

NFPA[®]

70B

Recommended Practice for Electrical Equipment Maintenance

2019



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NFPA® 70B

Recommended Practice for Electrical Equipment Maintenance

2019 Edition

This edition of NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*, was prepared by the Technical Committee on Electrical Equipment Maintenance and released by the Correlating Committee on National Electrical Code®. It was issued by the Standards Council on November 5, 2018, with an effective date of November 25, 2018, and supersedes all previous editions.

This edition of NFPA 70B was approved as an American National Standard on November 25, 2018.

Origin and Development of NFPA 70B

The National Electrical Code Committee had received several requests to include maintenance recommendations in the *National Electrical Code*® (NEC®). The National Electrical Code Correlating Committee determined that the NEC was not the proper document in which to cover the maintenance of electrical equipment. However, the committee recognized that “lack of maintenance” frequently resulted in serious injuries and fatalities as well as high monetary damage. An ad hoc committee on electrical equipment maintenance was authorized by NFPA in 1967 to determine the need for the development of a document on the subject. The document would give recommendations on the maintenance of various types of electrical installations, apparatus, and equipment usually found in industrial and large commercial-type installations.

The ad hoc committee noted that electrical safety information broke down logically into four main subdivisions: (1) design or product standards, (2) installation standards (the NEC and the *National Electrical Safety Code*®), (3) maintenance recommendations, and (4) use instructions. Work had not yet started on NFPA 70E®, *Standard for Electrical Safety in the Workplace*. In the interest of electrical safety, the committee explored whether something more needed to be done on the maintenance of electrical equipment.

Equipment manufacturers typically provide maintenance needs for specific types of equipment, and general maintenance guidance was available from a number of sources. Therefore, it was determined that compiling that information into a single document under the NFPA procedure in the form of general guidelines was advantageous. To this end, a tentative scope was presented to the NFPA Board of Directors with a recommendation that a committee on electrical equipment maintenance be authorized.

On June 27, 1968, NFPA authorized the establishment of the Committee on Electrical Equipment Maintenance with the following scope: “To develop suitable texts relating to preventive maintenance of electrical systems and equipment used in industrial-type applications with the view of reducing loss of life and property. The purpose is to correlate generally applicable procedures for preventive maintenance that have broad application to the more common classes of industrial electrical systems and equipment without duplicating or superseding instructions that manufacturers normally provide. Reports to the Association through the Correlating Committee of the National Electrical Code Committee.”

In 1973, NFPA 70B-T, *Tentative Recommended Practice for Electrical Equipment Maintenance*, represented the cumulative effort of the committee. The chapters covered “Why an Electrical Preventive Maintenance (EPM) Program Pays Dividends,” “What Is an Effective Electrical Preventive Maintenance Program?,” and “Planning and Developing an Electrical Preventive Maintenance Program.” The document was revised in 1974 to include a chapter on the fundamentals of electrical equipment maintenance, general maintenance requirements for various types of equipment, and a new appendix, “How to Instruct.” The tentative recommended practice was adopted as NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*, in 1975.



For the 1977 edition, titles of added chapters included Electronic Equipment, Ground-Fault Protection, Wiring Devices, and Maintenance of Electrical Equipment Subject to Long Intervals Between Shutdowns. New appendices addressed NEMA plug and receptacle configurations and guidelines for long-term maintenance.

In the 1983 edition, chapters on cable tray systems and on deenergizing and grounding of equipment to provide protection for maintenance personnel were added. An appendix covering equipment storage and maintenance during construction was also added.

The 1987 edition included distribution transformers as well as power transformers.

A chapter on uninterruptible power supply systems was added in the 1990 edition. The chapter Testing and Test Methods was amended by the addition of diagrams of different wave shapes for detecting problems in motors and generators using surge testing.

Three new chapters were added to the 1994 edition to cover power system studies, power quality, and vibration analysis pertaining to rotating machinery. The additions included a table on suggested vibration limits and a vibration severity chart for various-sized machines. Other revisions were made to comply with the NFPA *Manual of Style*.

For the 1998 edition, the chapter on power quality was rewritten and expanded. Maintenance techniques for stationary batteries and infrared inspections were updated and revised. Special handling and disposal considerations were introduced, and employee training was focused to emphasize workplace safety.

The 2002 edition was restructured to comply with the *Manual of Style for NFPA Technical Committee Documents*. The scope was revised to include preventive maintenance for electronic and communications equipment. A chapter was added for grounding provided definitions, symptoms, inspection, testing techniques, and solutions to grounding issues. A new section for gas insulated substations addressed the maintenance issues resulting from regulatory changes in the electrical utility industry.

Charts were added for troubleshooting motor controllers, switchboards, and panelboards. The chapter on power quality was enhanced with information on the latest technology on voltage fluctuation. A new annex suggested maintenance intervals for electrical equipment.

The 2006 edition included a significant change concerning safety. Safety precautions and information in previous editions were dispersed throughout the individual equipment chapters. A new chapter on safety was written and placed up front to provide more complete and updated coverage, as well as to emphasize the importance of safety. Updated test forms, revised testing schedules, and maintenance of supervisory control and data acquisition systems were included. An important part of maintenance is having a properly installed system with baseline performance data, and so a chapter on commissioning the electrical system at a new facility was added. With the industry trend shifted from routine maintenance to reliability-centered maintenance (RCM), a chapter on how to apply RCM and an extensive annex with detailed reliability data on many types of electrical equipment also was added. Information was updated for equipment cleaning, disconnects, busways, vibration testing, lamps, power quality, and rework and recertification of equipment.

The most noticeable change made to the 2010 edition was the reorganization of the document chapters and annexes to group like topics and equipment into a more logical arrangement. Major topic and equipment groupings used in the reorganization included introduction, overview of EPM, electrical systems issues, testing and monitoring, switchgear, cables and wiring, static apparatus, rotating apparatus, and specific-purpose equipment. The annex material was also reorganized using three major groupings that were general information, forms and diagrams, and maintenance. In addition to the reorganization of the document, the chapter on testing and test methods centralized the majority of test procedures formerly located in the individual equipment chapters. The consolidated testing procedures were organized based on equipment type.

A section on emergency preparedness and electrical system and equipment restoration was added to Chapter 6 to respond to the concerns of electrical equipment owners and maintainers. Procedures for emergency shutdown and post-emergency procedures were added to Chapter 6 and related annex material. Chapter 6 also included new material covering outsourcing of electrical equipment maintenance. The requirements on personnel safety were revised to correlate with and directly reference NFPA 70E.

Other changes in 2010 included reorganized recommendations on maintaining SCADA systems, new material on data collection methods, new forms for conducting power quality surveys, and new information on failure mode effects and criticality analysis to support reliability centered maintenance. Significant material supporting reliability centered maintenance was added to Annex N.

In the 2013 edition, new definitions were added for *arc flash hazard* and *arc flash hazard analysis*, both extracted from the 2012 edition of NFPA 70E. Four new chapters were added: Chapter 32, Electrical Disaster Recovery; Chapter 33, Photovoltaic Systems; Chapter 34, Electrical Vehicle Charging Systems; and Chapter 35, Wind Power Electrical Systems and Associated Equipment. New sections addressed counterfeit components, devices, tools, and equipment arc-flash hazard analysis studies; a test or calibration decal system; inspection and testing records; efficiency of lamps and ballasts; and light emitting diode lamps.

Upgrades were made to Chapter 11 sections on acceptance tests, field testing of circuit breakers, and tests for batteries and cables. Information regarding luminaire grounding was added in Chapter 14. The Chapter 15 section on stationary batteries and battery chargers was revised. The visual inspection and electrical testing sections in Chapter 19 were revised.

For the 2016 edition, torque recommendations were added to assist in minimizing electrical issues associated with poor connections, such as overheating, intermittent open circuits, and electrical arcs. Also, battery testing and maintenance recommendations were enhanced to provide greater detail regarding proper battery testing and safety considerations for persons performing battery maintenance.

The 2019 edition incorporates several editorial and stylistic updates to improve the consistency of the document. New references to the IEEE “dot standards” have been added to coordinate with the replacement of the IEEE “color books.” Recommendations for performing a maintenance-related design study correlate with NFPA 70E.

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Committee Scope: This Committee shall have the primary responsibility for documents relating to preventive maintenance of electrical, electronic, and communications systems and equipment used in industrial and commercial type applications with the view of: (1) reducing loss of life and property, and (2) improving reliability, performance, and efficiency in a cost-effective manner. The purpose is to provide generally applicable procedures for preventive maintenance that have broad application to the more common classes of industrial and commercial systems and equipment without duplicating or superseding instructions that manufacturers normally provide. This Committee shall report to Correlating Committee of the National Electrical Code.

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Recommended Practice for

Electrical Equipment Maintenance

2019 Edition

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Annex A.

A reference in brackets [] following a section or paragraph indicates material that has been extracted from another NFPA document. As an aid to the user, the complete title and edition of the source documents for extracts in mandatory sections of the document are given in Chapter 2 and those for extracts in informational sections are given in Annex R. Extracted text may be edited for consistency and style and may include the revision of internal paragraph references and other references as appropriate. Requests for interpretations or revisions of extracted text shall be sent to the technical committee responsible for the source document.

Information on referenced publications can be found in Chapter 2 and Annex R.

Chapter 1 Administration

1.1 Scope.

1.1.1 This recommended practice applies to preventive maintenance for electrical, electronic, and communication systems and equipment and is not intended to duplicate or supersede instructions that manufacturers normally provide. Systems and equipment covered are typical of those installed in industrial plants, institutional and commercial buildings, and large multi-family residential complexes.

1.1.2 Consumer appliances and equipment intended primarily for use in the home are not included.

1.2 Purpose. The purpose of this recommended practice is to reduce hazards to life and property that can result from failure or malfunction of industrial-type electrical systems and equipment.

1.2.1 Chapters 4, 5, and 6 of these recommendations for an effective electrical preventive maintenance (EPM) program have been prepared with the intent of providing a better understanding of benefits, both direct and intangible, that can be derived from a well-administered EPM program.

1.2.2 This recommended practice explains the function, requirements, and economic considerations that can be used to establish such an EPM program.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this recommended practice and should be considered part of the recommendations of this document.

2.2 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 70®, *National Electrical Code*®, 2017 edition.

NFPA 70E®, *Standard for Electrical Safety in the Workplace*®, 2018 edition.

NFPA 110, *Standard for Emergency and Standby Power Systems*, 2019 edition.

NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*, 2017 edition.

NFPA 780, *Standard for the Installation of Lightning Protection Systems*, 2017 edition.

NFPA 791, *Recommended Practice and Procedures for Unlabeled Electrical Equipment Evaluation*, 2018 edition.

NFPA 1600®, *Standard on Continuity, Emergency, and Crisis Management*, 2019 edition.

2.3 Other Publications.

2.3.1 ASTM Publications. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM D92, *Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester*, 2016b.

ASTM D445, *Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids and Calculation of Dynamic Viscosity*, 2017a.

ASTM D664, *Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration*, 2017.

ASTM D877/D877M, *Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes*, 2013.

ASTM D923, *Standard Practices for Sampling Electrical Insulating Liquids*, 2015.

ASTM D924, *Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids*, 2015.

ASTM D971, *Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method*, 2012.

ASTM D974, *Standard Test Methods for Acid and Base Number by Color-Indicator Titration*, 2014e2.

ASTM D1298, *Standard Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method*, 2012b (2017).

ASTM D1500, *Standard Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)*, 2012 (2017).

ASTM D1524, *Standard Test Method for Visual Examination of Used Electrical Insulating Oils of Petroleum Origin in the Field*, 2015.

ASTM D1533, *Standard Test Method for Water in Insulating Liquids by Coulometric Karl Fischer Titration*, 2012.

ASTM D1816, *Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes*, 2012.

ASTM D2129, *Standard Test Method for Color of Clear Electrical Insulating Liquids (Platinum-Cobalt Scale)*, 2017.

ASTM D2472, *Standard Specification for Sulfur Hexafluoride*, 2015.

ASTM D3284, *Standard Practice for Combustible Gases in the Gas Space of Electrical Apparatus Using Portable Meters*, 2005 (2011).

ASTM D3612, *Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography*, 2002 (2009).

2.3.2 EASA Publications. Electrical Apparatus Service Association, Inc., 1331 Baur Blvd, St. Louis, MO 63132.

ANSI/EASA AR100, *Recommended Practice for the Repair of Rotating Electrical Apparatus*, 2015.

2.3.3 IEEE Publications. IEEE, Three Park Avenue, 17th Floor, New York, NY 10016-5997.

IEEE 43, *Recommended Practice for Testing Insulation Resistance of Rotating Machinery*, 2013.

IEEE 80, *Guide for Safety in AC Substation Grounding*, 2013.

IEEE 81, *Guide for Measuring Earth Resistivity, Ground Impedance and Earth Surface Potentials of a Ground System*, 2012.

IEEE 95, *Recommended Practice for Insulation Testing of AC Electric Machinery (2300 V and Above) with High Direct Voltage*, 2002, reaffirmed 2012.

IEEE 141, *Recommended Practice for Electric Power Distribution for Industrial Plants*, 1993, revised 1999.

IEEE 142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems*, 2007, Errata, 2014.

IEEE 241, *Recommended Practice for Electric Power Systems in Commercial Buildings*, 1990.

IEEE 242, *Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems*, 2001, Errata, 2003.

IEEE 399, *Recommended Practice for Industrial and Commercial Power Systems Analysis*, 1997.

IEEE 400, *Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems*, 2012.

IEEE 400.1, *Guide for Field Testing of Laminated Dielectric, Shielded Power Cable Systems Rated 5 kV and Above with High Direct Current Voltage*, 2017.

IEEE 400.2, *Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF) Less Than 1 Hertz*, 2013.

IEEE 400.3, *Guide for Partial Discharge Testing of Shielded Power Cable Systems in a Field Environment*, 2006.

ANSI/IEEE 446, *Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications*, 1995, revised 2000.

ANSI/IEEE 450, *Recommended Practice for Maintenance, Testing and Replacement of Vented Lead-Acid Batteries for Stationary Applications*, 2010.

ANSI/IEEE 493, *Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems*, 2007.

ANSI/IEEE 519, *Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, 2014.

IEEE 1100, *Recommended Practice for Powering and Grounding Electronic Equipment*, 2005.

IEEE 1106, *Recommended Practice for Installation, Maintenance, Testing and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications*, 2015.

IEEE 1159, *Recommended Practice on Monitoring Electric Power Quality*, 2009.

IEEE 1188, *Recommended Practice for Maintenance, Testing and Replacement of Valve-Regulated Lead Acid (VRLA) Batteries for Stationary Applications*, 2005 (r2010 with 2014 amendment).

IEEE 1578, *IEEE Recommended Practice for Stationary Battery Electrolyte Spill Containment and Management*, 2007.

IEEE 1584™, *Guide for Performing Arc Flash Hazards Calculations*, 2002 (with Amendment 1 and 2).

IEEE 1657, *IEEE Recommended Practice for Personnel Qualifications for Installation and Maintenance of Stationary Batteries*, 2009 (2015 amendment).

IEEE 3007.1, *IEEE Recommended Practice for the Operation and Management of Industrial and Commercial Power Systems*, 2010.

IEEE 3007.2, *IEEE Recommended Practice for the Maintenance of Industrial and Commercial Power Systems*, 2010.

IEEE 3007.3, *IEEE Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems*, 2012.

IEEE C2, *National Electrical Safety Code® (NESC®)*, 2017.

ANSI/IEEE C37.13, *Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures*, 2015.

IEEE C37.20.1, *Standard for Metal-Enclosed Low-Voltage (1000 Vac and Below, 3200 Vdc and Below) Power Circuit Breaker Switchgear*, 2015.

IEEE C37.23, *Standard for Metal-Enclosed Bus*, 2015.

IEEE C37.122.1, *IEEE Guide for Gas-Insulated Substations Rated Above 52 kV*, 2014.

IEEE C37.122.5, *Guide for Moisture Measurement and Control SF₆ Gas-Insulated Equipment*, 2013.

ANSI/IEEE C57.104, *Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers*, 2008.

ANSI/IEEE C57.106, *Guide for Acceptance and Maintenance of Insulating Oil in Equipment*, 2015.

ANSI/IEEE C57.110, *Recommended Practice for Establishing Liquid-Filled and Dry-Type Power and Distribution Transformer Capability When Supplying Nonsinusoidal Load Currents*, 2008.

ANSI/IEEE C57.111, *Guide for Acceptance of Silicone Insulating Fluid and Its Maintenance in Transformers*, 2009.

ANSI/IEEE C57.121, *Guide for Acceptance and Maintenance of Less-Flammable Hydrocarbon Fluid in Transformers*, 1998 (2009).

IEEE C57.637, *Guide for the Reclamation of Mineral Insulating Oil and Criteria for its Use*, 2015.

▲ **2.3.4 ITI Publications.** Information Technology Industry Council, 1101 K Street, NW, Suite 610, Washington, DC 20005. www.itic.org.

ITI (CBEMA) Curve Application Note, 2000.

2.3.5 NEMA Publications. National Electrical Manufacturers Association, 1300 North 17th Street, Suite 900, Arlington, VA 22209.

Evaluating Water-Damaged Electrical Equipment, 2016.

Evaluating Fire- and Heat-Damaged Electrical Equipment, 2016.

ANSI/NEMA AB 4, *Guidelines for Inspection and Preventive Maintenance of Molded-Case Circuit Breakers Used in Commercial and Industrial Applications*, 2017.

ANSI/NEMA C84.1, *Electric Power Systems and Equipment, Voltage Ratings (60 Hertz)*, 2016.

NEMA MG 1, *Motors and Generators*, 2017.

ANSI/NEMA PB 2.1, *General Instructions for Proper Handling, Installation, Operation, and Maintenance of Dead Front Distribution Switchboards Rated 600 Volts or Less*, 2013.

ANSI/NEMA WD 6, *Wiring Devices — Dimensional Specifications*, 2016.

2.3.6 NETA Publications. InterNational Electrical Testing Association, 3050 Old Centre Ave., Suite 102, Portage, MI 49024.

ANSI/NETA ATS, *Standard for Acceptance Testing Specifications for Electrical Power Distribution Equipment and Systems*, 2017.

ANSI/NETA MTS, *Standard for Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems*, 2015.

2.3.7 OSHA Publications. Occupational Safety and Health Administration, 200 Constitution Ave., NW, Washington, DC 20210.

OSHA Safety & Health Information Bulletin (SHIB), “Certification of Workplace Products by Nationally Recognized Testing Laboratories,” 02-16-2010.

▲ **2.3.8 UL Publications.** Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

ANSI/UL 489, *Molded-Case Circuit Breakers, Molded-Case Switches and Circuit Breaker Enclosures*, 2016.

UL 1066, *Standard for Low-Voltage AC and DC Power Circuit Breakers Used in Enclosures*, 2012.

UL 1436, *Outlet Circuit Testers and Similar Indicating Devices*, 2016.

UL Firefighter Safety and Photovoltaic Installations Research Project, November 2011.

▲ **2.3.9 U.S. Government Publications.** U.S. Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401-0001.

Energy Policy Act of 1992, HR 776, 102nd Congress, 10/24/1992.

Federal Emergency Management Agency (FEMA), FEMA P-348, *Protecting Building Utilities from Flood Damage*, 1999 updated 2012.

Title 15, *United States Code*, Chapter 53, Toxic Substances Control Act, Environmental Protection Agency.

Title 29, *Code of Federal Regulations*, Part 1910.

Title 29, *Code of Federal Regulations*, Part 1910.94(a), “Occupational Health and Environmental Control — Ventilation.”

Title 29, *Code of Federal Regulations*, Part 1910.146, “Permit-Required Confined Spaces.”

Title 29, *Code of Federal Regulations*, Part 1910.242(b), “Hand and Portable Powered Tools and Other Hand Held Equipment.”

Title 29, *Code of Federal Regulations*, Part 1910.269, “Electric Power Generation, Transmission, and Distribution,” Paragraph (e), Enclosed Spaces.

Title 29, *Code of Federal Regulations*, Part 1926.

Title 40, *Code of Federal Regulations*, Part 761, “Protection of Environment — Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions.”

TM 5-694, *Commissioning of Electrical Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities*, 2006.

TM 5-698-1, *Reliability/Availability of Electrical and Mechanical Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities*, 2007.

TM 5-698-2, *Reliability-Centered Maintenance (RCM) for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities*, 2006.

TM 5-698-3, *Reliability Primer for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities*, 2005.

U.S. General Services Administration and U.S. Department of Energy, *Building Commissioning Guide*, 2009.

▲ **2.3.10 Other Publications.**

ABB Power T & D Company, Inc., *Instruction Book PC-2000 for WecolTM Fluid-Filled Primary and Secondary Unit Substation Transformers*.

Merriam-Webster’s Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2003.

Penn-Union Catalog, www.penn-union.com/Services/Literature.

PowerTest Annual Technical Conference, Flood Repair of Electrical Equipment, Pat Beisert, Shermco Industries, March 12, 2009.

Square D Catalog, Schneider Electric, www.schneider-electric.com/us.

Square D Services, *Procedures for Startup and Commissioning of Electrical Equipment*, PDF available at www.schneider-electric.us/en/download/document/0180IB0001

2.4 References for Extracts in Recommendations Sections.

NFPA 70®, *National Electrical Code*®, 2017 edition.

NFPA 70E®, *Standard for Electrical Safety in the Workplace*®, 2018 edition.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter apply to the terms used in this recommended practice. Where terms are not defined in this chapter or within another chapter, they should be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate Dictionary*, 11th edition, is the source for the ordinarily accepted meaning.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

3.2.3* Listed. Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

3.2.4 Recommended Practice. A document that is similar in content and structure to a code or standard but that contains only nonmandatory provisions using the word “should” to indicate recommendations in the body of the text.

3.2.5 Should. Indicates a recommendation or that which is advised but not required.

3.3 General Definitions.

Δ 3.3.1 Arc Flash Hazard. A source of possible injury or damage to health associated with the release of energy caused by an electric arc. [70E, 2018]

3.3.2 Bonding (Bonded). The permanent joining of metallic parts to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct safely any current likely to be imposed. The “permanent joining” can be accomplished by the normal devices used to fasten clean, noncorroded parts together. Machine screws, bolts, brackets, or retainers necessary to allow equipment to function properly are items typically employed for this purpose. While welding and

brazing can also be utilized, these preclude easy disassembly, and welding can increase rather than decrease resistance across joints. Metallic parts that are permanently joined to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct safely any current likely to be imposed are bonded.

3.3.3 Bonding Jumper. A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected. This conductor can be solid or stranded or braided, and connected by compatible fittings to separate parts to provide this electrically conductive path. The bonding jumper can also be a screw or a bolt. This bonding jumper can be used alone or in conjunction with other electrically conductive paths. It generally is associated with the equipment-grounding path, but might or might not be electrically linked for a lowest impedance path.

3.3.4 Case (Enclosure) Ground. See 3.3.39, Grounding Terminal.

3.3.5 Central Grounding Point. The location where the interconnected parts of the grounding system are connected in a common enclosure. The central grounding point provides a common connection point for termination of the feeder or branch-circuit equipment-grounding conductors.

3.3.6 Commissioning. A qualitative and quantitative process used to: (1) develop procedures to verify and document functional system-level and component-level requirements; (2) develop a testing and operational tune-up (system and component final adjustment) plan; (3) determine and record baseline information for operation and maintenance procedures; (4) evaluate initial system performance results and measurements.

3.3.7 Common Mode Noise. See 3.3.53.1.

3.3.8 Concurrent Maintenance. The testing, troubleshooting, repair, and/or replacement of a component or subsystem while redundant component(s) or subsystem(s) are serving the load, where the ability to perform concurrent maintenance is critical to attaining the specified reliability/availability criteria for the system or facility.

3.3.9 Continuous Duty. See 3.3.15.1.

3.3.10 Coordination (Selective). Localization of an overcurrent condition to restrict outages to the circuit or equipment affected, accomplished by the selection and installation of overcurrent protective devices and their ratings or settings or the full range of available overcurrents, from overload to the maximum available fault current, and for the full range of overcurrent protective device opening times associated with those overcurrents. [70, 2017]

3.3.11 Coordination Study. A system planning process used to assist in selecting and setting protective devices to improve power system reliability.

3.3.12* Corona. An electrical discharge phenomenon occurring in gaseous substances, such as air.

