

NFPA 70B

Recommended Practice for Electrical Equipment Maintenance

2006 Edition



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NFPA 70B
Recommended Practice for
Electrical Equipment Maintenance
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This edition of NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*, was prepared by the Technical Committee on Electrical Equipment Maintenance. It was issued by the Standards Council on January 27, 2006, with an effective date of February 16, 2006, and supersedes all previous editions.

This edition of NFPA 70B was approved as an American National Standard on February 16, 2006.

Origin and Development of NFPA 70B

In the fall of 1967, the Board of Directors of the National Fire Protection Association authorized the formation of an Ad Hoc Committee on Electrical Equipment Maintenance to determine the need for the development of a suitable document on this subject. The purpose of the document would be to give recommendations on the maintenance of various types of electrical installations, apparatus, and equipment usually found in industrial and large commercial-type installations. Various highly diversified interests and organizations were invited to participate.

At a meeting of the Ad Hoc Committee held January 10, 1968, in New York, with 31 representatives attending, it was pointed out that several requests had been made to the National Electrical Code Committee to include maintenance recommendations in the *National Electrical Code*[®]. The subject had been discussed by the Correlating Committee of the National Electrical Code Committee, and the decision was made that the Code was not the proper document in which to cover the maintenance of electrical equipment. However, the high frequency of electrical accidents attributed to lack of maintenance, which results annually in numerous fatalities and serious injuries as well as high monetary losses of property, caused the committee to recognize that it was a subject requiring attention.

It was noted that electrical safety information breaks down logically into four main subdivisions: (1) design or product standards, (2) installation standards (as covered by the *National Electrical Code* and the *National Electrical Safety Code*), (3) maintenance recommendations, and (4) use instructions. The problem was to explore whether something more should be done in the interest of electrical safety on the maintenance of electrical equipment and what form activity in this field should take.

It was recognized that much had been done to enunciate maintenance needs for specific types of equipment by the equipment manufacturers and that guidance was available on the general subject from a number of sources. However, it was also felt to be desirable to bring together some of the general guidelines in a single document under the NFPA procedure. The stature of the document would also be enhanced if it could in some way become associated with the *National Electrical Code*. To this end, a tentative scope was drafted for presentation to the Board of Directors of the National Fire Protection Association with a recommendation that an NFPA Committee on Electrical Equipment Maintenance be authorized.

On June 27, 1968, the NFPA Board of Directors authorized the establishment of an NFPA 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."

The committee was formed, and an organizational meeting was held December 12, 1968, in Boston. Twenty-nine members or representatives attended. The *Recommended Practice for Electrical Equipment Maintenance* represented the cumulative effort of the entire committee.

In 1973, the committee developed Part II, which became Chapters 5 through 15, and a new addition in the Appendix, "How to Instruct."

In 1976, the committee developed the chapters on Electronic Equipment, Ground-Fault Protection, Wiring Devices, and Maintenance of Electrical Equipment Subject to Long Intervals Between Shutdowns, and new additions in the Appendix, "NEMA Configurations," and "Long-Term Maintenance Guidelines."

In the 1983 edition, the committee developed the chapters on Deenergizing and Grounding of Equipment to Provide Protection for Electrical Maintenance Personnel and on Cable Tray Systems and added Appendix I, "Equipment Storage and Maintenance During Construction."

In the 1987 edition, the committee reorganized and reformatted the former Chapter 7, now Chapter 9, to include distribution transformers as well as power transformers.

In the 1990 edition, the committee developed the chapter on Uninterruptible Power Supply (UPS) Systems. This new chapter was developed with a significant contribution from several nonmembers who joined the Ad Hoc Technical Subcommittee to produce this new material. The committee recognized and extended its appreciation to Mr. Robert Adams, Liebert Corporation; Mr. Russ Grose, Liebert Corporation; and Mr. Ronald Mundt, U.S. Army Corps of Engineers. The chapter on 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.

In the 1994 edition, the committee added three new chapters to cover power system studies that include short circuit studies, coordination studies, load-flow studies, and reliability studies; power quality and information pertaining to harmonics, the problems created by harmonic distortion, causes of harmonic distortion, harmonic surveying and testing, and recommended solutions to harmonic problems; and vibration analysis pertaining to rotating machinery. The third new chapter included a table on suggested vibration limits and a vibration severity chart for various-sized machines. To more closely follow the NFPA *Manual of Style*, a new Referenced Publications chapter was created. Also, the Bibliography was moved to Appendix J.

For the 1998 edition, the chapter on Power Quality was rewritten and greatly expanded. In addition, the committee updated and revised maintenance techniques for stationary batteries and infrared inspections. Special handling and disposal considerations were introduced, and employee training was focused to emphasize workplace safety.

In the 2002 edition, the committee made several enhancements. The document was restructured to comply with the NFPA *Manual of Style*. The document scope was revised to include preventive maintenance for electronic and communications equipment. A new chapter added for Grounding provided definitions, symptoms, inspection, testing techniques, and solutions to grounding issues. A new section for Gas Insulated Substations was added to Chapter 8 to address the maintenance issues on industrial sites resulting from regulatory changes in the electrical utility industry. Charts were added in Chapter 11 for motor control troubleshooting for motor controllers, switchboards, and panelboards. Chapter 27 was enhanced with information on the latest technology on voltage fluctuation. A new annex was added that specified maintenance intervals for electrical equipment.

The 2006 edition of NFPA 70B includes a significant change concerning safety. Whereas safety precautions and information in previous editions were dispersed throughout the individual equipment chapters, an entire new chapter on safety has been written and placed up front in the document to provide more complete and updated coverage, as well as to emphasize the importance of safety. A series of updated test forms appears in Annex F, revised testing schedules in Chapter 21, and maintenance of supervisory control and data acquisition (SCADA) systems in Chapter 30. An important part of maintenance is having a properly installed system with baseline performance data, and so a new chapter on commissioning the electrical system at a new facility has been added. Because the industry trend is going 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 have been added. Finally, revisions have been made to update information on equipment cleaning, disconnects, busways, vibration testing, lamps, power quality, and rework and recertification of equipment.

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NOTE: Membership on a committee shall not in and of itself constitute an endorsement of the Association or any document developed by the committee on which the member serves.

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 have primary jurisdiction but shall report to the Association through the Technical Correlating Committee of the *National Electrical Code*.

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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 the recommendations sections of this document are given in Chapter 2 and those for extracts in the informational sections are given in Annex M. Editorial changes to extracted material consist of revising references to an appropriate division in this document or the inclusion of the document number with the division number when the reference is to the original document. Requests for interpretations or revisions of extracted text should be sent to the technical committee responsible for the source document.

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

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 multifamily 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*®, 2005 edition.

NFPA 70E, *Standard for Electrical Safety in the Workplace*, 2004 edition.

NFPA 496, *Standard for Purged and Pressurized Enclosures for Electrical Equipment*, 2003 edition.

2.3 Other Publications.

2.3.1 ANSI Publications. American National Standards Institute, Inc., 25 West 43rd Street, 4th Floor, New York, NY 10036.

ANSI/EASAAR100, *Recommended Practice for the Repair of Rotating Electrical Apparatus*, 2001.

ANSI/ASSE Z244.1, *Control of Hazardous Energy — Lockout/Tagout and Alternative*, 2003.

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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.

3.3.1 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, non-corroded 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.

3.3.2 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.

3.3.3 Case (Enclosure) Ground. See 3.3.41, Grounding Terminal.

3.3.4 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.

3.3.5 Common Mode Noise. See 3.3.50.1.

3.3.6 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.

3.3.7 Continuous Duty. See 3.3.13.1.

3.3.8 Coordination (Selective). Localization of an overcurrent condition to restrict outages to the circuit or equipment affected, accomplished by the choice of overcurrent protective devices and their ratings or settings. [70, 2005]

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

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

3.3.11 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 3.3.26, Equipotential Plane.

3.3.12 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.

3.3.13 Duty.

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

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

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

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

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

3.3.14 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.

3.3.15 Earthing. An IEC term for *ground*. See 3.3.27, Ground.

3.3.16 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.

3.3.17 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.

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

3.3.19 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.

3.3.20* 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.

3.3.21 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*.

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

3.3.23 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.

3.3.24 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.

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

3.3.26 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.

3.3.27 Ground. A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth. [70, 2005]

3.3.27.1 Lightning Ground. See 3.3.40, Grounding Electrode System.

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

3.3.27.3 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.

3.3.27.4 Safety Ground. See 3.3.27.3, Personnel Protective Ground.

3.3.28 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.

3.3.29 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.

3.3.30 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. Re-grounding 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.

3.3.31 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.

3.3.32 Ground Well. See 3.3.40, Grounding Electrode System.

3.3.33 Grounded. Connected to earth or to some conducting body that serves in place of the earth. [70, 2005]

3.3.34 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.

3.3.35* 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. Note: Class A Ground-Fault Circuit Interrupters trip when the current to ground has a value in the range of 4 mA to 6 mA. For further information, see UL 943, *Standard for Ground-Fault Circuit Interrupters*. [70, 2005]

3.3.36* 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, 2005]

3.3.37 Grounding.

3.3.37.1 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.

3.3.37.2 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.

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

3.3.38 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

3.3.39 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.

3.3.40 Grounding Electrode System. The interconnection of grounding electrodes.

3.3.41 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.

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

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

3.3.44 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.

3.3.45 Intermittent Duty. See 3.3.13.2.

3.3.46 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.

3.3.47 Lightning Ground. See 3.3.27.1.

3.3.48 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.]

3.3.49 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.

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

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

3.3.50.2 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.

3.3.51 Noise(less) Ground. See 3.3.27.2.

3.3.52 Periodic Duty. See 3.3.13.3.

3.3.53 Personnel Protective Ground. See 3.3.27.3.

3.3.54 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.

3.3.55 Protective Bonding Circuit. See 3.3.25, Equipotential Bonding.

3.3.56 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 29.1.6.15, *Equipment Grounding Conductor*.)

3.3.57 Protective Ground. See 3.3.25, Equipotential Bonding.

3.3.58 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.

3.3.59 RFI/EMI Grounding. See 3.3.29, Ground Leakage Current.

3.3.60 Safety Ground. See 3.3.27.3, Personnel Protective Ground.

3.3.61 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.

3.3.62 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.

3.3.63 Shield Ground. Intentional grounding of one or both ends of the shield of a cable.

3.3.63.1 Data Communications Cables. The shield of data communication cables can be connected to the equipment-grounding conductor at either one end of the cable (single end) or at both ends (double ended). When both ends of a shield are grounded, another shield should be provided inside the outer shield and that one single end grounded.

3.3.63.2 Shield Ground, Power Cables. The shield of power cables can be connected to the equipment-grounding conductor at either one end of the cable (single end) or at both ends (double ended). Shielding will ensure uniform dielectric stress along the length of the cable. When grounded at both ends, cable derating might be necessary because of heat due to ground loop current.

3.3.64 Short-Time Duty. See 3.3.13.4.

3.3.65 Single-Point Grounding. See 3.3.37.2.

3.3.66 Substation Ground. Grounding electrode system (grid) in a substation. See 29.1.6.28, Grounding Electrode System.

3.3.67 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.

3.3.68 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.

3.3.69 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–30 cycles; (2) momentary — 30 cycles–3 sec; and (3) temporary — 3 sec–1 min.

3.3.70 System Grounding. See 3.3.37.3.

3.3.71 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.

3.3.72 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.

3.3.73 Transverse Mode Noise. See 3.3.50.2.

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

3.3.75 Varying Duty. See 3.3.13.5.

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

4.1 Why EPM?

4.1.1 Electrical equipment deterioration is normal, but equipment failure is not inevitable. 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 failure 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 Although the benefits that result from improved safety are difficult to measure, direct, 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 lasts longer and performs better when it is covered by an EPM program. In many cases, the investment in EPM is small compared with the cost of equipment repair and the production losses associated with an unexpected equipment shutdown.

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.

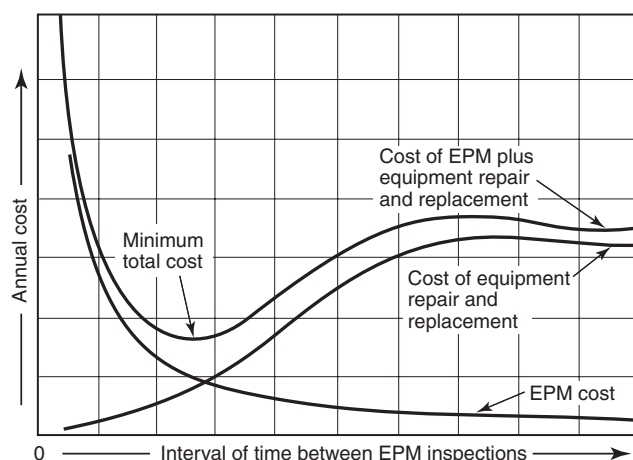


FIGURE 4.2.6 Effect of EPM Inspection Frequency on Overall Costs.

4.2.7 An EPM program is a form of protection against accidents, lost production, and loss of profit. An EPM program enables management to place a dollar 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 dollars and vital resources. Equipment that is well maintained operates more efficiently and utilizes less energy.

4.4 Case Histories.

4.4.1 In one industrial plant, the failure of a transformer caused a total plant shutdown. Contamination of the transformer's insulating oil caused the failure. The contamination went undetected because the oil had not been tested for several years. Fire damage and equipment replacement costs amounted to \$50,000, exclusive of the cost of plant downtime. This amount would have paid for the cost of operating an EPM program covering the entire plant's electrical distribution system for several years.

4.4.2 In another industrial plant, damage amounting to \$100,000 was attributed to the failure of the main switchgear. Fouling by dirt, gummy deposits, and iron filings caused the failure. The cost of this failure would have supported a comprehensive EPM program covering all of the plant's electrical distribution system for several years.

4.4.3 McCormick Place, a large exhibition hall in Chicago, was destroyed by a fire believed to have been started because of a defective extension cord serving a display booth. Direct property loss was \$60 million, and loss of the facility cost an additional \$100 million to the economy in the Chicago area. This fire might have been prevented if a program had been in effect to ensure that worn cords were replaced, that only heavy-duty cords were used, and that cords and their supply circuits were not overloaded.

4.4.4 The failure of a large motor shut down an entire industrial plant for 12 days. The cause of the failure was overheating resulting from dust-plugged cooling ducts. An EPM inspection would have detected the clogged ducts and averted the failure and accompanying plant outage.

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.

5.1.1 An effective electrical preventive maintenance program should include the following basic ingredients:

- (1) Personnel qualified to carry out the program
- (2) Regularly scheduled inspection, testing, and servicing of equipment

5.1.2 A successful program should also include the following:

- (1) Application of sound judgment in evaluating and interpreting results of inspections and tests
- (2) Keeping of concise but complete records

5.2 Planning an EPM Program. The basic factors listed in 5.2.1 through 5.2.3 should be considered in the planning of an EPM program.

5.2.1 Personnel Safety. Will an equipment failure endanger or threaten the safety of any personnel? What can be done to ensure personnel safety?

5.2.2 Equipment Loss. Is installed equipment — both electrical and mechanical — complex or so unique that required repairs would be unusually expensive?

5.2.3 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?

5.3 Main Parts of an EPM Program. An EPM program should consist of the following essential ingredients:

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

5.3.1 Personnel.

5.3.1.1 A well-qualified individual should be in charge of the program.

5.3.1.2 Personnel assigned to inspection and testing duties should be selected from the best maintenance personnel in the plant.

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

5.3.2 Survey and Analysis.

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

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

5.3.2.3 All electrical equipment — motors, transformers, circuit breakers, controls, and the like — 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.

5.3.2.4 In addition to determining the equipment's physical condition, the survey should determine if the equipment is operating within its rating.

5.3.2.5 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 operating condition ensures the safety of personnel, protection of equipment, and reduction of economic loss.

5.3.2.6 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 the nature and frequency of required inspections and tests.

5.3.3 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.

5.3.3.1 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.

5.3.3.2 Records.

5.3.3.2.1 Records should be accurate and contain all vital information.

5.3.3.2.2 Care should be taken to ensure that extraneous information does not become part of the record, because excessive record keeping can hamper the program.

5.3.4 EPM Support Procedures.

5.3.4.1 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.

5.3.5 Training for Safety and Technical Skills.

5.3.5.1 Training Requirements.

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

5.3.5.1.2 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.

5.3.5.1.3 Employees should be trained to identify and understand the relationship between electrical hazards and possible injury.

5.3.5.1.4 Refresher training should be provided as required.

5.3.5.2 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.

5.3.5.3 Emergency Procedures.

5.3.5.3.1 Employees working on or near exposed energized electrical conductors or circuit parts should be trained in methods of release of victims from contact with exposed energized conductors or circuit parts.

5.3.5.3.2 Employees working on or near exposed energized electrical conductors or circuit parts should be instructed regularly in methods of first aid and emergency procedures, such as approved methods of resuscitation.

