# NECA 90

## *Standard for Commissioning Building Electrical Systems*

**ANSI Recirculation Draft~~Canvass Ballot~~**
**August 2024~~0~~**

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*(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 systems shall be commissioned in accordance with NECA 90-2XXX, *Standard for Commissioning Building Electrical Systems* (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). Because they are quality Standards, *NEIS* may in some instances go beyond the minimum safety requirements of the NEC. 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 installation instructions when installing electrical products and systems.

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

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# 1. Scope

## 1.1 Products and Applications Included

This Standard describes installation procedures for start-up, testing, and commissioning newly installed or retrofitted building electrical systems, equipment, and components. It defines the commissioning process and provides sample guidelines for attaining optimum system performance that conform to design, specification, and industry accepted Codes and Standards.

This Standard addresses those commissioning activities that typically involve the Electrical Contractor and that are completed during and after the construction phase. The commissioning process also involves activities that are beyond the scope of this Standard.

## 1.2 Products and Applications Excluded

This Standard is not intended to cover specific commissioning processes for every type of electrical system, equipment, or component. Other *NEI*S documents that include commissioning and testing requirements for electrical systems, equipment, and components are included as references and are listed in Annex B.

In addition, this Standard does not cover:

- Procedures for commissioning systems such as fire alarm systems, telecommunications networks, closed circuit television (CCTV) systems, access control systems, and other limited energy systems.
- Testing 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.
- Commissioning and acceptance 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 commissioning and acceptance testing required by this Standard.
- On-going commissioning and/or maintenance 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). Installers shall follow the NEC, applicable state and local Codes, manufacturer instructions, and contract documents when commissioning building electrical systems.

Only qualified persons as defined in the NEC familiar with the commissioning of building electrical systems shall perform the technical work described in this publication. Administrative functions such as receiving, handling, and storing required in Section 4, 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 Practices for Good Workmanship in Electrical Construction (ANSI). Other NEIS provide additional guidance for installing 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 Standard 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 Standard 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 Standard 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 Standard, information related to another Code, Standard, or document, and supplemental application and design information and data, is included throughout this Standard 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 Standard are provided in informative annexes. Informative annexes are not part of the enforceable requirements of this Standard but are included for information purposes only.

# 2. Definitions

**Acceptable Performance**. Performance of systems, sub-systems, equipment, and components that meets specified design performance parameters under actual load, operational, and environmental conditions, and responds to changing conditions and parameters appropriately, as expected, and as specified.

**Acceptance Phase**. Phase of construction after startup and initial checkout when functional performance tests, operation and maintenance (O&M) documentation review, and training occur.

**Approval**. Acceptance that a piece of equipment or system has been properly installed and is functioning in the tested modes according to the contract documents.

**Architect / Engineer (A/E)**. The prime consultants who comprise the design team, generally the Architect, HVAC mechanical designer/engineer, the control system engineer/designer, and the electrical designer/engineer.

**Basis of Design (BOD)**. A document that records the design criteria and assumptions upon which the design is based.

**Commissioning**. A systematic process for verifying that building electrical systems perform in accordance with the design intent and the owner's operational requirements.

**Commissioning Authority (CA)**. Individual or company responsible for developing and coordinating the execution of a Commissioning Plan (CP), observing and documenting performance, and ensuring that building systems and equipment function in accordance with the design intent and the owner's operational requirements.

**Commissioning Plan (CP)**. A document that outlines the organization, scheduling, coordination, and allocation of resources and documentation for the overall commissioning process from the construction phase through the warranty period.

**Commissioning Team**. Working group made up of representatives from the Architect/Engineer (A/E), general contractor, sub-contractors, specialty manufacturers, suppliers, and the owner as required for implementation of the CP.

**Contract Documents**. Documents binding on parties involved in the completion of the Project (contracts, amendments, drawings, specifications, contract modifications or change orders, and CP).

**Contractor**. The general contractor or their authorized representative.

**Deferred Functional Tests**. Functional tests that are performed after substantial completion due to partial occupancy, seasonal loading requirements, design, or other site conditions that prevent tests from being performed prior to substantial completion.

**Deficiency**. A condition in the installation or function of a component, piece of equipment, or system that is not in compliance with the contract documents.

**Design Intent.** A narrative description of systems and equipment and their intended modes and

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sequences of operation as documented in the project documents, drawings and specifications.

