9 Measuring and Solving Power Quality Problems

9.1 INTRODUCTION

Comprehensive knowledge of power quality issues is important in today's electrical power system operating environment, but the ultimate purpose of learning about power quality is to be able to solve power quality problems. Whether the reader is going to put on personal protective equipment and set up instrumentation to determine the problem or entrust someone else to perform this task, information on how to actually accomplish this is vital. Solving power quality problems depends on acquiring meaningful data at the optimum location or locations and within an expedient time frame. In order to acquire useful and relevant data, instruments most suited for a particular application should be utilized. Most power quality problems that go unrecognized are due to use of instruments not ideally suited for that application. One also needs to have a sense about the location or locations where data need to be collected and for how long. After the data is acquired, sort it to determine what information is pertinent to the problem on hand and what is not. This process requires knowledge of the power system and knowledge of the affected equipment. Initially, all data not determined to be directly useful should be set aside for later use. All data deemed to be relevant should be prioritized and analyzed to obtain a solution to the problem. It should be stressed once again that some power quality problems require not a single solution but a combination of solutions to obtain the desired end results. In this chapter, some of the power quality instrumentation commonly used will be discussed and their application in the power quality field will be indicated.

9.2 POWER QUALITY MEASUREMENT DEVICES

9.2.1 Harmonic Analyzers

Harmonic analyzers or harmonic meters are relatively simple instruments for measuring and recording harmonic distortion data. Typically, harmonic analyzers contain a meter with a waveform display screen, voltage leads, and current probes. Some of the analyzers are handheld devices and others are intended for tabletop use. Some instruments provide a snapshot of the waveform and harmonic distortion pertaining to the instant during which the measurement is made. Other instruments are capable of recording snapshots as well as a continuous record of harmonic distortion over time. Obviously, units that provide more information cost more. Depending on the power quality issue, snapshots of the harmonic distortion might suffice. Other problems, however, might require knowledge of how the harmonic distortion characteristics change with plant loading and time.

What is the largest harmonic frequency of interest that should be included in the measurement? It has been the author's experience that measurements to the 25th harmonics are sufficient to indicate the makeup of the waveform. Harmonic analyzers from various manufacturers tend to have different, upper-harmonic-frequency measurement capability. As described in Chapter 4, harmonic distortion levels diminish substantially with the harmonic number. In order to accurately determine the frequency content, the sampling frequency of the measuring instrument must be greater than twice the frequency of the highest harmonic of interest. This rule is called the Nyquist frequency criteria. According to Nyquist criteria, to accurately determine the frequency content of a 60-Hz fundamental frequency waveform up to the 25th harmonic number, the harmonic measuring instrument must have a minimum sampling rate of 3000 ($25 \times 60 \times 2$) samples per second. Of course, higher sampling rates more accurately reflect the actual waveform.

Measurement of voltage harmonic data requires leads that can be attached to the points at which the distortion measurements are needed. Typical voltage leads are 4 to 6 ft long. At these lengths, cable inductance and capacitance are not a concern, as the highest frequency of interest is in the range of 1500 to 3000 Hz (25th to 50th harmonic); therefore, no significant attenuation or distortion should be introduced by the leads in the voltage distortion data.

Measuring current harmonic distortion data requires some special considerations. Most current probes use an iron core transformer designed to fit around the conductors in which harmonic measurements are needed (Figure 9.1). Iron-core current probes are susceptible to increased error at high frequencies and saturation at currents higher than the rated values. Prior to installing current probes for harmonic distortion tests, it is necessary to ensure that the probe is suitable for use at high frequencies without a significant loss in accuracy. Manufacturers provide data as to the usable frequency range for the current probes. The probe shown in Figure 9.1 is useful between the frequencies of 5 Hz and 10 kHz for a maximum current rating of 500 A RMS. It should be understood that, even though the probe might be rated for use at the higher frequencies, there is an accompanying loss of accuracy in the data. The aim is to keep the loss of accuracy as low as possible. At higher frequencies, currents and distortions normally looked at are considerably lower than at the lower frequencies, and some loss of accuracy at higher frequencies might not be all that important. Typically, a 5.0% loss in accuracy might be expected, if the waveform contains significant levels of higher order harmonics.

Figure 9.2 shows the use of a handheld harmonic measuring instrument. This particular instrument is a single-phase measurement device capable of being used in circuits of up to 600 VAC. Table 9.1 provides a printout of harmonic distortion data measured at a power distribution panel supplying a small office building. The table shows the voltage and current harmonic information to the 31st harmonic frequency. Along with harmonic distortion, the relative phase angle between the harmonics and the fundamental voltage is also given. Phase angle information is useful is assessing the direction of the harmonic flow and the location of the source of the harmonics.