5.3.5.4 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

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

5.3.6 Outside Service Agencies. 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.

5.3.7 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. 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 that can result from the failure or malfunction of electrical systems and equipment. The first part of these recommendations for an effective EPM program has 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. This chapter explains the function, requirements, and economic 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. In their simplest form, they are as follows:

- (1) Compile a listing of all equipment and systems.
- (2) Determine which equipment and systems are most critical and most important.
- (3) Develop a system for keeping up with what needs to be done.
- (4) Train people for the work that needs to be done or contract the special services that are needed.

6.1.3 The success of an EPM program depends on the caliber of personnel responsible for its implementation.

6.1.3.1 The primary responsibility for EPM program implementation and its success should lie with a single individual.

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

6.1.3.3 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

6.1.5.1 There should be adequate storage facilities for tools and test equipment that are common to the group.

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 practicable within the limits of safety and the skill of the craftsman. These procedures should be reviewed regularly in order 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 Supervisors find their best motivational opportunities through handling the results of running inspections. When the electrical maintenance supervisor initiates corrective action, the craftsperson should be so informed. The craftsperson who found the condition will then feel that his or her job was worthwhile and will be motivated to try even harder. However, if nothing is done, individual motivation might be affected adversely.

6.1.8 Trends in failure rates are hard to change and take a long time to reverse. For this reason, the inspection should continue and resulting work orders should be written, even though the work force might have been reduced. Using the backlog of work orders as an indicator, the electrical maintenance supervisor can predict trends before they develop. With the accumulation of a sizable backlog of work orders, an increase in electrical failures and production downtime can be expected.

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 take a look at the total package. Will the available manpower permit the survey of an entire system, process, or building, or should it be divided into segments?

6.2.1.2 Next, a priority should be assigned to each segment. Segments found to be sequential 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, and such, and might also require that manufacturers be contacted, to replace lost documents. All of the documents should be brought to a central location and marked immediately with some form of effective identification.

6.2.2 Diagrams and Data. The availability of up-to-date, accurate, and complete diagrams is the foundation of a successful EPM program. No EPM program can operate without them, and their importance cannot be overemphasized. 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 the electrical circuitry down to, and often including, the major items of utilization equipment. They 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, and equipment continuous 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 Short-circuit and coordination studies are important. Many managers have the misconception that these engineering studies are part of the initial facility design, after which the subject can be forgotten. However, a number of factors can affect the available short-circuit current in an electrical system. Among these factors are changes in the supply capacity of the utility company, changes in size or percent impedance of transformers, changes in conductor size, addition of motors, and changes in system operating conditions.

(A) 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.

(B) In a small facility, one receiving electrical energy at utilization voltage or from a single step-down transformer, the short-circuit study is simple. The available incoming short-circuit current can be obtained from the utility company sales engineer.

(C) In a larger system, it might be desirable to develop a computerized short-circuit study to improve accuracy and reduce engineering time. Should resources not be available within the plant organization, the short-circuit study can be performed on a contract basis. The short-circuit data are used to determine the required momentary and interrupting ratings of circuit breakers, fuses, and other equipment.

(D) 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, verified by electrical tests, and recorded for future reference.

(E) Personnel performing the tests should be trained and qualified in proper test procedures. 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.

(F) Additional guidance on electrical systems can be found in Chapter 25.

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

(A) Where control conductors or conductors of different systems are contained within the same raceway, the coding appropriate to each conductor should be noted.

(B) Vertical and horizontal runs with the location of taps, headers, and pull boxes should be shown.

(C) Access points should be noted where raceways pass through tunnels or shafts with limited access.

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.

(A) Switching equipment, transformers, control panels, mains, and feeders should be identified.

(B) 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 but arranged in their actual physical location.

6.2.2.6.1 Electromechanical components and strictly mechanical components interacting with electrical components should be shown. Of particular value is the designation of terminals and terminal strips with their appropriate numbers, letters, or colors.

6.2.2.6.2 Wiring diagrams should identify all equipment parts and devices by standard methods, symbols, and markings.

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

6.2.2.8 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 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 6.2.3.4.

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 lights and probably an automatic transfer switch to the emergency power system.

6.2.3.2 Ventilation. Ventilation systems normally comprise the heating, cooling, and air-filtering system. Exceptions include furnace, dryer, oven, casting, and similar areas where process heat is excessive and air conditioning is not practical. Numerous fans are used to exhaust the heated and possibly foul air. In some industries, such as chemical plants and those using large amounts of flammable solvents, large volumes of air are needed to remove hazardous vapors. 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.

6.2.3.3 Heating and Air Conditioning. 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, but all should be shown and complete information given for each.

6.2.3.4 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 craftsman to have a better concept 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. Optimum use of these procedures is made when they are bound for quick reference and posted in the area of the equipment or systems. 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 at a premium, 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, craftspersons (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, additional equipment not found in the toolbox should be readily available. The size of the plant, 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 plants in the area might well justify common ownership of the same device for joint use, making it quickly available at any time to any plant. Typical examples might be high-current or dc high-potential test 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 craftsperson 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) Wheel pullers
- (5) Feeler gauges to function as inside- and outside-diameter measuring gauges
- (6) Instruments for measuring torque, tension, compression, vibration, and speed
- (7) Standard and special mirrors with light sources for visual inspection
- (8) Industrial-type portable blowers and vacuums having insulated nozzles for removal of dust and foreign matter
- (9) Nontoxic, nonflammable cleaning solvents
- (10) 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 or near live electrical equipment. Prior to performing maintenance on or near live electrical equipment, NFPA 70E, *Standard for Electrical Safety in the Workplace*, 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 clear insulating face shields for protection against arcs
- (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. 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 other isolated source. This voltage level is a function of the ambient condition in which the portable lighting is used. The aim is to limit the exposure of personnel to hazardous current levels by limiting the voltage. Ample supply of battery lanterns and extra batteries should be available. Suitable extension cords should be provided.

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, and volt-amperes 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 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.

6.2.5.9.1 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 plant, the plant 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 qualified people:

- (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 go over 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 no problem 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 agitator drive motor for a kettle-type reactor can be extremely critical in that, if it fails to run for some period of time, when the charge materials are added to the reactor, the catalyst stratifies. If the motor is then started, a rapid reaction, rather than a slow, controlled reaction, could result that might run away, overpressurize, and destroy the reactor.
- (2) 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.
- (3) 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.

- (4) 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.
- (5) 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.
- (6) 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 the 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 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 There are parts of the system that are critical because they alert operating personnel to dangerous or out-of-control 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 will 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. Ideally, 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, *National Electrical Code*, requires special maintenance considerations. (See Section 23.2.)

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, *National Electrical Code*, 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 3.3.13.1.)
- (2) Intermittent duty (See 3.3.13.2.)
- (3) Periodic duty (See 3.3.13.3.)
- (4) Short-time duty (See 3.3.13.4.)
- (5) Varying duty (See 3.3.13.5.)

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 plant’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 having a good load factor and located in a favorable environment, the high-voltage oil circuit breakers might need an inspection only every two 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 companies 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 application is probably

unique, so the system per se should have an inspection and testing procedure developed for it.

6.5.2 Forms.

6.5.2.1 A variety of forms can go along 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. Field notes should be legibly transcribed. One copy of reports should go in the working file of the piece of equipment and one in the master file maintained by first line supervision. These forms should be used by the electrical maintenance personnel; they are not for general distribution. If reports to production or engineering are needed, they should be separate, and inspection reports should not be used.

6.5.2.2 The IT&R procedure folder 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) If major work was predicted at the last IT&R, a copy of the purchase order and receiving reports for the parts to do the work and references to unusual incidents reported by production that might be associated with the equipment

6.5.2.3 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 manpower capabilities. In general, facilities should be shut down 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 level out manpower requirements and limit downtime.

6.5.3.2 The very exercise of scheduling IT&R will point out design weaknesses that require excessive manpower 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. For example, the addition of one circuit breaker and a little cable can change a shutdown from three days to one day.

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 In many continuous-process plants, particularly newer ones, the trend is toward a large single-process line with no installed spares. This method of operation requires inspections and tests, since there will be a natural desire to extend the time between maintenance shutdowns. 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 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 to do the job
- (3) A check to see that the job has been completed
- (4) Noticing if 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 plant 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 destroy operator confidence. Loss of operator confidence can and will cause these systems to be bypassed and the intended safety lost. Maintenance should prove that each operation was valid and caused by an unsafe condition.

6.5.3.9 A good electrical preventive maintenance program should identify the less critical jobs, 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 contain safety procedures required in using their test equipment.

6.5.4.2 The test equipment (high voltage, high current, or other uses) 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 doing 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 protective equipment is in good condition and is on the job.

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 a smoke break, a lunch break, or overnight.

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 such checks as are necessary 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 results. Analysis of the records should guide the spending level for EPM and breakdown repair.

6.5.5.2 Records of Cost. Figures should be kept to show the total cost of each breakdown. 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.

(A) 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 manpower requirements.

(B) Work Order Log. An active log should be kept of unfinished work orders. A greater susceptibility to imminent breakdown is indicated by a large number of outstanding work orders resulting from the inspection function.

(C) 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 after the supervisor has learned to interpret and evaluate the reports. Near misses can be recorded and credit 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, pipe fitters, and mechanics. An overall emergency procedure for each anticipated emergency

situation should be developed cooperatively by the qualified personnel of each discipline involved, detailing steps to be followed, sequence of steps, and assignment of responsibility. The total procedure should then be run 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 poses some additional maintenance considerations.

6.6.1 Quick delivery of replacement parts cannot be taken for granted. Suppliers should be identified, and the replacement parts problem should be reflected in the in-plant spare parts inventory. In addition to considering possible slow 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. Problems in 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 23.2.

Chapter 7 Personnel Safety

7.1 Introduction.

7.1.1 NFPA 70E, *Standard for Electrical Safety in the Workplace*, deals with the issues of safety-related work practices (Chapter 1 of NFPA 70E) and safety-related maintenance requirements (Chapter 2 of NFPA 70E). NFPA 70E and the appropriate OSHA safety-related documents should be utilized for the development of programs and procedures associated with maintenance activities.

7.1.2 Personnel safety should be given prime consideration in system design and in establishing maintenance practices. Safety rules should be instituted and practiced to prevent injury to personnel, both persons who are performing tasks and others who might be exposed to the hazard. The principal personnel danger from electricity is that of shock, electrocution, and/or severe burns from the electrical arc or its effects, which can be similar to that of an explosion.

7.2 Qualified Personnel. Maintenance should be performed only by qualified personnel who are trained in safe maintenance practices and the special considerations necessary to maintain electrical equipment. These individuals should be familiar with the requirements for obtaining safe electrical installations. All employees who face a risk of electrical hazard should be trained to understand the specific hazards associated with electrical energy, such as backfeed.

7.2.1 A person does not have to be fully trained in all categories so long as the specific task information provided and the safety-related information provided are adequate and the employee has demonstrated he/she understands the procedure.

7.2.2 The “qualified person(s)” is expected to know the proper personal protection equipment (PPE) to avoid or mitigate electrical shock or burn exposure.

7.2.2.1 The qualified person should determine if the hazard exposure is limited and restricted against those not qualified for the particular task (so a person not qualified for a specific task, even though fully qualified in all other ways, should not be exposed to the hazard of that specific task).

7.2.2.2 Personnel should be alert to any signs of fatigue, nervousness, and/or inattention to duty/detail in themselves as well as their fellow workers while near the exposed hazard.

7.3 Personnel Training. All employees should be trained in safety-related work practices and required procedures as necessary to provide protection from electrical hazards associated with their respective jobs or task assignments. They should be able to identify and understand the relationship between electrical hazards and possible injury. Employees working on or near exposed energized electrical conductors or circuit parts should be instructed regularly in methods of first aid and emergency procedures, such as approved methods of resuscitation. They also should be trained in methods of release of victims from contact with exposed energized conductors or circuit parts. Employees should be instructed to report all shocks immediately, no matter how minor.

7.3.1 Specific training should be determined by the needs of the employee.

7.3.1.1 For example, the training should include applicable portions of NFPA 70E, *Standard for Electrical Safety in the Workplace*; NFPA 70, *National Electrical Code*; ANSI/IEEE C2, *National Electrical Safety Code*; ac electrical circuits, dc electrical circuits, and voltage levels to be encountered; motor connection and troubleshooting; transformer application and connections; equipment and personnel elevator systems onsite; electrical theory and principles; and additional statutory and federal electrical codes that apply.

7.3.1.2 The training should include information on the type of tools to be utilized. Instruction should be given in selecting the proper tool for the job and the limitations of the tool.

7.3.1.3 It is useful to be knowledgeable of the international standards affecting the task, including record keeping requirements. Safe workplace practices might be taught and demonstrated for material handling, machine/equipment handling, electrical devices, basic blueprint reading, advance wiring diagrams reading, and various power, hand, and calibration tools.

7.3.1.4 It is important to know where material safety data sheets (MSDS) are located and understood as to their application.

7.3.1.5 The training can be in the classroom, on the job, or both.

7.3.1.6 Refresher training should be provided as required.

7.4 Establishing an Electrically Safe Work Condition.

7.4.1 Electrically Safe Work Condition.

7.4.1.1 Prior to maintenance being performed on electrical circuits or equipment, NFPA 70E, *Standard for Electrical Safety in the Workplace*, requires the establishment of an electrically safe work condition, unless the employer can demonstrate that deenergizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations. [70E: 130.1]

7.4.1.2 An electrically safe work condition is a state in which the conductor or circuit part to be worked on or near has been disconnected from energized parts, locked/tagged in accordance with established standards (*see 7.4.4*), tested to ensure the absence of voltage, and grounded when determined necessary.

7.4.2 Achieving an Electrically Safe Work Condition. An electrically safe work condition is achieved when performed in accordance with the procedures of Section 120.2 of NFPA 70E, *Standard for Electrical Safety in the Workplace*, and verified by the following process:

- (1) Determine all possible sources of electrical supply to the specific equipment. Check applicable up-to-date drawings, diagrams, and identification tags.
- (2) After properly interrupting the load current, open the disconnecting device(s) for each source.
- (3) Wherever possible, visually verify that all blades of the disconnecting devices are fully open or that drawout-type circuit breakers are withdrawn to the fully disconnected position.
- (4) Apply lockout/tagout devices in accordance with a documented and established policy.
- (5) Use an adequately rated voltage detector to test each phase conductor or circuit part to verify they are deenergized. Test each phase conductor or circuit part both phase-to-phase and phase-to-ground. Before and after each test, determine that the voltage detector is operating satisfactorily.
- (6) Where the possibility of induced voltages or stored electrical energy exists, ground the phase conductors or circuit parts before touching them. Where it could be reasonably anticipated that the conductors or circuit parts being deenergized could contact other exposed energized conductors or circuit parts, apply ground-connecting devices rated for the available fault duty. [70E:120.1]

7.4.3 Personnel. All personnel connected with the work should be involved. Each individual should be personally satisfied that all necessary steps have been executed in the proper manner.

7.4.4 Lockout/Tagout. 29 CFR 1910.333, "Occupational Safety and Health Act" (OSHA), requires each disconnecting means used to deenergize circuits and equipment on which work is to be performed be locked and tagged in the open position. ANSI Z244.1 2003, *Personnel Protection — Lockout/Tagout of Energy Sources — Minimum Safety Requirements*, and NFPA 70E, *Standard for Electrical Safety in the Workplace*, are also strongly recommended as guides in the development of an effective lockout/tagout for electrical and other energy sources. The lockout/tagout procedure given in NFPA 70E meets or exceeds OSHA requirements.

7.4.4.1 OSHA requires the lock to be attached so as to prevent persons from operating the disconnecting means unless they resort to undue force or the use of tools. OSHA requires each tag to contain a statement prohibiting unauthorized operation of the disconnecting means and removal of the tag. The tag is to provide information as to why the circuit is open and the name of the person having the key for the lock.

7.4.4.2 OSHA allows for the use of a tag without a lock only if the equipment precludes the installation of a lock, and the tag shall be supplemented by at least one safety measure that provides a level of safety equivalent to that obtained by the use of a lock. Some examples of such safety measures include the

removal of an isolating circuit element, blocking of a controlling switch, or opening of an extra disconnecting device.

7.4.4.3 OSHA provides for installation of a lock without a tag only under all of the following conditions:

- (1) Only one circuit or piece of equipment is deenergized.
- (2) The lockout period does not extend beyond the work shift.
- (3) Employees exposed to the hazards associated with reenergizing the circuit of equipment are familiar with this procedure.

7.4.5 Work On or Near Live Parts. Article 130 of NFPA 70E, *Standard for Electrical Safety in the Workplace*, requires that electrical conductors and circuit parts that have not been deenergized or that have been disconnected [but not under lockout/tagout, tested, and grounded (where appropriate)] not be considered to be in an electrically safe work condition and that safe work practices appropriate for the circuit voltage and energy level be used.