**Factory Testing**. Testing of equipment at the factory by factory personnel, with an owner's representative present if deemed necessary by the owner.

**Functional Performance Tests**. A full range of checks and tests carried out to determine if all systems, sub-systems, equipment, and components function in accordance with the design intent. Systems are tested under various modes of operation, such as low load levels, high load levels, component failures, unoccupied periods, varying outside air temperatures, fire alarm activation, and power failure. Functional Performance Tests are performed after start-ups and Pre-Functional Checklists are complete.

**Integrated System Test**. A full range of checks and tests carried out to determine if systems that are integrated together and are dependent upon other systems for proper operation function and interact in accordance with the design intent. Systems are tested under various modes of operation, such as during low load levels, high load levels, component failures, unoccupied periods, varying outside air temperatures, fire alarm activation, and power failure. Integrated System Tests are performed after Functional Performance Tests are complete and prior to Substantial Completion.

**Method of Procedure (MOP)**. A script that is normally prepared for working on critical systems and equipment that details all elements of the work to be performed, typically in a checklist format, and includes spaces for dates and times of critical steps, and for authorization and signatures of responsible parties. Elements typically incorporated into an MOP includes safety requirements, staffing requirements, tool inventories, lists of materials, parts, and supplies needed, weather/environmental factors, notification of interested, involved, and affected parties, back-out plans, emergency responses, and the specific step-by-step sequence of tasks involved, among others.

**Non-Compliance**. See Deficiency.

**Non-Conformance**. See Deficiency.

**Owner's Project Requirements**. Documentation of the primary thought processes and assumptions behind design decisions and that describes the systems, components, conditions, and methods chosen to meet the Design Intent.

**Phased Commissioning**. Commissioning that is completed in phases (by system, by area, or by floors, for example) due to the complexity of the project, size of the structure, or other scheduling issues, in order minimize total construction time.

**Pre-Functional Procedures**. A full range of inspections and checks of material and components that verify proper installation of equipment (e.g., anchor bolts tightened, grounding connections complete, conductors terminated, connections torqued, compartments cleaned, and panels and covers installed, for example). Pre-functional procedures, checks and tests, are completed before Functional tests. Pre-functional procedures are typically documented in a checklist format, and typically include manufacturer start-up checklists.

**Start-up**. Activities where equipment is initially energized, operated, and tested. Start-up is completed prior to Functional Performance Tests.

**Test Requirements**. Requirements specifying the systems, operating modes, and functions that must be tested.

**Verification**. The full range of checks and tests carried out to determine if all components, sub-systems, systems, and interfaces between systems operate in accordance with the design intent and owner's requirements, including all modes and sequences of control operation, interlocks and conditional control responses, and specified responses to abnormal or emergency conditions.

**Warranty Period**. Time period for equipment, parts, and/or labor for the entire project, including individual equipment components and optional extended warranties that are included in the project, during which the Contractor makes repairs, replacements, or adjustments to the Contractor's work with no additional cost to the owner. Warranty begins at the time of Substantial Completion and typically extends for a minimum of one year, unless specifically noted otherwise in the Contract Documents and accepted submittals.

# 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.*

Commissioning 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 the proper use of 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, arc-blast), among others.

Prior to commissioning equipment, read all related installation, operation, and owner's manuals to become familiar with the equipment and with the hazards specific to the equipment. Read all related safety instructions and carefully observe all instructions, warnings, and precautions in this Standard 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 29CFR

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- ANSI/NFPA 70E, Standard for Electrical Safety in theRequirements for Employee Workplaces
- Accident Prevention Manual for Industrial Operations, National Safety Council
- Manufacturer instructions.
- Applicable state and local safety operating procedures
- Owner's safety practices

The following are examples of industry-recognized procedures to follow when commissioning 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 inspections, testing, or commissioning.
- 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. Confirm 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 personal protective equipment in accordance with the Arc Flash Hazard level of the equipment.

Use insulated hand tools when working on or around energized equipment. Use only tools that are properly rated 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, barriers, doors, covers, and panels are in place and secured. Install all devices, doors, covers, and panels 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 to be damp when working on or near 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, as open-circuited CT terminals can develop voltage near the nominal system voltage and are a significant shock hazard. Follow standard safety precautions, such as removing PT fuses and shorting CT secondaries.

All workers in manholes must have an OSHA Certification for Confined Space Access. 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.

## 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.

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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 to confirm that 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 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.

