# NECA 91-2023

AN AMERICAN NATIONAL STANDARD


Recommended Practice for

# Maintaining Electrical Equipment

Published by
National Electrical
Contractors Association

# NECA 91-2023

Recommended Practice for

# Maintaining Electrical Equipment

**An American National Standard**

Published by
National Electrical Contractors Association

| Revision History | |
|---|---|
| NECA 91-2023 | 06/2023 |



National Electrical Contractors Association
1201 Pennsylvania Ave. NW, Suite 1200
Washington, D.C. 20004
202-991-6300 • 202-217-4171 fax

# Table of Contents

<This page intentionally left blank>

*(This foreword is not a part of the standard)*

# Foreword

*National Electrical Installation Standards™ (NEIS®)* are designed to improve communication among specifiers, purchasers, and suppliers of electrical construction services. They define a minimum baseline of quality and workmanship for installing electrical products and systems. *NEIS®* are intended to be referenced in contract documents for electrical construction projects. The following language is recommended:

> Electrical infrastructure and equipment that is prefabricated either onsite or remote from the site must be designed, produced, installed, and maintained in accordance with NECA 91, *Recommended Practices for Maintaining Electrical Equipment* (ANSI).

Use of *NEIS* is voluntary, and the National Electrical Contractors Association (NECA) assumes no obligation or liability to users of this publication. Existence of a standard shall not preclude any member or non-member of NECA from specifying or using alternate construction methods permitted by applicable regulations.

This publication is intended to comply with the National Electrical Code (NEC) and NFPA 70B, *Standard for Electrical Equipment Maintenance.* Because they are quality Standards, *NEIS* may in some instances go beyond the minimum safety requirements of the NEC and NFPA 70B. It is the responsibility of users of this publication to comply with State and local electrical Codes and Federal and State OSHA safety regulations as well as follow manufacturer instructions when maintaining electrical products and systems.

Suggestions for revisions and improvements to this standard are welcome. They should be addressed to:


NECA Standards & Safety
1201 Pennsylvania Ave. NW, Suite 1200
Washington, D.C. 20004
202-991-6300 telephone
202-217-4171 fax
*www.neca-neis.org*
*neis@necanet.org*


To purchase *National Electrical Installation Standards,* contact the NECA Order Desk at 202-991-6295 or *orderdesk@necanet.org*. *NEIS* can also be purchased in PDF format at *www.neca-neis.org/standards.*

# 1. Scope

## 1.1 Structure of the Standard

This Recommended Practice describes general maintenance procedures for operating, servicing, inspecting, testing, maintaining, calibrating, repairing, and reconditioning building electrical systems, equipment, and components. This Recommended Practice includes industry-accepted practices and is intended to be used in conjunction with equipment-specific manufacturer instructions. *NOTE: See NFPA 70B, Standard for Electrical Equipment Maintenance.*

## 1.2 Products and Applications Excluded

This Recommended Practice is not intended to cover specific maintenance procedures for every type of electrical system, equipment, or component. Other *NEIS* documents that include maintenance and testing requirements for electrical systems, equipment, and components are included as references and are listed in Annex B.

In addition, this Recommended Practice does not cover:

- Start up or commissioning of new electrical equipment and systems (see NECA 90).
- Procedures for maintaining systems such as fire alarm systems (see NECA 305) or closed-circuit television (CCTV) systems (see NECA 303), or telecommunications networks, access control systems, and other limited energy systems.
- Maintenance of specialty equipment and systems, such as transformers, wiring, and line isolation monitors installed as part of isolated power systems for wet locations in healthcare facilities.
- Maintenance and testing required in accordance with applicable National, State, and local codes and regulations for life safety systems, emergency systems, and critical operations power systems (COPS) in addition to the generic service and maintenance procedures outlined by this Recommended Practice.
- On-going maintenance and testing required by applicable National, State, and local codes and regulations for specific applications and systems, such as healthcare facilities and emergency systems.

## 1.3 Regulatory and Other Requirements

All information in this publication is intended to conform to the National Electrical Code (ANSI/NFPA 70). Workers shall follow the NEC, applicable State and local Codes, manufacturer instructions, and contract documents when maintaining building electrical systems.

Only qualified persons as defined in the NEC familiar with the service, maintenance, and testing of building electrical equipment and systems shall perform the technical work described in this publication. Administrative functions and other tasks shall be performed under the supervision of a qualified person. All work shall be performed in accordance with NFPA 70E, *Standard for Electrical Safety in the Workplace.*

General requirements for installing electrical products and systems are described in NECA 1, *Standard for Good Workmanship in Electrical Construction* (ANSI). Other *NEIS* provide additional guidance for installing and maintaining particular types of electrical products and systems. A complete list of *NEIS* is provided in Annex B.

### 1.4 Mandatory Requirements, Permissive Requirements, Quality and Performance Recommendations, Explanatory Material, and Informative Annexes

Mandatory requirements in manufacturer instructions, Codes, or other mandatory Standards that may or may not be adopted into law are those that identify actions that are specifically required or prohibited and are characterized in this Recommended Practice by the use of the terms "must" or "must not," "shall" or "shall not," or "may not," or "are not permitted," or "are required," or by the use of positive phrasing of mandatory requirements. Examples of mandatory requirements may equally take the form of, "equipment must be protected…," "equipment shall be protected…," or "protect equipment…," with the latter interpreted (understood) as "(it is necessary to) protect equipment…"

Permissive requirements of manufacturer instructions, Codes, or other mandatory Standards that may or may not be adopted into law are those that identify actions that are allowed but not required or are normally used to describe options or alternative means and methods and are characterized in this Recommended Practice by the use of the terms "may," or "are permitted," or "are not required."

Quality and performance instructions identify actions that are recommended or not recommended to improve the overall quality or performance of the installation and are characterized in this Recommended Practice by the use of the terms "should" or "should not."

Explanatory material, such as references to other Codes, Standards, documents, references to related sections of this Recommended Practice, information related to another Code, Standard, or document, and supplemental application and design information and data, is included throughout this Recommended Practice to expand the understanding of mandatory requirements, permissive requirements, and quality and performance instructions. Such explanatory material is included for information only and is identified by the use of the term "NOTE," or by the use of italicized text.

Non-mandatory information and other reference Standards or documents relative to the application and use of materials, equipment, and systems covered by this Recommended Practice are provided in informative annexes. Informative annexes are not part of the enforceable requirements of this Recommended Practice but are included for information purposes only.

# 2. Definitions

These definitions apply to this Recommended Practice. 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.

**Approved:** Acceptable to authority having jurisdiction. *[N]*

**Arc Flash Hazard:** A source of possible injury or damage to health associated with the release of energy caused by an electric arc.

**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. *[N]*

**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.

**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.

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

**Device:** A unit of an electrical system, other than a conductor, that carries or controls electric energy as its principal function. *[N]*

**Disconnecting Means:** A device, or group of devices, or other means by which the conductors of a circuit can be disconnected from their source of supply. *[N]*

**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.

**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.

**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.

**Enclosure:** The case or housing of apparatus, or the fence or walls surrounding an installation to prevent personnel from accidentally contacting energized parts or to protect the equipment from physical damage. *[N]*

**Energized:** Electrically connected to, or is, a source of voltage. *[N]*

**Equipment:** A general term, including fittings, devices, appliances, luminaires, apparatus, machinery, and the like used as a part of, or in connection with, an electrical installation. *[N]*

**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.

**Exercise:** To operate equipment in such a manner that it performs all its intended functions to allow observation, testing, measurement, and diagnosis of its operational condition.

**Exposed (as applied to live parts):** Capable of being inadvertently touched or approached nearer than a safe distance by a person. *[N] NOTE: This term applies to parts that are not suitably guarded, isolated, or insulated.*

**Inspection:** Examination or measurement to verify whether an item or activity conforms to specified requirements.

**Ground:** The earth. *[N]*

**Grounded (Grounding):** Connected (connecting) to ground or to a conductive body that extends the ground connection. *[N]*

**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.

**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.

**Ground-Fault Current Path:** An electrically conductive path from the point of a ground fault on a wiring system through normally non–current-carrying conductors, equipment, or the earth to the electrical supply source. *[N] NOTE: Examples of ground-fault current paths are any combination of equipment grounding conductors, metallic raceways, metallic cable sheaths, electrical equipment, and any other electrically conductive material such as metal, water, and gas piping; steel framing members; stucco mesh; metal ducting; reinforcing steel; shields of communications cables; and the earth itself.*

**Ground-Fault Protection of Equipment (GFPE):** 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. *[N]*

**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 1.52 m (5 feet) 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), and (7) Conductive grid or mat used in substations.

**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. *[N]*

**Grounding Electrode System:** The interconnection of grounding electrodes.

**Guarded:** Covered, shielded, fenced, enclosed, or otherwise protected by means of suitable covers, casings, barriers, rails, screens, mats, or platforms to remove the likelihood of approach or contact by persons or objects to a point of danger. *[N]*

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

**Live Parts:** Energized conductive components.

**Manufacturer Published Data:** Data provided by the manufacturer concerning a specific piece of equipment.

**Mechanical Inspection:** Observation of the mechanical operation of equipment not requiring electrical stimulation, such as manual operation of circuit breaker trip and close functions. It may also include tightening of hardware, cleaning, and lubricating.

**Motor Control Center:** An assembly of one or more enclosed sections having a common power bus and principally containing motor control units. *[N]*

**Overcurrent:** Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault. *[N]*

**Overload:** Operation of equipment in excess of normal, full load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload. *[N]*

**Panelboard:** A single panel or group of panel units designed for assembly in the form of a single panel, including buses and automatic overcurrent devices, and equipped with or without switches for the control of light, heat, or power circuits; designed to be placed in a cabinet or cutout box placed in or against a wall, partition, or other support; and accessible only from the front. *[N]*

**Personal Protective Ground:** Bonding jumper that is intentionally installed to ground de-energized, 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.

**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 to recognize and avoid the hazards involved. *[N] NOTE: Refer to NFPA 70E, Standard for Electrical Safety in the Workplace, for electrical safety training requirements.*

**Reconditioned Equipment:** Electromechanical systems, equipment, apparatus, or components that are restored to operating conditions. This process differs from normal servicing of equipment that remains within a facility, or replacement of listed equipment on a one-to-one basis. *[N]*

**Switchboard:** A large single panel, frame, or assembly of panels on which are mounted on the face, back, or both, switches, overcurrent, and other protective devices, buses, and usually instruments. These assemblies are generally accessible from the rear as well as from the front and are not intended to be installed in cabinets. *[N]*

**Switchgear:** An assembly completely enclosed on all sides and top with sheet metal (except for ventilating openings and inspection windows) and containing primary power circuit switching, interrupting devices, or both, with buses and connections. The assembly may include control and auxiliary devices. Access to the interior of the enclosure is provided by doors, removable covers, or both. *[N] NOTE: All switchgear subject to NEC requirements is metal enclosed. Switchgear rated below 1000 V or less may be identified as "low-voltage power circuit breaker switchgear." Switchgear rated over 1000 V may be identified as "metal-enclosed switchgear" or "metal-clad switchgear." Switchgear is available in non–arc-resistant or arc-resistant construction.*

**Ungrounded:** Not connected to ground or to a conductive body that extends the ground connection. *[N]*

**Ventilated:** Provided with a means to permit circulation of air sufficient to remove an excess of heat, fumes, or vapors. *[N]*

**Verify:** To investigate by observation or by test to determine that a particular condition exists.

**Visual inspection:** Qualitative observation of physical characteristics, for example: cleanliness, physical integrity, and evidence of overheating and lubrication.

**Voltage, Nominal:** A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class (e.g., 120/240 volts, 480Y/277 volts, 600 volts). *[N]*

**Voltage to Ground:** For grounded circuits, the voltage between the given conductor and that point or conductor of the circuit that is grounded; for ungrounded circuits, the greatest voltage between the given conductor and any other conductor of the circuit. *[N]*

# 3. Safety

## 3.1 General

*NOTE: Many tests on electrical equipment involve the use of high test voltages and currents that are life hazards to personnel and are capable of damaging or destroying the equipment under test. Institute and practice safety rules to prevent injury to personnel who are performing the tests and others who might be exposed to hazards. Use test procedures designed to ensure that no intentional damage to equipment will result from the testing process.*

Servicing and maintaining electrical equipment includes inspecting and testing equipment during its operation. Hazards exist as an unavoidable characteristic of operating and testing electrical equipment. While the hazard remains, risk can be mitigated through good engineering design, proper work practices, and protective equipment.

Electrical equipment hazards include electric shock (energized equipment, stored energy in batteries and capacitors, multiple sources of electricity), toxic chemicals (electrolyte and hydrogen from batteries, engine-generator oil and coolant), asphyxiation (engine-generator exhaust fumes, products of combustion), explosion (hydrogen from batteries, fuels from engine-generators, arc-blast), rotating machinery (motors and engine-generators), corrosive liquids (battery electrolyte), corrosive vapors (cracked or leaky batteries), fire and explosion hazard (hydrogen gas generated during battery charging cycles, fuels for engine-generators), hazardous fumes or vapors (products of combustion due to fire), confined spaces (manholes), and thermal burns (engine-generator components, batteries, products of combustion), among others.

Prior to maintaining equipment, read all related installation, operation, and owner's manuals to become familiar with the equipment and the hazards specific to the equipment. Read all related safety instructions and carefully observe all instructions, warnings, and precautions in this Recommended Practice and in the equipment manufacturer instructions. Observe all safety warning labels on equipment.

Individuals performing tests and inspections shall be capable of working in a safe manner and with complete knowledge of the hazards and methods of mitigating the risks involved.

Safety practices shall include, but are not limited to, the following requirements:

- All applicable provisions of the Occupational Safety and Health Act, particularly OSHA 29 CFR 1910.
- ANSI/NFPA 70E, Standard for Electrical Safety Requirements for Employee Workplaces.
- Accident Prevention Manual for Industrial Operations, National Safety Council.
- Manufacturer instructions.
- Applicable state and local safety operating procedures.
- Company manuals and policies.
- Owner's safety practices.

The following are examples of good procedures to follow when maintaining electrical equipment:

- Conduct a hazard identification and risk analysis prior to any work on electrical equipment. The risk assessment shall be applicable to the specific task to be performed, and shall determine the appropriate level of personal protective equipment (PPE) to be worn while performing the task.

- Follow manufacturer instructions and recommendations for electrically isolating electrical equipment and components.
- Check electrical equipment and components for AC and DC voltages to ensure that equipment is electrically safe before performing any commissioning, inspections, or testing.
- Open all external disconnects or circuit breakers to completely isolate equipment from all AC and DC power sources.
- Open DC circuit breakers to completely isolate equipment from batteries.
- Check capacitors for voltage and discharge. Wait a minimum of five minutes for capacitors to discharge before entering electrical equipment cabinets.

Keep cabinet and access doors secured when not working inside electrical equipment to ensure proper cooling airflow and to protect personnel from dangerous voltages inside equipment. Ensure that doors cannot create a hazard when open due to door swing or limited work space around equipment. *NOTE: Some equipment may have lock-bars for compartment doors or removable doors for this purpose.*

## 3.2 Safe Work Practices

Perform preliminary inspections and tests prior to beginning work to determine existing conditions. Check existing conditions against available record documents. Resolve discrepancies between installed conditions and electrical drawings. Have drawings corrected, if required. Provide warning labels on equipment and cables where necessary to indicate unexpected and potentially hazardous conditions.

Visually verify conductor routing through all raceways, manholes, and vaults. Visually verify all conductor connections to equipment. Verify that supply and load conductors are connected properly to equipment. Keep in mind that transposed conductors may be connected to different terminals than expected.

Maintain as much distance as practical from equipment and devices that may arc during operation or handling, but not less than the arc flash protection boundary specified in NFPA 70E.

Use appropriate Personal Protective Equipment (PPE) and established safety procedures when working on or near energized electrical equipment or equipment that has not been de-energized, tested, grounded, and tagged in accordance with NFPA 70E. Wear appropriate PPE in accordance with the Arc Flash Hazard level of the equipment.

Use insulated hand tools when working on or around energized equipment. Use only properly rated tools for the energy present. Maintain tool inventories to ensure that all tools are accounted for prior to energizing equipment. Carefully inspect the work area and remove any tools and objects left inside before energizing equipment.

Operate electrical equipment only when all guards and electrical enclosures are in place. Install all devices, doors, and covers before energizing. Do not tamper with or defeat safeties or interlocks. Do not make any modifications to the equipment or operate the system with interlocks or safety barriers removed.

When performing tests, service, or maintenance on any part of energized equipment, service personnel and test equipment should be standing on rubber insulating mats. Do not wear damp clothing (particularly wet shoes) or allow skin surface to be damp when handling electrical equipment.

During normal operation, hazardous voltages are present on control circuits, potential transformers (PTs), current transformers (CTs), and terminal strips. PT and CT secondary circuits are capable of generating lethal voltages and currents with the primary circuits energized. Do not open-circuit current transformer secondary circuits while equipment is energized. Open-circuited CT terminals can develop voltage near the nominal system voltage, are a significant shock hazard, and can be lethal. Follow standard safety precautions, such as removing PT fuses and shorting CT secondaries.

All workers in manholes must have OSHA Certification for Confined Space Access. Follow the OSHA rules and regulations for confined space entry found in 29 CFR 1910.146, “Permit-Required Confined Spaces,” and 29 CFR 1910.269(e), “Electric Power Generation, Transmission, and Distribution,” Enclosed Spaces. Crews working in confined spaces shall consist of two or more persons with at least one remaining outside the confined space at all times. Maintain a personnel retrieval system at the site.

Test manholes and unventilated vaults for combustible or flammable gases and for oxygen deficiency before entry. Where combustible or flammable gases are detected, ventilate the work area to safe levels before entering. Provide continuous monitoring of occupied manholes and vaults for gasses and oxygen deficiency.

Provide continuous, mechanically supplied fresh air to manholes and vaults when occupied. Provide blowers to force fresh air into manholes or confined areas where free movement or circulation of air is obstructed. Ensure air flow from manholes or confined areas is properly ventilated at duct entrances into buildings.

Ensure adequate ventilation where open flames must be used in manholes or vaults.

Ensure that there is access to a fire extinguisher with an ABC or BC rating, or as recommended for electrical fires by the local Fire Code or an authorized agency.

Provide adequate ventilation when using cleaning agents and solvents to avoid fire, explosion, and health hazards.

## 3.3 De-energizing Electrical Equipment

Consider all ungrounded and grounded metal parts of equipment and devices to be energized at the highest voltage to which they are exposed unless they are de-energized, tested, locked, and red tagged in accordance with OSHA requirements. Electrical equipment may have multiple sources of power. Expect hazardous voltages in all interconnecting components and conductors. Keep in mind that high voltage DC is always present because of the nature of stored energy in battery systems.

Do not work on energized conductors or equipment (except batteries, which are always energized). Using established safety procedures, guard energized conductors and equipment in close proximity to work.

Render equipment electrically safe. De-energize as many loads as is practical before performing any switching procedures. Transfer loads to alternate sources of power, when possible. Follow manufacturer instructions for electrically isolating equipment. Open all external disconnects or circuit breakers to completely isolate all power sources, including batteries.

Verify that circuit breakers and switches are open by testing that the desired cables and equipment are de-energized. Use electrical testing equipment rated for the operating voltage of the system. Test voltage sensing equipment on a known, energized source immediately before and after testing the equipment to be tested to ensure that voltage sensing equipment is operating properly.

Follow lock-out/tag-out (LOTO) procedures. After compartments are opened, test for the presence of voltage and apply locks and tags in accordance with NFPA 70E and OSHA. Secure source circuit breakers and switches with locks and tags in accordance with NFPA 70E. Leave locks and tags in place until the work is completed and the equipment is ready to be put into service.

Attach Listed personal protective grounds on conductors and equipment that are sufficient for the available short circuit current from the supplier. For conductors equipped with reconnectable terminations, disconnect conductors from terminal bushings and park on stands. Follow the manufacturer instructions for grounding conductors with reconnectable terminations. Connect personal protective grounds to the line terminals of the main circuit breaker or main lugs, to the neutral terminal bus bar, if so equipped, and to the grounding terminal of equipment.

For transformers, consider the transformer enclosure energized until the case-ground connection is inspected and found to be adequate. De-energize transformers for any procedure except an external inspection. Test transformer terminals and verify the absence of voltage before grounding transformer terminals. Install personal protective grounds on transformer terminals prior to performing any work on transformers.

## 3.4 Battery Systems

Follow manufacturer installation, servicing, and maintenance instructions, and industry standards.

*NOTE: A battery is a source of stored energy. Voltage is always present in each battery string. Batteries connected in series and strings connected in parallel can have high voltage and current capacities. Opening the battery disconnecting means does not de-energize the voltage within the battery string itself. Shock potential is greatest at the terminals of a battery. Battery voltages can cause injury and death if contact is made between positive and negative terminals or conductors. Take care to avoid contact with both battery terminals at the same time.*

*NOTE: Contact of eyes and mucus membranes with electrolyte can cause severe burns and blindness. During charging, batteries can produce and/or emit a highly flammable mixture of hydrogen and oxygen which can be explosive in high concentrations.*

Appropriate safety equipment shall be used as deemed necessary by a risk assessment of the task being performed while in battery rooms or when working near batteries. Remove all jewelry before servicing equipment. *NOTE: Jewelry can short out electrical contacts and cause shock, burns, or death.* Goggles shall always be worn. Other PPE typically includes, but is not limited to, face shields, safety glasses with side shields and splash protection, head protection appropriate for environments with electrical hazards, insulated rubber gloves and sleeves suitable for the voltage class of equipment present, acid- or alkali-resistant gloves, protective or impermeable aprons, and acid- or alkali-resistant boots or overshoes.

Prior to work on a battery with free-flowing liquid electrolyte (such as vented lead-acid or vented nickel-cadmium batteries), verify the presence of a complete spill clean-up kit in the room that is appropriate for the hazard and risk. Sufficient neutralizing agent shall be readily available to neutralize, at a minimum, the total electrolyte in a single cell or multi-cell container, to a pH of 5-9. Spill prevention, abatement methods and equipment shall be in accordance with IEEE Standard. 1578, *Recommended Practice for Stationary Battery Spill Containment and Management.*

Egress from the work area shall be unobstructed.

Verify that fire suppression systems are:

- Suitable for use in electrical fires per the equipment safety data sheets.
- Suitable for use with any chemicals likely to be liberated if the battery is consumed in flame.
- Tested to be operational with the date of the most recent test readily available.

Use of $CO_2$ Class C fire extinguishers may not be permitted due to the potential of thermal shock and cracking battery containers, and the hazard of oxygen depletion within the space. Local codes identify the permissible fire protection methods.

If an emergency eye wash or quick-drench shower are located near the battery area they shall be maintained in accordance with the manufacturer recommendations and local, State, and Federal regulations pertaining to such equipment.

Do not attempt to disassemble or in any way handle batteries that are, or have recently been, involved in fire. Batteries can explode or release hazardous substances when exposed to extreme heat or fire.

### *3.4.1 Battery Electrical Safety*

Adhere to the following practices when working around battery systems or other stored energy devices to protect against electric shock or other hazards:

- Do not place tools or other conductive objects on battery cells, racks, or tiers.
- Use insulated tools to protect against shorting of cells.

- Use PPE based on the hazard analysis and risk assessment performed prior to work on the battery. PPE shall be appropriate for the task to be completed.
- Discharge static electricity from the body before touching cell terminal posts by first touching a grounded surface in the vicinity of the batteries but away from the cells and flame arrestors.

Disconnect the charging source prior to connecting or disconnecting battery terminals.

Verify the battery grounding method prior to working on the battery system. Inspect batteries for inadvertent grounding during maintenance. Remove inadvertent grounds to reduce the likelihood of shock. Disconnect battery ground connections only in accordance with manufacturer instructions.

### 3.4.2 Electrolyte

*NOTE: Electrolyte in contact with the eyes or mucus membranes can cause severe burns or blindness. If electrolyte comes in contact with eyes, nose, or mouth, flush the affected area immediately with copious amounts of water and obtain medical assistance immediately. Electrolyte in contact with the skin can cause an allergic reaction to some people. Electrolyte is about the same level of hazard as vinegar or lemon juice. If electrolyte comes in contact with the skin, wash thoroughly with soap and water. Refer to battery safety data sheets shipped with the system for further information.*

Wear personal protective equipment, including eye and skin protection, when performing tasks that potentially expose a worker to electrolyte.

Follow the manufacturer instructions to neutralize an electrolyte leak or spill. *NOTE: Some chemicals can cause damage to the cell container. A common neutralizer for lead-acid electrolyte is a bicarbonate of soda solution in a concentration of one pound per gallon of water to neutralize acid spilled on clothing or material. Apply the solution until bubbling stops, and then rinse with clear water.*

*NOTE: Guidelines for the design of electrolyte spill protection and response to electrolyte spills can be found in IEEE 1578, Recommended Practice for Stationary Battery Electrolyte Spill Containment and Management. Guidelines for personal protective equipment around batteries can be found in the manufacturer safety data sheets, in IEEE standards applicable to the battery technology, or in NFPA 70E, Standard for Electrical Safety in the Workplace.*

### 3.4.3 Hydrogen Gas

*NOTE: As batteries charge, hydrogen, which is a colorless, odorless, and tasteless gas that is non-toxic under normal conditions, may be released. Hydrogen is the smallest, the lightest, and one of the most common molecules in the known universe. Hydrogen diffuses rapidly with the slightest amount of air movement. Hydrogen is extremely difficult to contain and can even penetrate concrete blocks. Hydrogen will always tend to rise to the highest level of a confined space, rising two times faster than helium and six times faster than natural gas. Hydrogen is a severe fire hazard when exposed to heat, flame, or oxidizer, and can become explosive in high enough concentrations. The flammability range for hydrogen is very wide with a lower flammability limit of 4.1% by volume and the upper limit of 74.2%.*

Verify that battery rooms and compartments with lead-acid batteries are adequately ventilated to prevent hydrogen levels from exceeding levels specified in local codes. *NOTE: Fire codes typically stipulate a 1% concentration by volume of the space. Gassing rates can be affected by temperature, air pressure, the battery construction, and the amount of charge current passing through cells. Not all gases generated in a battery escape to the atmosphere. Calculations for hydrogen ventilation shall be performed by a qualified person based upon data provided by the battery manufacturer for the battery under specified conditions. Additional ventilation may be required during activation charging cycle or other charging regimens.*

Open flames, sparks, hot plates, smoking, or any other ignition sources are prohibited near batteries, gas ventilation paths, or anywhere that hydrogen can accumulate. Discharge static electricity from the body before touching batteries by first touching a grounded metal surface.

### 3.5 Automatic (Remote) Operation

*NOTE: Equipment that is controlled remotely or automatically may start and operate unexpectedly. Accidental or unexpected starting can cause severe injury or death.*

Protect against accidental energization of automatic or remotely controlled equipment by identifying, opening, locking, and tagging starting devices. Become familiar with equipment control schemes prior to maintenance. Do not enable controls or energize control power to electrical equipment until after maintenance work is complete and the equipment is ready to place back into service.

### 3.6 Rotating Machinery

Ensure that all panels, doors and covers are attached and closed whenever rotating equipment, such as flywheels, motors, and engine-generators, is operating. Operate equipment only when all guards, screens, and electrical enclosures are in place. Make sure that fasteners on equipment are secure. Ensure that supports and clamps are tight.

If adjustments must be made while equipment is running with protective guards and barriers removed, use extreme caution around moving parts.

Do not wear loose clothing or jewelry in the vicinity of moving parts, or while working on electrical equipment. *NOTE: Loose clothing, jewelry, hands, and hair can become caught in moving parts. Jewelry can short out electrical contacts and cause shock, burns, or death.*

### 3.7 Operating Temperatures

*NOTE: Some electrical equipment components can become extremely hot during operation and remain hot for a period of time after shutting down, such as motors, power electronics, and engines of engine-generators. Hot equipment components can cause severe injury or death.*

Avoid contact with hot components and parts. Do not work on equipment until it cools down. Use extreme caution working around hot electrical equipment when necessary to make adjustments while equipment is running.

### 3.8 Generator Fuel Systems and Exhaust Gases

*NOTE: Generator fuels and fuel vapors are flammable and can be explosive. Servicing the generator fuel system can result in an explosion or flash fire that can cause severe injury or death.*

Do not operate the generator if the smell of fuel is present or other explosive conditions exist. Never add fuel manually to a sub-base fuel tank or day tank while the engine is running. *NOTE: Spilled fuel may ignite on contact with hot parts or components, or from sparks.* When checking, draining, or adding diesel fuel to a generator, take care not to ingest, breathe the fumes, or contact the fuel.

Do not smoke or permit flames, cigarettes or other smoking materials, pilot lights, sparks, arcing equipment or other ignition source near the carburetor, fuel line, fuel filter, fuel pump, fuel tank, or other potential sources of spilled fuels or fuel vapors.

Do not operate the generator with the air filter or air cleaner cover removed. *NOTE: A sudden backfire can cause severe injury or death with the air filter or air cleaner removed.*

*NOTE: Exhaust gases contain carbon monoxide, which is odorless, colorless, and poisonous. Avoid breathing exhaust fumes when working on or near the generator. Carbon monoxide can cause light-headedness, throbbing in the temples, headache, dizziness, stomachache, severe nausea, vomiting, weakness, sleepiness, fatigue, muscular twitching, inability to concentrate or speak clearly, fainting, unconsciousness, or death.*

If anyone experiences any symptoms of carbon monoxide poisoning, evacuate the area, immediately move to fresh air, and stay active. Do not sit, lie down, or fall asleep. Alert others to the possibility of carbon monoxide poisoning. Seek medical attention if the condition of affected persons does not improve within minutes of breathing fresh air. Shut down the generator and do not operate the generator until it has been inspected and repaired. If symptoms persist, seek medical attention immediately.

### 3.9 Sulfur Hexafluoride (SF6) Gas

Safety during maintenance and repair requires that SF6-insulated equipment is electrically isolated, de-energized, grounded, and locked/tagged out before any work on the equipment. Do not de-pressurize SF6-insulated equipment until the equipment is de-energized and grounded.

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." Recycle and reuse SF6 gas whenever possible. Do not release SF6 into the atmosphere.

SF6 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. Pure SF6 gas is colorless, odorless, tasteless, nonflammable, and noncorrosive.

Although nontoxic, SF6 gas does not support life by itself and can result in asphyxiation. Do not enter any vessel previously containing SF6 gas 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 29 CFR 1910.269, "Electric Power Generation, Transmission, and Distribution," paragraph (e), for enclosed space entry.

Excessive heating, electric sparks, power arcs, and partial discharges cause the decomposition of SF6 and the generation of solid by-products and gaseous by-products, some of which are highly toxic and harmful to the eyes, nose, and lungs. Use appropriate PPE to avoid exposure to SF6 by-products when arcing has occurred, which is indicated by a rotten egg odor in the vicinity of the equipment. Do not vent gas from SF6 equipment. Do not inhale SF6 gas.

Solid by-products of SF6 decomposition include aluminum fluoride, which is a fine, talcum-like powder that is white or tan in color which absorbs the toxic gas by-products of SF6 decomposition and can enter the lungs. Powder by-products of SF6 decomposition are considered to be a hazardous waste and must be disposed of in accordance with manufacturer instructions and local, State, and Federal environmental regulations. Avoid direct contact with the products of SF6 arc decomposition.

See NFPA 70B for additional information.

# 4. Routine and Periodic Inspections

## 4.1 Routine Inspections

### *4.1.1 General*

Perform routine inspections of electrical equipment at regular intervals based on the importance of the equipment, the cleanliness of the operating environment, and the severity of the load conditions. Maintain records of routine inspections and compare with previous conditions.

Routine inspections typically consist of external visual inspections of equipment in conjunction with measurements of electrical operating parameters, such as operating voltage and load currents, and environmental characteristics such as checking for unusual noises and elevated sound level and taking temperature measurements in general, and liquid-levels and pressures for liquid-filled and/or sealed equipment. As such, routine inspections are typically performed with equipment energized and under load by inspecting meters and gauges of equipment. When voltage and current meters are not installed on equipment, follow manufacturer instructions, NFPA 70B, NFPA 70E, and Section 3 to safely measure electrical operating conditions.

Based on deficiencies identified during routine inspections, complete needed repairs, cleaning, and painting in accordance with manufacturer instructions and Section 5.

Consult the manufacturer for recommendations for any deficiencies identified during inspections, testing, and maintenance. Where the continued operation of equipment is suspected to be hazardous based on identified deficiencies, de-energize equipment and remove from service. Consult the manufacturer for recommendations for repairing or replacing suspect equipment.

Handle materials and dispose of refuse, debris, and used and excess liquids in accordance with local, State, and Federal environmental regulations.

### *4.1.2 Environmental and Load Conditions*

Measure and record environmental and operational load conditions during routine inspections, including load current, operating voltage, ambient temperature, and the general condition of the environment. Take load current, operating voltage, and ambient temperature readings during times of peak loading.

Measure the grounded conductor or neutral current of three-phase, four-wire systems using a true RMS ammeter. Check that neutral load currents are within the neutral conductor ampacity. Neutral load current may exceed the ampacity of the neutral conductor in normal operation due to unbalanced phase loading, non-sinusoidal (harmonic) load currents, or a combination of the two. Symptoms of a non-sinusoidal load condition include overheated conductors, deterioration of conductor insulation, carbonized insulation, and measurable voltage between the neutral and ground conductors (common-mode noise). If excessive neutral current is found, measure each phase current to identify the cause. If excessive neutral current is not due to high phase currents or phase current imbalance, analyze the phase and neutral currents for harmonic content.

Measure and record the sound level in equipment rooms. Investigate unusual noises, high sound levels, and any change in the sound level, which may be an indication of equipment degradation. Sources of excess noise include rigid raceway connections on equipment subject to vibration and movement, locating equipment in the corner of a room with hard, sound-reflecting side walls, and inadequate vibration isolators for equipment subject to vibration and movement.

Investigate and correct any equipment operating voltages outside of acceptable tolerances from the nominal voltage.

Check the balance of phase currents on three-phase equipment. Investigate significant current imbalance in accordance with manufacturer instructions. See Section 5 for equipment-specific information.

If the ambient temperature of the equipment operating environment is high, check the adequacy of ventilation for the room. If the equipment temperature is high and if any phase currents exceed the rated full load current of the equipment, reduce the loading on the equipment.

Excessive equipment operating temperature is an indication of an overload condition or some interference with the means of cooling the equipment or the environment. Prolonged operation at elevated temperature will shorten equipment life expectancy and can result in equipment failure. Investigate and correct equipment overheating.

#### *4.1.3 Cleanliness*

Inspect louvers and other ventilation openings of air-cooled equipment and remove dust, dirt, debris, or other obstructions. Remove any material or obstruction that would prevent free circulation of air around equipment.

Inspect equipment for dust, dirt, debris, and other contamination. Check equipment for rust, corrosion, and physical damage. Repair physical damage to equipment and restore finishes if practical and approved by the manufacturer. Check for evidence of liquid leaks into the room or onto equipment. Identify sources and correct sources of liquids. Provide leak protection for equipment installed below overhead pipes, if applicable.

### 4.1.4 Environmental Controls and Seals

For equipment with internal cooling fans, check fans and controls for proper operation. Measure and record the ambient temperature of equipment rooms. Check ventilation equipment, ducts, fans, and controls, for proper operation. Where installed, check high temperature alarms for proper operation.

For transformer and motor windings equipped with temperature sensors or RTDs, record winding hot-spot temperatures during peak load conditions. Verify that winding temperature detectors indicate the correct temperature. Compare with prior results. Investigate high and low temperature readings.

For equipment with internal heaters, verify the proper operation of heaters, thermostats, and associated controls. Check that thermostat settings are appropriate for heater operation under all climatic conditions to prevent condensation.

For outdoor equipment including walk-in enclosures, inspect roof and wall seams for evidence of leaks. Inspect the wall base and floors for openings that could permit the entry of water. Repair any leaking seams or openings using manufacturer approved caulk or grout as needed.

#### *4.1.5 Liquid-Filled Equipment*

Measure and record liquid level gauges of tanks and bushings, if so equipped. Check liquid levels at the end of a period of low loading. Check and record the maximum and present temperature gauge readings, if so equipped. Reset the maximum temperature indicator on gauges so equipped.

Inspect liquid-filled equipment and accessories, such as the tank, heat exchanger, cooling fins, tubes, radiators, tap changers, and all gasketed or other openings, for leaks, contamination, dirt, and corrosion.

#### *4.1.6 Sealed and Pressurized Equipment*

Compare the readings of pressure/vacuum gauges to the manufacturer recommended normal operating range. Investigate high- and low-pressure conditions, as high pressure may be an indication of an overload or internal problem with the equipment, and low or zero pressure may be an indication of a leak or compromised seal, a defective gauge, or that the equipment is open to the atmosphere.

## 4.2 Periodic Inspections

### *4.2.1 General*

Complete routine inspections in accordance with Section 4.1 prior to performing periodic inspections.

Perform periodic inspections of electrical equipment at regular intervals based on the importance of the equipment, the cleanliness of the operating environment, and the severity of the load conditions. Maintain records of periodic inspections and compare with previous conditions.

Periodic inspections typically consist of internal inspections of equipment in conjunction with measurements of electrical parameters, such as contact resistance. As such, periodic inspections are typically performed with equipment de-energized and locked out and/or tagged out of operation in accordance with NFPA 70E.

Based on deficiencies identified during periodic inspections, complete needed maintenance and repairs in accordance with manufacturer instructions and Section 5.

Consult the manufacturer for recommendations for any deficiencies identified during inspections, testing, and maintenance. Where the continued operation of equipment is suspected to be hazardous based on identified deficiencies, de-energize equipment and remove from service. Consult the manufacturer for recommendations for repairing or replacing suspect equipment.

### *4.2.2 Nameplate Data and System Compatibility*

Compare equipment, components, conductors, cables, connections, and terminations with contract documents, drawings and specifications, and with approved submittals, product data and shop drawings, if available.

Verify equipment nameplate information with contract documents, drawings and specifications, approved submittals, if available, and short circuit and coordination studies, if available, provided by others. Verify circuit breaker and fuse sizes, types, ampere ratings, and withstand and interrupt ratings conform to drawings and the coordination study, if available, provided by others.

Verify that circuit breakers and fuses are properly sized for motors served based on motor nameplate information, when applicable.

Verify that electrical connections of conductors and cables are consistent with single-line and three-line diagrams.

Verify that reconditioned equipment is marked with the name, trademark, or other descriptive marking by which the organization responsible for reconditioning the electrical equipment can be identified, along with the date of the reconditioning unless the conditions of maintenance and supervision ensure that only qualified persons service the equipment. Verify that reconditioned equipment is identified as “reconditioned.” Approval of reconditioned equipment is not based solely on the original listing of the equipment. *NOTE: Normal inspections, testing, or maintenance of electrical equipment is not considered to be reconditioning or refurbishing the equipment.*

### *4.2.3 Doors, Covers, and Access Panels*

Ensure that equipment and components are de-energized prior to entering equipment. Carefully remove doors, covers, and access panels prior to entering equipment. Keep in mind that current-carrying components may be within reach of openings upon entering equipment.

Inspect all doors, access panels, and covers to ensure that all hardware is in place and in good condition. Lubricate hinges, locks, and latches using manufacturer approved lubricants.

Inspect doors, access panels, covers, and sections of equipment for corrosion, damaged finishes, damaged paint, dents, and scratches, paying particular attention to missing and loose hardware, bent hinges, broken or missing lock handles or latches and warped panels. Check for proper clearances, anchorage, fit, and alignment, considering seismic requirements. Check for proper alignment and fit of doors, access panels, and components. Check for loose parts and hardware.

Correct any deficiencies found in accordance with manufacturer instructions.

### *4.2.4 Cleanliness and General Condition of Equipment*

Perform a visual and mechanical inspection of equipment, components, conductors, cables, connections, and terminations. Inspect for physical damage, evidence of overheating, tracking, and corona discharge. NOTE: Ultrasonic detection and light amplification or night-vision equipment is useful for detecting corona. Inspect for accumulations of dust, dirt, or debris on internal surfaces, buses, windings, insulators, and similar components. Check for evidence of tracking, carbonization, and overheating.

Inspect bushings and insulators, such as potheads, for physical damage, tracking, contamination, leaks, and cracked or chipped porcelain. Check gasketed plates, fittings, bushings, and insulator bases for leaks. Repair leaking gaskets. Clean porcelain surfaces and verify that connections are tight.

Verify that equipment and compartments are free of tools, debris, and storage of materials. Investigate and correct sources of damage and contamination. Repair or replace damaged insulation, such as from corona discharge and tracking, in accordance with manufacturer instructions.

Inspect internal components for evidence of overheating, such as discoloration and flaking of insulation or metal parts, arc spatter, sooty deposits, and tracking. Investigate and correct sources of arcing or overheating and replace damaged parts. Plated parts may become dark over time from oxidation. Do not remove the discoloration or abrade the plating, as it will reduce the thickness of the plating.