7.4.5.1 When it is necessary to work in the vicinity of energized equipment, safety precautions should be followed, such as roping off the dangerous area, using insulating rubber blankets for isolation, and using insulating rubber gloves and properly insulated tools and equipment.

7.4.5.2 Prior to maintenance being performed on or near live electrical equipment, NFPA 70E, *Standard for Electrical Safety in the Workplace*, should be used to identify the degree of personal protective equipment (PPE) required.

7.4.5.3 All insulating tools and PPE should be tested periodically. 29 CFR 1910.137, "Electrical Protective Devices," has requirements for the testing, care, marking, and use of rubber goods, such as insulating blankets, matting, covers, line hose, gloves, and sleeves.

7.4.5.4 The use of well-maintained safety equipment is essential and should be mandatory when working on or near live electrical equipment. Some of the more important articles that should be provided are as follows:

- (1) Heavy leather gloves
- (2) Insulating gloves with leather protectors, 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

7.5 Job Task Safety Analysis. A safety review of the job task to be accomplished should be completed prior to job initiation.

7.5.1 The personnel doing the job task should be briefed prior to starting the task to ensure that all facets affecting safety are understood.

7.5.2 All test instruments and tools should be used in compliance with the manufacturers' instructions. Failure to follow those instructions can result in injury to personnel.

7.5.2.1 When electrical tests are conducted within hazardous (classified) locations, the area should be verified as non-classified if the test equipment is not of an intrinsically safe type. The area should be verified as being non-classified during the period if non-intrinsically safe test equipment is used.

7.5.3 Use of wiring devices such as attachment plugs and receptacles to disconnect some equipment under some load conditions such as welders and running or stalled motors can be hazardous. Other load-interrupting means intended for this purpose should be used.

7.5.4 The following safety precautions should be observed:

- (1) Personnel should wear personal protective equipment (PPE) such as goggles, gloves, aprons, and respirators when working with solvents.
- (2) Care should be exercised in the selection of cleaning agents for any particular task, following all applicable environmental regulations.
- (3) Adequate ventilation should be provided where cleaning agents are used, to avoid fire, explosion, and health hazards.
- (4) A metal nozzle used for spraying flammable cleaning agents should be bonded to the supply drum and to the equipment being sprayed.
- (5) Screens, ropes, guards, and signs should be provided to prohibit access to persons other than those necessary to perform the task.
- (6) A procedure should be established to leave the test site in a safe condition when unattended.

7.5.5 The review process should include such checks as are necessary to ensure the equipment is ready for operation at the completion of the task.

7.6 Arc Flash Hazard. Switchboards, panelboards, industrial control panels, and motor control centers that are likely to require examination, adjustment, servicing, or maintenance while energized should be field marked to warn qualified persons of potential electric arc flash hazards. The marking should be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

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

7.7.1 As described in 7.4.5, 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. Optimum protection should be provided. A high level of protection should be provided for any work on high- and medium-voltage circuits; on the other hand, minimal protection might be sufficient for work on minor branch circuits. Balance should be struck between the two extremes of optimum and minimal-but-adequate protection.

7.7.2 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

7.7.3 Providing proper protection begins with establishing an electrically safe work condition as described in Section 7.4.

7.7.4 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.

7.7.4.1 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 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.

7.7.4.2 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 7.7.4.2.1 through 7.7.4.2.5 into consideration.

7.7.4.2.1 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.

7.7.4.2.2 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.

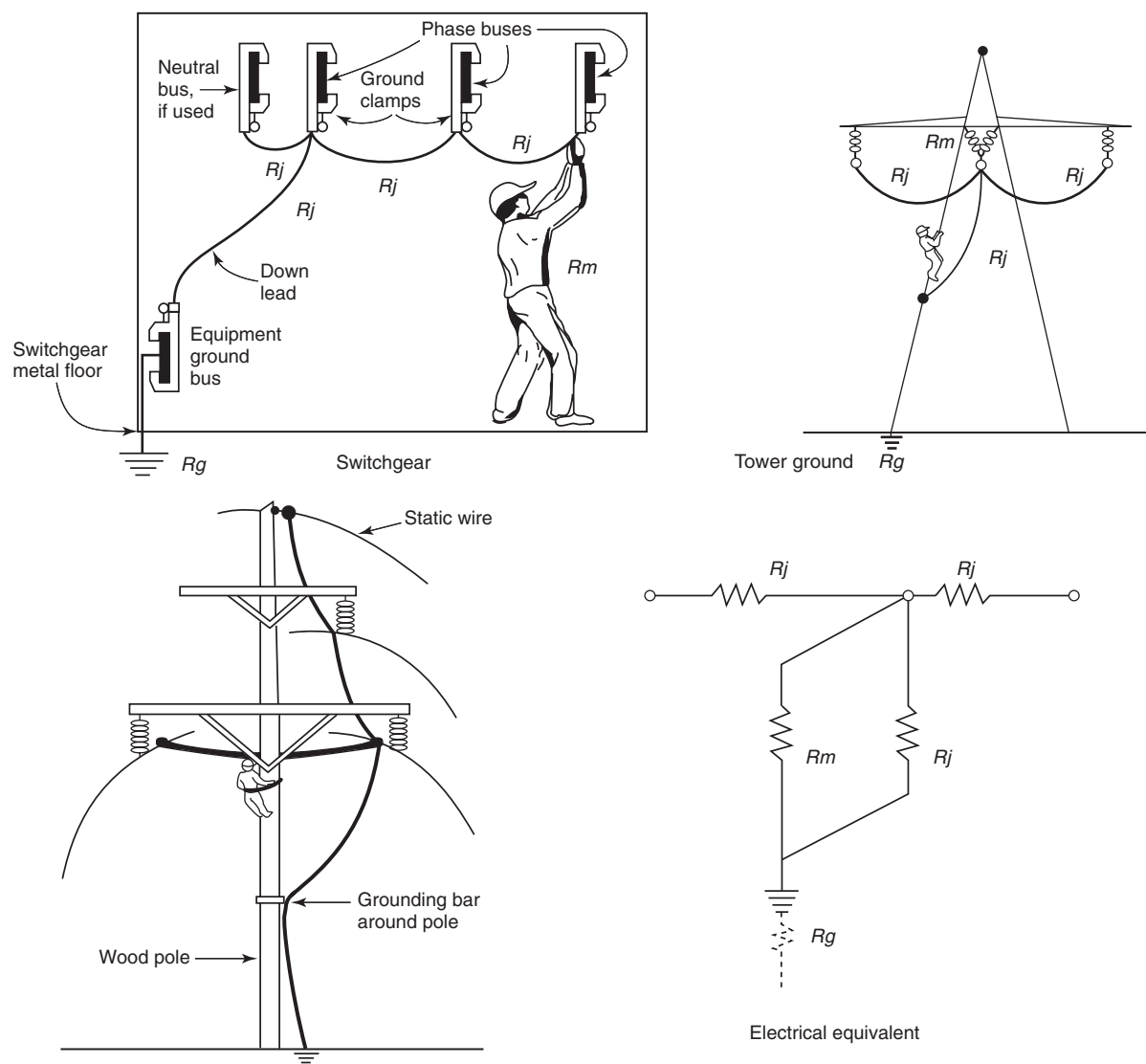
7.7.4.2.3 Solid metal-to-metal connections are essential between grounding clamps and the deenergized conductors. Conductors are often corroded and are sometimes covered with paint. Ground clamps should have serrated jaws because it is often impractical to clean the conductors. The clamps should be slightly 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.

7.7.4.2.4 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.

7.7.4.2.5 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 7.7.4.2.5 with the equivalent electrical diagram.

7.7.4.3 In Figure 7.7.4.2.5 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_j), 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 7.7.4.2.5 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.

7.7.4.4 Connecting the phase conductors together with short cables and clamps of adequate capacity, as shown in Figure 7.7.4.2.5, minimizes resistance between phases for fast action of the circuit overcurrent protective devices to deenergize the circuit, if it is inadvertently reenergized.



In the electrical equivalent diagram, it can be presumed that the resistance of the person's body (R_m) is 500 ohms. He or she is in parallel with only the resistance of a single cable (R_j), 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 person would be subjected to only about 1 volt imposed across the work area; therefore, the current flow through his or her body would be negligible.

FIGURE 7.7.4.2.5 Preferred Grounding Arrangement.

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 7.7.4.2.5 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.

7.7.4.5 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.

7.7.4.6 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.

7.7.4.7 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.

7.7.4.8 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.

7.7.4.9 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.

7.7.4.10 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.

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

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

7.7.4.13 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. Such maintenance tasks can be performed when the equipment is energized, provided provisions are made to allow maintenance to be performed safely. For the purposes of this chapter, *deenergized* means locked and tagged out in accordance with 7.4.4. 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 shut down and 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 taking transformer oil samples and observing and recording operating temperatures, load conditions, corona, noise, or lamp output.

8.1.1.3 Coordinating maintenance with planned production outages and providing system flexibility such as by duplication of 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 to be performed on 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. Duplication of equipment enables maintenance to be performed economically without costly premium time and ensures continuous production in the event of an accidental breakdown.

8.1.3 Selection of quality equipment that is adequate for the present and projected load growth is a prime factor in reducing maintenance cost. 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 of the equipment in order to minimize maintenance cost.

8.1.4 Too often, installation cost without sufficient regard for efficient and economic maintenance influences 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.

8.1.5 As equipment grows older and is possibly worked harder, scheduling outages to perform accelerated maintenance could become a major problem.

8.2 Scheduling Maintenance.

8.2.1 In larger plants, routine maintenance scheduling is often done by a computer program that prints out the work orders for projects to be accomplished on a weekly or monthly basis. In smaller plants, the maintenance schedule is often carried in the maintenance supervisor's head. It goes without saying that an effective maintenance program requires a positive mechanism for scheduling and recording the work that has been accomplished.

8.2.2 A thankless task is that of working with production management in attempting to obtain production outages necessary to accommodate maintenance. Many production managers still look at maintenance as a necessary evil. Maintenance outages, particularly in plants that operate 24 hours a day, 7 days a week, are difficult to schedule; however, there are some areas that can be relieved with a nominal investment.

8.2.2.1 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, overhauled, and tested at almost any convenient time. The in-service breakers could then be exchanged with spares at an opportune time, with negligible production downtime.

8.2.3 Many plants schedule vacation shutdowns of 1 to 3 weeks duration to perform needed periodic maintenance on vital production apparatus that cannot be taken out of service at any other time. A total plant shutdown resolves the problem of scheduling partial outages around limited production operations. Even so, some difficulty might be encountered in providing power requirements for maintenance operations and still performing the needed maintenance on the electrical system.

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

8.2.5 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) The potential of equipment failure to endanger or threaten personnel safety (*See Section 5.2.*)
- (2) Manufacturers' service manual recommended practices and procedures (*See 6.4.4.2.*)
- (3) Operating environment (*See 5.3.3, 6.4.1, 6.4.3.*)
- (4) Operating load conditions and equipment rating (*See 5.3.4, 6.4.2, 6.4.4.4.*)
- (5) Unusually expensive equipment repairs (*See Section 5.2.*)
- (6) Failure and repair of failed equipment causing extensive downtime and lost production dollars (*See Section 5.2.*)
- (7) Equipment condition (*See 6.3.3, 6.3.5.*)
- (8) Operating load conditions and equipment rating (*See 5.3.4 and 5.3.5.*)
- (9) Production and operating schedules (*See 6.1.6, 6.5.3.*)
- (10) Ability to take equipment out of service (*See 6.1.6.*)
- (11) Failure history (*See 6.1.6, 6.4.4.5.*)
- (12) Inspection history (*See 6.4.4.5.*)

8.2.5.1 A guide for maintenance intervals is included in Annex I.

8.3 Equipment Safety.

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

8.3.2 The protective device, fuse, relay, and series or static trip on low-voltage breakers generally sense overcurrent. Ideally, the device should not be applied or set to respond to normal load excursions, yet it should function on a low-level fault. This is an impossible situation unless ground-fault protection is utilized, since the magnitude of a phase-to-ground fault could be less than normal load current.

8.3.3 Destructive energy, capable of disintegrating an entire switchgear assembly in a matter of a few minutes, can be released in a low-voltage phase-to-phase or phase-to-enclosure, sustained arcing fault. The fault current, in the order of thousands of amperes, multiplied by the arc voltage drop (approximately 100 volts on a 480Y/277 system) multiplied by the duration of the arc in seconds is a measure of the energy released (watt-seconds).

8.4 Protective Scheme.

8.4.1 While the application of circuit protection, as developed in a short-circuit and coordination study, is an engineering function and hence recognized as a facet of system design, assurance the this designed protection remains in operation is a maintenance responsibility. Applying the settings and periodic testing of the protective devices, relays, and series and static trip elements is definitely a maintenance function. Similarly, checking the proper type and ampere rating of the fuses used in the system is part of the maintenance function.

8.4.2 In larger plants, interpretation of the short-circuit and coordination study is generally made by plant engineering, and the settings and test points for the adjustable protective devices are furnished by 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 in understanding the 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. The momentary and interrupting rating requirements of the protective devices should be analyzed, that is, will the circuit breaker or fuse safely interrupt the fault or explode in attempting to perform this function?

8.4.3.1 Another phase of the study is that of developing the application of the protective device to realize minimum equipment damage and the least disturbance to the system in the event of a fault.

8.5 Acceptance Testing. The initial acceptance testing of the electrical system is part of design and plant construction and hence not part of maintenance. However, the acceptance test data do provide the 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 plant engineer for the maintenance records.

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 factory reconditioned under rebuilding programs.

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 sought for repaired or rebuilt equipment.

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

8.7 Equipment Cleaning.

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

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. Waste rags should not be used because lint will 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. Blowing out with compressed air is likely to spread contamination and damage insulation.

8.7.2.3 Where dirt cannot be removed by wiping or vacuuming, compressed-air blowing might be necessary. Care should be exercised because the use of compressed air can cause contaminants to become airborne, which can compromise the integrity of insulation surfaces or foul the mechanical operation of nearby equipment. Provisions might need to be made to remove the equipment to a suitable location for cleaning or to cover other equipment to guard it from cross contamination. Air should be dry and directed in a manner to avoid further blockage of ventilation ducts and recesses in insulations.

CAUTION: Cleaning with compressed air can create a hazard to personnel and cause equipment to fail or malfunction.

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

8.7.2.4 Accumulated dirt, oil, or grease might require a solvent to remove it. A rag 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 specified by the equipment manufacturer, because of the risk of residues causing damage, interfering with electrical or mechanical functions, or compromising the integrity of insulation surfaces.

8.7.2.5 Equipment might require cleaning by nonconductive sandblasting.

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 might cause equipment to fail or malfunction.

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 Asbestos is a toxic substance subject to government regulations. A knowledge of government regulations is required in 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 Industry Office of Toxic Substances, Environmental Protection Agency, Washington, DC 20460. Call 202-554-1404.)

8.7.2.7 If sweeping of a substation 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 switchgear.

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(A) through 8.8.1(I).

(A) 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. Airborne asbestos fibers can endanger health. (See 8.7.2.6.)

(B) Polychlorinated Biphenyls (PCBs). Askarels and other PCBs previously were used as a noncombustible dielectric fluid or added to transformer oil. 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. (See 10.2.1.3.)

(C) Lead. The disposal of paper-insulated, lead-covered cables can be an environmental concern. Abandoning a lead product, like a lead-covered cable, in the ground is prohibited in some jurisdictions. The lead can leach soluble lead salts into the environment. Reclaiming and reusing the lead or treating the lead to curtail leaching are two means of handling the environmental threat.

(D) Mineral Oil. 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 oil spills require state and regional EPA notification.

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

(F) Trichloroethane. Vapors from trichloroethane, an electrical cleaning and degreasing solvent, are toxic and an environmental threat. Handling and disposal of the liquid require special precautions because trichloroethane is an ozone-

depleting chemical. Some jurisdictions have already banned the use of trichloro products.

(G) Mercury Vapor and Phosphor Coatings. Fluorescent lamps and similar gas tubes can 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.

(H) Radioactive Materials. Devices containing radioactive materials can require special precautions.

(I) 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 old 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 chemical, 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 Lubrication. Lubrication is the application of grease or oil to the bearings of motors, rotating shafts, gears, and so on. It can also include 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.

Chapter 9 Substations and Switchgear Assemblies

9.1 Substations.

9.1.1 Introduction.

9.1.1.1 Substations in an electrical system perform the functions of voltage transformation, system protection, power factor correction metering, and circuit switching. They are comprised of electrical power products, such as transformers, regulators, air switches, circuit breakers, capacitors, and lightning arresters.

9.1.1.2 Maintenance of the substation is of a general nature. Maintenance of the individual power products are discussed under the appropriate headings. (See Section 9.8 for additional consideration in the maintenance of gas-insulated substations and gas-insulated equipment.)

9.1.1.3 The recommended frequency of maintenance depends on the environment in which the substation is operating. In many cases, it is an outdoor installation and exposed to the atmospheric contaminations in the neighborhood. In areas of industrial contamination or in coastal areas where ocean vapors are prevalent, inspections are recommended at intervals of 6 weeks to 2 months. Less frequent inspections are recommended in areas of relatively clean atmosphere.