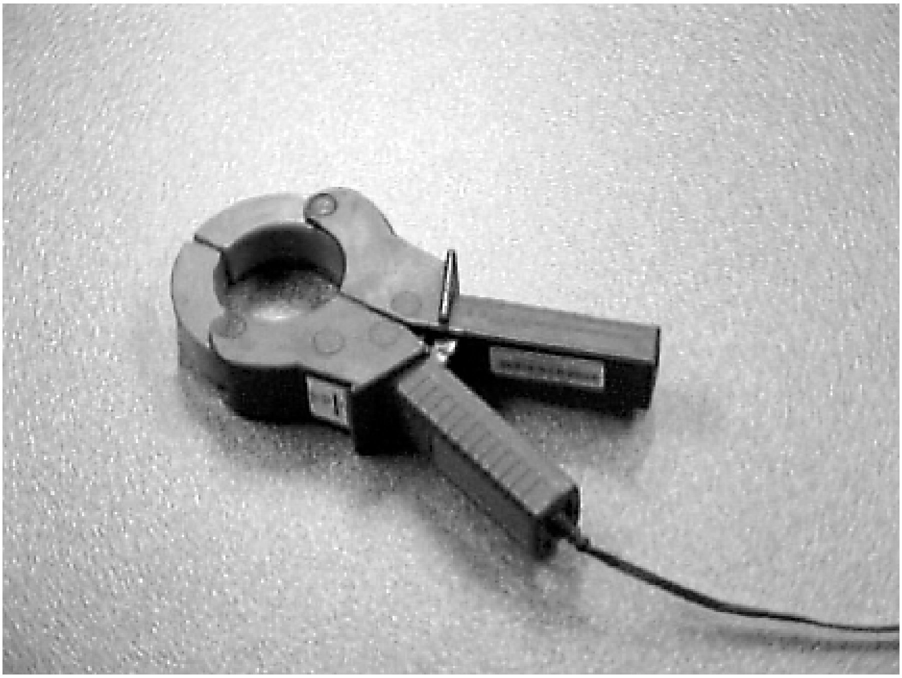


FIGURE 9.1 Current probe for measuring currents with waveform distortion due to harmonics.

A point worth noting is that the harmonics are shown as a percent of the total RMS value. IEEE convention presents the harmonics as a percent of the fundamental component. Using the IEEE convention would result in higher harmonic percent values. As pointed out in Chapter 4, it does not really matter what convention is used as long as the same convention is maintained throughout the discussion.

Figure 9.3 shows a tabletop harmonic analyzer for measuring harmonic distortion snapshots and harmonic distortion history data for a specified duration. Table 9.2 contains the harmonic current distortion snapshot data recorded at a lighting panel in a high-rise building. Figure 9.4 provides the current waveform and a record of the current history at the panel over 5 days. The harmonic distortion snapshots along with the history graph are very useful in determining the nature of the harmonics and their occurrence pattern.

9.2.2 Transient-Disturbance Analyzers

Transient-disturbance analyzers are advanced data acquisition devices for capturing, storing, and presenting short-duration, subcycle power system disturbances. As one might expect, the sampling rates for these instruments are high. It is not untypical for transient-disturbance recorders to have sampling rates in the range of 2 to 4 million samples per second. Higher sampling rates provide greater accuracy in describing transient events in terms of their amplitude and frequency content. Both

FIGURE 9.2 Handheld harmonic analyzer showing voltage leads and current probe for voltage and current harmonic measurements. (Photograph courtesy of Fluke.)

these attributes are essential for performing transient analysis. The amplitude of the waveform provides information about the potential for damage to the affected equipment. The frequency content informs us as to how the events may couple to other circuits and how they might be mitigated. Figure 9.5 shows a transient that reached peak amplitude of 562 V with a frequency content of approximately 200 kHz. Once such information is determined, equipment susceptibility should be determined. For instance, a 200-V peak impulse applied to a 480-V motor might not have any effect on the motor life; however, the same impulse applied to a process controller could produce immediate failure. Equipment that contains power supplies or capacitor filter circuits is especially susceptible to fast rise-time transients with high-frequency content.

When measuring fast rise time or higher frequency transients, the length of the wires used to connect the instrumentation to the test points becomes very important. In all of these measurements, the leads should be kept as short as possible. Typically, lead lengths of 6 ft or less should not introduce significant errors in the measurements of fast transients. At higher frequencies, cable inductance as well as capacitance become important factors. The use of longer cable lengths in transient measurements results in higher inductance and capacitance and greater attenuation of the transient waveform. Also, in order to minimize noise pickup from external sources, the voltage leads should be kept away from high-voltage and high-current conductors, welding equipment, motors, and transformers. The leads should be kept as straight as possible

TABLE 9.1
Voltage and Current Harmonic Spectrum at an Office Building

Harmonics	Frequency	V Magnitude	% V RMS	V (Phase)	I Magnitude	% I RMS	I (Phase)
DC	0	0.09	0.07	0	0.06	0.14	0
1	59.91	122.84	99.82	0	43.44	97.17	–18
2	119.82	0.09	0.07	74	0.11	0.24	–63
3	179.73	6.33	5.14	42	7.63	17.07	150
4	239.64	0.06	0.05	135	0.09	0.21	90
5	299.56	0.2	0.17	–67	6.3	14.09	–49
6	359.47	0.03	0.03	–156	0.05	0.11	–70
7	419.38	1.15	0.93	20	2.22	4.96	116
8	479.29	0.05	0.04	–80	0	0	105
9	539.2	0.91	0.74	108	0.34	0.77	–150
10	599.11	0.02	0.02	–5	0.01	0.01	45
11	659.02	0.42	0.34	–160	0.81	1.8	–56
12	718.93	0.04	0.03	82	0.01	0.03	165
13	778.84	0.13	0.11	–80	0.52	1.16	96
14	838.76	0.02	0.01	60	0.03	0.07	–88
15	898.67	0.66	0.53	84	0.13	0.28	–159
16	958.58	0.01	0.01	–174	0.01	0.03	63
17	1018.49	0.28	0.23	120	0.37	0.82	–124
18	1078.4	0.01	0.01	–146	0.02	0.04	–129
19	1138.31	0.05	0.04	–145	0.33	0.74	52
20	1198.22	0.01	0.01	–13	0.01	0.03	124
21	1258.13	0.17	0.14	44	0.14	0.31	–179
22	1318.04	0.02	0.01	36	0.02	0.04	–90
23	1377.96	0.15	0.12	101	0.08	0.18	–157
24	1437.87	0.02	0.02	–162	0.01	0.03	–156
25	1497.78	0.02	0.02	167	0.12	0.27	–9
26	1557.69	0.04	0.03	–169	0.01	0.03	–86
27	1617.6	0.09	0.07	–32	0.1	0.22	146
28	1677.51	0.02	0.02	–62	0.04	0.1	34
29	1737.42	0.04	0.03	–29	0.03	0.07	70
30	1797.33	0.02	0.02	–33	0.01	0.03	4
31	1857.24	0.04	0.03	–80	0.08	0.18	–39

Note: The table shows the harmonic number, harmonic frequency, magnitudes, percent harmonic in terms of the total RMS, and the phase angle of each with respect to the fundamental voltage.

without sharp bends or loops. In any case, excess lead length should never be wound into a coil.