Ensure that insulating materials are properly installed, secured, and intact. Inspect insulating materials for damage, such as chips or breakage, and for evidence of overheating, thermal damage, arcing, partial discharge, or corona discharge. Investigate and correct sources of damage and repair or replace damaged insulating materials. Insulating materials that have mild discoloration from overheating may be retained if the cause of the overheating is corrected. Evidence of overheating and thermal damage includes:

- Discoloration of materials and finishes (typically darkening)
- Cracking, flaking and delaminating materials or finishes, such as labels, paint, or varnish
- Brittle insulating materials, including tapes
- Carbon buildup on materials that does not resemble tracking or treeing
- Insulating materials that are melted or appear to have oozed, dripped, or boiled out of equipment or an insulating assembly

Check for evidence of localized heat damage to paint. Investigate sources of heat. Correct internal sources of heat. Remove external sources of heat. Repair damaged painted surfaces.

Check for evidence of moisture, water, or condensation on internal components. Moisture causes insulation failure and rapid oxidation of current-carrying components. Check raceway entries for the entrance of water. Investigate and eliminate sources of water. Remove any moisture present inside equipment. Seal off all leaks, cracks, or openings where moisture has entered equipment. Seal connections where raceways enter equipment, as needed. Verify that all unused openings are sealed in accordance with the NEC. Verify that appropriate seals and gaskets are intact and properly installed in outdoor equipment. Consult the manufacturer for recommendations for addressing condensation, such as adding heat and/or air circulation, if needed. Replace any components that show evidence of damage from moisture.

Check interior and exterior lighting systems in close proximity to electrical equipment for proper operation.

Check for unusual sounds after energizing equipment, components, conductors, and systems. Investigate the source of any unusual sounds, such as sizzling.

Investigate the source of any unusual odors, such as burning or ozone.

### *4.2.5 Ventilation and Clearances*

Verify proper mechanical, maintenance, and ventilation clearances for equipment.

Verify proper separation and clearances of conductors and cables, including primary and secondary conductors for transformers. Verify that field-installed wiring is clear of current-carrying bus of switchgear, switchboards, and motor control centers.

### *4.2.6 Identification, Labeling, and Directories*

Verify the identification and correct arrangement of cables, conductors, connections, and terminations. Check that each conductor, each connection, and each termination is properly identified (cable number, wire number) and color coded in accordance with drawings, if available, and in accordance with the NEC. Verify identification of all lighting circuits and branch circuits on panel directories.

### *4.2.7 Safety Devices and Interlocks*

Turn switches to the "OFF" position before opening doors and access panels. Do not defeat safety interlocks to gain access to internal components with switches closed and/or energized.

Test all safety devices, fail-safe functions, and all keyed, mechanical, and electrical safety and interlock systems for correct operation and sequencing. Test positive interlock features of drawout equipment, such as circuit breakers, that prevent the insertion and withdrawal of the circuit breaker while in the closed position.

Attempt to close locked open devices. Attempt to open locked closed devices. Exchange keys and attempt operation with devices operated in off-normal positions. Verify proper operation of all padlocking means. Interlocks should operate in accordance with the design of the system.

Verify that key interlock operational procedures are available to authorized personnel where the interlocks might be operated only annually or in emergencies. Verify that spare keys are identified and controlled to prevent unauthorized use.

Lubricate mechanical interlocks using manufacturer recommended lubricants.

### *4.2.8 Mechanical Operation and Moving Components*

Use manufacturer approved lubricants for current-carrying and non-current-carrying moving and sliding parts and surfaces. Ensure that new lubricants are compatible with existing lubricants on equipment. Follow manufacturer instructions for applying any lubricants to electrical equipment. Exercise caution when using penetrating solvents, which may not be acceptable as lubricants in accordance with the manufacturer specifications.

Verify appropriate contact lubricant on moving and sliding parts and surfaces. Ensure that lubricants, where used, are applied only to surfaces recommended by the manufacturer. Wipe off excess lubricant to avoid contamination.

Verify proper racking mechanism operation for removable units, such as circuit breakers, motor control center components, and potential transformer cabinets in switchgear.

Verify that insulating shutters are properly installed and operating correctly in accordance with the manufacturer design. Exercise all active components and verify correct operation of indicating devices in accordance with system design.

For motors and rotating machinery, lubricate bearings and rotating shafts in accordance with manufacturer instructions for the quantity of lubricant, the frequency of lubrication, the method of application, the type of lubricant used, and the expected temperature range of service. Carefully monitor bearing lubrication as both insufficient and excessive lubrication will result in bearing failure. Regrease bearings in accordance with manufacturer instructions. Check the level of oil lubricating systems and add manufacturer approved oil as needed. *NOTE: Oil lubricating systems should typically be drained and refilled on an annual basis.*

*Wick-oil systems typically require the addition of oil quarterly, and the wick should be saturated.*

### 4.2.9 Raceways and Cable Trays

Inspect raceways and cable trays for signs of deterioration and mechanical damage. Inspect accessible raceway and cable tray joints for signs of corrosion. Clean raceways and cable trays in accordance with manufacturer instructions. Repair or replace damaged or deteriorated raceways and cable trays, where practical, in accordance with manufacturer instructions.

Verify that raceway and cable tray mounting hardware is properly installed, secure, and tight in accordance with manufacturer instructions.

Check couplings, bushings, set-screws, and locknuts of metal raceways. Ensure components are tight and properly seated. Check set-screws stripped threads. Replace or repair as necessary using manufacturer-recommended parts.

Inspect cable tray covers for physical damage. Damage should not reduce spacings or damage cables. Repair or replace damaged components. Check for missing or damaged hardware. Replace missing or damaged hardware using manufacturer recommended parts.

Check that cable tray bonding jumpers and grounding connections are tight. Replace damaged components and hardware. Verify that takeoff raceways are bonded to the cable tray.

Inspect cable tray for the intrusion of foreign systems, such as pipes, hangers, or other equipment that could damage cables.

### 4.2.10 Conductors

Inspect the condition of exposed cable and conductor insulation, jacketing, and field-applied fireproofing, where installed. Check for cracked jackets in non-lead cables.

Inspect cables for sharp bends. Verify that visible cable bends meet or exceed ICEA and/or manufacturer minimum allowable bending radius.

Check that conductors and cables are supported independently of terminations and connections.

Verify that conductors and cables are supported and secured in accordance with manufacturer instructions to withstand the effects of fault currents.

Inspect conductors for frayed, broken, or missing strands, rust, corrosion, discoloration, arcing, pitting, melting, and flaking of insulation and/or metal parts. Repair, replace, or rework damaged components.

### 4.2.11 Bus Bars and Bus Bar Assemblies

Inspect bus bars and bus bar assemblies for evidence of pitting, corrosion, discoloration, and annealing due to heat. Replace damaged components using manufacturer recommended components. Use hardware and washers of a grade identical to or better than the hardware being replaced.

Retighten conical spring-steel or Belleville washers according to manufacturer instructions, or retighten until washers are flat, if no instructions are available. Consult manufacturer instructions concerning bus bar joints and retorque where required, keeping in mind that some manufacturers indicate that their joints are maintenance-free and that additional tightening after installation may degrade connections.

Inspect all bus bracing and insulators for contamination, tracking, and broken or missing parts, and cracked or chipped insulators. Check for loose insulators, clamps, spacers, and hardware. Check for missing, damaged, or deteriorated insulating barriers. Check for corroded or loose electrical connections, including grounding and bonding connections, and for signs of overheating. Check for supports that are loose or missing. Repair or replace damaged, loose, or missing components.

Inspect insulators for evidence of physical damage or contaminated surfaces. Inspect terminations, connections, and lugs for alignment, physical damage, burns, corrosion, discoloration, flaking, thermal damage, arcing, pitting, melting, deterioration, carbonization, cracks, chips, breaks, partial discharge, or moisture. Check terminations and lugs for proper ampacity and temperature ratings. Verify that load currents do not exceed the ampacity of terminations and lugs. Replace terminations and lugs with inadequate ratings. Investigate and eliminate sources of damage. Replace overheated connections. Repair or replace damaged components.

#### *4.2.12 Grounding and Bonding*

Verify proper grounding in accordance with contract documents, drawings and specifications, and in accordance with the NEC. Verify that the grounded conductor or neutral is bonded to the grounding electrode conductor only at the service and at each separately derived source, where used.

Ensure that equipment grounding conductors, grounding electrode conductors, and bonding jumpers are properly sized, properly installed, and properly torqued.

Verify that all grounding and shorting contacts for instrument transformers (potential transformers and current transformers) provide proper contact. Verify proper operation of disconnecting and grounding devices associated with drawout devices, such as circuit breakers, control power transformers, and potential transformers, including control contacts, grounding contacts, and withdrawal mechanisms, if applicable.

#### *4.2.13 Connections and Terminations*

Where installed, inspect aluminum conductors for extrusion and rework terminations, if required, keeping in mind that repeated tightening of loose connections will extrude aluminum conductors and may cause adverse operating conditions. Carefully inspect aluminum-to-copper connections for evidence of corrosion, overheating, or looseness. Rework connections as needed. See NECA 104 for additional information.

Inspect terminations and splices of non-lead cables for tracking or signs of corona. *NOTE: Ultrasonic detection and light amplification or night-vision equipment is useful for detecting corona.*

Using a calibrated torque wrench, verify the tightness of accessible bolted electrical connection and terminations in accordance with the manufacturer published data. When there is no sign of degradation of the connection or termination, check the existing connection at 90% of the specified torque value. In the absence of manufacturer torque tables, tighten terminals in accordance with Annex I of NFPA 70. Alternatively, inspect bolted electrical connections and terminations for high resistance using a low-resistance ohmmeter or perform infrared survey. See Annex A for additional information. When there are signs of degradation of a connection or termination, remove damaged components and re-make the connection or termination.

Inspect Belleville or concave, spring-type washers for proper compression. A flat or discolored Belleville washer may indicate an over-torqued connection or a connection that has overheated, causing the washer to lose its temper. Replace flat or discolored Belleville washers in accordance with manufacturer instructions. Inspect field markings of fasteners for signs of movement or loosening.

Inspect compression-applied connectors and terminations for correct cable match and indentation. Inspect conductor and cable shield grounding, cable supports, and terminations. For shielded cables that are terminated through window-type current transformers, inspect window-type current transformers to verify that shield, neutral, and ground conductors are correctly terminated for proper operation of protective devices.

#### *4.2.14 Relays and Overcurrent Protection, Circuit Breakers, and Fuses*

Ensure that conductors and equipment are protected by overcurrent protection within their ampacity and insulation temperature limitations.

Manually operate disconnecting means, circuit breakers and switches, to verify proper alignment and smooth operation. Electrically exercise all electrically-operated devices such as circuit breakers, under no-load condition to verify proper operation. Leave disconnecting means, circuit breakers and switches, in the OPEN position after inspecting and operating and before re-energizing equipment.

Verify that circuit breaker sizes and types and the settings for alarm, control, and trip setpoints for adjustable trip circuit breakers, relays, meters, and temperature indicators are in accordance with manufacturer instructions and one-line diagrams and coordination studies, if available, provided by others. Verify that circuit breaker addresses for microprocessor-communication packages correspond to drawings and the coordination study, if available, provided by others. Notify the owner of discrepancies between actual circuit breaker settings and the coordination study.

Check all fuses to ensure that the correct rating and type are installed. Replace renewable fuses with modern current-limiting fuses that fit into the same fuse clips. Ensure that non-current-limiting devices are not used as replacements for current-limiting devices. Verify that expulsion-type devices are in place on all fuses having expulsion-type elements. Do not defeat rejection mechanisms that are provided to prevent the installation of the wrong types of fuses.

Ensure that equipment is de-energized before replacing fuses. See Section 3. Check both the line and load ends of fuses for the presence of voltage before replacing fuses.

Check the continuity of fuses. Replace open fuses. Measure the resistance of fuses. Compare fuse resistance values with the manufacturer recommended values. Fuse resistance values should be within 15% for identical fuses. Replace deficient fuses. Verify that a dummy fuse, copper slug, copper pipe, or length of wire is not used as a substitute for a fuse. Replace such devices with a fuse of the proper type and ratings.

Clean contact areas of fuses, fuseholders, and clips that are corroded or oxidized. Do not abrade silver-plated surfaces. Clean contact surfaces using a non-corrosive cleaning agent approved by the manufacturer. Clean the insulating area of fuses.

Look for evidence of overheating of cartridge fuses. Replace fuses having discolored or weakened casings. Investigate and correct the cause of overheating.

Inspect ferrules or knife blades of cartridge fuses for corrosion or oxidation. Clean and polish contact surfaces using a noncorrosive cleaning agent. Plated parts may become dark over a period of time due to oxidation. Do not remove this discoloration, as it will reduce the thickness of the plating.

Ensure that fuses are completely inserted in fuseholders when installing fuses.

Follow manufacturer instructions for inspecting, testing, and maintaining fuses rated over 1000V. De-energize the system before replacing fuses that are not load-break rated. Disconnect fuses and de-energize mountings from all power sources before servicing. See Section 3. Inspect insulators for breaks, cracks, and burns. Clean insulators to avoid flashover as a result of the accumulation of foreign substances on their surfaces, such as salt deposits, cement dust, or acid precipitate. Inspect contact surfaces for pitting, burning, alignment, and pressure. Replace badly pitted or burned contacts. Examine the fuse body or fuse tube for corrosion of the fuse element or connecting conductors, excessive erosion of the inside of the fuse tube, discharge (tracking) and dirt on the outside of the fuse tube, and improper assembly that might prevent proper operation. Replace fuses and fuse tubes that show signs of deterioration. Ensure that mounting hardware, such as bolts, nuts, washers, pins, and terminal connectors are in place and in good condition. Refinish fuse tubes made of organic (Class A) material as required and as specified by the manufacturer. Inspect the sealing disc of vented, expulsion type fuses with a dropout feature that have been left in an inverted, disconnected position in service. Replace fuses with damaged seals or that show evidence of leakage or that moisture has entered the interrupting chamber. See NFPA 70B for additional information.

#### *4.2.15 Controls and Indicating Devices*

Verify the correct operation of all sensing devices, alarms, and indicating devices. Check indicating lights for proper operation, and replace burned-out lamps.

Check for proper operation of all control devices, such as pushbuttons, selector switches, indicating lights, timers, auxiliary relays, and electrical and mechanical interlocks. Inspect exposed contacts. Check for loose connections. Check for proper mechanical operation. Check for signs of overheating. Replace non-operational indicating lamps. Investigate and correct any causes of malfunction.

#### *4.2.16 Liquid-Filled Equipment*

Verify the presence of PCB content labeling for liquid-filled equipment, such as transformers, reactors, switches, and capacitors.

Measure and record the level of liquid in liquid-filled devices, such as liquid-filled transformers and reactors, tanks, liquid-filled switches, and liquid-filled bushings, along with the maximum and present temperature gauge readings, if so equipped, and check for leaks. Check liquid levels at the end of a period of low loading. For equipment with no provision for checking liquid levels, follow the manufacturer instructions for checking liquid levels in equipment. Certain electrical equipment that are not equipped with a liquid level indicator can be checked by de-energizing the equipment and removing an inspection plate, such as some liquid-filled transformers, or by removing the top of the tank if no inspection plate is available. Alternatively, perform infrared survey of the exterior of the equipment, including the tank and cooling fins, if so equipped, to determine liquid levels and to identify any restrictions in cooling fins or tubes, if applicable. Verify that the insulating liquid levels are in accordance with the manufacturer recommended tolerances. Reset the maximum temperature indicator on gauges so equipped.

When needed, add liquid to equipment in accordance with manufacturer instructions using approved liquids compatible with the equipment and existing liquids. Store insulating liquids in sealed containers. De-energize equipment before adding liquid. Add liquid before the level falls below the sight glass or the bottom reading of the level indicator, if so equipped. Avoid contaminating insulating liquid. When necessary, avoid opening the tank when humidity is high unless the work is absolutely necessary and cannot be delayed. Protect the opening from inclement weather.

Perform a dielectric breakdown test of new insulating liquid immediately prior to use. When adding a relatively large volume of insulating liquid, allow the equipment to remain de-energized for a period of time sufficient to permit air entrained in the liquid to escape, or add insulating liquid under a vacuum or using a pump, in accordance with manufacturer instructions.

Inspect liquid-filled equipment and accessories, such as tanks, heat exchangers, cooling fins, tubes, radiators, tap changers, and all gasketed or other openings, for leaks, contamination, dirt, and corrosion.

#### *4.2.17 Cleaning Equipment*

Clean equipment in accordance with the type of contamination to be removed and how soon the equipment will be returned to service, considering that cleaning with a solvent or other liquid will require drying equipment.

In general, do not use liquids, solvents, or detergents when cleaning electrical equipment. When used, only use manufacturer approved liquids that do not deteriorate insulation to clean electrical equipment in accordance with manufacturer instructions.

Wipe off dirt and contamination from external surfaces and interiors of accessible electrical equipment using clean, dry, lint-free cloths or soft-bristled brushes. Remove loose material, dust, debris, and other foreign materials using a vacuum. Exercise care to avoid damage to delicate parts and components.

If vacuuming is insufficient and if permitted by the manufacturer, use clean, dry compressed air at a pressure less than a gauge pressure of 208.85 kPa (30 psi) to avoid damage to equipment. Use compressed air in accordance with OSHA regulations in 29 CFR 1910.242(b), “Hand and Portable Powered Tools and Other Hand Held Equipment.” Use appropriate PPE. Protect adjacent equipment and components from airborne contaminants.

Verify that clean ventilation filters are installed and that ventilation slots are open and clear of obstructions. Check that ventilation screens are in place to prevent the entry of insects, rodents, or small animals. Clean dirty ventilation screens. Replace dirty, clogged, or damaged ventilation filters.

Vacuum clean all ventilating ducts and the top and bottom of the windings of dry-type transformers.

#### *4.2.18 Conductors and Buses*

Check the continuity of each conductor from end-to-end, including ground conductors and ground shields of shielded cables and conductors, to ensure correct cable connections. Perform a shield-continuity test on each shielded cable using a low-resistance ohmmeter. Shielding must exhibit continuity. Investigate any shield resistance values that exceed ten ohms per 1000 feet of cable.

Measure the resistance of conductors connected in parallel, including the resistance of feeder conductors for generators operating in parallel. Investigate deviations in resistance between parallel conductors.

Perform a phasing check on equipment supplied from multiple sources, such as double-ended switchgear, to insure correct bus phasing from each source.

Perform insulation resistance testing of conductors and buses. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for solid-state components. See Annex A for additional information.

Perform infrared survey of equipment and components under maximum load conditions to identify loose connections and other localized heating or hot spots. See Annex A for additional information.

# 5. Testing and Maintenance Requirements

## 5.1 General

Follow the manufacturer equipment-specific instructions for operating, servicing, inspecting, testing, maintaining, repairing, and reconditioning equipment and components, including performing specific inspections and testing as recommended by the manufacturer in addition to the general inspections, testing, and maintenance contained within this Recommended Practice.

Perform testing and maintenance of equipment and components in accordance with manufacturer instructions and in accordance with NFPA 70, NFPA 70B, and NFPA 70E. See Section 3 for additional guidance for electrical safety.

Perform routine inspections in accordance with Section 4.1, and perform periodic inspections in accordance with Section 4.2 prior to testing and maintaining equipment.

Perform testing and maintenance with electrical equipment de-energized unless equipment must be energized to perform specific testing or maintenance requirements. Exercise care when inspecting and testing energized equipment. See Section 3 for additional guidance.

Ensure that any required special tools, equipment, and materials are available for testing and maintaining equipment before beginning testing and maintenance procedures.

Maintain equipment and systems in accordance with manufacturer instructions, including frequency of maintenance based on observations, level of importance of the equipment and system, personnel safety, trending of equipment condition and operating characteristics over time, and experience. Frequent inspections are recommended for newer equipment.

Recommended intervals for cleaning, inspections, maintenance, and testing may be adjusted accordingly for the operating environment, such as duty cycle, ambient temperature, exposure to contaminants, age and condition of the equipment, manufacturer recommendations, and trending established through testing.

Perform as-found testing, if applicable, prior to cleaning. Upon completion of all inspections, cleaning, maintenance, and testing, restore all connections, settings, programming, and equipment to normal operating conditions in accordance with as-found conditions.

Consult the manufacturer for recommendations for any deficiencies identified during inspections, testing, and maintenance. Where the continued operation of equipment is suspected to be hazardous based on identified deficiencies, de-energize equipment and remove from service. Consult the manufacturer for recommendations for repairing or replacing suspect equipment.

Use only manufacturer approved replacement parts and components when making repairs. Ensure that manufacturer listing and labeling requirements are maintained. Recondition equipment in accordance with the NEC and industry standards.

Maintain records of inspections, testing and maintenance activities, along with any repairs, replacements, and adjustments made, for future reference.

Perform testing and maintenance on fixed- or bolted-type circuit breakers with the breaker in place in equipment. Ensure that the equipment and all control circuits are de-energized, locked out, and tagged. Remove drawout type circuit breakers from equipment and place in a secure, convenient location for testing and maintenance. Discharge circuit breaker stored-energy closing mechanisms before testing and maintenance. Follow all applicable lockout/tagout procedures. See Section 3.

## 5.2 Test Equipment

See Annex A for additional requirements for test and measurement equipment, testing procedures, and methodologies.

Maintaining electrical equipment may require special tools and instruments for measurement of the equipment performance. All electrical testing equipment must be of sufficient quality and accuracy to test and/or measure the system performance within tolerance levels specified in the manufacturer specifications and design documents.

Companies providing testing typically provide all tools, material, test instruments, instrumentation, equipment, labor, and technical supervision to perform such tests and inspections. Utilities are typically furnished by the facility.

Test equipment must be calibrated, in good mechanical and electrical condition, and used by qualified operators. Field test metering used to check the calibration of power system meters must be more accurate (a minimum of twice the accuracy) than the instrument being tested. The calibrated accuracy of metering in test equipment must be appropriate for the test being performed. The waveshape and frequency of test equipment output waveforms must be appropriate for the test and for the equipment being tested.

### *5.2.1 Calibration*

Use a regulated, high quality power supply for test equipment during testing, as supply voltage, frequency, and waveform variation can produce invalid results. Operate all equipment in accordance with its instruction manual.

All test equipment and instrumentation used for maintenance must be calibrated according to the manufacturer recommended intervals, and when mishandled, dropped, or damaged. Dated calibration labels or tags must be visible on all test equipment, or calibration certificates must be readily available. Maintain up-to-date testing and calibration records indicating the dates and results of instruments calibrated or tested.

Each testing organization must have a calibration program and documentation that all applicable test instruments are maintained within the required rated accuracy for each test instrument calibrated. Firms providing calibration services must maintain up-to-date instrument calibration instructions and procedures for each test instrument calibrated. The accuracy of test equipment must be traceable to the National Bureau of Standards (NBS) in an unbroken chain.

Ensure that test equipment used for performance verifications during maintenance has been calibrated within one year of its use for testing. Field instruments should be calibrated within 6 months of use for testing. In the absence of other calibration requirements, test instruments should be calibrated in accordance with the following maximum frequency schedule:

- Field instruments: Analog, 6 months maximum. Digital, 12 months maximum.
- Laboratory instruments: 12 months maximum.
- Leased specialty equipment: 12 months maximum.

### *5.2.2 Data Logging*

Use data logging instruments and software as needed to measure the performance of electrical equipment and systems over a specified period of time to ensure that equipment and systems are functioning in accordance with the design intent and specifications. Data logging may require energy management control system trending, standalone data log monitoring, or manual functional testing.

## 5.3 Low Voltage Power Cable (600V or below)

Where installed, inspect aluminum conductors for extrusion and rework terminations, if required, keeping in mind that repeated tightening of loose connections will extrude aluminum conductors and may cause adverse operating conditions. Carefully inspect aluminum-to-copper connections for evidence of corrosion, overheating, or looseness. Rework connections as needed. See NECA 104 for additional information.

Perform insulation resistance testing in accordance with Annex A.

### 5.4 Medium and High Voltage Power Cables (above 600V)

Observe the general condition of cable, terminations, and splices. Inspect taped connections for deterioration or charring of tape. Inspect connectors for damage, overheating, corona, discoloration, and oxidation. *NOTE: Ultrasonic detection and light amplification or night-vision equipment is useful for detecting corona.* Correct sources of damage and repair or replace damaged components in accordance with manufacturer instructions.

Inspect exposed compression-applied connectors for correct cable match and indention. Notify owner of noncompliant connectors.

Inspect cables in manholes for evidence of cable movement, physical damage, and excessive tension. Check cables for evidence of oil leaks and pitting. Inspect the bottom surface of cables for wear or scraping due to movement at the point of entrance into raceways, conduits, ducts, and manholes, and where cables rest on supports. Notify owner of evidence of cable movement.

Inspect manholes for evidence of spalling concrete or other deterioration, both above ground and internally. It may be necessary to pump water from manholes prior to entrance. Inspect and clean drains, where equipped, as necessary. Notify owner of manhole conditions.

Check cable identification tags and markings and compare with record documents and drawings, if available. Repair or replace damaged or missing identification tags and markings.

Where accessible, check the outer jacket of cables and conductors in raceways and cable trays for evidence of movement, abrasion, or other mechanical damage.

Inspect porcelain terminations for chips, cracks, leaks, and signs of tracking. Check tightness of exposed connections. Tighten loose connections. Clean porcelain. Replace damaged porcelain terminations.

Inspect cables, terminations, connections, and splices for swelling of insulation, soft spots, and for evidence of surface tracking or corona. X-ray splices or terminations with soft spots, or disassemble to determine the extent of damage. Repair or replace damaged cables, terminations, connections, and splices in accordance with manufacturer instructions.

Check plastic cable jackets for longitudinal shrinkage from terminations and splices. Jacket shrinkage can result in damage to shielding tapes or stress cones. Consult cable manufacturer for recommendations.

Check all accessible bolted electrical connections for tightness using a calibrated torque wrench. Tighten connections in accordance with manufacturer instructions.

Inspect the cable grounding conductors, metallic sheath bonding, connections, and cable supports for corrosion and tightness. Ensure cable grounding continuity with main grounding system. Inspect the ground braid for corrosion and tight connections.

Perform maintenance testing of medium-voltage cable in accordance with industry standards, contract documents (drawings and specifications), if applicable, and manufacturer instructions.

Maintenance testing consists of withstand testing and other cable diagnostic tests. Withstand tests can be performed as an Alternating Current (AC) voltage test by applying an AC voltage test at the power line frequency (60 Hz) that stresses the cable insulation system by applying an AC voltage waveform similar to what the cable would experience in normal operation, or as a Very Low Frequency (VLF) test by using a VLF test unit using an AC test voltage typically three times the rated voltage or less in the frequency range from 0.01 Hz to 1.0 Hz for a specified time, typically one hour or less. Diagnostic tests for medium-voltage cable include dissipation factor (Tan Delta) testing and Partial Discharge testing.

Perform testing in accordance with power cable consensus Standards and the ICEA, IEC and/or IEEE, and in accordance with Annex A. Evaluate alternative testing methods in selecting the appropriate acceptance test for each given cable installation considering cable performance, failure history, cable system components, cable system composition, system reliability requirements, historical testing data, prior test results, and the impact to operations for a cable to fail while under test. Do not exceed 80% of the cable manufacturer factory test value or the maximum test voltage in Annex A, whichever is less. Keep in mind that the maximum test voltage may be limited by cable terminations or splices that may have lower maximum voltage ratings than the maximum recommended maintenance test voltages.

Ensure that cables are disconnected from equipment and de-energized. Lower test voltages are required when cables remain connected to equipment and accessories. Ensure that the maximum test voltage does not exceed the limits for terminators specified in ANSI/IEEE 48, IEEE 386, or manufacturer specifications. Disconnect and ground surge protective devices (SPDs), potential transformers, and capacitors. Ensure that conductors under test are properly isolated from ground and are guarded against inadvertent contact by personnel. Tie back cables as needed to ensure adequate clearance from any grounded objects.

Test each conductor individually. Test each cable section individually. Ground all conductors and shields and drain wires not under test. Prepare and clean exposed ends of cable prior to testing in order to minimize any leakage current using manufacturer approved materials, such as denatured alcohol or approved equivalent. Terminations must be adequately corona-suppressed by guard ring, field reduction sphere, or other suitable method, as necessary.

Current-sensing circuits in test equipment, when used, must measure only the leakage current associated with the cable under test and must not include internal leakage of the test equipment. If maintenance testing is performed by means of direct current (DC), reduce the test set potential to zero and measure residual voltage at discrete intervals. Apply grounds for a time period adequate to drain all insulation stored charge.

Perform a continuity test on shielded cable by measuring shield resistance. Investigate any breaks in continuity, along with any resistance values in excess of 10 ohms per 320 m (1000 feet) of cable.

Measure insulation resistance for each conductor with all other phase and shield conductors grounded in accordance with Annex A.

Perform partial discharge testing in accordance with Annex A.

Perform Tan-Delta (dissipation factor) testing in accordance with Annex A.

DC high potential, very low frequency (VLF) AC high potential testing, or any other type of withstand or destructive testing is not recommended as a maintenance test on any medium-voltage cable over five years old, and especially XLPE cable that has been in service in a wet environment for more than five years.

Compare all test results to prior test results, if available. Investigate any test results that deviate from prior results under similar conditions by 50% or more. Consult the manufacturer for recommendations.

For damaged cables, repair the damaged section, replace splices or terminations, or replace the entire cable with new in accordance with manufacturer instructions.

For deteriorated cables, consult the cable manufacturer for instructions for chemical injection rejuvenation of cables, keeping in mind that some manufacturers expressly forbid chemical injections.

After re-energizing cables, check for unusual sounds that might indicate partial discharge (corona) or loose connections. Perform infrared survey in accordance with Annex A.

See NECA 600 for additional guidance.

### 5.5 Metal-Enclosed (Medium Voltage) Bus and Low-Voltage Busway

Check the manufacturer labels to verify proper physical orientation of the busway for adequate cooling. Check outdoor busway to verify that weep-hole plugs have been removed, if applicable, and that joint shields have been correctly installed.

Inspect busway joint covers and plug-in covers. Ensure covers are in place and tight to prevent accidental contact with energized busway components.

Verify that busways and connected plug-in devices, raceways, feeders, and equipment are properly grounded, as applicable.

For busways with plug-in devices, check circuit breaker and fusible switch devices for proper operation and maintain in accordance with the applicable Section of this Recommended Practice. Check that plug-in device connecting hardware to the busway is tight to ensure proper grounding. Verify that hook sticks are available for plug-in devices that require hook sticks for their operation.

Inspect bolted connections between bus joints for corrosion and for evidence of arcing between bus joints. Tighten bus joints in accordance with the manufacturer specifications. Inspect busway supports and insulators for evidence of dirt or tracking. Clean dirty insulators and supports. Replace insulators and supports that are cracked or broken or that show signs of tracking.

Measure the insulation resistance of each bus phase-to-phase and each phase-to-ground for a minimum of one minute in accordance with the manufacturer published data and Annex A, with phases not under test grounded. Convert measured insulation resistance values to an equivalent 1000-foot nominal busway run for comparison. Investigate measured resistance values less than the manufacturer recommended minimum values. Do not perform dielectric withstand testing if insulation resistance test results are less than minimum recommended values.

Perform dielectric withstand testing of each phase-to-ground with phases not under test grounded for one minute in accordance with the manufacturer published data and in accordance with Annex A. Follow manufacturer recommended test voltage, or recommendations found in IEEE C37.20.1, Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear, and IEEE C37.23, Standard for Metal-Enclosed Bus and Calculating Losses in Isolated-Phase Bus. Do not exceed 75% of the insulation withstand level of metal enclosed bus. Apply test voltage for one minute. Busway insulation should withstand the overpotential test voltage applied.

Perform contact resistance test on each connection point of uninsulated busway. On insulated busway, measure resistance of assembled busway sections and compare values with adjacent phases. See Annex A for additional information.

Perform on-line partial discharge testing in accordance with Annex A. Partial discharge testing results should be in accordance with the manufacturer published data.

After energizing busway, perform infrared survey of all accessible bus joints and cable connections while maintaining maximum load on the bus for at least one hour, or until temperature has stabilized, to detect loose or high resistance connections and other circuit anomalies. See Annex A for additional information.

See NECA 408 for additional guidance.

### 5.6 Fiber Optic Cables

Inspect fiber optic cables for evidence of physical and mechanical damage. Check that cable bending radius is greater than the manufacturer recommended minimum bending radius. Replace damaged cables.

Verify that all fiber optic cable connectors, termination, and splices are suitable for the application and installed environment, and are installed in accordance with industry-accepted standards. Replace suspect cables, connectors, terminations, and splices as needed.

Using an optical time domain reflectometer (OTDR), measure cable length, inspect for fiber fractures and construction defects, and perform connector and splice integrity tests. Review the reflected power/distance graph for evidence of cable backscatter and for excessive connection or splice attenuation. Replace suspect cables, connectors, terminations, and splices as needed.

Using an optical power loss test set, measure cable attenuation loss. Measure connector and splice attenuation loss from both ends of the optical cable. Attenuation losses should be within the site-specific requirements. If no site-specific requirements are provided, attenuation losses should be within manufacturer recommendations.

Measure transmit and receive power levels from remote and local devices. Compare transmit and receive power levels to prior test results and with the manufacturer published data.

## 5.7 Dry-Type Transformers

Consider the transformer enclosure energized until the case-ground connection is inspected and found to be adequate. Inspect the case ground for corrosion or a loose connection.

Maintain winding temperatures above ambient to prevent condensation in the transformer windings. If dry-type transformers are permitted to cool to ambient temperature, or for dry-type transformers operating in a high humidity environment, it may be necessary to dry the transformer before re-energizing and returning to operation. Refer to manufacturer instructions and NECA 409 for drying procedures.

Sealed dry-type transformers require special procedures and equipment for opening the transformer, drying out the windings, purging and refilling the tank, and repairing seals. Maintain, service, and repair sealed dry-type transformers in accordance with manufacturer instructions.

Perform an insulation resistance test and calculate dielectric absorption or polarization index in accordance with Annex A. Perform testing for each winding-to-winding and on each winding-to-ground. Minimum insulation resistance values should be in accordance with the manufacturer published data or Annex A. Investigate any insulation resistance test results below recommended values. Compare dielectric absorption or polarization index results to prior results. Dielectric absorption or polarization index should not be less than 1.0.

Perform a turns-ratio test at the connected as-found tap position using a turns-ratio test set. Verify that the tap setting is appropriate for the connected primary voltage. Turns-ratio test results should not deviate more than one-half percent from either the adjacent coils or from the calculated nameplate ratio,

Perform the following additional inspections, maintenance, and tests for all transformers with windings rated higher than 600V, all single-phase transformer rated higher than 167 kVA, and all three-phase transformers rated higher than 500 kVA.

Where installed, verify proper operation of auxiliary devices, such as cooling fans and controls, alarms, indicators, and tap changers, in accordance with the manufacturer recommendations for operating ranges. Test the temperature control panel and verify alarm settings on temperature indicators, and test interlocks for shutdown. Adjust settings in accordance with manufacturer instructions as needed. Verify that cooling fan motors have correct overcurrent protection.

Perform insulation power factor or dissipation factor tests on all windings rated greater than 2500V, each winding to ground and each winding to every other winding, in accordance with test equipment manufacturer instructions and Annex A. Primary winding and secondary winding power factor and dissipation factor test results will vary due to differences in supports, insulators, and bus work used in manufacturing dry-type transformers. Consult the transformer and test equipment manufacturer published data for additional information.

Perform excitation current tests in accordance with test equipment manufacturer published data and Annex A. Typical excitation current test data pattern for a three-legged core transformer is two similar current readings and one lower current reading.

Measure winding resistance at the connected tap position. Compare temperature-corrected winding resistance values to prior test results. Consult the manufacturer if temperature-corrected winding resistance test results vary more than 1% from prior test results.

Perform core insulation resistance test. If the transformer core is insulated and the core ground strap is removable, remove the core ground strap and measure the insulation resistance of the transformer core at 500VDC. Core insulation resistance values should be comparable to factory test results, but not less than 1.0 megohm at 500VDC. See Annex A for additional information.

Verify the presence of surge protective devices. Maintain surge protective devices in accordance with Sections 5.47 and 5.48 as applicable.

Verify secondary phase to phase and phase to neutral voltages after re-energization and prior to loading, and under normal load operating conditions. Phase-to-phase and phase-to-neutral voltages should be consistent with the transformer nameplate information.

Perform on-line partial discharge testing on each winding rated higher than 600V in accordance with Annex A. Partial discharge testing results should be in accordance with the manufacturer published data.

See NECA 409 for additional guidance.

## 5.8 Liquid-Filled Transformers

Consider the transformer enclosure energized until the case-ground connection is inspected and found to be adequate. Inspect the case ground for corrosion or a loose connection. Measure the resistance of the transformer grounding electrode in accordance with Section 5.44.

Clean the transformer bushings and control cabinets, if applicable.

Where installed, verify proper operation of alarm, control and trip circuits and settings from temperature and level indicators, pressure relief device, and fault pressure relay in accordance with the manufacturer recommendations for operating ranges.

Where installed, verify that cooling fans and/or pumps operate correctly and that fan and pump motors have correct overcurrent protection.

Verify that gas-blanketed transformers have positive pressure. Add gases when needed in accordance with manufacturer instructions.

Verify the presence of surge protective devices. Maintain surge protective devices in accordance with Sections 5.47 and 5.48 as applicable.

Measure resistance through bolted electrical connections using a low-resistance ohmmeter. See Annex A for additional information.

Measure the contact/pole resistance at each tap setting of load tap changers at all positions, and at the as-found setting of no-load tap changers, if so equipped. See Annex A for additional information. Maintain load tap-changers in accordance with Section 5.9, if so equipped.

Perform an insulation resistance test and calculate dielectric absorption or polarization index on all transformers in accordance with Annex A. Perform testing for each winding-to-winding and on each winding-to-ground. Minimum insulation resistance values should be in accordance with the manufacturer published data or Annex A. Investigate any insulation resistance test results below recommended values. Compare dielectric absorption or polarization index results to prior results. Dielectric absorption or polarization index should not be less than 1.0.

Perform a turns-ratio test on each winding at the as-found no-load tap position and on all load tap-changer positions using a turns-ratio test set. Verify that the no-load tap setting is left in the as-found position. Verify that winding polarities are in accordance with nameplate data. Turns-ratio test results should not deviate more than one-half percent from either the adjacent coils or the calculated nameplate ratio.

Perform insulation power factor or dissipation factor tests on all windings, each winding to ground and each winding to every other winding, in accordance with test equipment manufacturer instructions and Annex A. Correct maximum power-factor or dissipation-factor values to 20°C (68°F). Results should be in accordance with the transformer manufacturer published data.

Perform a power factor test on transformer bushings rated above 600V that are equipped with power factor taps, or perform hot collar watts-loss test on bushings that are not equipped with power factor taps, in accordance with Annex A.

Perform excitation current tests in accordance with test equipment manufacturer published data and Annex A. Typical excitation current test data pattern for a three-legged core transformer is two similar current readings and one lower current reading.

Measure winding resistance at the connected tap position. Compare temperature-corrected winding resistance values to prior test results. Consult the manufacturer if winding resistance measurements vary more than 2% from prior test results.

Perform core insulation resistance test. Core insulation resistance values should be comparable to prior test results, but not less than 1.0 megohm at 500VDC. See Annex A for additional information.

Test for the presence of oxygen in the transformer gas blanket, if applicable. Investigate the presence of any oxygen in the gas blanket.

Remove a sample of insulating liquid and perform dissolved-gas analysis (DGA) and other tests in accordance with Annex A. Insulating liquid must comply with manufacturer instructions and recognized national standards. Recondition, reclaim, or replace transformer insulating liquid in accordance with manufacturer instructions.

For large power transformers, remove a sample of insulating liquid and analyze the metal content. Metal content should comply with manufacturer instructions and recognized national standards. Consult the manufacturer for recommendations for excess metal content.

Where installed, test transformer neutral grounding impedance devices. Compare grounding impedance device test results to prior test results, if available, and/or to manufacturer published data.

Consult the manufacturer for recommendations when testing results indicate internal problems.

See NECA 410 for additional guidance.

## 5.9 Load Tap-Changers

Record the position indicator as-found, along with the maximum and minimum values. Inspect the general condition. Verify proper operation of the automatic load tap changer mechanism, motor, and drive train. The mechanism, motor, and drive train should operate in accordance with the manufacturer specifications and design intent. Verify proper operation of the automatic motor cutoff at maximum lower and maximum raise. The automatic motor cutoff should operate properly at the maximum lower and maximum raise positions.

Record the as-found and as-left operation counter readings. Verify that the operations counter has an incremental change in accordance with the tap changer operation, typically advancing incrementally per operation. Follow the manufacturer instructions on maintenance and number of operations between contact replacements.

Verify that the load tap changer is properly grounded. Verify that ground connections are tight.

Verify proper operation of auxiliary devices, if so equipped. Auxiliary device operation should be in accordance with the manufacturer specifications and design intent.

Verify that wear/erosion indicators on vacuum bottles are within manufacturer recommended tolerances. Consult the manufacturer for recommendations for deficiencies.

Measure the contact/pole resistance at each tap setting of load tap changers at all positions. See Annex A for additional information.