9.1.2 Insulators.

9.1.2.1 Insulators should be inspected for evidence of contaminated surfaces or physical damage, such as cracked or

broken segments. Contaminated insulator surfaces should be cleaned, and damaged insulators replaced.

9.1.2.2 Evidence of violent corona when the substation is energized should be reported. (*See 3.3.10 for the definition of corona.*) Ultrasonic detection and light amplification (night vision) equipment are useful for detecting corona.

9.1.2.3 Mild corona might be normal and is more pronounced when humidity is high.

9.1.3 Conductors. All exposed conductors should be inspected for evidence of overheating at bolted joints. Extreme overheating will discolor copper conductors. If the substation is deenergized, bolted connections should be checked for tightness. Bolts should be tightened where required, with care being taken not to overstress the bolts. There are infrared detectors that can be used on energized systems to check for overheating by scanning from a distance. Where aluminum-to-copper joints exist, they should be inspected carefully for evidence of corrosion, overheating, or looseness.

9.1.4 Air-Disconnecting Switches.

9.1.4.1 Air-disconnecting switches are normally operated infrequently in service and usually are energized during routine substation maintenance. In that case, maintenance of the switch is limited to those areas that can be approached safely. The insulators and conducting parts should be examined as described earlier in 9.1.2 and 9.1.3. Interphase linkages and operating rods should be inspected to make sure that the linkage has not been bent or distorted and that all fastenings are secure. The position of the toggle latch of the switch-operating linkage should be observed on all closed switches to verify that the switch is mechanically locked in a closed position.

9.1.4.2 Power-operated switches should be operated periodically to ensure that the switches and their mechanism and control features are functioning properly. When the circuit condition does not permit operating the switch while energized and the circuit cannot be deenergized for routine maintenance, the operating mechanism should be disengaged from the linkage to allow the control circuits and mechanism to be checked, provided that this method does not adversely affect the overall adjustment.

9.1.4.2.1 The maintenance instructions of the particular manufacturer of each mechanism should be followed.

9.1.4.2.2 In addition, the following features should be checked:

- (1) Limit switch adjustment
- (2) Associated relays for poor contacts, burned-out coils, and inadequate supply voltage
- (3) Any other condition that might prevent proper functioning of the switch assembly

9.1.4.3 If the switches cannot be deenergized during routine maintenance, a scheduled outage should be planned periodically and thorough maintenance performed as follows:

- (1) The switch should be operated several times manually and checked for approximate simultaneous closing of all blades and for complete contact closing, and the blade lock or latch should be checked in the fully closed position.
- (2) If so equipped, the switch should be power operated and checked in accordance with the procedure in 9.1.4.3(1).
- (3) Contacts should be inspected for alignment, pressure, burns, or corrosion.

- (a) Pitted or badly burned contacts should be replaced.
- (b) If pitting is of a minor nature, the surface should be smoothed down with clean, fine sandpaper.
- (c) Arcing horns should be inspected for signs of excessive burning and should be replaced if necessary.
- (4) Insulation should be inspected for breaks, cracks, or burns and cleaned where abnormal conditions, such as salt deposits, cement dust, or acid fumes, prevail.
- (5) Gear boxes should be checked for moisture that could cause corrosion or difficulty in the switch due to ice formation.
- (6) Flexible braids or slip ring contacts commonly used for grounding the operating handle should be inspected, and braids showing signs of corrosion, wear, or broken strands should be replaced.
- (7) All safety interlocks should be inspected, checked, and tested for proper operation.

9.1.4.4 If it is known that a switch has carried heavy short-circuit current, special effort should be made to inspect it at the earliest possible time, since the ability of the switch to carry rated load current or fault current might be seriously impaired if the contacts are not maintained properly.

9.1.5 Grounding Equipment. All the station grounds, enclosure grounds, and apparatus grounds should be inspected and tested when possible. All grounding connections should be inspected for tightness and absence of corrosion.

9.1.6 Enclosures. The security of fences or other enclosures should be checked to ensure against entry of animals or unauthorized personnel. The gates or doors, especially where equipped with panic hardware, should be checked for security and proper operation. The enclosed area should not be used for storage of anything other than the most frequently used spare parts directly associated with the enclosed equipment.

9.1.7 Miscellaneous Equipment.

9.1.7.1 The availability and condition of rack-out devices, hoisting or handling apparatus, grounding equipment, hot sticks, rubber gloves, statiscopes, and other test equipment should be checked.

9.1.7.2 The proper operation of floodlights and other auxiliary apparatus, such as cooling fans on transformers, should be checked.

9.1.7.3 Any indication of warning lights or warning flags on temperature gauges, pressure gauges, or liquid level gauges should be reported.

9.2 Switchgear Assemblies.

9.2.1 Introduction.

9.2.1.1 A switchgear assembly is assembled equipment (indoor or outdoor) that includes, but is not limited to, one or more of the following: switching, interrupting, control, metering, protective, or regulating devices together with their supporting structure, enclosure, conductors, electric interconnections, and accessories.

9.2.1.2 A switchgear assembly can be an open type, as part of a substation assembly, or an enclosed type. The open type was covered in Section 9.1. This section covers enclosed-type assemblies and, more specifically, metal-enclosed assemblies, because other types of enclosures are rarely found.

9.2.1.3 Metal-enclosed switchgear assemblies are enclosed on all sides and at the top with sheet metal. Access into the enclosure is provided by doors or a removable cover. The bus and bus connections are bare in all except metal-clad-type switchgear assemblies. Although the bus and the connections are insulated in metal-clad switchgear assemblies, the insulation is not designed to protect against electrical shock. Contact with the bus or its connections should be avoided when the switchgear is energized.

9.2.1.4 Low-voltage metal-enclosed switchgear assemblies have a maximum nominal voltage rating of 600 volts. Medium- and high-voltage metal-enclosed switchgear assemblies have nominal voltage ratings from 5,000 volts to 69,000 volts inclusive.

9.2.1.5 These switchgear assemblies are normally constructed in modules or cubicles, each of which contains either one or more interrupting devices (low-voltage cubicles usually contain two or more interrupting devices, whereas medium- and high-voltage cubicles contain only one device) or auxiliary equipment, such as metering transformers, auxiliary power transformer, control relaying, and battery chargers. Power is fed throughout the assembly by the main power bus.

9.2.1.6 Metal-enclosed switchgear assemblies are normally connected to one or more supply transformers, either closely connected to the transformer throat or remotely connected by cable or metal-enclosed bus. They might be found outdoors as a part of a substation or indoors as a power distribution center.

9.2.2 Frequency of Maintenance.

9.2.2.1 Recommended frequency of maintenance depends on environmental and operating conditions, so no fixed rule can govern all applications.

9.2.2.1.1 An annual inspection of the entire switchgear assembly, including withdrawable elements during the first 3 years of service, is usually suggested as a minimum when no other criteria can be identified.

9.2.2.1.2 Inspection frequency can be increased or decreased depending on observations and experience. It is good practice to follow specific manufacturers' recommendations regarding inspection and maintenance until sufficient knowledge is accumulated that permits modifying these practices based on experience. It is recommended that frequent inspections be made initially; the interval can then be gradually extended as conditions warrant.

9.2.2.2 The following factors affect the decision on when to inspect:

- (1) Scheduled shutdowns
- (2) Emergency shutdowns
- (3) Periods of sustained unusual or abnormal operating conditions (e.g., switching or lightning surges and sustained overloads)
- (4) Feeder, bus, or system fault occurrence
- (5) Extremes in atmospheric conditions, such as heat, cold, heavy dust, high winds, rain, snow, fog, smog, fumes of many kinds, fly ash, salt spray, high humidity, unusual temperature changes, and lightning
- (6) Maintenance requirements and schedules for related equipment, either component parts of the switchgear assembly or items apart from but connected to the switchgear circuits (Time is the most universal criterion, but other indicators, such as number of operations, can be used as a guide.)

9.2.2.3 Partial inspections can be made even when the entire switchgear assembly cannot be deenergized.

9.2.2.4 Specific circuits can be taken out of service even though the main bus is not deenergized. This permits an insulation inspection of bus risers and supports in the load side or "off" side of the switchgear unit.

9.2.2.5 Where operating conditions are such that a full shutdown of an entire switchgear assembly for inspection of insulation is impractical, partial inspections can dictate the decision on whether a full shutdown is mandatory to avoid a potential developing failure. Conditions in those areas accessible for partial inspection, however, cannot be guaranteed to be indicative of conditions in areas not accessible for inspection under energized conditions.

9.2.3 Enclosure. A good maintenance program will ensure the continuation of the two functions of an enclosure:

- (1) To prevent exposure of live parts and operating mechanisms
- (2) To protect the equipment from exposure to moisture and air contaminants outside the enclosure

9.2.4 Security. All doors and access panels should be inspected to ensure that all hardware is in place and in good condition. Hinges, locks, and latches should be lubricated. Screens covering ventilation openings should be in place to prevent entry of rodents or small animals.

9.2.5 Leakage. On outdoor assemblies, roof or wall seams should be checked for evidence of leakage, and any leaking seams should be caulked. Although leakage might not be prevalent at the time of inspection, prior leakage can be identified by rust or water marks on surfaces adjacent to and below leaky seams. The base should be checked for openings that could permit water to drain into the interior, and any such openings should be caulked or grouted.

9.2.6 Moisture.

9.2.6.1 Moisture accumulation might occur on internal surfaces of enclosures even though they are weathertight. The source of this moisture is condensation. When the temperature of any surface drops below the dew point of the air with which it is in contact, condensation will occur. Humidity of the outside atmosphere cannot be controlled as it enters the enclosure. However, water vapor can be added to the internal atmosphere if there are pools of water at the base of the enclosure in the vicinity of floor openings or bottom wall ventilation openings. All floor openings, other than those specifically provided for drainage purposes, should be effectively sealed. All unused conduits or openings around cables at entrance ducts should be sealed with an electrical grade of caulking compound. Water pools should be eliminated permanently.

9.2.6.2 Conditions causing condensation are intermittent and might not be prevalent at the time of inspection. All internal surfaces should be examined for signs of previous moisture such as the following:

- (1) Droplet depressions or craters on heavily dust-laden surfaces
- (2) Dust patterns, such as those that occur if an auto is subjected to a light rain shower shortly after it has been driven on a dusty road
- (3) Deposit patterns, such as those that might occur where a film of dirty water is left to evaporate on a flat surface
- (4) Excessive rust anywhere on the metal housing

9.2.6.3 Moisture accumulation is prevented by heat and air circulation. It is important, therefore, to make sure the heating and ventilating systems are functioning properly.

9.2.7 Heating. Heat losses in switchgear assemblies carrying not less than 75 percent full load will probably prevent condensation except in those cubicles containing auxiliary equipment. Where space heaters are provided in each cubicle and in outdoor metal-enclosed bus runs to supply supplementary heat, they should be checked to ensure that they are in good condition and are operating properly. If they are thermostatically controlled, the thermostat should be checked for proper operation and setting. A thermostat set too low will not control the heaters properly under all climatic conditions.

9.2.8 Ventilation. Where ventilators are supplied on enclosures, including metal-enclosed bus enclosures, they should be checked to ensure that they are clear of obstructions and that the air filters are clean and in good condition. Base foundations should be examined to ensure that structural members have not blocked floor ventilation.

9.2.9 Lighting and Housekeeping. All interior and exterior lighting should be checked for proper operation. Availability of spare equipment and handling devices should be checked. They should be stored in such a manner as to be readily available yet not hamper normal manual operation or block ventilation passages.

9.2.10 Insulation.

9.2.10.1 With proper maintenance, the insulation of metal-enclosed switchgear assemblies is designed and expected to withstand operating voltages for periods on the order of 20 to 30 years. During this time, the insulation will be subject to an accumulation of deteriorating conditions that detract from its voltage-withstanding capability.

9.2.10.2 Moisture combined with dirt is the greatest deteriorating factor for insulation. Perfectly dry dirt is mostly harmless, but even small amounts of moisture, such as condensation, will result in electrical leakage that leads to tracking and eventual flashover if allowed to continue to accumulate. It is important in the maintenance of switchgear to know the condition of the insulation. This is especially true in the older installations in unfavorable locations where deteriorating effects might be significant.

9.2.10.3 The surfaces of all insulating members should be inspected before any cleaning or dust removal and repeated after cleaning. Moisture droplets often leave little craters or depressions in a heavy dust layer without staining the member under the dust. Conversely, a carbon track starting to form on a bus support sometime prior to inspection might be completely masked by later deposits of dust.

9.2.11 Electrical Distress. The following specific areas in which electrical distress is more likely to occur should be given special attention:

- (1) Boundaries between two adjoining insulators
 - (2) Boundaries between an insulating member and the grounded metal structure
 - (3) Taped or compounded splices or junctions
 - (4) Bridging paths across insulating surfaces, either phase-to-phase or phase-to-ground
 - (5) Hidden surfaces such as the adjacent edges between the upper and lower members of split-type bus supports or the edges of a slot through which a bus bar protrudes
- (6) Edges of insulation surrounding mounting hardware either grounded to the metal structure or floating within the insulating member

9.2.11.1 Damage caused by electrical distress normally is evident on the surface of insulating members in the form of corona erosion or markings or tracking paths.

9.2.12 Corona.

9.2.12.1 If corona occurs in switchgear assemblies, it is usually localized in thin air gaps that exist between a high-voltage bus bar and its adjacent insulation or between two adjacent insulating members. It might form around bolt heads or other sharp projections that are not properly insulated or shielded. Corona in low-voltage switchgear is practically nonexistent.

9.2.12.2 Organic insulating materials, when exposed to corona discharge, initially develop white powdery deposits on their surface. These deposits can be wiped off with solvent. If the surface has not eroded, further maintenance is not required. Prolonged exposure to corona discharge will result in erosion of the surface of the insulating material. In some materials, corona deterioration has the appearance of worm-eaten wood. If the corrosion paths have not progressed to significant depths, surface repair probably can be accomplished. Manufacturers' recommendations should be followed for such repair.

9.2.13 Tracking.

9.2.13.1 Tracking is an electrical discharge phenomenon caused by electrical stress on insulation. This stress can occur phase-to-phase or phase-to-ground. Although tracking can occur internally in certain insulating materials, these materials as a rule are not used in medium- or high-voltage switchgear insulation. Tracking, when it occurs in switchgear assemblies, normally is found on insulation surfaces.

9.2.13.2 Tracking develops in the form of streamers or sputter arcs on the surface of insulation, usually adjacent to high-voltage electrodes. One or more irregular carbon lines in the shape of tree branches is the most common sign of tracking.

9.2.13.3 Surface tracking can occur on the surfaces of organic insulation or on contaminated surfaces of inorganic insulation. The signs of tracking on organic materials are eroded surfaces with carbon lines. On track-resistant organic materials, these erosion patterns are essentially free of carbon.

9.2.13.3.1 Tracking can propagate from either the high-voltage terminal or the ground terminal. It does not necessarily progress in a regular pattern or by the shortest possible path.

9.2.13.4 Tracking conditions on surfaces of inorganic material can be completely removed by cleaning its surfaces, because no actual damage to the material occurs. In the case of organic material, the surface is damaged in varying degrees, depending on the intensity of the electric discharge and the duration of exposure. If the damage is not too severe, it can be repaired by sanding and application of track-resistant varnish in accordance with the manufacturers' instructions.

9.2.14 Thermal Damage.

9.2.14.1 Temperatures even slightly over design levels for prolonged periods can significantly shorten the electrical life of organic insulating materials. Prolonged exposure to higher than rated temperatures can cause physical deterioration of the materials, resulting in lowered mechanical strength.

9.2.14.2 Localized heating (hot spots) can sometimes occur, but they can be masked because the overall temperature of the surroundings is not raised appreciably. Loosely bolted connections in a bus bar splice or void spaces (dead air) in a taped assembly are examples of this difficult problem.

9.2.14.3 Because power should be removed prior to inspection, it is relatively unlikely that temperature itself can be relied on to signal potentially damaging heat. Other external conditions, therefore, form the basis for detecting heat damage, including the following:

- (1) Discoloration, usually a darkening, of materials or finishes
- (2) Cracking, cracking, and flaking of varnish coatings
- (3) Embrittlement of tapes and cable insulation
- (4) Delamination
- (5) Generalized carbonization of materials or finishes
- (6) Melting, oozing, or exuding of substances from within an insulating assembly

9.2.14.3.1 Insulating materials that have been physically damaged should be replaced. Mild discoloration is permissible if the cause of overheating is corrected.

9.2.14.3.2 In summary, there are two important things to remember in maintenance of insulation: KEEP IT CLEAN and KEEP IT DRY.

9.3 Circuit Interrupters. Circuit interrupters in switchgear assemblies are either circuit breakers or interrupter switches. Technically, fuses are interrupters, but they are covered separately in Chapter 16.