3.3.13 Counterpoise. A conductor or system of conductors arranged beneath the transmission/distribution supply line; located on, above, or most frequently below the surface of the earth; and connected to the grounding system of the towers or poles supporting the line. (This conductor(s) might or might not be the continuous length of the supply path. It is often used to provide a lower surge impedance path to earth for

lightning protection when there is a transition from overhead supply conductors to underground insulated cable.) Counterpoise is also used in communication systems, where it is a system of conductors, physically elevated above and insulated from the ground, forming a lower system of conductors of an antenna. Note that the purpose of a counterpoise is to provide a relatively high capacitance and thus a relatively low impedance path to earth. The counterpoise is sometimes used in medium- and low-frequency applications where it would be more difficult to provide an effective ground connection. Sometimes counterpoise is confused with equipotential plane. (See also 3.3.28, *Equipotential Plane*.)

3.3.14 Down Conductor. A conductor from a lightning protection system to earth ground designed to provide a low impedance path for the current from a lightning strike and/or dissipate the charge buildup that precedes a lightning strike. This conductor typically goes from the air terminals to earth. Due to the very high currents at very high frequencies, the impedance of the entire system is very critical. Normal wiring conductors are not suitable for the down conductor. Typically, they are braided conductors. There might be certain instances where additional investigation about the interconnection between the lightning and the grounding electrode system is warranted.

3.3.15 Duty.

3.3.15.1 Continuous Duty. Operation at a substantially constant load for an indefinitely long time.

3.3.15.2 Intermittent Duty. Operation for alternate intervals of (1) load and no load; (2) load and rest; and (3) load, no load, and rest.

3.3.15.3 Periodic Duty. Intermittent operation in which the load conditions are regularly recurrent.

3.3.15.4 Short-Time Duty. Operation at a substantially constant load for a short and definitely specified time.

3.3.15.5 Varying Duty. Operation at loads, and for intervals of time, both of which might be subject to wide variation.

3.3.16 Earth Grounding. The intentional connection to earth through a grounding electrode of sufficiently low impedance to minimize damage to electrical components and prevent an electric shock that can occur from a superimposed voltage from lightning and voltage transients. In addition, earth grounding helps prevent the buildup of static charges on equipment and material. It also establishes a common voltage reference point to enable the proper performance of sensitive electronic and communications equipment.

3.3.17 Earthing. An IEC term for *ground*. (See 3.3.29, *Ground*.)

3.3.18 Effective Grounding Path. The path to ground from circuits, equipment, and metal enclosures for conductors shall (1) be permanent and electrically continuous, (2) have capacity to conduct safely any fault current likely to be imposed on it, and (3) have sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit protection devices. The earth should not be used as the sole equipment-grounding conductor.

3.3.19 Effectively Grounded (as applied to equipment or structures). Intentionally connected to earth (or some conducting body in place of earth) through a ground connection or connections of sufficiently low impedance and having sufficient

current-carrying capacity to prevent the buildup of voltages that might result in undue hazards to connected equipment or to persons.

3.3.20 Effectively Grounded (as applied to systems). This is defined by ratios of impedance values that must be within prescribed limits.

3.3.21 Electrical Equipment. A general term applied to the material, fittings, devices, fixtures, and apparatus that are part of, or are used in connection with, an electrical installation and includes the electrical power-generating system; substations; distribution systems; utilization equipment; and associated control, protective, and monitoring devices.

3.3.22* Electrical Preventive Maintenance (EPM). A managed program of inspecting, testing, analyzing, and servicing electrical systems and equipment with the purpose of maintaining safe operations and production by reducing or eliminating system interruptions and equipment breakdowns.

3.3.23 Electrostatic Discharge (ESD) Grounding. The conductive path created to reduce or dissipate the electrostatic charge where it builds up as a result of equipment operation or induced from an electrostatically charged person or material coming in contact with the equipment. Also referred to as *static grounding*.

3.3.24 Equipment Bonding Jumper. The connection between two or more portions of the equipment-grounding conductor.

3.3.25 Equipment Ground. An ambiguous term that can mean either case ground, equipment-grounding conductor or equipment bonding jumper; hence, use of this term should be avoided.

3.3.26 Equipment-Grounding Conductor. The conductor used to connect the noncurrent-carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor, the grounding electrode conductor, or both, at the service equipment or at the source of a separately derived system.

3.3.27 Equipotential Bonding. Electrical connection putting various exposed conductive parts and extraneous conductive parts at a substantially equal potential.

3.3.28 Equipotential Plane. (1) (as applied to livestock) An area accessible to livestock where a wire mesh or other conductive elements are embedded in concrete, are bonded to all metal structures and fixed nonelectrical metal equipment that might become energized, and are connected to the electrical grounding system to prevent a difference in voltage from developing within the plane. (2) (as applied to equipment) A mass or masses of conducting material that, when bonded together, provide a uniformly low impedance to current flow over a large range of frequencies. Sometimes the equipotential plane is confused with counterpoise.

3.3.29 Ground. The earth. [70, 2017]

3.3.29.1 Lightning Ground. See 3.3.38, Grounding Electrode System.

3.3.29.2 Noise(less) Ground. The supplemental equipment-grounding electrode installed at machines, or the isolated equipment-grounding conductor, intended to reduce electrical noise.

3.3.29.3 Personnel Protective Ground. Bonding jumper that is intentionally installed to ground deenergized, normally ungrounded circuit conductors when personnel are working on them, to minimize voltage differences between different parts of the equipment and personnel, so as to protect against shock hazard and/or equipment damage.

3.3.29.4 Safety Ground. See 3.3.29.3, Personnel Protective Ground.

3.3.30 Grounded (Grounding). Connected (connecting) to ground or to a conductive body that extends the ground connection. [70, 2017]

3.3.31 Grounded Conductor. A system or circuit conductor that is intentionally grounded. This intentional grounding to earth or some conducting body that serves in place of earth takes place at the premises service location or at a separately derived source. Control circuit transformers are permitted to have a secondary conductor bonded to a metallic surface that is in turn bonded to the supply equipment-grounding conductor. Examples of grounded system conductors would be a grounded system neutral conductor (three phase or split phase) or a grounded phase conductor of a 3-phase, three-wire, delta system.

3.3.32 Ground Fault. Unintentional contact between an ungrounded conductor and earth or conductive body that serves in place of earth. Within a facility, this is typically a fault between a current-carrying conductor and the equipment-grounding path that results in the operation of the overcurrent protection.

3.3.33* Ground-Fault Circuit Interrupter (GFCI). A device intended for the protection of personnel that functions to deenergize a circuit or portion thereof within an established period of time when a current to ground exceeds the values established for a Class A device. [70, 2017]

3.3.34* Ground-Fault Protection of Equipment (GFP). A system intended to provide protection of equipment from damaging line-to-ground fault currents by operating to cause a disconnecting means to open all ungrounded conductors of the faulted circuit. This protection is provided at current levels less than those required to protect conductors from damage through the operation of a supply circuit overcurrent device. [70, 2017]

3.3.35 Grounding.

3.3.35.1 Multipoint Grounding. Multipoint grounding consists of interconnecting primary and secondary neutrals of the transformer. The secondary and primary neutral are common, and they both utilize the same grounding electrode that connects the system to earth.

3.3.35.2 Single-Point Grounding. The single-point grounding of a transformer means connecting the secondary side of the transformer to earth ground through one or more grounding electrodes. This connection should be made at any point on the separately derived system from the source to the first system-disconnecting means or overcurrent device.

3.3.35.3 System Grounding. The intentional connection of an electrical supply system to its associated grounding electrode(s).

3.3.36 Grounding Electrode. A conductive body deliberately inserted into earth to make electrical connection to earth. Typical grounding electrodes include the following: (1) The nearest effectively grounded metal member of the building structure (2) The nearest effectively grounded metal water pipe, but only if the connection to the grounding electrode conductor is within 5 ft of the point of entrance of the water pipe to the building (3) Any metal underground structure that is effectively grounded (4) Concrete encased electrode in the foundation or footing (e.g., Ufer ground) (5) Ground ring completely encircling the building or structure (6) Made electrodes (e.g., ground rods or ground wells) (7) Conductive grid or mat used in substations.

3.3.37 Grounding Electrode Conductor. The conductor used to connect the grounding electrode to the equipment-grounding conductor, to the grounded conductor, or to both, of the circuit at the service equipment or at the source of a separately derived system. This conductor must be connected to provide the lowest impedance to earth for surge current due to lightning, switching activities from either or both of the supply and load side, and to reduce touch potentials when equipment insulation failures occur.

3.3.38 Grounding Electrode System. The interconnection of grounding electrodes.

3.3.39 Grounding Terminal. A terminal, lug, or other provision provided on some equipment cases (enclosures) to connect the conductive portion of the enclosure to the equipment-grounding conductor.

3.3.40 Grounding-Type Receptacle. A receptacle with a dedicated terminal that is to be connected to the equipment grounding conductor.

3.3.41 Ground Leakage Current. Current that is introduced into the grounding conductor by normal equipment operation, such as capacitive coupling. Many RFI/EMI filters in electronic equipment have capacitors from current-carrying conductors to the equipment-grounding conductor to shunt noise emitted from or injected into their power supplies. While there are relatively low current level limits imposed by regulatory agencies (e.g., UL specifies maximum 3.5 mA, hospital equipment 0.5 mA), not all equipment is listed. Even with listed equipment, the sum of the current from a large quantity of such equipment in a facility can result in significant ground currents.

3.3.42 Ground Loop. Multiple intentional or unintentional connections from a conductive path to ground or the conductive body that serves in place of earth. Current will flow in the ground loop if there is voltage difference between the connection nodes. Regrounding of the grounded circuit conductor (neutral) beyond the service point will result in ground loops. This might or might not be harmful depending on the application.

3.3.43 Ground Resistance/Impedance Measurement. The use of special test equipment to measure the grounding electrode resistance or impedance to earth at a single frequency at or near power line frequency.

3.3.44 Ground Well. See 3.3.38, Grounding Electrode System.

3.3.45 Harmonics. Those voltages or currents whose frequencies are integer multiples of the fundamental frequency.

3.3.46 Interharmonics. Not all frequencies that occur on an electrical power system are integer multiples of the fundamental frequency (usually 60 Hz), as are harmonics. Some loads draw currents that result in voltages that are between harmonic frequencies or less than the fundamental frequency. These frequencies are referred to as interharmonics and can be made of discrete frequencies or as a wide-band spectrum. A special category of these interharmonics is called subharmonics, in which the frequencies involved are less than the fundamental power line frequency.

3.3.47 Intermittent Duty. See 3.3.15.2.

3.3.48 Isolated Equipment-Grounding Conductor. An insulated equipment-grounding conductor that has one intentional connection to the equipment-grounding system. The isolated equipment-grounding conductor is typically connected to an equipment-grounding terminal either in the facility's service enclosure or in the first applicable enclosure of a separately derived system. The isolated equipment-grounding conductor should be connected to the equipment-grounding system within the circuits' derived system.

3.3.49 Labeled. Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner. [70, 2017]

3.3.50 Lightning Ground. See 3.3.29.1.

3.3.51 Long Duration Undervoltage. A decrease of the supply voltage to less than 90 percent of the nominal voltage for a time duration greater than 1 minute. [See IEEE 1159, *Recommended Practice on Monitoring Electric Power Quality*, Table 4-2.]

3.3.52 Multipoint Grounding. Multipoint grounding consists of interconnecting primary and secondary neutrals of the transformer. The secondary and primary neutral are common, and they both utilize the same grounding electrode that connects the system to earth.

3.3.53 Noise. Undesirable electrical signals in an electrical or electronic circuit.

3.3.53.1 Common Mode Noise. Undesirable electrical signals that exist between a circuit conductor and the grounding conductor.

3.3.53.2 Transverse Mode Noise. Undesirable electrical signals that exist between a pair of circuit conductors. These signals are sometimes referred to as normal or differential mode noise.

3.3.54 Noise(less) Ground. See 3.3.29.2.

3.3.55 Periodic Duty. See 3.3.15.3.

3.3.56 Personnel Protective Ground. See 3.3.29.3.

3.3.57 Power Transformers. Determines the type of transformer and is defined as those larger than 500 kVA, while distribution transformers are those 500 kVA or smaller.

3.3.58 Protective Bonding Circuit. See 3.3.27, Equipotential Bonding.

3.3.59 Protective Conductor. A conductor required by some measures for protection against electric shock for electrically connecting any of the following parts: exposed conductive parts, extraneous conductive parts, or main (grounding) earthing terminal. Also identified in some instances as the protective external (PE) conductor. (See also 3.3.26, *Equipment-Grounding Conductor*.)

3.3.60 Protective Ground. See 3.3.27, Equipotential Bonding.

3.3.61 Qualified Person. One who has the skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training on the hazards involved.

3.3.62 RFI/EMI Grounding. See 3.3.41, Ground Leakage Current.

3.3.63 Risk Assessment. An overall process that identifies hazards, estimates the likelihood of occurrence of injury or damage to health, estimates the potential severity of injury or damage to health, and determines if protective measures are required. [70E, 2018]

3.3.64 Safety Ground. See 3.3.29.3, Personnel Protective Ground.

3.3.65 Sag. A decrease to between 10 percent and 90 percent of the normal voltage at the power frequency for durations of 0.5 cycle to 1 minute. (If the voltage drops below 10 percent of the normal voltage, then this is classified as an interruption.) It is further classified into three categories: (1) instantaneous — 0.5 cycle to 30 cycles; (2) momentary — 30 cycles to 3 seconds; and (3) temporary — 3 seconds to 1 minute.

3.3.66 Separately Derived System. A premises wiring system whose power is derived from a battery, a solar photovoltaic system, or from a generator, transformer, or converter windings, and that has no direct electrical connection, including a solidly connected grounded circuit conductor, to supply conductors originating in another system. Equipment-grounding conductors are not supply conductors and are to be interconnected.

3.3.67 Short-Time Duty. See 3.3.15.4.

3.3.68 Single-Point Grounding. See 3.3.35.2.

3.3.69 Substation Ground. Grounding electrode system (grid) in a substation. (See 3.3.38, *Grounding Electrode System*.)

3.3.70 Survey. The collection of accurate data on the electrical system and the evaluation of this data to obtain the necessary information for developing the EPM program. The systems and equipment covered in specific parts of the survey should be based on logical divisions of the electrical system.

3.3.71 Sustained Voltage Interruption. The loss of the supply voltage to less than 10 percent on one or more phases for a period greater than 1 minute.

3.3.72 Swell. An increase to between 110 percent and 180 percent in normal voltage at the power frequency durations from 0.5 cycle to 1 minute. It is further classified into three categories: (1) instantaneous — 0.5 cycle to 30 cycles; (2) momentary — 30 cycles to 3 seconds; and (3) temporary — 3 seconds to 1 minute.

3.3.73 System Grounding. See 3.3.35.3.

3.3.74 Transformer. A device for changing energy in an alternating current system from one voltage to another; usually includes two or more insulated coils on an iron core.

3.3.75 Transients. Transients (formerly referred to as surges, spikes, or impulses) are very short duration, high amplitude excursions outside of the limits of the normal voltage and current waveform. Waveshapes of the excursions are usually unidirectional pulses or decaying amplitude, high frequency oscillations. Durations range from fractions of a microsecond to milliseconds, and the maximum duration is in the order of one half-cycle of the power frequency. Instantaneous amplitudes of voltage transients can reach thousands of volts.

3.3.76 Transverse Mode Noise. See 3.3.53.2.

3.3.77 Unbalanced Voltages. Unequal voltage values on 3-phase circuits that can exist anywhere on the power distribution system.

3.3.78 Varying Duty. See 3.3.15.5.

Chapter 4 Why an Effective Electrical Preventive Maintenance (EPM) Program Pays Dividends

4.1 Why EPM?

4.1.1 Electrical equipment deterioration is normal, and equipment failure is inevitable. However, equipment failure can be delayed through appropriate EPM. As soon as new equipment is installed, a process of normal deterioration begins. Unchecked, the deterioration process can cause malfunction or an electrical failure. Deterioration can be accelerated by factors such as a hostile environment, overload, or severe duty cycle. An effective EPM program identifies and recognizes these factors and provides measures for coping with them.

4.1.2 In addition to normal deterioration, other potential causes of equipment degradation can be detected and corrected through EPM. Among these are load changes or additions, circuit alterations, improperly set or improperly selected protective devices, and changing voltage conditions.

4.1.3 Without an EPM program, management assumes a greatly increased risk of a serious electrical failure and its consequences.

4.2 Value and Benefits of a Properly Administered EPM Program.

4.2.1 A well-administered EPM program reduces accidents, saves lives, and minimizes costly breakdowns and unplanned shutdowns of production equipment. Impending troubles can be identified — and solutions applied — before they become major problems requiring more expensive, time-consuming solutions.

4.2.2 Benefits of an effective EPM program fall into two general categories. Direct, measurable economic benefits are derived from reduced cost of repairs and reduced equipment downtime. Less measurable but very real benefits result from improved safety. To understand fully how personnel and equipment safety are served by an EPM program, the mechanics of the program — inspection, testing, and repair procedures — should be understood. Such an understanding explains other intangible benefits such as improved employee morale, better workmanship and increased productivity, reduced absenteeism, reduced interruption of production, and improved insurance

considerations. Improved morale comes with employee awareness of a conscious management effort to promote safety by reducing the likelihood of electrical injuries or fatalities, electrical explosions, and fires. Reduced personnel injuries and property loss claims can help keep insurance premiums at favorable rates.

4.2.3 Some of the benefits that result from improved safety are difficult to measure. However, direct and measurable economic benefits can be documented by equipment repair cost and equipment downtime records after an EPM program has been implemented.

4.2.4 Dependability can be engineered and built into equipment, but effective maintenance is required to keep it dependable. Experience shows that equipment is reduced when it is covered by an EPM program. In many cases, the investment in EPM is small compared with the cost of accidents, equipment repair, and the production losses associated with unexpected outages.

4.2.5 Careful planning is the key to the economic success of an EPM program. With proper planning, maintenance costs can be held to a practical minimum, while production is maintained at a practical maximum.

4.2.6 An EPM program requires the support of top management, because top management provides the funds that are required to initiate and maintain the program. The maintenance of industrial electrical equipment is essentially a matter of business economics. Maintenance costs can be placed in either of two basic categories: preventive maintenance or breakdown repairs. The money spent for preventive maintenance will be reflected as less money required for breakdown repairs. An effective EPM program holds the sum of these two expenditures to a minimum. Figure 4.2.6 is a typical curve illustrating this principle. According to this curve, as the interval of time between EPM inspections increases, the cost of the EPM diminishes and the cost of breakdown repairs and replacement of failed equipment increases. The lowest total annual expense is realized by maintaining an inspection frequency that keeps the sum of repair/replacement and EPM costs at a minimum.

4.2.7 An EPM program is a form of protection against accidents, lost production, and loss of profit. An EPM program

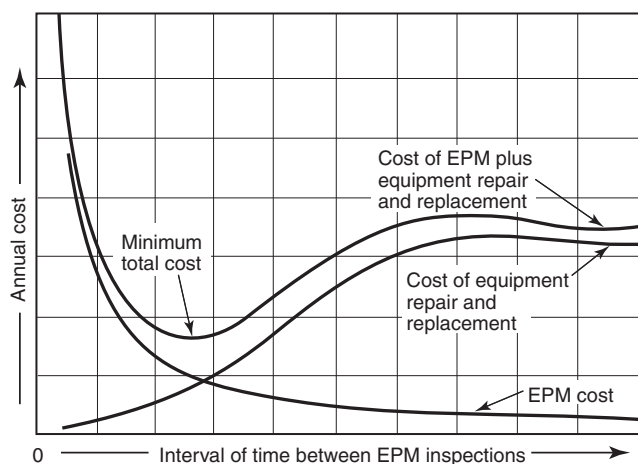


FIGURE 4.2.6 Effect of EPM Inspection Frequency on Overall Costs.

enables management to place a monetary value on the cost of such protection. An effective EPM program satisfies an important part of management's responsibility for keeping costs down and production up.

4.2.8* Insurance statistics document the high cost of inadequate electrical maintenance.

4.3 EPM and Energy Conservation. Energy conservation is one of the worthwhile benefits associated with an EPM program, saving money and vital resources. Equipment that is well maintained operates more efficiently and utilizes less energy.

4.4 Case Histories. Case histories should be utilized to educate workers and management on the positive results of proper, regular maintenance as well as the negative consequences that might result by lack of or improper maintenance. (See Annex Q for case histories.)

Chapter 5 What Is an Effective Electrical Preventive Maintenance (EPM) Program?

5.1 Introduction. An effective electrical preventive maintenance (EPM) program should enhance safety and also reduce equipment failure to a minimum consistent with good economic judgment.

5.2 Essential Elements of an EPM Program. An EPM program should consist of the following essential elements:

- (1) Responsible and qualified personnel
- (2) Regularly scheduled inspection, testing, and servicing of equipment
- (3) Survey and analysis of electrical equipment and systems to determine maintenance requirements and priorities
- (4) Programmed routine inspections and suitable tests
- (5) Accurate analysis of inspection and test reports so that proper corrective measures can be prescribed
- (6) Performance of necessary work
- (7) Concise but complete records

5.3 Planning an EPM Program. The following factors should be considered in the planning of an EPM program.

- (1) *Personnel Safety:* Will an equipment failure endanger or threaten the safety of any personnel? What can be done to ensure personnel safety?
- (2) *Equipment Loss:* Is installed equipment — both electrical and mechanical — complex or so unique that required repairs would be unusually expensive?
- (3) *Production Economics:* Will breakdown repairs or replacement of failed equipment require extensive downtime? How many production dollars will be lost in the event of an equipment failure? Which equipment is most vital to production?

5.4 Personnel.

5.4.1 A well-qualified individual should be in charge of the program. (See 6.1.3.2.)

5.4.2 Personnel assigned to electrical preventive maintenance duties should be selected from the most technically qualified personnel in the plant.

5.4.3 Where in-plant personnel are not qualified, a technically competent maintenance contractor should be employed.

5.5 Survey and Analysis.

5.5.1 Survey and analysis should cover equipment and systems that have been determined to be essential in accordance with a priority plan.

5.5.2 Regardless of the size of the program being contemplated, the EPM supervisor should determine the scope of the work to be done and where to begin.

5.5.3 All electrical equipment — such as motors, transformers, circuit breakers, and controls — should receive a thorough inspection and evaluation to permit the EPM supervisor to make a qualified judgment as to how, where, and when each piece of equipment should fit into the program.

5.5.4 In addition to determining the equipment's physical condition, the survey should determine if the equipment is operating within its rating, and how the load level could affect the frequency of maintenance.

5.5.5 It should be stressed that environmental or operating conditions of a specific installation should be considered and might dictate a different frequency of maintenance.

5.5.6 In the course of the survey, the condition of electrical protective devices such as fuses, circuit breakers, protective relays, and motor overload relays should be checked. These devices are the safety valves of an electrical system, and their proper operation ensures the safety of personnel, protection of equipment, and reduction of economic loss.

5.5.7 After the survey has been completed, data should be evaluated to determine equipment condition. Equipment condition will reveal repair work to be done, as well as determine the nature and frequency of required inspections and tests.

5.6 Programmed Inspections. Inspection and testing procedures should be carefully tailored to requirements. In some plants, regularly scheduled tests will call for scheduled outages of production or process equipment. In such cases, close coordination between maintenance and production personnel is necessary.

5.6.1 Analysis of Inspection and Test Reports. Analysis of inspection and test reports should be followed by implementation of appropriate corrective measures. Follow-through with necessary repairs, replacement, and adjustment is the end purpose of an effective EPM program.

5.6.2 Records.

5.6.2.1 Records should be accurate and contain all vital information.

5.6.2.2 Care should be taken to ensure that all relevant information becomes part of the record.

5.6.3 EPM Support Procedures.

5.6.3.1 Design for Ease of Maintenance. Effective electrical preventive maintenance begins with good design. In the design of new facilities, a conscious effort to ensure optimum maintainability is recommended. Dual circuits, tie circuits, auxiliary power sources, and drawout protective devices make it easier to schedule maintenance and to perform maintenance work with minimum interruption of production. Other effective design techniques include equipment rooms to provide environmental protection, grouping of equipment for more convenience

and accessibility, and standardization of equipment and components.

5.6.4 Training for Safety and Technical Skills.

5.6.4.1 Training Requirements.

5.6.4.1.1 All employees who face a risk of electrical hazard should be trained to understand the specific hazards and related injuries associated with electrical energy.