Perform insulation resistance tests in any off-neutral position using voltage levels in accordance with manufacturer instructions. Consult the manufacturer for recommendations when insulation resistance values are less than the manufacturer published data. See Annex A for additional information.

Measure the transformer turns-ratio at all tap positions using a turns-ratio test set. The turns-ratio should not deviate more than one-half percent from the calculated voltage ratio. Consult the manufacturer for recommendations for any deficiencies.

Perform vacuum bottle integrity (overpotential) testing across each vacuum bottle with the contacts in the open position in strict accordance with the manufacturer published data. Do not exceed the maximum voltage recommended by the manufacturer for this test. *NOTE: Some DC high-potential test sets are half wave rectified and may produce peak voltages in excess of the vacuum bottle manufacturer recommended maximum.* See Annex A for additional information. Provide adequate barriers and protection against X-ray radiation during this test. Do not perform this test unless the contact gap of each interrupter is within manufacturer tolerances. The vacuum bottle must withstand the overpotential voltage applied.

Remove a sample of insulating liquid and perform dissolved-gas analysis (DGA) and other tests in accordance with Annex A. Insulating liquid must comply with manufacturer instructions and recognized national standards. Recondition, reclaim, or replace insulating liquid in accordance with manufacturer instructions.

When recommended by the manufacturer, perform an internal inspection of load tap changers in accordance with manufacturer instructions. Clean carbon residue and debris from the compartment. Inspect contacts for wear and alignment. Contact wear and alignment should be within manufacturer recommended tolerances. Replace damaged or worn contacts in accordance with manufacturer instructions. Torque all electrical and mechanical connections to manufacturer recommended tightness using a calibrated torque-wrench. Inspect the tap-changer compartment terminal board, contact support boards, and insulated operating components for evidence of moisture, cracks, excessive wear, breakage, and/or signs of electrical tracking. No evidence of moisture, cracks, excessive wear, breakage, or electrical tracking should be found. Clean, repair, or replace contaminated or damaged components. Verify that the tap changer operates properly by electrically operating the tap-changer through the full range of taps. Consult the manufacturer for recommendations for any deficiencies.

## 5.10 Step Voltage Regulators

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Maintain load tap changers in accordance with Section 5.9.

Record the position indicator as-found, along with the maximum and minimum values.

Clean step voltage regulators.

Verify proper operation of auxiliary devices. Auxiliary devices should operate in accordance with system design.

Verify correct operation of the motor, drive train, and automatic motor cutoff at maximum lower and maximum raise positions. Motor, drive train, and automatic cutoff should operate in accordance with the manufacturer design intent. Automatic motor cutoff should operate at maximum lower and maximum raise positions.

Perform specific inspections, mechanical tests, special tests, and adjustments as recommended by the manufacturer.

Perform insulation resistance tests on each winding-to-ground in any off-neutral position using voltage levels in accordance with manufacturer instructions. Consult the manufacturer for recommendations when insulation resistance values are less than the manufacturer published data. See Annex A for additional information. Calculate the polarization index.

Perform insulation power factor or dissipation factor tests on winding insulation in accordance with test equipment manufacturer instructions and Annex A. Correct maximum power-factor or dissipation-factor values to 20°C (68°F). Results should be in accordance with the manufacturer published data.

Perform a power factor test on bushings that are equipped with power factor taps, or perform hot collar watts-loss test on bushings that are not equipped with power factor taps, in accordance with Annex A.

Measure winding resistance of the source windings at the neutral position. Measure the winding resistance of the load windings at all tap positions. Compare temperature-corrected winding resistance values to prior test results. Consult the manufacturer if temperature-corrected winding resistance test results vary more than 2% from the test results of adjacent phases.

For step voltage regulators that have a separate tap-changer compartment, test for the presence of oxygen in the nitrogen gas blanket in the main tank. Investigate the presence of any oxygen in the nitrogen gas blanket.

Perform a turns-ratio test at each voltage step position using a turns-ratio test set. Verify that the tap position indicator correctly identifies each tap position. Turns-ratio test results should maintain a normal deviation between each voltage step and should not deviate more than one-half percent from either the adjacent coils or the calculated nameplate ratio,

Verify the operation accuracy of the voltage range limiter. The voltage range limiter should operate within the manufacturer recommended tolerances.

Verify the proper operation and accuracy of the bandwidth, time delay, voltage, and line-drop compensation adjustments of the tap-changer control device. The accuracy of the bandwidth, time-delay, voltage, and live drop compensation adjustments should be as specified.

Remove a sample of insulating liquid from the main tank, common tank, and/or tap-changer tank and perform dissolved-gas analysis (DGA) and other tests in accordance with Annex A. Compare results of dissolved-gas analysis to previous test results. Insulating liquid must comply with manufacturer instructions and recognized national standards. Recondition, reclaim, or replace transformer insulating liquid in accordance with manufacturer instructions.

When warranted, perform internal inspections in accordance with manufacturer instructions. Remove insulating liquid. Clean debris and clean carbon residue from the tank. Inspect contacts for wear, pitting, or erosion. Check contact pressure and alignment. Contact alignment and wear should be within manufacturer recommendations for continued service. Check all bolted electrical and mechanical connections for tightness using a calibrated torque tool. Tighten connections in accordance with manufacturer instructions. Inspect the tap-changer compartment terminal board, contact support boards, and insulated operating components for evidence of moisture, cracks, excessive wear, breakage, and/or signs of electrical tracking. No evidence of moisture, cracks, excessive wear, breakage, or electrical tracking should be found. Clean, repair, or replace contaminated or damaged components. Verify that the tap changer operates properly by electrically operating the tap-changer through the full range of taps. Consult the manufacturer for recommendations for any deficiencies. Replace all gaskets and seal the compartment. Refill the compartment with approved new or filtered insulating liquid to correct levels.

## 5.11 Induction Regulators

Record the position indicator as-found, along with the maximum and minimum values.

Verify proper operation of auxiliary devices. Auxiliary devices should operate in accordance with system design.

Verify correct operation of the motor, drive train, and automatic motor cutoff at maximum lower and maximum raise positions. Motor, drive train, and automatic cutoff should operate in accordance with the manufacturer design intent. Automatic motor cutoff should operate at maximum lower and maximum raise positions.

Perform specific inspections, mechanical tests, special tests, and adjustments as recommended by the manufacturer.

Perform insulation resistance tests from each winding-to-winding and each winding-to-ground in accordance with Annex A. Calculate polarization index. Minimum insulation resistance values should be in accordance with the manufacturer published data or Annex A. Investigate any insulation resistance test results below recommended values. Compare polarization index results to prior results. Polarization index should not be less than 1.0.

Perform insulation power factor or dissipation factor tests on winding insulation in accordance with test equipment manufacturer instructions and Annex A. Correct maximum power-factor or dissipation-factor values to 20°C (68°F). Results should be in accordance with the manufacturer published data.

Perform a power factor test on bushings that are equipped with power factor taps, or perform hot collar watts-loss test on bushings that are not equipped with power factor taps, in accordance with Annex A.

Verify that the voltage regulation is a linear ratio throughout the range between the maximum raise and the maximum lower positions.

Verify that the indicator identifies the neutral position correctly.

Measure winding resistance of each winding. Compare temperature-corrected winding resistance values to prior test results. Consult the manufacturer if temperature-corrected winding resistance test results vary more than 2% from the test results of adjacent phases.

For liquid-filled induction regulators, remove a sample of insulating liquid and perform dissolved-gas analysis (DGA) and other tests in accordance with Annex A. Compare results of dissolved-gas analysis to previous test results. Insulating liquid must comply with manufacturer instructions and recognized national standards. Recondition, reclaim, or replace insulating liquid in accordance with manufacturer instructions.

For liquid-filled induction regulators, test for the presence of oxygen in the nitrogen gas blanket. Investigate the presence of any oxygen in the nitrogen gas blanket.

## 5.12 Dry-Type Reactors (Shunt and Current-Limiting)

Verify that tap connections are as specified, if applicable.

Perform an insulation resistance test from winding to ground using voltage levels in accordance with manufacturer instructions. Consult the manufacturer for recommendations when insulation resistance values are less than the manufacturer published data. See Annex A for additional information.

Measure winding resistance. Consult the manufacturer for recommendations if winding resistance test results vary more than 1% from factory tests. See Annex A for additional information.

## 5.13 Liquid-Filled Reactors (Shunt and Current-Limiting)

Verify the settings and proper operation of all temperature devices, if so equipped. Verify that cooling fans and pump motors operate properly and have the correct overcurrent protection, if so equipped. The operation of temperature devices, cooling fans, and pumps should be in accordance with the manufacturer recommendations and system requirements.

Verify the proper operation of all alarm, control, and trip circuits from temperature indicators, level indicators, pressure relief device, and fault pressure relays, if so equipped. Consult the manufacturer for recommendations for any deficiencies.

Verify that nitrogen-blanketed reactors have positive pressure. Investigate the cause of zero pressure or negative pressure gauge readings. Measure the percentage of oxygen in the nitrogen gas blanket. Investigate the cause of any oxygen present in the nitrogen gas blanket. Filter and/or add nitrogen when needed in accordance with manufacturer instructions.

Verify that the tap connections are as specified and are appropriate for the system in accordance with nameplate ratings.

Perform an insulation resistance test from winding to ground using voltage levels in accordance with manufacturer instructions. Calculate polarization index. Consult the manufacturer for recommendations when insulation resistance values are less than the manufacturer published data. Compare the polarization index to prior test results. Polarization index should be greater than 1.0. See Annex A for additional information.

Perform insulation power factor or dissipation factor tests on windings in accordance with the test equipment manufacturer instructions. Perform a power factor test on bushings that are equipped with power factor taps, or perform hot collar watts-loss test on filled bushings that are not equipped with power factor taps, in accordance with the test equipment manufacturer published data. The maximum power factor or dissipation factor values of windings should be in accordance with the manufacturer published data or the test equipment manufacturer published data. The power factor or dissipation factor and capacitance values of bushings should be within 10% of the nameplate rating. For hot collar tests, compare the milliampere/milliwatt loss to results from similar bushings. See Annex A for additional information.

Measure winding resistance. Consult the manufacturer for recommendations if winding resistance test results vary more than 2% from factory tests. See Annex A for additional information.

Remove a sample of insulating liquid and perform dissolved-gas analysis (DGA) and other tests in accordance with Annex A. Insulating liquid must comply with manufacturer instructions and recognized national standards. Recondition, reclaim, or replace insulating liquid in accordance with manufacturer instructions.

## 5.14 Capacitors

Capacitors may be a source of power quality issues, including the potential for harmonic resonance. See NECA 702 for information regarding monitoring and mitigating such power quality issues.

Examine capacitor enclosures for discoloration, leaks, distortion, bulges, swelling, and rupture. Replace liquid-filled capacitors that are bulging or leaking.

Clean the capacitor case, insulating bushings, and any connections that are dirty or corroded in accordance with manufacturer instructions. Remove any obstructions from capacitor housing ventilation openings, if so equipped.

Verify that capacitors are electrically connected in an appropriate configuration for the system in accordance with nameplate ratings.

Check voltage balance while capacitors are energized. Investigate blown fuses on one phase of a three-phase capacitor bank as a source of voltage imbalance. Investigate the cause of blown fuses. Consult the manufacturer for recommendations.

Perform a continuity check on capacitor fuses. Replace blown fuses with the type recommended by the manufacturer. Do not remove fuses until the capacitor has been fully discharged. Investigate the cause of blown fuses. Consult the manufacturer for recommendations.

Measure the ground and/or neutral current, and determine the phase and neutral current harmonic content under load. Consult the manufacturer for recommendations when harmonic currents are found.

Perform insulation resistance tests on each capacitor from the phase terminal to ground and from the phase terminal to the case for a minimum of one minute using voltage levels in accordance with manufacturer instructions. Minimum resistance levels should be in accordance with the manufacturer published data. See Annex A for additional information.

Measure the capacitance of all terminal combinations. Investigate values that differ from the manufacturer published data.

Measure the resistance of capacitor internal discharge resistors. Investigate values that differ from the manufacturer published data. Verify that the capacitor residual voltage is reduced to 50V or less in one minute for capacitors rated 600V and less, and in five minutes for capacitors rated greater than 600V after being de-energized.

## 5.15 Switchgear and Switchboard Assemblies Rated 1200A or Greater

Check that wiring is supported, secured, and physically protected to prevent damage from the routine operation of moving parts. Check that wiring connections and terminations are tight.

Check for signs of dielectric stress on insulating members, such as evidence of corona erosion, markings, or tracking paths in the following specific areas:

- Locations of physical contact between adjoining insulators.
- Locations of physical contact between an insulator and the grounded metal structure.
- Splices or junctions that are taped or filled with compound.
- Insulating surfaces that bridge between phases or between phases and ground.
- Normally hidden surfaces, including the edges of sheet metal slots used for routing bus bars between sections, and the adjacent edges between the upper and lower members of split-type bus supports.
- The edges of insulation mounting hardware, such as bolts, nuts, and washers.

*NOTE: Ultrasonic detection and light amplification or night-vision equipment is useful for detecting corona.*

Perform an insulation resistance test on each bus section phase-to-phase and phase-to-ground for one minute in accordance with manufacturer instructions and Annex A. *NOTE: When performing dielectric tests, disconnect all instrument and control transformers, lightning arrestors, surge protective devices (SPDs), digital meters and relays, and other sensitive electronic equipment that may cause erroneous results or cause damage to equipment that is not rated in accordance with switchgear or switchboard industry standards.* Apply test voltage for one minute. Minimum resistance levels should be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests of control power transformers from winding-to-winding and each winding-to-ground in accordance with the manufacturer published data and Annex A. Control power transformer insulation resistance test results should be in accordance with the manufacturer published data or Annex A for liquid-filled or dry-type transformers. Investigate insulation resistance test results less than the manufacturer published data or Annex A.

After achieving acceptable insulation resistance test results, perform dielectric withstand testing on each bus section phase-to-phase and phase-to-ground with phases not under test grounded in accordance with the manufacturer published data and Annex A. Apply the test voltage for one minute. Switchgear and switchboards are considered to have passed the test if no evidence of distress or insulation failure is observed by the end of the test.

Perform ground resistance testing in accordance with Section 5.44.

Maintain instrument transformers in accordance with Section 5.40.

Maintain protective and control relays and metering devices in accordance with Section 5.41. Verify the proper operation of control transfer relays located in switchgear with multiple control power sources.

Maintain surge protective devices in accordance with Sections 5.47 and 5.48 as applicable.

Perform on-line partial discharge testing in accordance with Annex A. Partial discharge testing results should be in accordance with the manufacturer published data.

Functionally test source transfer controls, when so equipped. Functionally test generator controls, including parallel operation, in accordance with Section 5.52, when so equipped.

Perform infrared survey in accordance with Annex A. Identify all hot spots, and promptly correct sources of heating problems.

Maintain station batteries and battery chargers in accordance with Section 5.59.

See NECA 400 and NECA 430 for additional guidance.

## 5.16 Panelboards

Verify that wiring connections are tight. Verify that wiring is supported and secured to prevent damage to connections and terminals.

Measure and record current readings on all phase conductors and the grounded conductor or neutral using a true RMS ammeter. Check all panelboards for proper load balance between phase conductors and adjust the loads as necessary to bring unbalanced phases within 20% of the average load current. Update conductor and circuit identification and the panel schedule as needed after load balancing.

Perform an insulation resistance test on each bus phase-to-phase, and phase-to-ground in accordance with manufacturer instructions and Annex A. Apply test voltage for one minute. Minimum resistance levels should be in accordance with the manufacturer published data.

Perform infrared survey in accordance with Annex A. Perform infrared survey after each panel has been operating with maximum load for at least one hour or until the temperature has stabilized. Identify all hot spots, and promptly correct sources of heating problems.

Maintain surge protective devices in accordance with Section 5.47.

See NECA 407 for additional guidance.

## 5.17 Motor Control Centers (MCCs)

Clean bus bars, conductors, supports, insulators, terminals, and other major insulating surfaces and other parts with clean, dry, lint-free cloths or soft-bristled brushes. Do not use chemicals or petroleum-based solvents on plastics or insulating materials, since these may degrade plastics or insulating materials. Do not use liquids, solvents, or detergents when cleaning MCCs or components. Avoid blowing dust into MCCs when cleaning. Do not use a blower or compressed air to clean MCCs.

Remove dust, soot, grease, moisture, and foreign material from the surface of circuit breakers, adjustable speed drives, and other internal MCC components. Thoroughly clean fusible switches inside and outside.

Check for signs of dielectric stress on insulating members, such as evidence of corona erosion, markings, or tracking paths in the following specific areas:

- Locations of physical contact between adjoining insulators.
- Locations of physical contact between an insulator and the grounded metal structure.
- Splices or junctions that are taped or filled with compound.
- Insulating surfaces that bridge between phases or between phases and ground.
- Normally hidden surfaces, including the edges of sheet metal slots used for routing bus bars between sections, and the adjacent edges between the upper and lower members of split-type bus supports.
- The edges of insulation mounting hardware, such as bolts, nuts, and washers.

*NOTE: Ultrasonic detection and light amplification or night-vision equipment is useful for detecting corona.*

Perform an insulation resistance test on each bus section phase-to-phase and phase-to-ground in accordance with manufacturer instructions and Annex A. *NOTE: When performing dielectric tests, disconnect all instrument and control transformers, lightning arrestors, surge protective devices (SPDs), digital meters and relays, and other sensitive electronic equipment that may cause erroneous results or cause damage to equipment that is not rated in accordance with switchgear or switchboard industry standards.* Apply test voltage for one minute. Minimum resistance levels should be in accordance with the manufacturer published data. See Annex A for additional information.

After achieving acceptable insulation resistance test results, perform dielectric withstand testing on each bus section phase-to-phase and phase-to-ground with phases not under test grounded in accordance with the manufacturer published data and Annex A. Apply the test voltage for one minute. MCCs are considered to have passed the test if no evidence of distress or insulation failure is observed by the end of the test.

Perform on-line partial discharge testing in accordance with Annex A. Partial discharge testing results should be in accordance with the manufacturer published data.

Maintain motor control center starters and switches in accordance with Sections 5.18 or 5.19 as applicable.

Maintain motor control circuit breakers in accordance with Sections 5.24, 5.25, 5.27, 5.28, or 5.29 as applicable.

Maintain surge protective devices in accordance with Sections 5.47 and 5.48 as applicable.

After re-energizing, perform infrared survey in accordance with Annex A. Identify all hot spots and correct sources of heating problems promptly.

See NECA 402 for additional guidance.

## 5.18 Low-Voltage Motor Starters

Inspect contactors. Check for loose terminal or thermal element connections, and signs of overheating. Verify proper mechanical operation. Check and adjust motor starter contact gap, wipe, alignment, and pressure in accordance with the manufacturer published data. Adjust as needed in accordance with manufacturer instructions.

Remove dust or other fine particles in electromechanical contactors by vacuuming, wiping with a clean, dry cloth, or brushing with a soft bristle brush. Do not scrape, file, or otherwise abrade insulating surfaces of contactors.

Inspect contactor contacts for excessive wear, burning, unusual pitting, or other erosion of the contact surface, and for beads of molten material. *NOTE: Contacts will be pitted from normal operation.* Do not file, burnish, or otherwise dress normally pitted contacts. Replace contactors with unusually pitted, spattered, or excessively worn contacts, or replace individual contacts with manufacturer approved components in accordance with manufacturer instructions. Replace all contacts of multipole devices to avoid misalignment or uneven contact pressure.

Inspect arc chutes and arc hoods of electromechanical contactors. Replace arc chutes and arc hoods if they are damaged, broken, or deeply eroded.

Inspect relay and contactor solenoids for excessive noise, which may indicate an overvoltage or undervoltage condition, failure to properly seat, or a broken or loose coil. Investigate and correct causes of noisy solenoids. Replace solenoids that show signs of overheating, such as melted coil insulation or cracked or burned insulation. Clean or replace any parts or components that are damaged.

Test motor overload protective devices in accordance with manufacturer instructions and manufacturer published data. Verify that overload element ratings are correct for their application. If motor overload protection is provided by fuses, verify correct fuse ratings considering power factor improvement capacitors that are installed downstream of the fuses. Verify that adjustable or programmable device settings are in accordance with the protective device coordination study, if available, provided by others.

Test overload elements using primary injection current. Compare with the manufacturer curves for performance. Replace overload elements that operate outside of the manufacturer curves or that show signs of excessive heating. See Annex A for additional information.

Determine and correct the cause of motor overload relay operation during motor operation before resetting the relay. Failure of the motor overload relay thermal element (heater) can occur when the element is subjected to short-circuit currents. Replace failed relays.

Do not replace or adjust the thermal element of motor overload relays to a higher setting without taking into account the ambient temperature of both the motor and the motor controller, and the motor full load current and service factor found on the motor nameplate, along with the proper manufacturer thermal element selection and application charts.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the starter closed and overload relays in the open position, and across each open pole for one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for solid-state components. See Annex A for additional information.

Maintain circuit breakers in accordance with Section 5.24.

Maintain switches and fuseholders in accordance with Section 5.31.

Perform infrared survey in accordance with Annex A.

## 5.19 Medium-Voltage Motor Starters

Inspect contactors. Verify proper mechanical operation. Check for loose terminal or thermal element connections, and signs of overheating. Check and adjust motor starter contact gap, wipe, alignment, and pressure in accordance with the manufacturer published data. Adjust as needed in accordance with manufacturer instructions.

Test motor protective devices in accordance with manufacturer instructions and manufacturer published data. Verify proper motor overload protection by comparing with the motor nameplate information. Set adjustable or programmable devices in accordance with the protective device coordination study, if available, provided by others.

Perform insulation resistance tests on contactors phase-to-phase, phase-to-ground, and across open contacts for one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for solid-state components. See Annex A for additional information.

Perform magnetic atmospheric condition (MAC) testing of each vacuum interrupter in accordance with Annex A.

Perform vacuum bottle integrity (overpotential) testing across each vacuum bottle with the contacts in the open position in strict accordance with the manufacturer published data. Do not exceed the maximum voltage recommended by the manufacturer for this test. *NOTE: Some DC high-potential test sets are half wave rectified and may produce peak voltages in excess of the vacuum bottle manufacturer recommended maximum.* See Annex A for additional information. Provide adequate barriers and protection against X-ray radiation during this test. Do not perform this test unless the contact gap of each interrupter is within manufacturer tolerances. The interrupter must withstand the overpotential voltage applied.

Perform contact resistance testing in accordance with Annex A.

Measure the resistance of the blowout coil circuit. Resistance values should be in accordance with the manufacturer published data.

Energize each contactor using an auxiliary source. Adjust the armature to minimize vibration during operation, where applicable.

Perform insulation resistance tests of control power transformers from winding-to-winding and each winding-to-ground in accordance with the manufacturer published data and Annex A. Control power transformer insulation resistance test results should be in accordance with the manufacturer published data or Annex A for liquid-filled or dry-type transformers. Investigate insulation resistance test results less than the manufacturer published data or Annex A.

Maintain starter transformers in accordance with Section 5.6, if applicable.

Maintain starter reactors in accordance with Section 5.12, if applicable.

Maintain motor protection devices in accordance with manufacturer instructions and published data. In the absence of manufacturer instructions and data, maintain in accordance with Section 5.41.

Maintain instrument transformers in accordance with Section 5.40.

## 5.20 Variable Frequency Drives (VFDs)

VFDs may be a source of power quality issues, including harmonics. See NECA 702 for information regarding monitoring and mitigating power quality issues.

Operate, test, maintain, repair, and calibrate VFDs in accordance with manufacturer instructions and detailed test procedures. Record any changes to the software programming for future reference.

Ensure vent path openings of VFDs are free from debris and that heat transfer surfaces are not fouled by oil, dust, or dirt.

Verify that all electrical connections are tight. Verify correct connections of circuit boards, wiring, disconnects, and ribbon cables. Verify correct fuse sizing in accordance with the manufacturer published data.

Measure and record the input phase currents and phase-to-phase voltages. Phase currents should be within the VFD nameplate rating. Voltages should be balanced within 3% of the average and within 10% of the VFD nameplate rating.

Calibrate VFDs to the system's minimum and maximum speed control signals. Check that adjustable parameters match the settings provided by the owner, if applicable. Test and record output voltage and current while the drive is at 25%, 50%, and 100% of rated speed with the attached load. Observe for balance and performance within manufacturer specifications.

Verify correct settings for motor running protection. Compare the overcurrent set points with the motor full-load current. Where VFDs are used to operate several motors, compare the individual overload element ratings with motor full-load current ratings. Apply minimum and maximum speed set points. Confirm set points are within limitations of the load coupled to the motor.

Start and run the VFD while observing the test, metering, and fault indicators, if so equipped. Activate the various safety devices, when possible, to ensure proper operation. Test and calibrate relays in accordance with Section 5.41. Calibrate relays and test parameters for input phase loss protection, input overvoltage protection, output phase rotation, over-frequency protection, drive overload protection, over-temperature protection, DC overvoltage protection, and fault alarm outputs.

Perform operational tests of VFDs by initiating control devices. Slowly vary VFD speed between minimum and maximum speeds. Observe the motor and load for unusual noise or vibration. Program VFDs to skip frequencies that cause excessive noise or vibration, when possible. Verify proper VFD operation from all remote start/stop and speed control signals.

Check and program all the necessary software parameters such as acceleration time, deceleration time, application (constant torque, variable torque), carrier frequency, motor voltage, and motor overload protection level in accordance with manufacturer instructions.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for solid-state components. See Annex A for additional information. Verify the tightness of all control connections.

Test the motor overload relay elements by primary current injection through the overload circuit and monitoring trip time of the overload element. Overload test trip times at 300% of overload element rating should be in accordance with the manufacturer published time-current curve. See Annex A for additional information.

Test the VFD input circuit breaker by primary current injection in accordance with Section 5.24.

## 5.21 AC Synchronous Machines (Motors and Generators)

When invasive cleaning is required due to extensive internal contamination, clean synchronous machines and dry in accordance with NFPA 70B and manufacturer instructions. Repair or replace all corroded parts and components.

Check for loose items such as shaft keys, couplings, and cooling fans.

Inspect air baffles and filter media. Clean air passages and clean or replace filter media as needed. Clean external motor surfaces.

Inspect cooling fans. Cooling fans should be intact, operational, and securely attached.

Inspect rotor, stator core, and stator windings. The rotor field winding should be clean with no evidence of burning, movement of coils on poles, or cracks in insulation or pole washers. The stator core should be clean with no ventilation duct blockage, loose laminations, burning, or evidence of rubbing contact with the rotor. The stator winding should be clean with no evidence of overheating, cracking, tracking, or surface partial discharge.

Inspect insulating surfaces for cracks, crazing, flaking, powdering, or other evidence of degradation. Consult the manufacturer for recommendations for restoring degraded insulation, such as applying one or more coats of air-drying varnish.

Inspect the windings for evidence of moisture, oil, or grease. If necessary, thoroughly clean windings with a solvent solution in accordance with manufacturer instructions. Dry the motor in accordance with manufacturer instructions.

Inspect slip rings, brushes, and brush rigging for any evidence of mis-operation, such as sparking or chatter of brushes in the holder. Check brush holders for fit, free play, or end play, and for staggering to prevent grooving of the rings during operation. Replace brushes that are excessively worn, such as worn down to the brush rivet. Brush faces should be free of chipped toes or heels and heat cracks. Replace any damaged brushes.

Check that brush shunts are properly secured to the brushes and holders. Verify that the correct grade of brush is used in accordance with the manufacturer recommendations. Check that slip ring wear and brushes are within manufacturer tolerances for continued use. Brush rigging should be intact. Tighten brush studs that might have become loose from the drying and shrinking of insulating washers. Check brush spring pressure using the spring balance method. Adjust spring pressure in accordance with manufacturer instructions.

Check that the slip ring has a smooth and concentric surface. Measure insulation resistance between the slip ring and the motor shaft to detect cracked or defective bushings and collars. Clean the slip ring using manufacturer recommended materials and methods, such as using a stiff bristle brush and solvent cleaner, if recommended by the manufacturer. Machine the slip ring face when rings have worn eccentric with the shaft.

Inspect the brushless exciter, including rotating diode rectifier and field discharge resistor for contamination, signs of overheating, or other defects.

Check motors for increased operating temperature, excessive bearing noise, excessive vibration, and leaking lubricants. Inspect bearings for evidence of overheating, contamination, damage to the rotating shaft, electrical damage, and insufficient lubrication. Maintain, clean, and lubricate bearings in accordance with the manufacturer instructions for the type of bearing.

Perform vibration tests and analysis on all rotating equipment greater than 7.5 HP (or smaller if highly critical to operations) in accordance with Annex A. Laser align motor shaft as needed.

Measure the resistance of resistance temperature detector (RTD) circuits. Verify that RTD circuits conform to the design intent and/or the machine protection device manufacturer specifications.

Perform insulation resistance tests and dielectric absorption tests (polarization index and/or dielectric absorption ratio) on the main rotating field winding, the exciter field winding, and the exciter-armature winding in accordance with ANSI/IEEE Standard 43 and in accordance with manufacturer instructions. See Annex A for additional information.

Perform DC overpotential testing on motors rated 2300V and greater in accordance with IEEE 95. Test each phase separately with the other phases and the winding temperature detectors grounded. Disconnect any capacitors and surge protective devices during the test. Motors are considered to have passed the test if no evidence of distress or insulation failure is observed by the end of the test.

Perform DC overpotential testing on the excitation system in accordance with IEEE 421.3, IEEE Standard for High-Potential Test Requirements for Excitation Systems for Synchronous Machines. Motors are considered to have passed the test if no evidence of distress or insulation failure is observed by the end of the test.

Measure the phase-to-phase resistance on each stator of machines rated 2300 volts and greater. Investigate phase-to-phase stator resistance values that deviate from the average value by more than 5%.

Perform insulation power factor or dissipation factor tests in accordance with test equipment manufacturer instructions and Annex A.

Perform insulation resistance testing on insulated bearings in accordance with manufacturer instructions. Insulation resistance of bearings should be within the manufacturer published tolerances. In the absence of manufacturer published tolerances, compare the insulation resistance values of bearings of similar machines.

Measure the resistance of machine-field winding, exciter-stator winding, exciter-rotor windings, and field discharge resistors. Compare the measured resistance values of machine-field windings, exciter-stator windings, exciter rotor windings, and field-discharge resistors to the manufacturer recommended values.

Prior to re-energizing, apply voltage to the exciter supply and adjust the exciter-field current to the nameplate value in accordance with manufacturer instructions.

Verify that the field application timer and the enable timer for the power factor relay are set to the motor drive manufacturer recommended values. Test the field application timer and the enable timer for proper operation in accordance with the manufacturer recommended values.

Upon startup, verify the absence of unusual mechanical or electrical noise or signs of overheating. Measure operating temperature under normal running load conditions.

Perform current signature analysis test at normal operating speed under normal running load conditions. Investigate any current signature analysis tests that indicate evidence of broken bars, non-uniform air gaps, rolling element bearing defects, or other damage or defects in accordance with the manufacturer recommendations.

Test surge protection devices in accordance with Sections 5.47 and 5.48 as applicable.

Test motor starters and motor controllers in accordance with Sections 5.18, 5.19, and 5.20 as applicable.

## 5.22 AC Induction Machines (Motors and Alternators)

When invasive cleaning is required due to extensive internal contamination, clean induction machines and dry in accordance with NFPA 70B and manufacturer instructions. Repair or replace all corroded parts and components.

Check for loose items such as shaft keys, couplings, and cooling fans.

Inspect air baffles and filter media. Clean air passages and clean or replace filter media as needed. Clean external motor surfaces.

Inspect cooling fans. Cooling fans should operate properly, be intact with no cracks, and be securely attached to the rotor shaft.

Inspect rotor, stator core, and stator windings. The rotor field winding should be clean with no evidence of overheating or discolored or cracked rotor bars or cracked end rings, and with no evidence of rubbing contact with the stator core. The stator core should be clean with no ventilation duct blockage, loose laminations, burning, or rubs from contact with the rotor. The stator winding should be clean with no evidence of overheating, cracking, tracking, or surface partial discharge. Squirrel cage rotors should have no cracks in the bars or shorting rings or in the joints between them.

Inspect insulating surfaces for cracks, crazing, flaking, powdering, or other evidence of degradation. Consult the manufacturer for recommendations for restoring degraded insulation, such as applying one or more coats of air-drying varnish.

Inspect the windings for evidence of moisture, oil, or grease. If necessary, thoroughly clean windings with a solvent solution in accordance with manufacturer instructions. Dry the motor in accordance with manufacturer instructions.

Inspect slip rings, brushes, and brush rigging for any evidence if mis-operation, such as sparking or chatter of brushes in the holder. Check brush holders for fit, free play, or end play, and for staggering to prevent grooving of the rings during operation. Replace brushes that are excessively worn, such as worn down to the brush rivet. Brush faces should be free of chipped toes or heels and heat cracks. Replace any damaged brushes.

Check that brush shunts are properly secured to the brushes and holders. Verify that the correct grade of brush is used in accordance with the manufacturer recommendations. Check that slip ring wear and brushes are within manufacturer tolerances for continued use. Brush rigging should be intact.

Tighten brush studs that might have become loose from the drying and shrinking of insulating washers. Check brush spring pressure using the spring balance method. Adjust spring pressure in accordance with manufacturer instructions.

Check that the slip ring has a smooth and concentric surface. Measure insulation resistance between the slip ring and the motor shaft to detect cracked or defective bushings and collars. Clean the slip ring using manufacturer recommended materials and methods, such as using a stiff bristle brush and solvent cleaner, if recommended by the manufacturer. Machine the slip ring face when rings have worn eccentric with the shaft.

Check motors for increased operating temperature, excessive bearing noise, excessive vibration, and leaking lubricants. Inspect bearings for evidence of overheating, contamination, damage to the rotating shaft, electrical damage, and insufficient lubrication. Maintain, clean, and lubricate bearings in accordance with the manufacturer instructions for the type of bearing.

Perform vibration tests and analysis on all rotating equipment greater than 7.5 HP (or smaller if highly critical to operations). Conduct tests at normal operating speed under normal running load conditions. The motor must meet the vibration criteria in Tables 3 and 4 (Annex A). See Annex A for additional information.

Perform laser alignment on all shaft coupled machines (see Figure 1, Annex A). All shaft-to-shaft center line alignments should meet the requirements of Table 5 (Annex A) unless more precise tolerances are specified by the machine manufacturer. The tolerances specified in Table 5 are the maximum allowable deviations from Zero-Zero Specifications or alignment target specifications (i.e., an intention targeted offset and/or angularity). Figure 2 (Annex A) illustrates the concept of offset and angular motor alignment.

Perform resistance tests on resistance temperature detector (RTD) circuits. Verify that RTD circuits conform to the design intent and/or the machine protection device manufacturer specifications.

Perform insulation resistance tests in accordance with ANSI/IEEE Standard 43 and in accordance with manufacturer instructions. Calculate the dielectric absorption ratio or the polarization index, as applicable. See Annex A for additional information.

Perform DC overpotential testing on motors rated 2300V and greater in accordance with IEEE 95. Test each phase separately with the other phases and the winding temperature detectors grounded. Disconnect any capacitors and surge protective devices during the test. Motors are considered to have passed the test if no evidence of distress or insulation failure is observed by the end of the test.

Perform phase-to-phase stator resistance test on machines 2300 volts and greater. Investigate phase-to-phase stator resistance values that deviate from the average value by more than 5%.

Perform insulation power factor or dissipation factor tests in accordance with test equipment manufacturer instructions and Annex A.

Perform insulation resistance testing on insulated bearings in accordance with manufacturer instructions. Insulation resistance of bearings should be within the manufacturer published tolerances. In the absence of manufacturer published tolerances, compare the insulation resistance values of bearings of similar machines.

Upon startup, verify the absence of unusual mechanical or electrical noise or signs of overheating. Measure operating temperature under normal running load conditions.

Perform current signature analysis test at normal operating speed under normal running load conditions. Investigate any current signature analysis tests that indicate evidence of cracks or breaks in squirrel cage windings, broken bars, non-uniform air gaps, rolling element bearing defects, or other damage or defects in accordance with the manufacturer recommendations.

Test surge protection devices in accordance with Sections 5.47 and 5.48 as applicable.

Test motor starters and motor controllers in accordance with Sections 5.18, 5.19, and 5.20 as applicable.

### 5.23 DC Machines (Motors and Generators)

When invasive cleaning is required due to extensive internal contamination, clean DC machines and dry in accordance with NFPA 70B and manufacturer instructions. Repair or replace all corroded parts and components.

Check for loose items such as shaft keys, couplings, and cooling fans.

Inspect air baffles and filter media. Clean air passages and clean or replace filter media as needed. Clean external motor surfaces.

Inspect the windings for evidence of moisture, oil, or grease. If necessary, thoroughly clean the winding with a solvent solution in accordance with manufacturer instructions. Dry the motor in accordance with manufacturer instructions.

Inspect insulating surfaces for cracks, crazing, flaking, powdering, or other evidence of degradation. Consult the manufacturer for recommendations for restoring degraded insulation, such as applying one or more coats of air-drying varnish.

Inspect commutators, brushes, and brush rigging for any evidence if mis-operation, such as sparking or chatter of brushes in the holder. Check brush holders for fit, free play, or end play, and for staggering to prevent grooving of the rings during operation. Replace brushes that are excessively worn, such as worn down to the brush rivet. Brush faces should be free of chipped toes or heels and heat cracks. Replace any damaged brushes.

Check that brush shunts are properly secured to the brushes and holders. Verify that the correct grade of brush is used in accordance with the manufacturer recommendations. Tighten brush studs that might have become loose from the drying and shrinking of insulating washers. Check brush spring pressure using the spring balance method. Adjust spring pressure in accordance with manufacturer instructions.

Inspect cooling fans. Cooling fans should operate properly.

Inspect field poles and yokes and armature. Field poles and yokes and armature should show no evidence of overheating, contamination, or other defects.

Inspect the commutator, tachometer generator, brushes, and brush rigging. The commutator should show no evidence of overheating, contamination, or other defects. Evaluate the commutator wear and marking pattern to determine if defects are indicated. The commutator and tachometer generator should be in accordance with the manufacturer published data and/or system design. Brushes should be within manufacturer tolerances for continued use. Brush rigging should be intact.

Check commutator concentricity with a dial gauge if sufficient evidence indicates that the commutator is out of round. A dial indicator reading of 0.001 in. on highspeed machines to several thousandths of an inch on low-speed machines can be considered normal.

Examine the commutator surface for high bars, grooving, evidence of scratches, or roughness. In light cases, the commutator can be burnished by hand using a commutator cleaning stone, but for extreme roughness, turning of the commutator in the lathe is recommended. Consult the manufacturer for recommendations when high or pitted mica is found. Repair, condition, and clean the commutator in accordance with ANSI/EASA AR100, Recommended Practice for the Repair of Rotating Electrical Apparatus.

Check motors for increased operating temperature, excessive bearing noise, excessive vibration, and leaking lubricants. Inspect bearings for evidence of overheating, contamination, damage to the rotating shaft, electrical damage, and insufficient lubrication. Maintain, clean, and lubricate bearings in accordance with the manufacturer instructions for the type of bearing.

Perform air gap spacing tests in accordance with the manufacturer and test equipment manufacturer instructions. Air gap spacing should be within manufacturer tolerances.

Perform laser alignment on all shaft coupled machines (see Figure 1, Annex A). All shaft-to-shaft center line alignments should meet the requirements of Table 5 (Annex A) unless more precise tolerances are specified by the machine manufacturer. The tolerances specified in Table 5 are the maximum allowable deviations from Zero-Zero Specifications or alignment target specifications (i.e., an intention targeted offset and/or angularity). Figure 2 (Annex A) illustrates the concept of offset and angular motor alignment.

Perform insulation resistance tests on all windings in accordance with ANSI/IEEE Standard 43 and in accordance with manufacturer instructions. Calculate the dielectric absorption ratio or the polarization index, as applicable. See Annex A for additional information.

Perform DC overpotential testing in accordance with NEMA MG 1. Windings are considered to have passed the test if no evidence of distress or insulation failure is observed by the end of the test.

Perform an AC voltage-drop test on all field poles. The pole-to-pole voltage drop should not exceed 5% of the average between poles.

Measure the armature running current and field current or voltage. The measured running current and field current or voltage should be comparable to the nameplate ratings.

Perform vibration tests and analysis on all rotating equipment greater than 7.5 HP (or smaller if highly critical to operations). Conduct tests at normal operating speed under normal running load conditions. The motor must meet the vibration criteria in Tables 3 and 4 (Annex A). See Annex A for additional information.

Test surge protection devices in accordance with Sections 5.47 and 5.48 as applicable.

Test motor starters and motor controllers in accordance with Sections 5.18, 5.19, and 5.20 as applicable.

### 5.24 Low-Voltage Insulated Case and Molded Case Circuit Breakers

*NOTE: See ANSI/NEMA AB4, Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications, for additional guidance in the testing of low-voltage insulated case and molded case circuit breakers.*

Clean contamination from the external cases of circuit breakers. Inspect circuit breakers for visual defects, chipping, cracks, breaks, burns, deterioration, and correct mounting. Visually check circuit breakers for evidence of overheating and thermal damage. Investigate and eliminate sources of overheating. Inspect the contacts and arc chutes in unsealed circuit breakers. Verify the proper operation of the circuit breaker charging mechanism, if so equipped. Replace damaged circuit breakers.