9.4 Air Circuit Breakers.

9.4.1 Introduction.

9.4.1.1 Before any maintenance work is performed, manufacturers' instruction manuals should be obtained and read carefully. If the breaker is a drawout type, it should be removed from its cubicle and placed in a secure, convenient location for maintenance. A stored-energy-type circuit breaker or its mechanism never should be worked on while its closing spring is charged.

9.4.1.2 Maintenance on fixed- or bolted-type circuit breakers normally should be performed with the breaker in place inside its cubicle. Special precaution should be exercised to ensure that the equipment is deenergized and the circuit in which it is connected is properly secured from a safety standpoint. All control circuits should be deenergized. Stored-energy closing mechanisms should be discharged.

9.4.1.3 Subsections 9.4.2 through 9.5.3 break down maintenance operations on air circuit breakers into five categories: insulation, contacts, arc interrupters, operating mechanisms, and breaker auxiliary devices.

9.4.2 Insulation. Interphase barriers should be removed and then cleaned, along with all other insulating surfaces, with a vacuum cleaner or clean lint-free rags and solvents as recommended by the manufacturer, if needed, to remove hardened or encrusted contamination. An inspection should be made for signs of corona, tracking, or thermal damage as described in 9.2.12 through 9.2.14. The maintenance theme here again is KEEP IT CLEAN and KEEP IT DRY.

9.4.3 Contacts.

9.4.3.1 The major function of the air circuit breaker depends on, among other things, correct operation of its contacts. Air

circuit breakers normally have at least two distinct sets of contacts on each pole, main and arcing. Some have an intermediate pair of contacts that open after the main current-carrying contacts and before the arcing contacts. When closed, practically the entire load current passes through the main contacts. Also, high-overload or short-circuit current passes through them during opening or closing faulted lines. If the resistance of these contacts becomes high, they will overheat. Increased contact resistance can be caused by pitted contact surfaces, foreign material embedded on contact surfaces, or weakened contact spring pressure. This resistance will cause excessive current to be diverted through the arcing contacts, with consequent overheating and burning. The pressure should be kept normal, which is usually described in the manufacturer's instructions.

9.4.3.2 Arcing contacts are the last to open; any arcing normally originates on them. In circuit interruption, they carry current only momentarily, but that current might be equal to the interrupting rating of the breaker. In closing against a short circuit, they can momentarily carry considerably more than the short-circuit interrupting rating. Therefore, there must be positive contact when they are touching. If not, the main contacts can be badly burned, interrupting heavy faults. Failure to interrupt might also result.

9.4.3.2.1 On magnetic blow-out air breakers, the arc is quickly removed from the arcing contacts by a magnetic blow-out field and travels to arcing horns, or runners, in the arc interrupter. The arcing contacts are expendable and will eventually burn enough to require replacement.

9.4.3.3 The general rules for maintaining contacts on all types of breakers are as follows:

- (1) They should be kept clean, smooth, and in good alignment.
- (2) The pressure should be kept normal, as prescribed in the manufacturers' literature.

9.4.3.4 The main contact surfaces should be clean and bright. Discoloration of the silvered surfaces, however, is not usually harmful unless it is caused by insulating deposits. Insulating deposits should be removed with alcohol or a silver cleaner. Slight impressions on the stationary contacts are caused by the pressure and wiping action of the movable contacts. Minor burrs or pitting are allowed, and projecting burrs can be removed by dressing. Nothing more abrasive than crocus cloth should be used on the silvered contact surfaces. Where serious overheating is indicated by discoloration of metal and surrounding insulation, the contacts and spring assemblies should be replaced in line with the manufacturers' instructions.

9.4.3.5 The circuit breaker should be closed manually to check for proper wipe, pressure, and contact alignment and to ensure that all contacts are made at approximately the same time. The spacing between stationary and movable contacts should be checked in the fully open position. Adjustments should be made in accordance with the manufacturers' recommendations.

9.4.3.6 Laminated copper or brush-style contacts found on older circuit breakers should be replaced when they are badly burned. Repairs are impractical because the laminations tend to weld together when burning occurs, and contact pressure and wipe are greatly reduced. They can be dressed with a file to remove burrs or to restore their original shape. They should be replaced when they are burned sufficiently to prevent adequate circuit-breaker operation or when half of the contact surface is burned away. Carbon contacts, used on older circuit

breakers, require little maintenance. However, inadequate contact pressure caused by erosion or repeated dressing might cause overheating or interfere with their function as arcing contacts.

9.4.3.7 The drawout contacts on the circuit breaker and the stationary contacts in the cubicle should be cleaned and inspected for overheating, proper alignment, and broken or weak springs. The contact surfaces should be lightly coated with a contact lubricant to facilitate ease of the mating operation.

9.4.4 Arc Interrupters.

9.4.4.1 Modern arc interrupters of medium-voltage magnetic blow-out air circuit breakers are built with only inorganic materials exposed to the arc. Such materials line the throats of the interrupter and constitute the interrupter plates or fins, which act to cool and disperse the arc. The insulation parts of the interrupter remain in the circuit across contacts at all times. During the time that the contacts are open, these insulating parts are subject to full potential across the breaker. The ability to withstand this potential depends on the care given the insulation.

9.4.4.2 Particular care should be taken at all times to keep the interrupter assembly dry. The materials are not affected much by humidity, but the ceramic material especially will absorb water.

9.4.4.3 The interrupters should be inspected each time the contacts are inspected. Any residue, dirt, or arc products should be removed with a cloth or by a light sanding. A wire brush or emery cloth should not be used for this purpose because of the possibility of embedding conducting particles in the ceramic material.

9.4.4.4 An interrupter should be inspected for broken or cracked ceramic parts, erosion of ceramics, and dirt.

(A) Broken or Cracked Ceramic Parts. Small pieces broken from the ceramics or small cracks are not important. Large breaks or expansive cracks, however, can interfere with top performance of the interrupter. Hence, if more than one or two broken or badly cracked plates are apparent, renewal of the ceramic stack is indicated.

(B) Erosion of Ceramics. When an arc strikes a ceramic part in the interrupter, the surface of the ceramic will be melted slightly. When solidified again, the surface will have a glazed, whitish appearance. At low and medium currents, the effect is slight. However, large-current arcs repeated many times can boil away appreciable amounts of the ceramic. When that happens, the ceramic stack assembly should be replaced.

(C) Dirt in Interrupter. While in service, the arc chute assembly can become dirty. Dust or loose soot deposited on the inside surface of the arc chute can be removed by vacuuming or by wiping with cloths that are free of grease or metallic particles. Deposits can accumulate on ceramic arc shields from the arcing process. These deposits, from the metal vapors boiled out of the contacts and arc horns, can accumulate to a harmful amount in breakers that receive many operations at low- or medium-interrupting currents. Particular attention should be paid to any dirt on the plastic surfaces below the ceramic arc shield. These surfaces should be wiped clean, if possible, especially if the dirt contains carbon or metallic deposits. On breakers that operate thousands of times at low and medium currents, sufficient tightly adhering dirt can accumulate on the ceramic arc shields to impair proper interrupting performance. These arc chutes are of a very hard material,

and a hard nonconducting abrasive is necessary for cleaning. A flexible, abrasive aluminum oxide disc on an electric drill can be useful in cleaning arc chutes. The ceramic arc shields might appear dirty and yet have sufficient dielectric strength. The following insulation test can be used as a guide in determining when a complete or major cleaning operation is required. The arc chutes of medium-voltage circuit breakers should withstand the 60 Hz-rated maximum voltage for 1 minute between the front and rear arc horns. In some applications, circuit breakers can be exposed to overvoltages, in which case such circuit breakers should have an appropriate overpotential test applied across the open contacts. Some manufacturers also recommend a surface dielectric test of the ceramic surfaces near the contacts to verify adequate dielectric strength of these surfaces.

9.4.4.5 Air-puffer devices used to blow the arc up into the interrupter should be checked for proper operation. One accepted method is as follows. With the interrupter mounted on the breaker in its normal position, a piece of tissue paper is placed over the discharge area of the interrupter and observed for movement when the breaker is opened. Any perceptible movement of the paper indicates that the puffer is functioning properly.

9.4.4.6 Low-voltage air circuit-breaker arc chutes are of relatively simple construction, consisting primarily of a wedge-shaped vertical stack of splitter plates enclosed in an insulating jacket. An arc chute is mounted on each pole unit directly above the main contacts. Arc interruptions produce erosion of the splitter plates. The lower inside surfaces of the insulating jackets will also experience some erosion and sooty discoloration.

9.4.4.6.1 The arc chutes should be removed and examined as part of routine maintenance. If the splitter plates are seriously eroded, they should be replaced. If the interior surfaces of the enclosing jackets are discolored or contaminated with arc products, they should be sanded with sandpaper or replaced. Occasionally, the whole arc chute might need replacing, depending on the severity of the duty.

9.4.5 Operating Mechanism.

9.4.5.1 The purpose of the operating mechanism is to open and close the contacts. This usually is done by linkages connected, for most power breakers, to a power-operating device such as a solenoid or closing spring for closing, and that contains one or more small solenoids or other types of electromagnets for tripping. Tripping is accomplished mechanically, independently from the closing device, so that the breaker contacts will open even though the closing device still might be in the closed position. This combination is called a mechanically trip-free mechanism. After closing, the primary function of the operating mechanism is to open the breaker when it is desired, which is whenever the tripping coil is energized at above its rated minimum operating voltage.

9.4.5.2 The operating mechanism should be inspected for loose or broken parts, missing cotter pins or retaining keepers, missing nuts and bolts, and binding or excessive wear. All moving parts are subject to wear. Long-wearing and corrosion-resistant materials are used by manufacturers, and some wear can be tolerated before improper operation occurs.

9.4.5.2.1 Excessive wear usually results in the loss of travel of the breaker contacts. It can affect operation of latches; they could stick or slip off and prematurely trip the breaker. Adjustments for wear are provided in certain parts. In others, replacement is necessary.

9.4.5.2.2 The closing and tripping action should be quick and positive. Any binding, slow action, delay in operation, or failure to trip or latch must be corrected prior to returning to service.

9.4.5.3 The two essentials to apply in maintenance of the operating mechanism are KEEP IT SNUG and KEEP IT FRICTION FREE.

9.4.6 Breaker Auxiliary Devices.

9.4.6.1 The closing motor or solenoid, shunt trip, auxiliary switches, and bell alarm switch should be inspected for correct operation, insulation condition, and tightness of connections.

9.4.6.2 On/off indicators, spring-charge indicators, mechanical and electrical interlocks, key interlocks, and padlocking fixtures should be checked for proper operation and should be lubricated where required. In particular, the positive interlock feature that prevents the insertion and withdrawal of the circuit breaker should be tested while it is in the closed position.

9.4.6.3 The protective relay circuits should be checked by closing the breaker in the test position and manually closing the contacts of each protective relay to trip the circuit breaker. Test procedures are given in 21.10.3.

9.4.6.4 Trip devices on low-voltage breakers might be the electromechanical series overcurrent type with an air or fluid dashpot for time delay. These devices should be tested periodically for proper calibration and operation with low-voltage/high-current test devices. Calibration tests should be made to verify that the performance of the breaker is within the manufacturer's published curves. It is important that manufacturers' calibration curves for each specific breaker rating be used. The fact that current-time curves are plotted as a band of values rather than a single line curve should be taken into account. It should be realized that short-time calibration cannot be checked accurately because factory calibration equipment has synchronized timing devices to ensure symmetrical currents, whereas field-test equipment features random closing and might produce asymmetrical currents that result in faulty readings. If the trip devices do not operate properly, the calibration and timing components should be repaired or replaced in line with the manufacturer's recommendations.

9.4.6.5 If the breakers are equipped with static-tripping devices, they should be checked for proper operation and timing in line with the manufacturer's recommendations. Some manufacturers recommend replacement of electromagnetic devices with static devices in the interest of realizing more precision and a higher degree of reliability with the latter devices.

9.5 Vacuum Circuit Breakers.

9.5.1 The principal difference between vacuum circuit breakers and air circuit breakers is in the main contact and interrupter equipment. In the vacuum circuit breaker, these components are in the vacuum bottle and are not available for cleaning, repair, or adjustment. Contact-wear indicators are available for measuring contact wear.

9.5.2 Vacuum integrity is checked by application of test voltage across the open contacts of the bottle. This test should be performed strictly in accordance with the manufacturer's instructions.

CAUTION: Application of high voltage across an open gap in vacuum can produce x-ray emission.

9.5.2.1 The level of x-ray emission from a vacuum breaker with proper contact spacing and subjected to standard test voltages is extremely small and well below the maximum level permitted by standards. In view of the possibility that the contacts are out of adjustment or that the applied voltage is greater than prescribed, it is advisable that during the overvoltage test all personnel stand behind the front steel barrier and remain farther from the breaker than would otherwise be necessary for reasons of electrical safety. During the high-voltage test, the vapor shield inside the interrupter can acquire an electrostatic charge. This charge should be bled off immediately after the test.

9.5.3 All other maintenance on vacuum circuit breakers should be performed in accordance with that recommended on air circuit breakers.

9.6 Oil Circuit Breakers.

9.6.1 Introduction.

9.6.1.1 Oil circuit breakers are seldom found in modern metal-enclosed switchgear assemblies. They are prevalent in older metal-enclosed switchgear assemblies and in open-type outdoor substations.

9.6.1.2 Although oil circuit breakers perform the same function in switchgear assemblies as air circuit breakers, they are different in appearance and mechanical construction. The principal insulating medium is oil rather than air.

9.6.2 Insulation.

9.6.2.1 External insulation is provided by insulating bushings. Outdoor oil circuit breakers have porcelain bushings, whereas indoor breakers can have either porcelain bushings or organic tubing. The bushings should be examined for evidence of damage or surface contamination. If they are damaged to the extent that the electrical creepage path has been reduced or the glazed surface on porcelain bushings damaged, they should be replaced. Otherwise they should be cleaned thoroughly as required to remove all surface contamination.

9.6.2.2 The oil, in addition to providing insulation, acts as an arc-extinguishing medium in current interrupters. In this process, it absorbs arc products and experiences some decomposition in the process. For that reason, maintenance of the oil is important. Oil maintenance involves detection and correction of any condition that would lower its quality. The principal contaminants are moisture, carbon, and sludge. Moisture will appear as droplets on horizontal members, while free water will accumulate in the bottom of the tank. Sludge caused by oxidation will appear as a milky translucent substance. Carbon initially appears as a black trace. It eventually will disperse and go into suspension, causing the oil to darken.

9.6.2.3 A dielectric breakdown test is a positive method of determining the insulating value of the oil. Samples can be taken and tested as covered in ASTM D 877, *Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes*, and as outlined in 10.2.8.1 and 10.2.8.2. Oil that tests too low should be immediately reconditioned and retested or replaced with new oil. Oil should be tested periodically or following a fault interruption.

9.6.2.4 In replacing the oil, only the oil recommended by the manufacturer should be used, and it should have been stored in sealed containers. In addition, the oil should be given a dielectric breakdown test immediately prior to use and to

avoid air entrapment when it is added. An oil pump or other means should be used, to avoid aeration.

9.6.2.5 In the event entrapment of air cannot be avoided, the entrapped air should be removed by application of vacuum, or the equipment should be allowed to stand for 8 to 12 hours prior to being energized.

9.6.3 Contacts. The main contacts of an oil circuit breaker are not readily accessible for routine inspection. Contact resistance should be measured. Contact engagement can be measured by measuring the travel of the lift rod from the start of contact opening to the point where contacts separate, as indicated by an ohmmeter.

9.6.3.1 More extensive maintenance on main contacts might require removal of the oil and lowering the tank and should therefore be performed less frequently than routine maintenance. The frequency should be determined by the severity of the breaker duty, for example, the number of operations and operating current levels. Any time the breaker has interrupted a fault current at or near its maximum rating, this type of maintenance should be performed. The contacts should be inspected for erosion or pitting. Contact pressures and alignment should be checked. All bolted connections and contact springs should be inspected for looseness.

9.6.4 Arc-Quenching Assemblies.

9.6.4.1 Arc-quenching assemblies should be inspected for carbon deposits or other surface contamination in the areas of arc interruption.

9.6.4.2 If cleaning of these surfaces is necessary, manufacturers' instructions should be followed.

9.6.5 Operating Mechanism. Maintenance of the operating mechanism should follow the same procedure as recommended for air circuit breakers. (See 9.4.5.)

9.6.6 Breaker Auxiliary Devices. Breaker-auxiliary-device maintenance should follow the same procedure as recommended for air circuit breakers (see 9.4.6) when applicable. Other accessories, such as oil level gauges, sight glasses, valves, gaskets, breathers, oil lines, and tank lifters should be inspected. The breaker should be taken out of service immediately if the oil level is below the level gauge or sight glass.

9.7 Interrupter Switches.

9.7.1 A medium-voltage interrupter switch is an air switch equipped with an interrupter for making or breaking specified currents, or both. It can be either the fixed mounted type or the draw-out type and can be either manually or electrically operated. If fixed mounted, it will be interlocked with access doors or panels to prevent access to closed switches.