5.6.4.1.2 All employees should be trained in safety-related work practices and required procedures as necessary to provide protection from electrical hazards associated with their jobs or task assignments.

5.6.4.1.3 Refresher training should be provided as required.

5.6.4.2 Type of Training. The training can be in the classroom, on the job, or both. The type of training should be determined by the needs of the employee.

5.6.4.3 Emergency Procedures. Employees working on or near exposed energized electrical conductors or circuit parts should be instructed regularly and be familiar with methods of first aid and emergency procedures, such as approved methods of resuscitation, release of victims from contact with exposed energized conductors or circuit parts, and any other emergency procedures that are related to their work and necessary for their safety.

5.6.4.4 Training Scope. Employees should be trained and knowledgeable in the following:

- (1) Construction and operation of equipment
- (2) Specific work method
- (3) Electrical hazards that can be present with respect to specific equipment or work method
- (4) Proper use of special precautionary techniques, personal protective equipment, insulating and shielding materials, and insulated tools and test equipment
- (5) Skills and techniques necessary to distinguish exposed, energized parts from other parts of electrical equipment
- (6) Skills and techniques necessary to determine the nominal voltage of exposed energized parts
- (7) Decision-making process necessary to determine the degree and extent of hazard
- (8) Job planning necessary to perform the task safely
- (9) Self-discipline necessary to maintain a safe work environment

5.6.4.5 Record Keeping. Records of training should be maintained for each employee.

5.6.5 Outside Service Firms. Some maintenance and testing operations, such as relay and circuit-breaker inspection and testing, require specialized skills and special equipment. In small organizations, it might be impractical to develop the skills and acquire the equipment needed for this type of work. In such cases, it might be advisable to contract the work to firms that specialize in providing such services.

5.6.6 Tools and Instruments. Proper tools and instruments are an important part of an EPM program, and safety protective gear is an essential part of the necessary equipment. Proper tools, instruments, and other equipment should be used to ensure maximum safety and productivity from the maintenance crew. There should be adequate storage facilities for tools and test equipment that are common to each maintenance work group. Where specialized instruments and test

equipment are needed only occasionally, they can be rented from a variety of sources.

Chapter 6 Planning and Developing an Electrical Preventive Maintenance (EPM) Program

6.1 Introduction.

6.1.1 The purpose of an EPM program is to reduce hazard to life and property resulting from the failure or malfunction of electrical systems and equipment. This chapter explains the planning and development considerations that can be used to establish such a program.

6.1.2 The following four basic steps should be taken in the planning and development of an EPM program:

- (1) Compile a listing of all equipment and systems.
- (2) Determine which equipment and systems are most critical.
- (3) Develop a system for monitoring.
- (4) Determine the internal and/or external personnel needed to implement and maintain the EPM program.

6.1.3 A single individual should have the overall responsibility for EPM program implementation.

6.1.3.1 The individual responsible for the EPM program should be given the authority to perform the job and should have the cooperation of management, production, and other departments whose operations might affect the EPM program.

6.1.3.2 Ideally, the person designated to head the EPM program should have the following qualifications:

- (1) *Technical competence.* The person should, by education, training, and experience, be well-rounded in all aspects of electrical maintenance.
- (2) *Administrative and supervisory skills.* The person should be skilled in the planning and development of long-range objectives to achieve specific results and should be able to command respect and solicit the cooperation of all persons involved in the program.

6.1.4 The maintenance supervisor should have open lines of communication with design supervision. Frequently, an unsafe installation or one that requires excessive maintenance can be traced to improper design or construction methods or misapplication of hardware.

6.1.5 The work center of each maintenance work group should be conveniently located. This work center should contain the following:

- (1) Copies of all the inspection and testing procedures for that zone
- (2) Copies of previous reports
- (3) Single-line diagrams
- (4) Schematic diagrams
- (5) Records of complete nameplate data
- (6) Vendors' catalogs
- (7) Facility stores' catalogs
- (8) Supplies of report forms

6.1.6 In a continuously operating facility, running inspections (inspections made with equipment operating) play a vital role in the continuity of service. The development of running inspection procedures varies with the type of operation. Running inspection procedures should be as thorough as prac-

licable within the limits of safety and the skill of the maintenance personnel. These procedures should be reviewed to keep them current. Each failure of electrical equipment, be it an electrical or a mechanical failure, should be reviewed against the running inspection procedure to determine if some other inspection technique would have indicated the impending failure. If so, the procedure should be modified to reflect the findings.

6.1.7 When the electrical maintenance supervisor initiates corrective action, the maintenance personnel should be so informed. The maintenance personnel who found the condition will then realize their importance in the EPM program. However, if nothing is done, individual motivation and the EPM program might be affected adversely.

6.2 Survey of Electrical Installation.

6.2.1 Data Collection.

6.2.1.1 The first step in organizing a survey should be to examine available resources. Will the available personnel permit the survey of an entire system, process, or building, or should it be divided into segments?

6.2.1.2 Where the project will be divided into segments, a priority should be assigned to each segment. Segments found to be related should be identified before the actual work commences.

6.2.1.3 The third step should be the assembling of all documentation. This might necessitate a search of desks, cabinets, computers, and such, and might also require that manufacturers be contacted, to replace lost documents. All of the documents should be centralized, controlled, and maintained. The documentation should include recommended practices and procedures for some or all of the following:

- (1) Installation
- (2) Disassembly/assembly (interconnections)
- (3) Wiring diagrams, schematics, bills of materials
- (4) Operation (set-up and adjustment)
- (5) Maintenance (including parts list and recommended spares)
- (6) Software program (if applicable)
- (7) Troubleshooting

6.2.2 Diagrams and Data. The availability of up-to-date, accurate, and complete diagrams is the foundation of a successful EPM program. The diagrams discussed in 6.2.2.1 through 6.2.2.8.2 are some of those in common use.

6.2.2.1 Single-line diagrams should show all electrical equipment in the power system and give all pertinent ratings. In making this type of diagram, it is basic that voltage, frequency, phase, and normal operating position be included. No less important, but perhaps less obvious, are items such as transformer impedance, available short-circuit current, all overcurrent protective device types, ampere ratings, settings, and interrupting ratings. Other items include current and potential transformers and their ratios, surge capacitors, and protective relays. If one diagram cannot cover all the equipment involved, additional diagrams, appropriately noted on the main diagram, can be drawn.

6.2.2.2 Some managers have the misconception that these engineering studies are part of the initial facility design, after which the subject can be forgotten. Engineering studies such as short-circuit coordination and arc flash studies are important

and should be updated periodically based on a number of factors including changes in the supply capacity of the source of power, changes in size or percent impedance of transformers, changes in conductor size, addition of motors, and changes in system operating conditions.

6.2.2.2.1 In the course of periodic maintenance testing of protective equipment, such as relays and series or shunt-trip devices, equipment settings should be evaluated. Along with the proper sizing of fuses, this evaluation is part of the coordination study.

6.2.2.2.2 It is desirable to develop a computerized short-circuit study to improve accuracy and reduce engineering time. Should resources not be available within the facility organization, the short-circuit study can be performed on a contract basis.

6.2.2.2.3 Fuses are rated on the basis of their current-carrying and interrupting capacities. These ratings should be determined and recorded. Other protective devices are usually adjustable as to pickup point and time-current characteristics. The settings of such protective devices should be determined by engineering studies, verified by electrical tests, and recorded for future reference.

6.2.2.2.4 Personnel performing the tests should be trained and qualified. Various organizations and manufacturers of power and test equipment periodically schedule seminars in which participants are taught the principles of maintenance and testing of electrical protective devices.

6.2.2.2.5 The available short-circuit current data is used as follows:

- (1) To determine the momentary and interrupting ratings of circuit breakers and fuses
- (2) To determine the short-circuit current ratings for equipment
- (3) As required information to conduct the following:
 - (a) Overcurrent protective device coordination studies
 - (b) Risk assessment

6.2.2.2.6 Additional guidance on electrical systems can be found in Chapter 28.

6.2.2.3 Circuit-routing diagrams, cable maps, or raceway layouts should show the physical location of conductors. In addition to voltage, such diagrams should also indicate the type of raceway, number and size of conductors, and type of insulation.

6.2.2.3.1 Where control conductors or conductors of different systems are contained within the same raceway, the identification appropriate to each conductor should be noted.

6.2.2.3.2 The location of taps, headers, and pull boxes should be shown on the circuit routing diagrams.

6.2.2.3.3 Access points for raceways should be noted.

6.2.2.4 Layout diagrams, plot plans, equipment location plans, or facility maps should show the physical layout (and in some cases, the elevations) of all equipment in place.

6.2.2.4.1 Switching equipment, transformers, control panels, mains, and feeders should be identified.

6.2.2.4.2 Voltage and current ratings should be shown for each piece of equipment.

6.2.2.5 Schematic diagrams should be arranged for simplicity and ease of understanding circuits without regard for the actual physical location of any components. The schematic should always be drawn with switches and contacts shown in a deenergized position.

6.2.2.6 Wiring diagrams, like schematics, should show all components in the circuit and arranged in their actual physical location. Wiring diagrams should identify all equipment parts and devices by standard methods, symbols, and markings. Of particular value is the designation of terminals and terminal strips with their appropriate numbers, letters, or colors.

6.2.2.7 An effective EPM program should have manufacturers' service manuals and instructions. These manuals should include recommended practices and procedures.

6.2.2.8 Electrical Equipment Installation Change. The documentation of the changes that result from engineering decisions, planned revisions, and so on, should be the responsibility of the engineering group that initiates the revisions.

6.2.2.8.1 Periodically, changes occur as a result of an EPM program. The EPM program might also uncover undocumented practices or installations.

6.2.2.8.2 A responsibility of those responsible for the EPM program is to highlight these changes, note them in an appropriate manner, and formally submit the revisions to the organization responsible for the maintenance of the documentation.

6.2.3 System Diagrams. System diagrams should be provided to complete the data being assembled. The importance of the system determines the extent of information shown. The information can be shown on the most appropriate type of diagram but should include the same basic information, source and type of power, conductor and raceway information, and switching and protective devices with their physical locations. It is vital to show where the system might interface with another system, such as with emergency power; hydraulic, pneumatic, or mechanical systems; security and fire-alarm systems; and monitoring and control systems. Some of the more common of these are described in 6.2.3.1 through 6.2.3.3.

6.2.3.1 Lighting System Diagrams. Lighting system diagrams (normal and emergency) can terminate at the branch circuit panelboard, listing the number of fixtures, type and lamp size for each area, and design lighting level. The diagram should show watchman night lighting lights and probably an automatic transfer switch to the emergency power system.

6.2.3.2 Heating, Ventilation, and Air-Conditioning. Ventilation systems normally comprise the heating, cooling, and air-filtering system. Basic information, including motor and fan sizes, motor or pneumatically operated dampers, and so on, should be shown. Additionally, many safety features can be involved to ensure that fans start before the process — airflow switches to shut down an operation on loss of ventilation and other interlocks of similar nature. Each of these should be identified with respect to type, function, physical location, and operating limits. Heating and air-conditioning systems are usually manufactured and installed as a unit, furnished with diagrams and operating and maintenance manuals. This information should be updated as the system is changed or modified. Because these systems are often critical to the facility operation, additional equipment might have been incorporated — for example, humidity, lint, and dust control for textile, electronic, and similar processes, and corrosive and flammable

vapor control for chemical and related industries. Invariably, these systems interface with other electrical or nonelectrical systems; pneumatic or electromechanical operation of dampers, valves, and so on, electric operation for normal and abnormal temperature control, and manual control stations for emergency smoke removal are just a few. There might be others, and all should be shown and complete information given for each.

6.2.3.3 Control and Monitoring. Control and monitoring system diagrams should be provided to describe how these complicated systems function. They usually are in the form of a schematic diagram and can refer to specific wiring diagrams. Maximum benefit can be obtained only when every switching device is shown, its function is indicated, and it is identified for ease in finding a replacement. These devices often involve interfaces with other systems, whether electromechanical (heating or cooling medium) pumps and valves, electro-pneumatic temperature and damper controls, or safety and emergency operations. A sequence-of-operation chart and a list of safety precautions should be included to promote the safety of personnel and equipment. Understanding these complex circuits is best accomplished by breaking down the circuits into their natural functions, such as heating, cooling, process, or humidity controls. The knowledge of how each function relates to another enables the maintenance personnel to have a better understanding of the entire system and thus perform assignments more efficiently.

6.2.4 Emergency Procedures. Emergency procedures should list, step by step, the action to be taken in case of emergency or for the safe shutdown or start-up of equipment or systems. (*See Section 6.9 for details.*) Optimum use of these procedures is made when they are readily available near the area of the equipment or systems. If an emergency could make some areas of the facility inaccessible, the associated emergency procedures should be located outside the potentially affected area. Some possible items to consider for inclusion in the emergency procedures are interlock types and locations, interconnections with other systems, and tagging procedures of the equipment or systems. Accurate single-line diagrams posted in strategic places are particularly helpful in emergency situations. The production of such diagrams in anticipation of an emergency is essential to a complete EPM program. Diagrams are a particularly important training tool in developing a state of preparedness. Complete and up-to-date diagrams provide a quick review of the emergency plan. During an actual emergency, when time is of the essence, they provide a simple, quick reference guide.

6.2.5 Test and Maintenance Equipment.

6.2.5.1 All maintenance work requires the use of proper tools and equipment to properly perform the task to be done. In addition to their ordinary tools, maintenance personnel (such as carpenters, pipe fitters, and machinists) use special tools or equipment based on the nature of the work to be performed. The electrician is no exception, but for EPM, special-use tools should be readily available. The size of the facility, the nature of its operations, and the extent of its maintenance, repair, and test facilities are all factors that determine the use frequency of the equipment. Economics seldom justify purchasing an infrequently used, expensive tool when it can be rented. However, a corporation having a number of facilities in the area might well justify common ownership of the same device for joint use, making it quickly available at any time to any facility. Typical

examples might be high-current test equipment, infrared thermography equipment, or a ground-fault locator.

6.2.5.2 Because a certain amount of mechanical maintenance is often a part of the EPM program being conducted on associated equipment, the electrical maintenance personnel should have ready access to such items as the following:

- (1) Assorted lubrication tools and equipment
- (2) Various types and sizes of wrenches
- (3) Nonmetallic hammers and blocks to protect against injury to machined surfaces
- (4) Feeler gauges to function as inside- and outside-diameter measuring gauges
- (5) Instruments for measuring torque, tension, compression, vibration, and speed
- (6) Standard and special mirrors with light sources for visual inspection
- (7) Industrial-type portable blowers and vacuums having insulated nozzles for removal of dust and foreign matter
- (8) Nontoxic, nonflammable cleaning solvents
- (9) Clean, lint-free wiping cloths

6.2.5.3 The use of well-maintained safety equipment is essential and should be mandatory for work on energized electrical conductors or circuit parts. Prior to performing maintenance on energized electrical conductors or circuit parts, NFPA 70E should be used to identify the degree of personal protective equipment (PPE) required. Some of the more important equipment that should be provided includes the following:

- (1) Heavy leather gloves
- (2) Insulating gloves, mats, blankets, baskets, boots, jackets, and coats
- (3) Insulated hand tools such as screwdrivers and pliers
- (4) Nonmetallic hard hats with suitable arc-rated face protection
- (5) Poles with hooks and hot sticks to safely open isolating switches

6.2.5.3.1 A statoscope is recommended to indicate the presence of high voltage on certain types of equipment.

6.2.5.4 Portable electric lighting should be provided, particularly in emergencies involving the power supply. Suitable extension cords should be provided.

6.2.5.4.1 Portable electric lighting used for maintenance areas that are normally wet or where personnel will be working within grounded metal structures such as drums, tanks, and vessels should be operated at an appropriate low voltage from an isolating transformer or through a GFCI device. The aim is to limit the exposure of personnel to hazardous current levels, or limit the voltage.

6.2.5.5 Portable meters and instruments are necessary for testing and troubleshooting, especially on circuits of 600 volts or less. These include general-purpose volt meters, volt-ohmmeters, and clamp-on-type ammeters with multiscale ranges. In addition to conventional instruments, recording meters are useful for measuring magnitudes and fluctuations of current, voltage, power factor, watts, volt-amperes, and transients versus time values. These instruments are a definite aid in defining specific electrical problems and determining if equipment malfunction is due to abnormal electrical conditions. Other valuable test equipment includes devices to measure the insulation resistance of motors and similar equipment in the megohm range and similar instruments in the low range for

determining ground resistance, lightning protection systems, and grounding systems. Continuity testers are particularly valuable for checking control circuits and for circuit identification.

6.2.5.6 Special instruments can be used to test the impedance of the grounding circuit conductor or the grounding path of energized low-voltage distribution systems and equipment. These instruments can be used to test the equipment-grounding circuit path of electrical equipment.

6.2.5.7 Insulation resistance-measuring equipment should be used to indicate insulation baseline values at the time equipment is put into service. Later measurements might indicate any deterioration trend of the insulation values of the equipment. High-potential ac and dc testers are used effectively to indicate dielectric strength and insulation resistance of the insulation, respectively. It should be recognized that the possibility of breakdown under test due to concealed weakness is always present. High-potential testing should be performed with caution and only by qualified operators.

6.2.5.8 Portable ground-fault locators can be used to test ungrounded power systems. Such devices will indicate ground location while the power system is energized. They thus provide a valuable aid for safe operation by indicating where to take corrective steps before an insulation breakdown occurs on another phase.

6.2.5.9 Receptacle circuit testers are devices that, by a pattern of lights, indicate some types of incorrect wiring of 15- and 20-ampere, 125-volt grounding-type receptacles.

CAUTION: Although these test devices can provide useful and easily acquired information, some have limitations, and the test results should be used with caution. For example, a high-resistance ground can give a correct wiring display, as can some multiple wiring errors. An incorrect display can be considered a valid indication that there is an incorrect situation, but a correct wiring display should not be accepted without further investigation.

6.3 Identification of Critical Equipment.

6.3.1 Equipment (electric or otherwise) should be considered critical if its failure to operate normally and under complete control will cause a serious threat to people, property, or the product. Electric power, like process steam, water, and so forth, might be essential to the operation of a machine, but unless loss of one or more of these supplies causes the machine to become hazardous to people, property, or production, that machine might not be critical. The combined knowledge and experience of several people might be needed to make this determination. In a small facility, the facility engineer or master mechanic working with the operating superintendent should be able to make this determination.

6.3.1.1 A large operation should use a team comprising the following personnel:

- (1) The electrical foreman or superintendent
- (2) Production personnel thoroughly familiar with the operation capabilities of the equipment and the effect its loss will have on final production
- (3) The senior maintenance person who is generally familiar with the maintenance and repair history of the equipment or process

- (4) A technical person knowledgeable in the theoretical fundamentals of the process and its hazards (in a chemical plant, a chemist; in a mine, a geologist; etc.)
- (5) A safety engineer or the person responsible for the overall security of the plant and its personnel against fire and accidents of all kinds

6.3.1.2 The team should review the entire plant or each of its operating segments in detail, considering each unit of equipment as related to the entire operation and the effect of its loss on safety and production.

6.3.2 There are entire systems that might be critical by their very nature. Depending on the size and complexity of the operation, a plant can contain any or all of the following examples: emergency power, emergency lighting, fire-alarm systems, fire pumps, and certain communications systems. There should be a clear determination in establishing whether a system is critical and in having the proper amount of emphasis placed on its maintenance.

6.3.3 More difficult to identify are the parts of a system that are critical because of the function of the utilization equipment and its associated hardware. Some examples are as follows:

- (1) The cooling water source of an exothermic reactor might have associated with it some electrical equipment such as a drive motor, solenoid valves, controls, or the like. Failure of the cooling water might allow the exothermic reaction to go beyond the stable point and overpressurize and destroy the vessel.
- (2) A process furnace recirculating fan drive motor or fan might fail, nullifying the effects of temperature-sensing points and thus allowing hot spots to develop, with serious side reactions.
- (3) The failure of gas analysis equipment and interlocks in a drying oven or annealing furnace might allow the atmosphere in the drying oven or furnace to become flammable, with the possibility of an explosion.
- (4) The failure of any of the safety combustion controls on a large firebox, such as a boiler or an incinerator, can cause a serious explosion.
- (5) Two paralleled pump motors might be needed to provide the total requirements of a continuous process. Failure of either motor can cause a complete shutdown, rather than simply reduce production.

6.3.4 There are parts of a system that are critical because they reduce the widespread effect of a fault in electrical equipment. The determination of these parts should be primarily the responsibility of the electrical person on the team. Among the things that fall into this category are the following:

- (1) Source overcurrent protective devices, such as circuit breakers or fuses, including the relays, control circuits, and coordination of trip characteristics of the devices
- (2) Automatic bus transfer switches or other transfer switches that would supply critical loads with power from the emergency power source if the primary source failed; includes instrument power supplies as well as load power supplies

6.3.5 Parts of the control system are critical because they monitor the process and automatically shut down equipment or take other action to prevent catastrophe. These items are the interlocks, cutout devices, or shutdown devices installed throughout the plant or operation. Each interlock or shutdown device should be considered carefully by the entire team to

establish whether it is a critical shutdown or a “convenience” shutdown. The maintenance group should thoroughly understand which shutdowns are critical and which are convenience. Critical shutdown devices are normally characterized by their use in sensing an abnormal condition and might have a sensing device separate from the normal control device. They probably have separate, final, or end devices that cause action to take place. Once the critical shutdown systems have been determined, they should be distinctly identified on drawings, on records, and on the hardware itself. Some examples of critical shutdown devices are overspeed trips; high or low temperature, pressure, flow, or level trips; low-lube-oil pressure trips; pressure-relief valves; overcurrent trips; and low-voltage trips.

6.3.6 Some parts of a system are critical because they alert operating personnel to dangerous, out-of-control, or abnormal conditions. These are normally referred to as alarms. Like shutdown devices, alarms fall into at least three categories: (1) those that signify a true pending catastrophe, (2) those that indicate out-of-control conditions, and (3) those that indicate the end of an operation or similar condition. The entire team should consider each alarm in the system with the same thoroughness with which they have considered the shutdown circuits. A truly critical alarm should be characterized by its separate sensing device, a separate readout device, and, preferably, separate circuitry and power source. The maintenance department should thoroughly understand the critical level of each alarm. The critical alarms and their significance should be distinctly marked on drawings, in records, and on the operating unit. For an alarm to be critical does not necessarily mean that it is complex or related to complex action. A simple valve position indicator can be one of the most critical alarms in an operating unit.

6.4 Establishment of a Systematic Program. The purpose of any inspection and testing program is to establish the condition of equipment to determine what work should be done and to verify that it will continue to function until the next scheduled servicing occurs. Inspection and testing are best done in conjunction with routine maintenance. In this way, many minor items that require no special tools, training, or equipment can be corrected as they are found. The inspection and testing program is probably the most important function of a maintenance department in that it establishes what should be done to keep the system in service to perform the function for which it is required.

6.4.1 Atmosphere or Environment.

6.4.1.1 The atmosphere or environment in which electrical equipment is located has a definite effect on its operating capabilities and the degree of maintenance required. An ideal environment is one in which the air is (1) clean or filtered to remove dust, harmful vapor, excess moisture, and so on; (2) maintained in the temperature range of 15°C to 29°C (60°F to 85°F); and (3) in the range of 40 percent to 70 percent humidity. Under such conditions, the need for maintenance will be minimized. Where these conditions are not maintained, the performance of electrical equipment could be adversely affected. Good housekeeping contributes to a good environment and reduced maintenance.

6.4.1.2 Dust can foul cooling passages and thus reduce the capabilities of motors, transformers, switchgear, and so on, by raising their operating temperatures above rated limits, decreasing operating efficiencies, and increasing fire hazard. Similarly, chemicals and vapors can coat and reduce the heat

transfer capabilities of heating and cooling equipment. Chemicals, dusts, and vapors can be highly flammable, explosive, or conductive, increasing the hazard of fire, explosion, ground faults, and short circuits. Chemicals and corrosive vapors can cause high contact resistance that will decrease contact life and increase contact power losses with possible fire hazard or false overload conditions due to excess heat. Large temperature changes combined with high humidity can cause condensation problems, malfunction of operating and safety devices, and lubrication problems. High ambient temperatures in areas where thermally sensitive protective equipment is located can cause such protective equipment to operate below its intended operating point. Preferably, both the electrical apparatus and its protective equipment should be located within the same ambient temperature. Where the ambient-temperature difference between equipment and its protective device is extreme, compensation in the protective equipment should be made.

