

Chapter 5

Conducting On-Site Surveys

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CONDUCTING ON-SITE SURVEYS

Electronic systems and equipment are much more sensitive to power disturbances than conventional electrical equipment. They can experience significant operational problems such as data errors, system interruptions, memory or program loss, and even equipment damage due to power disturbances. In fact, a single power disturbance can cost more in downtime and equipment damage than the investment in power quality protection that would have prevented the disturbance from occurring. Meeting the needs of sensitive equipment often requires surveying the present power distribution system in a building and making appropriate changes.

Survey Objective

In facilities experiencing equipment problems that appear to be power related, on-site surveys generally are required in order to verify that power disturbances are the cause of electronic equipment malfunction or failure. The specific objectives of such a survey, listed in order of priority, follow:

- Determine condition and adequacy of the wiring and grounding system
- Determine ac voltage quality at the point of use
- Determine sources of power disturbances and their impacts of power disturbances on equipment performance
- Analyze findings to identify immediate and long-term cost-effective solutions

Survey procedures employed depend largely on the magnitude and severity of the power quality problems and budgetary limitations. Several types of on-site surveys can be undertaken, ranging from basic to comprehensive. Critical to an effective on-site survey is the order in which problem areas are tested and analyzed. In all cases, power distribution (wiring) and grounding should be tested and analyzed before any testing is conducted to determine ac voltage quality or site environmental parameters (e.g., temperature, humidity, electrostatic discharges, and radiated EMI). Some of these procedures can affect the operation of loads, so they must be carefully coordinated with the customer.

A detailed log of problems should be kept by the customer. If no log exists, encourage the customers to begin logging problems immediately.

Basic Survey

The basic survey only involves testing and analysis of the power distribution and grounding system. Recent EPRI studies indicate that roughly 80% of electronic equipment malfunctions or failures can be attributed to wiring and grounding system problems. (12) Such problems can include loose connections, reversed conductors, and improper or poor quality connections in the wiring and grounding from the power source to the load.

Installation problems such as those listed above are detectable through effective testing and analysis of the wiring and grounding system. However, a single line diagram of the power system supplying the equipment is needed to determine the types of tests needed, as well as the location and quantities of tests. Wiring and grounding tests should be performed by a qualified electrical contractor. A good place to begin testing is the main building service panel or supply transformer. If the quality of the earth ground systems is questionable, an earth ground tester can be used to measure the resistance of the grounding system. Additional tests performed at this location should include RMS voltage levels (phase-to-phase, phase-to-neutral, phase-to-ground, and neutral-to-ground), peak voltage levels, current levels (phase, neutral, and ground), and verification of proper neutral-ground bonding. From this point, each panel in the power distribution system serving the affected equipment should be tested or verified. Tests should include voltages, currents, phase rotation, ground impedance, and neutral impedance. Verification also should include proper isolation of neutral conductor, proper conductor sizing, tightness of connections, and types of loads being served.

Upon completion of the transformer and/or panel testing, it is necessary to verify all branch circuits supplying the sensitive equipment. Verification tests should include voltages, proper conductor termination (wiring errors), the absence of neutral-ground, and isolated ground shorts, as well as measurement ground and neutral impedance levels.

Several measurements and other steps are required to successfully resolve distribution and grounding problems. These are as follows:

- **Initial Physical Site Examination**—Before conducting a survey to identify distribution and grounding problems, an initial physical site examination is recommended. It typically begins at the location of the sensitive electronic load equipment and progresses back to the service entrance through the following sequence: sensitive load equipment, branch circuit wiring, breaker panel, feeder wiring, transformer, main breaker panel, switchboard, and service entrance.