9.7.2 Maintenance procedures should correspond to those recommended for air circuit breakers except for the interrupter device. This device, on most interrupter switches, is of simple open-type construction and can be inspected and cleaned easily without being removed from the switch. Enclosed interrupters should be removed from the switch and disassembled for maintenance in accordance with the manufacturer's recommendation. Dielectric tests are not required as a part of maintenance. Air puffers are not employed in this type of interrupter.

9.8 Gas-Insulated Substations and Gas-Insulated Equipment.

9.8.1 Introduction. A gas-insulated substation (GIS) is a manufactured assembly of gas-insulated equipment (GIE)

typically installed on electric systems rated 72.5 kV and above. While a few GISs are operated by industrials, most are operated by utilities. A GIS might include such GIE as circuit breakers, disconnect switches, ground switches, voltage transformers, current transformers, capacitors, gas-to-air bushings, gas-to-cable terminations, buses, associated enclosures, and control and monitoring equipment.

9.8.1.1 GIE is installed as components such as circuit breakers for application on industrial medium- and high-voltage electrical systems. In addition to the general guidelines provided in this document, manufacturers' maintenance procedures for GIE should be followed.

9.8.1.2 Some circuit-interrupting devices are inside a hermetically sealed enclosure containing a prescribed amount of sulfur hexafluoride (SF₆) gas and are not serviceable. These devices typically are found in some medium-voltage metal-enclosed switchgear and medium-voltage outdoor power circuit breakers, and they also are used in some medium- and high-voltage interrupter switches. Generally, this equipment utilizes devices that provide a visual indication of loss of gas. Replacement of the entire sealed unit is required when this occurs.

9.8.1.3 Other GIE units contain gas density gauges to monitor temperature and pressure, providing indication of sufficient gas to maintain the equipment ratings.

9.8.2 Sulfur Hexafluoride (SF₆) Gas.

9.8.2.1 SF₆ gas, under pressure, is used as the dielectric and interrupting medium in circuit breakers and switches. SF₆ has been identified as a "greenhouse gas," whose release to the environment could contribute to global warming. Therefore, SF₆ gas should be reused and recycled whenever possible and should never be released into the atmosphere unnecessarily. SF₆ in its pure state is odorless, colorless, tasteless, nonflammable, noncorrosive, and nontoxic. It is five times heavier than air and will settle to the bottom of an enclosed vessel, displacing any breathable air to the top of the vessel. Although nontoxic, SF₆ gas does not support life by itself and will result in asphyxiation. For that reason, any vessel previously containing SF₆ gas should not be entered unless thorough ventilation has been achieved and the oxygen content verified. See OSHA 29 CFR 1910.146, "Occupational Safety and Health Standards," for practices and procedures to protect employees from the hazards of entry into permit-required confined spaces and Part 7 of Title 29 CFR 1910.269, "Electric Power Generation, Transmission, and Distribution," paragraph (e), for enclosed space entry.

9.8.2.2 SF₆ gas used in GIE can be tested and should conform to ASTM D 2472, *Standard Specification for Sulfur Hexafluoride*.

9.8.3 Causes of SF₆ Decomposition. SF₆ decomposes as a result of excessive heating, electric sparks, power arcs, and partial discharges. The rate of decomposition of the gas during operation is determined by the equipment design and the inclusion of desiccants and adsorbents within the equipment. A power arc associated with a fault in the equipment results in decomposition of SF₆ within a compartment and the generation of gaseous and solid by-products.

9.8.4 Decomposition By-Products.

9.8.4.1 Gaseous By-Products. The major gaseous by-products include S₂F₂, SOF₂, SO₂F₂, SF₄, SO₂, and HF. Some of these gases are highly toxic. The reaction of some of these gases with available moisture produces additional quantities of toxic

gases. Arcing causes SF₆ to decompose into other sulfur fluorides and, in the presence of moisture, hydrogen fluoride. These decomposition products are toxic and harmful to the eyes, nose, and lungs. When arcing has occurred, breathing of any SF₆ by-products should be avoided. A rotten-egg odor in the vicinity of the equipment is indicative of contaminated SF₆.

9.8.4.1.1 DO NOT vent gas from the equipment or attempt to sniff it.

9.8.4.2 Solid Arcing By-Products. Solid decomposition by-products are produced in the form of a fine, talcum-like powder. This powder is a metal fluoride and is white or tan in color. The danger from solid arcing by-products comes more from the gases adsorbed on the surface area of the powder than from the toxicity of the base material. The aluminum fluoride (AlF₃) powder that normally dominates solid arcing by-products is so fine that the lungs do not easily expel it.

9.8.5 Maintenance and Repair of the GIS and GIE.

9.8.5.1 General.

9.8.5.1.1 Instruction books or equipment manuals furnished with the GIS or GIE are necessary for operating and maintenance personnel. This instructional literature should include information pertaining to safe operating and maintenance procedures.

9.8.5.1.2 Safety during maintenance and repair requires that the components on which work is to be performed are electrically isolated, deenergized, grounded, and locked/tagged out.

9.8.5.1.3 Equipment should never be depressurized until it is deenergized and grounded.

9.8.5.1.4 Cleanliness, in accordance with manufacturer's instructions, should be observed at all times. The area around the access point to be opened, including supporting steel and other parts from which dirt or contaminants could fall or be blown into the enclosure, should be vacuumed and wiped with lint-free cloths.

9.8.5.1.5 Do not stand or step on small piping or connections.

9.8.5.1.6 Gas is handled through commercially available gas-processing trailers (carts) that contain vacuum-pumping equipment, gas storage tanks, compressors, filters, and dryers. Suitable evacuating equipment and a heat source to counteract the chilling effect of the expanding gas can permit filling directly from gas cylinders or gas-handling equipment. The specific requirements for gas purity, handling, processing, filling, and refilling that the equipment manufacturer provides should be followed to ensure proper equipment operation.

9.8.5.1.7 Evacuate to 133 Pa all gas from the compartment by a closed evacuation system and pass it through a filter capable of removing arc decomposition by-products. Allow dry air to enter and refill the compartment to atmospheric pressure (101 kPa) before opening the access port.

9.8.5.1.8 Upon opening of the compartment, ensure proper ventilation and oxygen content of enclosure prior to personnel entry.

9.8.5.1.9 Maintenance workers who conduct the initial opening of the faulted gas compartment and removal of the solid arcing by-products should employ air respirators and wear disposable protective clothing covering all garments, boots, hair, and hands. Avoid direct contact with arc decomposition by-products (fine powder).

9.8.5.1.10 Work quickly because the exposure of the solid arcing by-products to moist air will result in toxic fumes with a strong rotten-egg odor. Immediate removal of the solid by-products should be the first priority, because they will become sticky and more difficult to remove with continued exposure to moist air.

9.8.5.1.11 A commercial-type vacuum cleaner with high-efficiency particulate air (HEPA) filters and nonmetallic accessories should be used to remove the arc solid by-products. Precautions should be taken to avoid breathing the exhaust air from the vacuum cleaner, since dust particles might go through the collection system. Following vacuuming, the affected area should be wiped down with a solvent (typically ethyl alcohol denatured with 5 percent or 10 percent methyl alcohol) by workers continuing to wear respirators, appropriate personal protective equipment, and disposable clothing.

9.8.5.1.12 All work should be completed safely and as quickly as possible. When delays are encountered, any open sections should be covered immediately with suitable seals. It might also be necessary to add heat to prevent condensation. When any section is left overnight or longer, it should be pressurized with dry air to a pressure of approximately 136 kPa to avoid condensation or entrance of moist air.

9.8.5.1.13 To achieve the required fill density, it is important that the gas pressure and temperature curve from the manufacturer's instruction book be used. Sufficient time should be allowed for equalization of the gas temperature.

9.8.5.1.14 After recharging, several measurements of the moisture content of the gas in the equipment should be taken to ensure that the moisture content of the SF₆ remains within acceptable limits. If the moisture content of the gas rises to an unacceptable level, recirculation through the dehydration portion of the gas-processing trailer (cart) is required to remove the excess moisture. (See ANSI/IEEE 1125, *Guide for Moisture Measurement and Control in SF₆ Gas-Insulated Equipment*.)

9.8.5.2 References. For specific maintenance, repair considerations, and procedures, consult the equipment manufacturer's instructions; NETA *Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems*, Section 7.5.4, SF₆ Switches, and Section 7.6.4, SF₆ HV Circuit Breakers; and the following sections of IEEE C37.122.1, *IEEE Guide for Gas-Insulated Substations*:

- (1) 4.2, Installation and equipment handling
- (2) 4.4, Gas handling-SF₆ and GIS
- (3) 4.5, Safe operating procedures
- (4) 4.8, Partial discharge (PD) testing
- (5) 4.10, Field dielectric testing
- (6) 4.11, Maintenance and repair

9.9 Auxiliary Equipment.

9.9.1 Fuses. Fuse maintenance is covered as a separate category of electrical equipment in Chapter 16.

9.9.2 Surge Arresters.

9.9.2.1 Surge arresters should be inspected periodically for evidence of damage to the porcelain housing or surface contamination. If the porcelain is damaged to the extent that the creepage path over its surface is reduced or the porcelain glazed surface is seriously damaged, the arrester should be replaced. Otherwise, the porcelain surface should be cleaned thoroughly as required to remove all surface contamination.

9.9.2.2 There are no simple practical field tests that will determine the complete protective characteristics of lightning arresters. There are, however, certain tests that can be made with apparatus usually available that will give sufficient information to determine whether the arrester can be relied on to be an insulator under normal conditions. These tests are 60-cycle spark-over and hold tests, watts-loss and leakage-current tests, insulation resistance tests, and grounding-electrode circuit-resistance tests. These tests should be done strictly in accordance with the manufacturers' recommendations and the results interpreted in line with manufacturers' criteria.

9.9.3 Capacitors.

9.9.3.1 Capacitors should always be discharged before handling or making connections by closing the ground devices that are usually installed with large capacitor banks. An insulated short-circuit jumper should be used for dissipating the charge; however, it should be applied only with full knowledge of the circuit and with the use of appropriate protective equipment.

CAUTION: Capacitors, even though they have discharge resistors, might possess a stored charge that is capable of injuring a person coming into contact with the terminals.

9.9.3.2 The capacitor case, the insulating bushings, and any connections that are dirty or corroded should be cleaned. Each capacitor case should be inspected for leaks, bulges, or discoloration. Any liquid-filled capacitor found to be bulging or leaking should be replaced. (*See Section 10.2 on liquid-filled transformers.*)

9.9.3.3 Power capacitors are generally provided with individual fuses to protect the system in case of a short circuit within the capacitor. In addition to a faulty capacitor, a fuse can also be blown by an abnormal voltage surge. A check should be made for blown fuses, which should be replaced with the type recommended by the manufacturer. Fuses should not be removed by hand until the capacitor has been discharged completely.

9.9.3.4 Adequate ventilation is necessary to remove the heat generated by continuous full-load duty. Any obstructions at ventilation openings in capacitor housings should be removed, and adequate ventilation must be provided and maintained.

9.9.4 Stationary Batteries and Battery Chargers.

9.9.4.1 General. Stationary batteries are a primary power source for critical systems, ac power generation equipment, switchgear, and control circuits. Stationary batteries also provide backup power for essential equipment during outages of the primary power supply. Because these applications require reliable service, stationary batteries should be serviced regularly. The maintenance required depends on each battery's application, type, construction features and materials, and environment.

9.9.4.1.1 Lead-acid batteries are of two technologies: flooded wet cell design and sealed valve regulated lead-acid (VRLA) designs. Stationary batteries are typically lead-acid batteries with lead-antimony or lead-calcium grids. Some stationary batteries are nickel-cadmium (Ni-Cad) units. VRLA batteries have a shorter service life than flooded cells, cannot be tested in the same manner, and are not addressed in this document.

9.9.4.1.2 Battery chargers play a critical role in battery maintenance because they supply normal dc requirements and maintain batteries at appropriate levels of charge. Chargers should be set and maintained according to manufacturers' instructions.

9.9.4.2 Maintenance Program. Battery maintenance normally consists of periodic inspections and tests. Visual inspections include checking electrolyte level and internal conditions in jar-type cells. Many battery problems can be detected by visual inspections. Tests aid in evaluating performance and permit comparisons with standards and with historical test results. Battery manufacturers are good sources of information for maintenance programs.

9.9.4.3 Safety Guidelines. Personnel should be aware of the hazards associated with stationary batteries. A battery can produce and emit a mixture of hydrogen and oxygen gas that is explosive. Exposing skin and eyes to electrolyte can cause severe burns and blindness. Voltages present can cause injury and death. As a minimum, the safety precautions in 9.9.4.3.1 through 9.9.4.3.7 should be observed.

9.9.4.3.1 Maintenance personnel should be trained to perform the tasks properly. Training should include using personal protective equipment, handling the electrolyte safely, using the proper tools, and following the battery manufacturer's service and maintenance instructions.

9.9.4.3.2 The room or compartment in which operating lead-acid batteries are located should be ventilated adequately.

9.9.4.3.3 Appropriate safety equipment should be worn, including goggles, gloves, and aprons, by persons working with the batteries. Eyewash and quick drench facilities should be provided near the batteries.

9.9.4.3.4 Open flames, sparks, hot plates, and other ignition sources should be kept away from storage batteries, gas ventilation paths, and places where hydrogen can accumulate.

9.9.4.3.5 Metal objects should not be placed on battery cells. Insulated tools should be used to protect against shorting of cells.

9.9.4.3.6 When electrolyte is being prepared, personal protective equipment should include a full face shield. **POUR ACID INTO WATER, NOT WATER INTO ACID.** If the electrolyte comes in contact with skin or eyes, the affected area should be immediately flushed with water and medical assistance obtained.

9.9.4.3.7 Unauthorized access to the battery area should be prohibited.

9.9.4.4 Guide for Visual Inspections and Associated Servicing.

9.9.4.4.1 Jars and covers should be checked for cracks and structural damage. Maintenance of flame arrester-type vent caps should consist of rinsing them in clear water and air drying. Damaged units and vent caps should be replaced.

9.9.4.4.2 Plates of clear jars should be checked for buckling, warping, scaling, swelling, cracking, and changes in color. Damaged cells should be replaced.

9.9.4.4.3 The charger should be checked for proper operation. Interconnection cables, cell connectors, and other conductors should be examined for wear, contamination, corrosion, and discoloration. Racks should be checked for corrosion, cleanliness, and structural integrity.

9.9.4.4.4 A check should be made for spilled electrolyte. Bicarbonate of soda solution should be used to neutralize lead-acid battery spills, and boric acid solution should be used for Ni-Cad spills.

9.9.4.4.5 The electrolyte level should be checked. It should be determined that electrolyte and cells are clear, with minimal deposits, gassing, or rings, and that there is only minor sediment below the plates. The amounts of water added to the cells should be recorded. Excessive water consumption can be a sign of overcharging. For lead-antimony batteries, water consumption increases gradually with age. Distilled water should be used unless otherwise recommended by the battery manufacturer.

CAUTION: Never add acid to a battery when refilling.

9.9.4.4.6 Ventilation and the suitability and condition of electrical equipment in the area should be checked. Battery proximity to combustibles and ignition sources should be evaluated. Local sources of heat can create cell temperature differentials that cause battery damage.

9.9.4.4.7 Ambient temperature should be checked. The optimum ambient operating temperature for lead-acid batteries is 25°C (77°F). Ni-Cad batteries can operate satisfactorily over a range of temperatures, generally from 25°C to 45°C (77°F to 113°F). High ambient temperatures reduce cell life. Every 9°C (15°F) increase in temperature above 25°C (77°F) reduces lead-acid cell life 50 percent and Ni-Cad cell life 20 percent. Lower ambient cell temperatures reduce cell capacity. A battery operating at 16°C (60°F) loses about 10 percent of its designed capacity.

9.9.4.4.8 Area heating, air conditioning, seismic protection, dc circuit overcurrent protection, distilled water supply, alarm circuits, grounding connections, cable clamps, and all other installed protective systems and devices should be checked.

9.9.4.5 Mechanical and Miscellaneous Investigation Guidelines.

9.9.4.5.1 Terminal connectors, battery posts, and cable ends should be checked and all corrosion and dirt removed. Battery posts should be cleaned according to manufacturers' recommendations.

9.9.4.5.2 Lead-acid battery surfaces should be cleaned with water and sodium bicarbonate to avoid leakage currents caused by electrolyte on the battery. Ni-Cad battery surfaces should be cleaned with a boric acid solution. Cleaners, soaps, or solvents should not be used to clean battery jars and covers, since damage can result.

9.9.4.5.3 The intercell connectors (links) should be checked annually and torqued to specified values.

9.9.4.5.4 Alarm relays, lights, and horns should be checked for proper operation. The battery room emergency light should be checked.