## 3.4 Battery Systems

Follow manufacturer installation, servicing, and maintenance instructions, or follow 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. Personal protective equipment (PPE) required for working on battery systems is identified in NFPA 70E. Remove all jewelry before servicing equipment. 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 that a complete spill clean-up kit that is appropriate for the hazard and risk is readily available in the room. 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 Std. 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 released if the battery is consumed in flame
- Tested to be operational with the date of the most recent test readily available

Keep in mind that the 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 typically identify the permissible fire protection methods.

If an emergency eye wash or quick-drench shower are located near the battery area they must be maintained in accordance with manufacturer recommendations and Federal, state, and local 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 appropriate for the task to be completed based on the hazard analysis and risk assessment performed prior to the work
- 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 installation and maintenance. Remove inadvertent grounds to reduce the likelihood of shock. Disconnect battery ground connections only in accordance with the 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 skin can cause an allergic reaction in some people. Electrolyte is about the same level of hazard as vinegar or lemon juice. If electrolyte comes in contact with skin, wash the area 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 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 percent by volume and the upper limit of 74.2 percent.*

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 one percent 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 gas generated in a battery escapes 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 an 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. Do not connect controls or control power to electrical equipment until the installation is complete and the equipment is ready to operate. Become familiar with equipment control schemes prior to commissioning.

## 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, are operating. Operate equipment only when all guards, barriers, 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 and 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 when working around hot electrical equipment is 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 highly 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 otherwise make contact with the fuel.

Do not smoke or permit flames, cigarettes, pilot lights, sparks, arcing equipment, or other sources of ignition near the carburetor or injectors, fuel line, fuel filter, fuel or injection 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.*

*NOTE: Exhaust gases contain carbon monoxide, which is odorless, colorless, and poisonous. Avoid breathing exhaust fumes when working on or near a 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 as needed. If symptoms persist, seek medical attention immediately.

# 4. Commissioning Process

## 4.1 Overview

The intention of commissioning is to ensure that all electrical equipment, components, sub-systems, and systems are installed according to the contract documents, drawings and specifications, to manufacturer instructions, and to industry-accepted Standards, and that installed electrical equipment, components, sub-systems, and systems, are complete, and that they receive adequate operational checkout and detailed testing, calibration, and adjustment by the installing contractor.

*NOTE: It is not the intent of the commissioning process or this Standard to duplicate efforts or to require the contractor or any subcontractor to perform any check or test twice. Checks and testing are expected to occur once in the normal sequence of installation and checkout, if appropriate coordination has occurred, allowing the owner and the Commissioning Authority (CA) to witness and document installation and testing.*

Commissioning of building electrical systems is a systematic process of ensuring that all procedures, checks, and testing is rigorously executed and documented, and that all systems perform in accordance with the design intent and the owner's requirements. This is achieved by verifying that the performance meets or exceeds the designer's intent as documented in the project drawings and specifications.

The electrical commissioning process integrates the traditionally separate functions of equipment startup, control system calibration, testing and balancing (including electrical load balancing as required in the NEC), functional performance testing, system documentation, and training. Commissioning may include deferred and/or seasonal tests as approved by the owner.

*NOTE: The commissioning process does not reduce the responsibility of the installing contractors to provide a complete, finished, and fully functioning product. In general, the CA does not have the authority to provide direction to contractors. Any issues arising during commissioning which impact schedules, costs, or contractual obligations must be addressed by the owner for resolution.*

The documented procedures which comprise the construction-phase commissioning process generally include the following:

- Pre-Commissioning that consists of normally specified checks and testing, and wiring and controls point-to-point verification completed by the respective contractor or subcontractor before the formal commissioning process begins.
- Pre-Functional Procedures (PFPs) that consist of a series of field observations conducted during the installation of equipment yet to be commissioned to verify that equipment and systems are installed in accordance with contract documents and are ready for startup.
- Pre-Startup Testing that consists of the typically-specified Contractor testing, such as meter testing of electrical equipment.

- Equipment Startup Procedures that ensure that startup is performed in accordance with the manufacturer-recommended procedures, and that those startup activities and data are documented for future reference.
- Contractor Post-Startup Testing that consists of typical contractor testing activities as required by contract documents that occur after startup and before Functional Performance Procedures, such as debugging.
- Functional Performance Procedures (FPPs) that consist of determining if equipment and systems operate in accordance with the design intent and contract documents.
- Operation and Maintenance Manuals that will be reviewed for both content and organization. *NOTE: The objective of the review process is to provide the owner with useful, complete, project-specific information needed to successfully operate and maintain the facility after turnover*.
- Operator Training that will be provided and coordinated by the contractor and overseen by the owner to help ensure that operating and maintenance staff is adequately prepared to operate and maintain the facility at turnover.