- Sensitive Load Equipment—Start at the load equipment to check the wiring for code violations, adequate insulation, visible damage, miswired connectors (e.g., phase and neutral-reversed or phase sequence reversed); secure connections; and measure the phase, neutral, and ground voltages and currents.
- Breaker Panel—Verify that the breakers in the panel feed the sensitive electronic load. Check that no other loads are on a dedicated circuit. Visually check for any code violations, the use of wire nuts, insulation, other visible damage, and for secure connections. Look for signs of burnt areas or carbonization, which indicate previous faults, flashovers, arcing, etc. Note the size of incoming and outgoing conductors and make sure that they are adequately sized for the load, especially the neutral. Check for shared neutrals and possible overloads with high harmonic loads. Check the temperature of the insulated face of circuit breakers and for visual signs of overheating. Smell the panel, which may indicate overheating conditions. Measure phase, neutral, and ground voltages and currents, as well as the voltage drop across each critical breaker. More than about 0.1-V indicates a possibly bad unit.
- Transformer—Verify that it feeds the electronic load equipment. Record the nameplate data of the transformer. Check the transformer for code violations, connections, and visible damage; primary and secondary conductors, including the neutral and ground; for neutral overheating; and the transformer temperature. Measure and record primary and secondary voltages and currents, including neutral and grounds, as well as the current in the neutral-to-ground bond. If the latter is more than a few hundred milliamperes, additional neutral-to-ground bonds exist. Listen to the transformer for hissing and buzzing noise.
- Main Breaker Panel and Switchboards—Check for code violations, insulation, visible damages, and secure connections. The voltage drop across a breaker when current is flowing through it should not exceed 50 to 100 millivolts. Look for signs of previous faults such as burnt areas, flashovers, arcing, etc. Note the size of incoming and outgoing conductors. Check for visual signs of overheating. Use an infrared camera, if available, for examining the hot spots in the main breaker panel and switchboard.
- Service Entrance—Visually inspect incoming service, including the wiring. Note whether there are demand meters and/or power factor meters. Also determine whether there are switched capacitors for power factor correction in the building or at the service entrance, and whether there are inductive loads regulated by a demand controller.
- Examination of Data—Analyze occurrences of disturbance and the problem log. Is there a correlation with the equipment failure and occurrence of the disturbance? Can the disturbance be correlated with shift changes, machine cycles, air

conditioning cycles, etc.? Are the disturbances of sufficient magnitude to disrupt the sensitive electronic loads? If they are, further examination may be required.

- **Wiring and Grounding**—Wiring and grounding measurements detect problems in the feeders and branch circuits serving the critical load. The test instruments used to conduct these tests should be selected carefully. Commonly available three-light circuit testers should be used with caution. These instruments have limitations and can provide a “correct” indication when the circuit being tested actually has one or more problems. They also are incapable of indicating the integrity of power conductors. Recommended instruments for these measurements include true RMS multimeter, clamp-on ammeter, and ground impedance testers. These are described later in this section.
- **Continuity of Conduit/Enclosure Grounds**—Electronic equipment should be grounded with a separate equipment grounding conductor. This conductor can be terminated in an isolated grounding system, insulated from the conduit ground, or in the conduit ground system. This is because both are ultimately connected to the building ground systems. However, the isolated ground and conduit ground must terminate at the first upstream neutral-ground bonding point. Try to avoid long runs of isolated grounding conductor, as they have significant impedance and this can create noise voltages and possible safety problems.

Ground impedance testers can be used to measure the quality of both the isolated ground and conduit ground systems from the equipment to the power source. To achieve good performance from sensitive electronic loads, phase, neutral, and equipment grounding conductors should be routed through continuously grounded metallic conduit. Continuously grounded metal conduit provides a shield for radiated interference.

Load Phase and Neutral Currents—Measurements of load-phase current and neutral current are necessary to determine whether the load is sharing a neutral conductor with other loads. They also determine whether the neutral conductor sizing is adequate. When sizing neutral conductors, remember that the current in the neutral can exceed current in the phase conductor in three-phase circuits supplying single-phase loads with nonlinear current characteristics. A true RMS reading clamp-on ammeter must be used to make phase and neutral conductor measurements. To determine whether the neutral serving the sensitive electronic load is shared with other loads, check the neutral current with the sensitive load turned off. If the current is not zero, a shared neutral is being used.

- **Transformer Sizing**—Measurements for transformer sizing are necessary to verify that the transformers are sized according to load. Recommended practices for transformer derating for nonlinear loads are discussed in Chapter 6.

- **Neutral-Ground Bonds**—The NEC requires bonding of the neutral and equipment grounding conductor at the main service panel (NEC Article 250-24, -28) and the secondary side of separately derived systems (NEC Article 250-30). If not properly bonded, a significant neutral-ground voltage may occur, possibly creating shock hazards for operating personnel and degrading sensitive electronic equipment performance. These bonds can be detected using a wiring and grounding tester.