9.9.4.5.5 Ventilation openings should be checked to be sure they are clear of obstructions.

9.9.4.6 General Observations.

9.9.4.6.1 Excessive gassing can result from overcharging.

9.9.4.6.2 Vibration reduces battery life. Excessive vibration can be detected by observing vibration of plates and sediment in the jar.

9.9.4.6.3 A lead-acid battery electrolyte begins to freeze at -29°C (-20°F), but it can freeze at warmer temperatures if its specific gravity is low. Once ice crystals form, damage to the cell is irreparable.

9.9.4.6.4 Hydration occurs when a lead-acid battery is overdischarged without an immediate recharge, or when a dry-charge battery is accidentally filled with water. A sign of hydration is a whitish ring in the jar, which eventually shorts the positive and negative plates. Hydration is an irreversible condition.

9.9.4.6.5 Overcharging of lead-acid cells or charging at excessive rates leads to mossing. Mossing is the development of sponge-like material high on the negative plates and the resulting sedimentation in the cells. Continued mossing shorts out the plates.

9.9.4.6.6 The average battery tolerates approximately 50 full discharges in its life. Fully discharging a stationary battery more than twice in one year can reduce its life.

9.9.4.7 Battery Test and Measurement Guidelines. Tests should be performed and results recorded to establish trends that can be used in predicting battery life. For lead-acid batteries, a pilot cell from each group of six cells should be selected to obtain a representative temperature while the recommended voltage and specific gravity measurements are made. Alternate pilot cells should be chosen quarterly to minimize cell electrolyte loss and contamination during testing.

9.9.4.7.1 Pilot cell voltage, specific gravity, and electrolyte temperature should be measured and recorded monthly. Common float voltage range for lead-calcium cells is 2.20 volts to 2.30 volts per cell. Lead-antimony cells float at about 2.17 volts to 2.21 volts per cell. Ni-Cad cells charge at approximately 1.42 volts per cell. Manufacturers' literature should be referred to for specific charge potentials.

9.9.4.7.2 For lead-acid batteries, the specific gravity of electrolyte in all pilot cells should be measured and recorded monthly. The specific gravity of electrolyte in all cells should be measured and recorded quarterly. Specific gravity readings should be adjusted for pilot cell temperature. Test results should be as indicated by the manufacturer, usually between 1.205 and 1.225. For accurate results, specific gravity should not be measured within 72 hours after application of an equalizing charge or after water has been added to the battery. Specific gravity readings are not required for Ni-Cad batteries.

9.9.4.7.3 A capacity test should be performed within the first 2 years of installation and every 3 to 5 years thereafter, depending on the load reliability requirements and environmental conditions of the installation. The frequency of battery tests should be increased to yearly when the battery reaches 85 percent of its service life or when it shows signs of deterioration. Once the capacity drops by 20 percent in extended operation, the cell should be replaced.

9.9.4.7.4 A sample (e.g., 25 percent) of intercell connectors and terminal connection resistances should be measured quarterly, in accordance with the manufacturers' instructions.

9.9.4.7.5 Batteries should be examined under load with an infrared scanning device. The abnormal temperature of a cell, a poor connection at a battery post, and a deteriorated link, strap, or conductor are some of the problems that can be readily identified by thermographic surveys.

9.9.4.8 Other Tests. Test readings should be recorded for future reference along with log notations of the visual inspection and corrective action. A copy of the battery record is included as Figure F.21 of Annex F.

9.9.5 Instrument Transformers and Auxiliary Transformers.

9.9.5.1 Instrument transformers and auxiliary transformers might be the outdoor type, although in some cases they can be

mounted inside metal-enclosed switchgear assemblies. These transformers are similar to other outdoor transformers in that they are liquid filled and equipped with outdoor bushings. All recommendations for maintenance of outdoor transformers apply.

9.9.5.2 Indoor-type instrument and auxiliary transformers are normally dry type, except that potential transformers might be enclosed in compound-filled metal cases. All of the transformers above are of the completely molded type, with only the terminals exposed. Maintenance recommendations for indoor transformer types are the same as those for metal-enclosed switchgear assemblies insulation (*see 9.2.10*). The same conditions of environment and electrical and thermal distress prevail. In other words, KEEP THEM CLEAN and KEEP THEM DRY.

9.9.6 Alarm and Indicators.

9.9.6.1 Alarms. Alarms associated with transformer overtemperature, high or low pressure, circuit-breaker trip, accidental ground on an ungrounded system, cooling waterflow or overtemperature, or other system conditions should be tested periodically to ensure proper operation.

9.9.6.2 Indicators. Circuit-breaker open/close indicators can be checked during their regular maintenance.

9.9.6.2.1 Ground indicator lamps for ungrounded electric systems should be checked daily or weekly for proper operation. Other miscellaneous indicators, such as flow, overtemperature, and excess pressure, should be checked or operated periodically to ensure proper operation.

9.9.7 Protective Relays, Meters, and Instruments.

9.9.7.1 The current elements of protective relays, meters, and instruments are usually connected in the secondary circuit of current transformers.

CAUTION: Opening the secondary circuit of an energized current transformer will produce a very high voltage that can be fatal.

9.9.7.1.1 The secondary terminals of an energized current transformer are required to be short-circuited before the secondary circuit is opened. Some relays and instruments have special test terminals or test switches that make a closed circuit in the current transformer secondaries during test. Upon completion of tests, it is necessary to remove the short-circuit jumper to permit the current transformer to function.

9.9.7.2 Because protective relays and instruments play such an important role in the prevention of hazard to personnel and plant equipment, they should be given first-line maintenance attention. Furthermore, because the only time they operate is during an abnormal electric power system condition, the only way to ensure correct operation is by a comprehensive inspection, maintenance, and testing program.

9.9.7.3 Meters, instruments, and relays should be examined to ensure that all moving parts are free of friction or binding. Wiring should be checked for loose connections. Contacts should be inspected for pitting or erosion. Evidence of overheating should be looked for in solenoid coils or armatures. Cracked glass or damaged covers or cases should be replaced. (*See 21.10.3 for testing recommendations.*)

9.9.8 Interlocks and Safety Devices. Interlocks and safety devices are employed for the protection of personnel and equipment and should, therefore, never be made inoperative or

bypassed. Proper functioning of these devices should be ensured by the following procedures:

- (1) The adjustments and operation of the devices should be checked as follows:
 - (a) Mechanical interlocks on drawout mechanisms should prevent withdrawal or insertion of circuit breakers in the closed position.
 - (b) Safety shutters, where provided, should automatically cover the "stab-in" ports.
 - (c) Limit switches should prevent overtravel of motorized lifting devices.
- (2) Key interlock systems should be operated in proper sequence, and suitable operation ensured by the following:
 - (a) Adjustments should be made and the system lubricated as necessary.
 - (b) Instructions should be posted on complicated systems, especially where the interlocks might be operated only annually or in emergencies.
- (3) Spare keys should be identified and stored in the custody of the supervisor.
- (4) Grounding switches used in medium-voltage switchgear should be maintained to the same degree as the circuit breaker itself.
 - (a) If stored indoors, they should be covered to prevent dust accumulation.
 - (b) If stored outdoors, they should be stored in a weather-proof covering.

9.9.9 Grounding.

9.9.9.1 Equipment-grounding circuits are not inherently self-monitoring as are circuits that normally carry current. To ensure that the equipment-grounding conductors continue to be effective when called on to carry ground-fault current, they should be checked periodically.

9.9.9.2 Checking a system to determine the adequacy of the equipment ground involves inspection of connections that can be supplemented by an impedance test to enable an evaluation of those parts of the system not accessible for inspection. (*See Section 21.13.*)

9.9.9.3 Terminal connections of all equipment-grounding conductors and bonding jumpers should be checked to see that they are tight and free of corrosion. Bonding jumpers should also be examined for physical abuse, and those with broken strands should be replaced. Where metal raceway is used as the equipment-grounding path, couplings, bushings, set-screws, and locknuts should be checked to see that they are tight and properly seated. Any metal raceway used as the equipment-grounding path should be examined carefully for rigid mounting and secure joints; screws and bolts should be retightened.

9.9.10 Ground-Fault Indicators.

9.9.10.1 Ground-fault indicators can be installed on all ungrounded or resistance-grounded low-voltage systems. The indicator can consist of a simple set of lamps wired phase-to-ground. A ground on one phase will cause the lamp on that phase to be dark, while the other two lamps will have increased brilliance.

9.9.10.2 A more elaborate system provides audible as well as visual indication so the ground is more readily detected.

9.9.10.3 Once a ground has been detected, prompt location and correction are important, since the system will be highly

vulnerable in the event of a ground on another phase. Through the process of elimination, searching for the ground requires circuit or system interruptions and isolation of the circuit(s) until the ground fault is located and eliminated. The use of an instrument that permits location of such ground faults without power interruptions is recommended.

9.9.10.4 Maintenance of ground fault detectors should include a complete inspection of the signal elements such as lamps, horns, or buzzers. Audible devices should be operated to ensure that they are in operable condition. Wiring should be checked for loose connections or damaged wiring.

9.9.10.5 A complete, effective maintenance program for substations and assembled switchgear will result if the four “keepers” are observed:

- (1) If it is insulation, KEEP IT CLEAN and KEEP IT DRY.
- (2) If it is mechanical, KEEP IT SNUG and KEEP IT FRICTION FREE.

9.9.11 Network Protectors.

9.9.11.1 A network protector is an air circuit breaker equipped with specialized relays that sense network circuit conditions and command the circuit breaker to either open or close. There is no separate power source for control. All control power is taken from the system.

9.9.11.1.1 A routine maintenance schedule for network protectors should be observed. Frequency of inspection will vary to a great extent depending on the location and the environment in which a protector is installed.

9.9.11.1.2 Maintenance should include the cleaning of any accumulated dust from the unit, a thorough visual inspection, and overall operational test. Should any part look suspicious, the manufacturers’ instructions for operation, adjustment, and replacement of these parts should be consulted. If relays are out of calibration, they should be recalibrated by competent personnel.

9.9.11.2 Safety. Network protectors are used where a large amount of power is distributed to high-load-density areas. As a result, any short circuit at any point in the system involves very high fault currents. Due to the nature of a secondary network, it might be necessary for some maintenance to be performed while the system is energized.

CAUTION: In this work, always use insulated tools and wear safety gloves. Rigid clearance procedures must be observed.

9.9.11.2.1 Extensive use of barriers is a salient feature in the design of network protectors. The barriers should be kept in place, and any that have been broken should be replaced immediately. Only skilled maintenance personnel who are thoroughly familiar with the construction and operation of network protectors should be permitted to perform maintenance on an energized unit. The first procedure in performing maintenance is to trip the protector to the open position.

9.9.11.3 Maintenance. The circuit-breaker mechanism and relay panel assembly are usually constructed as an integral drawout unit that should be withdrawn from the housing for maintenance. Removal of the fuses at the top and the disconnecting links at the bottom (some modern protectors have bolt-actuated disconnecting fingers at the bottom) isolates the unit electrically from the system. Although this procedure provides comparative safety, work should be done cautiously, since it might be assumed that normally

there is voltage on the transformer and the network leads. With the drawout unit outside the enclosure on the extension rails, the following inspection and maintenance operations should be performed on the drawout unit. (Paragraph 9.9.11.3.11 applies only to the containing structure, not the drawout unit.)

9.9.11.3.1 The complete unit should be cleaned. Use of a vacuum-type cleaner is preferred. Cloth rags free of oil or greases should be used to remove clinging dirt.

9.9.11.3.2 Arc chutes should be removed. Any broken splitter plates should be replaced.

9.9.11.3.3 Main contacts should be inspected.

(A) Any heavily frosted area should be smoothed with a fine file, stone, crocus cloth, or other suitable abrasive that does not shed abrasive particles.

(B) The hinge joint should be protected from falling particles during dressing.

9.9.11.3.4 During normal operation, arcing contacts become rough due to arcing. Any especially high projections of metal should be filed smooth.

9.9.11.3.5 All electrical connections should be checked to see that they are tight.

9.9.11.3.6 Any abrasion of wire insulation should be observed.

9.9.11.3.7 Control wire and current-carrying parts should be checked for overheating.

9.9.11.3.8 All springs should be checked to see that they are in place and not broken.

9.9.11.3.9 All nuts, pins, snap rings, and screws should be checked to see that they are in place and tight.

9.9.11.3.10 Any broken barriers should be replaced.

9.9.11.3.11 With the rollout unit removed, the following maintenance operations should be performed inside the enclosure.

CAUTION: Both network and transformer connections should be treated as though they are energized. When working in housing or on frame, use only insulated tools and wear safety protective equipment. Do not remove any barriers from the enclosure.

(A) Loose hardware should be looked for on the floor or beneath the frame. If any is found, it should be traced to its source.

(B) Stand-off bus insulators should be cleaned.

(C) Any oxide film should be removed from terminal contacts if necessary.

9.9.11.3.12 The protector should be closed manually in accordance with the manufacturer’s instructions.

(A) It should close with a definite snap action. Sluggish closing indicates excessive friction.

(B) The trip level should be moved to the “tripped” position.

(C) The breaker should snap open.

9.9.11.3.13 An operational test is best performed using a network protector test kit.

9.9.11.3.14 An insulation resistance test, a dielectric test, and electrical operating tests should be performed strictly in accordance with the manufacturers' recommendations.

Chapter 10 Power and Distribution Transformers

10.1 Introduction.

10.1.1 In industrial installations, transformers are usually used to transform or step down a higher distribution level voltage to a lower utilization level. They are vital links in electrical power systems and are among the most reliable components in the system. If they are not overloaded or otherwise abused, they should provide long, trouble-free service. Established records of reliable performance, coupled with a lack of movement, noise, or other sign of action, often result in general disregard and neglect. Because a transformer failure is usually of a very serious nature, requiring extensive repair and long downtime, regular maintenance procedures are the best assurance of continued high reliability.

10.1.2 Power and distribution transformers require regular maintenance if they are to have a normal service life. The extent and frequency of maintenance should be based not only on size or voltage but also on the relative importance of the transformer in the system. The failure of a small distribution transformer serving a critical load can have more impact on an operation than the failure of a larger or higher-voltage unit. Also, on some smaller systems, the failure of a distribution transformer can result in an outage of the complete system. When the level of maintenance on a transformer is being planned, consideration should also be given to other factors, such as replacement lead time.

10.1.3 Transformers can be divided into two general categories, according to their insulating medium and construction: liquid filled and dry type. Each has several variations listed under the specific maintenance recommendations, and each requires different maintenance techniques. In general, insulation tests, such as power-factor testing and insulation-resistance testing, and diagnostic tests, such as turns-ratio testing and exciting-current testing, are the major maintenance tests for all transformers. In addition, liquid-filled transformers should be tested to determine the quality of the insulating liquid.

10.2 Liquid-Filled Transformers.

10.2.1 Introduction.

10.2.1.1 The core and coils of liquid-filled transformers are immersed in a liquid. The liquid serves two purposes. It is an important part of the insulating medium, and it serves to transfer heat away from the windings to be dissipated by the cooling fins, tank surface, or radiator.

10.2.1.2 Two types of insulating liquid in common use are mineral-insulating oil and askarel. Other types of liquids used are less-flammable liquids, such as silicone or stabilized hydrocarbon liquids. Each liquid has definite characteristics, and **THEY SHOULD NOT BE MIXED**. Manufacturers' instructions should be carefully followed with all insulating liquids.

10.2.1.3 Askarel is identified by various brand names and consists largely of polychlorinated biphenyls (PCBs). It is subject to strict government regulation as a toxic substance. A knowledge of government regulations is necessary because

any liquid-filled transformer might contain some level of PCBs. One reference is 40 CFR 761, "Protection of Environment — Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions."

10.2.1.4 There are several types of transformer construction regarding the preservation of the liquid. *Preservation* means minimizing exposure of the insulating liquid to the atmosphere. The types are as follows:

- (1) Free breathing (open to the atmosphere)
- (2) Restricted breathing (open to the atmosphere through dehydrating compounds)
- (3) Conservator or expansion tank (exposure to air limited to the liquid in the conservator tank)
- (4) Sealed tanks (a gas space above the liquid serves as a cushion for internal pressure)
- (5) Gas-oil seal (exposure to air limited to the oil in the auxiliary tank)
- (6) Inert gas (gas space above liquid maintained under positive pressure by gas supplied from a nitrogen cylinder)

10.2.1.5 Some common cooling methods are as follows:

- (1) Self-cooled (OA or OISC) — heat is dissipated by the tank surface and cooling fins or tubes
- (2) Forced-air cooled (FA) — fans are employed to force air over the cooling surfaces to augment the self-cooled rating
- (3) Forced-air cooled/forced-oil cooled (FA/FOA) — an oil pump circulates oil through a fan-blown oil-to-air heat exchanger
- (4) Water cooled (FOW) — heat exchange by means of water pumped through a pipe coil installed inside or outside the transformer tank

10.2.2 Regular Inspections.

10.2.2.1 Inspections of transformers should be made on a regular basis. The frequency of inspection should be based on the importance of the transformer, the operating environment, and the severity of the loading conditions. Typical regular inspection data can include load current, voltage, liquid level, liquid temperature, winding hot-spot temperature, ambient temperature, leaks, and general condition.