*NOTE: The project is generally not considered to be substantially complete until the conclusion of functional performance procedures as defined in the CP. The CA reviews and coordinates the training provided by the contractors and verifies that it was completed. Deferred or seasonal testing is conducted as specified or required.*

## 4.2 Commissioning Plan (CP)

The Commissioning Plan (CP) is typically developed and coordinated by the Commissioning Authority (CA) and is typically provided as part of the contract bid documents. The CP provides guidance for the execution of commissioning activities, and provides a broad outline of the entire commissioning process.

The CP typically details the commissioning activities during design and construction, along with occupancy and operational commissioning activities and the roles and responsibilities of all commissioning team members, by name, firm, and trade specialty, for performance of each commissioning task. Commissioning team members include the CA, owner, general contractor, design engineers or Architect/Engineer (A/E), and mechanical and electrical subcontractors.

The CP is a dynamic document that is continuously updated throughout the design, construction, and warranty phases of the project.

Commissioning of building electrical systems requires full cooperation and coordination between all trades. The roles and responsibilities of the CA. the electrical design engineer, general contractor, mechanical contractor, and electrical contractor are typically delineated in the contract documents and in the CP.

## 4.3 Commissioning Authority (CA) Roles and Responsibilities

The Commissioning Authority (CA) is responsible for coordinating and directing commissioning activities in a logical, sequential, and efficient manner, using standard forms and centralized documentation.

The CA is responsible for developing the CP (typically during the design phase) and for coordinating the execution of the CP, such as observing and documenting equipment and system performance, and ensuring that electrical systems are functioning in accordance with the documented design intent and with contract documents. The CA does not have authority to approve materials, methods, and systems, but can recommend their approval to the owner, project manager, or contracting officer.

The CA is the primary point of responsibility to inform the contractor, subcontractors, owner, and design team on the status, integration, and performance of mechanical and electrical systems within the facility. The CA conducts an initial commissioning meeting where the commissioning process is reviewed with the members, and conducts additional meetings throughout construction, with necessary parties attending, to plan, coordinate, and schedule future activities, and to resolve problems.

The CA is typically a knowledgeable industry professional, such as an electrical contractor, an electrical design engineer, or a third party contracted to perform the commissioning process. In general, the CA is an independent third-party agency working under a separate contract and reporting directly to the owner.

Tasks typically completed by the CA include, but are not limited to:

- Obtaining and reviewing design and construction documents to determine the overall design intent and the required system configurations.
- Preparing an initial CP, including an overall testing plan and schedule for electrical systems that lists the equipment, modes to be tested, the scheduling requirements of testing, and the parties conducting the tests.
- Coordinating scheduled commissioning activities with the overall project schedule, incorporating commissioning tests and tasks into the master construction schedule, maintaining the CP, and updating the schedule.
- Collaborating with each contractor and subcontractor to develop startup plans, project-specific functional performance test procedures, checklists, and test forms for electrical equipment, components, and systems scheduled for commissioning.
- Periodically reviewing updated as-built documentation for accuracy and completeness, and verifying that documents are being kept up-to-date.
- Developing and distributing standard forms used by the commissioning team, including startup documentation formats and construction checklists to be completed during the installation and startup process, for consistency of approach, and the type of information recorded.
- Performing site visits, as necessary, to observe equipment, component and system installations.
- Reviewing submittals and shop drawings for installation criteria and construction details as they support and define system features.
- Coordinating, witnessing, and verifying acceptability of functional performance tests performed by the installing contractors. Coordinating re-testing as necessary until satisfactory performance is achieved.
- Notifying the owner’s representative and other concerned parties of the commissioning schedule and of deficiencies and follow-up services undertaken to correct and re-test deficient items for conformance with design intent and prevailing industry Standards.
- Reviewing and verifying acceptability of Operation and Maintenance (O&M) materials, control sequences and interlocks, contractor startup procedures, and checkout procedures for completeness and accuracy.
- Providing detailed, data-driven reports of all test records, testing, results, and recommendations. Documenting the dates of acceptance as determined by the general contractor, owner, and design team.