Current transformers used in transient current measurements must have a peak current rating at least equal to the maximum expected currents; otherwise, current peaks are lost in the data due to saturation of the current probe. Figure 9.6 indicates how current probe saturation resulted in a flat-top current waveform and loss of vital information, making power quality analysis more difficult.

TABLE 9.2
Current Harmonic Spectrum for a Lighting Panel Supplying Fluorescent Lighting[a]

Harmonics	RMS Value	Phase	% of Fundamental
0	10.298	180	74.603
1	13.804	157.645	100
2	0.209	337.166	1.511
3	2.014	62.148	14.588
4	0.136	333.435	0.983
5	1.187	81.18	8.603
6	0.051	0	0.366
7	0.372	45	2.695
8	0.121	270	0.879
9	0.551	20.433	3.989
10	0.087	324.462	0.63
11	0.272	15.068	1.973
12	0.101	143.13	0.733
13	0.285	6.116	2.064
14	0.083	345.964	0.604
15	0.083	75.964	0.604
16	0.042	284.036	0.302
17	0.243	45	1.762
18	0.054	21.801	0.395
19	0.051	53.13	0.366
20	0.103	348.69	0.747
21	0.04	0	0.293
22	0.103	281.31	0.747
23	0.036	123.69	0.264
24	0.103	101.31	0.747
25	0.02	90	0.147
26	0.062	189.462	0.446
27	0.068	206.565	0.492
28	0.052	78.69	0.374
29	0.187	49.399	1.351
30	0.03	270	0.22
31	0.145	155.225	1.049
32	0.059	210.964	0.427
33	0.113	10.305	0.819
34	0.074	285.945	0.534
35	0.045	26.565	0.328
36	0.096	341.565	0.695
37	0.136	318.013	0.986
38	0.074	254.055	0.534
39	0.109	201.801	0.789
40	0.109	248.199	0.789
41	0.051	143.13	0.366
42	0.103	281.31	0.747

TABLE 9.2 (CONTINUED)
Current Harmonic Spectrum for a Lighting Panel Supplying Fluorescent Lighting[a]

Harmonics	RMS Value	Phase	% of Fundamental
43	0.103	101.31	0.747
44	0.045	153.435	0.328
45	0.082	330.255	0.591
46	0.136	228.013	0.986
47	0.043	45	0.311
48	0.152	53.13	1.099
49	0.064	251.565	0.463
50	0.02	270	0.147
51	0.133	278.746	0.964
52	0.086	315	0.622
53	0.125	345.964	0.906
54	0.132	274.399	0.956
55	0.032	341.565	0.232
56	0.045	116.565	0.328
57	0.162	90	1.173
58	0.136	131.987	0.986
59	0.064	288.435	0.463
60	0.154	336.801	1.116
61	0.165	47.49	1.193
62	0.122	221.634	0.882
63	0.051	143.13	0.366

Note: Total harmonic distortion = 18.7%.

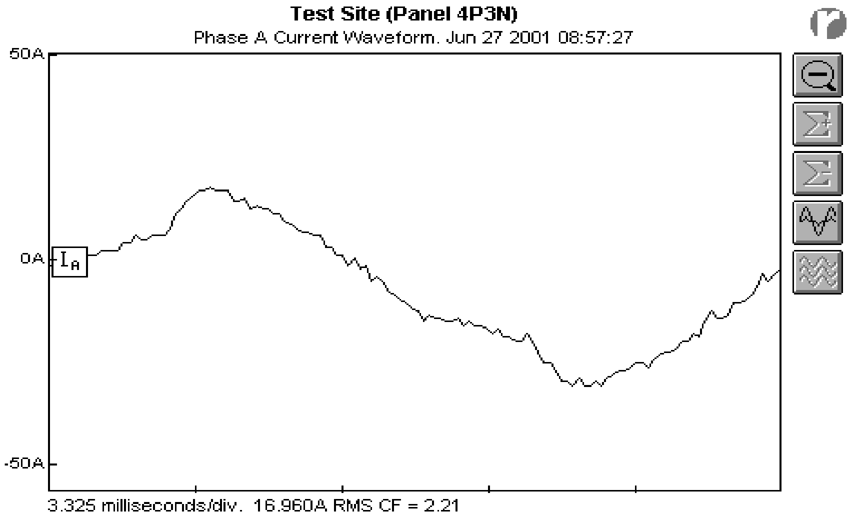
[a] Phase A current harmonics, June 27, 2001, 08:57:27.

9.2.3 Oscilloscopes

Oscilloscopes are useful for measuring repetitive high-frequency waveforms or waveforms containing superimposed high-frequency noise on power and control circuits. Oscilloscopes have sampling rates far higher than transient-disturbance analyzers. Oscilloscopes with sampling rates of several hundred million samples per second are common. This allows the instrument to accurately record recurring noise and high-frequency waveforms. Figure 9.7 shows the pulse-width-modulated waveform of the voltage input to an adjustable speed AC motor. Such data are not within the capabilities of harmonic analyzers and transient-disturbance recorders. Digital storage oscilloscopes have the ability to capture and store waveform data for later use. Using multiple-channel, digital storage oscilloscopes, more than one electrical parameter may be viewed and stored. Figure 9.8 shows the noise in the ground grid of a microchip manufacturing facility that could not be detected using other instrumentation. The noise in the ground circuit was responsible for production shutdown at this facility.