6.4.1.3 Electrical equipment installed in hazardous (classified) locations as described in *NFPA 70* requires special maintenance considerations. (See Section 27.2.)

6.4.2 Load Conditions.

6.4.2.1 Equipment is designed and rated to perform satisfactorily when subjected to specific operating and load conditions. A motor designed for safe continuous operation at rated load might not be satisfactory for frequent intermittent operation, which can produce excessive winding temperatures or mechanical trouble. The resistance grid or transformer of a reduced-voltage starter will overheat if left in the starting position. So-called “jogging” or “inching” service imposes severe demands on equipment such as motors, starters, and controls. Each type of duty influences the type of equipment used and the extent of maintenance required. The five most common types of duty are defined in *NFPA 70* and they are repeated in 6.4.2.2.

6.4.2.2 The following definitions can be found in Chapter 3 and are unique to this chapter:

- (1) Continuous duty (See 3.3.15.1.)
- (2) Intermittent duty (See 3.3.15.2.)
- (3) Periodic duty (See 3.3.15.3.)
- (4) Short-time duty (See 3.3.15.4.)
- (5) Varying duty (See 3.3.15.5.)

6.4.2.3 Some devices used in establishing a proper maintenance period are running-time meters (to measure total “on” or “use” time); counters to measure number of starts, stops, or load-on, load-off, and rest periods; and recording ammeters to graphically record load and no-load conditions. These devices can be applied to any system or equipment and will help classify the duty. They will help establish a proper frequency of preventive maintenance.

6.4.2.4 Safety and limit controls are devices whose sole function is to ensure that values remain within the safe design level of the system. Because these devices function only during an abnormal situation in which an undesirable or unsafe condition is reached, each device should be periodically and carefully inspected, checked, and tested to be certain that it is in reliable operating condition.

6.4.3 Wherever practical, a history of each electrical system should be developed for all equipment or parts of a system vital to a facility's operation, production, or process. The record should include all pertinent information for proper operation and maintenance. This information is useful in developing

repair cost trends, items replaced, design changes or modifications, significant trouble or failure patterns, and replacement parts or devices that should be stocked. System and equipment information should include the following:

- (1) Types of electrical equipment, such as motors, starters, contactors, heaters, relays
- (2) Types of mechanical equipment, such as valves, controls, and so on, and driven equipment, such as pumps, compressors, fans, and whether they are direct, geared, or belt driven
- (3) Nameplate data
- (4) Equipment use
- (5) Installation date
- (6) Available replacement parts
- (7) Maintenance test and inspection dates: type and frequency of lubrication; electrical inspections, test, and repair; mechanical inspections, test, and repair; replacement parts list with manufacturer's identification; electrical and mechanical drawings for assembly, repair, and operation

6.4.4 Inspection Frequency. Those pieces of equipment found to be critical should require the most frequent inspections and tests. Depending on the degree of reliability required, other items can be inspected and tested much less frequently.

6.4.4.1* Manufacturers' service manuals should have a recommended frequency of inspection. The frequency given is based on standard or usual operating conditions and environments. It would be impossible for a manufacturer to list all combinations of environmental and operating conditions. However, a manufacturer's service manual is a good basis from which to begin considering the frequency for inspection and testing.

6.4.4.2 There are several points to consider in establishing the initial frequency of inspections and tests. Electrical equipment located in a separate air-conditioned control room or switch room certainly would not be considered normal, so the inspection interval might be extended 30 percent. However, if the equipment is located near another unit or operating plant that discharges dust or corrosive vapors, this time might be reduced by as much as 50 percent.

6.4.4.3 Continuously operating units with steady loads or with less than the rated full load tend to operate much longer and more reliably than intermittently operated or standby units. For this reason, the interval between inspections might be extended 10 to 20 percent for continuously operating equipment and possibly reduced by 20 to 40 percent for standby or infrequently operated equipment.

6.4.4.4 Once the initial frequency for inspection and tests has been established, this frequency should be adhered to for at least four maintenance cycles unless undue failures occur. For equipment that has unexpected failures, the interval between inspections should be reduced by 50 percent as soon as the trouble occurs. On the other hand, after four cycles of inspections have been completed, a pattern should have developed. If equipment consistently goes through more than two inspections without requiring service, the inspection period can be extended by 50 percent. Loss of production due to an emergency shutdown is almost always more expensive than loss of production due to a planned shutdown. Accordingly, the interval between inspections should be planned to avoid the diminishing returns of either too long or too short an interval.

6.4.4.5 Adjustment in the interval between inspections should continue until the optimum interval is reached. This adjustment time can be minimized and the optimum interval approximated more closely initially by providing the person responsible for establishing the first interval with as much pertinent history and technology as possible.

6.4.4.6 The frequency of inspection for similar equipment operating under differing conditions can differ widely. Typical examples are as follows:

- (1) In a continuously operating plant using less than full design load factor and located in a favorable environment, the high-voltage oil circuit breakers might need an inspection only every 2 years. On the other hand, an electrolytic process plant using similar oil circuit breakers for controlling furnaces might find it necessary to inspect and service them as frequently as every 7 to 10 days.
- (2) An emergency generator to provide power for noncritical loads can be tested on a monthly basis. Yet the same generator in another plant having processes sensitive to explosion on loss of power might need to be tested during each shift.

6.5 Methods and Procedures.

6.5.1 General.

6.5.1.1 If a system is to operate without failure, not only should the discrete components of the system be maintained, but the connections between these components also should be covered by a thorough set of methods and procedures. Overlooking this important link in the system causes many facilities to suffer high losses every year.

6.5.1.2 Other areas where the maintenance department should develop its own procedures are shutdown safeguards, interlocks, and alarms. Although the individual pieces of equipment can have testing and calibrating procedures furnished by the manufacturer, the equipment application is probably unique, so the system should have an inspection and testing procedure developed.

6.5.2 Forms and Reports.

6.5.2.1 A variety of forms can be included with the inspection, testing, and repair (IT&R) procedure; these forms should be detailed and direct, yet simple and durable enough to be used in the field.

6.5.2.2 The reports should go in the master file maintained by first-line electrical maintenance supervision. A document control system should be in place to assure current documents are utilized by personnel. If reports to production or engineering are needed, they should be separate, and inspection reports should not be used. See Annex H for a set of forms that might be applicable.

6.5.2.3 The IT&R procedure file for a piece of equipment should list the following items:

- (1) All the special tools, materials, and equipment necessary to do the job
- (2) The estimated or actual average time to do the job
- (3) Appropriate references to technical manuals
- (4) Previous work done on the equipment
- (5) Points for special attention indicated by previous IT&R
- (6) References to unusual incidents reported by production that might be associated with the equipment

- (7) If major work was predicted at the last IT&R, copies of the repair work orders and parts references

6.5.2.4 Special precautions relative to operation, such as the following, should be part of the IT&R document:

- (1) What other equipment is affected and in what way?
- (2) Who has to be informed that the IT&R is going to be done?
- (3) How long will the equipment be out of service if all goes well? How long if major problems are uncovered?

6.5.3 Planning.

6.5.3.1 After the IT&R procedures have been developed and the frequency has been established (even though preliminary), the task of scheduling should be handled. Scheduling in a continuous-process plant (as opposed to a batch-process plant) is most critically affected by availability of equipment in blocks consistent with maintenance personnel capabilities. In general, facilities should be shut down in whole or in part on some regular basis for overall maintenance and repair. Some of the electrical maintenance items should be done at this time. IT&R that could be done while equipment is in service should be done prior to shutdown. Only work that needs to be done during shutdown should be scheduled at that time, to limit personnel requirements and limit downtime.

6.5.3.2 The very exercise of scheduling IT&R will point out design weaknesses that require excessive personnel during critical shutdown periods or that require excessive downtime to do the job with the personnel available. Once these weaknesses have been uncovered, consideration can be given to rectifying them.

6.5.3.3 Availability of spare equipment affects scheduling in many ways. Older facilities might have installed spares for a major part of the equipment, or the facility might be made up of many parallel lines so that they can be shut down, one at a time, without seriously curtailing operations. This concept is particularly adaptable to electrical distribution. The use of a circuit breaker and a transfer bus can extend the interval between total shutdown on a main transformer station from once a year to once in 5 years or more.

6.5.3.4 Many continuous-process plants use a large single-process line with no installed spares. This method of operation requires ongoing inspections and tests. Downtime in such plants is particularly costly, so it is desirable to build as much monitoring into the electrical systems as possible.

6.5.3.5 Planning running inspections can vary from a simple desk calendar to a computer program. Any program for scheduling should have at least the following four facets:

- (1) A reminder to order parts and equipment with sufficient lead time to have them on the job when needed
- (2) The date and man-hours estimate to do the job
- (3) A check to see that the job has been completed
- (4) Identifying if additional parts will be needed for the next IT&R and when they should be ordered

6.5.3.6 Planning shutdown IT&R is governed by the time between shutdowns, established by the limitations of the process or production units involved. Reliability of electrical equipment can and should be built in to correspond to almost any length of time.

6.5.3.7 Small plants should use, in an abbreviated form, the following shutdown recommendations of a large facility IT&R:

- (1) Know how many personnel-shifts the work will take.
- (2) Know how many persons will be available.
- (3) Inform production of how many shifts the electrical maintenance will require.
- (4) Have all the necessary tools, materials, and spare parts assembled on the job site. Overage is better than shortage.
- (5) Plan the work so that each person is used to best suit his or her skills.
- (6) Plan what each person will be doing during each hour of the shutdown. Allow sufficient off time so that if a job is not finished as scheduled, the person working on that job can be held over without becoming overtired for the next shift. This procedure will allow the schedule to be kept.
- (7) Additional clerical people during shutdown IT&R will make the job go more smoothly, help prevent omission of some important function, and allow an easier transition back to normal.
- (8) Supply copies of the electrical group plan to the overall shutdown coordinator so it can be incorporated into the overall plan. The overall plan should be presented in a form that is easy to use by all levels of supervision. In a large, complex operation, a critical path program or some similar program should be used.

6.5.3.8 Automatic shutdown systems and alarm systems that have been determined as critical should be designed and maintained so that nuisance tripping does not reduce operator confidence. Loss of operator confidence could cause these systems to be bypassed and the intended safety lost. Maintenance of these systems should prove that each shutdown and alarm operation was valid and was caused by an unsafe condition.

6.5.3.9 A good electrical preventive maintenance program should identify the hierarchy of job criticality so it is clear to first-line supervision which EPM can be delayed to make personnel available for emergency breakdown repair.

6.5.4 Analysis of Safety Procedures.

6.5.4.1 It is beyond the scope of this recommended practice to cover the details of safety procedures for each IT&R activity. Manufacturers' instructions typically contain safety procedures required in using their test equipment. See Chapter 7 for more detailed information on personnel safety.

6.5.4.2 The electrical test equipment should be inspected in accordance with vendor recommendations before the job is started. Any unsafe condition should be corrected before proceeding.

6.5.4.3 The people performing the IT&R should be briefed to be sure that all facets of safety before, during, and after the IT&R are understood. It is important that all personal protective equipment (PPE) is in good condition and available and used when required.

6.5.4.4 Screens, ropes, guards, and signs needed to protect people other than the IT&R team should be provided and used.

6.5.4.5 A procedure should be developed, understood, and used for leaving the test site in a safe condition when unattended at times such as breaks or overnight work.

6.5.4.6 A procedure should be developed, understood, and used to ensure safety to and from the process before, during, and after the IT&R. The process or other operation should be put in a safe condition for the IT&R by the operating people before the work is started. The procedure should include checks to ensure that the unit is ready for operation after the IT&R is completed and before the operation is restarted.

6.5.5 Records.

6.5.5.1 General. Sufficient records should be kept by maintenance management to evaluate overall EPM results. Analysis of the records should guide budget planning for EPM and breakdown repair.

6.5.5.2 Records of Cost. Figures should be kept to show the total cost of each unplanned outage. This should be the actual cost plus an estimated cost of the business interruption. This figure is a powerful indicator for the guidance of expenditures for EPM.

6.5.5.3 Records Kept by First-Line Supervisor of EPM. Of the many approaches to this phase of the program, the following approach is a typical one that fulfills the minimum requirements.

6.5.5.3.1 Inspection Schedule. The first-line supervisor should maintain, in some easy-to-use form, a schedule of inspections so that he or she can plan personnel requirements.

6.5.5.3.2 Work Order Log. An active log should be kept of unfinished work orders. A greater probability of breakdown may be indicated by a large number of outstanding work orders resulting from the inspection function.

6.5.5.3.3 Unusual Event Log. As the name implies, this log lists unusual events that affect the electrical system in any way. This record is derived from reports of operating and other personnel and is a good tool for finding likely problems. Near misses can be recorded and recognition given for averting trouble.

6.5.6 Emergency Procedures. It should be recognized that properly trained electrical maintenance personnel have the potential to make an important contribution in the emergency situations that are most likely to occur. However, most such situations will also involve other crafts and disciplines, such as operating personnel and mechanics. Emergency procedure for each anticipated emergency situation should be developed. Qualified personnel of each discipline should be involved, detailing steps to be followed, sequence of steps, and assignment of responsibility. The total procedure should then be performed periodically as an emergency drill to ensure that all involved personnel are kept thoroughly familiar with the tasks they are to perform.

6.6 Maintenance of Imported Electrical Equipment. Imported equipment can pose additional maintenance considerations, and the original equipment manufacturer's documentation and local codes and standards should be referenced for any special needs or requirements.

6.6.1 Timely delivery of replacement parts cannot be taken for granted. Suppliers should be identified, and any replacement parts issues should be reflected in the facility spare parts inventory. In addition to considering possible delays in delivery of replacement parts, knowledgeable outside sources of engineering services for the imported equipment should be established.

6.6.2 Parts catalogs, maintenance manuals, and drawings should be available in the language of the user. Documents created in a different language and then translated should not be presumed to be understandable. Unclear portions of the translation should be identified as soon as literature is received to ensure that material will be fully understood later, when actual maintenance must be performed.

6.7 Maintenance of Electrical Equipment for Use in Hazardous (Classified) Locations. (See Section 27.2.)

6.8 Outsourcing of Electrical Equipment Maintenance.

6.8.1 General. This section describes the process for a facility to request the services of qualified contractors to perform maintenance on electrical equipment.

6.8.2 Contract Elements. Elements in a contract for outsourcing electrical maintenance service are to include, but are not limited to, the following:

- (1) Define project scope of work, what is included and not included, along with equipment specifications on any new or replacement parts, and the time period(s) in which the activities are to be performed.
- (2) Determine if it is a performance-based or detailed (step-by-step) specification.
- (3) Determine which safety and maintenance codes and standards are to be followed, including appropriate permits.
- (4) Determine methodology for pricing: lump sum or unit price.
- (5) Determine the qualifications of potential contractors and develop and maintain a list of such.
- (6) Obtain appropriate liability, insurance coverage, and warranty information.
- (7) Assemble the appropriate up-to-date and accurate facility and equipment specific documents, such as, but not limited to, the following:
 - (a) Facility one line diagrams
 - (b) Facility layout drawings showing location of substations and major facility electrical equipment
 - (c) Facility equipment list (if facility drawings show equipment, facility drawings may be used in lieu of specific equipment lists)
 - (d) Equipment manufacturers' requirements (these include equipment service manuals, equipment drawings, etc.)
 - (e) Risk assessment, short circuit analysis, and time-current coordination studies
- (8) Conduct a pre-bid/negotiation walk through with the potential contractor.
- (9) Conduct a post-work walk-through to verify proper completion of scope of work, and review written report from the contractor on findings and recommendations, as applicable.

6.8.3 Sample Forms. Sample forms for electrical maintenance service are found in Annex H.

6.9 Emergency Preparedness and Electrical System and Equipment Restoration (EPnSR).

6.9.1 Introduction.

6.9.1.1 A plan should be developed for a safe and orderly shut down of the facility in event of an emergency, and for post-emergency actions required to restore normal operations in the facility. This includes, but is not limited to, the following:

- (1) The information provided in 6.2.4.
- (2) Preparation of a primary contact matrix, as illustrated in Annex J, which should be updated yearly, prominently posted, and visible to maintenance personnel during an emergency.
- (3) Spare parts stocking, including the determination of which ones should be stocked and determination of accessible storage location.

6.9.1.2 For further information on disaster and emergency management, see *NFPA 1600* and *NEMA Evaluating Water-Damaged Electrical Equipment*.

6.9.2 Procedure for Emergency Shutdown.

6.9.2.1 A procedure should be developed for the shutdown of the electrical system and incorporated in the overall plant shutdown and evacuation plan.

6.9.2.2 In the absence of notification by the authority having jurisdiction (AHJ), the determination to cease operations is based on when the qualified person decides that the facility personnel can no longer safely and properly operate and maintain the equipment and the facility.

6.9.2.3 Notify the appropriate authorities that the facility has been shut down and evacuated.

▲ 6.9.3 Procedure for Post-Emergency Actions. See Chapter 32.

6.9.4 Training. Refer to 6.5.6 for additional information about emergency procedures.

6.10 Counterfeit Components, Devices, Tools, and Equipment.

6.10.1 When the maintenance of electrical equipment requires the replacement of existing components, devices, tools, or equipment, care should be exercised to minimize the inadvertent use or installation of counterfeit goods.

6.10.2 Products should be purchased from an authorized vendor.

6.10.3 Careful visual inspection of the goods and packaging can distinguish counterfeit goods from those of the legitimate manufacturer. The product and/or packaging could contain grammatical or spelling errors, missing or improper certification marks, or lack of applicable safety warnings and instructions.

6.10.4 If it is suspected that the goods are counterfeit, contact the manufacturer; and where labeled, contact the listing organization.

Chapter 7 Personnel Safety

7.1 Introduction.

7.1.1 Personnel safety is a primary consideration in system design and in establishing safety-related work practices where performing preventative maintenance for electrical, electronic, and communication systems and equipment. Maintenance should be performed only by qualified persons trained in safe maintenance practices and the special considerations necessary to maintain electrical equipment. Safe work practices should be instituted and followed to prevent injury to those who are performing tasks as well as others who might be exposed to the hazards. Among the hazards associated with working on energized electrical conductors or circuit parts are shock, arc flash, and arc blast, any of which, may result in severe injury or death. Preventive maintenance should be performed only when equipment is in an electrically safe work condition.

7.1.2 NFPA 70E; IEEE C2, *National Electrical Safety Code*; IEEE 3007.3, *IEEE Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems*; and OSHA 29 CFR 1926 and 1910 are among the references that should be utilized for the development of programs and procedures associated with maintenance activities, and are necessary to be used in conjunction with this document.

7.1.3 Chapter 1 of NFPA 70E covers electrical safety-related work practices and procedures for employees who work on or near exposed energized electrical conductors or circuit parts in workplaces that are included in the scope of that standard. These practices and procedures are intended to provide for employee safety relative to electrical hazards in the workplace. All maintenance personnel should confirm that the requirements of NFPA 70E are adhered to where performing electrical maintenance procedures.

7.1.3.1 The following are some of the considerations in Article 110 of NFPA 70E:

- (1) Training requirements (*see 110.2*)
- (2) Electrical safety program (*see 110.1*)
- (3) Use of electrical equipment (*see 110.4*)

7.1.3.2 The following are some of the considerations in Article 120 of NFPA 70E:

- (1) Verification of an electrically safe work condition (*see 120.1*)
- (2) Deenergized electrical equipment that has lockout/tagout devices applied (*see 120.2*)
- (3) Temporary protective grounding equipment (*see 120.3*)

7.1.3.3 The following are some of the considerations in Article 130 of NFPA 70E:

- (1) Energized work [*see 130.2(A)*]
- (2) Approach boundaries to energized electrical conductors or circuit parts for shock protection (*see 130.4*)
- (3) Test instruments and equipment use (*see 130.4*)
- (4) Limited approach boundary [*see 130.4(C)*]
- (5) Other precautions for personnel activities (*see 130.6*)
- (6) Personal and other protective equipment (*see 130.7*)

7.2 Grounding of Equipment to Provide Protection for Electrical Maintenance Personnel.

7.2.1 Personnel working on, or in close proximity to, deenergized lines or conductors in electrical equipment should be protected against shock hazard and flash burns that could

occur if the circuit were to be inadvertently reenergized. Sound judgment should be exercised in deciding the extent of protection to be provided and determining the type of protective equipment and procedures that should be applied. The extent of protection that should be provided will be dictated by specific circumstances.

7.2.2 The following possible conditions and occurrences should be considered in determining the type and extent of protection to be provided:

- (1) Induced voltages from adjacent energized conductors, which can be appreciably increased when high fault currents flow in adjacent circuits
- (2) Switching errors causing inadvertent reenergizing of the circuit
- (3) Any unusual condition that might bring an energized conductor into electrical contact with the deenergized circuit
- (4) Extremely high voltages caused by direct or nearby lightning strikes
- (5) Stored charges from capacitors or other equipment

7.2.3 Providing proper protection begins with establishing an electrically safe work condition.

7.2.4 In spite of all precautions, deenergized circuits can be inadvertently reenergized. When this occurs, adequate grounding is the only protection for personnel working on those circuits. For this reason, it is especially important that adequate grounding procedures be established and rigidly enforced.

7.2.4.1 A variety of terms are used to identify the grounding of deenergized electrical equipment to permit personnel to safely perform work on it without using special insulated tools. Some of these terms are *safety grounding*, *temporary grounding*, and *personnel protective grounding*. Throughout this chapter, the word *grounding* is used to refer to this activity; it does not refer to permanent grounding of system neutrals or non-current-carrying metal parts of electrical equipment.

7.2.4.2 Grounding equipment consists mainly of special heavy-duty clamps that are connected to cables of adequate capacity for the system fault current. This current, which might well be in excess of 100,000 amperes, will flow until the circuit overcurrent protective devices operate to deenergize the conductors. The grounding equipment should not be larger than necessary, because bulkiness and weight hinder personnel connecting them to the conductors, especially when they are working with hot-line sticks. Selection of grounding equipment should take the provisions of 7.2.4.2.1 through 7.2.4.2.5 into consideration.

7.2.4.2.1 Grounding clamps should be of proper size to fit the conductors and have adequate capacity for the fault current. An inadequate clamp can melt or be blown off under fault conditions. Hot-line clamps should not be used for grounding deenergized conductors because they are not designed to carry the high current that would flow if the circuit were to be inadvertently reenergized. They are intended to be used only for connecting tap conductors to energized overhead lines by means of hot-line sticks and are designed to carry only normal load current. If hot-line clamps are used for grounding, high fault current could melt or blow them off without operating the overcurrent protective devices to deenergize the conductors, thereby exposing personnel to lethal voltages and arc burns.