A voltage measurement between neutral and ground at the outlets may indicate voltage from a millivolt to few volts range under normal operating conditions. A zero voltage indicates the presence of a nearby neutral-ground bond. Excessive current on equipment grounds in distribution panels also indicates the possibility of a load-side neutral-ground bond. Generally, neutral-to-ground voltage greater than about 2 volts will exceed some manufacturers recommendations; greater than about 4 volts indicates overloaded neutral or wiring problems.

- **Equipment Grounding Conductor Impedance**—Equipment grounding conductor impedance is measured using a ground impedance tester. Properly installed and maintained equipment ground conductors exhibit very low impedance levels. A high impedance measurement indicates poor quality connections in the equipment grounding system or an improperly installed equipment grounding conductor. An “open ground” measurement reveals no equipment grounding conductor connection. Recommended practice is to verify an impedance level of 0.25 ohms or less. This also helps assure personnel protection under fault conditions.
- **Neutral Conductor Impedance**—Neutral conductor impedance is measured because a low impedance neutral is essential to minimize neutral-ground potentials at the load and help reduce common-mode noise. A ground impedance tester can be used to conduct these measurements. It is necessary for neutral conductors to have low impedance.
- **Grounding Electrode Resistance**—The grounding electrode system provides an earth reference point for the facility and a path for lightning and static electricity. The electrode conductor serves as the connection between the building grounding system and the grounding electrode system. An accurate measurement of grounding electrode resistance can be taken only when the grounding electrode is disconnected from all other grounds. This is not recommended for a building in service. For new construction, the resistance of the grounding electrode system is measured with an earth ground tester using the “fall-of-potential” method. It is recommended that the measured resistance be in accordance with the design values and NEC.
- **Current flow in the grounding electrode conductor** can be measured using a clamp-on ammeter. In most cases, small current flow will exist. However, zero current

flow usually indicates an open connection. Current flow on the order of the phase currents indicates serious problems or possible fault conditions.

- **Isolated Ground and Conduit Ground Systems**—The quality of both the isolated ground and conduit ground systems from the equipment to the ground source needs to be measured. This is to ensure that sensitive electronic loads are grounded with a separate equipment grounding conductor and are ultimately connected to the building grounding system. Both ground systems terminate at the first upstream neutral-ground bonding point. The phase, neutral, and equipment grounding conductors should be routed through continuously grounded metallic conduit. As a result, better performance of sensitive electronic equipment is achieved and safety codes are met.
- **Dedicated Feeders and Direct Path Routing**—Measuring phase currents with the critical loads turned off is one way to determine if sensitive electronic loads are being served by dedicated feeders and branch circuits. These should have conductor routing as short and direct as possible. If there is any current flow, the feeder is being used to serve other loads.
- **Separately Derived Systems**—No direct electrical connection should exist in separately derived systems between output and input phase conductors. Separately derived systems are required by the NEC to have a load-side neutral-ground bond connected to the grounding electrode system. All equipment ground conductors, any isolated grounding conductors, neutral conductors, and the metal enclosure of the separately derived systems are required to be bonded together and bonded to the grounding electrode conductor. Visual inspections and measurements with a ground impedance tester can determine the quality of these connections.
- **Documentation**—All survey and test results should be properly recorded to ensure effective data analysis. A standard survey form should be developed. The type of data that needs to be recorded is listed in Table 5-1.
- **Data Analysis and Recommendations Development**— Once testing has been completed, all survey and test data should be analyzed. Computer software packages can simplify this task. Upon completion of this analysis, a formal list of recommendations should be prepared in writing and forwarded to the enduser or individual responsible for implementation of recommendations. Immediate corrective steps must be undertaken to correct any condition(s) found during the on-site survey that represent a serious safety hazard to personnel or equipment.

Intermediate Survey

The intermediate survey involves all procedures described in the basic survey, in addition to the monitoring of ac voltage supplying the affected electronic equipment.

Note, however, the distribution and grounding system must be tested and analyzed before any monitoring is undertaken to determine the quality of ac voltage.