Check circuit breakers for proper mounting, conductor size (ampacity), and feeder designation in accordance with one-line diagrams, if available.

Inspect interchangeable trip units of circuit breakers for tightness.

Check circuit breaker terminals and connections for tightness using a calibrated torque tool. Refer to the manufacturer instructions and markings for proper torque values. In the absence of manufacturer torque tables, tighten terminals in accordance with Annex I of NFPA 70.

Where installed, inspect aluminum conductors for extrusion and rework terminations, if required, keeping in mind that repeated tightening of loose connections will extrude aluminum conductors and may cause adverse operating conditions. Carefully inspect aluminum-to-copper connections for evidence of corrosion, overheating, or looseness. Rework connections as needed. See NECA 104 for additional information.

Operate circuit breakers several times to exercise mechanisms and contacts, and to ensure smooth operation. Preferably, use circuit breaker test features that trip, exercise, and lubricate the mechanism, if so equipped. Run self-diagnostics on circuit breakers equipped with solid-state circuitry or a microprocessor. Otherwise, operate circuit breakers manually. Make sure each operator mechanism quickly and positively throws contacts to the fully "ON" and fully "OFF" positions. Do not oil or grease parts of molded case circuit breakers.

For electronic-trip circuit breakers, use the test set to run trip unit tests automatically with user prompts.

Adjust the settings of circuit breakers in accordance with the coordination study, if available, provided by others.

Verify that all circuit breaker contacts are open when the handle is in the OFF position and closed when the handle is in the ON position using an ohmmeter or other indicating device. Replace circuit breakers when the contacts are not open with the breaker in the tripped or OFF position, when the contacts are not closed with the breaker in the ON position, when the breaker does not reset, and when the mechanical trip provisions do not trip the breaker, if so equipped.

Perform insulation resistance tests on each pole, phase-to-phase, and phase-to-ground with circuit breaker closed and across each open pole for a minimum of one minute. Test voltage must be in accordance with the manufacturer published data. Follow manufacturer instructions for testing solid-state components. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for testing solid-state components. Review the circuit breaker markings and instructional material. When recommended by the manufacturer, remove the rating plug or other connections before performing insulation resistance testing to prevent damage to the trip system. See Annex A for additional information.

Perform static contact/pole resistance tests. See Annex A for additional information.

For circuit breakers equipped with solid state (static) trip devices, check for proper operation and timing in accordance with manufacturer instructions.

Perform primary current injection testing to determine minimum long-time pickup current and time delay (at 300% pickup current), short-time pickup and time delay, and instantaneous pickup current, and ground-fault pick up and time delay for circuit breakers with solid-state trip units so equipped. For instantaneous-only circuit breakers or motor protectors, test instantaneous pickup values. Determine instantaneous pickup current by run-up or pulse method. Compare results with the time-current coordination curve for each circuit breaker. Pickup values should be as specified in the coordination study, provided by others, if available. Trip characteristics should not exceed the manufacturer published time-current characteristic tolerance band, including adjustment factors, if applicable. Instantaneous pickup values of molded-case circuit breakers and instantaneous-only circuit breakers should fall within manufacturer published tolerances. Replace defective devices, including circuit breakers with trip times varying from the published tolerance band by more than 10% at 300% current, and adjust and retest where necessary. *NOTE: Remove or otherwise bypass current-limiting fuses from circuit breakers so equipped prior to applying simulated overload and fault current.*

Perform secondary injection testing to test the functions of the trip unit. Verify trip unit characteristics. Set adjustable or programmable devices according to the protective device coordination study, if available, provided by others. Pickup values and trip characteristics should be within manufacturer published tolerances. Replace defective devices, including circuit breakers with trip times varying from published tolerance band by more than 10% at 300% current, and adjust and retest where necessary. *NOTE: Remove or otherwise bypass current-limiting fuses from circuit breakers so equipped prior to applying simulated overload and fault current.*

Perform minimum pickup voltage test on shunt trip and close coils in accordance with manufacturer instructions. Minimum pickup voltage should be in accordance with the manufacturer published data. Verify the proper operation of shunt trip devices by activating auxiliary protective devices, such as ground fault or undervoltage relays. Test ground-fault to ensure activation based on the time current coordination curve for the ground fault relay.

Verify proper operation of auxiliary functions, such as trip unit battery condition, electrical close and trip operation, trip and pickup indicators, trip-free, anti-pump function, and zone interlocking, if so equipped, in accordance with manufacturer instructions. Circuit breaker open, close, trip, trip-free, anti-pump, and auxiliary features should function as designed by the manufacturer.

Test AFCI and GFCI molded case circuit breakers in accordance with manufacturer instructions. Turn off and unplug all appliances from receptacles supplied by AFCI and GFCI circuit breakers prior to testing. Test circuit breakers by pressing the TEST button. Circuit breakers should trip when the TEST button is pressed, and the handle should move to the center or TRIPPED position. Reset circuit breakers by moving the handle fully to the OFF position, then fully to the ON position. If the circuit breaker opens when the TEST button is pressed and can be reset, the circuit breaker is functioning properly. If the circuit breaker does not open when the test button is pressed or cannot be reset, the circuit breaker is defective and must be replaced. *NOTE: OSHA does not recognize the use of hand-held AFCI test indicators, and circuit breaker manufacturers only recognize the use of the test button on circuit breakers as the proper test method for AFCI circuit breakers.* See NECA 169 for additional information for GFCI and AFCI circuit breakers.

Reset all trip logs and indicators, if applicable.

## 5.25 Low-Voltage Power Circuit Breakers

Test and maintain low-voltage power circuit breakers in accordance with manufacturer instructions. Verify that maintenance devices are available for testing, maintaining, and operating the circuit breaker before beginning work.

Verify that necessary documentation is available, such as the manufacturer instructions, one-line diagram, provided by others, and the coordination study, if available, provided by others, and that suitable test instruments necessary for testing and maintaining power circuit breakers are available prior to the start of work.

Discharge stored energy mechanisms and remove drawout type circuit breakers from their cubicles and place in a secure, convenient location for testing and maintenance. Do not test or maintain a stored-energy-type circuit breaker while its closing spring is charged. Verify proper racking mechanism operation.

Test and maintain fixed-mounted power circuit breakers with the breaker in place inside its cubicle. Ensure that equipment is de-energized and all circuits connected to the circuit breaker, including power circuits and control circuits, are in an electrically safe work condition, and that all stored-energy devices are discharged. See Section 3.

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Remove interphase barriers and clean with a vacuum. Vacuum other insulating surfaces. Use clean lint-free rags and solvents only if recommended by the manufacturer, if needed, to remove hardened or encrusted contamination.

Inspect the arc interrupters for any residue, dirt, arc spatter, or any other arc products. Clean arc interrupters in accordance with manufacturer instructions. Remove dust or loose deposits on the inside of arc chutes by vacuuming or by wiping with clean, dry, lint-free cloths that are free of grease or metallic particles. Use solvents only if recommended by the manufacturer, if needed, to remove hardened or encrusted contamination. Remove residue, dirt, and arc products with a clean, dry, lint-free cloth or by light sanding. Do not use a wire brush or emery cloth due to the possibility of embedding conducting particles in the ceramic material.

Check ceramic materials for erosion, scratches, chips, cracks, and breaks. Small chips or small cracks may not require replacement. Consult the manufacturer for recommendations. Replace the ceramic stack if any broken or badly cracked ceramic plates are discovered.

Remove the arc chutes and check the ceramic parts of arc interrupters for erosion, which occurs when arcing causes ceramic to melt slightly and re-solidify. Such ceramic appears glazed with a whitish finish, which is normal. Excessive arcing will cause appreciable amounts of ceramic material to boil away. In such cases, replace the ceramic stack assembly. Replace significantly eroded components. Replace significantly eroded splitter plates. Check interior surfaces of enclosing jackets for discoloration or contamination with soot, spatter, or other arc products. Clean or replace damaged enclosing jackets. Depending upon the severity of damage, the entire arc chute may need to be replaced.

Check the plastic surfaces below the ceramic arc shield of arc interrupters for dirt or deposits of metal vapors boiled out of contacts and arc horns. Wipe these surfaces clean, if possible, especially if the dirt contains carbon or metallic deposits.

Check ceramic arc shields for deposits from the metal vapors boiled out of the contacts and arc horns. If there are appreciable deposits, test the insulation resistance of the assembly by applying the 60Hz rated maximum voltage for one minute between the front and rear arc horns, which should withstand the test voltage. Use a higher test voltage for circuit breakers that are reasonably expected to be exposed to overvoltages. *NOTE: Some manufacturers recommend a dielectric test of the ceramic surfaces near the contacts to verify adequate dielectric strength of these surfaces.* For deficient test results, clean the arc chutes using a hard non-conductive abrasive in accordance with manufacturer instructions and retest. Replace any arc interrupter assemblies that fail this test.

Inspect puffers for proper operation. With the arc interrupter mounted on the breaker in its normal position, place a piece of tissue paper over the discharge area of the interrupter and check for movement when the breaker is opened. Any perceptible movement of the paper indicates that the puffer is functioning properly.

Inspect main and arcing contacts for condition, wear, and alignment. Verify that contact surfaces are clean, smooth, and in alignment. Verify that contact pressure is in accordance with the manufacturer specifications.

Main contacts should appear clean and bright. Discoloration of silver contact surfaces is generally not detrimental unless the discoloration is due to insulating deposits. Remove insulating deposits from silver-alloy contacts using alcohol or silver cleaner. Slight impressions on the stationary contacts are normal and are caused by the pressure and wiping action of the movable contacts. Minor burrs or pitting are typical. Dress contacts to remove projecting burrs using non-abrasive methods in accordance with manufacturer instructions. Where discoloration extends beyond the contacts to other metal and surrounding insulation, replace the contacts and the spring assemblies in accordance with manufacturer instructions.

Manually close the circuit breaker to check for proper contact wipe, pressure, and contact alignment and to ensure that all contact surfaces are made simultaneously. Check the spacing between stationary and movable contacts in the fully open position. Make adjustments in accordance with manufacturer instructions.

Clean the drawout primary disconnect contacts of drawout type circuit breakers and the stationary contacts in the cubicle. Inspect for overheating, proper alignment, and broken or weak springs. Lightly coat the drawout primary disconnect contact surfaces with a contact lubricant to facilitate ease of the mating operation.

Perform all mechanical operator and contact alignment tests in accordance with manufacturer instructions. Circuit breaker closing and tripping action should be quick and positive. Correct any binding, slow action, or delay in operation, or failure to trip or latch.

Inspect the operating mechanism for loose or broken parts, missing cotter pins or retaining keepers, missing nuts and bolts, and binding or excessive wear. Inspect linkages, solenoids, and springs and all moving parts for excessive wear. Excessive wear may result in the loss of travel of the breaker contacts, and can affect the operation of latches, causing them to stick or slip off and prematurely trip the breaker. Adjust operating mechanisms for wear in accordance with manufacturer instructions. Replace excessively worn components.

Verify proper operation of the circuit breaker charging mechanism. The charging mechanism should operate in accordance with the manufacturer published data.

Verify proper racking mechanism operation for removable breakers. Check on/off indicators and spring-charge indicators for proper operation. Check the closing motor or solenoid, shunt trip, auxiliary switches, and bell alarm switch for proper operation, insulation condition, and tightness of connections

Set adjustable or programmable protective device settings according to the protective device coordination study, if available, provided by others, in accordance with manufacturer instructions.

Perform insulation resistance tests on each pole, phase to phase and phase-to-ground with the circuit breaker closed and across each open pole for one minute. Test voltage must be in accordance with the manufacturer published data. Insulation resistance values should be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for solid-state components. See Annex A for additional information.

Perform a contact/pole resistance test. See Annex A for additional information.

For circuit breakers equipped with solid state (static) trip devices, check for proper operation and timing in accordance with manufacturer instructions. *NOTE: Primary injection test sets will test the entire tripping system, which validates the measurement functions and interconnectivity of sensing and trip devices. Secondary injection tests only validate the functionality of the trip unit and circuit breaker opening, but do not test the power supply, the current sensor, or interconnecting wiring. Because of the unique designs of power circuit breakers, consult the* *manufacturer for breaker-specific test kits and test instructions. Do not attempt to repair solid-state trip units in the field. Consult the manufacturer for recommendations for any malfunctioning units.*

Power circuit breakers that require very high interrupting ratings are available with integral current-limiting fuses. Remove or otherwise bypass current-limiting fuses from circuit breakers so equipped prior to applying simulated overload and fault current.

Perform primary current injection testing to determine minimum long-time pickup current and time delay (at 300% pickup current), short-time pickup and time delay, and instantaneous pickup current, and ground-fault pick up and time delay, if applicable. Determine instantaneous pickup current by run-up or pulse method. Clearing times should be within six cycles or less. Record trip times. Compare results with the time-current coordination curve for each circuit breaker. Pickup values should be as specified in the coordination study, if available, provided by others. Trip characteristics should not exceed the manufacturer published time-current characteristic tolerance band, including adjustment factors, if applicable. Instantaneous pickup values should fall within the manufacturer published tolerances. Replace defective calibration and timing components, including when circuit breaker trip times vary from the published tolerance band by more than 10% at 300% current. Adjust and retest where necessary.

Perform secondary injection testing to test the functions of the trip unit. Verify trip unit characteristics. Set adjustable or programmable devices according to the protective device coordination study, if available, provided by others. Pickup values and trip characteristics should be within manufacturer published tolerances. Replace defective devices, including when circuit breaker trip times vary from the published tolerance band by more than 10% at 300% current, and adjust and retest where necessary.

Perform minimum pickup voltage test on shunt trip and close coils in accordance with manufacturer instructions. Minimum pickup voltage should be in accordance with the manufacturer published data. Verify the proper operation of shunt trip devices by activating auxiliary protective devices, such as ground fault or undervoltage relays. Test ground-fault to ensure activation based on time current coordination curve for the ground fault relay.

Verify proper operation of any auxiliary devices and features, such as trip and pickup indicators, zone interlocking, electrical close and trip operation, trip-free, anti-pump function, and trip unit battery condition, if so equipped, in accordance with manufacturer instructions. Circuit breaker open, close, trip, trip-free, anti-pump, and auxiliary features should function as designed by the manufacturer.

With the breaker in the test position, trip and close each breaker with the control switch. Trip each breaker by operating each of its protective and control relays. Verify proper mechanism charge. Breaker mechanism charge should function in accordance with the manufacturer design.

Reset all trip logs and indicators, if applicable.

## 5.26 Low-Voltage (600V Class) Network Protectors

Test and maintain network protectors in accordance with manufacturer instructions. Verify that maintenance devices are available for testing, maintaining, and operating the network protector, such as a network protector test kit.

Consider network and transformer connections to be energized at all times. Use only insulated tools. Wear appropriate PPE. Do not remove any barriers from the enclosure. See Section 3.

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Prior to performing any testing and maintenance, ensure that the network protector is in the “open” position and remove the circuit breaker mechanism and relay panel assembly from the enclosure or housing. Verify proper racking mechanism operation. Electrically isolate the network protector from the system by removing the fuses at the top and the disconnecting links at the bottom. *NOTE: Some modern network protectors have bolt-actuated disconnecting fingers at the bottom.*

Within the network protector enclosure, identify any loose hardware found on the floor or beneath the equipment frame and reinstall. Clean bus stand-off insulators. Remove oxide film from terminal contacts, if any. Perform a leak test on submersible enclosures in accordance with manufacturer instructions.

Clean the network protector of any accumulations of dust using a vacuum cleaner. Remove dirt by wiping with clean, lint free cloths.

Verify arc chutes are intact. Replace any damaged splitter plates. Inspect dynamic and stationary contacts for condition, wear, and alignment. Smooth any damaged areas with a fine file, stone, crocus cloth, or other suitable abrasive that does not shed particles. Smooth rough areas and high projections of metal on arcing contacts. Protect the hinge joint from falling particles during dressing. Verify that primary and secondary contact wipe and other dimensions vital to satisfactory operation of the breaker are correct. Perform mechanical operator and contact alignment tests on both the breaker and its operating mechanism.

Verify that springs are in place and unbroken. Verify that hardware, such as nuts, pins, snap rings, and screws, are in place, tight, and secured. Secure any loose barriers. Replace any broken or damaged barriers.

Use a network protector test kit to operationally test the network protector. Manually close and open the network protector in accordance with manufacturer instructions. The network protector should close with a definite snap action, and snap open. Check the position indicator for proper operation. Sluggish closing action indicates excessive friction and should be investigated. Consult the manufacturer for recommendations for deficient operation.

Perform insulation resistance tests on each pole, phase-to-phase, and phase-to-ground with the network protector closed and across each open pole for a minimum of one minute. Follow manufacturer instructions for testing solid-state components. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for testing solid-state components. See Annex A for additional information.

Perform static contact/pole resistance tests. See Annex A for additional information.

Measure the resistance of each power fuse for protectors so equipped. Fuse resistance values should be within 15% for identical fuses. Replace deficient fuses.

Measure the minimum pickup voltage of the motor control relay. The minimum pickup voltage should be in accordance with the manufacturer published data and must not exceed 75% of rated control circuit voltage.

Verify that the motor can charge the closing mechanism at the minimum voltage specified by the manufacturer. The minimum acceptable motor closing voltage should not exceed 75% of rated control circuit voltage.

Measure the minimum pickup voltage of the trip actuator. The minimum voltage to operate the trip actuator must not exceed 75% of rated control circuit voltage. Verify that the actuator resets correctly.

Calibrate the network protector relays in accordance with manufacturer instructions and Section 5.41. Adjust relay settings in accordance with the short circuit and coordination study, if available, provided by others.

Verify trip-free operation. Verify correct operation of the auto-open-close control handle. Verify that the protector closes automatically with source voltage on the transformer side only. Verify that the protector opens automatically when the source feeder breaker is opened. Network protector operation should be in accordance with the manufacturer design.

## 5.27 Medium-Voltage Air Circuit Breakers

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Remove interphase barriers and clean with a vacuum. Vacuum other insulating surfaces. Use clean lint-free rags and solvents only if recommended by the manufacturer, if needed, to remove hardened or encrusted contamination.

Verify proper racking mechanism operation for removable breakers. Check on/off indicators and spring-charge indicators for proper operation. Check the closing motor or solenoid, shunt trip, auxiliary switches, and bell alarm switch for proper operation, insulation condition, and tightness of connections

Clean the drawout primary disconnect contacts of drawout type circuit breakers and the stationary contacts in the cubicle and inspect for signs of overheating, proper alignment, and broken or weak springs. Lightly coat the drawout primary disconnect contact surfaces with a contact lubricant as recommended by the manufacturer to facilitate ease of the mating operation.

Perform all mechanical operation tests on the operating mechanism in accordance with manufacturer instructions. Circuit breaker closing and tripping action should be quick and positive. Correct any binding, slow action, or delay in operation, or failure to trip or latch.

Inspect the operating mechanism for loose or broken parts, missing cotter pins or retaining keepers, missing nuts and bolts, and binding or excessive wear. Check all moving parts for excessive wear. Excessive wear may result in the loss of travel of the breaker contacts, and can affect the operation of latches, causing them to stick or slip off and prematurely trip the breaker. Adjust operating mechanisms for wear in accordance with manufacturer instructions. Replace excessively worn components.

Manually close the circuit breaker to check for proper contact wipe, pressure, and contact alignment and to ensure that all contact surfaces are made simultaneously. Check the spacing between stationary and movable contacts in the fully open position. Make adjustments in accordance with manufacturer instructions.

For older circuit breakers with laminated copper or brush-style contacts, the laminations tend to weld together when burning occurs, greatly reducing contact pressure and wipe. Dress contacts with a file to remove burrs or to restore their original shape. Replace contacts when they are burned sufficiently to prevent adequate circuit-breaker operation or when approximately half of the contact surface is burned away.

Carbon contacts used on older circuit breakers require little maintenance unless inadequate contact pressure caused by erosion or repeated dressing causes overheating or interferes with their function as arcing contacts. Consult the manufacturer for recommendations in such cases.

If recommended by the manufacturer, slow close/open the breaker and check for binding, friction, contact alignment, and penetration. Verify that the contact sequence and alignment is in accordance with the manufacturer published data. In the absence of manufacturer published data, refer to ANSI/IEEE C37.04.

Inspect moving and stationary contacts for wear, condition, and alignment. The main contacts should appear clean and bright. Discoloration of the contact surfaces is generally not detrimental unless the discoloration is due to insulating deposits. Remove insulating deposits from silver-alloy contacts using alcohol or silver cleaner. Slight impressions on the stationary contacts are normal and are caused by the pressure and wiping action of the movable contacts. Minor burrs or pitting are typical. Dress contacts to remove projecting burrs using non-abrasive methods in accordance with manufacturer instructions. Where discoloration extends beyond the contacts to other metal and surrounding insulation, replace the contacts and the spring assemblies in accordance with manufacturer instructions.

Verify that the arc chutes are intact. Check that arc interrupters are clean and dry. Inspect the arc interrupters for any residue, dirt, arc spatter, or any other arc products. Remove dust or loose deposits on the inside of arc chutes by vacuuming or by wiping with clean, dry, lint-free cloths that are free of grease or metallic particles. Use solvents only if recommended by the manufacturer, if needed to remove hardened or encrusted contamination. Remove contamination with a cloth or by lightly sanding in accordance with manufacturer instructions. Do not use a wire brush or emery cloth to prevent embedding conductive particles in the ceramic insulating material. Check ceramic materials for erosion, scratches, chips, cracks, and breaks. Small chips or small cracks may not require replacement. Consult the manufacturer for recommendations. Replace the ceramic stack if any broken or badly cracked ceramic plates are discovered.

Check ceramic parts of arc interrupters for erosion, which occurs when arcing causes ceramic to melt slightly and re-solidify. Such ceramic appears glazed with a whitish finish, which is normal. Excessive arcing will cause appreciable amounts of ceramic material to boil away. In such cases, replace the ceramic stack assembly.

Check the plastic surfaces below the ceramic arc shield of arc interrupters for dirt or deposits of metal vapors boiled out of contacts and arc horns. Wipe these surfaces clean, if possible, especially if the dirt contains carbon or metallic deposits.

Check ceramic arc shields for deposits from the metal vapors boiled out of the contacts and arc horns. If there are appreciable deposits, test the insulation resistance of the assembly by applying the 60Hz rated maximum voltage for one minute between the front and rear arc horns, which should withstand the test voltage. Use a higher test voltage for circuit breakers that are reasonably expected to be exposed to overvoltages. For deficient test results, clean the arc chutes using a hard non-conductive abrasive in accordance with manufacturer instructions and retest. Replace any arc interrupter assemblies that fail this test.

Remove the arc chutes and check for erosion. Replace seriously eroded components. Check interior surfaces of enclosing jackets for discoloration and contamination with soot, spatter, or other arc products. Clean or replace damaged enclosing jackets. Depending upon the severity of damage, the entire arc chute may need to be replaced.

Inspect puffer operation. With the arc interrupter mounted on the breaker in its normal position, place a piece of tissue paper over the discharge area of the interrupter and check for movement when the breaker is opened. Any perceptible movement of the paper indicates that the puffer is functioning properly.

Perform circuit breaker time travel analysis to determine the opening and closing speeds of each breaker, the interval for closing and tripping, and the contact bounce. See Annex A for additional information.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with circuit breaker closed and across each open pole using the manufacturer recommended test voltage for one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for solid-state components. See Annex A for additional information.

Perform a contact/pole resistance test. See Annex A for additional information.

Measure the continuity and the resistance of the blowout coil circuit. The blowout coil circuit should exhibit continuity, and resistance values should be in accordance with the manufacturer published data.

With the breaker in the test position, trip and close each breaker with the control switch. Trip each breaker by operating each of its protective and control relays. Verify mechanism charge, trip-free, and anti-pump functions. Breaker mechanism charge, open, close, trip-free, and anti-pump features should function in accordance with the manufacturer design.

Perform minimum pickup voltage tests on trip and close coils in accordance with manufacturer instructions. Minimum pickup for trip and close coils must be in accordance with the manufacturer published data.

Perform a power factor/dissipation factor test with the breaker in both the open and closed positions. Perform test both with and without arc chutes. Compare power factor or dissipation factor test results with prior tests of similar breakers or the manufacturer published data. See Annex A for additional information.

Perform an overpotential test on each phase with the circuit breaker closed and the poles not under test grounded. Limit test voltage in accordance with manufacturer instructions. Circuit breakers are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

Maintain instrument transformers in accordance with Section 5.40.

Maintain protective and control relays in accordance with Section 5.41 as applicable.

See NECA 430 for additional guidance.

## 5.28 Medium-Voltage Vacuum Circuit Breakers

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Perform an operator analysis (first-trip) test. Compare the first-trip operation time and trip-coil current waveform to manufacturer published data. In the absence of manufacturer published data, compare the first-trip operation time and trip-coil current waveform to prior test results.

Remove interphase barriers and clean with a vacuum. Vacuum other insulating surfaces. Use clean lint-free rags and solvents only if recommended by the manufacturer, if needed, to remove hardened or encrusted contamination. Replace any broken or damaged barriers.

Inspect vacuum bottle assemblies. Measure critical distances such as the contact gap as recommended by the manufacturer. Contact displacement must be in accordance with the factory recorded data marked on the nameplate of each vacuum breaker or bottle. Measure contact wear. Contact wear indicators are available for measuring contact wear within the vacuum bottle assembly.

Verify proper racking mechanism operation for removable breakers. Check on/off indicators and spring-charge indicators for proper operation. Check the closing motor or solenoid, shunt trip, and auxiliary switches for proper operation, insulation condition, and tightness of connections.

Clean the drawout primary disconnect contacts of drawout type circuit breakers and the stationary contacts in the cubicle and inspect for signs of overheating, proper alignment, and broken or weak springs. Lightly coat the drawout primary disconnect contact surfaces with a contact lubricant as recommended by the manufacturer to facilitate ease of the mating operation.

If recommended by the manufacturer, slow close/open the breaker and check for binding, friction, contact alignment, and penetration. Verify that the contact sequence and alignment is in accordance with the manufacturer published data. In the absence of manufacturer published data, refer to ANSI/IEEE C37.04.

Perform all mechanical operation tests on the operating mechanism in accordance with manufacturer instructions. Circuit breaker closing and tripping action should be quick and positive. Correct any binding, slow action, or delay in operation, or failure to trip or latch.

Perform circuit breaker time travel analysis to determine the opening and closing speeds of each breaker, the interval for closing and tripping, and the contact bounce. Inspect vacuum bellows operation. See Annex A for additional information.

Perform a mechanism-motion analysis. Travel and velocity values must be in accordance with the manufacturer published data and previous test data.

Perform trip/close coil current signature analysis. Trip/close coil current values must be in accordance with the manufacturer published data and previous test data.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the circuit breaker closed and across each open pole for one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for solid-state components. See Annex A for additional information.

Perform a contact/pole resistance test. See Annex A for additional information.

With the breaker in the test position, trip and close each breaker with the control switch. Trip each breaker by operating each of its protective and control relays. Verify mechanism charge, trip-free, and anti-pump functions. Breaker mechanism charge, open, close, trip-free, and anti-pump features should function in accordance with the manufacturer design.

Perform minimum pickup voltage tests on trip and close coils in accordance with the manufacturer instructions. Minimum pickup for trip and close coils must be in accordance with the manufacturer published data.

Perform power factor or dissipation factor tests on each pole with the breaker open and each phase with the breaker closed. Measure power factor or dissipation factor of each bushing using either the power factor or capacitance tap, if so equipped, or using a hot collar test using a test electrode around the outside shell of the bushing. Compare power factor or dissipation factor test results to manufacturer published data. In the absence of manufacturer published data, compare results to similar breakers. See Annex A for additional information.

Perform vacuum bottle integrity (overpotential) testing. Measure the leakage current on each phase across each vacuum bottle with the circuit breaker in the open position. Perform testing in strict accordance with the manufacturer published data. Do not exceed the maximum voltage recommended by the manufacturer for this test. *NOTE: Some DC high-potential test sets are half wave rectified and may produce peak voltages in excess of the vacuum bottle manufacturer recommended maximum.* Provide adequate barriers and protection against X-ray radiation during this test. Do not perform this test unless the contact displacement of each interrupter is within the manufacturer tolerances. The interrupter must withstand the overpotential voltage applied with no evidence of distress or insulation failure observed by the end of the test. See Annex A for additional information.

Perform a magnetron atmospheric condition (MAC) test on each vacuum interrupter. See Annex A for additional information.

Perform an overpotential test on each phase with the circuit breaker closed and the poles not under test grounded. Limit test voltage in accordance with manufacturer instructions. Circuit breakers are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

Maintain instrument transformers in accordance with Section 5.40.

Maintain protective and control relays in accordance with Section 5.41 as applicable.

See NECA 430 for additional guidance.

## 5.29 Medium-Voltage SF6 (Sulfur Hexafluoride) Circuit Breakers

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Perform an operator analysis (first-trip) test. Compare the first-trip operation time and trip-coil current waveform to the manufacturer published data. In the absence of manufacturer published data, compare the first-trip operation time and trip-coil current waveform to prior test results.

Inspect and service the operating mechanism and/or hydraulic or pneumatic system and SF6 gas-insulated system in accordance with the manufacturer published data.

Verify correct operation of alarms, pressure, switches, and-limit switches for pneumatic and/or hydraulic operators and SF6 gas pressure in accordance with manufacturer instructions. Settings for alarms, pressure, and limit switches should be in accordance with the manufacturer published data.

Test for SF6 gas leaks in accordance with manufacturer instructions. Check gas leak indicators of permanently sealed equipment. No leaks should be detected. When leaks are detected, safely de-energize the equipment, remove from service, and replace the entire sealed unit.

Remove a sample of SF6 gas where provisions are made for sampling and test in accordance with ASTM D2472, Standard Specification for Sulfur Hexafluoride. Do not damage or break seals or otherwise distort permanently sealed interrupters. Test results should be in conformance with ASTM D2472.

If recommended by the manufacturer, slow close/open the breaker and check for binding, friction, contact alignment, and penetration. Verify that the contact sequence and alignment is in accordance with the manufacturer published data. In the absence of manufacturer published data, refer to ANSI/IEEE C37.04.

Perform all mechanical operation tests on the operating mechanism in accordance with manufacturer instructions. Circuit breaker closing and tripping action should be quick and positive. Correct any binding, slow action, or delay in operation, or failure to trip or latch.

Verify proper racking mechanism operation for removable breakers. Check on/off indicators and spring-charge indicators for proper operation. Check the closing motor or solenoid, shunt trip, auxiliary switches, and bell alarm switch for proper operation, insulation condition, and tightness of connections

Clean the drawout primary disconnect contacts of drawout type circuit breakers and the stationary contacts in the cubicle and inspect for signs of overheating, proper alignment, and broken or weak springs. Lightly coat the drawout primary disconnect contact surfaces with a contact lubricant as recommended by the manufacturer to facilitate ease of the mating operation.

Perform circuit breaker time travel analysis to determine the opening and closing speeds of each breaker, the interval for closing and tripping, and the contact bounce. See Annex A for additional information.

Perform a mechanism-motion analysis. Travel and velocity values must be in accordance with the manufacturer published data and previous test data.

Perform trip/close coil current signature analysis. Trip/close coil current values must be in accordance with the manufacturer published data and previous test data.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the circuit breaker closed and across each open pole for one minute. For single-tank circuit breakers, perform insulation resistance testing from pole-to-pole. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for solid-state components. See Annex A for additional information.

Perform static and dynamic contact/pole resistance tests. See Annex A for additional information.

With the breaker in the test position, trip and close each breaker with the control switch. Trip each breaker by operating each of its protective and control relays. Verify mechanism charge, trip-free, and anti-pump functions. Breaker mechanism charge, open, close, trip-free, and anti-pump features should function in accordance with the manufacturer design.

Perform minimum pickup voltage tests on trip and close coils in accordance with manufacturer instructions. Minimum pickup for trip and close coils must be in accordance with the manufacturer published data.

Perform power factor or dissipation factor tests on each pole with the breaker open and each phase with the breaker closed. Measure power factor or dissipation factor of each bushing using either the power factor or capacitance tap, if so equipped, or using a hot collar test using a test electrode around the outside shell of the bushing. Compare power factor or dissipation factor test results to manufacturer published data. In the absence of manufacturer published data, compare results to similar breakers. See Annex A for additional information.

Perform an overpotential test on each phase with the circuit breaker closed and the poles not under test grounded. Limit test voltage in accordance with manufacturer instructions. Circuit breakers are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

Maintain instrument transformers in accordance with Section 5.40.

Maintain protective and control relays in accordance with Section 5.41 as applicable.

## 5.30 Medium- and High-Voltage Oil Circuit Breakers

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Perform an operator analysis (first-trip) test. Compare the first-trip operation time and trip-coil current waveform to the manufacturer published data. In the absence of manufacturer published data, compare the first-trip operation time and trip-coil current waveform to prior test results.

Verify proper racking mechanism operation. Check on/off indicators and spring-charge indicators for proper operation. Check the closing motor or solenoid, shunt trip, auxiliary switches, and bell alarm switch for proper operation, insulation condition, and tightness of connections

Verify that breather vents are clear.

Inspect circuit breaker insulating bushings for evidence of damage or surface contamination. Clean bushing surfaces in accordance with manufacturer instructions to remove all surface contamination. Replace bushings exhibiting damage to the extent that the electrical creepage path has been reduced or the glazed surface on porcelain bushings is damaged.

Inspect and service hydraulic or pneumatic system and/or air compressor in accordance with the manufacturer published data. Test alarms, pressure switches, and limit switches for pneumatic and/or hydraulic operators in accordance with manufacturer instructions. Settings for alarm, pressure, and limit switches should be in accordance with the manufacturer published data.

Perform all mechanical operation tests on the operating mechanism in accordance with manufacturer instructions. Circuit breaker closing and tripping action should be quick and positive. Correct any binding, slow action, or delay in operation, or failure to trip or latch.

Inspect the operating mechanism for loose or broken parts, missing cotter pins or retaining keepers, missing nuts and bolts, and binding or excessive wear. Check all moving parts for excessive wear. Excessive wear may result in the loss of travel of the breaker contacts, and can affect the operation of latches, causing them to stick or slip off and prematurely trip the breaker. Adjust operating mechanisms for wear in accordance with manufacturer instructions. Replace excessively worn components.

Measure contact resistance of the circuit breaker main contacts. Measure contact engagement by measuring the travel of the lift rod from the start of contact opening to the point where the contacts separate, as indicated by an ohmmeter. More extensive maintenance on the main contacts could require removal of the insulating liquid and lowering of the tank and should be performed less frequently as determined by the severity of the circuit breaker duty, such as the number of operations and operating current levels, and after the circuit breaker has interrupted a fault current at or near its maximum rating.

When warranted, perform internal inspections in accordance with manufacturer instructions. Remove the oil. Lower tanks or remove manhole covers as necessary. Inspect the bottom of tank for broken parts and debris and clean carbon residue from the tank. Inspect the lift rod and toggle assemblies, interrupters, bumpers, dashpots, bushing current transformers, tank liners, and gaskets. Inspect the contacts for pitting or erosion. Check contact pressure and alignment. Check all bolted connections and contact springs for looseness. If recommended by the manufacturer, slow close/open the breaker and check for binding, friction, contact alignment, and penetration. Verify that the contact sequence is in accordance with the manufacturer published data. In the absence of manufacturer published data, refer to IEEE C37.04. Refill the tank(s) with new or filtered insulating liquid to correct levels.

Inspect arc-quenching assemblies for carbon deposits or other surface contamination in the areas of arc interruption. Clean assemblies in accordance with manufacturer instructions.

Inspect circuit breaker accessories, such as oil level gauges, sight glasses, valves, gaskets, breathers, oil lines, and tank lifters. Correct any deficiencies. Immediately de-energize circuit breakers and remove if the insulating liquid is below the level gauge or site glass, and remove from service until deficiencies are corrected.

Perform circuit breaker time travel analysis to determine the opening and closing speeds of each breaker, the interval for closing and tripping, and the contact bounce. See Annex A for additional information.

Perform a mechanism-motion analysis. Travel and velocity values must be in accordance with the manufacturer published data and previous test data.

Perform trip/close coil current signature analysis. Trip/close coil current values must be in accordance with the manufacturer published data and previous test data.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the circuit breaker closed and across each open pole for one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for solid-state components. See Annex A for additional information.

Perform a static and dynamic contact/pole resistance test. See Annex A for additional information.

Remove a sample of insulating liquid and perform tests in accordance with Annex A. Insulating liquid must comply with the manufacturer published data and recognized national standards. Recondition, reclaim, or replace insulating liquid in accordance with manufacturer instructions.

With the breaker in the test position, trip and close each breaker with the control switch. Trip each breaker by operating each of its protective and control relays. Verify mechanism charge, trip-free, and anti-pump functions. Breaker mechanism charge, open, close, trip-free, and anti-pump features should function in accordance with the manufacturer design.

Perform minimum pickup voltage tests on trip and close coils in accordance with manufacturer instructions. Minimum pickup for trip and close coils must be in accordance with the manufacturer published data.

Perform a power factor/dissipation factor test with the breaker in both the open and closed positions. Determine the tank loss index. Compare power factor or dissipation factor test results and tank loss index with the manufacturer published data, prior tests of similar breakers, or test equipment manufacturer data. See Annex A for additional information.

Measure power factor or dissipation factor on each bushing. Tests should be made of each bushing using either the power factor or capacitance tap, if so equipped, or using a "hot collar" test using a test electrode around the outside shell of the bushing. Perform tests in accordance with the test equipment manufacturer published data. Power factor or dissipation factor and capacitance values should be within 10% of the nameplate rating for bushings. Hot collar tests are evaluated on a milliampere/milliwatt loss basis, and the results should be compared to results from similar bushings. See Annex A for additional information.

Perform an overpotential test on each phase with the circuit breaker closed and the poles not under test grounded. Limit test voltage in accordance with manufacturer instructions. Circuit breakers are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

Maintain instrument transformers in accordance with Section 5.40.

Maintain protective and control relays in accordance with Section 5.41 as applicable.

## 5.31 Low Voltage Air Switches

Check for evidence of corona when equipment is energized, which may be more pronounced in high humidity, if applicable. *NOTE: Ultrasonic detection and light amplification or night-vision equipment is useful for detecting corona.* Mild corona might be normal. Consult the manufacturer for recommendations and correct if necessary.

Turn fusible switches to the "OFF" position before opening doors. Do not defeat cover interlocks to gain access to fuses. Visually check the position of the switch blades to verify that all switch blades have disconnected from their line connection. If all switch blades are not in the correct position, consult the manufacturer for recommendations.

Inspect insulators and conducting parts for evidence of contaminated surfaces or physical damage, such as cracked or broken segments. Clean contaminated insulator surfaces. Replace damaged insulators.

Inspect interphase linkages and operating rods to ensure that the linkage has not been bent or distorted and that all fasteners are secure. Observe the position of the toggle latch of the switch-operating linkage on all closed switches to verify that the switch is mechanically locked in a closed position.

For power-operated switches, operate the switch, mechanism, and control features to ensure proper operation. Check the limit switch for proper adjustment and operation. Check control relays for damaged contacts, defective coils, and inadequate supply voltage. Check for any other condition that might inhibit proper functioning of the switch assembly. For in-service power-operated switches that cannot be operated due to being energized under load, and when permitted by the manufacturer and only if the overall adjustment of the linkage and mechanism is not adversely affected, disengage the operating mechanism from the linkage and test the control circuits and mechanism for proper operation.

Operate the switch several times and check for free movement, proper spring tension, and excessive wear, and for the simultaneous opening and closing of all blades and for complete contact closing. Check the blade lock or latch in the fully closed position. Verify proper blade penetration, travel stops, and mechanical operation. Adjust, repair, or replace defective parts, components, and devices in accordance with manufacturer instructions.

Inspect contacts for alignment, pressure, pitting and arcing, or corrosion. Replace badly pitted or burned contacts. If pitting is minor, leave the surface as is. Inspect arcing horns for signs of excessive burning. Replace arcing horns if needed.

Inspect insulation for breaks, cracks, or burns. Clean salt deposits, cement dust, acid fumes, or other contaminants as needed.

Check gear boxes, linkages, and contact pivots for proper lubricants in accordance with manufacture instructions. Check for the evidence of moisture that could cause corrosion or difficulty in switch operation due to ice formation, if applicable.

Inspect flexible braids or slip ring contacts commonly used for grounding the operating handle for signs of corrosion, wear, or broken strands. Replace braids or slip ring contacts as needed.

Inspect contact surfaces, blades, and jaws for discoloration, overheating, pitting, arcing, and corona. Clean and dress readily-accessible copper electrical contacts, blades, and jaws in accordance with manufacturer instructions. Many contact surfaces, such as arcing contacts, are silver tungsten or other types of materials that must never be dressed. When contacts of these materials require maintenance, they must be replaced. Plated parts may become dark over a period of time due to oxidation. Do not remove this discoloration, as it will reduce the thickness of the plating.