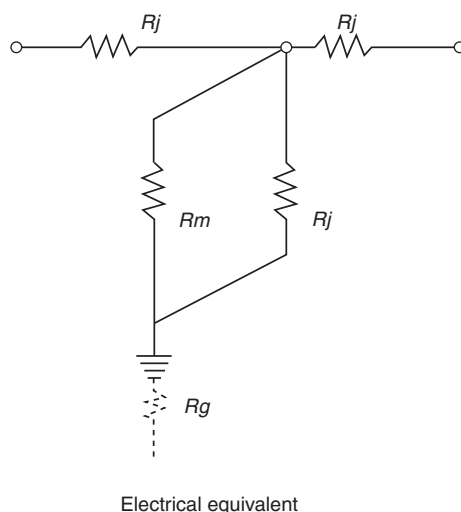
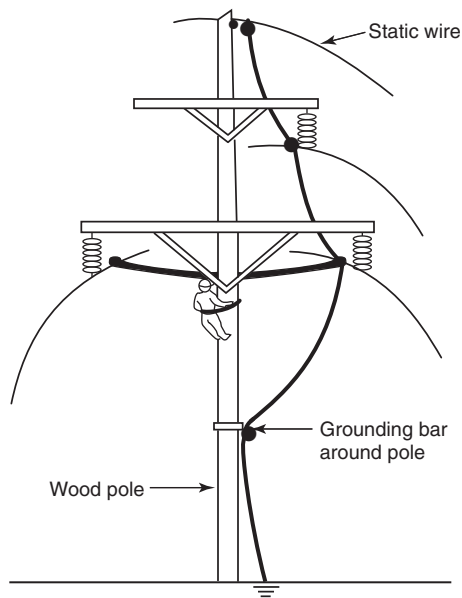
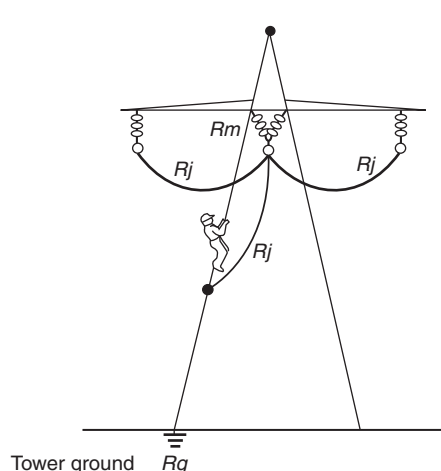
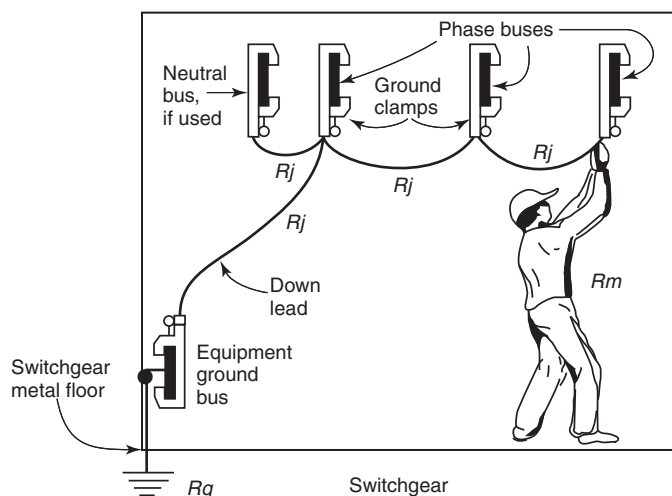
7.2.4.2.2 Grounding cables should be of adequate capacity, which, in some instances, might require two or more to be paralleled. Three factors contribute to adequate capacity: (1) terminal strength, which largely depends on the ferrules installed on the cable ends; (2) size to carry maximum current without melting; and (3) low resistance to keep the voltage drop across the areas in which the personnel are working at a safe level during any period of inadvertent reenergization.

7.2.4.2.3 Solid metal-to-metal connections are essential between grounding clamps and the deenergized conductors. Conductors are often corroded and are sometimes covered with paint. Ground clamps should have serrated jaws because it is often impractical to clean the conductors. The clamps should be slightly tightened in place, given a slight rotation on the conductors to provide cleaning action by the serrated jaws, and then securely tightened. Ground clamps that attach to the steel tower, switchgear, or station ground bus are equipped with pointed or cupped set screws that should be tightened to

ensure penetration through corrosion and paint to provide adequate connections.

7.2.4.2.4 Grounding cables should be no longer than is necessary to keep resistance as low as possible and to minimize slack in cables to prevent their violent movement under fault conditions. If the circuit should be inadvertently reenergized, the fault current and resultant magnetic forces could cause severe and dangerous movement of slack grounding cables in the area where personnel are working. Proper routing of grounding cables to avoid excessive slack is essential for personnel safety.

7.2.4.2.5 Grounding cables should be connected between phases to the grounded structure and to the system neutral (when available) to minimize the voltage drop across the work area if inadvertent reenergization should occur. The arrangement is shown in Figure 7.2.4.2.5 with the equivalent electrical diagram.



Note: See 7.2.4.3.

FIGURE 7.2.4.2.5 Preferred Grounding Arrangement.

7.2.4.3 In Figure 7.2.4.2.5, electrical equivalent diagram, it can be presumed that the resistance of the worker's body (R_m) is 500 ohms. The worker is in parallel with only the resistance of a single cable (R_f), which can be on the order of 0.001 ohm. R_g is the ground resistance of the switchgear or structure area. If a 1000-ampere current should flow in the circuit grounded in this manner, the worker in Figure 7.2.4.2.5 would be subjected to only about 1 volt imposed across the work area; therefore, the current flow through the worker's body would be negligible.

7.2.4.4 Connecting the phase conductors together with short cables and clamps of adequate capacity, as shown in Figure 7.2.4.2.5, minimizes resistance between phases for fast action of the circuit overcurrent protective devices to deenergize the circuit, if it is inadvertently reenergized. The short down-lead cable between the jumpered phase conductors and the grounded tower or switchgear ground bus reduces resistance to ground and the amount of cable that can move violently in the work area during high current flow. If there is a system neutral conductor at the work location, a cable should also be connected to that conductor for more complete protection and to ensure lowest resistance in the ground return path to the source. Figure 7.2.4.2.5 shows buses and a person working inside switchgear; the same conditions would apply to personnel on overhead line towers and outdoor substation steel structures. Someone working on such properly grounded areas is in parallel with a minimum of resistance so he or she would be exposed to minimum voltage drop in the event of current flow in the system, and the low resistance would cause rapid operation of the fuses or circuit breakers, thus minimizing the time the person is exposed to the voltage drop.

7.2.4.5 Prior to installation, grounding equipment should be inspected for broken strands in the conductors, loose connections to the clamp terminals, and defective clamp mechanisms. Defective equipment should not be used.

7.2.4.6 Grounding equipment should be installed at each point where work is being performed on deenergized equipment. Often it is advisable to install grounding equipment on each side of a work point or at each end of a deenergized circuit.

7.2.4.7 One end of the grounding down lead should be connected to the metal structure or ground bus of the switchgear before the other end is connected to a phase conductor of the deenergized equipment. Then, and only then, should the grounding cables be connected between phase conductors.

7.2.4.8 When grounding equipment is removed, the above installation procedure should be reversed by first disconnecting the cables between phases, then disconnecting the down lead from the phase conductor, and, finally, disconnecting the down lead from the metal structure or ground bus.

7.2.4.9 Removal of grounding equipment before the circuit is intentionally reenergized is equally as important as was its initial installation, but for other reasons. If grounding equipment is forgotten or overlooked after the work is completed and the circuit is intentionally reenergized, the supply circuit overcurrent protective devices will immediately open because the conductors are jumpered and grounded. The short-circuit current can damage the contacts of a breaker having adequate interrupting capacity and can cause an inadequate breaker or fuses to explode. If the grounding cables are inadequate, they can melt and initiate damaging power arcs. A procedure

should be established to ensure removal of all grounding equipment before the circuit is intentionally reenergized. Recommendations for such a procedure are as follows:

- (1) An identification number should be assigned to each grounding equipment set, and all sets that are available for use by all parties, including contractor personnel, should be rigidly controlled.
 - (a) The number and location of each set that is **installed** should be recorded.
 - (b) That number should be crossed off the record when each set is removed.
- (2) Before the circuit is reenergized, all sets of grounding equipment should be accounted for by number to ensure that all have been removed.
- (3) Doors should not be allowed to be closed nor should covers be allowed to be replaced where a set of grounding equipment has been installed inside switchgear. If it is necessary to do so to conceal grounding equipment, a highly visible sign should be placed on the door or cover to remind personnel that a ground is inside.
- (4) Before reenergizing the circuit, personnel should inspect interiors of equipment to verify that all grounding sets, including small ones used in testing potential transformers, relays, and so on, have been removed.
- (5) Before the circuit is reenergized, all conductors should be tested with a megohmmeter to ascertain if any are grounded. If so, the cause should be determined and corrective action taken.

7.2.4.10 Use of insulated hot-line sticks, rubber gloves, or similar protective equipment by personnel is advisable while installing grounding equipment on ungrounded, deenergized overhead line conductors and also while removing the grounding equipment.

7.2.4.11 Data available from grounding-equipment manufacturers should be referred to for ampacities of cables and clamps and for detailed application information.

7.2.4.12 In some instances, specialized grounding equipment might be required, such as traveling grounds on new overhead line conductors being strung adjacent to energized circuits.

7.2.4.13 Drawout-type grounding and testing devices are available for insertion into some models of switchgear to temporarily replace circuit breakers. These devices provide a positive and convenient grounding means for switchgear buses or associated circuits by connecting to the switchgear buses or line stabs in the same manner as drawout breakers. One such device has two sets of primary disconnecting stabs: the set designated "BUS" connects to the switchgear bus stabs, and the other set, designated "LINE," connects to the switchgear supply line or load circuit stabs. Another type of grounding device has only one set of primary disconnecting stabs that can be positioned to connect to either the switchgear "BUS" stabs or the "LINE" stabs. Grounding cables can be connected from the selected disconnecting stud terminals in one of these devices to the switchgear ground bus. When the device is fully inserted into the switchgear, it grounds the deenergized buses or lines that were previously selected. Utmost care should be exercised when using these devices to prevent the inadvertent grounding of an energized bus or circuit. Such a mistake could expose personnel to flash burns and could seriously damage the switchgear. Before a device with grounding cables connected to it is inserted into switchgear, it is essential that the stabs that are

to be grounded are tested for NO VOLTAGE and to verify that only the proper and matching disconnecting stud terminals in the device are grounded.

Chapter 8 Fundamentals of Electrical Equipment Maintenance

8.1 Design to Accommodate Maintenance.

8.1.1 Equipment should be deenergized for inspections, tests, repairs, and other servicing. Where maintenance tasks must be performed when the equipment is energized, provisions are to be made to allow maintenance to be performed safely. Refer to NFPA 70E, IEEE 3007.1, *IEEE Recommended Practice for the Operation and Management of Industrial and Commercial Power Systems*; IEEE 3007.2, *IEEE Recommended Practice for the Maintenance of Industrial and Commercial Power Systems*; and IEEE 3007.3, *IEEE Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems*. For the purposes of this chapter, *deenergized* means the equipment has been placed in an electrically safe work condition in accordance with 7.1.3.2. See Chapter 7 for examples of typical safety-related work practices that might need to be implemented.

8.1.1.1 Many maintenance tasks require equipment to be deenergized for effective results.

8.1.1.2 Other maintenance tasks might specifically require or permit equipment to be energized and in service while the tasks are performed. Examples include removing transformer oil for analysis, observing and recording operating characteristics such as temperatures, load conditions, corona, noise, lamp output, or performing thermographic surveys while the equipment is under normal operating conditions and load.

8.1.1.3 Coordinating maintenance with planned production outages and providing system flexibility with redundant equipment and processes are two recommended means to avoid major disruptions of operations. An example of flexibility is a selective radial distribution system incorporating double-ended low-voltage substations. This system permits maintenance and testing of equipment such as the primary feeders, transformers, and main, and tie circuit breakers during periods of light loads.

8.1.2 Larger production equipment, such as air compressors, air-conditioning units, and pumps, that can be difficult to repair or replace quickly is often installed in multiples to provide reserve capacity. Redundant equipment and systems enable maintenance to be performed economically without costly premium time and ensures continuous production in the event of a breakdown.

8.1.3 Selection of equipment that is adequate for present and projected load growth is a prime factor in reducing maintenance costs. Overloaded equipment or equipment not suited for the application will have a short service life and will be costly to maintain. Abnormal conditions, such as a corrosive atmosphere, excessive temperature, high humidity, abrasive or conducting particles, and frequent starting and stopping, require special consideration in the selection and location of the equipment in order to minimize maintenance costs.

8.1.4 Installation costs without sufficient regard and planning for efficient and economic maintenance influence system design. Within a few years, the added cost of performing maintenance, plus production loss from forced outages due to lack of maintenance, will more than offset the savings in initial cost.

As equipment ages and is possibly worked harder or becomes more critical to facility operations, scheduling outages to perform accelerated maintenance could become a major challenge.

8.2 Scheduling Maintenance.

8.2.1 In larger facilities, routine maintenance scheduling is often done by a computerized maintenance planning program that generates work orders for projects to be accomplished on a daily, weekly, or monthly basis. In smaller facilities, the maintenance schedule is oftentimes not formally structured and relies on facility maintenance personnel to perform the required maintenance tasks. An effective maintenance program requires a positive mechanism for scheduling and recording of work that needs to be accomplished.

8.2.2 Maintenance outages, particularly in facilities that operate 24 hours a day, 7 days a week, are difficult to schedule; however, there are areas that can be relieved with a nominal investment. For example, low-voltage power circuit breakers should be inspected on an annual basis and tested under simulated overload and fault conditions every 3 to 5 years. An investment in a few spare circuit breakers, one or two of each make and size in use, would allow them to be inspected, and tested at a more convenient time. The in-service breakers could then be exchanged with spares at the opportune time, with negligible production downtime.

8.2.3 The scope of the maintenance work should be confined to the limited time and available personnel. Contracting maintenance to qualified electrical personnel can relieve these and other support tasks associated with preventive maintenance. Electrical contractors who specialize in this type of work have trained technicians along with the proper tools and equipment. Many of them carry inventories of spare electrical parts and equipment.

▲ 8.2.4 It is necessary to establish intervals for performing specific tasks when scheduling maintenance. The following considerations should be reviewed during development of a routine maintenance schedule:

- (1) Potential of equipment failure to endanger or threaten personnel safety (*see Section 5.3*)
- (2) Manufacturer's recommended service and maintenance practices and procedures (*see 6.4.4.1*)
- (3) Operating environment (*see Section 5.6, 6.4.1, and 6.4.3*)
- (4) Operating load conditions and equipment rating (*see 5.6.3, 5.6.4, 6.4.2, and 6.4.4.4*)
- (5) Unusually expensive equipment repairs (*see Section 5.3*)
- (6) Failure and repair of equipment causing extensive downtime and lost production dollars (*see Section 5.3*)
- (7) Equipment condition (*see 6.3.3 and 6.3.5*)
- (8) Production and operating schedules (*see 6.1.6 and 6.5.3*)
- (9) Ability to take equipment out of service (*see 6.1.6*)
- (10) Failure history (*see 6.1.6 and 6.4.4.5*)
- (11) Inspection history (*see 6.4.4.5*)

8.2.4.1 A guide for maintenance intervals is included in Annex L.

8.3 Equipment Safety.

8.3.1 Destructive energy, capable of disintegrating an entire switchgear or switchboard assembly in a very short period of time, can be released during a low-voltage phase-to-phase or phase-to-ground sustained arcing fault. The fault current, in

the order of thousands of amperes, multiplied by the arc voltage drop multiplied by the duration of the arc (in seconds) is a measure of the energy released (watt-seconds).

8.3.2 Equipment safety demands sensitive and effective protection. The equipment protective device should be capable of immediately sensing an abnormality and causing it to be isolated with the least possible damage and disturbance to the system. The degree of sensitivity and speed of response is vital to the effectiveness of the protection.

8.3.3 The protective device, such as a fuse, relay, sensor, transducer, etc. generally responds to abnormal conditions. Ideally, the device should not be applied or set to respond to normal load excursions, yet it should have the ability to function on a low-level fault. This can be a difficult situation to monitor and control without properly applied protective devices. For example, unless ground-fault protection is utilized, a phase-to-ground fault could be less than normal load current and may not be sensed as a problem until catastrophic failure of the equipment causes a fault trip from the upstream protective device.

8.4 Protective Scheme.

8.4.1 Proper application of circuit protection, as developed in a short-circuit and coordination study, is typically an engineering function and therefore recognized as a facet of system design. Maintenance functions include, but are not limited to, the following:

- (1) Assuring that this designed protection system remains in operation.
- (2) Applying the engineered settings and periodic testing, lubricating, and cleaning of the protective devices, relays, and trip elements.
- (3) Verifying the proper type and ampere rating of the fuses used within the system.

8.4.2 In larger facilities, interpretation of the short-circuit and coordination study is generally made by facility engineering, and the settings and test points for the adjustable protective devices are furnished to the maintenance department, as are the type and ampere rating of the fuses. While the maintenance personnel need not be able to formulate the engineering study, they should be able to interpret the time-current curves and understand the anticipated performance of the protective device being tested.

8.4.3 An up-to-date short-circuit and coordination study is essential for the safety of personnel and equipment. As a function of the study, the momentary and interrupting rating requirements of the protective devices should be analyzed and verification made that the circuit breaker or fuse will safely interrupt a fault during fault conditions.

8.4.3.1 Additionally, the study should provide the application of the protective device to realize minimum equipment damage and the least disturbance to the system in the event of a fault by properly clearing downstream devices nearest to the point of a fault.

8.5 Acceptance Testing. The initial acceptance testing of the electrical system is part of design and facility construction and typically not part of maintenance. However, the acceptance test data does provide important benchmarks for subsequent maintenance testing. The acceptance testing should be witnessed by the owner's representative, and a copy of the test reports

should be forwarded to the facility engineer for inclusion into the maintenance records. See Chapter 31 for more detailed information on commissioning and acceptance testing.

8.6 Guidelines and Impact of Additions/Rework to Retrofitting Equipment.

8.6.1 Rework, remanufacturing, or retrofitting of equipment typically involves replacement or refurbishing of major components of equipment or systems.

8.6.2 Repairs or modifications not authorized by the original equipment manufacturer might void the equipment warranties and third-party certifications.

8.6.3 Equipment can be reconditioned under rebuild programs, provided the reconditioning follows established guidelines.

8.6.4 The rework, remanufacturing, or retrofitting process can be conducted by the original manufacturer or by another party with sufficient facilities, technical knowledge, and manufacturing skills (as evaluated by an accepted certification organization). Safety certifications should be maintained for repaired or rebuilt equipment.

8.6.5 Refurbished or remanufactured equipment should be marked to identify it as such.

8.6.6 When repairing, rebuilding, and/or remanufacturing equipment, the work should be conducted by a qualified person or organization to assure that no changes are made to the equipment that might prevent the equipment from meeting the applicable performance and safety requirements used to list the equipment. [See also NEPA 791 and OSHA Safety & Health Information Bulletin (SHIB), "Certification of Workplace Products by Nationally Recognized Testing Laboratories."]

8.6.7 The AHJ can assess the acceptability of modifications to determine if the modifications are significant enough to require re-evaluation of the modified product by the organization that listed the equipment.

8.7 Equipment Cleaning.

8.7.1 General. When cleaning equipment, the method used should be determined by the type of contamination to be removed and whether the apparatus is to be returned to service immediately. Drying is necessary after using a solvent or water. Insulation should be tested to determine if it has been properly cleaned. Enclosure and substation room filters should be cleaned at regular intervals and replaced if they are damaged or clogged. Loose hardware, dust, and debris should be removed from equipment enclosures. When properly cleaned, new or unusual wear or loss of parts can be detected during subsequent maintenance operations.

8.7.2 Methods of Cleaning.

8.7.2.1 Wiping off dirt with a clean, dry, lint-free cloth or soft brush is usually satisfactory if the apparatus is small, the surfaces to be cleaned are accessible, and only dry dirt is to be removed. Lint-free rags should be used so lint will not adhere to the insulation and act as a further dirt-collecting agent. Care should be used to avoid damage to delicate parts.

8.7.2.2 To remove loose dust, dirt, and particles, suction cleaning methods should be used.

8.7.2.3 Where dirt cannot be removed by wiping or vacuuming, compressed-air blowing might be necessary.

8.7.2.3.1 If compressed air is used, protection should be provided against injury to workers' faces and eyes from flying debris and to their lungs from dust inhalation. The use of compressed air should comply with OSHA regulations in 29 CFR 1910.242(b), "Hand and Portable Powered Tools and Other Hand Held Equipment," including limiting air pressure for such cleaning to less than a gauge pressure of 208.85 kPa (30 psi) and the provision of effective chip guarding and appropriate personal protective equipment.

8.7.2.3.2 Care should be exercised as compressed air can cause contaminants to become airborne, which can compromise the integrity of insulation surfaces or affect the mechanical operation of nearby equipment. Provisions should be made to remove the equipment to a suitable location for cleaning or to cover other equipment and guard it from cross contamination. Air should be dry and directed in a manner to avoid further blockage of ventilation ducts and recesses in insulation surfaces.

8.7.2.3.3 Protection might also be needed against contamination of other equipment if the insulation is cleaned in place with compressed air. If feasible, equipment should be removed to a suitable location for cleaning, or other exposed equipment should be covered before cleaning to keep the debris from entering exposed equipment.

8.7.2.4 Accumulated dirt, oil, or grease might require a solvent to remove it. A lint-free cloth barely moistened (not wet) with a nonflammable solvent can be used for wiping. Solvents used for cleaning of electrical equipment should be selected carefully to ensure compatibility with materials being cleaned. Liquid cleaners, including spray cleaners, are not recommended unless solvent compatibility is verified with the equipment manufacturer, as residues could cause damage, interfere with electrical or mechanical functions, or compromise the integrity of insulation surfaces.

8.7.2.5 Some equipment could require cleaning by nonconductive abrasive blasting.

8.7.2.5.1 Shot blasting should not be used.

CAUTION: Cleaning with abrasives or abrasive blasting methods can create a hazard to personnel and equipment.

8.7.2.5.2 Abrasive blasting operations should comply with OSHA regulations in 29 CFR 1910.94(a), "Occupational Health and Environmental Control — Ventilation." Protection should be provided against injury to workers' faces and eyes from abrasives and flying debris and to their lungs from dust inhalation.

8.7.2.6 Airborne asbestos fibers can endanger health and are subject to government regulations. Knowledge of government regulations related to the handling of asbestos is required before handling asbestos and other such materials. (Copies of the *Toxic Substances Control Act* as defined in the U.S. Code of Federal Regulations can be obtained from the U.S. Environmental Protection Agency.)

8.7.2.7 If sweeping of an electrical equipment room is required, a sweeping compound should be used to limit the amount of dirt and dust becoming airborne. During mopping, the mop bucket should be kept as far as practical from the electrical equipment.

8.8 Special Handling and Disposal Considerations.

8.8.1 The handling and disposal of certain electrical equipment, components, and materials can present special maintenance obligations. Examples of such materials are given in 8.8.1.1 through 8.8.1.9.

8.8.1.1 Asbestos. Asbestos-containing materials can be present in equipment such as wire, switches, circuit protectors, panelboards, and circuit breakers, particularly in various arc chute constructions. (See 8.7.2.6.)

8.8.1.2 Polychlorinated Biphenyls (PCBs). PCBs were used as noncombustible dielectric fluids in transformers, capacitors, cables, and fluorescent ballasts. Although PCBs are no longer manufactured in the United States and are no longer put in new equipment, PCBs might still exist in older transformers, power capacitors, oil-insulated cables, and fluorescent lighting ballasts. Unless verified and labeled as PCB free, the device should be carefully handled until verified PCB free. (See 21.2.1.3.)

8.8.1.3 Lead. The disposal of paper-insulated, lead-covered cables can be an environmental concern. Abandoning a lead product in the ground, such as lead-covered cable, is prohibited in some jurisdictions. If left abandoned, the lead can leach soluble lead salts into the environment.

8.8.1.4 Mineral Oil. Mineral oil is a petroleum product, therefore, the disposal of ordinary transformer oil can be an environmental concern. Spent oil should be sent to a manufacturer or processor for recycling. In the United States, certain quantities of oil spills require state and regional EPA notification.

8.8.1.5 Tetrachlorethylene. Some transformers contain tetrachlorethylene, a toxic substance. Where possible, recycling should be considered.

8.8.1.6 Trichloroethane. Vapors from trichloroethane, sometimes used as an electrical cleaning and degreasing solvent, are toxic and present an environmental threat. Handling and disposal of the liquid require special precautions, as trichloroethane is an ozone-depleting chemical. Many jurisdictions have banned the use of trichloroethane products.

8.8.1.7 Mercury Vapor and Phosphor Coatings. Fluorescent lamps and similar gas tubes could contain mercury vapor and phosphor coatings. If the tube breaks, these materials can escape into the environment. The disposal of large quantities of tubes warrants capturing these materials.

8.8.1.8 Radioactive Materials. Devices containing radioactive materials require special precautions.

8.8.1.9 Other Harmful Agents. Hazards presented by materials and processes should be reviewed whenever changes are planned. For example, a substitute cleaning agent might be more hazardous than the original cleaner, and special handling precautions might be needed for the new cleaner. Or, because of a planned change in operations, a fabric filter might soon be collecting a toxic substance, and new procedures for filter replacement and disposal might be needed.

8.8.2 Those responsible for establishing and sustaining maintenance programs should keep abreast of relevant material-handling and disposal issues, including knowledge of toxic substances, environmental threats, and the latest technologies for waste handling and salvage. Testing might be required to determine the presence of toxic substances.

8.8.3 Health and environmental issues, governmental regulations, and salvage values should all be addressed in disposal-planning programs.

8.9 Supervisory Control and Data Acquisition (SCADA) Systems.

8.9.1 General. A comprehensive maintenance program is critical to attaining long-term reliable performance of supervisory control and data acquisition (SCADA) systems. Periodic device calibration, preventive maintenance, and testing allow potential problems to be identified before they can cause a failure of intended mission or function. Prompt corrective maintenance ensures reliability by minimizing downtime of redundant components.

