph the magnitude and duration data on one single scatter plot. This method may also include an equipment tolerance (e.g., ITIC) overlay. Figure 6 shows a summary of the measured rms variation events along with an ITIC overlay. The graph also shows the number of events that are outside the equipment sensitivity characteristic.

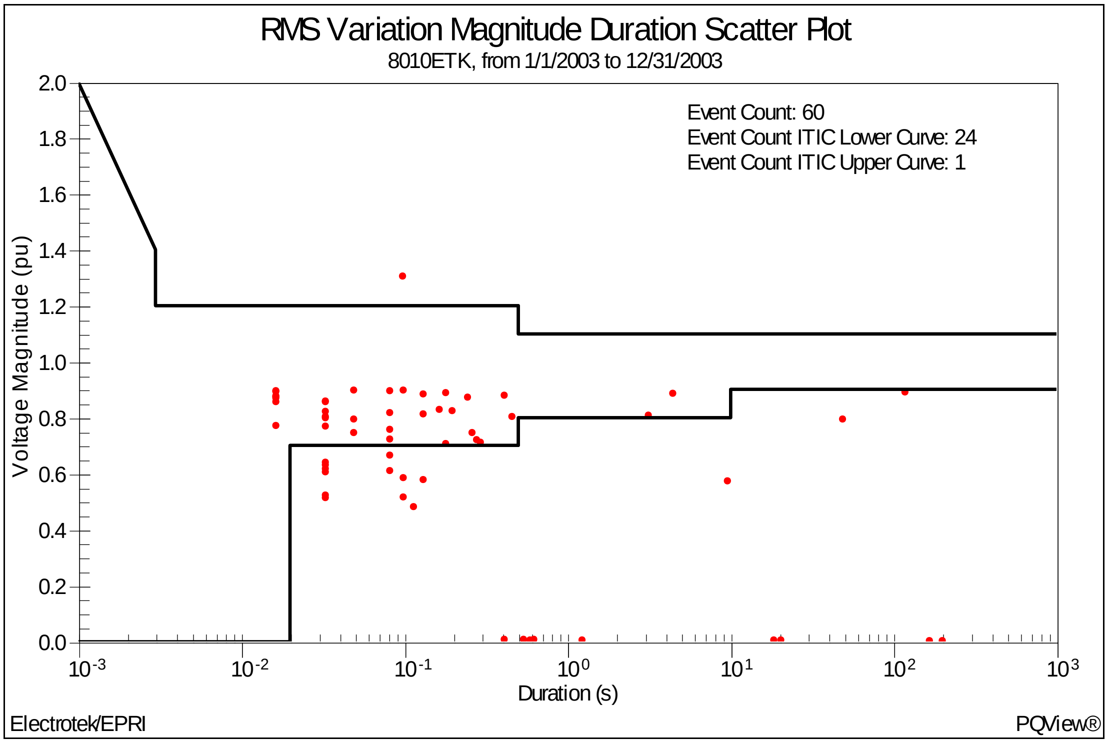


Figure 6 - Measured Customer RMS Variation Magnitude Duration Characteristic

Voltage variation indices may be used to assess the service quality for a customer. One commonly used benchmarking value is known as *SARFI*, which stands for System Average RMS Variation Frequency Index. SARFI represents the average number of specified rms variation measurements that occurred over the assessed period. For example, SARFI_{70} is a measure of the number of voltage sags that can be expected with a minimum voltage below 70%. Another popular use of SARFI is to define the threshold as a curve. For example, $\text{SARFI}_{\text{CMEBA}}$ would represent the number of rms variation events outside the commonly used CBEMA voltage tolerance envelope. The CBEMA curve was originally developed by the Computer Business Equipment Manufacturers Association. The curve was first published in IEEE Std. 446-1995.

The calculated SARFI values for the twelve-month monitoring period are summarized in Table 2. The SARFI_{90} value of fifty-six can be determined by counting the number of events with a voltage magnitude below 90%. In addition, the $\text{SARFI}_{\text{ITIC}}$ value of twenty-four that is shown in the table corresponds to the data previously shown in Figure 6.

Table 2 - Summary of RMS Voltage Variation SARFI Values

SARFI-CBEMA	SARFI-ITIC	SARFI-SEMI	SARFI-90	SARFI-70	SARFI-50	SARFI-10
32	24	13	56	20	8	7

The causes of the transients measured during the monitoring period included capacitor bank switching, transformer energizing, single-phase faults, switch failure, recloser operations, and current-limiting fuse operations.

Table 3 shows a transient event summary listing for several of the representative transients that were measured during the twelve-month monitoring period. There were several thousand oscillatory transients that were captured. The table shows the date-and-time for each event, as well as the peak phase-to-neutral voltage magnitude in both volts (kV_{pk}) and per-unit and the event duration in both seconds and cycles.

