8.1. Power Quality Measurement

- 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.

8.2. Power Quality Measurement Devices

8.2.1 Harmonic Analysers

- A Harmonic Analysers or harmonic meters are relatively simple instruments for measuring and recording harmonic distortion data. Typically, harmonic Analysers contain a meter with a waveform display screen, voltage leads, and current probes.
- 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.
- 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.
- Harmonic Analysers from various manufacturers tend to have different, upper-harmonic-frequency measurement capability.
- 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 50-Hz fundamental frequency waveform up to the 25th harmonic number, the harmonic measuring instrument must have a minimum sampling rate of 2500 ($25 \times 50 \times 2$) 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 2500 to 5000 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. 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.
- 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.

8.2.2 Transient Disturbance Analysers

- 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 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.
- Equipment that contains power supplies or capacitor filter circuits is especially susceptible to fast rise-time transients with high-frequency content.
- 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.
- 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.

8.2.3 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.
- The pulse-width-modulated waveform of the voltage input to an adjustable speed AC motor, 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.

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

8.2.4 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 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.

8.2.5 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.
- 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.

8.3. 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.

  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.

8.4. 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.

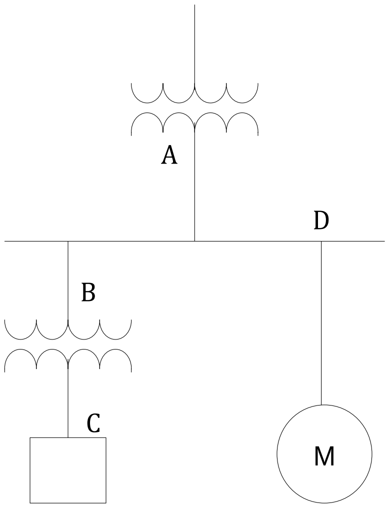

Figure 8.1 Test locations for power quality instrumentation

- 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 8.1, 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.

8.5. Test Duration

- 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.
- 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 trips were thought to be due to the starting currents, which exceeded the setting of the starter protection. The actual cause, however, was severe under voltage 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 under voltage 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.

8.6. 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.
- 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 power quality instrument setup and testing.

8.7. 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.