8.9.2 Special Term. The following special term is used in this chapter.

8.9.2.1 Concurrent Maintenance. The testing, troubleshooting, repair, and/or replacement of a component or subsystem while redundant component(s) or subsystem(s) are serving the load, where the ability to perform concurrent maintenance is critical to attaining the specified reliability/availability criteria for the system or facility.

8.9.3 Preventive Maintenance. The SCADA system should be part of the overall preventive maintenance program for the facility. The recommended maintenance activities and frequencies can be found in Annex L for the various components of SCADA. Preventive maintenance schedules for SCADA components and subsystems should be coordinated with those for the mechanical/electrical systems that they serve, to minimize overall schedule downtime.

8.9.4 Testing. Many components of SCADA systems, such as dead-bus relays, are not required to function under normal system operating modes. For this reason, the system should be tested periodically under actual or simulated contingency conditions. Periodic system testing procedures can duplicate or be derived from the recommended functional performance testing procedures of individual components, as provided by the manufacturers.

8.9.5 Concurrent Maintenance. Maintenance should be scheduled to occur during maintenance of associated equipment.

8.10 Lubrication. Lubrication is the application of grease or oil to the bearings of motors, rotating shafts, circuit breaker mechanisms, gears, and so forth. It also includes light lubrication to door hinges or other sliding surfaces on the equipment. Some special parts are identified as being prelubricated for life and should require no further lubrication.

8.10.1 Proper application of lubricants, compatible with existing lubricants on the equipment, is paramount if the equipment is to operate as intended. Manufacturer's instruction bulletins and maintenance procedures should be referenced before applying any lubricants to electrical equipment. Caution should be exercised in the use of products identified as penetrating solvents because they may not be acceptable as lubricants in accordance with manufacturer's specifications.

8.11 Threaded Connections and Terminations. It is important for threaded connections and terminations to be properly tightened. Verifying torque values after initial installation is not reliable. It is normal for metal relaxation to occur after installation.

8.11.1 Initial Installation. When installing equipment, use a calibrated torque measurement tool and torque the screw or bolt to the assembly or component manufacturer's specification, which is typically on the device label or in the instructions or datasheet. The torque values are part of the testing and listing procedures and listed or labeled equipment is to be installed in accordance with instructions.

8.11.1.1 If the equipment or device manufacturer does not have the torque value on the device label, in the instructions or datasheet, or otherwise published, then use the torque data found in Table I.1 through Table I.3 of *NFPA 70*, or values from another industry standard.

8.11.1.2 After tightening to the initial torque, mark a straight line that spans the screw or bolt as well as the stationary part of the connection or termination. This mark provides evidence if the screw or bolt has moved after the proper torque has been applied.

8.11.2 Methods for Verifying Proper Tightness After Initial Installation. Inspect electrical connections and terminations for high resistance using one or more of the following methods:

- (1) Use a low-resistance ohmmeter to compare connection and termination resistance values to values of similar connections and terminations. Investigate values that deviate from those of similar connections or terminations by more than 50 percent of the lowest value in accordance with ANSI/NETA MTS, *Maintenance Testing Specifications for Electrical Power Equipment and Systems*.
- (2) Verify the tightness of accessible connections and terminations using a calibrated torque measurement tool in accordance with 8.11.3, 8.11.4, and 8.11.5.
- (3) Perform a thermographic survey. (See Section 11.17.)

8.11.3 Checking Tightness Where There Are No Signs of Degradation. After a connection or termination is torqued to the specified value there can be metal relaxation. It is not appropriate to check an existing connection or termination for tightness to the prescribed specified value with a calibrated torque measurement tool. Doing so can result in an improperly terminated conductor or cause damage to the connection and might void the listing. One industry practice is to use a calibrated torque measuring tool to check existing connections and terminations at 90 percent of the specified torque value as determined in 8.11.1. If the screw or bolt does not move, the existing connection or termination is considered properly torqued. If the screw or bolt moves it is an indication the connection or termination is not properly torqued and the connection or termination should be reinstalled.

8.11.4 Checking Tightness When There Are Signs of Degradation. If a connection or termination shows signs of degradation, such as a loose connection, overheating, equipment misalignment, or deformation, or if a thermal scan shows overheating, then further investigation might be necessary. If signs of degradation are present at terminations, cut the damaged end of the conductor and reinstall per 8.11.1. When cutting the conductor end, be sure to remove any portion of the conductor that shows signs of having been overheated. If the device is damaged, the device should be replaced. Bolted connections need to be disassembled, inspected, repaired, and torqued to the proper value.

8.11.5 Tightening Battery Terminal Connections. Terminal post connections should only be tightened when the need is

indicated by resistance readings or infrared scan. Because the posts are usually made of lead, frequent tightening can degrade and permanently damage the posts. Clean and torque only in accordance with the battery manufacturer's recommended practice. Note that voltage is always present. It might be necessary to disconnect the battery from its critical load to service the terminal connections.

Chapter 9 System Studies

9.1 Introduction. Electrical studies are an integral part of system design, operations, and maintenance. These engineering studies generally cover the following areas:

- (1) Short-circuit studies
- (2) Coordination studies
- (3) Load-flow studies
- (4) Reliability studies
- (5) Risk assessment study
- (6) Maintenance-related design study

9.1.1 Copies of single-line diagrams and system study data should be given to the facility maintenance department. It is critical to efficient, safe system operation that the maintenance department keep the single-line diagrams current and discuss significant changes with the facility engineering department or consulting electrical engineer. It should be noted, however, that the information required for system studies is highly specialized, and outside help might be necessary.

9.2 Short-Circuit Studies.

9.2.1 Short circuits or fault currents represent a significant amount of destructive energy that can be released into electrical systems under abnormal conditions. During normal system operation, electrical energy is controlled and does useful work. However, under fault conditions, short-circuit currents can cause serious damage to electrical systems and equipment and create the potential for serious injury to personnel. Short-circuit currents can approach values as large as several hundred thousands of amperes.

9.2.1.1 During short-circuit conditions, thermal energy and magnetic forces are released into the electrical system. The thermal energy can cause insulation and conductor melting as well as explosions contributing to major equipment burn-downs. Magnetic forces can bend bus bars and cause violent conductor whipping and distortion. These conditions have grim consequences on electrical systems, equipment, and personnel.

9.2.1.2* Protecting electrical systems against damage during short-circuit faults is required in Sections 110.9 and 110.10 of *NFPA 70*. Additional information on short-circuit currents can be found in ANSI/IEEE 242, *Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book)*; ANSI/IEEE 141, *Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book)*; ANSI/IEEE 241, *Recommended Practice for Electric Power Systems in Commercial Buildings (IEEE Gray Book)*; and ANSI/IEEE 399, *Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE Brown Book)*.

9.2.2 Baseline short-circuit studies should be performed when the facility electrical system is designed. They should be updated when a major modification or renovation takes place, but no more frequently than every 5 years. A copy of the most

recent study should be kept with other important maintenance documents.

9.2.2.1 The following are some of the conditions that might require an update of the baseline short-circuit study:

- (1) A change by the utility
- (2) A change in the primary or secondary system configuration within the facility
- (3) A change in the transformer size (kVA) or impedance (percent Z)
- (4) A change in conductor lengths or sizes
- (5) A change in the motors connected to the system

9.2.2.2 A periodic review of the electrical system configuration and equipment ratings should be checked against the permanent records. Specific attention should be paid to the physical changes in equipment, including changes in type and quantity. Significant changes should be communicated to the maintenance supervisor, the facility engineering department, or the electrical engineer.

9.2.2.3 A comprehensive treatment of short-circuit currents is beyond the scope of this document. However, there is a simple method to determine the maximum available short-circuit current at the transformer secondary terminals. This value can be calculated by multiplying the transformer full load amperes by 100, and dividing the product by the percent impedance of the transformer.

9.2.2.3.1 Figure 9.2.2.3.1 shows an example: 500 kVA transformer, 3-phase, 480 V primary, 208 Y/120 V secondary, 2 percent Z.

9.2.2.3.2 There are several computer programs commercially available to conduct thorough short-circuit calculation studies.

9.2.2.4 When modifications to the electrical system increase the value of available short-circuit amperes, a review of overcurrent protection device interrupting ratings and equipment withstand ratings should take place. This might require replacing overcurrent protective devices with devices having higher interrupting ratings or installing current-limiting devices such as current-limiting fuses, current-limiting circuit breakers, or current-limiting reactors. For silicon control rectifier (SCR) or diode input devices, change of the source impedance can affect equipment performance. Proper operation of this equipment depends on maintaining the source impedance within the rated range of the device. The solutions to these engineering problems are the responsibility of the maintenance supervisor, the facility engineering department, or the electrical engineer.

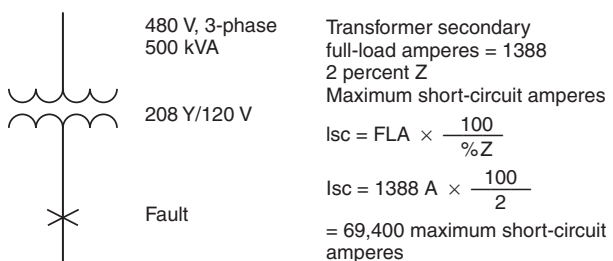


FIGURE 9.2.2.3.1 Example Calculation of Maximum Available Short-Circuit Current at the Transformer Secondary Terminals.

9.3 Coordination Studies.

9.3.1 A coordination study, sometimes called a selectivity study, is done to improve power system reliability. [See 3.3.10, *Coordination (Selective)*.]

9.3.1.1 Improper coordination can cause unnecessary power outages. For example, branch-circuit faults can open multiple upstream overcurrent devices. This process can escalate and cause major blackouts, resulting in the loss of production. Blackouts also affect personnel safety.

9.3.1.2 NFPA 70 and various IEEE standards contain the requirements and suggested practices to coordinate electrical systems. The IEEE standards include ANSI/IEEE 242, *Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book)*; ANSI/IEEE 141, *Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book)*; ANSI/IEEE 241, *Recommended Practice for Electric Power Systems in Commercial Buildings (IEEE Gray Book)*; and ANSI/IEEE 399, *Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE Brown Book)*. (See A.9.2.1.2.)

9.3.2 A baseline coordination study is generally made when the electrical system is designed. A copy of the study should be kept with other important facility maintenance documents.

9.3.3 Changes affecting the coordination of overcurrent devices in the electrical system include the following:

- (1) A change in the available short-circuit current
- (2) Replacing overcurrent devices with devices having different ratings or operating characteristics
- (3) Adjusting the settings on circuit breakers or relays
- (4) Changes in the electrical system configuration
- (5) Inadequate maintenance, testing, and calibration

9.3.4 The facility electrical system should be periodically reviewed for configuration changes, available short-circuit current changes, changes in fuse class or rating, changes in circuit-breaker type or ratings, and changes in adjustable trip settings on circuit breakers and relays.

9.3.4.1 Any changes noted in the coordinated performance of overcurrent protective devices should be reported to the maintenance supervisor, the facility engineering department, or the consulting electrical engineer.

9.3.4.2 Time-current curves should be kept up to date. Usually this is the responsibility of the facility engineering department or the consulting electrical engineer. However, it is vitally important for facility maintenance to observe and communicate coordination information to the maintenance supervisor, facility engineering department, or consulting electrical engineer.

9.4 Load-Flow Studies.

9.4.1 Load-flow studies show the direction and amount of power flowing from available sources to every load. By means of such a study, the voltage, current, power, reactive power, and power factor at each point in the system can be determined.

9.4.1.1 This information is necessary before changes to the system can be planned and will assist in determining the operating configuration. This study also helps determine losses in the system. ANSI/IEEE 399, *Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE Brown Book)*, provides more detailed information.

9.4.1.2 Load-flow studies should be done during the design phase of an electrical distribution system. This is called the baseline load-flow study. The study should be kept current and revised whenever significant increases or changes to the electrical system are completed.

9.4.1.3 Some of the events that result in load-flow changes include changing motors, motor horsepower, transformer size, or impedance; operating configurations not planned for in the existing study; adding or removing power-factor correction capacitors; and adding or removing loads.

9.4.2 It is important that the system single-line diagrams and operating configurations (both normal and emergency) be kept current along with the load-flow study.

9.4.3 Some signs that indicate a need to review a load-flow study include unbalanced voltages, voltage levels outside the equipment rating, inability of motors to accelerate to full load, motor starters dropping off line when other loads are energized, or other signs of voltage drop. Additional signs also include poor system power factor; transformer or circuit overloading during normal system operation, and unacceptable overloading when the system is operated in the emergency configuration.

9.4.4 When changes to the electrical system are made, the maintenance department should note the changes on their copy of the single-line diagram. Significant changes, as mentioned in 9.4.1.3, should be reviewed with the maintenance supervisor, facility engineering department, or the consulting electrical engineer to determine if changes are necessary to the single-line diagram.

9.4.5 Data Collection Methods. In order to conduct short circuit, coordination, and arc flash studies, specific data should be collected. This data should be included on a single line diagram: utility company points of contact, and data records for equipment such as, but not limited to transformers, cables, overhead lines, fuses, medium voltage breakers, reclosers, capacitor banks, low voltage breakers, disconnects, generators, and motors. This information should be developed for each type of operating conditions. Typical data collection forms are included in Figure H.47 through Figure H.49.

9.4.5.1 Utility information should at least include the minimum and maximum short circuit MVA and the X/R ratio at the service point; point of contact name, address, and telephone number in addition to a facility point of contact, address, and telephone number.

9.4.5.2 Transformer data records should include location, rated kVA, maximum kVA, primary voltage, secondary voltage, impedance in percent, type of primary and secondary connection, ground impedance, and if appropriate, the voltage tap.

9.4.5.3 Cable data should include “to” and “from,” rated volts, nominal volts, single conductor or three conductor cable, the number of conductors per phase, the neutral size, copper or aluminum, and length in feet.

9.4.5.4 Raceway material (magnetic or nonmagnetic) should be noted.

9.4.5.5 Overhead line information should include “to” and “from,” connection configuration, nominal volts, number of lines, lines per phase, ground size, type of cable (material), and length in feet.

9.4.5.6 Medium voltage breaker information should include location of the breaker, manufacturer, type, rated volts, interrupting current, interrupting time (cycles), close/latch amps and for the associated relays the manufacturer/type, time delay range and existing tap, time dial, instantaneous range and existing tap, and CT ratio.

9.4.5.7 Recloser information should include location, CT ratio, nominal volts, manufacturer, type, BIL, continuous current rating, interrupting rating, minimum trip, operational sequence, reclosing times (if available), and tripping curves (if available).

9.4.5.8 Low voltage information for the breaker should include: location, manufacturer, type, rated volts, frame rating, and interrupting rating; for the trip device: manufacturer, type, long time delay range and bands available, short time delay range and bands available, instantaneous range, and ground range and bands available.

9.4.5.9 Generator information should include location, type, kVA rating, generated volts, rated current, rpm, wiring connection (e.g., delta or wye), system ground, subtransient impedance, ground impedance, and power factor.

9.4.5.10 Motor information should include location, type, horsepower, rated volts, full load amps, rpm, code letter, locked rotor amps, power factor, and starter type.

9.4.5.11 Capacitor bank information should include the location, kVAR rating, rated volts, and wiring connection (e.g., delta or wye).

9.4.5.12 Fuse information should include the location, voltage rating, interruption rating, fuse type or class, manufacturer, and manufacturer's part number.

9.5 Reliability Studies.

9.5.1 A reliability study is conducted on facility electrical systems to identify equipment and circuit configurations that can lead to unplanned outages.

9.5.1.1 The study methods are based on probability theory. The computed reliability of alternative system designs as well as the selection and maintenance of components can be made to determine the most economical system improvements. A complete study considering all the alternatives to improve system performance add technical credibility to budgetary requests for capital improvements.

9.5.1.2 An immediate benefit from this investigation is the listing of all system components with their failure modes, frequencies, and consequences. This allows weakness in component selection to be identified prior to calculation of risk indices.

9.5.1.3 ANSI/IEEE 399, *Recommended Practice for Industrial and Commercial Power Systems Analysis (IEEE Brown Book)*, Chapter 12, provides more detailed information. In addition, there are publications that deal with reliability calculations, including TM 5-698-1, *Reliability/Availability of Electrical and Mechanical Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities*; TM 5-698-2, *Reliability-Centered Maintenance (RCM) for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities*; and TM 5-698-3, *Reliability Primer for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance (C4ISR) Facilities*.

9.5.2 A reliability study can be conducted when alternative systems, components, or technologies are being considered to improve reliability. Changes affecting the reliability of an electrical system or component can include one or more of the following:

- (1) System design
- (2) Reliability of the power source
- (3) Equipment selection
- (4) Quality of maintenance
- (5) Age of equipment
- (6) Equipment operating environment
- (7) Availability of spare parts

9.5.2.1 Generally, the existing system design cannot be significantly altered; however, it is possible to meet with the utility and discuss methods for increasing the reliability of service. The selection of reliable equipment and the need for additional maintenance can be evaluated from an economic standpoint. The age of equipment and the environment in which it is operated affects the probability of equipment failure. Spare parts should be monitored and inspected periodically to ensure that they will be available when needed. The study should be kept current and revised whenever a significant change to the electrical system has been made.

9.5.3 A reliability study begins with the system configuration documented by a single-line diagram. Reliability numerics are applied to a system model identifying system outages based on component downtime and system interactions. A failure modes and effect analysis (FMEA) is used to generate a list of events that can lead to system interruption and includes the probability of each event and its consequences. An example of an FMEA table for a facility's electrical equipment is shown in Table 9.5.3. The frequency of failures per year can be obtained from ANSI/IEEE 493, *Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (IEEE Gold Book)*.

9.5.4 The information in Table 9.5.3 can be analyzed using event-tree analysis or by computing a system reliability index. The event tree is used to further break down each system or component failure into a series of possible scenarios, each with an assigned probability. The outcome is a range of consequences for each event tree.

9.5.4.1 A system reliability index assigns a number (usually expressed in hours down per year) for each system configuration. The calculations for alternative system configurations can be redone until an acceptable downtime per year is obtained. For details on how to conduct a reliability study and how to obtain the number of hours down per year, see Chapter 30.

▲ Table 9.5.3 Sample FMEA Table

System/ Component	Failure Mode	Frequency per Year	Consequence (\$1000)
Breaker B1	Internal fault	0.0036	150
Transformer T1	Winding failure	0.0062	260
Motor M1	Stator damage	0.0762	225

9.6 Risk Assessment Studies.

9.6.1 A risk assessment study is conducted on facility electrical systems to determine the following for each designated piece of electrical equipment:

- (1) Incident energy exposure at working distance
- (2) Arc flash boundary
- (3) Appropriate arc-rated personal protective equipment required within the arc flash boundary

Δ 9.6.1.1 A risk assessment study is an important consideration for electrical safe work practices. Refer to NFPA 70E and IEEE 3007.3, *IEEE Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems*, for guidance on risk assessment and selection of PPE.

9.6.2 The benefit of a risk assessment is being able to provide the necessary information to a qualified electrical worker so that proper safe work practices can be followed if the worker has to work on or near electrical equipment not in an electrically safe work condition.

9.6.3 The available short-circuit current and the total clearing time at each designated piece of electrical equipment is needed to perform a risk assessment. NFPA 70E and OSHA provides the requirements. *IEEE 1584, Guide for Performing Arc Flash Hazards Calculations*, provides suggested calculation methods.

9.6.4 Where the result of the risk assessment at a designated piece of equipment is greater than what is appropriate for the available PPE, a means to reduce the hazard level should be implemented.

9.6.5 The risk assessment study results are field marked by a label on the equipment. The documentation for the arc flash hazard analysis should be retained for reference and use as needed.

9.6.6 The risk assessment should be repeated if there are changes that occur that affect the arc flash hazard, such as changes in the available short-circuit current or in the overcurrent protective devices.

N 9.7 Maintenance-Related Design Study.

N 9.7.1 A maintenance-related design study should develop design options that eliminate or reduce hazards or reduce risk for maintenance or daily operations. This study should use input that can include the electrical system design, the equipment maintenance instructions, and the company's historical maintenance data, as well as results of other available studies such as reliability and risk assessment studies. The study should evaluate design and operational concepts for electrical equipment and installations that impact the safety of maintenance practices and then make recommendations for improvement. Facilities management should use this study to make implementation decisions. Design considerations to enhance operations should include the entire life cycle cost of the building or system. The initial cost for efficient use of energy and for providing an efficient maintenance environment should be considered as valuable long-term investments that support daily operations. Workspaces and systems should be designed to allow safe maintenance or urgent repair while other operations continue. System-monitoring equipment can be used for planning predictive maintenance and help prevent unplanned outages.

N 9.7.2 A maintenance-related design study should include an evaluation of various maintenance-related design element options such as, but not limited to, the following:

- (1) Sufficient clearances to remove and install drawout circuit breakers
- (2) Remote operating controls and remote racking for circuit breakers
- (3) Lift mechanisms to allow safe removal of drawout circuit breakers
- (4) Motor control centers having the capability to rack individual buckets in or out remotely
- (5) Permanently mounted absence-of-voltage testers
- (6) Perform an incident energy analysis in addition to short circuit and coordination studies
- (7) Design redundancy into the electrical power system to facilitate personnel to perform maintenance on equipment in an electrically safe work condition and still power the loads
- (8) Motor overload relays that can be reset without exposing the worker to energized conductors or circuit parts
- (9) Infrared windows to allow for testing and inspection without exposing workers to energized parts
- (10) Thermal sensors for critical terminations, ultrasonic sensors in medium-voltage equipment, and partial discharge monitoring of critical cables and equipment
- (11) Automatic transfer switches having maintenance bypass switches

N 9.7.3 After the risk assessment study in Section 9.6 is complete, Annex O of NFPA 70E should be referenced for additional items that could be evaluated in the maintenance-related design study.

Chapter 10 Power Quality

10.1 Introduction.

Δ 10.1.1 Special Terms. The special term in 10.1.1.1 is used in this chapter.

10.1.1.1 Multipoint Grounding. The interconnection of primary and secondary neutrals of the transformer where the primary and secondary neutrals are common and both utilize the same grounding electrode that connects the system to earth.

10.1.1.1.1 These interconnections provide corresponding neutral circuit conductors in both the primary and secondary single-phase and wye-connected windings. This provides a low impedance path between each system and allows ground current disturbances to flow freely between them with little or no attenuation. Although there are advantages to these "wye-wye" systems, they can contribute to a common mode noise problem.

10.1.1.1.2 Multipoint grounding can also be found with systems where one or both windings are delta connected.

10.1.1.1.3 The primary and secondary windings are only casually interconnected, and this provides significant impedance to any current flow between them as there are no corresponding circuit conductors that can be directly connected together. Grounding a circuit conductor at any point up to the service entrance disconnect location of the premises is permitted. Multipoint grounding of separately derived systems is not

permitted, and single-phase 2-wire, single-phase 3-wire (split-phase), or delta-wye multiphase systems are recommended.

10.1.2 General.

10.1.2.1 Power quality addresses deviations and interruptions from the pure, ideal power supply. Alternating-current (ac) power used to run equipment often consists of distorted, nonsinusoidal waveforms (nonlinear); waveforms in the three phases of a 3-phase circuit commonly differs slightly in size and shape; and circuit voltage can change as the load on the circuit changes.

10.1.2.2 Historically, most equipment has been moderately tolerant of typical power quality problems. Some equipment with electronic components is more susceptible to power quality problems. Some equipment conducts current during only part of the power frequency cycle. These are typically called nonlinear loads and are sources of harmonic currents. Rectified input switch-mode power supplies; arcing devices, including fluorescent lamps; and other nonlinear devices affect waveforms and cause a decrease in power quality.

10.1.2.3 Power quality problems are frequently caused by equipment or conditions on the customer's premises. Power quality problems are less frequently caused by utility generating, transmission, or distribution equipment. However, off-site equipment belonging to neighbors and line exposures such as from capacitor switching, lightning, vehicles, contaminants, and wildlife can create problems that are carried by the utility to its customers.

10.1.2.4 Poor power quality can cause electrical faults, jeopardize personal safety, damage or reduce the life of electrical and electronic equipment, cause an increased fire hazard, and reduce equipment performance and productivity. Poor power quality can also affect data and communications. Maintaining the quality of the entire process might require monitoring of the process transducers and associated communication systems, as well as the electrical supply.