Examine all readily-accessible arc chutes and insulating parts for cracks or breakage and for arc splatter, sooty deposits, oil, or arc tracking. Clean off arc splatter, oil, and sooty deposits, and inspect for burning, charring, or carbon tracking. Consult the manufacturer to determine whether such wear requires replacement. Replace insulating parts and arc chutes that are cracked or broken.

Tighten fuseholder connections in accordance with manufacturer instructions. Check that each fuseholder has adequate support for the fuse and that the fuseholder is securely attached to the mounting base.

Examine fuse clips for discoloration, overheating, corrosion, or physical damage. If there is any sign of overheating or looseness, check the spring pressure and the tightness of clamps. Check fuse clip spring pressure with that of similar fuse clips. Replace weak or burned clips with new fuse clips and suitable clamps using manufacturer-recommended replacement parts.

Verify that fuse sizes and types are in accordance with manufacturer instructions, one-line drawings, if applicable, and the coordination study, if available, provided by others. Measure fuse resistance. Fuse resistance values should be within 15% of values for similar fuses. Replace deficient fuses. Verify that each fuse has adequate mechanical support and contact integrity. Check that fuse clips are tight, secure, and free of corrosion. Verify correct phase barrier installation. Secure any loose barriers. Replace any broken or damaged barriers.

Measure contact resistance across each switchblade and fuseholder. See Annex A for additional information.

Perform insulation resistance tests on each pole, phase-to-phase, and phase-to-ground with the switch closed and across each open pole for a minimum of one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Verify correct operation of all indicating and control devices.

Where installed, maintain ground-fault protection systems in accordance with Section 5.45.

Where installed, maintain instrument transformers in accordance with Section 5.40.

Where installed, maintain protective and control relays in accordance with Section 5.41.

## 5.32 Medium-Voltage Metal-Enclosed Air Switches (Load Interrupter Switches)

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Remove interphase barriers and clean with a vacuum. Vacuum other insulating surfaces. Use clean, lint-free rags and solvents only if recommended by the manufacturer, if needed, to remove hardened or encrusted contamination.

Verify switch fit and alignment. Verify proper racking mechanism operation for removable switches. Check on/off indicators for proper operation.

Perform all mechanical operation tests on the operating mechanism in accordance with manufacturer instructions. Switch closing and tripping action should be quick and positive. Correct any binding, slow action, or delay in operation.

Inspect the operating mechanism for loose or broken parts, missing cotter pins or retaining keepers, missing nuts and bolts, and binding or excessive wear. Check all moving parts for excessive wear. Adjust operating mechanisms for wear in accordance with manufacturer instructions. Replace excessively worn components.

Manually operate the switch. Verify correct blade alignment, blade penetration, travel stops, arc interrupter operation, and mechanical operation. Make necessary adjustments in accordance with manufacturer instructions.

Inspect, clean, test, and maintain interrupters in accordance with manufacturer instructions. Remove enclosed interrupters from the switch and disassemble for maintenance in accordance with manufacturer instructions.

For power-operated switches, operate the switch, mechanism, and control features to ensure proper operation. Check the limit switch for proper adjustment and operation. Check control relays for damaged contacts, defective coils, and inadequate supply voltage. Check for any other condition that might inhibit proper functioning of the switch assembly. For in-service power-operated switches that cannot be operated due to being energized under load, and when permitted by the manufacturer and only if the overall adjustment of the linkage and mechanism is not adversely affected, disengage the operating mechanism from the linkage and test the control circuits and mechanism for proper operation.

Measure contact resistance across each switchblade and fuseholder. Verify that each fuse and fuseholder has adequate mechanical support and contact integrity. Check that fuse clips are tight, secure, and free of corrosion. See Annex A for additional information.

Verify correct phase barrier installation. Secure any loose barriers. Replace any broken or damaged barriers.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the switch closed and across each open pole for a minimum of one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform an overpotential test on each pole to ground with the switch closed and the poles not under test grounded. Limit test voltage in accordance with manufacturer instructions. Switches are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

Perform on-line partial discharge testing in accordance with Annex A. Partial discharge testing results should be in accordance with the manufacturer published data.

Verify correct operation of all indicating and control devices.

Where installed, maintain ground-fault protection systems in accordance with Section 5.45.

Where installed, maintain instrument transformers in accordance with Section 5.40.

Where installed, maintain protective and control relays in accordance with Section 5.41.

## 5.33 Medium-Voltage Vacuum Switches

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Perform all mechanical operation tests on the operating mechanism in accordance with manufacturer instructions. Switch closing and tripping action should be quick and positive. Correct any binding, slow action, or delay in operation.

Perform all mechanical operator tests in accordance with manufacturer instructions. Measure operating mechanism critical distances in accordance with manufacturer instructions. Critical distances should be in accordance with the manufacturer published data.

Verify proper operation of the motor operator. Adjust motor operator limit switches and mechanical interlocks in accordance with manufacturer instructions.

Verify proper open and close operation from control devices. The switch should open and close in accordance with the design of the system and in accordance with manufacturer instructions.

Inspect insulating assemblies for contamination and for evidence of physical damage. Remove interphase barriers and clean with a vacuum. Vacuum other insulating surfaces. Use clean lint-free rags and solvents only if recommended by the manufacturer, if needed, to remove hardened or encrusted contamination. Replace any broken or damaged barriers.

Inspect vacuum bottle assemblies. Measure critical distances such as contact gap as recommended by the manufacturer. Contact displacement must be in accordance with factory recorded data marked on the nameplate of each vacuum bottle. Measure contact wear. Contact wear indicators are available for measuring contact wear within the vacuum bottle assembly.

Measure contact resistance across each switchblade and fuseholder. Check that each fuseholder has adequate support for the fuse and that the fuseholder is securely attached to the mounting base. Verify that each fuse has adequate contact integrity. Check that fuse clips are tight, secure, and free of corrosion.

Perform a contact/pole resistance test. See Annex A for additional information.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the switch closed and across each open pole for a minimum of one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for testing solid-state components. See Annex A for additional information.

Perform vacuum bottle integrity (overpotential) testing. Measure the leakage current on each phase across each vacuum bottle with the switch in the open position. Perform testing in strict accordance with the manufacturer published data. Do not exceed the maximum voltage recommended by the manufacturer for this test. *NOTE: Some DC high-potential test sets are half wave rectified and may produce peak voltages in excess of the vacuum bottle manufacturer recommended maximum.* Provide adequate barriers and protection against X-ray radiation during this test. Do not perform this test unless the contact displacement of each vacuum bottle is within manufacturer tolerances. The vacuum bottle must withstand the overpotential voltage applied with no evidence of distress or insulation failure observed by the end of the test. See Annex A for additional information.

Perform a magnetron atmospheric condition (MAC) test on each vacuum interrupter. See Annex A for additional information.

Perform an overpotential test on each pole to ground with the switch closed and the poles not under test grounded. Limit test voltage in accordance with manufacturer instructions. Switches are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

### 5.34 Medium-Voltage SF6 Switches

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Perform all mechanical operation tests on the operating mechanism in accordance with manufacturer instructions. Switch closing and tripping action should be quick and positive. Correct any binding, slow action, or delay in operation.

Perform all mechanical operator tests in accordance with manufacturer instructions. Measure operating mechanism critical distances in accordance with manufacturer instructions. Critical distances should be in accordance with the manufacturer published data.

Inspect and service the operating mechanism and SF6 gas-insulated system in accordance with the manufacturer published data. Verify proper operation of the motor operator. Adjust motor operator limit switches and mechanical interlocks in accordance with manufacturer instructions.

Verify correct operation of limit switches and alarms for SF6 gas pressure switches in accordance with manufacturer instructions. Settings for alarms, pressure, and limit switches should be in accordance with the manufacturer published data.

Test for SF6 gas leaks in accordance with manufacturer instructions. Check gas leak indicators of permanently sealed equipment. No leaks should be detected. When leaks are detected, safely de-energize the equipment, remove from service, and replace the entire sealed unit.

Remove a sample of SF6 gas where provisions are made for sampling and test in accordance with ASTM D2472, Standard Specification for Sulfur Hexafluoride. Do not damage or break seals or otherwise distort permanently sealed interrupters. Test results should be in conformance with ASTM D2472.

Verify proper open and close operation from control devices. The switch should open and close in accordance with the design of the system and in accordance with manufacturer instructions.

Inspect insulating assemblies for contamination and for evidence of physical damage. Remove interphase barriers and clean with a vacuum. Vacuum other insulating surfaces. Use clean lint-free rags and solvents only if recommended by the manufacturer, if needed, to remove hardened or encrusted contamination. Replace any broken or damaged barriers.

Measure contact resistance across each switchblade and fuseholder. Check that each fuseholder has adequate support for the fuse and that the fuseholder is securely attached to the mounting base. Verify that each fuse has adequate contact integrity. Check that fuse clips are tight, secure, and free of corrosion.

Perform a contact resistance test. See Annex A for additional information.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the switch closed and across each open pole for a minimum of one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for testing solid-state components. See Annex A for additional information.

Perform dielectric withstand (overpotential) testing across each gas bottle with the switch in the open position. Perform testing in strict accordance with the manufacturer published data. Do not exceed the maximum voltage recommended by the manufacturer for this test. *NOTE: Some DC high-potential test sets are half wave rectified and may produce peak voltages in excess of the gas bottle manufacturer recommended maximum.* Provide adequate barriers and protection against X-ray radiation during this test. Do not perform this test unless the contact displacement of each gas bottle is within manufacturer tolerances. The gas bottle must withstand the overpotential voltage applied with no evidence of distress or insulation failure observed by the end of the test. See Annex A for additional information.

Perform an overpotential test on each pole to ground with the switch closed and the poles not under test grounded. Limit test voltage in accordance with manufacturer instructions. Switches are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

## 5.35 Medium-Voltage Oil Switches

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Verify proper operation of the motor operator. Adjust motor operator limit switches and mechanical interlocks in accordance with manufacturer instructions, if needed.

Manually operate the switch. Verify correct blade alignment, blade penetration, travel stops, arc interrupter operation, and mechanical operation. Make necessary adjustments in accordance with manufacturer instructions.

Measure contact resistance across each switchblade and fuseholder. Check that each fuseholder has adequate support for the fuse and that the fuseholder is securely attached to the mounting base. Verify that each fuse has adequate contact integrity. Check that fuse clips are tight, secure, and free of corrosion.

Inspect gaskets in accordance with manufacturer instructions. Replace gaskets when needed.

Perform a contact/pole resistance test. See Annex A for additional information.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the switch closed and across each open pole for a minimum of one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for testing solid-state components. See Annex A for additional information.

Perform an overpotential test on each pole to ground with the switch closed and the poles not under test grounded. Limit test voltage in accordance with manufacturer instructions. Switches are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

Remove a sample of insulating liquid and perform tests in accordance with Annex A. Insulating liquid must comply with manufacturer instructions and recognized national standards. Recondition, reclaim, or replace insulating liquid in accordance with manufacturer instructions.

## 5.36 Cutout Switches

Manually operate the switch. Verify correct blade alignment, blade penetration, travel stops, latching mechanism, and mechanical operation. Make necessary adjustments in accordance with manufacturer instructions.

Measure contact resistance across each cutout. Check that each fuseholder has adequate support for the fuse and that the fuseholder is securely attached to the mounting base. Verify that each fuse has adequate contact integrity.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the switch closed and across each open pole for a minimum of one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform an overpotential test on each pole to ground with the cutout closed and the poles not under test grounded. Limit test voltage in accordance with manufacturer instructions. Switches are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

## 5.37 Circuit Switchers

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Perform all mechanical operation tests on the circuit switcher and its operating mechanism in accordance with manufacturer instructions.

Verify proper operation of the $SF_6$ interrupters in accordance with the manufacturer published data. Interrupters should operate in accordance with the manufacturer published data.

Verify that $SF_6$ pressure is in accordance with the manufacturer published data. Test for $SF_6$ gas leaks in accordance with manufacturer instructions. No leaks should be detected. When leaks are detected, safely de-energize the equipment, and remove from service. Consult the manufacturer for recommendations for repairing or replacing equipment.

Verify proper operation of the isolating switch in accordance with the manufacturer published data. The isolating switch should operate in accordance with the manufacturer design.

Verify proper operation of all interlocking systems and sequencing. The interlocking systems should operate in accordance with the system lockout design.

Verify correct operation of all indicating and control devices.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the circuit switcher closed and across each open pole for a minimum of one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for testing solid-state components. See Annex A for additional information.

Measure the minimum pickup voltage on trip and close coils. Results should be in accordance with the manufacturer published data.

Verify proper operation of auxiliary functions, such as electrical close and trip operation, trip and pickup indicators, trip-free, and anti-pump function, if so equipped, in accordance with manufacturer instructions. Circuit breaker open, close, trip, trip-free, anti-pump, and auxiliary features should function as designed by the manufacturer.

Verify proper trip and close operation by each protective and control device. Verify that interrupters trip properly. The results of open and close operation from protective and control devices should be in accordance with the system design. Interrupters should operate as designed.

Perform an overpotential test on each pole to ground with the circuit switcher closed and the poles not under test grounded. Limit test voltage in accordance with manufacturer instructions. Circuit switchers are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

## 5.38 Oil and Vacuum Automatic Circuit Reclosers

Perform all mechanical operator and contact alignment tests on both the recloser and the operating mechanism in accordance with manufacturer instructions. Closing and tripping action should be quick and positive. Mechanical operation and contact alignment should be in accordance with the manufacturer published data. Correct any binding, slow action, or delay in operation, or failure to trip or latch in accordance with manufacturer instructions.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the recloser closed and across each pole with the recloser open for a minimum of one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for testing solid-state components. See Annex A for additional information.

Perform static contact/pole resistance tests. See Annex A for additional information.

Remove a sample of insulating liquid and perform tests in accordance with Annex A. Insulating liquid must comply with manufacturer instructions and recognized national standards. Recondition, reclaim, or replace insulating liquid in accordance with manufacturer instructions.

Perform minimum pickup voltage test on the trip and close coils in accordance with manufacturer instructions. Minimum pickup voltage should be in accordance with the manufacturer published data.

Perform a power factor/dissipation factor test on each pole with the recloser in both the open and closed positions. Determine the tank loss index. Compare power factor or dissipation factor test results and tank loss index with the manufacturer published data, prior tests of similar reclosers, or test equipment manufacturer data. See Annex A for additional information.

Measure power factor or dissipation factor on each bushing. Tests should be made of each bushing using either the power factor or capacitance tap, if so equipped, or using a "hot collar" test using a test electrode around the outside shell of the bushing. Perform tests in accordance with the test equipment manufacturer published data. Power factor or dissipation factor and capacitance values should be within 10% of nameplate rating for bushings. Hot collar tests are evaluated on a milliampere/milliwatt loss basis, and the results should be compared to results from similar bushings. See Annex A for additional information.

Perform vacuum bottle integrity (overpotential) testing across each vacuum bottle with the contacts in the open position in strict accordance with the manufacturer published data. Do not exceed the maximum voltage recommended by the manufacturer for this test. *NOTE: Some DC high-potential test sets are half wave rectified and may produce peak voltages in excess of the vacuum bottle manufacturer recommended maximum.* Provide adequate barriers and protection against X-ray radiation during this test. Do not perform this test unless the contact gap of each vacuum bottle is within manufacturer tolerances. The vacuum bottle must withstand the overpotential voltage applied.

Perform an overpotential test on each phase with the recloser closed and the poles not under test grounded. Limit test voltage in accordance with manufacturer instructions. Reclosers are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

Test protective and control functions in accordance with manufacturer instructions.

Maintain instrument transformers in accordance with Section 5.40.

Maintain all metering and instrumentation in accordance with Section 5.41.

## 5.39 Oil-Filled Automatic Sectionalizers

Record the as-found and as-left operation counter readings. Ensure that the operations counter only advances one digit per close-open cycle.

Perform all mechanical operator and contact alignment tests on both the sectionalizer and the operating mechanism in accordance with manufacturer instructions. Closing and tripping action should be quick and positive. Mechanical operation and contact alignment should be in accordance with the manufacturer published data. Correct any binding, slow action, or delay in operation, or failure to trip or latch in accordance with manufacturer instructions.

Perform insulation resistance tests on each pole, phase-to-phase and phase-to-ground with the sectionalizer closed and across each pole with the sectionalizer open for a minimum of one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional information.

Perform contact/pole resistance tests. See Annex A for additional information.

Remove a sample of insulating liquid and perform tests in accordance with Annex A. Insulating liquid must comply with manufacturer instructions and recognized national standards. Recondition, reclaim, or replace insulating liquid in accordance with manufacturer instructions.

Perform an overpotential test on each phase-to-phase and each phase-to-ground. Limit test voltage in accordance with manufacturer instructions. Reclosers are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

Verify the sectionalizer counting function by applying a simulated fault current that is greater than 160% of the continuous current rating. The operations counter should advance one digit per open/close cycle. Verify proper lockout operation for all sectionalizer counting positions. The lockout function should operate in accordance with the manufacturer published data.

Verify proper reset of the trip actuator. Measure the reset timing. Trip actuator operation and reset timing should be in accordance with the manufacturer published data.

Perform a power factor/dissipation factor test on each pole with the sectionalizer in both the open and closed positions. Determine the tank loss index. Compare power factor or dissipation factor test results and tank loss index with the manufacturer published data, prior tests of similar sectionalizers, or test equipment manufacturer data. See Annex A for additional information.

Measure power factor or dissipation factor on each bushing. Tests should be made of each bushing using either the power factor or capacitance tap, if so equipped, or using a “hot collar” test using a test electrode around the outside shell of the bushing. Perform tests in accordance with the test equipment manufacturer published data. Power factor or dissipation factor and capacitance values should be within 10% of the nameplate rating for bushings. Hot collar tests are evaluated on a milliampere/milliwatt loss basis, and the results should be compared to results from similar bushings. See Annex A for additional information.

## 5.40 Instrument Transformers

When installed as part of an assembly, check instrument transformers for signs of dielectric stress on insulating members, such as evidence of corona erosion, markings, or tracking paths. *NOTE: Ultrasonic detection and light amplification or night-vision equipment is useful for detecting corona.* See Section 5.7 for additional information.

Measure resistance through inspect bolted electrical connections using a low-resistance ohmmeter. See Annex A for additional information.

Verify correct primary and secondary fuse sizing for voltage transformers.

Verify that current transformer and potential transformer winding ratios correspond to drawings and are appropriate for the application.

Perform insulation resistance testing of each current transformer primary winding with the secondary winding grounded, and on wiring to ground at 1000VDC for one minute in accordance with Annex A. Perform insulation resistance testing of each potential transformer, including coupling-capacitor voltage transformers (CCPT), from each winding-to-winding and from each winding-to-ground for one minute in accordance with Annex A. Follow manufacturer instructions for performing insulation resistance testing on instrument transformers with solid state components not rated for the applied test voltages. Test results should be in accordance with Annex A.

Perform a polarity test for each instrument transformer in accordance with IEEE C57.13.1. Polarity results should agree with transformer markings.

Perform a ratio verification test for CTs using the voltage or current method in accordance with IEEE C57.13.1. Ratio errors should not be greater than values shown in IEEE C57.13.

Measure the transformer turns-ratio at the as-found tap position, if so equipped, using a turns-ratio test set.

Perform an excitation test on CTs used for relaying applications in accordance with IEEE C57.13.1. Excitation results should match the curve supplied by the manufacturer or be in accordance with IEEE C57.13.1.

Measure current circuit burdens at CT terminals. Measure voltage circuit burdens at voltage transformer (PT and CCPT) terminals. Compare measured burdens to instrument transformer ratings.

Perform dielectric withstand voltage tests on the CT primary winding with the secondary grounded. Perform a dielectric withstand test for PTs and CCPTs on the primary windings with the secondary windings connected to ground for one minute. Conduct dielectric withstand tests in accordance with

IEEE C57.13, including the maximum recommended dielectric withstand test voltage. The transformer is considered to have passed the test if no evidence of distress or insulation failure is observed by the end of the test.

Perform insulation power factor or dissipation factor tests in accordance with the manufacturer published data, test equipment instructions, and Annex A. Measured values should be in accordance with instrument transformer manufacturer or test equipment manufacturer published data.

Verify that CT current circuits and that potential circuits are grounded and have only one grounding point in accordance with ANSI/IEEE C57.13.3, unless otherwise permitted by the NEC to be ungrounded, such as current transformer secondaries connected in a three-phase Delta configuration or circuits where the primary windings are connected to circuits of 1000 volts or less with no live parts or wiring that are either exposed or accessible to other than qualified persons.

Measure the capacitance of CCPT capacitor sections. Capacitance of capacitor sections of CCPTs must be in accordance with the manufacturer published data.

## 5.41 Protective Relays and Metering Devices

Exercise caution when working with energized secondary CT circuits. Short circuit secondary CT circuits. Do not open the secondary circuit of an energized current transformer, which will produce a very high voltage that can be lethal. See Section 3. Short circuit secondary circuits in accordance with system and equipment design and in accordance with manufacturer instructions. Remove short circuits upon completion of testing and maintenance.

Verify that necessary documentation is available, such as the manufacturer instructions, one-line diagram, provided by others, and the coordination study, if available, provided by others, and that suitable test instruments necessary for testing and maintaining protective relays and metering devices are available prior to the start of work.

If testing and maintenance of protective relays and metering devices occurs with equipment energized and in service where single-phase relays are installed, remove only one relay at a time to retain system protection and control during the work.

Inspect meters, relays, and cases for physical damage and broken parts, especially where subject to movement. Check for pinched wires in doors or access panels.

Clean relays and cases. If relay design permits, remove each relay from its case to inspect and clean. Inspect for loose screws, friction in moving parts, iron filings between the induction disk and permanent magnet, and any evidence of distress with the relay. Inspect meters and relays for foreign material, particularly in disk slots of damping and electromagnets. Remove any foreign material from the case.

Verify connections in accordance with single line meter and relay diagrams. Tighten case connections in accordance with manufacturer instructions. Check solenoid coils, armatures, and circuit boards for evidence of overheating. Verify the tightness of mounting hardware and connections.

Inspect covers for correct gasket seal. Clean cover glass. Clean connection paddles and/or knife switches. Inspect shorting hardware, case-shorting contacts, connection paddles, and/or knife switches. Verify the target reset.

Verify disk clearances. Verify contact clearance and spring bias. Inspect spiral spring convolutions. Spiral spring should be concentric and show no signs of overheating. Inspect disks and contacts for freedom of movement, end play, alignment of rotating disk(s) and correct travel. Contacts should be clean and make good contact. Burnish contacts as needed. Fine silver contacts should only be cleaned using a burnishing tool. Inspect bearings and/or pivots. Bearings and pivots should be clean and allow freedom of movement. Make adjustments in accordance with manufacturer instructions.

Perform insulation resistance tests on protective and control relays from circuit-to-frame in accordance with relay or metering component and test instrument manufacturer instructions. Disconnect and isolate conductors, components, and equipment normally connected to equipment under test, including phase and neutral connections, surge protective devices, meters, relays, and control power and instrument transformers. Ground conductors, components, and equipment not being tested. Follow the manufacturer instructions for allowable testing procedures for solid-state and microprocessor-based relays. *NOTE: Do not perform insulation resistance testing of solid state, electronic devices, relays or meters. Perform diagnostic tests on electronic, solid-state components in accordance with manufacturer instructions.*

Inspect targets and indicators. Determine the pickup and dropout of electromechanical targets. Pickup and dropout should be in accordance with the manufacturer specifications. Verify the correct operation of all light-emitting diode indicators. Set the contrast for liquid-crystal display readouts.

Determine the accuracy of all meters and verify watthour meter operation. Verify the accuracy of meters at all cardinal points. Meter accuracy should be in accordance with the manufacturer specifications. Calibrate watthour meters according to manufacturer published data, if needed. Calibrate all meters at mid-scale. *NOTE: Calibration instrument precision should be 50% or less than the precision of the instrument being tested. For example, if the instrument being tested has a precision of plus or minus 10%, the precision of the calibration instrument should be plus or minus 5% or better.* Calibrate watt-hour meters to 0.50-percent. Calibration should be within the manufacturer specified tolerances. Verify instrument multipliers. Multipliers should be in accordance with specified system design.

Set relays and verify proper fuse sizes and types in accordance with manufacturer instructions, one-line drawings, if applicable, and coordination study, if available, provided by others. Test meters and protective relays at the specified settings.

- Timing Relay (ANSI Device Number 2 or 62): Determine the time delay. Verify proper operation of the instantaneous contacts.
- Distance Relay (ANSI Device Number 21): Determine the maximum reach. Determine the maximum torque angle and directional characteristic. Determine the offset.
- Volts Per Hertz Relay (ANSI Device Number 24): Determine the pickup frequency at rated voltage. Determine the pickup frequency at a second voltage level. Determine the time delay.
- Synchronism-Check Relay (ANSI Device Number 25): Determine the closing zone at rated voltage. Determine the maximum voltage differential that permits closing at zero degrees. Determine the live line, live bus, dead line, and dead bus set points. Determine the time delay. Verify the dead bus/live line, dead line/live bus, and dead bus/dead line control functions.
- Undervoltage Relay (ANSI Device Number 27): Determine the dropout voltage. Determine the time delay. Determine the time delay at a second point on the timing curve for inverse time relays.
- Directional Power Relay (ANSI Device Number 32): Determine the minimum pickup at maximum torque angle. Determine the contact closing zone. Determine the maximum torque angle. Determine the time delay. Verify the time delay at a second point on the timing curve for inverse time relays. Perform phase angle and magnitude contribution tests to vectorially prove polarity and connection of differential and directional relays.
- Loss of Excitation Relay (ANSI Device Number 40): Determine the maximum reach. Determine the maximum torque. Determine the offset.
- Reverse Phase or Phase Current Balance Relay (ANSI Device Number 46): Determine the pickup of each unit. Determine the percent slope. Determine the time delay.
- Negative Sequence Current Relay (ANSI Device Number 46N): Determine the negative sequence alarm level. Determine the negative sequence minimum trip level. Determine the maximum time delay. Verify two points on the

time-current characteristic curve.

- Phase Sequence Voltage Relay (ANSI Device Number 47): Determine the positive sequence voltage to close the normally open contact. Determine the positive sequence voltage to open the normally closed contact (undervoltage trip). Verify the negative sequence trip. Determine the time delay to close the normally open contact with the sudden application of 120% of pickup. Determine the time delay to close the normally closed contact upon removal of voltage when previously set to rated system voltage.
- Machine or Transformer Replica-type Thermal Relay (ANSI Device Number 49R): Determine the time delay at 300% of setting. Determine a second point on the operating curve. Determine the minimum pickup.
- Machine or Transformer Temperature Relay (ANSI Device Number 49T): Determine the trip resistance. Determine the reset resistance.
- Instantaneous Overcurrent Relay (ANSI Device Number 50): Determine the pickup. Determine the dropout. Determine the time delay.
- Breaker Failure Relay (ANSI Device Number 50BF): Determine current supervision pickup. Determine time delays. Test all input and output contacts that are used.
- AC Time Overcurrent Relay (ANSI Device Number 51): Determine the minimum pickup. Determine the time delays at two points on the time current curve.
- Power Factor Relay (ANSI Device Number 55): Determine the tripping lead and lag angle. Determine the enable time delay. Determine the operate time delay.
- Overvoltage Relay (ANSI Device Number 59): Determine the overvoltage pickup. Determine the time delay to close the contact with the sudden application of 120% of pickup.
- Voltage Balance Relay (ANSI Device Number 60): Determine the voltage difference to close the contacts with one source at rated voltage.
- Transformer Sudden Pressure Relay (ANSI Device 63): Determine the rate-of-rise or the pickup level of suddenly applied pressure in accordance with the manufacturer specifications. Verify the operation of the 63 FPX seal-in circuit. Verify the trip circuit to a remote operating device.
- Ground-Protective Relay (ANSI Device Number 64): Determine the maximum impedance to ground causing relay pickup.
- AC Directional Overcurrent Relay (ANSI Device Number 67): Determine the directional unit minimum pickup at maximum torque angle. Determine the contact closing zone. Determine the overcurrent unit pickup. Determine the overcurrent unit time delay at two points on the time-current curve. Perform phase angle and magnitude contribution tests, to vectorially prove polarity and connection of differential and directional relays.
- AC Reclosing Relay (ANSI Device Number 79): Determine the time delay for each programmed reclosing interval. Verify lockout for unsuccessful reclosing. Determine the reset time. Verify the instantaneous overcurrent lockout.
- Frequency Relay (ANSI Device Number 81): Verify the frequency set points. Determine the time delay. Determine the undervoltage cutoff.
- Carrier or Pilot-Wire Receiver Relay (ANSI Device Number 85): Determine the overcurrent pickup. Determine the undercurrent pickup. Determine the pilot wire ground pickup level.
- Differential Relay (ANSI Device Number 87): Determine the operating unit pickup. Determine the operation of each restraint unit. Determine the slope. Determine the harmonic restraint. Determine the instantaneous pickup. Perform phase angle and magnitude contribution tests, to vectorially prove polarity and connection of differential and directional relays.

For multi-function solid-state and microprocessor-based relays, perform manufacturer recommended tests and self-testing of relays. Document functional settings of relays using printouts or by scrolling through relay settings. Record the model number, style number, serial number, firmware revision, software revision, and rated control voltage. Download all events from the event recorder in filtered and unfiltered mode before performing any tests on the relay. Download the sequence-of-events recorder prior to testing the relay. Verify the proper operation of light-emitting diodes, display, and targets. Record the passwords for all access levels. Clean the front panel and remove foreign material from the case. Verify that the frame is grounded in accordance with manufacturer instructions. Download settings from the relay. Print a copy of the settings for the report and compare the settings to those specified in the coordination study, if available, provided by others. Record the time and date from the display and determine the difference between the display and the actual time and date, if any. Apply voltage or current to all analog inputs and verify correct registration of the relay meter functions. Check the functional operation of each element used in the protection scheme as described above for each relay function. Check the operation of all active digital inputs. For pilot schemes, perform a loop-back test to check the receive and transmit communication circuits. For pilot schemes with direct transfer trip (DTT), perform transmit and received DTT at each terminal. Upon completion of testing, reset all minimum/maximum recorders, fault counters, sequence of events recorder, and all event records. Verify all inputs, outputs, internal logic, and timing elements used in protection, metering, and control functions. Verify that measurements and indications are consistent with energized system loads.

Verify that each set of relay contacts perform its intended function in the control scheme including breaker trip tests, close inhibit tests, 86 lockout tests, auxiliary relays, and alarm functions.

Use the manufacturer recommended tolerances when other tolerances are not specified. When critical test points are specified in contract documents or engineering reports, calibrate the relay to those points even though other test points may be out of tolerance.

See NECA 430 for additional guidance.

## 5.42 Outdoor Bus Structures

Inspect insulating materials and standoff insulators for signs of contamination, dirt, grease, grime, and oil. Vacuum to remove dust and other loose debris. Use clean lint-free rags and solvents only if recommended by the manufacturer, if needed, to remove hardened or encrusted contamination.

Measure the resistance of bolted connections in accordance with Annex A. Compare resistance values to the results from similar connections. Investigate values that deviate by more than 50% of the lowest value from similar bolted connections.

For equipment rated less than 46kV, perform insulation resistance tests on each bus, phase-to-ground with the other phases grounded using test voltage levels in accordance with manufacturer instructions. Consult the manufacturer for recommendations when insulation resistance values are less than the manufacturer published data. See Annex A for additional information.

Perform an overpotential test for a minimum of one minute on each bus phase, phase-to-ground with other phases grounded in accordance with the manufacturer published data. Limit test voltage in accordance with manufacturer instructions. Outdoor bus structures are considered to have passed if no evidence of distress or insulation failure is observed by the end of the total time of voltage application. See Annex A for additional information.

Perform insulation power factor or dissipation factor tests on each bus phase, phase-to ground with other phases grounded, in accordance with the manufacturer published data, test equipment instructions, and Annex A. Measured values should be in accordance with instrument transformer manufacturer. test equipment manufacturer published data, or prior test results.

## 5.43 Gas-Insulated Equipment (GIE)

Follow the safety guidance for pressurized SF6 gas systems found in Section 3.9.

A gas-insulated substation might include other GIE. Refer to the appropriate sections for gas-insulated circuit breakers, switches, transformers, capacitors, bushings, terminations, buses, and associated enclosures, and their associated controls and monitoring equipment.

In addition to the general guidance provided by this Recommended Practice, follow all manufacturer instructions for inspecting, testing, and maintaining specific equipment.

Some GIE is permanently sealed and is not serviceable. Such equipment is typically provided with a visual means of checking for sufficient levels of gas in the equipment. Replace such sealed units when there is a visual indication of the loss of gas.

Check GIE gas density gauges to monitor internal temperature and pressure, if so equipped, to verify sufficient quantities of gas needed to maintain the equipment ratings. Add gas to GIE in accordance with manufacturer instructions when needed.

Ensure that GIE is electrically isolated, de-energized, grounded, and locked/tagged out prior to performing any testing or maintenance. Do not depressurize GIE prior to de-energizing and grounding the equipment. See Section 3 for additional guidance.

Ensure that dust, dirt, and other contaminants do not enter GIE. Clean areas around GIE access locations, such as doors, covers, and panels, including supporting steel and other parts from which dust, dirt, or other contaminants could enter the enclosure, using a vacuum or by wiping with clean, lint-free cloths.

Use appropriate gas handling equipment, such as gas processing carts or trailers, that include vacuum/pumping equipment, gas filtration equipment including dryers, and gas storage tanks. Use a suitable heat source when needed to counteract the chilling effect of expanding gas when filling directly from gas cylinders or gas-handling equipment. Follow manufacturer requirements for gas purity when evacuating, handling, processing, filling and refilling GIE.

Evacuate all gas from the compartment to 133 Pa using a closed evacuation system. Filter the gas using a filter capable of removing particulates caused by arc decomposition of gas. Refill the compartment with dry air to atmospheric pressure (101 kPa) prior to opening any access ports. Ensure proper ventilation and oxygen content prior to entering GIE enclosures.

Wear appropriate PPE, such as air respirators and disposable protective clothing covering all garments, including shoes, head, and hands, when initially entering equipment to remove the solid by-products of arc decomposition of gas.

Working quickly, remove the solid by-products of arc decomposition using a commercial-type HEPA filter vacuum and using non-metallic accessories. Take precautions to avoid breathing dust particles that pass through the vacuum cleaner exhaust air. Wipe down vacuumed areas using manufacturer approved solvents. *NOTE: With prolonged exposure to moist air, the solid by-products of arc decomposition will become tacky and more difficult to remove, and will create toxic fumes.* See Section 3.9 for additional guidance.

When work is delayed, protect openings with suitable seals. Provide heat when needed to prevent condensation. When work must be delayed for an extended period of time, pressurize the system with dry air to a pressure of 136kPa to prevent condensation or the entrance of moisture in GIE.

Maintain the specific type of equipment in accordance with the appropriate Section of this Recommended Practice.

Follow manufacturer instructions when filling GIE. Refer to the manufacturer gas pressure and temperature curve found in the manufacturer instructions to achieve the required fill density. Allow sufficient time for the equalization of gas temperature during filling. Take several measurements after filling to ensure that the gas moisture content remains within acceptable limits. When moisture content rises to an unacceptable level, process the gas as required to remove excess moisture.

### 5.44 Grounding Systems

Building electrical grounding and bonding should be in accordance with NEC Article 250. Inspect grounding and bonding conductors, ground buses, and connections for conformance with NEC requirements. Verify that grounding and bonding conductors, including the grounded conductor or neutral, are sized in accordance with NEC requirements. Also, see NECA 331 for additional information.

Visually examine grounding conductors and pathways, including raceway couplings, fittings, and connectors. Electrical and mechanical connections should be free of corrosion. Check corroded components for dissimilar metals that have caused galvanic corrosion. Replace dissimilar metals or install suitable connectors listed for use with the dissimilar metals. Repair or replace damaged or corroded components.

Check the tightness of raceway connections. Tighten loose raceway connectors and fittings.

Inspect and clean grounding connections.

Inspect bolted electrical connections for high resistance using a low-resistance ohmmeter or using a calibrated torque wrench method. Similar bolted connections should have similar resistance values. Investigate values which deviate from those of similar bolted connections by more than 50% of the lowest value. Bolt-torque levels should be in accordance with manufacturer specifications.

Measure the voltage between the grounded conductor or neutral and the equipment-grounding conductor at multiple locations throughout the electrical power distribution system, as applicable. Measured voltage should be less than 0.1VAC at the main bonding jumper location. Due to voltage drop across the grounded or neutral conductor during normal equipment operation, measured voltage from neutral-to-ground is expected downstream from the main bonding jumper in energized circuits. Investigate measured voltage readings in excess of 3VAC or less than 0.5VAC in such locations to determine whether this indicates a grounding deficiency in the system.

Check for objectionable current flow on equipment grounding conductors using a true RMS ammeter. Investigate and correct any steady-state current flow on equipment grounding conductors.

Where installed, verify that lightning protections systems are installed with a separate grounding electrode system. Verify that the lightning protection grounding electrode system is bonded to the building electrical grounding electrode system. See Section 5.46 for additional information.

Perform three-point fall-of-potential tests in accordance with IEEE 81 on the main grounding electrode system. Conduct ground resistance testing when the earth is dry, and a minimum of 48 hours after the most recent precipitation. Record the ambient temperature, date, time, approximate water table level (as obtained from local geologists), type of earth materials, and measured earth resistivity. Test each ground rod individually, and test all ground rods interconnected as a system. *NOTE: Grounding electrodes that will not be accessible after installation, such as concrete-encased electrodes, should be provided with access wells, hand-holes, or similar means to enable periodic maintenance and testing of the ground system.* The resistance between the main grounding electrode and ground should be no greater than five ohms for large commercial or industrial grounding systems and 1.0 ohm or less for generating or transmission station grounding systems in accordance with IEEE 142.

Perform the two-point method test in accordance with IEEE 81 to determine the ground resistance between the main ground system and all major electrical equipment frames, system neutral, and/or derived neutral points. In general, maximum resistance to ground should be less than 5 ohms. Alternatively, perform ground continuity test between main ground system and equipment frame, system neutral and/or derived neutral point by passing a minimum of 10 amperes DC current between the ground reference system and the ground point to be tested. Measure voltage drop and calculate resistance by the voltage drop method. Investigate point-to-point resistance values which exceed 0.5 ohm.

Verify that the neutral is grounded only at the service equipment. Verify that the neutral is not grounded on the load side of the service disconnecting means enclosure. Coordinate ground testing and follow proper test procedures when performing insulation resistance testing on conductors and equipment.

After energizing, measure phase-to-phase, phase-to-neutral, and neutral-to-ground voltages to verify proper neutral-to-ground bonding.

## 5.45 Ground-Fault Protection of Equipment (GFPE) Systems

Conduct testing in accordance with manufacturer instructions, the NEC, and AHJ requirements. Maintain a written record of testing and make available to the authority having jurisdiction in accordance with NEC Section 230.95.

See NEC Section 230.95 and NECA 90 for performance testing and recordkeeping requirements for GFPE systems when first installed at the site.

For Healthcare Facilities and Critical Operations Power Systems, test each level of ground-fault protection. Ensure that all levels of ground-fault protection achieve 100% selectivity. See NECA 700 for additional guidance.

Complete testing and maintenance of the grounding system, Section 5.44, prior to testing and maintenance of GFPE systems.

Identify, mark, or otherwise label GFPE conductors, components, and connections prior to disconnecting, when needed. Maintain proper polarity and phasing when reconnecting GFPE conductors and components.

Inspect ground-fault protection system equipment and components for damage. Verify proper polarity of both the primary and the secondary circuits of CTs. Exercise extreme caution around current transformer circuits. A current transformer carrying primary current can develop high secondary terminal voltages if the secondary terminals are open-circuited. See Section 3.

Inspect the main bonding jumper. Verify that the grounded conductor is solidly grounded.

Check that the ground-fault sensor is properly installed and that conductors are properly connected and routed. Ensure that the ground fault sensor location is on the load side of the main bonding jumper termination. For ground-strap systems, the ground fault sensor should be installed on the main bonding jumper. For residual-ground fault systems, the ground fault sensor should be installed around all current-carrying conductors, including the neutral (grounded conductor) of three-phase, four-wire systems. Ensure that all conductors are routed in the same direction through the ground fault sensor, and that no grounding conductors are routed through the ground-fault sensor.

Prior to testing, ensure that all grounding conductors and connections, including the grounding electrode, neutral disconnect link, neutral system conductor, and main bonding jumper are installed.

Check all functions of the self-test panel, if so equipped. Verify trip operation, no trip test, and non-automatic reset.

Verify that pick up and time delay settings are in accordance with the coordination study, if available, provided by others.

Disconnect the neutral link and perform neutral insulation resistance testing. See Annex A for additional information. Record the insulation resistance, and replace the neutral link. System neutral-to-ground insulation resistance should be a minimum of one megohm.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for solid-state components. See Annex A for additional information.

Determine the relay pickup current by primary current injection at the sensor and the circuit interrupting device operated. Relay pickup current must be within 10% of the device dial or fixed setting, and should be greater than 90% of the pickup setting and less than 1200A or 125% of the pickup setting, whichever is smaller.