FIGURE 9.3 Three-phase harmonic and disturbance analyzer for measuring voltage and current harmonics, voltage and current history over a period of time, voltage transients, and power, power factor, and demand. (Photograph courtesy of Reliable Power Meters.)

Selection of voltage probes is essential for proper use of oscilloscopes. Voltage probes for oscilloscopes are broadly classified into passive probes and active probes. Passive probes use passive components (resistance and capacitance) to provide the necessary filtering and scale factors necessary. Passive probes are typically for use in circuits up to 300 VAC. Higher voltage passive probes can be used in circuits of up to 1000 VAC. Most passive probes are designed to measure voltages with respect to ground. Passive probes, where the probe is isolated from the ground, are useful for making measurements when connection to the ground is to be avoided. Active probes use active components such as field effect transistors to provide high input impedance to the measurements. High input impedance is essential for measuring low-level signals to minimize the possibility of signal attenuation due to loading by the probe itself. Active probes are more expensive than passive probes. The high-frequency current probe is an important accessory for troubleshooting problems



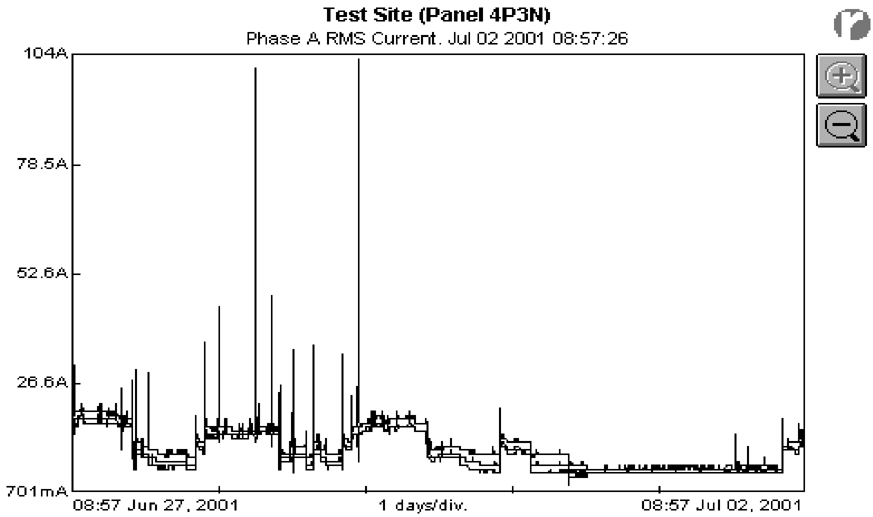
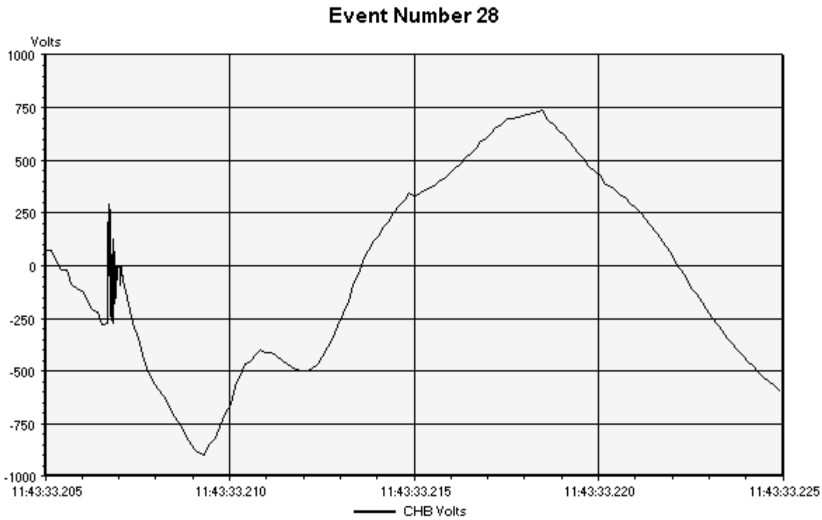


FIGURE 9.4 Current waveform and current history graph at a lighting panel supplying fluorescent lighting.

using an oscilloscope. By using the current probe, stray noise and ground loop currents in the ground grid can be detected.

9.2.4 Data Loggers and Chart Recorders

Data loggers and chart recorders are sometimes used to record voltage, current, demand, and temperature data in electrical power systems. Data loggers and chart



AV,BV Impulse event at 07/10/98 11:43:33.20

	PrevRMS	MinRMS	MaxRMS	WorstIMP	Phase	HFHits
AV Volts	441.5	458.7	468.8	-234.0	210 deg	1
BV Volts	446.6	471.7	473.4	562.0	213 deg	1
CV Volts	3.40	0.43	3.26	0.00	0 deg	0
DV Volts	3.50	0.56	3.45	0.00	0 deg	0

FIGURE 9.5 Switching transient disturbance with a peak of 562 V and a frequency content of 20 kHz.

recorders are slow-response devices that are useful for measuring steady-state data over a long period of time. These devices record one sample of the event at predetermined duration, such as 1 sec, 2 sec, 5 sec, etc. The data are normally stored within the loggers until they are retrieved for analysis. The data from data loggers and chart recorders are sufficient for determining variation of the voltage or current at a particular location over an extended period and if there is no need to determine instantaneous changes in the values. In some applications, this information is all that is needed. But, in power quality assessments involving transient conditions, these devices are not suitable. The advantage of data loggers is that they are relatively inexpensive compared to power quality recording instrumentation. They are also easier to set up and easier to use. The data from the device may be presented in a text format or in a graphical format. Figure 9.9 is the recording of current data at the output of a power transformer using a data logger. The data were produced at the rate one sample every 5 sec. Data loggers and chart recorders are not intended for installation directly on power lines. They are designed to operate using the low-level output of suitable voltage, current, or temperature transducers; however, care should be exercised in the installation and routing of the wires from the transducers to ensure that the output of the transducers is not compromised due to stray noise pickup. Also, data loggers and chart recorders do not provide information about the waveshape of the measured quantity. If that level of information is needed, a power quality analyzer should be used instead.