10.1.2.5 While power quality problems are often identified by maintenance personnel, diagnosing problems and finding solutions can be difficult. Some solutions require knowledge of electrical engineering, testing, and specialized equipment. A solution might require a custom-engineered approach, not merely equipment repair, upgrade, or replacement.

10.1.2.6 Power quality disturbances include the following:

- (1) Harmonics imposed on the fundamental sine wave
- (2) Voltage transients
- (3) Voltage sags and swells
- (4) Long-duration undervoltage and sustained voltage interruptions
- (5) Unbalanced voltages and single phasing (partial interruption)
- (6) Inadvertent and inadequate grounding
- (7) Electrical noise
- (8) Interharmonics
- (9) Voltage fluctuations (light flicker)

10.1.2.6.1 For common power system disturbances, a waveform of a sag cleared by the supply line circuit breaker, and a waveform with transient from power factor capacitor switching, see Figure 10.1.2.6.1(a), Figure 10.1.2.6.1(b), and Figure 10.1.2.6.1(c).

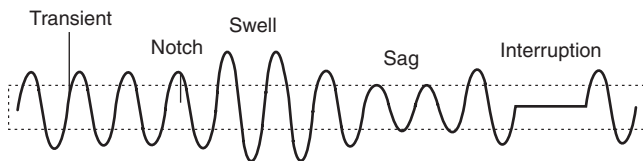


FIGURE 10.1.2.6.1(a) Common Power System Disturbances.

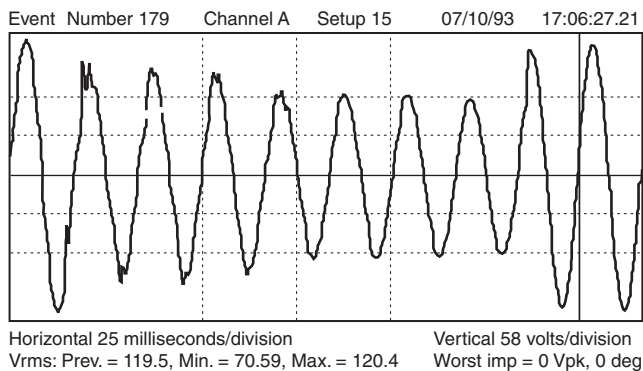


FIGURE 10.1.2.6.1(b) Waveform of Sag Cleared by Supply Line Breaker Operation.

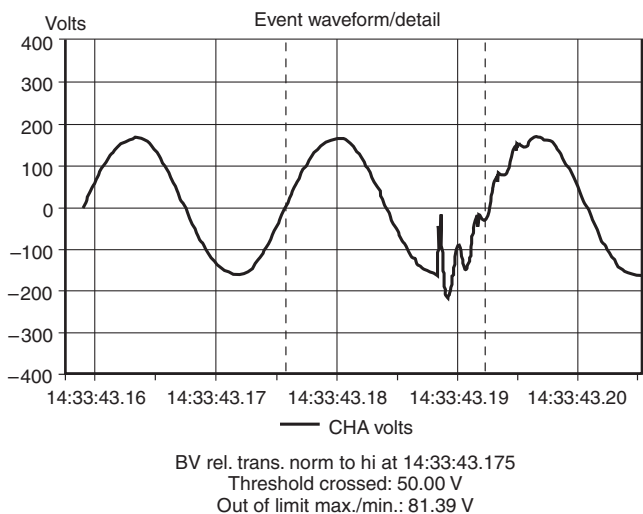


FIGURE 10.1.2.6.1(c) Waveform with Transient from Power Factor Capacitor Switching.

10.2 Harmonics.

10.2.1 Introduction.

10.2.1.1 The fundamental frequency (usually 60 Hz) is the predominant, intended frequency of a power system. Harmonics are identified by their harmonic number. For example, with a 60 Hz fundamental frequency, 120 Hz is the second harmonic, 180 Hz the third harmonic, and 300 Hz the fifth harmonic.

10.2.1.2 Harmonics distort and change the rms magnitude of the waveform. (See Figure 10.2.1.2.)

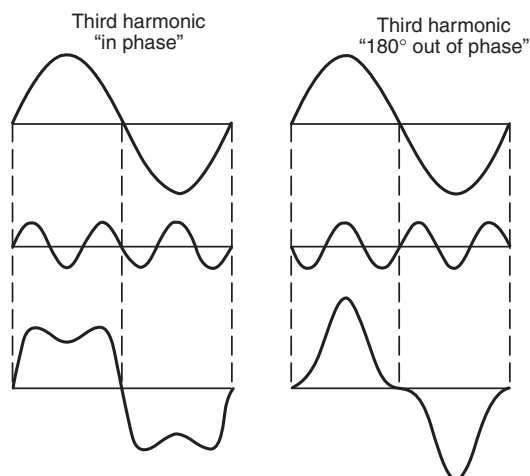


FIGURE 10.2.1.2 Harmonics and the Fundamental Waveform.

10.2.1.3 Harmonics imposed on the power system are typically calculated from measurements over either 10 or 12 cycles, depending on whether the fundamental frequency is 50 Hz or 60 Hz, respectively, and are usually expressed as a percentage of the fundamental voltage or current. For example, the total harmonic distortion (THD) of a voltage waveform is stated as a percentage and can be defined as 100 times the square root of the ratio of the sum of the squares of the rms amplitudes of the individual harmonics, or root mean square (rms), divided by the square of the voltage at the fundamental frequency and is represented by the following formula:

$$THD = \left(\frac{100 \times \sqrt{\sum V_h^2}}{V_f} \right) \% \quad [10.2.1.3]$$

where:

THD = total harmonic distortion (percent)

V_h = rms voltage of the individual harmonic

V_f = rms voltage of the fundamental frequency

10.2.1.3.1 This value should be considered related to the maximum load capacity when used for current THD. For example, a circuit may have 1A of current flowing on a 30A circuit, where 50 percent of the current is harmonic current. A load of 0.5A of harmonic current is normally not a problem on a 30A circuit. However, if the situation was 50 percent current THD on a circuit and the total current was 25A, this may cause problems. Instead, Total Demand Distortion (TDD) should be used. See ANSI/IEEE 519, *Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*.

10.2.1.4 Line voltage notching is a form of harmonic distortion, as shown in Figure 10.2.1.4. In many cases, line voltage notching caused by phase-controlled rectifiers can be more of a problem than current harmonics. Commutation notches can affect the performance of electronic equipment.

10.2.2 Harmonic Symptoms and Effects.

10.2.2.1 Harmonics are caused by nonlinear loads in which the current waveform does not conform to the waveform of the

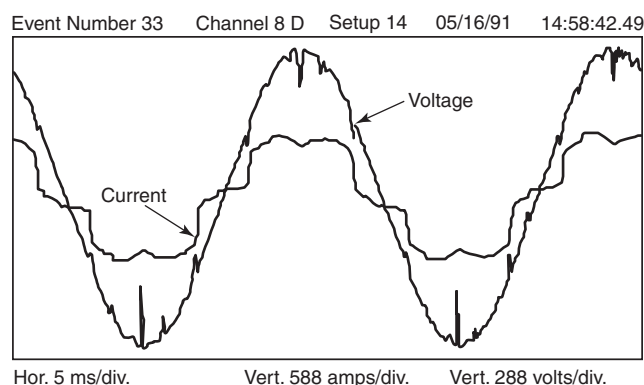


FIGURE 10.2.1.4 Line Voltage Notching Harmonic Distortion.

impressed voltage. Some of the symptoms and effects of nonlinear loads are comparable to other, more readily recognized symptoms such as overloading and can be difficult to diagnose.

10.2.2.1.1 Problems created by harmonics might include the following:

- (1) Excessive neutral current
- (2) Overheating of transformers, motors, generators, solenoid coils, and lighting ballasts
- (3) Nuisance operation of protective devices
- (4) Unexplained blowing of fuses on power-factor correction capacitors
- (5) Unusual audible noise in electrical switchgear
- (6) Voltage and current waveform distortion that results in misoperation or failure of solid-state electronic equipment
- (7) Audible noise interference on telephone circuits
- (8) Loss of data on computer systems
- (9) False operation of facility distribution power line carrier control systems such as lights, clocks, and load shedding
- (10) Failure of uninterruptible power supply (UPS) systems to properly transfer
- (11) Shaft voltages and currents on electric motors causing bearing failure if the bearings are not insulated

10.2.2.1.2 The neutrals of 3-phase, 4-wire systems are especially susceptible to harmonic problems. On such circuits, each phase is displaced by 120 electrical degrees from adjacent phases. If the load is balanced and no harmonics are present, the phase currents cancel vectorially, and the neutral current is zero. However, odd triplen harmonics, such as the third, ninth, and fifteenth, are additive rather than subtractive in the neutral and do not cancel.

10.2.2.1.3 For example, in a 3-phase, 4-wire system, if there are 30 amperes of triplen harmonic current present in a 100-ampere phase current, 90 amperes of triplen harmonic current will flow in the neutral. Neutral current will be higher if the phase currents are unbalanced.

10.2.2.2 Capacitors do not create harmonics, but capacitor failures and blown fuses on power-factor improvement capacitors are often attributable to harmonics. This situation occurs because capacitance can combine with circuit inductance to establish a resonant condition when harmonics are present. Resonance can cause high voltages to appear across elements of the power system and can cause high currents to flow.

10.2.2.2.1 Proper analysis of harmonics involves determining the amount of harmonic current that can be injected by nonlinear loads and then determining the system response to these harmonic currents. The system response usually will be dominated by the interaction of shunt capacitor banks (power-factor correction capacitors) with the system source inductance (step-down transformer). An example of frequency response characteristic is shown in Figure 10.2.2.2.1.

10.2.2.2.2 The parallel resonance occurs at the frequency where the shunt capacitive reactance is equal to the inductive source reactance and can be expressed in terms of the 60 Hz values as follows:

[10.2.2.2.2]

$$h = \sqrt{\frac{X_c}{X_{sc}}} = \sqrt{\frac{kVA_{sc}}{kVAR_{cap}}}$$

where:

h = resonant frequency as a multiple of the fundamental frequency

X_c = shunt capacitive reactance of capacitor

X_{sc} = short-circuit reactance of source

kVA_{sc} = short-circuit kVA of source

$kVAR_{cap}$ = total capacitor kVAR

10.2.2.2.3* This simple relationship provides an excellent first check of whether harmonics are likely to be a problem. An overvoltage condition problem occurs when this parallel resonance moves close to the fifth or seventh harmonic, since these are the largest harmonic current components in most nonlinear loads that contain 3-phase, full wave rectifiers. However, the eleventh and thirteenth harmonics can also be a problem when nonlinear loads are a large percentage of the total load. If a parallel resonance exists at one of the characteristic harmonics, the harmonic currents injected by the nonlinear loads are magnified, and high magnitudes of voltage distortion occur.

10.2.2.3 Harmonics can cause overheating, overvoltage, and excessive noise in transformers. Overheating is a compound effect of increased winding I^2R losses due to both excessive current and skin effect and increased eddy current and hysteresis losses in the transformer core.

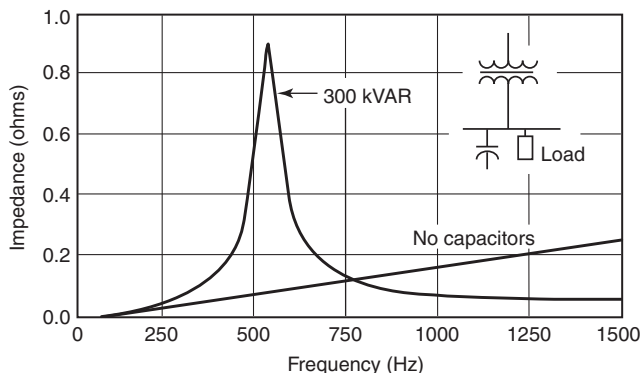


FIGURE 10.2.2.2.1 Example of Frequency Response Characteristic for a 1500 kVA, 13.8/0.48 kV, 6.0 Percent Transformer and a 300 kVAR, 480 V Capacitor Bank.

10.2.2.3.1 On a 3-phase delta-wye-connected transformer, third harmonics generated by the transformer secondary loads are reflected into the primary in the form of circulating currents in the delta-connected primary. It is therefore especially important to use a true rms-reading ammeter when checking a transformer's secondary line, neutral, and, where practical and safe, primary winding current, for possible overload.

10.2.2.3.2 Transformers with relatively high impedance are susceptible to overvoltage and core saturation in the presence of harmonics, causing increased current flow and resultant additional heating. Higher voltages can cause excessive 60 Hz hum, and harmonics can contribute higher-pitched audible noise.

10.2.2.3.3 Motors are also subject to overheating in the presence of harmonics, because of skin effect and increased iron losses. Where fifth harmonics are present, negative-sequence currents will also flow in opposition to the current necessary to develop the torque required for rotation. This counter torque contributes to overheating, and in some extreme cases can result in pulsating torque and excessive vibration.

10.2.2.4 Generators are susceptible to overheating in the presence of harmonics for essentially the same reasons as are motors. Generators equipped with solid-state controls can also operate erratically in the presence of harmonics, especially if the controls incorporate zero-crossing sensing circuits. Generators can cause harmonics due to internal construction. The type of generating winding pitch can determine the magnitude and types of harmonics generated.

10.2.2.4.1 Generators operating in parallel should have the same winding pitch to minimize problems. Where generators operate in parallel with a common neutral, third harmonic currents can circulate between the machines and cause overheating. High resistance grounding of these generators can adequately limit the harmonic current.

10.2.2.5 As is the case with all equipment operating on the principle of electromagnetic induction, ferromagnetic ballasts will also develop excessive heating where harmonics are present. The presence of harmonics can contribute to inaccurate readings (high or low) of induction disc meters.

10.2.2.6 Electrical panels and cables can also exhibit overheating because of excessive neutral current; excessive heating might be detected as discoloration. Harmonics can also cause conductor-insulation failure because of voltage stress and corona discharge.

10.2.2.7 Instrumentation transformers such as current and potential transformers can transfer harmonics from a primary to a secondary, resulting in misoperation of instrumentation, protective relaying, and control circuits.

10.2.2.8 Computers and other computer-type equipment such as programmable logic controllers (PLCs) are susceptible to harmonic-distorted waveforms, and the possibility of harmonics should be investigated on circuits serving such equipment where neutral-to-ground voltages in excess of 2 volts are measured at the equipment. Harmonic effects on such equipment can range from data errors, process controls operating out of sequence, and erratic operation of production robots or machine tools, through total failure of the electronic equipment.

10.2.2.8.1 In addition to polluting data and control signal transmissions, harmonics can be a source of audible noise on telephone communication circuits. Audible noise can be induced in communication conductors that run in proximity to conductors containing harmonic currents, such as with integral hp adjustable speed drives or other equipment that has power rectifiers without proper filters. For this reason, voice communication lines should be shielded or rerouted for wider separation. ANSI/IEEE 519, *Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, and ANSI/IEEE 1100, *Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (IEEE Emerald Book)*, contain additional information on the telephone interference factor (TIF).

10.2.3 Causes of Harmonic Distortion. Harmonics from neighboring utility customers can be introduced to the premises by the incoming utility supply. Harmonics originate on the premises in most cases.

10.2.3.1 All equipment operating on the principle of ferromagnetics produces harmonics when operating in the saturation region of the magnetic core. This equipment includes transformers, motors, generators, induction heaters, solenoid coils, lifting magnets, and iron-core arc-discharge lighting ballasts. The extent to which harmonics are generated varies with the type of equipment.

10.2.3.2 Arc-producing equipment, such as welding machines and arc furnaces, also develops harmonics. Arc-discharge lamps produce harmonics over and above those introduced by the lamp ballast.

10.2.3.3 The most significant contributor to harmonics is often electronic equipment, especially equipment that utilizes a rectified-input switching-mode power supply. The wave-chopping characteristic operation of thyristors, silicon-controlled rectifiers, transistors, and diodes develops current waveforms that do not conform to the applied voltage waveform and therefore develops harmonics. Included among electronic equipment that is rich in harmonic generation are welders, battery chargers, rectifiers, ac and dc adjustable-speed motor drives, electronic lighting ballasts, computers, printers, reproducing machines, and programmable logic controllers.

10.2.4 Harmonic Surveying and Testing.

10.2.4.1 Where harmonics are suspected as the cause of problems, it is necessary to determine the magnitude of the harmonic frequencies and their contribution to THD. This information will define the extent of the harmonic problem, provide clues as to causes of the harmonics, and provide the data needed to engineer solutions. It will also permit calculation of transformer derating factors in accordance with ANSI/IEEE C57.110, *Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents*.

10.2.4.2 The extent of harmonic surveying and testing will vary widely depending on the severity of the problem, available resources, and the facility's particular needs. A simple test can be performed to confirm or refute the existence of harmonics.

10.2.4.2.1 Where the test is conducted by taking current readings with an average responding ammeter and a true rms responding ammeter, the average responding instrument generally yields a lower reading than the rms responding meter if harmonics are present.

10.2.4.3 The presence of odd triplen harmonics (third, ninth, fifteenth, and so on) can be readily determined on 4-wire "wye" circuits by measuring neutral current with a true rms responding ammeter and comparing it with current to be expected on the basis of rms phase currents. Neutral-to-ground voltages in excess of 2 volts measured at the equipment can also indicate the presence of triplen harmonics. Where such readings determine that triplen harmonics are present, analysis should be undertaken to determine their specific frequencies and magnitudes. Instruments available for harmonic analysis include oscilloscopes, harmonic analyzers, and spectrum analyzers.

10.2.4.4 Oscilloscopes readily permit visual observation of the waveform to determine if it deviates from a sine wave or if line voltage notching exists.

CAUTION: Because one side of the oscilloscope probe might be common to the case, a line isolation device should be used between the probe and the line voltage being measured.

10.2.4.4.1 Harmonic analyzers measure the contribution of harmonic voltage and current at each frequency and calculate THD. Harmonic analyzers are available in a broad range of sophistication, with some also measuring circuit parameters such as kW, kVA, and power factor and some determining transformer derating factors and telephone interference factors. Spectrum analyzers provide detailed waveform analysis indicating the harmonic frequencies imposed on the fundamental.

10.2.4.5 Total harmonic distortion can vary significantly with load. Therefore, readings should be taken under different load conditions. Measurements should be taken to determine the location and extent of harmonics. Readings should be taken on all phases and neutrals of 3-phase, 4-wire systems and especially on 3-phase circuits that serve single-phase loads.

10.2.4.6 Voltage measurements on low-voltage circuits can be taken easily by connecting instrumentation directly to the measured point. High voltages, however, require the use of instrument potential transformers (PTs). The PTs should be dedicated to the test; existing bus PTs serving relaying and bus instrumentation should not be used. The measurement instrument should have an input impedance of at least 100 kilohms, and the instrument manufacturer's connection and operating instructions should always be followed.

10.2.4.7 Each facility differs in its tolerance to harmonic distortion. There are guidelines that can be followed to determine if harmonics are within acceptable limits. ANSI/IEEE 519, *Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, is one such standard. Other information sources include the following:

- (1) ANSI/IEEE C57.110, *Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents*
- (2) ANSI/IEEE 1100, *Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (IEEE Emerald Book)*

10.2.5 Recommended Solutions to Harmonic Problems. Solutions to harmonic problems are unique in nature and depend on the results of the harmonic survey and testing and subsequent analysis. Recommended solutions include any or all of the following:

- (1) Derating of existing equipment
- (2) Replacement of existing equipment with higher rated equipment

- (3) Use of delta-wye- or delta-delta-connected transformers as appropriate
- (4) Use of equipment specifically rated for harmonic circuits
- (5) Better selection and application of protective and metering devices
- (6) Use of rms-sensing protective devices
- (7) Balancing of single-phase loads on 3-phase systems
- (8) Use of 3-phase rectifiers instead of single-phase rectifiers
- (9) Relocating power-factor improvement capacitors
- (10) Shielding of conductors and electronic equipment
- (11) Isolation of harmonic-sensitive loads
- (12) Use of filters to block or shunt off harmonics
- (13) Specification of new equipment for low harmonic content
- (14) Periodic surveys and power-system adjustments/modifications as might be indicated by survey results
- (15) Increased neutral conductor size
- (16) Replacement or repair of harmonic producing equipment
- (17) Utilization of a motor or generator with an insulated bearing

10.2.5.1 In some cases, solutions can be engineered and implemented with in-house personnel; in other cases, it might be necessary to engage personnel with specialized expertise and equipment.

10.3 Transients (Surges).

10.3.1 Introduction. Transient current is proportional to the transient voltage and the system impedance. System impedance includes source impedance and transient impedance. For rating transient protective devices, transient energy is usually expressed in joules (watt-seconds).

10.3.2 Transient Symptoms and Effects.

10.3.2.1 The effect and the severity of the transient depend on magnitude, duration, and frequency. Low-energy transients can cause equipment to malfunction. High-energy transients can damage equipment. When transient-sensitive equipment or transient-producing equipment is installed, problems previously not encountered with existing equipment can occur. In addition, if transient-sensitive equipment and transient-producing equipment are moved electrically closer to each other, problems can result.

10.3.2.2 Within electrical systems without transient voltage protection, transient voltages are limited by flashover of clearances. When the transient reaches breakdown voltage, an arc is established through the air or across the surface of insulation, limiting the maximum transient voltage on the system. Typically, in low-voltage (1000 volts or less) distribution, the maximum transient is limited to about 6 kV for indoor systems and to about 10 kV to 20 kV for outdoor systems. The transient voltage can be limited to lesser values by surge protective devices.

10.3.2.3 Problems associated with transients include the following:

- (1) Unusual equipment damage due to insulation failures or arc-over, even with proven maintenance practices
- (2) Damage to electronic equipment components due to their inability to withstand transient voltages
- (3) Total failure, lock-up, or misoperation of computer or other microprocessor-based equipment

10.3.3 Causes of Transients.

10.3.3.1 Transient voltages in low-voltage ac power circuits usually originate from lightning effects (direct or indirect) on the power system or from switching operation.

10.3.3.2 Lightning strikes can cause severe transients because of the very high voltages and currents. Lightning can enter the electrical circuit directly or can be induced by nearby strikes. This might also produce a transient on the grounded and grounding systems.

10.3.3.3 Transients can be caused by the switching of inductive or capacitive loads, such as motors, ballasts, transformers, or capacitor banks. Arcing contacts can also cause transients.

10.3.3.4 Transients can result from abnormal conditions on the power system, such as phase-to-phase or phase-to-ground short circuits.

10.3.4 Transient Monitoring.

10.3.4.1 Monitoring can be used to determine the presence of transients. Storage-type, high-bandwidth oscilloscopes with high-voltage capability can be used, but more information can be obtained from the use of power disturbance analyzers specifically designed for transient and other types of power-quality problems. Monitoring might be required over an extended period of time, due to the characteristics of transients, which vary as loads and system configurations change.

10.3.4.2 Monitoring is often performed at specific locations where a sensitive load is connected or is to be connected. Other devices on the monitored circuit, such as the power quality monitor itself, can contain surge-protection devices that limit transients and distort the results. If possible, use an alternative power source for powering monitoring equipment.

10.3.4.3 Monitoring can be required phase-to-phase, phase-to-ground, phase-to-neutral, and neutral-to-ground to develop a complete profile of the system.

10.3.5 Recommended Solutions to Transient Problems.

10.3.5.1 The following are devices intended for the suppression of transients: surge arresters, surge capacitors, surge protectors, inductive reactors, and surge suppressors. Proper grounding of all circuits intended to be grounded is required for correct operation of these devices. The manufacturer's instructions should be followed when any of these devices is installed. Engineering evaluation might be required to select the proper type and rating of these devices.

10.3.5.2 Surge arresters are intended to be installed ahead of the service entrance equipment for limiting transient voltage by discharging or bypassing transient currents to ground. They typically provide protection for the effects of lightning.

10.3.5.3 Surge capacitors are placed in a circuit to slow the transient voltage rise time. By spreading out the voltage increase over a longer time span, less electrical stress occurs to equipment subjected to the transient.

10.3.5.4 Surge protectors are gas-tube devices or assemblies composed of one or more gas-tube devices. They are used for low-voltage applications (up to 1000 volts rms or 1200 volts dc).

10.3.5.5 A transient voltage surge suppressor (TVSS) is a device intended for installation on the load side of the main overcurrent protection in circuits not exceeding 600 volts rms.