Table 3 - Event Listing for Measured Transient Events

Event Number	Event Time	Magnitude ($kV_{\varphi N}$)	Magnitude (per-unit)	Duration (sec)	Duration (cycles)
1	1/31/2003 02:34:55.0000	0.531	1.355	5.667E-03	0.340
2	3/09/2003 23:35:31.0000	0.538	1.373	7.001E-03	0.420
3	9/19/2003 05:06:45.6250	0.591	1.508	8.203E-03	0.492

One of the common transient events measured throughout the monitoring period was during energization of the 300 kVAr capacitor bank on the utility distribution feeder. Figure 7 shows a representative measured three-phase customer secondary voltage waveform during uncontrolled energization of the pole-mounted 300 kVAr capacitor bank on feeder #1 (Event #3 in Table 3). The utility capacitor bank was switched on-and-off each day using time clock controls in an attempt to maintain a relatively constant voltage profile. The peak magnitude of the measured transient voltage was 591.1 V (1.51 per-unit) and the principal frequency for the capacitor energizing waveform was approximately 900 Hz. The duration of the transient event was approximately 8.203msec or 0.492 cycles. The capacitor bank was energized using a three-phase oil switch.

Typical voltage magnitude levels for switching distribution capacitor banks range from 1.3 to 1.5 per-unit and typical transient frequencies generally fall in the range from 300 to 1000 Hz. Power quality problems related to utility capacitor bank switching include customer equipment damage or failure, nuisance tripping of adjustable-speed drives or other process equipment, transient voltage surge suppressor failure, and computer network problems.

Utilities switch capacitor banks in-and-out of service routinely to provide voltage support and to improve power factor. One potential disadvantage of capacitor bank switching is the effect that such an operation can have on the topology of the system. Switching capacitor banks into mostly inductive circuits can tune the natural frequency of the circuit closer to harmonic frequencies that might be prevalent on the system. Obviously, this can be a significant problem, possibly resulting in severe voltage and current distortion, increased losses, and overheating of system equipment.

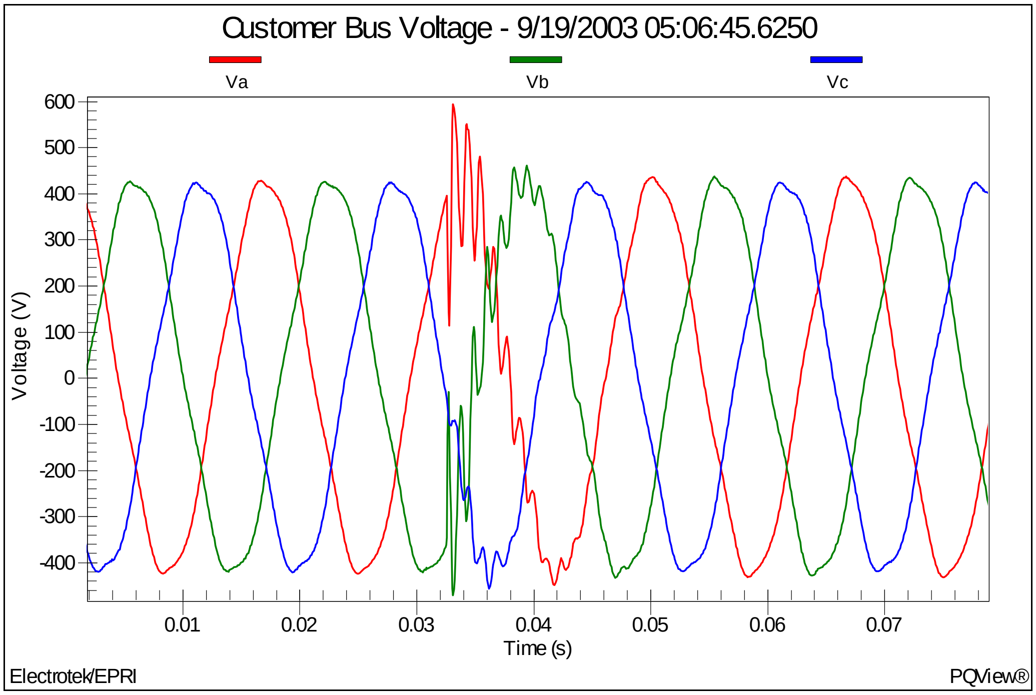


Figure 7 - Measured Customer Transient Voltage during Capacitor Bank Switching

Another relatively common transient event was during a fuse operation on one of the utility distribution feeders. A representative three-phase waveform is shown in Figure 8. The peak magnitude of the measured transient voltage was 593.8 V (1.52 per-unit) and the principal frequency for the transient waveform was approximately 300 Hz.