## 4.4 Electrical Design Engineer Roles and Responsibilities

The electrical design engineer's responsibilities during the commissioning process typically include, but are not limited to:

- Developing design intent documentation and establishing the basis of design (BOD) for the project by evaluating the owner's requirements for equipment and systems.
- Establishing the design criteria, evaluating design concepts, and developing the technical drawings and specifications for the project.
- Distributing equipment documentation to the CA during the normal submittal process, including detailed startup procedures.
- Reviewing submittals, shop drawings, and O&M documentation for conformance with project requirements, and recommending their approval or acceptance.
- Responding to Requests for Information (RFIs).
- Developing technical requirements for contract modifications or change orders, as needed.
- Performing periodic construction progress inspections.
- Ensuring compliance with applicable Codes and Standards.
- Converting red-lined as-built drawings to a digital format.

## 4.5 Contractor Roles and Responsibilities

Contractors typically maintain current marked-up as-built drawings and specifications of all contract documents and contractor-generated coordination and shop drawings during construction, including updating these documents after the completion of commissioning activities and any deferred or seasonal testing. *NOTE: Do not wait to update drawings until the end of construction. Maintain updated documents at all times.* As-built drawings and data books must be made available for review and use by the design engineers (A/E) and other members of the commissioning team approximately two weeks prior to the start of commissioning activities

Contractors coordinate outside suppliers, equipment manufacturers, test agencies and others as required by the contract documents and the CP. Contractors coordinate work schedules and staffing to ensure that qualified technicians are available and present during the agreed upon schedules and for sufficient duration to complete checks, sequences, procedures, tests, and adjustments, and to resolve deficiencies that are identified in a timely fashion.

Contractors complete and submit the final as-built documents, drawings and specifications, test reports, completed checklists, and updated shop drawings after commissioning is complete for inclusion in the O&M manuals that are turned over to the owner as part of the required deliverables for final acceptance.

Each contractor participating in the commissioning process should designate a single-point contact person to work with the owner and other commissioning team members. The contractor's contact person should have the authority to coordinate commissioning activities on behalf of the contractor.

Contractors typically provide the documentation required for commissioning, such as shop drawings and product submittal data, detailed startup procedures (including manufacturer startup procedures), pre-functional checklists, full sequences of operation, operating and maintenance data, factory performance data, factory prototype test results, functional performance test procedures, control drawings, details of owner-contracted tests, equipment startup certification forms, manufacturer field or factory performance tests, and startup test documentation.

When factory startup is specified by contract documents, the respective contractor coordinates factory startups with the witnessing parties, such as the CA, owner, A/E and/or other interested commissioning team members. *NOTE: Factory startup activities are generally reviewed and checked prior to functional performance tests.*

Additionally, when testing is completed by one or more independent testing agencies, the respective contractor typically coordinates with each independent testing agency so that the CA, owner, A/E, and/or any interested commission team member can witness such tests to ensure that applicable aspects of the test meet contractual and commissioning requirements, such as requirements of the pre-functional checklists, startups, and/or functional performance tests for the equipment or systems.

Functional test procedures are reviewed with the A/E, CA, and the respective contractors. Functional testing and procedures are executed by the respective contractors under the direction of and documented by the CA. During initial functional testing and for critical equipment, the A/E may also witness any testing.

In general, all of the trade contractors participate in the resolution of system deficiencies and any non-compliance in materials, installation, or setup that are identified during the commissioning process in accordance with contract documents and the owner's project requirements.

### *4.5.1 General Contractor Roles and Responsibilities*

During construction, the general contractor's responsibilities include, but are not limited to:

- Coordinate commissioning activities with the CA.
- Ensure that commissioning activities are coordinated with the master construction schedule.
- Ensure that O&M manual content, marked-up as-built copies of drawings and specifications, component submittal drawings, and other pertinent documents are available at the project site during construction for review.
- Track and maintain all construction documents, addenda, requests for information (RFIs), contract modifications or change orders, and approved submittals and shop drawings related to commissioned equipment and systems.
- Prepare O&M manuals, according to the contract documents, including clarifying and updating the original sequences of operation to as-built conditions.
- Provide all requested submittal data, including detailed startup procedures and specific responsibilities of the owner to keep warranties in force.
- Provide updated, final as-built documents, drawings and specifications, to the CA and A/E for review, approval, and incorporation into record documentation.