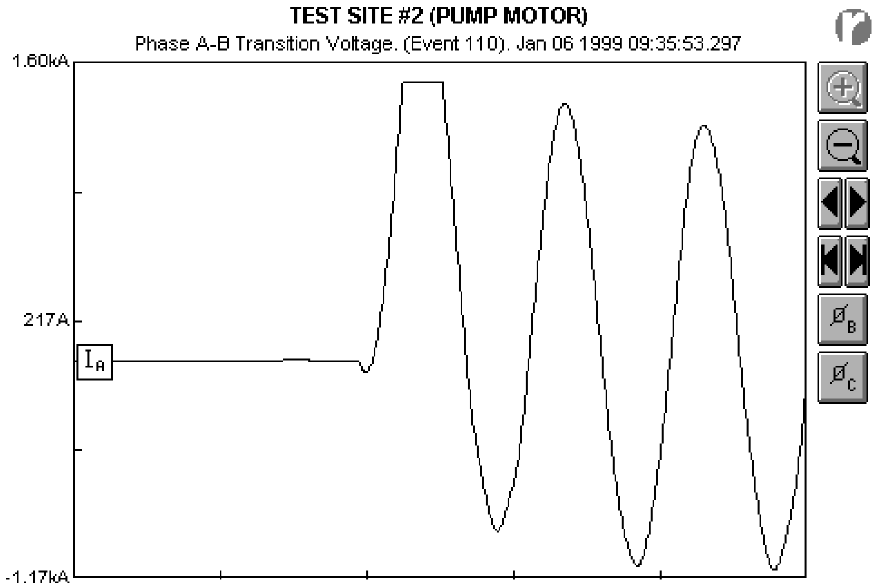


FIGURE 9.6 Current transformer saturation resulting in the loss of vital peak current information.

9.2.5 True RMS Meters

The term *true RMS* is commonly used in power quality applications. What are true RMS meters? As we saw in previous chapters, the RMS value of the current or voltage can be substantially different from the fundamental component of the voltage or current. Using a meter that measures average or peak value of a quantity can produce erroneous results if we need the RMS value of the waveform. For waveforms rich in harmonics, the average and peak values would be considerably different than waveforms that are purely sinusoidal or close to sinusoidal. Measuring the average or peak value of a signal and scaling the values to derive a RMS value would lead to errors.

For example, consider a square wave of current as shown in Figure 9.10. The average and peak reading meters indicate values of 111 A and 70.7 A RMS current, respectively. The square waveform has an average value of 100 A. The peak value of the waveform also has a value of 100 A. In order to arrive at the RMS value, the 100 A average value is multiplied by 1.11, The ratio between the RMS and the average value of a pure sinusoidal waveform is 1.11. The peak reading meter would read the 100 A peak value and multiply it by 0.707 to arrive at the RMS value of 70.7 A, with 0.707 being the ratio between the RMS value and the peak value of a pure sinusoid waveform. The disparities in the values are quite apparent. Figure 9.10 also shows a triangular waveform and the corresponding current data that would be reported by each of the measuring instruments.

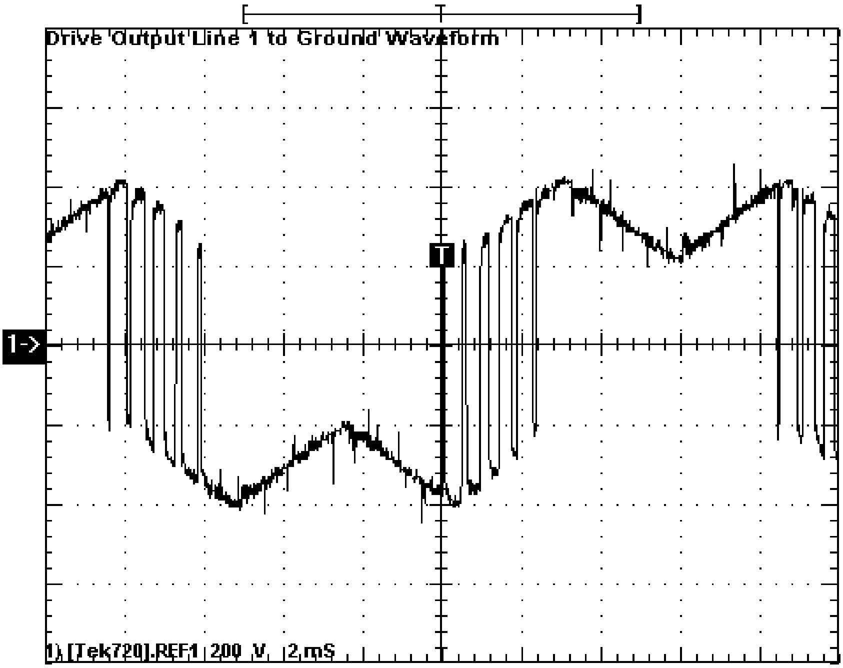


FIGURE 9.7 Pulse-width-modulated waveform from an adjustable speed drive output.

Analog panel meters give erroneous readings when measuring nonsinusoidal currents. Due to higher frequency components, analog meters tend to indicate values that are lower than the actual values. The presence of voltage and current transformers in the metering circuit also introduces additional errors in the measurements.