10.2.2.2 The current, voltage, and temperature readings should be taken at the time of peak load and the liquid level reading at the end of a low-load period. Permanent records should be kept of the readings. Keeping such records helps ensure that the readings will be made and provides a means of ready comparison with previous conditions. Further explanations are covered in 10.2.3 through 10.2.5.2.

10.2.3 Current and Voltage Readings.

10.2.3.1 Load currents are a very important part of the recommended regular inspections. If the observed current in any phase exceeds the rated full-load value, and the rated maximum temperature is exceeded, steps should be taken to reduce the load.

10.2.3.2 Overvoltages and undervoltages can be detrimental to the transformer and the load it serves. The cause should be investigated immediately and corrective action taken to bring the voltage within acceptable limits.

10.2.4 Temperature Readings.

10.2.4.1 Transformers are rated to carry their nameplate load in kVA with a given heat rise when the ambient temperature is

at a standard level. Exact values are stated on the nameplate. For instance, a liquid-filled transformer might be rated to deliver nameplate capacity with a 65°C (149°F) temperature rise above a 30°C (86°F) ambient temperature (24-hour average).

10.2.4.2 If transformers have temperature gauges, readings should be taken regularly and recorded. If the gauge is also equipped with a maximum-temperature indicator, readings from both indicators should be recorded, and the maximum-temperature indicator should be reset. Excessive temperature indicates an overload or perhaps some interference with the normal means of cooling. Prolonged operation at overtemperature accelerates deterioration of the liquid and results in reduced life expectancy of the solid insulation, greatly increasing the risk of failure. In some installations, constant monitoring against overtemperature is provided by special alarm contacts on the temperature gauge.

10.2.5 Liquid-Level Indicator and Pressure/Vacuum Gauges.

10.2.5.1 The liquid level should be checked regularly, especially after a long period of low load at low ambient temperature, when the level should be at its lowest point. It is important that liquid be added before the level falls below the sight glass or bottom reading of the indicator. If a transformer is not equipped with a liquid-level indicator, the liquid level can be checked by removing the inspection plate on the top of the transformer or by removing the top if no inspection plate is available. It is necessary to deenergize the transformer prior to either of those two procedures. (*See 10.2.7 for precautions relative to deenergizing the transformer and for the recommended procedures for adding liquid.*)

10.2.5.2 Pressure/vacuum gauges are commonly found on sealed-type transformers and are valuable indicators of the integrity of the sealed construction. Most sealed transformers have provisions for adding a pressure/vacuum gauge, and, if feasible, the gauge should be added. The readings should be compared to the recommendations of the manufacturer for normal operating ranges. High pressures indicate an overload or internal trouble and should be investigated immediately. A sustained zero pressure reading indicates a leak or a defective gauge.

10.2.6 Miscellaneous. The features of special types of transformer construction that should be included in regular inspections include the following:

- (1) The water-in and water-out temperatures of water-cooled transformers.
- (2) The oil-in and oil-out temperatures of forced-oil-cooled transformers with oil-to-air or oil-to-water heat exchangers.
- (3) The pressure in the nitrogen cylinder for a transformer equipped with an automatic gas-pressure system — if the pressure drops below the manufacturer's recommended value [usually about 1034 kPa (150 psi)], the cylinder should be replaced and leaks repaired.
- (4) Dehydrating breathers should be checked to ensure that they are free from restriction and have not absorbed excessive moisture.

10.2.7 Special Inspections and Repairs.

10.2.7.1 Because of the wide variety of liquid-filled transformer types, sizes, and uses, the special inspection and repair recommendations given in 10.2.7.2 through 10.2.7.8 are general in nature. For specific directions, the manufacturer's recommendations should be followed.

10.2.7.2 If a transformer is given an external visual examination, the case of the transformer should be regarded as energized until the tank ground connection is inspected and found to be adequate. If any procedure more extensive than an external visual examination is to be performed, the first precaution that should always be observed is to deenergize the transformer. Deenergization should always be accompanied by approved positive lockout or lockout/tagout procedures to ensure against an unexpected reenergization and resulting hazard to personnel or equipment. Deenergization should be immediately followed by a test to ensure that the equipment is deenergized. The equipment should be grounded prior to the start of any work. (*See Chapter 29, Grounding.*)

10.2.7.3 All connections should be inspected for signs of overheating and corrosion. Insulators and the insulating surfaces of bushings should be inspected for tracking, cracks, or chipped skirts, and the gasketed bases should be checked for leaks. The insulating surfaces should be cleaned of any surface contamination. Damaged insulators or bushings should be replaced. Leaks should be repaired. Pressure-relief devices should be inspected to ensure that there are no leaks or corrosion and that the diaphragm or other pressure-relief device is intact and ready to function. A cracked or leaking diaphragm should be replaced at once.

10.2.7.4 The tank, cooling fins, tubes, radiators, tap changer, and all gasketed or other openings should be inspected for leaks, deposits of dirt, or corrosion. Leak repair, cleaning, and painting should be done as required. Infrared inspection can be used to detect fluid levels as well as flow restrictions in cooling tubes.

10.2.7.5 The tank ground should be inspected for corrosion or loose connections. A grounding-electrode resistance test should be made, as covered in Section 21.15.

10.2.7.6 Cooling fans, circulating oil pumps, and protective relays (e.g., Bucholtz relays and sudden-gas relays) should be inspected regularly in accordance with manufacturers' recommended practices.

10.2.7.7 The conservator tank, inert gas atmosphere, and dehydrating breather equipment should be inspected and tested according to the manufacturer's instructions. Since most modern, large, liquid-filled power transformers have features to minimize exposure of the liquid to air, opening of this type of transformer for internal inspection is recommended only when the need is positively indicated, and then the manufacturer's instructions should be carefully followed or technical assistance employed.

10.2.7.7.1 Contamination or impairment of the insulating liquid should be carefully avoided. If the humidity is high, exposure should be avoided entirely unless the work is absolutely necessary and cannot be postponed, in which case special humidity-control steps should be taken.

10.2.7.8 If liquid is to be added, it should be given a dielectric-breakdown test. The liquid to be added should be at least as warm as the liquid in the transformers. If a large amount of liquid is added, the transformer should remain deenergized for 12 hours or more to permit the escape of entrapped air bubbles. A desirable method is to add the liquid with the transformer tank under a vacuum. (Check the manufacturer's instructions for further information.)

10.2.8 Liquid Maintenance and Analysis.

10.2.8.1 Liquid Analysis. For insulating oils, the tests routinely performed are dielectric breakdown, acidity, color, power factor, interfacial tension, and visual examination. These tests are covered in Section 21.19. For other insulating liquids, the manufacturers' recommendations should be followed.

10.2.8.1.1 Tests can also be performed to determine levels of PCBs. Test results might require service or replacement of the transformer tested as specified by government regulations. (See 10.2.1.3.)

10.2.8.1.2 Samples should never be taken from energized transformers except by means of an external sampling valve. If the transformer has no external sampling valve, the unit should first be deenergized and a sample taken internally. (See ASTM D 923, *Standard Test Method for Sampling Electrical Insulating Liquids*.)

10.2.8.2 Maintenance. If any test indicates that an insulating liquid is not in satisfactory condition, the liquid can be restored by reconditioning or reclaiming, or it can be completely replaced. Reconditioning is the removal of moisture and solid materials by mechanical means such as filter presses, centrifuges, or vacuum dehydrators. Reclaiming is the removal of acidic and colloidal contaminants and products of oxidation by chemical and absorbent means such as processes involving fuller's earth, either alone or in combination with other substances. Replacing the liquid involves draining, flushing, testing, and proper disposal of materials removed.

10.2.9 Other Tests.

10.2.9.1 Dielectric Tests of Solid Insulation. In addition to the tests of the insulating liquid, tests should also be made of the dielectric properties of the solid insulation. Several commonly used tests are the insulation-resistance test and the dielectric-absorption test. A power-factor test can be used to record the trend of insulation condition. These are nondestructive tests, which means that they can be performed without risk of damage to the insulation. All these tests are discussed in Chapter 21.

10.2.9.2 Turns-Ratio and Polarity Tests. The turns-ratio test is used to determine the number of turns in one winding of a transformer in relation to the number of turns in the other windings of the same phase of the transformer. The polarity test determines the vectoral relationships of the various transformer windings. The turns-ratio test is used as both an acceptance test and a maintenance test, while the polarity test is primarily an acceptance test.

10.2.9.2.1 The test equipment used is ordinarily a turns-ratio test set designed for the purpose. If not available, input and output voltages can be measured, with at least 0.25 percent full-scale accuracy voltmeters, for approximation.

10.2.9.2.2 When a turns-ratio test is performed, the ratio should be determined for all no-load taps. If the transformer is equipped with a load-tap changer (LTC), the ratio should be determined for each LTC position. If the transformer has both an LTC and a no-load-tap changer, then the ratio should be determined for each position of the LTC to one position of the no-load-tap changer and vice versa.

10.2.9.2.3 This test is useful in determining whether a transformer has any shorted turns or improper connections and, in acceptance testing, verifying nameplate information.

10.2.9.3 Fault-Gas Analysis. (See ASTM D 3284, *Standard Test Methods for Combustible Gases in the Gas Space of Electrical Apparatus Using Portable Meters in the Field*.) The determination of the percentage of combustible gases present in the nitrogen cap of sealed, pressurized oil-filled transformers can provide information as to the likelihood of incipient faults in the transformer. When arcing or excessive heating occurs below the top surface of the oil, insulation decomposition can occur. Some of the products of the decomposition are combustible gases that rise to the top of the oil and mix with the nitrogen above. A small sample of nitrogen is removed from the transformer and analyzed. The test set has a direct reading scale calibrated in percentages of combustible gas. Ordinarily, the nitrogen cap in a transformer has less than 0.5 percent combustible content. As a problem develops over a period of time, the combustible content can rise to 10 or 15 percent. A suggested evaluation of the test results is as shown in Table 10.2.9.3.

Table 10.2.9.3 Sample Test Results Evaluation

Percentage of Combustible Gas	Gas Evaluation
0.0 to 1.0	No reason for concern. Make tests at regularly scheduled intervals.
1.0 to 2.0	Indication of contamination or slight incipient fault. Make more frequent readings and watch trends.
2.0 to 5.0	Begin more frequent readings immediately. Prepare to investigate cause by internal inspection.
over 5.0	Remove transformers from service and make internal inspection.

10.2.9.4 Dissolved-Gas-in-Oil Analysis. A refinement of the fault-gas analysis is the dissolved-gas-in-oil test. (See ASTM D 3612, *Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography*.) In this test, an oil sample is withdrawn from the transformer, and the dissolved gases are extracted from the oil. A portion of the gases is then subjected to chromatographic analysis, which determines the exact gases present and the amount of each. Different types of incipient faults have different patterns of gas evolution. With this test, the nature of the problems can often be diagnosed. (See ANSI/IEEE C57.104, *Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers*.)

10.3 Dry-Type Transformers.

10.3.1 Introduction.

10.3.1.1 Dry-type transformers operate in air or gas rather than being liquid filled. The two general types of construction are the open or ventilated dry-type transformer and the sealed or closed-tank type. Dry transformers are usually varnish impregnated or cast coil construction. Sealed transformers are cooled and insulated by a high-dielectric inert gas, such as nitrogen, sulfur hexafluoride, or perfluoropropane.

10.3.1.2 The air or gas serves as an insulating medium and also to dissipate heat from the windings. Standard insulation classes are 80°C (176°F) rise, 115°C (239°F) rise, and 150°C (302°F) rise.

10.3.2 Regular Inspections. The recommendations in 10.2.2 regarding regular inspections of liquid-filled transformers also apply to dry-type transformers, with the exception of those that obviously pertain strictly to liquid-filled construction.

10.3.3 Current and Voltage Readings. The recommendations in 10.2.3 regarding current and voltage readings also apply to dry-type transformers.

10.3.4 Temperature Readings. The recommendations in 10.2.4 regarding temperature readings also apply to dry-type transformers. However, dry-type transformers usually have high-temperature insulation and might operate at higher temperatures than liquid-filled units.

10.3.5 Pressure/Vacuum Gauge.

10.3.5.1 Sealed dry-type transformers are usually equipped with pressure/vacuum gauges. The gauge should be read periodically and the readings recorded. The readings should be compared to the manufacturer's recommended normal operating range. Lower-than-normal or zero readings are an indication of a leak in the tank. If the leak is not severe, it might be desirable to periodically replace the gas or recharge the transformer instead of locating and sealing the leak. The replacement gas should be either the same as the original or an approved substitute. (*See 10.3.7 for recommendations covering severe leaks.*)

10.3.5.2 High pressures are an indication of electrical overload or internal trouble; they should be investigated immediately, and corrective action should be taken. Excessive pressure can result in distortion or rupture of the tank.

10.3.6 Miscellaneous. The louvers in the enclosures of ventilated dry-type transformers should be inspected to see that they are not clogged with dirt or otherwise obstructed. Also, the operation of integral ventilating fans should be checked. Dry-type transformers are usually installed indoors and sometimes in a vault. The temperature of the vault or room should be measured regularly and recorded. Proper ventilation is essential to the operation of a transformer. Any material or obstruction that might prevent the free circulation of air around a transformer should be removed. If the room or vault has power-driven ventilating fans, their correct operation [air velocity should not exceed 122 m/min (400 ft/min)] should be determined and overtemperature alarms, if provided, should be tested. Corrosion of the transformer enclosure, the intrusion of dirt, and evidence of water leaks into the room or vault should also be carefully checked and corrective measures taken as required. A high noise level or change in level could indicate improper installation or loose windings or barriers.

10.3.7 Special Inspections and Repairs.

10.3.7.1 When a transformer is given an external visual examination, the transformer case should be regarded as energized until the case-ground connection is inspected and found to be adequate. If any procedure more extensive than an external visual examination is to be performed, the first precaution that should always be taken is to deenergize the transformer. Deenergization should be accompanied by approved positive lockout procedures to ensure against an unplanned reenergization and resulting hazard to personnel or equipment. Deenergization should be followed immediately by a test to ensure that the equipment is deenergized. The equipment should be grounded prior to the start of any work. (*See Chapter 24.*)

10.3.7.2 Enclosure covers of ventilated dry-type transformers should be removed carefully. An inspection should be made for the following problems:

- (1) Accumulations of dirt on windings, insulators, and where cooling airflow might be restricted
- (2) Discoloration caused by overheating
- (3) Tracking and carbonization
- (4) Cracked or chipped insulators
- (5) Loose insulators, clamps, or coil spacers
- (6) Deterioration of barriers
- (7) Corroded or loose electrical connections.

10.3.7.2.1 In addition, the equipment ground should be inspected for corrosion or loose connections. A grounding-electrode resistance test should be made, as covered in Section 21.15.

10.3.7.3 Dirt and dust should be cleaned from the windings with a vacuum cleaner. After vacuum cleaning, compressed air can be used only if it is clean, dry, and applied at a low pressure to avoid damage to windings. In particular, ventilating ducts and the top and bottom of the windings should be cleaned. Liquid cleaners should be used only when it is known that they will not have a deteriorating effect on the insulation.

10.3.7.4 Best service life results if the windings are maintained above the ambient-temperature level. For that reason, transformers operating in high humidity should be kept energized, if feasible. If a transformer is to be deenergized long enough for it to cool, special drying procedures might be necessary before the transformer is reenergized. Refer to the manufacturers' recommendations for the drying procedures to be followed.

10.3.7.5 Sealing severe leaks or opening and resealing the tanks of sealed dry-type transformers requires special procedures and equipment. The manufacturer of the transformer, an experienced transformer repair facility, or a qualified electrical maintenance contractor should perform this work. In addition, special procedures for drying out the windings, plus purging and refilling the tank, might be necessary.

10.3.8 Insulation Tests. The insulation tests covered in 10.2.9.1 and 10.2.9.2 can also be applied to dry-type transformers.

Chapter 11 Power Cables

11.1 Introduction. Preventive maintenance is the best way to ensure continued reliable service from electrical cable installations. Visual inspection and electrical testing of the insulation are the major maintenance procedures. However, it should be stressed that no amount of maintenance can correct improper application or physical damage done during installation.

11.2 Visual Inspection.

11.2.1 If, in addition to the visual inspection, cables are to be touched or moved, they should be deenergized.

11.2.2 Cables in manholes should be inspected for sharp bends, physical damage, excessive tension, oil leaks, pits, cable movement, insulation swelling, soft spots, cracked jackets in nonlead cables, damaged fireproofing, poor ground connections, deterioration of metallic sheath bonding, as well as corroded and weakened cable supports and the continuity of any main grounding system. Terminations and splices of nonlead cables should be squeezed in search of soft spots and inspected for tracking or