During the warranty period, the general contractor's responsibilities include, but are not limited to:

- Ensure that subcontractors execute seasonal or deferred functional performance testing, witnessed by the CA, in accordance with the specifications.
- Ensure that subcontractors correct deficiencies and make necessary adjustments to O&M manuals and as-built drawings for applicable issues identified during any deferred or seasonal testing.

### *4.5.2 Mechanical Contractor Roles and Responsibilities*

Mechanical equipment frequently has electrical and electronic components, such as motors and controls.

The mechanical contractor provides and installs mechanical equipment in accordance with the contract documents, performs pre-functional and functional tests as defined in the CP, and coordinates work with other trades.

In general, motors are factory-installed on mechanical equipment or are field-installed on mechanical equipment by the mechanical contractor. For this reason, the mechanical contractor is typically responsible for functional testing of motors involving vibration monitoring, balancing, and adjustment.

In general, the controls contractor is responsible for functional testing of mechanical and environmental control systems, such as a building automation system (BAS).

### *4.5.3 Electrical Contractor Roles and Responsibilities*

The electrical contractor provides and installs the electrical equipment and furnishes all tools needed to start up, check out, and conduct functional performance procedures on electrical equipment, components, and systems.

The electrical contractor's responsibilities include, but are not limited to:

- Coordinate commissioning activities with the general contractor and the CA.
- Assist the CA in developing test procedures, checklists, and forms.
- Execute and document testing according to the specific commissioning requirements of the project.
- Monitor the installation of equipment and systems to ensure the equipment, configuration, and quality of construction meets the design requirements and approved submittals and shop drawings.
- Coordinate electrical work related to mechanical systems, including power requirements of mechanical equipment, and safeties and interlocks.
- Participate in the functional performance procedures as required to achieve design intent.
- Schedule manufacturer or factory technicians and representatives, or other specialty trade representatives as needed for factory startup and to demonstrate the performance of equipment and systems in accordance with contract requirements.
- Demonstrate the performance of each piece of equipment to the CA and/or owner.
- Participate in off-season mode testing as required to achieve design intent.
- Provide O&M data on electrical equipment to the general contractor.
- Provide updated as-built documents, drawings and specifications, to the general contractor.
- Conduct training on electrical equipment, components, and systems.

## 4.6 Documentation

Contractor commissioning documents which will be completed by the various contractors include, but are not limited to, the following:

- Weekly commissioning status reports.
- Pre-startup contractor test procedures and test forms.
- Equipment startup plans and forms.
- Post-startup contractor test forms and reports.
- Pre-functional tests and checklists.
- Functional performance procedures and tests.

- Operating and maintenance (O&M) manuals.

Commissioning forms, checklists, and related documents are completed concurrently with the commissioning activities being documented. Do not document commissioning activities after-the-fact. Commissioning forms are generally signed by the individuals having responsibility and authority for witnessing completion of the respective inspections and tests.

# 5. Testing Requirements

In general, procedures and tests are witnessed by the CA, general contractor, and/or owner. Coordinate procedures and tests in advance to ensure that the appropriate personnel will be available to witness procedures and tests. Keep in mind that tests that are not witnessed by the CA or owner may be rejected and may be subject to retesting.

Perform inspections and testing with electrical equipment de-energized when possible. Exercise care when inspecting and testing energized equipment. See Section 3.

Upon completion of all testing, restore all connections, settings, programming, and equipment to normal operating conditions in accordance with contract documents.

Document any deficiencies discovered during testing or other commissioning procedures. See Section 6.2 for additional guidance. Correct deficiencies and retest equipment, sub-systems, or systems to ensure conformance to the design intent.

## 5.1 Test Equipment

Commissioning electrical equipment may require special tools and instruments for the measurement of the equipment performance. Suitability of test equipment and calibration requirements shall be in accordance with ANSI/NETA ECS Standard for Electrical Commissioning Specifications for Electrical Power Equipment and Systems Sections 5.3 and 5.4. See Annex A for additional requirements for test and measurement equipment, testing procedures, and methodologies.

Commissioning 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 should provide all tools, materials, test instruments, instrumentation, equipment, labor, and technical supervision to perform such tests and inspections. Utilities are typically furnished in accordance with contract documents.

Test equipment shall be calibrated, be in good mechanical and electrical condition, and be 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 shall be appropriate for the test being performed. The waveshape and frequency of test equipment output waveforms shall be appropriate for the test and for the equipment being tested.