True RMS meters overcome these problems by deriving the heating effect of the waveform to produce an accurate RMS value indication. After all, RMS value represents the heating effect of a voltage or current signal. Most true RMS meters do not provide any indication of the waveform of the quantity being measured. To accomplish this, the meters require high-frequency signal sampling capability. The sampling rate should satisfy Nyquist criteria in order to produce reasonably accurate results. Some benchtop RMS meters do have the sampling capability and ports to send the information to a computer for waveform display.

9.3 POWER QUALITY MEASUREMENTS

The first step in solving power quality problems is to determine the test location or locations. Even the best available power quality instrumentation is only as good as the personnel using it. Setting up instrumentation at a location that is not optimum with respect to the affected equipment can yield misleading or insufficient information. Electrical transients are especially prone to errors depending on the type of the instrument used and its location. The following example might help to make this point clear.

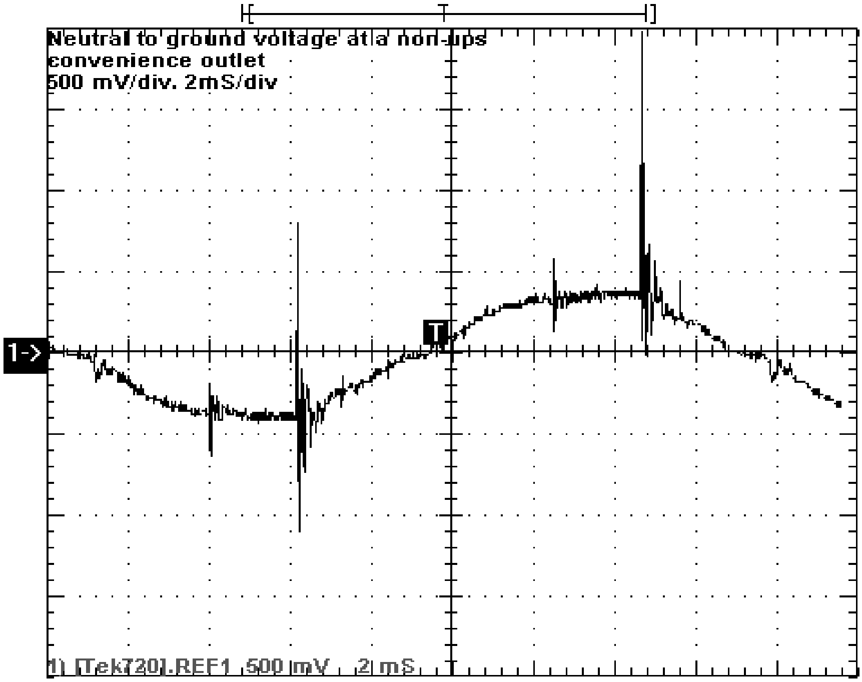


FIGURE 9.8 Electrical noise in the ground grid of a computer center at a microchip manufacturing plant.

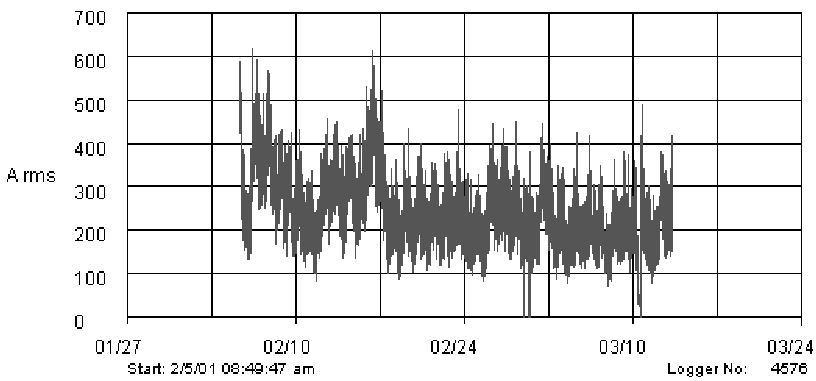


FIGURE 9.9 Current data from a data logger for one month of tests.

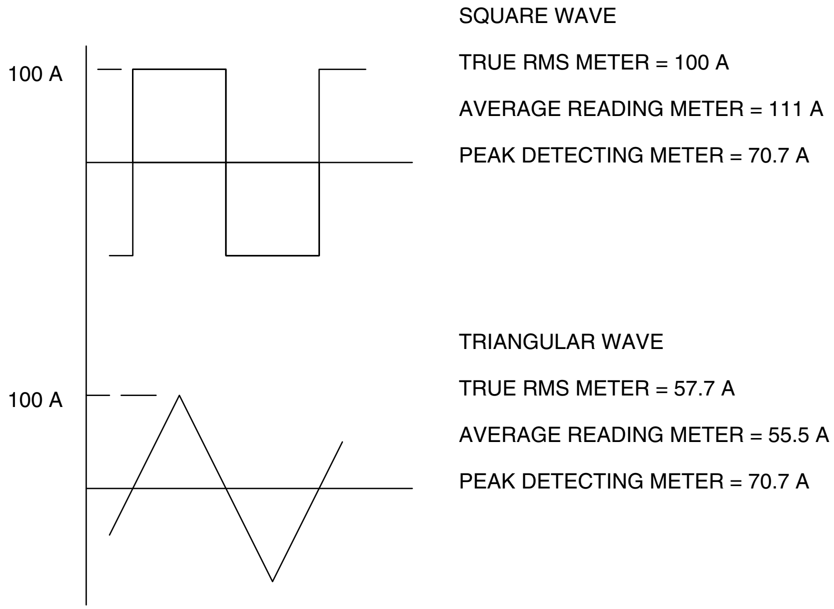


FIGURE 9.10 Variation in rms measurements when using different types of meters.