Table 5-1
Typical survey data.

General Data	Transformer Data	Distribution Panel Information	Nature of Problems and Possible Solutions
Site Location Building uses Activity System type	Manufacturer Type Rating (kVA) Primary voltage Secondary voltage Taps and tap position Phase rotation Neutral-to-ground bond Power	Source of power <ul style="list-style-type: none"> • Panel description (manufacturer, model, ampere rating, number of volts, main lugs or main CB, etc.) • Feeder description (size, number of conductors including neutral and ground, etc.) • Branch circuit loads (circuit breaker, size, type of load, number of conductors) • Branch circuit tests (voltage, current, wiring, N/G short, ground z, neutral z) 	Load description (sensitive equipment type, power requirements) Nature of problem Coincidence of events Power quality problem source Site observations and comments Possible solutions

Power Monitoring

Power disturbance monitors typically are used to detect various types of voltage disturbances. Figures 5-1, 5-2, and 5-3 illustrate recommended hookup procedures for power monitors in various applications. Using twisted pair cables for monitor inputs reduces the possibility of picking up radiated RFI/EMI fields. It is also recommended that the monitor be connected in the same mode as the equipment i.e., phase-to-phase or phase-to-neutral.

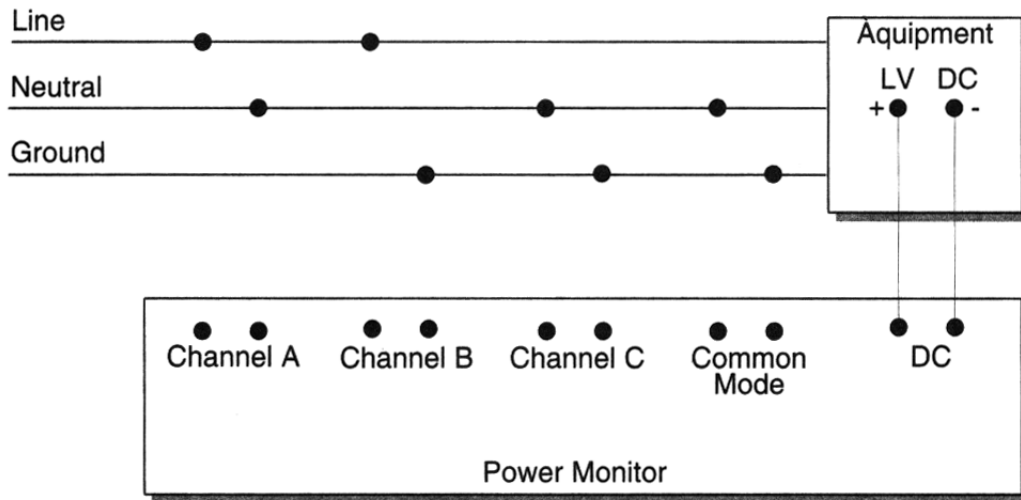


Figure 5-1
Example of power monitor hookup procedure for single-phase application.

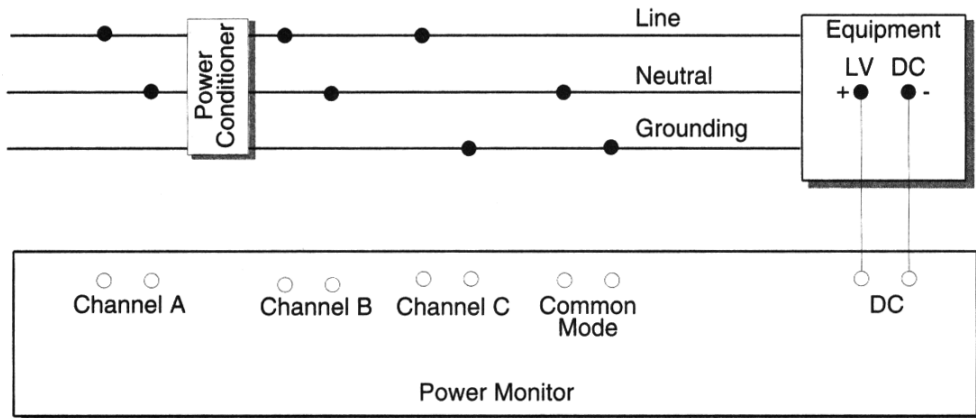


Figure 5-2
Example of power monitor hookup procedure for single-phase application with power conditioner.