Method of Procedures (MOPs) that detail the sequence of steps necessary to commission equipment are typically developed by the organization completing the commissioning procedure. Emergency procedures must be developed in the event a problem occurs during testing. Include the telephone numbers of the local electric utility service provider in the MOP.

#### *5.1.1 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 commissioning procedures shall be calibrated according to the manufacturer-recommended intervals, and after mishandling, or being dropped or damaged. Dated calibration labels or tags shall be visible on all test equipment, or calibration certificates shall be readily available. Maintain up-to-date testing and calibration records indicating the dates and results of instruments calibrated or tested.

Each testing organization shall 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 shall maintain up-to-date instrument calibration instructions and procedures for each test instrument calibrated. The accuracy of test equipment shall be traceable to the National Bureau of Standards (NBS) in an unbroken chain.

Ensure that test equipment used for performance verifications during the commissioning process 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.

#### *5.1.2 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.

### 5.2 Contractor Pre-Startup, Startup, and Post-Startup Procedures

*NOTE: General commissioning requirements of electrical equipment, components, conductors, cables, connections, and terminations may be completed at any time prior to acceptance testing or final commissioning procedures. See Section 5.5 for commissioning requirements of electrical equipment that include inspections, checks, and tests that may be completed during pre-startup, startup, and post-startup of equipment, components, and systems.*

The equipment manufacturer standard startup procedures and forms are typically used as the basis of the

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commissioning equipment startup procedure and documentation. All startup forms are typically submitted to the CA and owner for review and approval prior to equipment startup, and are submitted to the CA and owner for review and acceptance upon completion.

After equipment startup, adjust settings and calibration of equipment in accordance with manufacturer instructions, and in accordance with design intent documents, and contract documents, drawings and specifications. Provide documentations of the conditions under which tests and adjustments were conducted, including (as applicable) ambient conditions, set points, override conditions, and status and operating conditions that impact the results of the test.

## 5.3 Pre-Functional Performance Procedures and Checklists

*NOTE: See Section 5.5 for commissioning requirements of electrical equipment that include inspections, checks, and tests that may be completed during pre-functional performance procedures for equipment, components, and systems.*

Pre-functional performance testing is performed to document that the specified equipment, components, sub-system, or system is installed correctly, has started up properly, and is ready for functional performance testing. Pre-functional performance tests include checking all operating modes, safety interlocks, control responses, and specific responses to abnormal or emergency operating conditions. Pre-functional performance tests are often documented in a checklist format, and are based on design intent documentation and equipment submittals.

Completed checklists and forms are typically submitted to the CA and owner for review upon completion of the respective tests. Completed original pre-functional checklists are typically maintained on-site as part of the as-built record commissioning documents to be delivered to the owner upon project completion.

The CA and/or owner will generally provide oversight to the contractors during the execution of pre-functional testing and will periodically review the contractors' in-progress pre-functional checklists for accuracy and completeness, and to verify that checklists are being updated.

Pre-functional performance checklists include, at a minimum, that:

- Installed equipment matches the specifications and approved submittals and shop drawings.
- Equipment is installed in accordance with contract documents, drawings and specifications, and manufacturer instructions.
- Utility connections to equipment have been successfully completed.
- All related equipment has been started up, with start-up reports and pre-functional checklists submitted and approved as ready for functional performance testing.
- Testing, balancing, and calibration is complete and accepted by the CA.
- All control system functions and all interlocking systems are programmed and operable per contract documents, including final set points and schedules, with debugging, loop tuning, and sensor calibrations completed.
- All architectural/engineering (A/E) punch list items for equipment, sub-systems, and systems have been corrected.
- Functional test procedures have been reviewed and approved by the installing contractor.
- Safety, operating ranges, and functions have been reviewed by the CA.
- Code-required clearance around equipment is provided for service and maintenance.
- A record has been made of all values for pre-test set points that were changed to accommodate

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testing. Check boxes can be used to verify that all pre-test set points (control parameters, limits, delays, lockouts, and schedules) have been returned to original values.
- Other operational, safety, alarm checks, and startup reports have been completed successfully.