These devices comprise any combination of linear or nonlinear circuit elements (i.e., varistors, avalanche diodes, and gas tubes) and are intended for limiting transient voltages by diverting or limiting surge current. Filters for electromagnetic interference (EMI) reduction can also be incorporated within TVSS devices.

10.3.5.6 The following are typical locations where transient protection is installed: power circuits at the service entrance, communication circuits entering the building, computer room power, and at susceptible loads.

10.3.5.7 Inductive reactors placed in series with the supply circuit can attenuate off-site transients. Inductive reactors placed in series with noisy equipment can localize transients to the equipment.

10.4 Voltage Sags and Swells.

10.4.1 Sags and swells are the most common types of power quality disturbances. Millions of dollars are lost in productivity

each year in the United States due to these disturbances. A simple understanding of their causes will help obtain effective solutions to minimize these disturbances.

10.4.1.1 Different equipment might require a different susceptibility curve. (See Figure 10.4.1.1 for an example of a curve.)

10.4.1.2 Sags are the most common type of voltage disturbance. Typically, sags occur twice as often as swells.

10.4.2 Symptoms of Sags and Swells.

10.4.2.1 Introduction. The effects of a sag are more noticeable than those of a swell. A sag duration longer than three cycles is visible because lighting output is reduced. Sags often are not distinguishable from momentary interruptions, and the effects to the equipment can be the same. Sensitive equipment, such as computers, can experience intermittent lockups or garbled data. Even relays and contactors in motor starters can be sensitive to voltage sags, resulting in shutdown of a process when they drop out.

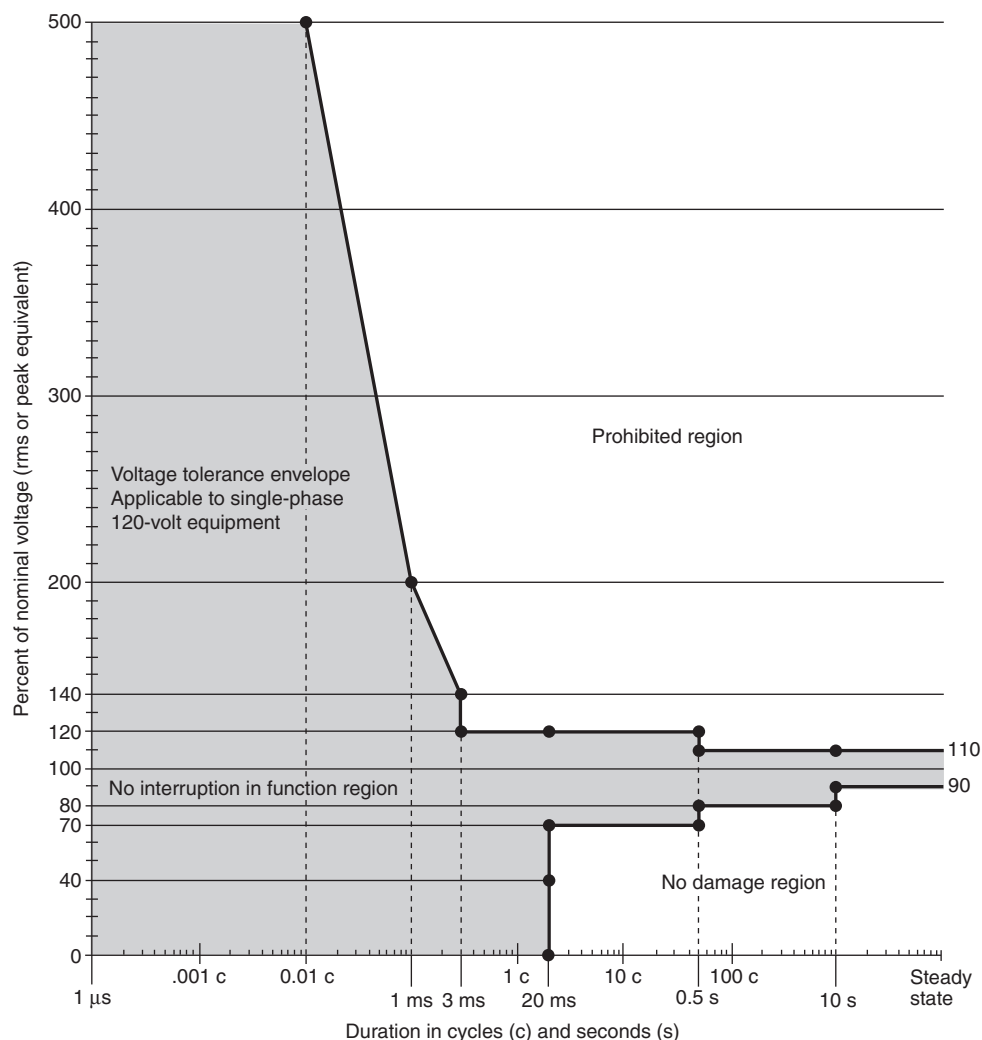


FIGURE 10.4.1.1 ITI Curve. [Courtesy of Information Technology Industry Council (ITI).] For proper use of this figure, refer to complete text of ITI (CBEMA) Curve Application Note.

10.4.2.2 Sophisticated Equipment. Equipment used in industrial plants (e.g., process controllers, programmable logic controllers, adjustable-speed drives, and robotics) is increasingly sensitive to voltage sags as the equipment becomes more complex. For example, computers are faster, operate at lower logic voltages, and have less power supply ride-through, making them much more vulnerable to voltage sags.

10.4.2.3 Loss of Memory. Voltage sags can cause the loss of stored data in programmable electronic systems.

10.4.2.4 Equipment Shutdowns. Motor contactors and electromechanical relays can drop out with a sag to 70 percent of rated voltage lasting 1 cycle or longer. High-intensity discharge (HID) lamps generally require restriking for sags below 80 percent. The ride-through of some adjustable-speed drives varies from 0.05 second to 0.5 second. Remote I/O units of some programmable logic controllers trip on a reduction to 90 percent of rated voltage for just a few cycles.

10.4.2.5 Component Breakdown. The effects of a swell can be more physically destructive to the equipment than those of a sag. The overvoltage can cause breakdown of components in the power supplies of the equipment. This can be a gradual, cumulative effect.

10.4.3 Causes of Voltage Sags and Swells. Sags and swells occur in utility transmission and distribution systems and facility power distribution systems. A common, underlying cause in all three areas is a sudden change of current flow.

10.4.3.1 Sag Causes — Transmission Systems.

10.4.3.1.1 Outside Sources. Severe weather, construction accidents, transportation accidents, or animals can cause faults that result in sags. Lightning is a common cause of faults on overhead transmission and distribution lines. A fault can occur by lightning directly striking a phase conductor or striking a nearby grounded object, such as a transmission shield wire or tower.

10.4.3.1.2 Sag Duration. Transmission system voltage sags normally are shorter in duration than utility distribution sags. The fault-clearing mechanisms (the relay/breaker schemes) are designed to react faster for transmission faults. Sags to 75 percent in a facility have been caused from transmission faults 300 miles away.

10.4.3.2 Sag Causes — Utility Distribution Systems.

10.4.3.2.1 Outside Causes. In addition to transmission system causes, contact with tree limbs and motor vehicle accidents can result in voltage sags. Such faults can be 3-phase, line-to-line or line-to-ground. The 3-phase faults are the most severe but are relatively uncommon. Single line-to-ground faults on the utility system are a common cause of voltage sags in an industrial plant. A fault on a single feeder can result in an interruption to loads on that feeder, as well as a sag on the other feeders.

10.4.3.2.2 Sag Duration. Typically, distribution system sags are 6 cycles to 20 cycles. Repeated sags can occur with reclosing on the same fault. Depending on the number of reclosures, feeders can experience several voltage sags in succession.

10.4.3.3 Sag Causes — Facility Power Systems.

10.4.3.3.1 Sudden increases in the current demand within a facility can cause sags until the large current demand decreases. The sudden increases can be the result of fault conditions

in the building or the startup of large inductive loads, such as motors. In one large-scale study (*see Section 10.10*), 50 percent or more of the sags and swells recorded were caused by load equipment in the same building.

10.4.3.3.2 A voltage sag from energization of large high-current-demand motors, can last for 30 cycles.

10.4.3.3.3 A utility fault usually creates a more severe sag than a motor start sag. The sag will last until the fault is cleared or removed.

10.4.3.4 Swell Causes.

10.4.3.4.1 Swells are less common than voltage sags and are usually associated with system fault conditions. A swell can occur due to a single line-to-ground fault on the system, which can result in a temporary voltage rise on the unfaulted phases.

10.4.3.4.2 Swells can also be generated by sudden load decreases. The abrupt interruption of current can generate a large voltage, proportional to the inductance and the rate of change of the current. Switching on a large capacitor bank can also cause a swell, although it more often causes a high-frequency transient.

10.4.4 Monitoring and Testing for Sags and Swells.

10.4.4.1 Equipment. Different types of monitoring equipment are available to monitor sags and swells. These range from event indicators that visually indicate that a sag or swell has occurred to monitors that provide a cycle-by-cycle graph of the disturbance and record the minimum/maximum values, duration, and time of occurrence.

10.4.4.2 Finding the Source. Data on the timing and magnitude of the sag or swell can often identify the source of the initiating condition. If the phase current levels of the load did not change prior to the voltage sag, the source is more likely to be upstream. When the magnitude of the sag is severe, it is likely that the source was close by. A power-factor correction capacitor being switched on can result in an oscillatory transient followed by a swell.

10.4.4.3 Initial Placement. Unless there is significant information pointing to the source of the disturbance, it is common practice to begin monitoring at the point where the utility service connects to the facility equipment.

10.4.4.4 Other Locations. If the source of the disturbance is determined to be internal to the facility, then placing multiple monitors on the various circuits within the facility most likely would identify the source of the problem quickly.

10.4.4.5 Monitoring Instrument Sensitivity. Power monitoring instruments are quite sensitive, and outside factors can influence their accuracy. Long measurement leads are susceptible to RFI/EMI pickup, which can distort the results.

10.4.5 Solutions for Sags and Swells.

10.4.5.1 A transformer tap change can be used to raise or lower the nominal voltage level and make the system less susceptible to sags or swells. Automatic solid-state tap-changing transformers that are controlled by electronic sensing circuits can react relatively quickly (one cycle to three cycles).

10.4.5.2 Different transformer configurations can be used to minimize the effects of events that cause sags and swells. For

example, a delta-delta configuration tends to hold voltage levels higher than a delta-wye or wye-delta configuration.

10.4.5.3 Fault current limiters, zero voltage independent pole closing capacitor switches, and high-energy surge arresters can be added to the electric system.

10.4.5.4 Ferroresonant transformers, also called constant-voltage transformers, can handle most short-duration voltage sags. They provide excellent regulation but have limited overload capacity and poor efficiency at low loads.

10.4.5.5 Magnetic controlled voltage regulators use transformers, inductors, and capacitors to synthesize 3-phase voltage outputs. Enough energy is stored in the capacitors to ride through 1 cycle. The overall response time is relatively slow (3 cycles to 10 cycles).

10.4.5.6 A UPS can provide isolation from power line disturbances, in addition to providing ride-through during a sag. (See Chapter 28.)

10.4.5.7 A static transfer switch is capable of transferring the supply voltage from one voltage source to another within a quarter-cycle.

10.5 Long-Duration Undervoltages and Sustained Voltage Interruptions.

10.5.1 Normal Supply Voltage Variations. Variations in the normal supply voltage are to be expected because loads on the supply system and plant distribution system are not constant. Electric utilities, equipment manufacturers, and end users have established standards for steady-state operating voltage limits that accommodate these variations. Facility utilization equipment can be designed and rated to operate within the range of supply system voltage while allowing for voltage drop in the plant system. [See ANSI/NEMA C84.1, *Electric Power Systems and Equipment, Voltage Ratings (60 Hertz)*.]

10.5.1.1 Electric Utilities. Electric utilities can be required by regulatory commissions to maintain service voltages within prescribed limits for the various types of service. Plant electrical people should be aware of any required service voltage limits for their type of service. The utility generally works with the customer to ensure that the service voltage remains within the required limitations or within standard design limits where there are no required limitations.

10.5.1.2 As the system load varies, the utility automatic voltage-regulating equipment maintains the service voltage within the required range. When the serving utility's electrical system is severely stressed, the utility can implement a load-reduction strategy by reducing the voltage on its distribution lines, typically up to 5 percent. During these periods, the service voltage can be near the lower limit of the required range. As a result, a long-term undervoltage condition can exist at plant utilization equipment. It is strongly recommended that plant distribution system voltage drops be kept to a reasonable level.

10.5.2 Symptoms of Long-Duration Undervoltage. Undervoltage might not be readily apparent. Depending on the length and magnitude of the undervoltage, there can be a detrimental effect on electric and electronic equipment. Equipment such as induction motors might run hotter. Electronic equipment such as computers or microprocessor-based devices might function erratically.

10.5.3 Causes of Long-Duration Undervoltage. A long-duration undervoltage can originate on the electric utility system or on the plant electrical system. The utility system can be stressed due to line or equipment failure or system load conditions exceeding the supply capability. The plant electrical system or connected loads can result in unacceptable voltage drops even though the voltage is normal at the service point.

10.5.4 Monitoring and Testing of Long-Duration Undervoltages. Because the occurrence of a long-duration undervoltage might not be obvious, and damage to equipment and systems can result, an appropriate monitoring system is recommended where reliability is vital.

10.5.4.1 The monitoring system can consist of a sophisticated warning scheme with visual and audible alarms at appropriate locations. Alternatively, it can simply be a voltage-sensing relay located at the facility service entrance or at sensitive equipment with alarms placed in appropriate locations.

10.5.5 Solutions for Long-Duration Undervoltages. When a long-duration undervoltage occurs, costly or sensitive equipment should be disconnected to prevent possible damage. If it is necessary to keep the equipment or system in operation, an alternative power supply should be provided.

10.5.6 Symptoms of a Sustained Voltage Interruption. A sustained voltage interruption is obvious because electric power is unavailable for an extended period of time except for equipment served by an alternative power source.

10.5.7 Causes of Sustained Voltage Interruption. Sustained voltage interruptions are caused by power system disruptions such as power lines going down in a storm, the utility's distribution transformer failing, a fault condition causing a circuit protective device to open, or plant wiring problems.

10.5.8 Solutions for Sustained Voltage Interruptions. Solutions include generator sets, multiple power sources, and battery banks.

10.6 Unbalanced Voltages and Single Phasing. (See 3.3.77, *Unbalanced Voltages*.)

10.6.1 Percentage Limitations. On 3-phase circuits, unbalanced voltages can cause serious problems, particularly to motors, transformers, and other inductive devices.

10.6.1.1 Single phasing, which is the complete loss of a phase, is the worst-case voltage unbalance condition for a 3-phase circuit.

10.6.1.2 The National Electrical Manufacturers Association (NEMA) in MG1, *Motors and Generators*, part 14.36, defines voltage unbalance as follows: percent unbalance = $100 \times (\text{maximum voltage deviation from the average voltage} / \text{average voltage})$.

10.6.1.3 NEMA states that polyphase motors shall operate successfully under running conditions at rated load when the voltage unbalance at the motor terminals does not exceed 1 percent. Also, operation of a motor with more than 5 percent unbalance condition is not recommended and will probably result in damage to the motor.

10.6.1.4 For example, with line-to-line voltages of 460, 467, and 450, the average is 459, the maximum deviation from average is 9, and the percent unbalance equals $100 \times (9/459) = 1.96$ percent, which exceeds the 1 percent limit.

10.6.1.5 The use of sequence components as a means of measuring unbalance, including the ratio of negative sequence to positive sequence and the ratio of zero sequence to positive sequence is recommended. In situations where the measured voltage or current has harmonic distortion, this method should be used as it has been proven to be a more accurate representation of the unbalance condition. (See *IEEE 1159, Recommended Practice on Monitoring Electric Power Quality*.)

10.6.2 Causes of Unbalanced Voltages.

10.6.2.1 Unbalanced voltages usually occur because of variations in the load. When phases are unequally loaded, unbalanced voltages will result because of different impedances.

10.6.2.2 Symptoms and causes of unbalanced voltages include the following:

- (1) Unequal impedance in conductors of power supply wiring
- (2) Unbalanced distribution of single-phase loads such as lighting
- (3) Heavy reactive single-phase loads such as welders
- (4) Unbalanced incoming utility supply
- (5) Unequal transformer tap settings
- (6) Large single-phase load on the system
- (7) Open phase on the primary of a 3-phase transformer
- (8) Open delta-connected transformer banks
- (9) A blown fuse on a 3-phase bank of power factor correction capacitors

10.6.3 Symptoms of Unbalanced Voltages.

10.6.3.1 General. The most common symptoms of unbalanced voltages are improper operation of or damage to electric motors, power supply wiring, transformers, and generators.

10.6.3.2 Phase Current Unbalance at Motor Terminals. Unbalanced voltages at motor terminals can cause phase current unbalance to range from 6 to 10 times the voltage unbalance for a fully loaded motor. As an example, if a voltage unbalance is 2 percent, then current unbalance could be anywhere from 12 percent to 20 percent. This causes motor overcurrent, resulting in excessive heat, which shortens motor life.

10.6.3.2.1 Speed and Torque at Motor Terminals. The unbalanced voltages at the motor terminals will also cause speed and torque to be reduced. If the voltage unbalance is great enough, the reduced torque capability might not be adequate for the application. Noise and vibration levels can also increase as a result of voltage unbalance.

▲ 10.6.3.3 Motor Heating and Losses. Insulation life is approximately halved for every 10°C (18°F) increase in winding temperature. Table 10.6.3.3 illustrates the typical percentage increases in motor losses and heating for various levels of voltage unbalance.

10.6.3.3.1 The motor often continues to operate with unbalanced voltages; however, its efficiency is reduced. This reduction of efficiency is caused by both increased current (I) and increased resistance (R) due to heating. Essentially, this means that as the resulting losses increase, the heating intensifies rapidly. This can lead to a condition of uncontrollable heat rise, called thermal runaway, which results in a rapid deterioration of the winding insulation, ending in winding failure.

▲ Table 10.6.3.3 Voltage Unbalance Versus Temperature Rise at Average Voltage of 230

Percent Unbalanced Voltage	Percent Unbalanced Current	Increased Temperature Rise	
		(°C)	(°F)
0.3	0.4	0	0
2.3	17.7	30	54
5.4	40	40	72

10.6.3.4 Motor Operation Under Single-Phase Condition.

Single-phase operation of a 3-phase motor will cause overheating due to excessive current and decreased output capability. If the motor is at or near full load when single phasing occurs, it will not develop enough torque and therefore will stall. This results in high currents, causing an extremely rapid temperature rise. If motor protection is not adequate, the stator winding will fail, and the rotor might be damaged or destroyed.

10.6.3.4.1 Standard (thermal, bimetallic, eutectic alloy) overload relays normally are relied on to provide protection against single phasing where properly selected and applied. Protective relays or other devices can provide supplemental single-phasing protection.

10.6.4 Monitoring and Testing.

10.6.4.1 Measuring. The first step in testing for unbalanced voltages should be to measure line-to-line voltages at the machine terminals. If the motor starter is close by, the tests can be made at load or “T” terminals in the starter. The current in each supply phase should be measured to check for current unbalance.

10.6.4.2 Detecting Single Phasing.

10.6.4.2.1 Single phasing should be suspected when a motor fails to start. The voltage should be checked for balanced line-to-line voltages.

10.6.4.2.2 If the motor is running, the voltage and the current in each phase of the circuit should be measured. One phase will carry zero current when a single-phasing condition exists.

10.6.5 Solutions for Unbalanced Voltages.

10.6.5.1 Unbalanced voltages should be corrected; unbalance caused by excessively unequal load distribution among phases can be corrected by balancing the loads. Also, checking for a blown fuse on a 3-phase bank of power-factor correction capacitors is recommended.

10.6.5.2 When voltage unbalance exceeds 1 percent, the motor should be derated as indicated by the curve in Figure 14-1 of NEMA MG 1, *Motors and Generators*.

10.6.5.3 Automatic Voltage Regulator (AVR). AVRs can be used on a per phase basis to correct under- and overvoltage, as well as voltage unbalance. The AVR can compensate for voltage unbalance, provided that the input voltage to the AVR is within its range of magnitude.

10.6.5.4 Relays. Negative sequence voltage relays can detect single phasing, phase-voltage unbalance, and reversal of supply phase rotation. Reverse phase or phase sequence relays provide limited single-phasing protection by preventing the starting of a motor with one phase of the system open.

10.6.5.5 Transformer tap settings should be checked; unequal power transformer tap settings can be a cause of voltage unbalance. This condition should be checked prior to taking other steps.

10.6.5.6 An unsymmetrical transformer bank should be replaced. For example, an open delta bank can be replaced with a three-transformer bank.

10.7 Symptoms — Grounding.

10.7.1 General. If the equipment ground conductor and the service neutral are not electrically connected to the central grounding point, noise voltages can develop between them and appear as common mode noise.

10.7.1.1 Wiring without an equipment ground conductor and without electrically continuous conduit can produce common mode noise.

10.7.1.2 Ground loops are undesirable because they create a path for noise currents to flow.

10.7.2 Monitoring and Testing — Grounding. The electrical connection to earth can be measured using the three-point system referred to in ANSI/IEEE 142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book)*. Minimizing the impedance between the equipment grounded conductor and the grounding conductor is recommended, as follows:

- (1) A visual inspection should be made to verify the integrity of the grounding and bonding conductors and associated connections.
- (2) An impedance test should be performed on the equipment-grounding conductor.
- (3) Voltage should be measured between the equipment-grounding conductor and the grounded conductor.
- (4) A check should be made for abnormal currents on the equipment-grounding conductor.

10.7.3 Solutions — Grounding.

10.7.3.1 The grounded conductor should be connected to the equipment-grounding conductor only as permitted by Article 250 of *NFPA 70*.

10.7.3.2 Isolated Equipment Ground. One solution is to install an “isolated ground” receptacle (identified by orange color or an orange triangle) in which the equipment-grounding terminal is insulated from the mounting strap. An insulated equipment-grounding conductor is then connected from the grounding terminal of the receptacle in accordance with Article 250 of *NFPA 70*. The insulated equipment-grounding conductor is connected to the applicable derived system or service grounding terminal only at the power source.

10.7.3.3 Isolation Transformer. An isolation transformer has separate primary and secondary windings with an interwinding shield that has its own grounding connection. The bonding jumper between the equipment-grounding conductor and the secondary grounded conductor provides protection from common mode electrical noise.

10.7.3.4 Signal Circuit Isolation. Breaking the ground loop current path minimizes ground currents on signal circuits. This can be accomplished by one or more of the following:

- (1) Grounding at a single point per system [See ANSI/IEEE 142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems (IEEE Green Book)*, and ANSI/IEEE 1100, *Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (IEEE Emerald Book)*.]
- (2) Fiber-optic transmission over completely nonconducting path
- (3) Optical isolators
- (4) Signal circuit isolation transformers in signal circuit or power circuits

10.8 Noise in Electrical and Electronic Systems.

10.8.1 Introduction. Noise is undesirable electrical signals in an electrical or electronic circuit. It can be random or continuous in nature. Noise can occur at any frequency and amplitude. Noise can be introduced into a circuit from a multitude of sources and can manifest itself in equipment malfunction or data corruption.

10.8.1.1 Common Mode Noise. In a 3-phase system, common mode noise is seen equally and in phase between any phase conductor or neutral and the grounding conductor. Neutral-to-ground voltage or ground current can be a result of common mode noise. (See 3.3.53.1, *Common Mode Noise*.)

10.8.1.2 Transverse Mode Noise. In a 3-phase system, transverse mode noise occurs in phase on all 3-phase conductors and neutral. (See 3.3.53.2, *Transverse Mode Noise*.)

10.8.1.3 Interference. Interference that is electromagnetically coupled into a wiring system is called electromagnetic interference (EMI). Interference that is capacitively coupled into a wiring system is called radio frequency interference (RFI). Interference can appear as transverse or common mode noise.

10.8.2 Symptoms.

10.8.2.1 Electrical noise is present in all circuits to a certain degree. It might or might not present a problem. Unlike sags or swells, electrical noise does not normally destroy equipment. It does not cause circuit breakers to trip, unless the noise affects shunt trip or undervoltage release controls.

10.8.2.2 Electrical noise usually manifests itself in the form of data corruption or unexplained equipment malfunction. For example, electrical noise can create “hum” in a telephone system or “snow” on a video image or can cause a computer to lock up.