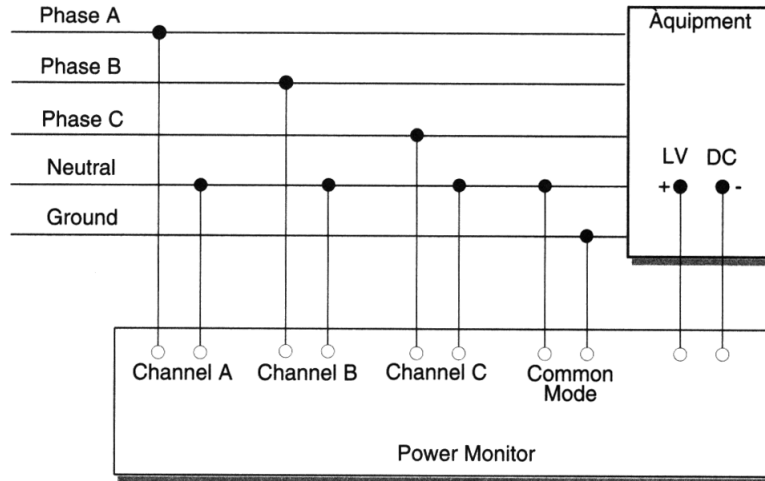


Figure 5-3
Example of three-phase Wye power monitoring.

Input power to the monitor should be provided from a circuit other than the circuit to be monitored. In addition, grounding of the power monitor should be carefully performed. Since a chassis ground is provided through the ac input power cord, any chassis ground connections to the circuit being monitored can create ground loops that result in additional noise being injected on the sensitive equipment feeder. To avoid this problem, it is recommended that no chassis ground connection be made to the circuit being monitored. The instrument manufacturer should be contacted for guidance, as required.

Power monitoring equipment requires selection of thresholds at which disturbances are to be recorded. Thresholds are designed to detect surges that cause component degradation or destruction. If equipment tolerance limits are unknown, a high-voltage threshold of 126 V and a low voltage of 108 V is recommended. However, in most cases, high- and low-voltage thresholds are set slightly within the voltage operating limits of the equipment. This permits detection of voltage levels close to the critical maximum or minimum voltage limits that can result in equipment overstress or failures. For detecting surges if no equipment surge limits are specified, a threshold approximately 100 V-peak could be used. If the monitor has high-frequency noise detection, a 2–3 V-peak threshold should be used for detection of high-frequency noise between the neutral and ground.

Location and duration of power monitoring equipment is also important. It is advantageous to install the monitor at the power panel feeding the system to obtain an overall profile of voltage, particularly at sites that serve several loads. The monitor can

then be relocated to the circuits serving individual loads such as CPUs, disk drives, and other such equipment experiencing malfunctions or failures. Power disturbance sources and solutions can be effectively found when disturbance data is compared.

Recommended practice is that the minimum monitoring period include at least one full business or process cycle, usually one week (7–8 days).

There are limitations on the ability of power monitoring equipment to predict power supply disturbances at a specific location. For example, severe disturbances may occur infrequently or on a seasonal basis. Therefore, monitoring periods of less than a year might produce an inaccurate power disturbance profile. Also, monitoring equipment produce only current information for changes within the site and neighboring sites and does not predict future problems.

Power monitor measurements can be adversely affected by surge protection devices (e.g., varistors) installed in the proximity of the point being monitored. They are affected in the following ways:

- Lower voltage surges are likely to be manifested in locations where voltage surges were previously identified. This assumes that there is no change in the source of the surges. In addition, current surges are likely to occur in the newly installed protective devices and their grounding connection.
- The presence of nearby varistors will change the peaks and waveforms of the observed voltages. If a varistor is located between the source of the surge and the recording instrument, the instrument records the clamping voltage of the varistor. This voltage will have lower peaks but longer time to half-peak than the original surge.
- If the instrument is located between the source of the surge and a varistor, or if a parallel circuit contains a varistor, the instrument records the clamping voltage of the varistor, preceded by a spike corresponding to the inductive drop in the line feeding the surge current to the varistor. If a varistor is connected between the line and neutral conductors, and the surge is impinging between the line and neutral at the service entrance (normal-mode), a new situation is created. The line-to-neutral voltage is clamped as intended; however, the inductive drop in the neutral conductor returning the surge current to the service entrance produces a surge voltage between the neutral and the grounding conductors.