For summation type systems utilizing phase and neutral current transformers, including molded case circuit breakers that use an external neutral current transformer, verify correct polarities by applying current to each phase-neutral current transformer pair. Relays should operate when the current direction is the same relative to polarity marks in the two current transformers. Relay should not operate when the current direction is opposite relative to polarity marks in the two current transformers.

Measure the time delay by injecting 150% and 300% of pickup current into the ground-fault sensor. Electrically monitor and record total trip time. Relay timing must be in accordance with the manufacturer published time current characteristics curves but in no case longer than one second at 3000 amperes.

Verify that the minimum tripping voltage capability is 55% for AC systems and 80% for DC systems. The circuit interrupting device should operate properly.

Test the zone interlock system by simultaneous sensor current injection and monitor the zone blocking function. Test results should be in accordance with the manufacturer design.

Maintain instrument transformers in accordance with Section 5.40. Verify that instrument transformers are clean and that terminals and connections are tight.

### *5.45.1 Ground-Fault Indicators*

Inspect ground-fault detector signal elements, such as lamps, horns, and buzzers for proper operation. Operate audible devices to ensure proper operation. Check for loose connections and damaged wiring.

Check ground-fault indicator lamps daily or weekly for proper operation where ground-fault indicator lamps are connected phase-to-ground on an ungrounded system, keeping in mind that a ground-fault will cause the lamp on that phase to be dark, while the lamps on the other two phases will be brighter than normal. Investigate any lamps that are dark. Replace burned out lamps.

Investigate and clear the cause of a ground-fault when a ground-fault is detected.

## 5.46 Lightning Protection Systems

Maintain lightning protection systems in accordance with NFPA 780, and in accordance with the following general guidance.

In general, it is recommended that lightning protection systems be visually inspected at least annually. In areas where severe climatic changes occur, it might be advisable to visually inspect systems semiannually or following extreme changes in ambient temperatures. Complete, in-depth inspections and electrical testing of lightning protection system should be completed every 3 to 5 years, with in-depth inspections and electrical testing of lightning protection systems for critical or particularly sensitive facilities recommended every 1 to 3 years, depending on occupancy or the environment where the protected structure is located.

In addition to periodic inspections, inspect lightning protection systems whenever any alterations or repairs are made to a protected structure, or following any known lightning discharge to the system.

Document and report any indication of damage produced by a lightning strike to a structure or its lightning protection system to the appropriate authority. Where permitted by the AHJ, obtain photographic records of damage suspected to have resulted from a lightning strike prior to making repairs.

Performing work on the lightning protection system during a thunderstorm may result in damage to property and equipment and personal injury or death. Do not conduct inspections, testing, or maintenance during the threat of a thunderstorm.

Visually inspect lightning protection systems. Verify that the system is generally in good repair. Check the general condition of air terminals, conductors, and other components. Check the general condition of corrosion-protection measures. Check for loose connections or corroded connections. Tighten clamps and splicers, as required. Check for the evidence of vibration. Verify that all roof conductors, down conductors, and grounding conductors are intact, connected, and without corrosion. Verify that connectors used for copper-to-aluminum connections are listed for use with both copper and aluminum. Verify that all conductors and system components are securely fastened to their mounting surfaces and are protected from mechanical damage or displacement as required. Refasten and tighten components and conductors as required. Check for any equipment or building additions or alterations to the protected structure that would require additional lightning protection that is absent. Maintain low-voltage surge protective devices in accordance with Section 5.47.

Electrically test lightning protection systems at least every 14 months using test instruments designed specifically for earth resistance testing in accordance with the test equipment manufacturer instructions. Where the location experiences significant seasonal variations in temperature and rainfall or other precipitation, stagger ground resistance testing during the different seasons to assess the effectiveness of the lightning protection grounding electrode system under differing environmental conditions. The DC resistance of any single object bonded to the lightning protection system should not exceed 200 milliohms. Document test measurement data of resistance to earth and bonding tests and make available for a time period acceptable to the AHJ.

Test the continuity of concealed lightning protection system components and conductors. Perform ground resistance testing of the grounding electrode system termination and at individual grounding electrodes, if disconnecting means have been provided, and compare with prior test results. Investigate significant deviations in test results. See Section 5.44 for additional guidance.

## 5.47 Low-Voltage Surge Protective Devices (SPDs)

Record the stroke counter and reset, if applicable.

Check for proper operation using the self-test feature, if so equipped. Investigate any fault and alarm indicators, such as open circuit and over temperature. Replace failed components, or replace the SPD in its entirety. Consult the manufacturer for recommendations.

Clean SPDs. Remove all surface contamination.

Verify that line and ground connections are tight. Verify that each SPD has a dedicated conductor that is attached to the ground bus or the grounding electrode.

Perform insulation resistance testing from the phase terminal to the case for a minimum of one minute using voltage levels in accordance with manufacturer instructions. The insulation resistance of all SPDs of the same rating and type should be approximately the same value. Minimum resistance levels should be in accordance with the manufacturer published data. See Annex A for additional information.

Test the ground connection for continuity. Measure the resistance of the ground connection. The resistance between the SPD ground terminal and the ground system should be less than 0.5 Ohm.

## 5.48 Medium and High-Voltage Surge Protective Devices (SPDs)

Visually inspect SPDs. Check surfaces for dirt and contamination. Check metal surfaces for rust. Check porcelain materials for cracks, chips, and breaks. Replace SPDs when the porcelain is damaged to the extent that the creepage path over its surface is reduced or the porcelain glazed surface is seriously damaged.

Clean SPDs. Remove all surface contamination. When approved by the manufacturer, apply silicone grease to porcelain surfaces in particularly contaminated areas. Remove and reapply silicone grease annually, as needed.

Verify that line and ground connections are tight. Verify that each SPD has a dedicated conductor that is attached to the ground bus or the grounding electrode.

Verify that the stroke counter is correctly mounted and electrically connected, if applicable.

Perform insulation power factor testing of SPDs in accordance with manufacturer instructions. See Annex A for additional information.

Perform insulation resistance testing from the phase terminal to the case for one minute using voltage levels in accordance with manufacturer instructions. The insulation resistance of all SPDs of the same rating and type should be approximately the same value. Minimum resistance levels should be in accordance with the manufacturer published data. See Annex A for additional information.

Measure the SPD watts-loss or milliwatts-loss. Compare results with similar SPDs and with test equipment manufacturer published data. See Annex A for additional information.

When SPD testing indicates the presence of contaminants, clean the internal porcelain surfaces of non-sealed SPDs in accordance with manufacturer instructions.

Test the ground connection for continuity. Measure the resistance of the ground connection. The resistance between the SPD ground terminal and the ground system should be less than 0.5 Ohm.

## 5.49 Wiring Devices

Inspect wiring devices for wear, corrosion, damage, breakage, cracking, distortion, and exposed contacts. Replace damaged and defective devices. Provide recommendations for relocating devices, installing a guarded operating means, or installing low-profile devices where damage is caused by repeated abuse.

Verify that devices are suitable and listed for use in adverse environments, such as highly corrosive environments, high-temperature locations, or hazardous (classified) locations.

For devices used in hazardous (classified) locations, inspect all mechanically and electrically interlocked plugs and receptacles for proper operation and for excessively worn or broken parts. Replace devices as required. Clean all parts and surfaces of devices of foreign material or corrosion. Inspect flame paths to ensure that safe gaps are not exceeded and that no scratches are on the ground joints. Verify that all screws holding the receptacle to the body are installed and tight. Verify that covers and threaded openings are properly tightened. Verify that the plug and receptacle markings agree with the present classification of the area in regard to the class, group, and division.

Verify that receptacle contacts retain inserted plugs firmly. Replace receptacles where unassisted disengagement of the plug from the receptacle is a recurring problem. Test the retention force of the grounding contact of each receptacle (except pin-and-sleeve and locking-type receptacles) using a receptacle tension tester. Replace devices with less than 115g (4 ounces) of retention force. For pin and sleeve devices, receptacle contacts should retain inserted plugs firmly. Replace receptacles found to contain corroded, deformed, or mechanically damaged contacts. Consider replacing plugs corresponding to pin-and-sleeve receptacles at the same time as replacing worn receptacles as both the male and female contacts are likely to have commensurate wear.

Test every installed receptacle and wiring device for proper polarity and grounding. Test for open ground, reversed polarity, open hot, open neutral, hot and ground reversed, and neutral and hot open. Verify the continuity of the grounding circuit in each receptacle and wiring device.

Check for loose terminations or insufficient contact pressure for devices with evidence of abnormal heating of the device or the device face, attachment plug, or connector insulation, or if there is evidence of arcing, tracking, or burning of the device or other damage. Replace damaged and defective devices.

Verify that wiring devices are firmly fastened to the box and that coverplates are secured in place. Where used, verify that gaskets are installed properly and intact. Tighten loose devices and coverplates. Adjust gaskets as needed. Replace damaged gaskets.

Check switches and other control devices for proper operation. Replace switches and control devices that are broken or where the mechanism, either mechanical or solid-state, does not function in a normal manner.

Check that wall plates and cover plates are suitable for the environment, location, and application, such as weatherproof-while-in-use covers for wet locations and outdoors. Replace cracked, bent, or broken wall plates and cover plates and spring-door covers.

Verify that boxes used for wiring devices are rigidly secured in place. Ensure that locknuts and conduit fittings are made up tight, where accessible. Check boxes for proper wiring fill where observed. Ensure that unused knockouts are closed. Where surface-mounted boxes sustain repeated abuse, provide recommendations for flush mounting or installing additional guarding means.

Inspect the cord clamps and strain relief fittings of pin and sleeve devices to ensure that they are tight and that the outer cord jacket is completely within the clamping area.

Inspect insulators and contacts of pin and sleeve devices for discoloration of the insulator or pitting of contacts. Abnormal heating on the plug surface might be caused by loose terminations, overloading, high ambient temperature, or equipment malfunction. Inspect the assembly of individual conductors to terminals. Individual conductor strands should be properly confined and terminations made tight. Do not solder conductor strands when used with binding head screws, which can cause overheating.

Replace devices if the plug or connector housing or interior is cracked or distorted, if pieces are missing or damaged, or if the pins or contacts are bent, missing, or discolored. Replace receptacles or plugs if their insulation is cracked, broken, or discolored.

Test each GFCI receptacle by pushing the TEST button and then the RESET button on at least a monthly basis in accordance with manufacturer instructions. Record the results and dates of tests. GFCI receptacles must be properly wired for testing to be considered accurate.

Replace GFCI receptacles whenever the GFCI indicator lights are warning of internal component failure (see manufacturer instructions for the "auto-monitoring" safety feature), and when GFCI receptacles repeatedly trip following each "Reset" operation or do not shut off power when the "Test" button is operated.

Test AFCI receptacles by pushing the TEST button and then the RESET button on at least a monthly basis in accordance with manufacturer instructions. *NOTE: In accordance with the listing and labeling (certification) of the product of UL1699, the only recognized method of testing AFCI receptacles is using the push-to-test and reset buttons as described in the manufacturer instructions.*

Replace defective AFCI and GFCI devices and retest. If the new receptacle provides the same result, troubleshoot devices, fixed wiring, and appliances connected to the circuit in accordance with NECA 169. Correct any deficiencies found and retest.

See NECA 130 and NECA 169 for additional guidance.

## 5.50 Luminaires and Lighting Systems

Retrofitting existing luminaires by removing the existing light source and photometric components and installing a different (newer, more energy efficient technology) light source and photometric components is beyond the scope of this Recommended Practice. Validating life safety compliance of emergency lighting equipment and systems is beyond the scope of this Recommended Practice.

Determine the approximate age of the luminaires. Determine the approximate age of the lamps. Estimate the total hours of lamp operation and compare with the rated life expectancy (hours of operation) of the lamps. Notify the owner that, when lamps have reached 70% to 80% of their life expectancy, group relamping, where all lamps are replaced at the same time, is recommended.

Verify that luminaires are listed for the location and the purpose. Verify that lamp types and ratings are appropriate for the luminaire and ballast, if applicable, and meet the manufacturer specifications.

Clean luminaires and components, lamps, reflectors, and lenses periodically, using periodic light meter readings to establish cleaning intervals when lighting levels fall approximately 15% to 20%, corrected for lamp lumen depreciation, if applicable. *NOTE: Incandescent or filament, fluorescent, and high-intensity discharge or HID light output depreciate at different rates, producing less light as they age.* Follow manufacturer instructions for washing and drying luminaire components. Avoid using strong alkaline or abrasive cleaning solutions.

Clean luminaires and components, reflectors and lenses, when replacing lamps as required by the type of lighting technology employed. When economically feasible, combine luminaire cleaning with group relamping, typically at 70% to 80% of their rated average life or when light output falls below a desired level. *NOTE: Cleaning may be required between group relamping for a particularly dirty environment.*

When cleaning or when replacing lamps, inspect the sockets, hangers, reflectors, and lenses for physical damage, cracks, breakage, and missing pieces. Replace damaged and missing components.

After cleaning luminaires, measure and record lighting levels in all areas after sunset to reduce the effect of daylight. Compare to prior lighting levels. Correct lighting levels for lamp lumen depreciation. Notify the owner when lighting levels fall approximately 15% to 20%, corrected for lamp lumen depreciation, if applicable.

Ensure that replacement lamps are identical to the existing lamps. Verify the type, color, wattage and voltage ratings of the lamps. Ensure that lamps are compatible with the existing ballast technology. When lamps are being replaced with more energy-efficient lamps during group relamping, verify that the replacement lamps are compatible with the existing ballast technology. Ensure that Metal Halide lamps are of the appropriate type for the luminaire and the orientation of the lamp when operating.

Measure the operating voltage at the luminaire. Investigate and correct any voltages outside of the luminaire rated operating voltage range.

Verify that luminaires are properly grounded in accordance with the NEC, including grounding and bonding requirements for metallic fixture whips, metallic armored cable wiring systems, metallic sheathed cable, and metallic outlet boxes. Notify the owner of any deficiencies found.

In indoor locations other than dwellings and associated accessory structures, when replacing existing ballasts in fluorescent luminaires without disconnecting means that use double-ended lamps and that contain one or more ballasts that can be serviced in place, install a disconnecting means either internal or external to the luminaire, except for (See NEC Section 410.130(G)(1)):

- Luminaires installed in hazardous (classified) location(s)
- Luminaires that provide emergency illumination required in NEC Section 700.16
- Cord-and-plug-connected luminaires, as an accessible separable connector or an accessible plug and receptacle is permitted to serve as the disconnecting means
- Where more than one luminaire is installed and supplied by other than a multiwire branch circuit, when the design of the installation includes disconnecting means where the illuminated space cannot be left in total darkness

Perform operational tests on lighting and lighting control systems, including testing all luminaires, dimmers, switches, switching configurations, and controls, such as occupancy sensors, time clocks, and daylight harvesting systems. Test lighting controls and integral components for proper operation to ensure that they respond appropriately to changing conditions and parameters, as needed. Walk test areas with occupancy sensors with the owner or owner's representative. Adjust sensitivity and time delays as needed. For programmable lighting control systems, simulate time-changes to witness automatic lighting controls. Verify proper occupant override operation. Record any issues observed during testing. Test daylight harvesting systems during daylight hours. Verify that controls automatically dim lighting in response to the available daylight and that changes in light levels are gradual so as to not distract the occupants. When needed, adjust lighting control systems in accordance with manufacturer instructions.

See NECA 500 for guidance for troubleshooting incandescent, halogen, fluorescent, and HID light sources.

See NECA/IESNA 500, NECA/IESNA 501, and NECA/IESNA 502 for additional information.

## 5.51 Automatic Transfer Switches (ATSs)

Operate, test, maintain, repair, and calibrate ATSs in accordance with manufacturer instructions. Test and maintain ATSs installed for life safety systems, emergency systems, and critical operations power systems (COPS) in accordance with applicable National, State, and local codes and regulations.

Coordinate the testing and maintenance of ATSs with the owner's operational schedule for the facility as some tasks could interrupt power to the load. Carefully review the tasks to be performed and obtain agreement prior to beginning work. Ensure that contingency plans are in place.

Verify that manual transfer instructions and warning labels are attached and visible. Perform manual transfer operation. Verify positive mechanical interlocking between normal and alternate sources.

Check transfer switches for completeness of assembly. Check switches for proper alignment, and for loose parts and insulation damage. Verify proper grounding.

For ATSs equipped with a bypass isolation switch, verify that the bypass isolation switch bypasses and electrically isolates the transfer switch from both sources and the load. Verify that the bypass isolation switch is capable of manual operation to connect the load to either source. Verify that the transfer switch is reconnected without a load interruption greater than the maximum time, in seconds, specified by the type of system.

Perform insulation resistance tests on all control wiring. Follow manufacturer instructions for solid-state components. See Annex A for additional information. Verify the tightness of all control connections.

Perform contact/pole resistance tests with the ATS load connected to the normal source, with the ATS load connected to the emergency source, with the ATS load supplied from the normal source in bypass mode, if applicable, and with the ATS load supplied from the emergency source in bypass mode, if applicable. Investigate any readings greater than 25% of the average of all poles when the ATS is de-energized. See Annex A for additional information.

With both the normal and emergency sources de-energized, or with the ATS in bypass mode with the transfer switch isolated, measure the contact resistance across the connections, below. Do not use a digital low-resistance ohmmeters to test energized circuits. Investigate any values greater than 20% of the average value of all similar type connections. Correct any deficiencies found.

- Normal source conductors to the ATS normal source bus, including the grounded conductor or neutral for four-pole switches
- Emergency source conductors to the ATS emergency source bus, including the grounded conductor or neutral for four-pole switches
- Load conductors to the ATS load bus, including the grounded conductor or neutral for four-pole switches
- For three-pole switches, grounded conductor or neutral conductors across the connection

Perform infrared survey with the ATS load connected to the normal source, with the ATS load connected to the emergency source, with the ATS load supplied from the normal source in bypass mode, and with the ATS load supplied from the emergency source in bypass mode in accordance with Annex A. Correct any deficiencies found.

Remove all protective covers, insulating barriers, and arc chutes. Inspect main contacts and other current-carrying parts for signs of corrosion or overheating, using infrared survey and contact/pole resistance test results as a guide. Inspect contacts for excessive wear, burning, unusual pitting, or other erosion of the contact surface, and for beads of molten material. Do not file, burnish, or otherwise dress normally pitted contacts. Replace contacts that are unusually pitted, spattered, or excessively worn. Replace all contacts of multipole devices to avoid misalignment or uneven contact pressure.

Inspect insulating materials and standoff insulators for signs of contamination, dirt, grease, grime, and oil. Vacuum to remove dust and other loose debris. Use clean lint-free rags and solvents as recommended by the manufacturer, if needed, to remove hardened or encrusted contamination. Verify that all protective covers, insulating barriers, and arc chutes are installed prior to energizing ATSs.

Perform automatic transfer tests. Automatic transfers should operate in accordance with manufacturer instructions and/or system design requirements. *NOTE: Transfer tests will cause the emergency power source to start and the ATS to transfer the load. Obtain the approval of the owner prior to the work. Ensure that all affected personnel are notified of transfer tests prior to the work.*

- Simulate the loss of normal power
- Simulate the restoration and return to normal power
- Simulate the loss of emergency power while on emergency power. Test that the return to normal source time delay is automatically bypassed if the emergency power source fails.
- Simulate all forms of single-phase conditions and verify proper operation

For systems with multiple ATSs and one or more engine-generators that serve as the alternate power source, initiate a separate test of the engine-generator by simulating a power outage using the test switch on each ATS to verify that each ATS has means of producing a start signal for its respective generator that is independent of all other ATSs.

Verify the settings and proper operation of relays, timers, and control devices. Calibrate and set all relays and timers in accordance with Section 5.41. Control devices, timers, and functions should be in accordance with NFPA 110 and manufacturer instructions and/or system design requirements. Measure and record the following data and setpoints:

- Normal source voltage sensing relays, phase to phase, phase to ground, and phase to neutral, and frequency sensing relays
- Emergency source voltage sensing relays, phase to phase, phase to ground, and phase to neutral, and frequency sensing relays
- Load current each phase
- Engine start time (from crank start to source available light or relay pickup)
- Momentary override normal deviation, where provided
- Transfer time delay, where provided
- Return to normal source time delay, where provided
- Engine cooldown, where provided, and shutdown

Verify that the ATS is programmed with a minimum of a five-minute engine shutdown time delay for the unloaded running of the generator prior to shutdown to allow the engine to cool down. *NOTE: The cool down time delay is not required for small generators rated 15 kW or less with air-cooled prime movers, when a utility feeder is used as the emergency source of power to the ATS, or when the cool down timer is included with the engine control panel programming.*

Verify the load priorities, load add, load shed, block loading, load demand control, load optimization, and other operating and control features for systems with multiple generators and multiple ATSs. Review the load priorities and logic controls with the owner and make adjustments as needed to reflect changes to the system.

Ensure a program timing device is provided to automatically exercise the generator in accordance with manufacturer instructions and NFPA 110, Chapter 8 requirements. Transfer switches must automatically connect the load to the generator for a proscribed time period. In the event of a generator failure, the transfer switch must automatically return the load to normal power. Exercising timers are permitted to be located at the engine control panel in lieu of in the transfer switch. A program timing device is not required in health care facilities that provide scheduled testing in accordance with NFPA 99.

## 5.52 Engine-Generators

### *5.52.1 General*

Major maintenance and repairs of engine-generators is beyond the scope of this Recommended Practice. Consult the manufacturer for recommendations.

Test and maintain generators installed for life safety systems, emergency systems, and critical operations power systems (COPS) in accordance with applicable National, State, and local codes and regulations.

Coordinate the testing and maintenance of engine-generators with the owner's operational schedule for the facility. When required by contract, work order, or purchase agreement, provide portable engine-generators as needed to maintain generator power capabilities for the duration of testing and maintenance procedures, such as for emergency power applications.

Verify that the generator is mounted in such a manner to prevent combustible materials from accumulating under the generator. Inspect for and remove any foreign objects or loose debris, such as materials, trash, rags, paper, and leaves, that could be drawn into the generator or alternator air intakes. Ensure that the generator and the surrounding area are clean, dry, and free from obstructions. Ensure that all covers and guards are in place and secure.

Verify all generator functions. Verify all alarms, meters, emergency power off (EPO), auxiliary functions, remote annunciator panels, and communication and interlocks to the building automation system (BAS) or energy management system (EMS). Protective features, shutdowns, and alarms should operate in accordance with manufacturer instructions, system design requirements, and owner's requirements.

Maintain written documentation of inspections, operational tests, exercising, repairs, and modifications for emergency generators, including the date of the maintenance report, identification of the servicing personnel, notation of any unsatisfactory condition and the corrective action taken, including parts replaced, and testing of any repair in the time recommended by the manufacturer. Provide copies of all reports to the owner.

### *5.52.2 Mechanical Testing and Maintenance*

Recommended practices for testing and maintaining engines, fuel delivery systems, and other mechanical systems found in this Section are provided for informational purposes and shall only be completed by knowledgeable, skilled, and qualified persons working within their respective trades.

Clean up liquid spills and dispose of used liquids in accordance with all local, State, and Federal environmental regulations.

Change engine coolant, engine oil and filters, air filters, and fuel filters in accordance with manufacturer instructions and the owner's service schedule, whichever is more frequent.

Replace engine belts, hoses, and starting batteries in accordance with manufacturer instructions and owner's service schedule, whichever is more frequent.

Check the engine coolant level for engine-mounted and remote radiators. Inspect radiators for dust, dirt, debris, and other obstructions. Clean radiators as needed. Inspect radiators, expansion tanks, manifolds, brackets, mountings, clamps, fittings, hoses, and flexible connections for leaks. For remote radiators, inspect cooling towers and heat exchangers for leaks and verify proper operation of auxiliary or remote water pumps and/or fan motors.

Repair minor coolant leaks as needed. Add the manufacturer recommended engine coolant when required and bleed air from the system as needed. Verify proper operation of jacket water heater(s), if so equipped.

Check the engine oil level. Check for oil leaks. Repair minor engine oil leaks as needed. Add the manufacturer recommended engine oil when required.

When required, draw a sample of crankcase oil annually and test for trace metals in accordance with manufacturer instructions. Notify the owner of any deficiencies.

Inspect air filters and clean as needed.

Check starting battery electrolyte level and specific gravity monthly. Add distilled water or electrolyte as needed. Verify proper operation of the battery charger and/or alternator. Replace defective starting batteries immediately.

Inspect the engine governor/actuator linkage.

Inspect the fuel delivery system, tanks, pumps, piping, filters, and fuel/water separators for leaks or low level. Verify proper operation of fuel level gauges. For day tanks equipped with a drain valve, drain condensation from the day tank and check for contamination. Verify proper operation of fuel transfer pump(s), if installed. Verify fuel system, fuel storage tank, leak detection, and level and low fuel indication alarms. When required, draw a sample of fuel annually and test in accordance with ASTM Standards or the manufacturer recommendations. When required by contract, work order, or purchase agreement, provide fuel tank and fuel system cleaning, and fuel filtering/polishing, additives, and other treatments as required.

Verify the proper operation of automatic louvers, if applicable.

Verify all generator shutdown, alarm, and warning functions. Functionally test engine shutdown for low oil pressure, over-temperature, over-speed, and other protection shutdown and alarm features as applicable. Verify all alarms, gauges, meters, and auxiliary functions. Protective features, shutdowns, and alarms should operate in accordance with manufacturer instructions, system design requirements, and owner's requirements.

### *5.52.3 Electrical Testing and Maintenance*

Check for proper operation of generator control instrumentation, displace screens, and separate meters, such as voltage, current, real power, apparent power, and power factor, if applicable.

Test warning, alarm, and fault lamps using the panel lamp test feature. Replace burned out lamps as needed.

Verify that the generator manually starts in the ON/RUN position, and starts automatically by a remote start signal in the AUTO position.

Verify proper operation of the engine governor and alternator voltage regulator systems upon start-up in accordance with manufacturer instructions. Verify proper operating frequency and voltage magnitude at no-load with the engine operating at rated speed. The engine governor and voltage regulator should operate in accordance with manufacturer instructions and system design requirements. Make any required adjustments in accordance with manufacture instructions.

For parallel generator installations, verify proper operating sequence, lead-lag generator controls, governors (frequency and phase matching), voltage regulators (voltage magnitude and reactive power generation), speed control, synchronization controls, and load sharing, including real and reactive power (cross-current compensation). Verify that load-sharing controls are set in accordance with manufacturer instructions. Functionally test the system by removing one generator from the system and verifying that the remaining generator(s) operate automatically and properly. Verify soft-loading capability of each generator for systems with a closed-transition between sources, when so equipped. Verify extended paralleling capabilities with utility sources, when so equipped. Investigate, identify, and correct operational issues. Consult the manufacturer for recommendations.

Test and maintain the synchronous alternator of engine-generators in accordance with Section 5.21.

Perform insulation resistance testing from the generator winding to ground in accordance with IEEE 43. Calculate the polarization index and dielectric absorption ratio. See Annex A for additional information. Insulation resistance values should be in accordance with IEEE 43. Compare the polarization index or dielectric absorption ratio to prior test results. Polarization index or dielectric absorption ratio should not be less than 1.

Perform vibration testing for each alternator main bearing cap. Compare vibration levels with baseline data. Vibration levels should be in accordance with the manufacturer published data. Consult the manufacturer for recommendation for any abnormal vibration.

For diesel-powered EPS (emergency power sources or engine-generators), review the past 12 months of periodic generator load tests to determine whether the generator has been loaded at least to the minimum required load In accordance with NFPA 110, the minimum required loading of diesel engine-generators to prevent wet-stacking of the generator exhaust is either the loading necessary to maintain the minimum engine exhaust gas temperature as recommended by the manufacturer, or the loading under operating temperature conditions and at not less than 30% of the standby nameplate kW rating.

When required, perform monthly load testing of each generator in accordance with NFPA 110 by simulating a power outage using the test switch(es) on the ATSs or by opening a normal breaker that supplies the normal side of an ATS. NOTE: Opening a normal breaker is not required. Where multiple ATSs are installed, rotate the ATS used to initiate the monthly load test to verify independent starting function on each ATS. Monthly load testing of generators must include a completely cold startup of each generator. Do not warm up the generator before initiating the start signal from an ATS.

When required, perform supplemental load or load bank testing of each generator annually. Apply a supplemental load of not less than 50% of the nameplate kW rating for not less than 30 continuous minutes and not less than 75% of the nameplate kW rating for not less than 1 continuous hour for a total test duration of not less than 1-1/2 continuous hours. Supplemental loads used for annual load bank testing must be automatically replaced with emergency loads in the event of a failure of the primary source of power for the facility. Record voltage, current, frequency, and all gaged engine conditions every 15 minutes during load bank testing. Verify all generator-running characteristics. Verify starting battery-charging system.

When required for Level 1 EPSS (emergency power supply systems), test generators under load for the duration of its assigned class, but not longer than four continuous hours, at least once every 36 months. *NOTE: Level 1 systems shall be installed where failure of the equipment to perform could result in loss of human life or serious injuries. Level 1 systems are typically considered to be emergency generators that supply egress illumination and life safety loads.* Initiate the test by operating at least one transfer switch test function and then by operating the test function of all remaining ATSs, or initiated by opening all switches or breakers supplying normal power to all ATSs that are part of the EPSS being tested. *NOTE: A power interruption to non-generator supplied loads is not required.* For diesel-powered engine-generators where the loading is less that required to maintain the minimum exhaust gas temperature as recommended by the manufacturer or is less than 30% of the nameplate kW rating of the generator, perform supplemental load or load bank testing. Apply a supplemental load of not less than 50% of the nameplate kW rating for not less than 3 continuous hours and not less than 75% of the nameplate kW rating for not less than 1 continuous hour for a total test duration of not less than 4 continuous hours. Supplemental loads used for annual load bank testing must be automatically replaced with emergency loads in the event of a failure of the primary source of power for the facility. Record voltage, current, frequency, and all gaged engine conditions every 15 minutes during full-load testing and load bank testing. Verify all generator-running characteristics. Verify the starting battery-charging system.

Verify that adjustable settings are set in accordance with manufacturer instructions and owner's requirements.

Where installed, test circuit breakers, switches, and fuses in accordance with the applicable section of this Recommended Practice.

Where installed, maintain instrument transformers in accordance with Section 5.40.

Where installed, maintain protective and control relays in accordance with Section 5.41.

See NECA/EGSA 404 and NECA 406 for additional guidance.

## 5.53 Hazardous (Classified) Locations

Maintain electrical equipment designed for use in hazardous (classified) locations through periodic inspections, tests, and servicing as recommended by the manufacturer. Documentation should define the classified area (the class, group, and division specification and the extent of the classified area) and the equipment maintenance required.

Maintenance should be performed only by qualified personnel who are trained in safe maintenance practices and the special considerations necessary to maintain electrical equipment for use in hazardous (classified) locations.

Where possible, perform repairs and maintenance outside of the hazardous (classified) area. For maintenance involving permanent electrical installations, an acceptable method of compliance can include de-energizing the electrical equipment and removing the hazardous atmosphere for the duration of the maintenance period.

De-energize equipment before disassembling any electrical equipment in a hazardous (classified) location. Allow parts to cool and stored electrical charges to dissipate. See Section 3.

Fully reassemble electrical equipment designed for use in hazardous (classified) locations with original components or approved replacement parts before the hazardous atmosphere is reintroduced and before equipment is re-energized. Ensure that joints and other openings in enclosures are properly sealed. Do not interchange covers unless identified for the purpose. When closing equipment, check for foreign objects, including burrs, pinched gaskets, pieces of insulation, and wiring, that prevent the proper closure of mating joints designed to prevent the propagation of flame upon explosion.

Inspect conduits and equipment for proper seals conforming to the requirements of NFPA 70 and manufacturer specifications. Repair or replace damaged seals. Replace equipment as needed when factory installed seals within equipment is damaged.

Verify that cover bolts and screws are properly torqued in accordance with manufacturer specifications. Do not energize electrical equipment when bolts or screws are missing. Replace missing bolts and screws with original components or approved replacement parts.

Avoid rough handling of electrical devices and components approved for us in hazardous (classified) locations. Do not use tools that can pry, impact, or abrade components or that can dent, scratch, nick, or otherwise mar close-tolerance, precision-machined joints and make them unsafe.

Grease, paint, and dirt should be cleaned from machined joints with a bristle (not wire) brush, an acceptable noncorrosive solvent, or other methods recommended by the manufacturer.

Clean and lubricate mating surfaces prior to replacing a cover on an enclosure designed to prevent flame propagation upon an explosion in accordance with manufacturer instructions.

## 5.54 Electronic Equipment

*NOTE: Electronic equipment includes equipment that employs power electronics, such as inverters, converters, rectifiers, battery chargers, uninterruptible power supplies (UPSs), static transfer switches, and other similar equipment. Refer to the applicable sections of this Recommended Practice for the requirements for specific equipment.*

Electronic equipment may be a source of power quality issues, including harmonics. See NECA 702 for information regarding monitoring and mitigating power quality issues.

Maintain equipment in accordance with manufacturer instructions, and in accordance with the following general guidance. Follow the manufacturer safety instructions. Observe all manufacturer warning labels. See Section 3 for additional safety precautions.

Ensure that all sources of power are disconnected prior to performing maintenance. Discharge all capacitors in accordance with manufacturer instructions.

Assume that all electronic equipment is electrostatic discharge (ESD) sensitive. Follow industry standard ESD procedures.

Inspect electronic equipment for signs of overheating as indicated by discoloration or other visual characteristics. Check conductors and components for suitable clearances and for evidence of movement, vibration, or displacement. Check for the overall condition and cleanliness of equipment, such as the accumulation of dust. Parts, connections, and joints should be free of corrosion, dust, dirt, debris, and other foreign materials.

Check soldered or screw terminal connections and mountings for tightness by slightly pulling on the conductor or checking the lug or terminal screw. Inspect printed circuit boards to determine whether they are fully inserted into the edge board connector. Check that printed circuit board locking tabs are fully engaged. Do not unplug and re-plug-in connectors unless a malfunction is suspected as repeatedly disconnecting and reconnecting can shorten the life expectancy of connectors.

Check for the evidence of moisture and corrosion. For ambient air with high humidity, provide space heaters, dehumidifiers, or conditioned air to reduce humidity. Verify the proper operation of internal heaters, if so equipped.

Check that ventilation ducts and openings are clear. Remove dust, dirt, debris, or other foreign materials. Clean or replace filter material as needed. Check that fans and controls function properly.

Clean electronic equipment, inside and out, in accordance with manufacturer instructions. Do not use solvents on printed circuit boards. Remove accumulations of dust using a vacuum cleaner.

Check electronic equipment calibration in accordance with manufacturer instructions. Check equipment operating parameters and adjust programmable equipment settings to maintain normal operating conditions, as needed, in accordance with manufacturer instructions.

Maintain electronic equipment in accordance with the applicable sections of this Recommended Practice for the requirements for specific equipment. Service, repair, or replacements should only be made at the printed circuit board or plug-in component level unless otherwise recommended by the manufacturer. Follow the manufacturer instructions for removing, handling, packaging, shipping, and replacing such components or modules to prevent strain on wires, cables, and connections.

## 5.55 Uninterruptible Power Supply (UPS) Systems

UPSs may be a source of power quality issues, including harmonics. See NECA 702 for information regarding monitoring and mitigating power quality issues.

Maintain UPSs in accordance with manufacturer instructions and NECA 411. The following guidance is generic in nature.

Schedule inspections, testing, and maintenance of UPSs with the owner well in advance and at times that will least affect operations. Coordinate the operational testing of UPSs with the testing of engine-generators and ATSs, if applicable. Do not proceed with inspections, testing, and maintenance of UPSs until all users have been notified. Exercise extreme caution when inspecting, testing, and maintaining UPSs to prevent an unscheduled outage to the UPS load. When an external maintenance bypass is provided, isolate the UPS from the load in accordance with the switching procedure established for the external maintenance bypass equipment before beginning work on the UPS.

Record all operating parameters of the UPS, including the AC input and output frequency, voltage, current, and power factor, and the DC voltage and current of the battery system, as applicable, with the UPS supplying its normal load.

Clean UPSs in accordance with manufacturer instructions.

Verify that ventilation openings are clear of obstructions. Check that air filter media is clean. Clean or replace air filters as needed. Verify that cooling fans operate properly. Replace failed fans and controllers. Replace all fans and controllers in accordance with the manufacturer recommended replacement intervals.

Inspect transformers and heat sinks for signs of overheating. Consult the manufacturer for recommendations for any signs of overheating.

Inspect input and output filter, inverter wave-forming, and DC bus capacitor enclosures for evidence of leakage, discoloration, distortion, swelling, and rupture. Check the equipment enclosure and the surrounding area for evidence of leakage. Perform a continuity check on capacitor fuses. Replace any suspect capacitors and failed fuses. Replace all capacitors in accordance with the manufacturer recommended replacement intervals.

Test static transfer switches for proper operation by switching from inverter to bypass and back using the actual UPS load when possible. The static transfer switch should function in accordance with the manufacturer published data without an electrical outage to the load. Verify the synchronizing indicators for static transfer switches and bypass switches. The synchronizing indicators should operate in accordance with design requirements.

Set the free running frequency of the oscillator. The oscillator free running frequency should be within manufacturer recommended tolerances.

Test the DC undervoltage trip level on the inverter input breaker. DC undervoltage should trip the inverter input breaker as designed. Adjust the DC undervoltage trip level in accordance with manufacturer instructions, if needed.

Test all system alarms, indicating lights, and emergency shutdown functions for proper operation. Simulate critical malfunctions. Verify that UPS loads properly transfer manually and automatically from UPS to bypass. Verify annunciation and protective device functions. Test alarm circuits. Alarm circuits should operate in accordance with design requirements and manufacturer specifications.

Measure the current on the output neutral conductor using a true RMS ammeter, if so equipped. Verify that the measured current does not exceed the ampacity of the neutral conductor. Investigate harmonic load currents as a source of excessive neutral current. Consult the manufacturer for recommendations for excessive neutral currents.

Perform an infrared survey of UPSs in accordance with manufacturer instructions. See Annex A for additional information.

When load testing UPS battery systems, place normal UPS loads on isolation bypass or external maintenance bypass, if so equipped, or connect to another source for the duration of tests, and perform load testing using an external load bank. Load test UPS modules individually and as a complete system where modules are installed and operated in parallel.

Block load test UPSs while supplied from the normal power source in accordance with manufacturer instructions. Verify that UPS voltage regulation and frequency stability are within manufacturer specifications. Use a high-speed recording device to record the transient response of voltage and frequency for the following block loads:

- From 0% to 50% to 0% of the UPS system rating.
- From 25% to 75% to 25% of the UPS system rating.
- From 50% to 100% to 50% of the UPS system rating.

- From 0% to 100% to 0% of the UPS system rating.

Load test UPS battery systems by removing the AC input power source while supplying a load bank at 100% of the UPS system rating. Record the output voltage, current, and frequency, along with the elapsed time until low battery voltage shutdown occurs. Compare the elapsed time with the class of the UPS and the UPS and battery manufacturer specifications. Restore the AC input power source to the UPS. Verify that the battery system is charging properly. Do not place the UPS back into normal operation until the battery is fully charged. See Section 5.59 for additional information.

Maintain low-voltage circuit breakers in accordance with Section 5.24 and Section 5.25 as applicable.

Maintain low-voltage automatic transfer switches in accordance with Section 5.51.

Maintain battery chargers and battery systems in accordance with Section 5.59.

Maintain rotating machines (rotary UPSs) in accordance with Sections 5.21, 5.22, and 5.23 as applicable.

## 5.56 Electric Vehicle Service Equipment (EVSE)

EVSE may be a source of power quality issues, including harmonics. See NECA 702 for information regarding monitoring and mitigating power quality issues.

Maintain EVSE in accordance with manufacturer instructions, and in accordance with the following general guidance. See NECA 413 for additional guidance for maintaining EVSE.

When performing maintenance, follow all manufacturer safety precautions and established safety procedures using appropriate tools, test equipment, and safety equipment. See Section 3.

Clean EVSE in accordance with manufacturer recommendations using recommended materials and methods. Generally, use a soft damp cloth with a mild detergent to wipe down the exterior of the EVSE with the main power service off. For EVSE with stainless steel surfaces, use standard stainless-steel polish only in accordance with manufacturer instructions.

Check all usable parts for wear, and conduct periodic inspections to ensure that all parts remain in proper working order. Check that communications systems are functioning properly, and that lamps are illuminated and working properly. Replace burned-out lamps, if so equipped, in accordance with manufacturer instructions. Check for damage and vandalism. Repair damage and vandalism in accordance with manufacturer instructions.

Inspect the charge connector, plugs, receptacles, cords, cables, and strain relief clamps for evidence of damage. Shake charge connectors, listening for sounds such as rattles that can indicate loose components. Check connectors and inlets for tightness. Replace SAE connectors that are misapplied, improperly installed, damaged, worn, that show signs of overheating or discoloration, or that show any sign of alterations of a blade or connection slot.