Example: A large mainframe printing machine was shutting down randomly with no apparent cause. The machine was installed in a computer data center environment and was supplied from an uninterruptible power source (UPS) located about 10 ft from the machine. The power cord from the UPS to the printer was a 15-ft, three-conductor cable. Simultaneous measurement of power quality at the printer input terminals and the UPS terminals supplying the printer revealed that, while transients were present at the machine, no corresponding transients were evident at the UPS. In this case, the 15 ft of cable was sufficient to mask the transient activity. It was determined that the transients were caused by the printer itself due to its large current inrush requirement during the course of printing. The printer contained sensitive voltage detection circuitry which was causing the printer to shut down. To take care of the problem, inline filters were installed at the printer input which reduced the transient amplitudes to levels that could be lived with. In this case, if the power quality measurement instrument had been installed at the UPS output only, the cause of the problem would have gone undetected.

The best approach to investigating power quality problems is to first examine the power quality to the affected equipment at a point as close as possible to the equipment. If power quality anomalies are noticed, then move upstream with a process-of-elimination plan. That is, at each location determine if the problem is due to load-side anomalies or line-side problems. Even though this process is time consuming and perhaps cost ineffective, valuable information can be obtained. Understanding and solving power quality problems is rarely quick and easy.

9.4 NUMBER OF TEST LOCATIONS

If at all possible, power quality tests should be conducted at multiple locations simultaneously. The data obtained by such means are useful in determining the nature of the power quality problem and its possible source as quickly as possible. If simultaneous monitoring is not feasible due to cost or other factors, each location may be individually monitored, taking care to ensure similar operating environments for testing at each location to allow direct comparison of information. The number of test locations would depend on the nature of the problem and the nature of the affected equipment. For example, in Figure 9.11, if power quality problems are observed at location C and not at B, it is not necessary to monitor A. On the other hand, if problems are noticed at C and B, then location A should be tested as well as location D, if necessary. The experience of the power quality engineer becomes important when trying to resolve the different scenarios. For a large facility with multiple transient sources and susceptible equipment, the challenge can be immense.

9.5 TEST DURATION

Deciding upon the length of time that each test point should be monitored for adequate data collection is something that even a well-trained engineer has to struggle with at times. Ideally, you would want to continue tests until the actual cause shows up. This is not always feasible, and the approach can be quite costly. In power quality tests, you are looking not only for the actual failure mode to repeat itself (which would be ideal) but also for any event that might show a tendency toward failure.

Example: The main circuit breaker for a large outlet store would trip randomly. Each occurrence was accompanied by a loss of revenue, not to mention customer dissatisfaction. To determine the cause, the three-phase currents as well as the sum of the phase and the neutral currents were monitored for 3 days. Even though no trips were produced during the time, appreciable phase-neutral residual current was noticed. The sum of the phase and the neutral currents should be zero except in case of a phase-to-ground fault. The problem was traced to a power distribution panel where the neutral bus was also bonded to ground, resulting in residual currents at the main switchboard. Under certain loading conditions, the residual current was high enough to cause the main circuit breaker to trip in a groundfault mode. Once this situation was corrected, the facility experienced no more breaker trips at the main. This is an example of how a particular power quality problem can lead to a solution even when the failure mode cannot be repeated during testing.

Another problem encountered by the author involved trips on a solid-state motor starter, which indicated that the problem was due to a ground fault. The circuit was monitored for a month before any indication of stray ground currents (Figure 9.12) was noticed. If the tests had been discontinued after a week or so, the cause of the trips would have gone undetected, which again emphasizes how difficult it can be to solve power quality problems.

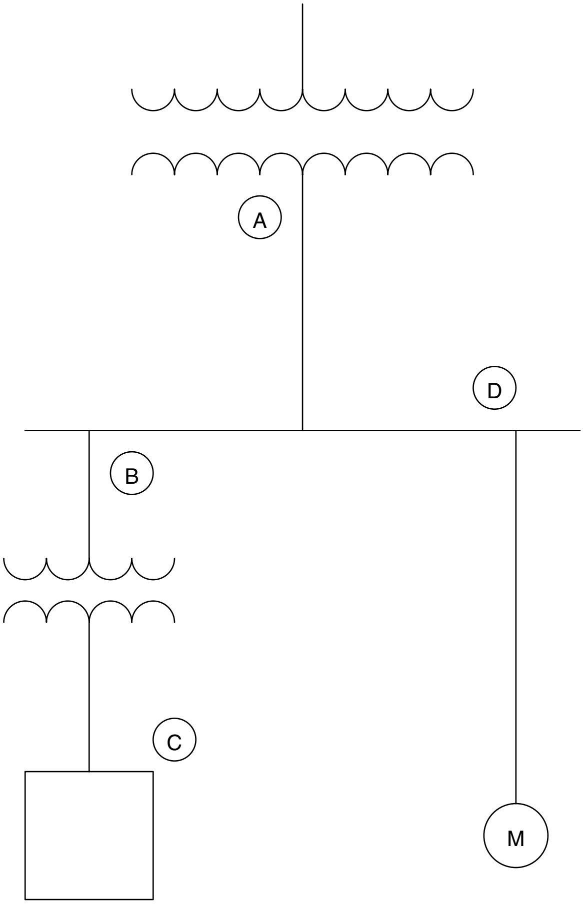
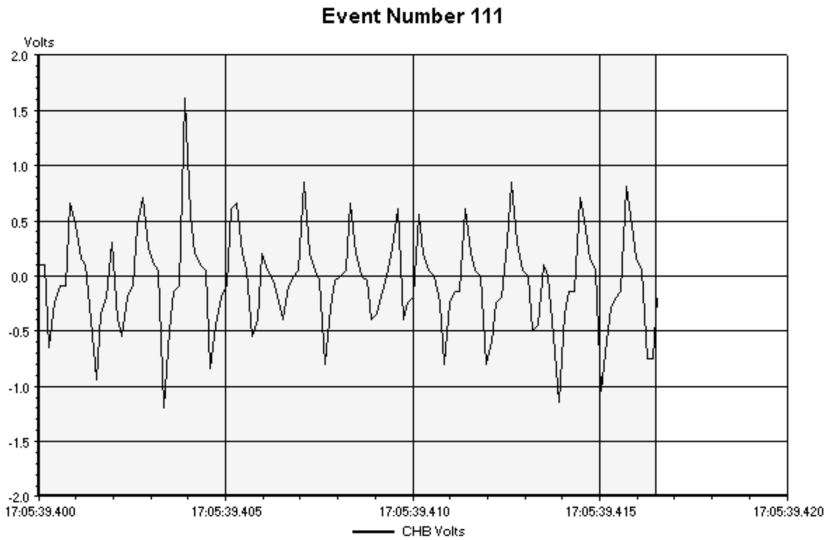