Documentation

In addition to documentation required for the basic survey, information such as the site name, date, circuit being monitored, hookup scheme, and other related data should be recorded at the beginning of data printout from the monitor to facilitate future reference to data. Most monitors can be accessed via an RS-232 port by a remote

terminal or computer. This feature can be very helpful in downloading data, changing thresholds, and performing other functions on several monitors in the field from a single terminal in the office.

Data Analysis and Recommendations Development

The data provided by the power monitor should be carefully analyzed to determine sources of voltage disturbances, as well as cost-effective methods for correction or elimination of disturbances. Although the determination of the power disturbance source(s) is a difficult task, the following guidelines will help:

- If the equipment experiencing malfunction is supplied by an isolation transformer or other power conditioner and disturbances are recorded on the output of the conditioner only, then the conditioner or the equipment may be the source of the disturbance.
- When comparing disturbances on the dc output of the power supply to events on the ac input to the equipment, if no time correlation can be made, the events on the dc channel could be originating at an external device and are being reflected into the system by the data or communication cables. If disturbances are occurring about the same time during the working day, determine what equipment is being operated in the facility at that time. If no time correlation can be obtained, the source of disturbance may be external to the facility.

The recommendations developed based on this survey must highlight the power disturbances being experienced and suggest solutions. However, the recommendations must stress that problems in the power and grounding distribution system must be corrected before problems relating to ac voltage quality are corrected.

Comprehensive Survey

The comprehensive survey involves all procedures described in the basic and intermediate surveys, in addition to monitoring of site environmental parameters. It requires additional measurements for electrostatic discharge, temperature, humidity, and electromagnetic interference (EMI). Measurements may be required at several locations and over a longer period of time. Instruments needed to conduct these measurements are discussed later in this section.

- Documentation—Data collected on site environmental parameters should be properly recorded and categorized to ensure effective analysis.
- Data Analysis and Recommendations Development—Information to be analyzed under this survey includes data collected from both basic and intermediate surveys

as well as data relative to the environmental parameters. Recommendations developed must prioritize actions required to mitigate power disturbance problems.

Instrumentation

Power quality surveys require a variety of instrumentation due to the many different measurements that must be performed. Test instruments recommended for use in each type of survey are summarized in Table 5-2. Note that a multimeter, ammeter, ground impedance tester, and power line monitor are absolutely essential equipment for minimum effective power disturbance detection and analysis.

RMS digital multimeters are used to measure voltage and continuity. Units with the ability to measure peak voltage within a one-millisecond time window are very useful to determine the actual peak voltage of a distorted sine wave. Most power supplies are sensitive to peak voltage, not RMS voltage.

True RMS clamp-on ammeters are used to measure current and analyze current waveforms, particularly when nonsinusoidal waveforms are involved. They are recommended due to their ease of use and broad bandwidth characteristics of transformer-based meter designs. Several types of ammeters are currently available, such as direct-reading and indirect-reading ammeters.

A ground impedance tester is a multifunctional instrument designed to detect wiring and ground problems in low-voltage power distribution systems. Such problems can include wiring errors, neutral ground shorts and reversals, isolated ground shorts, and ground and neutral impedance shorts. Some testers are designed for use on 120-VAC single-phase systems while others can be used on both single- and three-phase systems up to 600 VAC.

An earth ground tester is used to measure the ground electrode impedance. Ground resistance tests should be conducted with a fall-of-potential method instrument. Clamp-on instruments that do not require the grounding electrode to be isolated from the building grounding systems for the test generally are not recommended.

Table 5-2
Typical test instruments for conducting a site survey.