Inspect cables and conductors for signs of wear, abrasion, and damaged or worn insulation. Verify that the EV coupler and connector cables are securely fastened to boxes. Verify that appropriate coverplates and access panels are installed and secure, and that panels and covers are in contact with the finished surface on all edges.

Shut off, do not use, and replace damaged, discolored, disfigured, modified, hot, sparking, popping, or otherwise suspect EVSE couplers or plugs, or if ozone is detected in their immediate vicinity.

## 5.57 Photovoltaic (PV) Power Systems

PV power systems may be a source of power quality issues, including harmonics. See NECA 702 for information regarding monitoring and mitigating power quality issues.

Maintain PV power systems in accordance with manufacturer instructions, and in accordance with the following general guidance. See NECA 412 for additional guidance for inspecting, testing, and maintaining PV power systems.

When performing maintenance, follow all manufacturer safety precautions and established safety procedures using appropriate tools, test equipment, and safety equipment. See Section 3.

Exercise caution when servicing PV power systems to prevent unscheduled outages. Schedule inspections and maintenance at times that will least affect operations. Do not initiate inspections and maintenance until all users have been notified.

Whenever the shutdown of the system is required for maintenance, open the inverter AC output disconnecting means before opening the inverter DC input disconnecting means. Place opaque sheets, cloths, or tarpaulins over the solar panels, or use short circuit or open circuit techniques when taking the solar panels out of service. Open battery disconnecting means to isolate energy storage batteries from the system, where installed.

Take corrective action for any inspection item found to be deficient. Follow manufacturer instructions for inspecting, maintaining, repairing, and replacing equipment and components. When installed, replace batteries in accordance with the manufacturer recommendations. Replacement and disposal of batteries is governed by local, State, and Federal environmental regulations and must be carried out by licensed recyclers/disposers following prescribed methods.

Adjust the tilt angle of static, adjustable arrays every three months to maintain an optimum orientation to the sun, as needed.

Check PV energy production performance data and compare with historical PV energy production data, when available. When a noticeable reduction in PV power production is identified over time, inspect individual PV modules or panels for physical damage or failure and accumulations of dust, dirt, and debris as a potential cause. Replace damaged PV panels. Clean individual PV panels of accumulations of dust, dirt, and debris. See NECA 412 for additional guidance in troubleshooting PV power system misoperation.

Inspect solar panels and solar arrays for accumulations of leaves, tree branches and other debris periodically. Remove leaves, tree branches, and other debris from solar panels immediately.

Clean PV arrays in accordance with manufacturer instructions. Use only manufacturer approved cleaning solutions to prevent potential damage and premature failure of the PV modules.

Inspect solar panels for accumulations of dust. Rinse off regular accumulations of dust with clean water approximately every two weeks, depending upon the frequency of rain. In desert regions, construction areas with dust, or similar conditions, rinse solar panels more often. Rinse off solar panels during the cool of the day to prevent thermal shock to the surface of the panel.

When required, wash solar panels using a sponge or squeegee with a mild soap solution to remove accumulations of tree sap and bird droppings. Wash solar panels during the cool of the day to prevent thermal shock to the surface of the panel or array.

Check the appearance and cleanliness of PV power system equipment and the areas immediately around the inverter or charge controller and the solar array. Remove accumulations of dust and debris as needed.

Inspect areas under and around solar panels and solar arrays and inverters or charge controllers for plant growth and for accumulations of debris. Remove plants or accumulations of debris under or around solar panels that could restrict airflow around panels and that could cause water to pool during periods of severe rain. Remove plants or accumulations of debris around inverters and charge controllers.

Check that PV arrays are secured and that supports and structural components are intact.

Inspect PV arrays, equipment and conductors for loose, damaged, and frayed conductors. Check that wiring harnesses, where installed, are fully connected and secured.

Where PV arrays are installed on a roof, check roof penetrations for appropriate weather sealing and for leaks.

Inspect inverters, switches, and combiner boxes for physical damage and for proper mounting.

Inspect solar panels for cracks or broken glass. Replace solar panels with cracked or broken glass.

Check inverter and charge controller indicator lamps using the "lamp test" feature. Check all meters to ensure they are operating properly. Scroll through all of the monitoring and metering parameters of the inverter or charge controller. Record meter readings for input and output voltage, current, and frequency.

Visually inspect the inverter or charge controller, solar array, combiner boxes, disconnecting means, and other components externally. Check inverter and charge controller air intakes, vents, heatsinks, and filters, where installed. Check ventilation fans for proper operation and ensure that ventilation openings are clean and clear of obstructions. Brush debris and dust out of the inverter or charge controller heatsink or fan screen.

Check the ambient temperature in the area around the inverter or charge controller. Ensure that the inverter or charge controller is not exposed to direct sunlight during operation. Install a sunshade or relocate the inverter or charge controller out of direct sunlight during operation.

Open access doors and covers and inspect internal parts and components for evidence of overheating, and for physical and thermal damage, including worn insulation, and corrosion. Inspect terminals for loose or broken connections, frayed conductors, and burned insulation.

Check inverters and charge controllers for signs of leaking fluid from the wave-forming capacitors. Check for evidence of liquid contamination, battery electrolyte, and oil from capacitors. Check capacitors for swelling or discoloration.

Check that mounting supports and hardware are tight and secure. Tighten loose supports and hardware. Replace any missing hardware with stainless steel components.

Maintain batteries and charge controllers in accordance with Section 5.59.

## 5.58 Wind Power Systems

Wind-powered electric systems may be a source of power quality issues, including harmonics and the potential for harmonic resonance. See NECA 702 for information regarding monitoring and mitigating power quality issues.

Maintain wind-powered electric systems in accordance with manufacturer instructions, and in accordance with the following general guidance.

Plan maintenance activities in advance to ensure that the required resources, parts, tools, and personnel are available prior to the work. Shut down wind turbines before performing inspections, maintenance, and testing. Engage the wind turbine braking system or shorting switch. Ensure that wind turbines are stationary when performing inspections, testing, and maintenance. Lower tilt-down towers only when there is no wind. Constantly monitor the rotor position to ensure that the rotor is not damaged when the tower is lowered.

Inspect and maintain wind turbines on a regular basis. As weather conditions vary significantly from area to area, increased maintenance may be required in areas subject to a harsh climate. Environmental and operating conditions, such as high ambient temperature, high vibration levels, high operating altitude, dirt, humidity, or heavy loading, can significantly shorten component life expectancy. Reduce maintenance and component replacement intervals for harsh environmental and operating conditions.

Open battery disconnecting means to isolate the energy storage batteries from the system, when installed, before performing maintenance. Maintain batteries and charge controllers in accordance with Section 5.59.

When raising wind turbine towers for maintenance purposes, follow the guidance for raising and lowering towers in accordance with manufacturer instructions. Check that conductors and cables of equipment and moving parts are not trapped under pole bases. Check that all foundation and guy wire connections are secure prior to lowering towers. Monitor and maintain tension on guy wires during lowering. Check the gin pole and rigging, including block and tackle equipment, before raising and lowering the tower. Slowly raise and lower the tower, carefully monitoring the blades as the turbine approaches ground level. Provide supports for the tower once lowered.

Consult the manufacturer for recommendations to correct any deficiencies identified during service and maintenance.

### *5.58.1 Related Electrical Equipment Maintenance*

Check the grounding conductors and connections for the tower and other structural supports. Measure ground resistance in accordance with Section 5.44.

Maintain lightning protection systems in accordance with Section 5.46.

Maintain alternators and generators in accordance with Section 5.21. 5.22, and 5.23 as applicable.

Maintain transformers in accordance with Sections 5.7 and 5.8 as applicable.

Maintain converters in accordance with Section 5.54 for electronic equipment.

Maintain circuit breakers in accordance with Section 5.24 through 5.30 as applicable.

Maintain cable support systems, cables, and terminations in accordance with Section 5.3 through 5.6 as applicable.

Maintain switchgear and switchboards in accordance with Section 5.15.

Maintain panelboards in accordance with Section 5.16.

Maintain motor control centers (MCCs) in accordance with Section 5.17.

### *5.58.2 Quarterly Maintenance*

Every three months, check that the wind turbine is operating smoothly. Check that the hub and fan blades rotate freely and are still balanced. Check that the distance is the same between fan blade tips. Rebalance the rotor blades in accordance with manufacturer instructions, as needed.

Check that the tower mechanical connections and hardware are secure and have not worked loose. Check the general condition of the tower and base, foundation, welds, hinge bolts, and gin pole assembly. Check and adjust shims, and check and adjust fasteners and hardware as needed. Tighten hardware in accordance with manufacturer instructions, if needed.

For guy-supported towers, check guy wire tension. Ensure that guy wire tension is consistent between all wires. Guy wires should be neither too tight nor too loose and should have visible slack. Adjust guy wire tension as needed for stretching or climactic adjustments in accordance with manufacturer instructions.

Check the controller, inverter, charge controller, and similar equipment, and voltage and current meters for proper operation. Perform a "self-diagnostic" of the controller, inverter, charge controller, and similar equipment, if so equipped. Check that the phase-to-phase voltages of the wind turbine are balanced during operation. Check conductors, cables, and electrical connections and terminations for connectivity, damage, and corrosion. Rework connections as needed.

Inspect the slip ring assembly, if so equipped. Check slip ring connections, slip ring body, and top hat. Clean the slip ring body as needed. Check and adjust the slip ring brushes and fasteners and hardware as needed. Replace the slip ring brushes as needed.

Check brake operation, brake assembly parts, brake pads, brake rope condition, shackle or elastic, and brake levers. Replace brake pads and brake rope as needed. Check the operation of the brake shorting switch, if so equipped.

Check the condition of the blades and springs (if so equipped), blade and spring fixings (if so equipped), hinges, wedges, washers and clamps. Check and adjust fasteners and hardware as needed.

Check the overall condition of the wind turbine cover (nacelle), generator cover, and yaw cover. Check cable ties and replace as needed.

Check tower top electrical equipment, including navigational warning lighting and weather measurement devices, for proper operation.

Check yaw and pitch systems, electrical components, and wiring for signs of damage or overheating.

Check instrumentation and controls for proper operation. Test emergency and safety shutdown controls for proper operation.

Perform Supervisory Control and Data Acquisition System (SCADA) connectivity and data transfer tests to ensure proper operation.

#### *5.58.3 Semi-Annual Maintenance*

In addition to performing quarterly maintenance, check the torque on guy-wire supported tower anchors. Inspect stator, stator windings, rotor, and rotor windings. Inspect slip ring assembly and control and protection components. Inspect bearings. Inspect the cooling system.

#### *5.58.4 Annual Maintenance*

In addition to performing quarterly and semi-annual maintenance, check the general condition of the wind turbine. Check that the turbine is in good working condition and is suitable for continued service. Touch-up painted areas damaged by weather. Check the fit and finish of covers. Inspect welds for evidence of damage or cracking from stress.

Open the wind turbine cover, or nacelle hatch. Check the torque on mechanical connections, such as the turbine frame-to-nacelle bolts and tail damper. Check the turbine, alternator, and frame for proper alignment. Inspect the turbine frame for cracks. Inspect the furling cable, especially at the ball end/fork attachment to tail boom, if applicable. Close and secure the nacelle hatch.

Check the torque level of tower, foundation, turbine head and blade bolts to ensure that all bolts have remained adequately torqued.

Check the front and rear bearing seals of the alternator for integrity and grease loss. Clean and check the bearing shield insulation. Clean and lubricate non-sealed bearings, such as the main shaft bearings, mast bearing, blade bearing, yaw bearing, disc brake actuator, pitch regulator for the blades, generator, and yaw-gear, if applicable. Use manufacturer recommended lubricants for the gearbox and bearings. Ensure that lubricants are compatible with paints, seals, pumps, coolers, and hoses.

Inspect for grease leaking from bearings into the slip rings. Inspect electrical connections. Check the slip rings for arcing damage. Inspect the brushes in DC control motors for wear. Repair and replace brushes as required. Replace slip rings as needed. Replace the slip ring assembly and control and protection components as needed.

Inspect inverters, controllers, and resistive loads for general fit and finish and to ensure that all connections are tight. Remove dust build-up from inverter heat sinks.

Inspect blades for cracks, chips, dents, and damage. Inspect the base of the rotor blades where they attach to the rotor hub for signs of stress, cracking, or fatigue. Replace damaged rotor blades as needed. Check the torque on the blade attachment bolts. Clean dirt or debris build-up from the rotor blades with mild detergent and warm water. Change springs, if so equipped.

Check conductors, cables, and electrical connections for tightness, and inspect for corrosion and evidence of thermal damage, discoloration, and arc spatter. Check and tighten grounding connections. Test surge protection devices. Replace conductors and cables that are damaged or corroded.

Measure the insulation resistance of the wind turbine winding with a 500V (minimum) megohm resistance meter.

Clean the cooling system.

Inspect and replace brake pads as needed.

#### *5.58.5 Maintenance Every Three to Five Years*

Vacuum the stator, stator windings, rotor, and rotor windings. Replace bearings. Replace cooling system components.

#### *5.58.6 Maintenance Every Ten Years*

Replace rotor blades.

#### *5.58.7 Maintenance After Winter*

Check rotor blades for cracks or abnormal bends. Replace damaged or unbalanced blades.

Grease non-sealed bearings.

For guy-wire installations, check guy-wires for proper cable tension and adjust as needed.

Check electric power and control conductors for corrosion and damage. Replace cables that are damaged or corroded.

#### *5.58.8 Maintenance After a Storm or High Wind Conditions (Greater than 60 MPH)*

When possible, lower tilt-down towers prior to storms and high winds.

Inspect rotor blades, support structures or towers, and guy wires, if applicable, after wind turbines are exposed to extreme wind conditions, such as winds in excess of 60 MPH. Check the rotor blades for cracks or abnormal bends. Replace damaged or unbalanced blades. Check support structure or tower hardware for tightness. For guy-wire installations, check guy-wires for proper cable tension and adjust as needed.

## 5.59 Battery Systems

Exercise care when working around battery systems. Follow all safety instructions in accordance with NFPA 70E and Section 3.

Follow the manufacturer instructions for the use of pilot cells or blocks and for the range of float voltage applicable to a specific battery system. *NOTE: Pilot cells or blocks are a subset of all of the battery cells in the system that are used as a statistical representation, typically 10% or so, to perform more comprehensive sampling and testing.*

Prior to starting work, verify the existence of suitable eyewash equipment in close proximity to the battery system. Verify that the battery ventilation system, intake and exhaust systems, and the hydrogen detection system, if installed, is operational.

Ensure that the batteries are fully charged prior to performing inspections, testing, and maintenance.

Ensure that battery room ventilation openings are clear of obstructions. Check for uniform battery temperatures and for any local sources of heating and cooling that could create cell temperature differentials that cause battery damage. Identify and correct abnormal temperatures, temperature differentials, or restricted air movement around batteries.

Measure the ambient temperature of the battery room. Ambient room temperature should be within the manufacturer recommended temperature range, keeping in mind that high ambient temperatures reduce cell life and lower ambient cell temperatures reduce cell capacity. Compare the ambient room temperature with the measured battery cell temperature readings. Investigate and correct significant temperature differentials between the ambient room temperature and the measured battery cell temperatures. In general, a temperature differential of 3°C to 5°C (5°F to 9°F) between ambient room temperature and battery cell temperature is considered to be significant and may indicate impending thermal runaway, which requires immediate intervention.

Inspect the battery support racks and insulating covers or cabinets mounting, anchorage, alignment, clearances, and spill containment system, if applicable. Check for physical damage, loose connections, dielectric leaks, cracking, corrosion, dirt, seismic parts and spacers, electrical continuity and grounding, and mechanical and structural integrity. Check for spilled electrolyte. Neutralize spilled electrolyte in accordance with manufacturer instructions and IEEE 1578. See Section 3 for additional information. Tighten any loose hardware. Replace any missing hardware. Clean dirty or corroded components. Correct any deficiencies found.

Check battery containers and covers for cracks, structural damage, distortion, dielectric leaks, dirt, and corrosion. Inspect jar and post seals. Check vented lead-acid batteries and vented Nickel-Cadmium batteries for clogged flame arrestors. Replace any damaged or missing removable vent caps.

Visually inspect plates and internal parts of batteries with clear containers. Check for damage such as excessive positive plate growth, sulfate crystal formation on positive plates, buckling, warping, scaling, swelling, cracking, hydration rings, excessive sedimentation, mossing, copper contamination, internal post seal cracks, and changes in color. Excess sedimentation and plate damage can be caused by improper battery charger settings including excessive AC ripple current, vibration, excessive load cycling, age, and certain manufacturing defects in relatively new batteries. Consult the manufacturer for recommendations for repairs or replacements for any deficiencies found.

Inspect battery interconnection cables, cell connectors, and other conductors for wear, contamination, corrosion, and discoloration.

Prior to cleaning battery systems or adding electrolyte, if applicable, perform any required as-found tests.

Perform the specific maintenance indicated below for batteries and equipment.

Measure and record the resistance through all bolted connections using a low-resistance ohmmeter or micro-ohmmeter. Compare resistance values of bolted connections to prior test values of the same connections, and to results from similar connections. Investigate values which have increased more than 10% over previous test values or that deviate from those of similar bolted connections by more than 50% of the lowest value.

Measure the resistances of cell-to-cell or block-to-block connections and terminal connections in accordance with manufacturer instructions. Battery connection resistance value can vary depending upon the type of battery and the application. See the following Recommended Practices for battery-specific information:

- For valve-regulated lead-acid (VRLA) batteries, see IEEE 1188, Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications
- For vented lead-acid (VLA) batteries, see IEEE 450, Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications
- For Nickel-Cadmium (Ni-Cd) batteries, see IEEE 1106, Recommended Practice for Installation, Maintenance, Testing and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications

When a test set is not available or when intercell connections are not readily accessible, perform an infrared survey to determine if any intercell connections have high resistance. See Annex A for additional information.

Only tighten terminal post connections when needed based on resistance readings or infrared survey. Where a connection resistance is determined to be high in accordance with the manufacturer tolerances or industry-recognized Recommended Practices, clean the connection and torque in accordance with manufacturer instructions.

Check terminal connectors, battery posts, and cable ends for corrosion and dirt. Clean battery posts in accordance with manufacturer instructions.

For lead-acid battery systems equipped with a battery monitoring system, check the internal resistance of each cell. Compare test results with prior results to identify trends and to identify anomalies. Consult the manufacturer for recommendations when anomalies are detected.

Measure the battery charger float and equalizing voltage levels. Verify that the float and equalizing voltages between the battery system's most positive and most negative terminals are compatible with the battery type and application for the observed ambient temperature. Verify that the AC ripple current imposed on battery is in accordance with the battery manufacturer specifications. When needed, adjust the float and equalizing voltage levels in accordance with the battery manufacturer instructions.

Measure each battery/cell voltage and the total battery voltage with the charger energized and in float mode. The cell voltages of flooded lead-acid batteries and Nickel-Cadmium batteries should be within 0.05 volt of each other or in accordance with the manufacturer published data. The cell voltages of vented lead acid batteries should be in accordance with the manufacturer published data.

Measure the battery system voltage from the positive terminal to ground, and from the negative terminal to ground. For an ungrounded battery system, the voltage measured from the positive terminal to ground should be similar in magnitude to the voltage measured from the negative terminal to ground. Investigate significant differences in voltage, checking for unintentional grounding of the battery system. *NOTE: Unintentional grounding of the battery system can result in uncontrolled current flow and thermal runaway of the battery system.*

### 5.59.1 Battery Charging Equipment

Battery charging equipment may be a source of power quality issues, including harmonics. See NECA 702 for information regarding monitoring and mitigating power quality issues.

Maintain battery chargers in accordance with manufacturer instructions.

Inspect filter and tank capacitor enclosures for evidence of leakage, distortion, swelling, and rupture. Check the equipment enclosure and the surrounding area for evidence of leakage. Perform a continuity check on capacitor fuses. Replace any suspect capacitors and failed fuses.

Verify that ventilation openings are clear of obstructions. Clean filters if provided. Verify that cooling fans operate properly.

Measure and record the input and output voltage and current. Input and output voltages should be within the equipment nameplate ratings and in accordance with the manufacturer specifications.

Verify the battery charger high-voltage shutdown settings. The high-voltage shutdown settings should be in accordance with the manufacturer published data.

For parallel battery chargers, verify proper operation of load sharing controls. Load sharing between parallel chargers should be in accordance with the system design and manufacturer specifications.

Verify proper operation of alarm relays, lights, horns, and emergency lighting in accordance with the system design and manufacturer specifications.

Perform full load testing of the battery charger. Verify the current limit of the charger. The battery charger should be capable of producing rated full-load output and current limit in accordance with the specified settings.

Maintain relays and meters in accordance with Section 5.41.

### 5.59.2 Flooded or Vented Lead-Acid (VLA) Battery Systems

Measure and record battery electrolyte levels and the elapsed time between battery maintenance. Measure electrolyte specific gravity and temperature levels of all battery cells or only of pilot cells, if applicable. When pilot cells are used, measure temperature in at least 10% of the total battery cells in each string. *NOTE: It is also recommended to periodically change the pilot cells used for measuring specific gravity due to the amount of electrolyte that can be lost each time a specific gravity reading is taken.*

The electrolyte level and specific gravity of each battery should be within normal limits. Add clean distilled or deionized water as needed to raise electrolyte levels to the bottom of the high-level mark on each battery using manufacturer recommended materials and methods. Only add water to a battery unless recommended by the battery manufacturer. Excessive water consumption may be a sign of overcharging or cell damage. Record and track water consumption. Consult the manufacturer for recommendations. If deionized water is used, check for proper operation of the domestic water deionizer and whether the deionizing filters need replacement.

Verify that battery cells have flame arrestors.

Clean lead–acid battery surfaces with a solution of water and sodium bicarbonate to avoid leakage currents caused by electrolyte on battery surfaces. Consult the battery manufacturer for the proper solution and dilution. Do not use cleaners, soaps, or solvents to clean battery containers and covers to prevent damage.

Clean corroded/oxidized battery terminals. Apply an oxide inhibitor, if needed.

Measure the internal resistance of each cell. Internal resistance of each cell should not vary more that 25% between identical cells. Measure internal resistance at least quarterly unless a battery monitoring system is installed. Compare test results with prior results to identify trends and to identify anomalies. Consult the manufacturer for recommendations when anomalies are detected. See Annex A for additional guidance.

Perform battery load and capacity testing in accordance with manufacturer instructions or IEEE 450. Perform an infrared survey of batteries and connections concurrently with battery load testing. See Annex A for additional information. Test results should be in accordance with the manufacturer published data or IEEE 450. *NOTE: Battery load testing should be performed at approximately 25%, 50%, and 75% of the expected service life as determined by the initial design, or as recommended by the manufacturer, depending on the load reliability requirements and environmental conditions of the installation, and annually once the battery system reaches 85% of its expected service life or when the battery system shows signs of deterioration, whichever occurs first.* In general, do not fully discharge the battery system more than twice in one year.

#### *5.59.3 Vented Nickel-Cadmium (Ni-Cd) Battery Systems*

Measure and record battery electrolyte levels and the elapsed time between battery maintenance. Measure electrolyte specific gravity and temperature levels of all battery cells or only of pilot cells, if applicable. When pilot cells are used, measure temperature in at least 10% of the total battery cells in each string. *NOTE: It is also recommended to periodically change the pilot cells used for measuring specific gravity due to the amount of electrolyte that can be lost each time a specific gravity reading is taken.*

The electrolyte level and specific gravity of each battery should be within normal limits. Add clean distilled or deionized water as needed to raise electrolyte levels to the bottom of the high-level mark on each battery using manufacturer recommended materials and methods. Only add water to a battery unless recommended by the battery manufacturer. Excessive water consumption may be a sign of overcharging or cell damage. Record and track water consumption. Consult the manufacturer for recommendations. If deionized water is used, check for proper operation of the domestic water deionizer and whether the deionizing filters need replacement.

Clean Ni-Cd battery surfaces with a solution of boric acid and water to avoid leakage currents caused by electrolyte on battery surfaces. Consult the battery manufacturer for the proper solution and dilution. Do not use cleaners, soaps, or solvents to clean battery containers and covers to prevent damage.

Clean corroded/oxidized battery terminals. Apply an oxide inhibitor, if needed.

Perform battery load and capacity testing in accordance with manufacturer instructions or IEEE 1106. Perform an infrared survey of batteries and connections concurrently with battery load testing. See Annex A for additional information. Test results should be in accordance with the manufacturer published data or IEEE 1106. *NOTE: Battery load testing should be performed at approximately 25%, 50%, and 75% of the expected service life as determined by the initial design, or as recommended by the manufacturer, depending on the load reliability* *requirements and environmental conditions of the installation, and annually once the battery system reaches 85% of its expected service life or when the battery system shows signs of deterioration, whichever occurs first.* In general, do not fully discharge the battery system more than twice in one year.

### *5.59.3 Valve-Regulated Lead Acid (VRLA) Battery Systems*

Clean VRLA battery surfaces with a solution of water and sodium bicarbonate to avoid leakage currents caused by electrolyte on battery surfaces. Consult the battery manufacturer for the proper solution and dilution. Do not use cleaners, soaps, or solvents to clean battery containers and covers to prevent damage.

Clean corroded/oxidized battery terminals. Apply an oxide inhibitor, if needed.

Measure the temperature at each battery cell negative terminal or post, or only of pilot cells, if applicable. When pilot cells are used, measure temperature in at least 10% of the total battery cells in each string. Battery negative terminal temperature should be within manufacturer published data or IEEE 1188.

Measure the internal resistance of each cell. Internal resistance of each cell should not vary more that 25% between identical cells. Measure internal resistance at least quarterly unless a battery monitoring system is installed. Compare test results with prior results to identify trends and to identify anomalies. Consult the manufacturer for recommendations when anomalies are detected. See Annex A for additional guidance.

Perform battery load and capacity testing in accordance with manufacturer instructions or IEEE 1188. Perform an infrared survey of batteries and connections concurrently with battery load testing. See Annex A for additional information. Test results should be in accordance with the manufacturer published data or IEEE 1188. *NOTE: Battery load testing should be performed at approximately 25%, 50%, and 75% of the expected service life as determined by the initial design, or as recommended by the manufacturer, depending on the load reliability requirements and environmental conditions of the installation, and annually once the battery system reaches 85% of its expected service life or when the battery system shows signs of deterioration, whichever occurs first.* In general, do not fully discharge the battery system more than twice in one year.

*(This annex is not part of the standard)*

# Annex A: Electrical Testing Procedures

## A.1 General

Perform electrical testing in accordance with test equipment manufacturer instructions and industry accepted practices. Use test equipment of suitable ratings and sensitivity. Follow the manufacturer instructions for testing equipment and conductors. Observe all manufacturer warning labels. See Section 3 for additional safety precautions.

Limit test voltages to prevent damage to equipment and conductors, to prevent damage to splices, terminations, attached equipment, and accessories that are not rated to withstand test voltages, and to prevent voiding equipment warranties. Disconnect surge protective devices, potential transformers, and sensitive electronic and solid-state components from equipment under test to prevent damage.

Maintain a permanent record of all test results. Record wet- and dry-bulb temperatures or relative humidity and temperature when such factors can influence test results, such as overpotential or dielectric testing. Calculate temperature correction factors for test results in accordance with manufacturer instructions, when applicable.

## A.2 Vibration Testing and Monitoring

Excessive equipment vibration may be due to mechanical integrity such as from dynamic unbalance, misalignment, loose parts, or faulty bearings, or due to mechanical integrity, such as from an open rotor bar or cracked end ring in a squirrel cage motor, or a faulty power supply in a DC motor.

Vibration may be measured in units of velocity, such as mm per second or inches per second, which is independent of machine speed and a better general indicator of overall vibration severity, in units of acceleration, generally used to evaluate high frequency issues such as those related to bearings and gears, or in units of displacement, which is generally used as an indicator of vibration severity for both low-speed equipment operating at less than 1200 rpm and low-frequency vibration, such as dynamic unbalance, belt vibration, and shaft seal rub. Vibration is usually measured at the bearing housing.

Both analog and digital instruments are available to measure velocity, acceleration, and displacement in equipment, along with computerized vibration data collectors that can be used to identify faults in stator windings, rotator bars and end rings, and bearings.

Where a machine exhibits a large amplitude of vibration at a frequency equal to one of the machine's natural frequencies or critical frequencies, the machine is considered to be in resonance. Operate machines a minimum of 15 precent away from any resonant frequency. Where a machine passes through one or more resonant frequencies in coming up to running speed, it should pass through these quickly, such as programming VFDs to skip resonant frequencies. See Section 5.20.

When using a computerized vibration data collector, the following minimum requirements are recommended:

- Minimum of 400 lines of resolution
- Dynamic range greater than 70dB
- Frequency response of 5Hz-10kHz (300 to 600,000 cycles per minute (cpm)
- Capability to perform ensemble averaging
- Use of a Hanning window
- Auto-ranging frequency

- Minimum amplitude accuracy over the selected frequency range of +/– 20% or +/– 1.5 dB

The vibration data collector device must use either a stud-mounted or a low mass rare earth magnet-mounted accelerometer. Do not use hand-held accelerometers. The mass of the accelerometer and its mounting must have minimal influence on the frequency response of the system over the selected measurement range.

Sound discs must be a minimum of 25mm (1 inch) in diameter, manufactured of a magnetic stainless steel, such as alloy 410 or 416, have a surface finish of 32 micro-inches rms, and be attached by tack weld, be stud mounted, or be epoxy glued.

Perform vibration tests and analysis on all rotating equipment greater than 7.5 HP (or smaller if highly critical to operations). Conduct tests at normal operating speed under normal running load conditions. The motor must meet the vibration criteria in Tables A.2.1 and A.2.2. Retain data on vibration testing of equipment for future reference. Investigate any substantial change in vibration immediately.

To correct excessive vibration, tighten loose parts and components. Consider thermal expansion where equipment is exposed to extreme operating temperatures. Where excessive vibration is due to imbalance, balance machines in accordance with the manufacturer recommendations. Repair or replace worn components. Where excessive vibration is due to misalignment, align equipment in accordance with manufacturer instructions.

Perform laser alignment on all shaft coupled machines. See Figure 1, next page. All shaft-to-shaft center line alignments should meet the requirements of Table A.2.3 (next page) unless more precise tolerances are specified by the machine

**Table A.2.1 Motor Vibration Criteria**

| Frequency (X RPM) Motor Component | Maximum Amplitude (in/sec Peak) | Maximum Amplitude (mm/sec Peak) |
|---|---|---|
| Overall | 0.1 | 2.5 |
| 0.4-0.5 | Not detectable | |
| 1X | See Motor Balance Specifications | |
| 2X | 0.02 | 0.5 |
| Harmonics (NX) | Not detectable | |
| Roller Element Bearings | Not detectable | |
| Side Bands | Not detectable | |
| Rotor Bar/Stator Slot | Not detectable | |
| Line Frequency (60 Hz) | Not detectable | |
| 2X Line Frequency (120 Hz) | 0.02 | 0.5 |

**Table A.2.2 Motor Balance Specifications**

| Motor Speed (RPM) | Special Application | | Standard Application | |
|---|---|---|---|---|
| | (in/sec Peak) | (mm/sec Peak) | (in/sec Peak) | (mm/sec Peak) |
| 900 | 0.02 | 0.5 | 0.08 | 2.0 |
| 1200 | 0.026 | 0.66 | 0.08 | 2.0 |
| 1800 | 0.04 | 1.0 | 0.08 | 2.0 |
| 3600 | 0.04 | 1.0 | 0.08 | 2.0 |

manufacturer. The tolerances specified in Table A.2.3 are the maximum allowable deviations from Zero-Zero Specifications or alignment target specifications (i.e., an intention targeted offset and/or angularity). Figure A.2.2 (next page) illustrates the concept of offset and angular motor alignment.

## A.3 Contact Resistance

Inspect bolted electrical connections for high resistance using a low-resistance ohmmeter. Compare bolted connection resistance values to results from similar connections. Resistance values, micro-ohm or millivolt drop test values, should not exceed the high levels of the normal range of the manufacturer published data. If manufacturer data is not available, investigate any values which deviate from similar connections by more than 50% of the lowest value.

## A.4 Contact/Pole Resistance Test

This test is used to test the quality and condition of separable current-carrying contacts. The contact resistance should be kept as low as possible to prevent localized heating and/or arcing that will

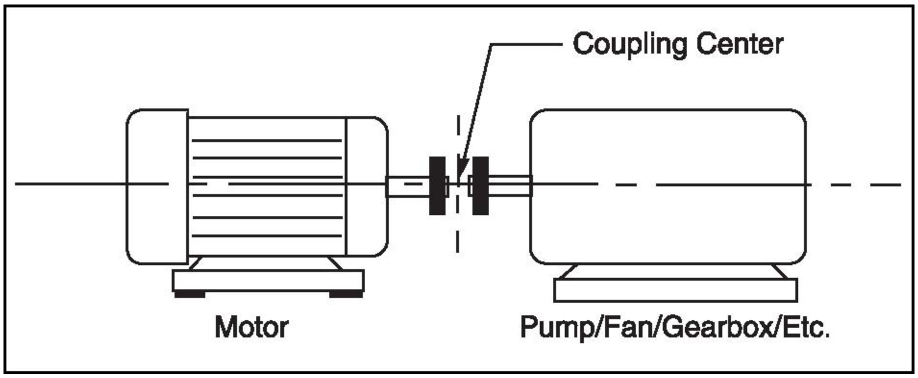


Figure A.2.1 Coupled Shafts Alignment

**Table A.2.3 Coupled Shaft Alignment Tolerance Values**

| | RPM | Tolerance Specification | |
|---|---|---|---|
| **Soft Foot** | All | <0.002 inch (0.0508 mm) at each foot | |
| | | **Horizontal & Vertical Parallel Offset per Inch (25.4 mm) of Spacer Length** | **Angularity/Gap Inch/10 inch (mm/254 mm) Coupling Diameter** |
| **Short Couplings** | <1000 | 0.005 in (1.2700 mm) | 0.015 in (0.3810 mm) |
| | 1200 | 0.004 in (1.0160 mm) | 0.010 in (0.2540 mm) |
| | 1800 | 0.003 in (0.7620 mm) | 0.005 in (0.1270 mm) |
| | 3600 | 0.002 in (0.5080 mm) | 0.003 in (0.0762 mm) |
| | 7200 | 0.001 in (0.2540 mm) | 0.0025 in (0.0635 mm) |
| | | | |
| **Couplings with Spacers** | <1000 | 0.0020 in (0.0508 mm) | |
| | 1200 | 0.0015 in (0.0381 mm) | |
| | 1800 | 0.0010 in (0.0254 mm) | |
| | 3600 | 0.0005 in (0.0127 mm) | |
| | 7200 | 0.0003 in (0.0076 mm) | |

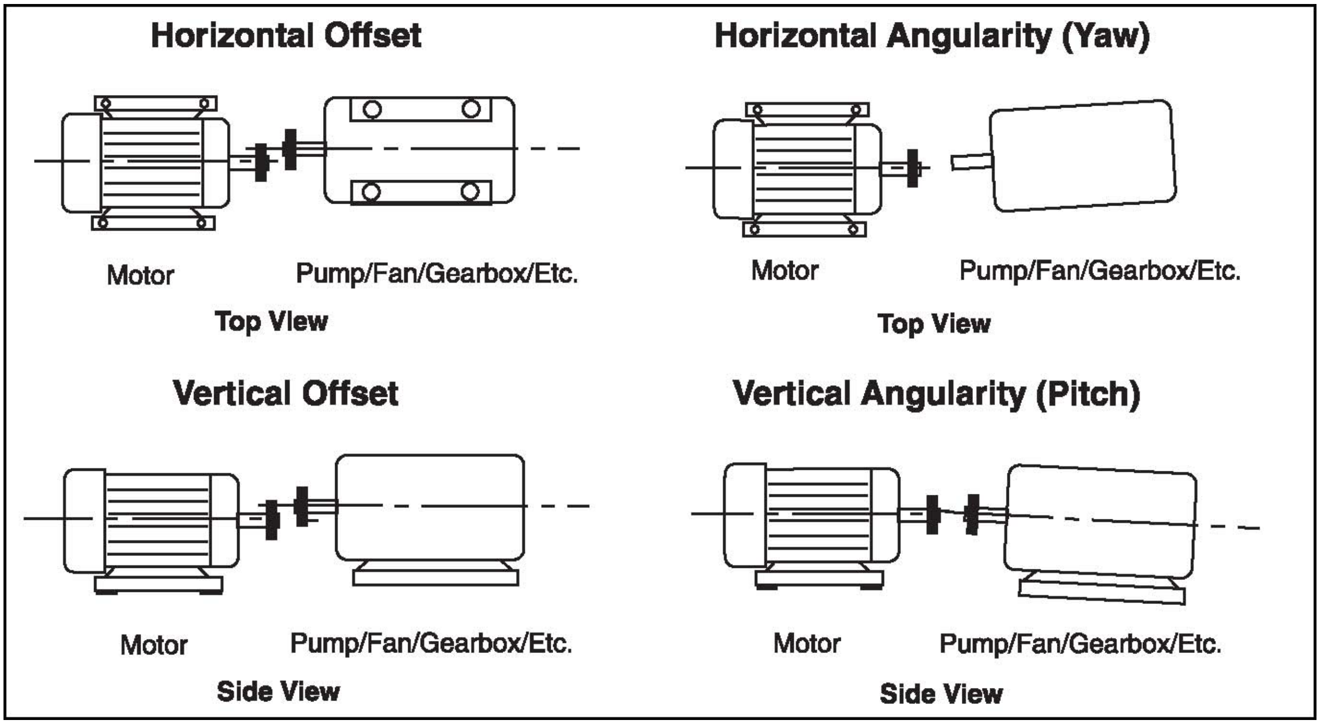


Figure A.2.2 Offset and Angular Motor Alignment

shorten the life of both the contacts and nearby insulation.

Increased contact resistance can be caused by pitted contact surfaces, foreign material embedded on contact surfaces, or weakened contact spring pressure. High resistance will cause excessive current to be diverted through the arcing contacts of certain high-capacity circuit breakers, resulting in overheating and burning.

Contact pressure should be within manufacturer specifications.

Measure the contact resistance across each pole using a low-resistance ohmmeter. Resistance values should not exceed the high levels of the normal range as indicated in the manufacturer published data. Dress, repair, or replace contacts and worn components in accordance with manufacturer recommendations.

## A.5 Infrared survey

Perform an infrared survey in accordance with test equipment manufacturer instructions. Use an infrared survey device designed to measure actual operating temperatures, or designed to detect significant deviations from surrounding conditions.

Perform an infrared survey at least annually, and more frequently where warranted by historical equipment failures, installation of new equipment, or changes in environmental, operational, or load conditions. Ensure that all critical equipment is included in the infrared survey.

Provide supplemental barriers and safety precautions during the infrared survey to prevent accidental contact with exposed energized components. Comply with NFPA 70E, Standard for Electrical Safety in the Workplace. Use appropriate personal protective equipment (PPE). See Section 3.

Shiny surfaces do not emit radiation energy efficiently, and can be hot while appearing cool in an infrared image. Additionally, plastic and glass covers in electrical enclosures are not transparent to infrared radiation. Do not test equipment when exposed to direct sunlight. Perform infrared inspections of outdoor equipment at night or provide shielding or shading for equipment under test.

Do not perform infrared inspections during time of moderate or high winds that can cool defective conductors and components and mask deficiencies.

Inspect distribution systems, equipment, and conductors with imaging equipment capable of detecting a minimum temperature difference of 1°C (1.8°F) at 30°C (86°F). Provide documentation of device calibration. Equipment should detect emitted radiation and convert detected radiation to a visual signal.

Prepare a report identifying the equipment and conductors tested, and describing the results of the infrared test. Include notations of deficiencies detected, causes of temperature differences, remedial action taken, results from retesting after remedial action, and inaccessible or unobservable areas and equipment. Maintain a permanent record of all infrared test results to track electrical characteristics of equipment, components, cables, conductors, connections, terminations, and splices over time.

De-energize equipment and conductors in accordance with established safety procedures. Remove accessible covers, plates, weathershields, and doors of equipment, manholes, junction boxes, and splice boxes to reveal equipment, components, cables, conductors, connections, terminations, and splices.

Energize equipment and conductors, and turn on all normal loads. Allow equipment and conductor temperatures to normalize.

Perform an infrared survey of all accessible current-carrying electrical components while conductors and equipment are energized and operating under maximum load conditions, but not less than 40% of the rated load of the electrical equipment being inspected. *NOTE: Infrared survey results could be inconclusive if equipment and conductors are lightly loaded.*

Temperature differences of 1°C to 3°C (1.8°F to 5.4°F) indicate possible deficiencies and warrant investigation. Temperature differences of 4°C to 15°C (7.2°F to 27°F) indicate deficiencies that may be repaired as time permits. Temperature differences of 16°C (28.8°F) and more indicate major deficiencies that must be repaired immediately.

Consult equipment, conductor, termination, splice, accessories, and component manufacturers for repair or replacement recommendations if infrared survey results indicate overheating of components.

Upon completion of the infrared survey, de-energize equipment in accordance with established safety procedures and reinstall accessible covers, plates, weathershields, and doors of equipment, manholes, junction boxes, and splice boxes. Energize equipment and conductors, and turn on all normal loads.