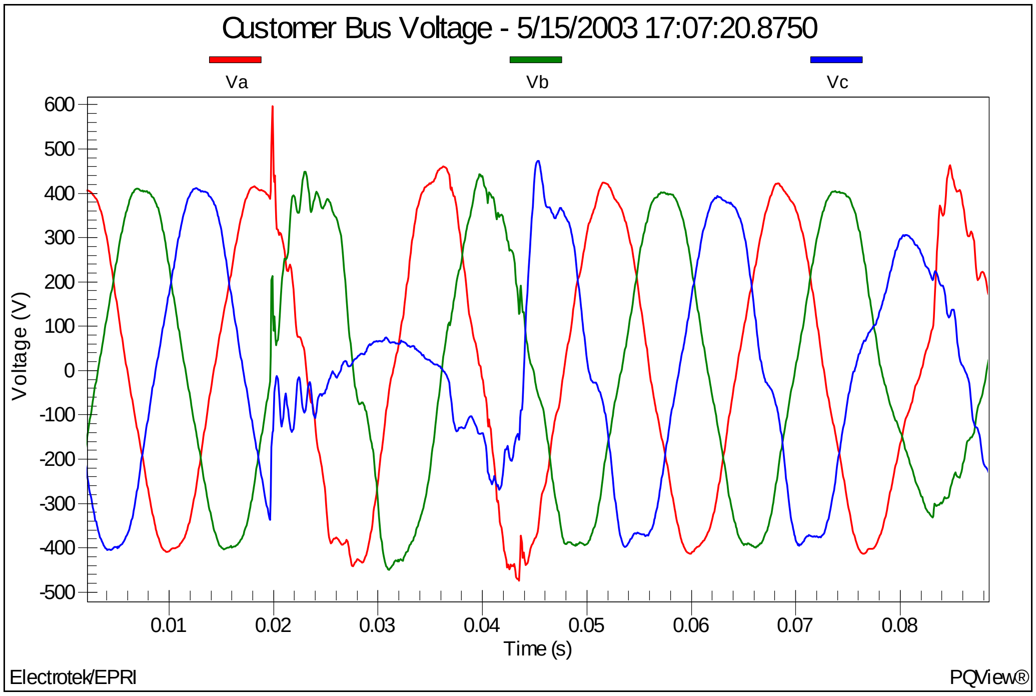


Figure 8 - Measured Customer Transient Voltage during Fuse Operation

Table 4 shows a summary of relevant terms and indices related to power quality problems on utility and customer power systems.

Table 4 - Power Quality Related Equations and Indices

Quantity	**Description**	**Equation**
kVA1ϕ	Single-Phase Apparent Power	$\frac{V_L * I_L}{1000}$
kVA3ϕ	Three-Phase Apparent Power	$\frac{\sqrt{3} * V_L * I_L}{1000} = \sqrt{kW^2 + kVAr^2}$
DPF	Displacement Power Factor	$\text{Cos}\theta = \frac{kW}{kVA}$
RMS	Root Mean Square	$\sqrt{\left(V_1^2 + V_2^2 + V_3^2 + \ldots + V_n^2\right)}$
THD	Total Harmonic Distortion (in percent)	$\frac{\sqrt{\left(V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2\right)}}{V_1} * 100$

SUMMARY

This case study summarized a commercial customer power quality measurement data analysis. The case showed that monitoring may be used to characterize power quality levels on customer power systems. The length of the monitoring period, which was twelve-months for this study, is dependent on the nature of the power quality problem. The analysis included trends and statistical summaries of the rms voltage and the harmonic voltage distortion levels. The results showed that the harmonic voltage distortion levels were below the assumed 5% voltage distortion limit.

The results of the analysis also showed that most of the rms variation events were short duration voltage sags. Constant voltage transformers, coil-lock devices, magnetic synthesizers, and a number of power-electronic based power conditioners may be used for protection against voltage sag events. Voltage sag protection may be implemented on a single coil or piece of equipment. Correction may also be chosen for large portions of a facility or even for the entire facility.

Mitigation alternatives for reducing harmonic distortion levels include methods for modifying the power system to reduce or eliminate the harmonic resonances that can cause very high current or voltage distortion levels. For example, a passive shunt harmonic filter may be added to the utility or customer system to divert the troublesome harmonic currents off the system and into the filter.

The causes of the transients measured during the monitoring period included capacitor bank switching, single-phase faults, recloser operations, and current-limiting fuse operations. Customer transient mitigation options include power conditioners and TVSSs.

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