FIGURE 9.11 Test locations for power quality instrumentation.

As a general rule, it is necessary to test each location for at least one week unless results definitely indicate power quality issues at the location that could be causing problems. In such a case, the interval could be shortened. Most power quality issues or tendencies present themselves within this time frame. The actual test durations depend on the experience of the power quality engineers and their comfort level for deriving conclusions based on the data produced. Test duration may be shortened if different power system operating conditions that can cause power system disturbances can be created to generate an adequate amount of data for a solution. Once again, an experienced power quality engineer can help in this process. It is also important to point out that using power quality tendencies to generate conclusions can be risky. This is because under certain conditions more than one power quality problem can produce the same type of symptoms, in which case all possible scenarios should be examined.

Example: A solid-state motor starter was tripping during startup of the motor. Power quality measurements indicated large current draw during the startup. The



CI Impulse event at 01/05/01 17:05:39.40

	PrevRMS	MinRMS	MaxRMS	WorstIMP	Phase	HFHits
AV Volts	117.3	118.3	118.3	0.0	0 deg	0
BV Volts	0.43	0.44	0.44	0.00	0 deg	0
CI Amps	0.026	0.023	0.023	0.140	174 deg	2

FIGURE 9.12 Stray ground current at the output of a motor that caused the adjustable speed drive to shut down. This event was not recorded until a month after the start of the test.

trips were thought to be due to the starting currents, which exceeded the setting of the starter protection. The actual cause, however, was severe undervoltage conditions produced during startup. The source feeding the starter was not a rigid circuit, causing a large voltage drop during motor start. The excessive current draw was due to severe undervoltage conditions. Once the source to the adjustable speed drive was made rigid, the problem disappeared. In this example, measuring only the current input to the adjustable speed drive would have led to inaccurate conclusions.

9.6 INSTRUMENT SETUP

Setting up instruments to collect power quality data is probably the most critical aspect of testing and also one that most often can decide the end results. Setting up is a time when utmost care must be exercised. The first step is making sure to observe certain safety rules. In the majority of cases, power to electrical equipment cannot be turned off to allow for instrument setup. The facility users want as few interruptions as possible, preferably none. Opening the covers of electrical switchboards and distribution panels requires diligence and patience. Personal protective equipment (PPE) is an important component of power quality testing. Minimum PPE should contain electrical gloves, safety glasses, and fire-retardant clothing. While removing panel covers and setting up instrument probes it is important to have someone else present in the room. The second person may not be trained in

FIGURE 9.13 Proper personal protective equipment (PPE), which is essential to performing power quality instrument setup and testing. The photograph shows the use of fire-retardant clothing, safety hat, and shoes. Safety glasses must be worn while connecting instrument probes to the test point. The test location shown here is properly barricaded to prevent unauthorized persons from entering the area.

power quality but should have some background in electricity and the hazards associated with it. Figure 9.13 demonstrates the proper use of PPE for performing power quality work.

9.7 INSTRUMENT SETUP GUIDELINES

Installing power quality instruments and probes requires special care. It is preferred that voltage and current probe leads do not run in close proximity to high-current cables or bus, especially if they are subjected to large current inrush. This can inductively induce voltages in the leads of the probes and cause erroneous data to be displayed. Voltage and current lead runs parallel to high-current bus or cable should be avoided or minimized to reduce the possibility of noise pickup. When connecting voltage probes, the connections must be secure. Loose connections are prone to intermittent contact, which can produce false indications of power quality problems. Voltage and current probe leads should be periodically inspected. Leads with damaged insulation or those that look suspect must be promptly replaced to avoid dangerous conditions. While making current measurements, one of the main causes of errors is improper closing of the jaws of the probe. Substantial errors in current measurements and phase angles can be produced due to air gaps across the jaws of the current probes.

It is important to keep the test location well guarded and secured to prevent unauthorized access. The test locations must be secured with barrier tapes or other means to warn people of the hazards. If power distribution panels or switchboards are monitored, all openings created as the result of instrument setup should be sealed to prevent entry by rodents and other pests. All these steps are necessary to ensure that the tests will be completed without accidents.

9.8 CONCLUSIONS

Measurement of power quality requires the use of proper instrumentation to suit the application. The user of the instrument must be well trained in the use and care of the instrumentation. The engineer should be knowledgeable in the field of power quality. Most importantly, the engineer should be safety conscious. All these factors are equally important in solving power quality problems. As indicated earlier, power quality work requires patience, diligence, and perseverance. It is very rare that the solution to a problem will present itself accidentally, although it does happen occasionally. Power quality work has its rewards. One that the author cherishes the most is the satisfaction of knowing that he has left clients happier than when he first met them.