## A.6 Insulation Power Factor and Dissipation Factor

Use a power factor test set with the following minimum requirements:

- Test voltage range of 500V to 12 kV.
- Ability to perform UST, GST, and GST-with guard tests.
- Readings for power factor, dissipation factor, capacitance, and watts-loss.
- Power factor/dissipation factor range of 0 to 200%.
- Capacitance measuring range of 0 to 0.20 pico-farads.

Follow the power factor test set manufacturer instructions for performing tests. Compare power factor or dissipation factor values with previous results from similar equipment.

### *A.6.1 Transformers*

Perform an insulation power factor test in accordance with transformer or test equipment manufacturer published data. Measure power factor for each winding to ground, and for each winding to all other windings. Correct results to 20°C in accordance with test equipment manufacturer instructions. Compare to manufacturer factory test results. If manufacturer data is not available, compare test results with the acceptance tests results, if available, and any prior test results. Investigate power factor test values more than 3% for dry-type transformers.

### *A.6.2 Bushings*

Perform a power factor test on bushings rated above 600V that are equipped with power factor taps, and perform a hot collar watts-loss test using a test electrode around the outside shell of bushings that are not equipped with power factor taps. Correct results to 20°C in accordance with test equipment manufacturer instructions. Maximum power factor of liquid-filled equipment corrected to 20°C must be in accordance with the manufacturer published data. If insulation power factor is measured at a relatively high temperature and the temperature-corrected values are higher than expected, allow the equipment to cool and repeat the insulation power factor test at or near 20°C.

Compare the test results with the test equipment manufacturer published data. Investigate bushing power factor and capacitance test results that vary from nameplate values by more than 5%. Investigate any bushing hot collar watts-loss results that exceed the test equipment manufacturer published data. For liquid-filled transformers, investigate any bushing hot-collar test values that exceed 0.1 Watts.

### *A.6.3 Medium-Voltage Air or Vacuum Circuit Breakers*

Perform a power factor test on each line-side and load-side bushing assembly complete with stationary contacts and interrupters with the circuit breaker open, and each phase of the circuit breaker with the breaker closed. Measure power factor or dissipation factor on each bushing. Test each bushing using either the power factor or capacitance tap if the bushing is so equipped or a hot collar test using a test electrode around the outside shell of the bushing. Bushing values should be within 10% of the nameplate rating for the bushings or manufacturer published data. Hot collar tests are evaluated on a milliampere milliwatt loss basis and the results should be compared to results from similar bushings or manufacturer published data.

## A.7 Battery Impedance

Use a battery impedance test set with the following minimum requirements:

- Ability to test battery cells of up to 2500 amp-hour capacities
- Maximum battery test voltage of 25 Volts DC
- Impedance range of 0.0 to 100 milliohms
- Ability to test both lead-acid and Nickel-Cadmium Batteries
- Test voltage stability of +/¬0.1%
- Resistance accuracy of +/¬5% at 1 megohm

Follow the battery impedance test set manufacturer instructions for performing tests. Compare test results with prior test results.

## A.8 Breaker Time Travel Analysis

Use a breaker timing test set with the following minimum requirements:

- Perform contact timing during breaker close, open, open-close, close-open, and open-close-open.
- Have a minimum of three dry contact inputs
- Have a minimum of two wet-input channels to monitor breaker secondary contacts
- Have a minimum resolution of + 0.0001 seconds over a one-second duration
- Have travel transducers capable of linear and rotary motion
- Be capable of slow close contact point measurement

Follow the breaker timing test set manufacturer instructions for performing tests.

Perform time travel analysis to determine whether the circuit breaker operating mechanism is operating properly. Use test instruments in strict compliance with manufacturer instructions. Failure to follow manufacturer instructions can result in personal injury and can compromise data.

Determine the opening and closing speeds of the breaker, the interval time for closing and tripping, and the contact bounce. Circuit breaker operation times must conform to manufacturer published data. If recommended by the manufacturer, slow close/open the breaker and check for binding, friction, contact alignment, and penetration.

Compare travel and velocity values to manufacturer published data and previous test results. In the absence of manufacturer published data, refer to ANSI/IEEE C37.04.

Investigate weak accelerating springs, defective shock absorbers, dashpots, buffers, and closing mechanisms as possible causes of deficient test results. Repair or replace suspect components in accordance with manufacturer instructions.

## A.9 Insulation Resistance Testing

Prior to performing insulation resistance testing, clean, inspect, and repair equipment, connections, buses, conductors, and terminations to minimize leakage currents during testing. Disconnect equipment and accessories from items under test, including voltage sources, instrument transformers, surge protective devices, capacitors, and similar equipment. Disconnect conductors under test and isolate from equipment when possible. When conductors are not disconnected from equipment, reduce the test voltage to prevent equipment damage when necessary. Additionally, when conductors are not disconnected from equipment under test, leakage currents may be due to conductor insulation damage or failure and not the equipment, which reduces the effectiveness of the testing.

**Table A.9.1 Minimum Test Voltage and Insulation Resistance**

| Voltage Rating | Minimum Test Voltage | Minimum Insulation Resistance |
|---|---|---|
| 0-250V | 500V DC | 25 Megohms |
| 250-600V | 1000V DC | 100 Megohms |
| 601-5000V | 2500V DC | 1000 Megohms |
| 5001-15,000V | 2500V DC | 5000 Megohms |

Apply voltage in accordance with the manufacturer published data. See Table A.9.1 for additional information. Use an insulation resistance test set with the following minimum requirements:

- Test voltage increments of 500V, 1000V, 2500V, and 5000V DC
- Resistance range of 0.0 to 500,000 Megohms at 500,000V DC
- A short-circuit terminal current of a minimum of 2.5 milliamps

Follow the insulation resistance test set manufacturer instructions for performing tests.

Conduct tests of electrical equipment, sub-systems, and systems using normal procedures and requirements to ensure safety. Disconnect sensitive electronic equipment, such as surge protective devices (SPDs), before insulation resistance testing. Disconnect one side of transformers and coils before testing.

Insulation resistance measurements specified are the minimum acceptable values at an ambient temperature of 16°C (60°F) with a relative humidity of less than 60%. Do not perform insulation resistance tests during times of high relative humidity. When insulation resistance measurements are taken at other than 16°C (60°F), convert test results to equivalent values at 16°C (60°F).

Do not perform tests on outdoor equipment during inclement weather. Do not perform tests on direct burial ground conductors or on ground rods within a 48-hour period following rainfall.

During cable tests, station an individual at each point where cable has exposed connections.

Perform insulation resistance testing from phase-to-ground and from phase-to-phase for equipment and conductors in accordance with the equipment and the test instrument manufacturer instructions. Measure insulation resistance of low-voltage circuit breakers, switches, and equipment phase-to-phase and phase-to-ground and across open poles. Isolate conductors and cables by opening switches or breakers at each end of the cable before testing, when possible. *NOTE: Where conductors and cables are directly connected to equipment with no disconnecting means, test as connected. Do not disconnect conductors or cables.* Ground equipment, conductors, and cable shields not being tested.

For conductors, perform insulation resistance testing for a minimum of one minute.

For liquid-filled and dry-type transformers and for rotating machines, perform insulation resistance testing for a minimum of ten minutes.

Do not exceed the voltage rating of the equipment and conductors under test. In general, perform insulation resistance testing using a test voltage of 1000V DC for 600 V rated insulation, and 500V DC for 300V rated insulation. For transformers rated 600V and below, use a minimum voltage of 1000V DC. For transformers rated 601-5000V, use a minimum voltage of 2500V DC. For transformers rated above 5000V, use a minimum voltage of 5000V DC.

Perform insulation resistance testing on control wiring with respect to ground in accordance with manufacturer instructions. Apply 500VDC for 300V rated conductors and 1000VDC for 600V rated conductors for a minimum of one minute. Follow manufacturer instructions for performing insulation resistance testing on equipment with solid state components not rated for the applied test voltages. Control wiring insulation resistance test values should be comparable to prior test results but not less than two Megohms.

For rotating machines, insulation resistance testing applies to armature and rotating or stationary field windings of equipment and machines. Operating machines should be tested immediately following shutdown when the windings are hot and dry. Record the temperature of large machines for conversion to a base temperature in accordance with ANSI/IEEE 43, Recommended Practice for Testing Insulation Resistance of Rotating Machinery, for comparison with prior test results. Disconnect voltage sources, surge protection devices (SPDs), capacitors, and any other potential low-insulation sources before testing.

For rotating machines, perform tests on armature and rotating or stationary field windings. For AC rotating machines with an external neutral connection, disconnect the neutral connection on the stator, and test each winding with respect to the other windings and to ground. Test each phase separately with the other phases and the winding temperature detectors grounded. Disconnect any capacitors and surge protective devices during the test.

- For AC synchronous motors and generators rated 200 HP and less, perform insulation resistance for one minute. Calculate the dielectric absorption ratio.
- For AC synchronous motors and generators rated more than 200 HP, perform insulation resistance testing for ten minutes. Calculate the polarization index.

For other electrical equipment and systems other than rotating machinery, use a minimum test voltage of 500VDC for systems of 250V nominal or less, a minimum of 1000VDC for systems rated over 250V to 2500V, a minimum of 2500VDC for systems rated over 2500V to 15,000V, and a minimum of 5000VDC for systems rated over 15,000V.

Measure insulation resistance at one-minute intervals following the application of the test voltage. Record the megohm values of each phase-to-ground and between each phase-to-phase, along with the description of the instrument, voltage level, humidity, temperature, time, and date of the test. Ground equipment and conductors at the completion of the test.

Compare test results with prior test results and with the manufacturer data corrected for temperature variations using manufacturer recommended correction factors. Consult the equipment manufacturer published data for acceptable test results. If published data is not available, investigate any values which deviate from prior test results under similar conditions by more than 50% of the lowest value.

Insulation resistance should not be less than 2 Megohms for circuits under 115V, 6 Megohms between conductor and ground on those 115V to 600V circuits (115V-600V) with total single conductor length of 2500 feet and over, and not less than 8 Megohms for 115V to 600V circuits with single conductor length of less than 2500 feet.

For liquid-filled transformers, insulation resistance should not be less than 100 Megohms for transformer windings rated less than 600V, not less than 1,000 Megohms for transformer windings rated 601V to 5,000V, and not less than 5,000 Megohms for transformer windings rated greater than 5,000V.

For dry-type transformers, insulation resistance should not be less than 500 Megohms for transformer windings rated less than 600V, not less than 5,000 Megohms for transformer windings rated 601V to 5,000V, and not less than 25,000 Megohms for transformer windings rated greater than 5,000V.

For electrical equipment and systems other than rotating machinery, insulation resistance test values are recommended to not be below the values shown in Table A.9.2.

For low-voltage air-insulated and insulated case circuit breakers, insulation resistance should not be less than fifty (50) Megohms.

**Table A.9.2 Minimum Recommended Insulation Resistance Values for Electrical Equipment Other Than Rotating Machinery**

| Nominal Voltage Rating of Equipment (Volts) | Minimum Recommended Insulation Resistance Values (Megohms) |
|---|---|
| 250 | 25 |
| 600 | 100 |
| 1,000 | 100 |
| 2,500 | 500 |
| 5,000 | 1,500 |
| 8,000 | 2,500 |
| 15,000 | 5,000 |
| 25,000 | 10,000 |
| 34,000 and greater | 100,000 |

For motors and generator alternators, correct the measured one-minute insulation resistance values to 40°C. For most motors and generators and random-wound stator coils and form wound coils rated less than 1000V and DC motor armatures, minimum insulation resistance at one minute is 5 Megohms. For most DC generator armatures and form wound coil AC windings manufactured after 1970, minimum insulation resistance is 100 Megohms. For most windings manufactured before 1970, all field windings, and all other windings not described above, minimum insulation resistance is the nominal phase-to-phase voltage rating in kV plus one. Do not perform overpotential testing on alternators with insulation resistance values lower than these minimums.

Investigate insulation resistance test values that fall below recommended values. When possible, test circuit components individually to identify the low insulation resistance reading. Deficient insulation resistance values may be an indication of contaminated and/or wet insulation. Clean insulation and dry equipment as needed. When comparing prior insulation resistance test results, any consistent downward trend is an indication of degrading insulation. Consult the manufacturer for recommendations.

When insulation resistance measurements fall below the specified minimum values at 16°C (60°F), it may be possible to dry the equipment and/or conductors under test by applying heat in accordance with manufacturer instructions with owner and/or AHJ approval. If drying is accomplished by energizing the equipment in accordance with manufacturer instructions, do not exceed the continuous voltage, current, or temperature ratings of the equipment being dried, directly or by induction.

### *A.9.1 Dielectric Absorption Ratio and Polarization Index*

Plot insulation resistance over time to determine the dielectric absorption characteristic of rotating machinery, motors and alternators, and liquid-filled and dry-type transformers from winding to winding and winding to ground, which can indicate the presence of moist or dirty windings. A steady rising curve is indicative of clean, dry windings. A quickly flattening curve is the result of leakage current through or over the surface of the winding and is indicative of moist or dirty windings.

Calculate the dielectric absorption ratio, which is the insulation resistance measurement at 60 seconds divided by the insulation resistance measurement at 30 seconds.

Calculate the polarization index, which is the insulation resistance measurement at ten minutes divided by the insulation resistance measurement at one minute.

Compare the dielectric absorption ratio and polarization index for liquid-filled and dry-type transformers and AC rotating machines to previous results. The dielectric absorption ratio and polarization index should be greater than 1.0

For DC machines, motors and generators, investigate dielectric absorption ratios less than 1.4 and polarization index ratios less than 2.0 for Class B insulation and Class F insulation. Compare to manufacturer factory test results. If manufacturer data is not available, acceptance tests results will serve as baseline data for future reference.

Record and retain test results for future reference.

Consult the manufacturer for recommendations for deficient results.

## A.10 Dielectric Withstand Overpotential Testing (DC Overpotential and Very Low Frequency (VLF) AC Overpotential Testing)

*NOTE: DC overpotential (dielectric withstand, high-potential, or hi-pot) testing can cause insulation failure and should be used with caution. Complete all insulation resistance testing prior to overpotential testing. Review insulation resistance test results to determine suitability for overpotential testing. Do not perform overpotential testing until insulation resistance levels are raised above minimum levels.*

Provide supplemental barriers and safety precautions during overpotential testing to prevent accidental contact with exposed energized components. Clean and dry equipment found in a wet or dirty condition before performing overpotential testing.

Humidity, wind, and surface conditions strongly affect the results of DC overpotential testing. Do not perform overpotential tests during times of high relative humidity. Follow the manufacturer instructions for performing overpotential testing of equipment and conductors. Follow the test equipment manufacturer instructions. Use the lowest possible test voltage as recommended by the equipment or conductor manufacturer and the test equipment manufacturer.

Check the overpotential test set for proper operation. Ensure that the input voltage to the test set is regulated. Ensure that DC overpotential test equipment only measures the leakage current associated with the equipment or conductor under test and does not include the internal leakage of the test equipment. Follow the test set manufacturer instructions for connecting leads and performing tests.

Apply the test voltage for a minimum of 15 minutes. Graph microampere leakage versus time. Plot values every 30 to 60 seconds. Discontinue tests if erratic results are observed. Make notations including the data and time of testing, and the ambient temperature and relative humidity at the time of testing.

Consult the manufacturer for equipment and conductors that fail overpotential testing. Repair or replace equipment and conductors that fail overpotential testing. Repeat overpotential testing in its entirety for equipment and conductors that are repaired or replaced.

### *A.10.1 DC Overpotential Testing*

Apply the test voltage slowly in a minimum of five equal increments until the maximum test voltage is reached, with no increment exceeding the conductor or equipment voltage rating, and with each voltage step being held for an equal interval of time long enough to allow the leakage current to reach stability, approximately one to two minutes.

See Table A.10.1 for the maximum recommended DC overpotential test voltages. Record readings of leakage current at 30 seconds and one minute, and at one-minute intervals thereafter until the 15-minute test duration is met.

Record leakage current in microamperes at the end of each interval before the voltage is raised to the next level. Plot test voltage versus leakage current on graph paper as the test progresses. *NOTE: A linear increase in leakage current is expected, and it should stabilize or decrease from the initial value at each step.* Calculate the resistance at each step. As long as the leakage current decreases or remains steady after it has leveled off, the test is considered satisfactory.

Any excessive or nonlinear increase in leakage current can indicate imminent insulation failure. If the leakage current starts to increase (excluding momentary increases due to test equipment power supply disturbances), extend the test to determine whether the rising trend continues. Increasing leakage current will result in the complete breakdown of already-damaged insulation, evidenced by an abrupt increase in leakage current accompanied by a sharp decrease in test voltage. In this case, discontinue the test and consult the manufacturer for recommendations. *NOTE: This is characteristic of approximately 80% of all DC overpotential test failures on cables with elastomeric insulation.*

At any step where the calculated leakage resistance decreases approximately 50% or more of that of the next lower voltage level, discontinue the test to prevent insulation failure and to retain the equipment in a serviceable condition until its replacement can be scheduled.

Sudden failure or flashover can occur if the insulation is already completely or nearly punctured. Voltage increases until it reaches the sparkover potential of the air gap length, then flashover occurs. *NOTE: Polyethylene cables exhibit this characteristic for all failure modes.*

After recording all measurements, rapidly turn the test equipment to zero volts and monitor cable voltage. Record the decaying voltage every 15 seconds for 90 seconds, and then every 60 seconds until the charge is down to 10% or less of the test voltage, then solidly ground the cable. Remove the test lead for connection to the next conductor. After testing, ground cables for a minimum of four times as long as the test voltage was applied during the overpotential tests to assure complete discharge, but not less than 30 minutes.

### *A.10.2 Very Low Frequency (VLF) AC Overpotential Testing*

Apply the test voltage for a minimum of 30 minutes. See Table A.10.2 for the maximum recommended VLF test voltage levels. If the VLF testing frequency is adjusted from a nominal 0.1 Hz, such as to compensate for very long cables, adjust the test time accordingly.

Several VLF test waveforms are possible. In the absence of other recommendations, perform VLF testing using a smooth, load independent Sinusoidal waveform (similar to that found in nominal 60 Hz AC power systems) with an optimized frequency held as close as possible to 0.1 Hz.

**Table A.10.1 Recommended Maximum Voltages for DC Overpotential Testing of Cables**

| Rated Circuit Voltage (KV) | Test Voltage (kV) | |
|---|---|---|
| | 100% Insulation | 133% Insulation |
| 5 | 25 | 35 |
| 8 | 35 | 45 |
| 15 | 55 | 65 |
| 25 | 80 | 96 |
| 28 | 85 | 100 |
| 35 | 100 | 125 |

Multiple parallel conductors within each phase may be bolted together for testing purposes to reduce overall test times. If test results are questionable with parallel conductors, test each conductor separately.

Cable that has been VLF tested is considered to have good insulation when no failure is detected during the test and the percent standard deviation of Tan-Delta measurements at all test voltages is less than 0.02 (See Section A.11). Cable with a percent standard deviation of Tan-Delta measurements greater than 0.02 should be tested further to determine the cause.

## A.11 Tan-Delta (Dissipation Factor) Testing Using Very Low Frequency (VLF) Testing

*NOTE: Tan-Delta testing is used to evaluate overall cable condition and can be used to detect water trees in medium-voltage cable. Test results may not be accurate for cables exceeding 1,600 m (5,000 feet) in length.*

Dissipation factor (Tan Delta) Testing is also known as loss angle or insulation power factor testing. Dissipation factor (Tan Delta) testing is a diagnostic method of testing cables to determine the loss factor of the insulation material. Because the loss factor increases during the aging process of the cable, the dissipation factor measurement can be used as a diagnostic method to predict overall cable health. For cables, the dissipation factor of each conductor with respect to ground should be obtained, and a hot-collar test should be performed on each pothead or porcelain termination assembly.

Perform Tan-Delta testing only on shielded cables using an appropriate test set in accordance with the test set manufacturer instructions. *NOTE: Unshielded cables do not have a consistent reference to ground.*

Ensure that conductors are disconnected from equipment. Test only one conductor at a time. Test parallel conductors individually.

Select the test voltage in accordance with manufacturer instructions. *NOTE: The test voltage, Vo, is typically calculated from the nominal system voltage, from phase-to-ground for wye-connected three-phase four-wire systems, and from phase-to-phase for delta-connected three-phase, three-wire systems. The test voltage may be lowered, such as when testing cables that are known to be degraded or when spare conductors are not available.*

Tan-Delta testing is conducted from each conductor to ground in three steps of three minutes each, with readings taken at the end of each three-minute step, with an applied test voltage of 0.5 times Vo for Step 1, 1.0 times Vo for Step 2, and 1.5 times Vo for Step 3.

NOTE: Undamaged cable behaves like a capacitor with a 90° phase shift between the voltage waveform and the current waveform. Cable that is damaged or degraded will have increased leakage current resulting in a measured phase displacement of less than 90°.

**Table A.10.2 Recommended Maximum Voltages for VLF AC Overpotential Testing of Cables**

| Rated Circuit Voltage (KV) | Installation Test Maximum RMS Voltage (Phase to Ground) | Acceptance Test Maximum RMS Voltage (Phase to Ground) |
|---|---|---|
| 5 | 9 | 10 |
| 8 | 11 | 13 |
| 15 | 18 | 20 |
| 25 | 27 | 31 |
| 35 | 39 | 44 |

Tan-Delta test results are typically that values increase with voltage level (higher Tan-Delta results at higher test voltages). Negative differences in Tan-Delta test results may indicate a faulty test procedure or may indicate significant defects with the cable, and further testing is recommended. Poor Tan-Delta test values typically indicate significant degradation of the overall cable.

Maintain a record of Tan-Delta measurements to track cable electrical characteristics over time.

## A.12 Partial Discharge Testing

Partial discharge testing evaluates the severity of electrical discharges from a conductor into the air, across surfaces, and through the insulating material. Partial discharges emit energy in various parts of the electromagnetic spectrum. Partial discharges appear as individual events of very short duration, and are always accompanied by emissions of light, sound, heat, and electromagnetic pulses, and often result in chemical reactions. The severity of partial discharges is an indication of the overall health of the conductor or equipment insulation system. Partial discharge testing can measure discharges on-line or off-line, with a comparison with a database of discharge signatures to determine the severity.

Partial discharge testing is used to detect physical damage of conductors, cables, terminations, and splices, contamination on terminations or improper spacing of unshielded parts of terminations that causes tracking, improperly connected, damaged, or corroded metallic shields, electrical trees resulting from water trees, and thermal damage due to overloads. Partial discharge testing may be performed using very low frequency (VLF) AC test methods.

Any partial discharge in the conductor insulation at voltage levels near or slightly above the nominal operating voltage of the cable indicates that cable failure is imminent under normal operating conditions.

Partial discharge testing may include one or more of Radio frequency interference (RFI) detection, electromagnetic detection, acoustical detection using ultrasonic sensors, and ultraviolet detection.

Select an appropriate partial discharge sensor technology based on the type of equipment or conductor being tested. Sensor technologies include transient-earth voltage (TEV), high-frequency current transformer (HFTC), Ultra-High Frequency (UHF), coupler technology on voltage indicator system (VIS) ports, and contact or airborne acoustic. Connect the appropriate sensor to an instrument that displays the signal intensity and phase relationship. Follow the test set manufacturer instructions for performing tests.

When partial discharges are identified, measure and record the Partial Discharge Inception Voltage (PDIV), or the voltage at which point the partial discharge is initiated, and the Partial Discharge Extinction Voltage (PDEV), or the lower voltage at which point the partial discharge is extinguished, which will help in evaluating the overall condition of the cable, which is a subjective process open to interpretation.

One drawback to partial discharge testing is that one location of significant partial discharge can mask areas of lesser partial discharge.

Maintain a record of partial discharge test results to track electrical characteristics over time.

## A.13 Transformer Excitation Current Test

Perform a transformer excitation current test using an appropriate test set in accordance with the test set manufacturer instructions.

The transformer excitation (magnetizing) current test should be performed during maintenance and after any abnormal operating condition, such as a through-fault. The excitation current test is used to detect short-circuited turn-to-turn insulation, short-circuited core laminations, loosening of the core clamping, or improper winding connections, and other internal physical damage, and provides information for a mechanical assessment of transformers.

Excitation current test results are compared between phases for three-phase transformers. For a transformer with no internal damage, the windings installed on the outer legs of the core for a core-type transformer will have similar test results while the center leg winding will be slightly less.

For a transformer with damage to the core and/or windings, such as a winding with a turn-to-turn fault, the excitation current will be much greater on the phase with the shorted turns. As such, the excitation current test can be used to verify suspect results from a transformer turns-ratio test.

The transformer core may have residual magnetism present after being disconnected from its power source, or from other off-line electrical testing of the transformer. Residual magnetism can result in higher-than-normal excitation current test results. When necessary, de-magnetize the transformer core in accordance with manufacturer instructions prior to repeating excitation current testing to obtain reliable results.

### A.14 Magnetron Atmospheric Condition (MAC) Testing of Vacuum Interrupters

Magnetron atmospheric condition (MAC) testing determines the internal pressure of vacuum interrupters. Vacuum interrupters gradually lose pressure over time. Periodically measuring the internal pressure of a vacuum interrupter can be used to predict its life expectancy with the ability to replace them prior to their failure. MAC testing has proven to be more reliable than overpotential testing in determining the life expectancy of vacuum interrupters.

Vacuum interrupters are typically manufactured with an internal pressure between 1x10-4 Pa and 1x10-5 Pa. Vacuum interrupters typically begin to fail overpotential testing when their internal pressure drops to approximately 1x10-1 Pa. Replacing vacuum interrupters before reaching this failure point reduces the risk of catastrophic failure, personal injury and/or death, and equipment damage. In addition to internal pressure, consider contact wear, the number of mechanical operations, and the general cleanliness of the vacuum interrupter in determining its overall condition.

Use a listed test set for MAC testing in accordance with the test set manufacturer instructions. Thoroughly clean any contamination from the outer surface of the vacuum interrupter to be tested using denatured alcohol and a clean cloth. Open the circuit breaker or contactor to open the vacuum interrupter. Verify that the separation of the vacuum interrupter contacts is within the gap specified by the manufacturer prior to testing.

For vacuum interrupters installed on a circuit breaker or contactor, select the appropriate flexible magnetic field coil from the test set. Wrap the flexible coil around the vacuum interrupter a minimum of five full wraps around the center of the vacuum interrupter with each winding wrapped tightly and in direct contact with the next winding wrap. Secure the flexible coil in place to prevent it from contacting any bus, brackets, or metal endcaps of the vacuum interrupter during the test. *NOTE: Not all circuit breaker and contactor designs have sufficient clearances to permit the installation of the flexible magnetic field coil. Only remove vacuum interrupters from circuit breakers and contactors for testing in accordance with manufacturer instructions.*

For interrupters that have been removed from the circuit breaker, open the contacts manually in accordance with manufacturer instructions. Protect the movable end of the interrupter from twisting when manually opening the contacts. *NOTE: Fixed magnetic field coils can be used when the vacuum interrupter is removed from the circuit breaker or contactor.* Place the vacuum interrupter into the fixed magnetic field coil with a small clearance between the interrupter and the interior of the coil in accordance with the test kit manufacturer instructions.

Connect test leads in accordance with the test kit manufacturer instructions. Ensure that the high voltage circuit and the magnetic field circuit are isolated from each other. *NOTE: The test equipment may be damaged if high voltage is inadvertently applied to the magnetic field coil.*

Ensure that the test equipment ground terminal is connected to a suitable ground. Ensure that the test equipment is programmed for the test parameters for each vacuum interrupter. Refer to the test equipment manufacturer instructions for specific operating procedures.

Log the test results for each vacuum interrupter to track its internal pressure over time. Typically, test results are compared with an ionization current/pressure curve and is used together with additional factors (previously discussed) to determine life expectancy.

Do not repeatedly test the same vacuum interrupter over a relatively short period of time as the capacitance of the vacuum interrupter will cause the pressure value test results to be progressively reduced in subsequent tests.

Evaluate each vacuum interrupter in accordance with the test equipment manufacturer instructions.

## A.15 Primary and Secondary Current Injection Tests

For circuit breakers equipped with solid state (static) trip devices, check for proper operation and timing in accordance with manufacturer instructions. *NOTE: Primary injection test sets will test the entire tripping system, which validates the measurement functions and interconnectivity of sensing and trip devices. Secondary injection tests only validate the functionality of the trip unit and circuit breaker opening, but do not test the power supply, the current sensor, or interconnecting wiring. Because of the unique designs of power circuit breakers, consult the manufacturer for breaker-specific test kits and test instructions. Do not attempt to repair solid-state trip units. Consult the manufacturer for recommendations for any malfunctioning units.*

Power circuit breakers that require very high interrupting ratings are available with integral current-limiting fuses. Remove or otherwise bypass current-limiting fuses from circuit breakers so equipped prior to applying simulated overload and fault current.

Perform primary current injection testing to determine minimum long-time pickup current and time delay (at 300% pickup current), short-time pickup and time delay, and instantaneous pickup current, and ground-fault pick up and time delay for circuit breakers with solid-state trip units so equipped. Determine instantaneous pickup current by run-up or pulse method. Clearing times should be within six cycles or less. Record trip times. Compare results with the time-current coordination curve for each circuit breaker. Pickup values should be as specified in the coordination study, if available, provided by others. Trip characteristics should not exceed the manufacturer published time-current characteristic tolerance band, including adjustment factors, if applicable. Instantaneous pickup values should fall within manufacturer published tolerances. Replace defective calibration and timing components, including when circuit breaker trip times vary from the published tolerance band by more than 10% at 300% current. Adjust and retest where necessary.

Perform secondary injection testing to test the functions of the trip unit. Verify trip unit characteristics. Set adjustable or programmable devices according to the protective device coordination study, if available, provided by others. Pickup values and trip characteristics should be within the manufacturer published tolerances. Replace defective devices, including when circuit breaker trip times vary from the published tolerance band by more than 10% at 300% current, and adjust and retest where necessary.

## A.16 Sampling and Testing of Insulating Liquids

Follow testing laboratory and manufacturer instructions when removing and handling samples of insulating liquid.

For liquid-filled transformers, reactors, step voltage regulators, induction regulators, and load tap changers, remove a sample of insulating liquid in accordance with ASTM D 3613 and a perform dissolved-gas analysis (DGA) in accordance with ASTM D3612 or ANSI/IEEE C57.104. Evaluate the results of the dissolved-gas analysis in accordance with ANSI/IEEE C57.104. Compare the test results with prior test results and with the manufacturer or industry recommended levels. Investigate any test results that are outside of recommended levels.

For liquid-filled transformers, remove a sample of insulating liquid in accordance with ASTM D-923 and test for the following:

- Dielectric breakdown voltage in accordance with ASTM D-877 and/or ASTM D-1816.
- Acid neutralization number in accordance with ASTM D-974.
- Specific gravity in accordance with ASTM D-1298.
- Interfacial tension in accordance with ASTM D-971 or ASTM D-2285.
- Color in accordance with ASTM D-1500.
- Visual condition in accordance with ASTM D-1524.
- Water content in accordance with ASTM D-1533. (Required for all liquid-filled transformers rated 25 kV or higher, and for all silicone-filled transformers.)
- Measure dissipation factor or power factor in accordance with ASTM D-924.

For liquid-filled reactors, remove a sample of insulating liquid in accordance with ASTM D-923 and test for the following:

- Dielectric breakdown voltage in accordance with ASTM D-877.
- Acid neutralization number in accordance with ASTM D-974.
- Specific gravity in accordance with ASTM D-1298.
- Interfacial tension in accordance with ASTM D-971.
- Color in accordance with ASTM D-1500.
- Visual condition in accordance with ASTM D-1524.
- Water content in accordance with ASTM D-1533.
- Measure dissipation factor or power factor in accordance with ASTM D-924.

For step voltage regulators, remove a sample of insulating liquid from the main tank or common tank in accordance with ASTM D923 and test for the following:

- Dielectric breakdown voltage in accordance with ASTM D-877 and/or ASTM D1816.
- Acid neutralization number in accordance with ASTM D-974.
- Specific gravity in accordance with ASTM D-1298.
- Interfacial tension in accordance with ASTM D-971.
- Color in accordance with ASTM D-1500.
- Visual condition in accordance with ASTM D-1524.
- Water content in accordance with ASTM D-1533.
- Measure power factor in accordance with ASTM D-924. (Required when the regulator voltage is rated 46 kV or higher.)

For induction regulators, remove a sample of insulating liquid from the main tank or common tank in accordance with ASTM D923 and test for the following:

- Dielectric breakdown voltage in accordance with ASTM D-877 and/or ASTM D1816.
- Acid neutralization number in accordance with ASTM D-974.
- Specific gravity in accordance with ASTM D-1298.
- Interfacial tension in accordance with ASTM D-971.
- Color in accordance with ASTM D-1500.
- Visual condition in accordance with ASTM D-1524.
- Water content in accordance with ASTM D-1533. (Required when the regulator voltage is rated 25 kV or higher.)
- Measure power factor in accordance with ASTM D-924. (Required when the regulator voltage is rated 46 kV or higher.)

For oil-filled circuit breakers and switches, remove a sample of insulating liquid in accordance with ASTM D-923 and test for the following:

- Dielectric breakdown voltage in accordance with ASTM D-877.
- Acid neutralization number in accordance with ASTM D-974.
- Interfacial tension in accordance with ASTM D-971.
- Color in accordance with ASTM D-1500.
- Visual condition in accordance with ASTM D-1524.
- Water content in accordance with ASTM D-1533.
- Measure power factor or dissipation factor in accordance with ASTM D-924.

For liquid-filled load tap changers, medium-voltage oil switches, oil and vacuum automatic reclosers, and oil-filled automatic sectionalizers, remove a sample of insulating liquid in accordance with ASTM D923 and test the following:

- Dielectric breakdown voltage in accordance with ASTM D877 and/or ASTM D1816.
- Color in accordance with ASTM D1500.
- Visual condition in accordance with ASTM D1524.

*(This annex is not part of the standard)*

# Annex B: Reference Standards

This publication, when used in conjunction with the National Electrical Code and manufacturer literature, provides recommended guidelines for maintaining building electrical systems, equipment, and components. The following publications may also provide useful information:

National Fire Protection Association
1 Batterymarch Park
Quincy, MA 02169-7471
(617) 770-3000 tel
(617) 770-3500 fax
*www.nfpa.org*

NFPA 70-2023, National Electrical Code (ANSI)

NFPA 70B-2023, Standard for Maintaining Electrical Equipment (ANSI)

InterNational Electrical Testing Association
3050 Old Centre Ave., Suite 102
Portage, MI 49024
(888) 300-638 tel
(269) 888-6382 tel
(269) 488-6383 fax
*www.netaworld.org*

NETA MTS-2023, Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems

IEEE Operations Center
445 Hoes Lane
Piscataway, NJ 08854-4141

IEEE 81, IEEE Guide For Measuring Earth Resistivity, Ground Impedance, And Earth Surface Potentials Of A Grounding System

IEEE 142, IEEE Recommended Practice For Grounding Of Industrial And Commercial Power Systems (Green Book)

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

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

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

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

IEEE C57.13, Standard Requirements for Instrument Transformers

IEEE C57.13.1-2017, IEEE Guide for Field Testing of Relaying Current Transformers

IEEE C57.13.3-2014, IEEE Guide for Grounding of Instrument Transformer Secondary Circuits and Cases

IEEE C37.20.1, Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear

IEEE C37.23, Standard for Metal-Enclosed Bus and Calculating Losses in Isolated-Phase Bus

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

Underwriters Laboratories
333 Pfingsten Rd.
Northbrook, IL 60062-2096

UL 489, Molded-Case Circuit Breakers, Molded-Case Switches and Circuit Breaker Enclosures

UL 1066, Low-Voltage AC and DC Power Circuit Breakers Used in Enclosures

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

ASTM D2472, Standard Specification for Sulfur Hexafluoride

### Current *National Electrical Installation Standards*™ published by NECA:

National Electrical Contractors Association
1201 Pennsylvania Ave. NW, Suite 1200
Washington, D.C. 20004
(202) 991-6300 tel
(202) 217-4171 fax
*www.necanet.org*

NECA 1-2023, *Standard for Good Workmanship in Electrical Construction* (ANSI)

NECA 5-2022, *Recommended Practice for Prefabrication of Electrical Installations for Construction* (ANSI)

NECA 90-2015, *Standard for Commissioning Building Electrical Systems* (ANSI)

NECA 91-2023, *Recommended Practice for Maintaining Electrical Equipment* (ANSI)

NECA 100-2013, *Symbols for Electrical Construction Drawings* (ANSI)

NECA 101-2020, *Standard for Installing Steel Conduits (Rigid, IMC, EMT)* (ANSI)

NECA 102-2004, *Standard for Installing Aluminum Rigid Metal Conduit* (ANSI)

NECA/NEMA 105-2015, *Standard for Installing Metal Cable Tray Systems* (ANSI)

NECA 111-2017, *Standard for Installing Nonmetallic Raceways (RNC, ENT, LFNC)* (ANSI)

NECA/NACMA 120-2018, *Standard for Installing Armored Cable (AC) and Metal-Clad Cable (MC)* (ANSI)

NECA 121-2007, *Standard for Installing Nonmetallic-Sheathed Cable (Type NM-B) and Underground Feeder and Branch-Circuit Cable (Type UF)*

NECA 130-2016, *Standard for Installing and Maintaining Wiring Devices* (ANSI)

NECA 169-2016, *Standard for Installing and Maintaining Arc-Fault Circuit Interrupters (AFCIs) and Ground-Fault Circuit Interrupters (GFCIs)* (ANSI)

NECA 200-2016, *Standard for Installing and Maintaining Temporary Electric Power at Construction Sites* (ANSI)

NECA 202-2013, *Standard for Installing and Maintaining Industrial Heat Tracing Systems* (ANSI)

NECA 230-2016, *Standard for Selecting, Installing, and Maintaining Electric Motors and Motor Controllers* (ANSI)

NECA/FOA 301-2016, *Standard for Installing and Testing Fiber Optic Cables* (ANSI)

NECA 303-2019, *Standard for Installing Closed-Circuit Television (CCTV) Systems*

NECA 305-2018, *Standard for Fire Alarm System Job Practices* (ANSI)

NECA 331-2020, *Standard for Building and Service Entrance Grounding and Bonding*

NECA 400-2007, *Standard for Installing and Maintaining Switchboards*

NECA 402-2020, *Standard for Installing and Maintaining Motor Control Centers* (ANSI)

NECA/EGSA 404-2014, *Standard for Installing Generator Sets* (ANSI)

NECA 405-2001, *Recommended Practice for Installing and Commissioning Interconnected Generation Systems*

NECA 407-2015, *Standard for Installing and Maintaining Panelboards* (ANSI)

NECA 408-2015, *Standard for Installing and Maintaining Busways* (ANSI)

NECA 409-2015, *Standard for Installing and Maintaining Dry-Type Transformers* (ANSI)

NECA 410-2013, *Standard for Installing and Maintaining Liquid-Filled Transformers* (ANSI)

NECA 411-2014, *Standard for Installing and Maintaining Uninterruptible Power Supplies (UPS)* (ANSI)

NECA 412-2012, *Standard for Installing and Maintaining Photovoltaic (PV) Power Systems* (ANSI)

NECA 413-2019, *Standard for Installing and Maintaining Electric Vehicle Supply Equipment* (ANSI)

NECA 416-2016, *Recommended Practice for Installing Energy Storage Systems (ESS)* (ANSI)

NECA 417-2019, *Recommended Practice for Installing, Operating and Maintaining Microgrids* (ANSI)

NECA 420-2014, *Standard for Fuse Applications* (ANSI)

NECA 430-2016, *Standard for Installing Medium-Voltage Switchgear* (ANSI)

NECA/IESNA 500-2006, *Standard for Installing Indoor Commercial Lighting Systems*

NECA/IESNA 501-2006, *Standard for Installing Exterior Lighting Systems*

NECA/IESNA 502-2006, *Standard for Installing Industrial Lighting Systems*

NECA 503-2005, *Standard for Installing Fiber Optic Lighting Systems*

NECA 505-2010, *Standard for Installing and Maintaining High Mast, Roadway and Area Lighting*

NECA/BICSI 568-2006, *Standard for Installing Commercial Building Telecommunications Cabling*

NECA/NCSCB 600-2020, *Standard for Installing and Maintaining Medium-Voltage Cable* (ANSI)

NECA/NEMA 605-2018, *Recommended Practice for Installing Underground Nonmetallic Utility Duct*

NECA/BICSI 607-2011, *Standard for Telecommunications Bonding and Grounding Planning and Installation Methods for Commercial Buildings*

NECA 700-2016, *Standard for Installing Overcurrent Protection to Achieve Selective Coordination* (ANSI)

NECA 701-2013, *Standard for Energy Management, Demand Response and Energy Solutions* (ANSI)

*<This page intentionally left blank>*

*<This page intentionally left blank>*

**National Electrical Contractors Association**
1201 Pennsylvania Ave. NW, Suite 1200
Washington, DC 20004
202-991-6300 • 202-217-4171 fax
***www.necanet.org***

Index # NECA 91-23 | 7/23