Measurement	Ground Impedance Tester	True RMS Multimeter	True RMS Clamp-on Ammeter	Earth Ground Tester	Oscilloscope with Line Decoupler	Oscilloscope with Current Transducer	Power Disturbance Monitor	Spectrum Analyzer
Conduit/enclosure ground continuity	●	●			●		●	
Load phase and neutral currents			●			●	●	
Natural-ground bonds		●			●		●	
Equipment grounding conductor impedance	●							
Neutral conductor impedance	●							
Grounding electrode conductor integrity			●					
Grounding electrode impedance				●				
Dedicated feeders/direct path routing			●			●	●	
Separately derived system grounding	●	●						
Voltage Disturbances		●			●		●	
Interruptions					●		●	
Frequency variations							●	●
Harmonics							●	●
Electrical noise					●	●	●	●

Oscilloscope

An oscilloscope can be used to a limited extent to detect harmonics in an electrical system. It can also be used to examine the voltage waveform and measure for noise when combined with a line decoupler. In this case, the input is connected to the voltage of interest with the appropriate lead. If a voltage above the range of the oscilloscope is to be examined, probes with resistance-divider networks are available to extend the range of the instrument.

The oscilloscope cannot measure current directly because only a voltage as current passes through the input resistance. Current measurements can be made through use of a current transformer and/or shunt (current-viewing resistor) if a differential input is provided to the oscilloscope. If only a single-ended input is available, the signal is then applied between the high input and the oscilloscope chassis, creating a ground loop. Attempts are then sometimes made to break this ground loop by disconnecting the equipment safety grounding conductor (green wire) of the oscilloscope. This practice, known as floating scope, is a safety risk and must be prohibited.

Power Disturbance Monitors

A power disturbance monitor detects ac (and dc) voltage disturbances. Some monitors can also be used to record current variations, temperature/humidity levels, and other parameters. Time-domain and limited-frequency domain measurements also are possible. These devices provide strip charts of voltage, frequency, impulses, temperature, humidity, etc.

Although developed for the common application of detecting voltage aberrations that affect the operation of electric equipment, power disturbance monitors have many characteristics. Differences include data output, measurement performance, channel capacity, and ancillary features that are of considerable importance to the user. Recording functions of power monitors used in on-site surveys are classified as follows:

- Digital peak recorders—Within this device, the surge is converted to a digital value that is recorded in a buffer memory for later playback, or printed out immediately after it occurs. Early recorders only registered the peak value, while later recorders registered the duration of the surge.
- Oscilloscope with camera—Surges that trigger a single sweep on the cathode ray tube (CRT) of the oscilloscope are recorded by a shutterless camera as they occur. In earlier types of these devices, differential measurements were not allowed.
- Storage screen oscilloscope—This device displays and stores the surge on the CTR.
- Digital storage oscilloscope—This device digitizes and stores the surge in a shift register for subsequent playback and display whenever a preset threshold is exceeded. The oscilloscope also has the capability of displaying events prior to the beginning of the surge.
- Digital waveform recorder—This device digitizes and stores the surge in a manner similar to the digital storage oscilloscope. Because of its data processing functions, which are incorporated in the instrument, the recorder allows reports of many different parameters of the disturbance, relating voltage to time.
- Threshold counters—Applied to a calibrated voltage divider, this device triggers a counter each time a preset voltage is exceeded. Early threshold counters were analog, but recent counters are digital.

Considerable progress has been made in the recording capability of monitoring instruments, primarily as a result of digital hardware and software. Improvements include multi-channel synchronized recording of different parameters, fast data acquisition, automated data reduction, and improved resolution. Some monitors can make simultaneous current and voltage measurements, which are helpful in

determining disturbances direction. Three types of power disturbance monitors are available: text monitors, event indicators, and waveform analyzers.

Spectrum Analyzers

A spectrum analyzer equipped with appropriate measurement capabilities can be used to measure harmonics, electronic noise, and frequency deviations. Special-purpose harmonic meters or low frequency or broad-band spectrum analyzers can also be used to measure these voltage and current disturbances.

Static meters are hand-held devices typically used to measure the electrostatic potential of surfaces. High electrostatic fields can easily damage electronic components.

Psychrometers are used to measure temperature and humidity in the environment, although such measurements can also be made with power monitoring devices equipped with special probes.

A field strength meter equipped with a special probe can be used to measure electric or magnetic field strength.

Infrared detectors can be used to detect overheating of transformers, circuit breakers, and other electrical apparatus.

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