### 5.4 Functional Performance Procedures

*NOTE: See Section 5.5 for commissioning requirements of electrical equipment that include inspections, checks, and tests that may be completed during functional performance procedures for equipment, components, and systems.*

In general, specific functional performance procedures and forms are developed by the CA to verify and document proper operation of each piece of equipment and each system. Procedures and forms are based on the design intent, contract documents, drawings and specifications, contract modifications or change orders affecting equipment, and approved submittals and shop drawings,

Complete functional performance procedures on equipment and systems monitored or controlled by a control system in conjunction with the controls contractor. Prior to commissioning, verify that the controls contractor has completed, debugged, validated, and forwarded all documentation for the control system, including point-to-point checks listing command and response values, verification that network communication between all devices and systems is established, and the sequence of operation checks out.

Begin functional performance testing after completing pre-functional checklists for systems, sub-systems, and equipment, and checklists have been approved, and after all issues and deficiencies affecting equipment and system operation or performance have been resolved.

Each functional performance test should be performed under conditions that simulate actual operating conditions as closely as possible. Optimally, each system and sub-system should be operated through all modes of operation, such as seasonal, occupied, unoccupied, warm-up, cool-down, partial load, and full-load, where there is a specified system response.

Verify the proper sequence of operation for equipment, and verify the settings of adjustable parameters for equipment and systems. Test each step in every written sequence and other significant modes, sequences, and operational features not mentioned in written sequences; including startup, normal operation, shutdown, scheduled on and off, unoccupied and manual modes, safeties, alarms, over-rides, lockouts, and power failures.

Verify shut down and restart capabilities both for scheduled and unscheduled events, such as power failure recovery and normal scheduled start/stop functions. When applicable, demonstrate a full cycle from off to on and no load to full load and then to no load and off. Verify time of day schedules and setpoints. Verify all energy saving control strategies.

Conduct seasonal functional performance testing on equipment during the season it is intended to operate, such as testing air conditioning equipment during the peak cooling season, and testing heating equipment during the peak heating season. Verify energy efficiency and self-diagnostic capability of equipment and systems.

Verify the proper operation of equipment and systems in normal and alternate modes of operation, and during abnormal operation conditions, such as (where applicable) fire, single-phasing, total power failure, equipment failure, and individual component failure. Verify the proper operation of safeties and interlocks. Verify proper operation of control systems, including response times, stability, and tunings.

Simulate conditions by imposing an artificial load when it is not practical to test design conditions under actual operating conditions, and only upon the approval of the CA and owner. Before simulating conditions, calibrate test instruments. Set and document simulated conditions and methods of simulation. When simulating conditions is not practical, alter set points to conduct functional testing only upon approval of the CA and owner.

Upon satisfactory completion of all verified tests, return equipment and system settings to normal operating conditions as required by the contract documents as a complete and operational system.

## 5.5 Commissioning Requirements of Electrical Equipment

For additional information, refer to ANSI/NETA Standard for Acceptance Testing Specifications (ATS) and ANSI/NETA Standard for Electrical Commissioning (ECS).

### *5.5.1 General Electrical Commissioning Requirements*

Perform specific inspections and mechanical tests of equipment and components in accordance with the manufacturer instructions and ANSI/NETA ATS and ECS specifications..

Compare equipment, components, conductors, cables, connections, and terminations with contract documents, drawings and specifications, and with approved submittals, product data and shop drawings. Verify equipment nameplate information with contract documents, drawings and specifications, approved submittals, and short circuit and coordination studies, if applicable. Verify circuit breaker and fuse sizes, types, and ratings conform to contract documents and approved submittals. Measure the resistance of fuses. Resistance values must not deviate by more than 15 percent between identical fuses.

Perform point-to-point wiring checks to ensure that each conductor is properly terminated. Verify that temporary wiring jumpers are removed. Check the continuity of each conductor from end-to-end, including ground conductors and ground shields of shielded cables and conductors. Perform a shield-continuity test on each shielded cable using a low-resistance ohmmeter. Shields must be disconnected from any bonding point and individually tested. Shielding must exhibit continuity less than 10 ohm resistance. Investigate any shield resistance values that exceed ten ohms per 1000 feet of cable.

Inspect the condition of exposed cable and conductor insulation, jacketing, and field-applied fireproofing, where installed. Verify that visible cable bends are not less than the ICEA and/or manufacturer minimum allowable bending radius. Check that conductors and cables are supported independently of terminations and connections.

Verify correct connections in accordance with single-line and three-line diagrams. Perform a phasing check on equipment supplied from multiple sources, such as double-ended switchgear, to insure correct bus phasing from each source.

Verify proper mechanical, maintenance, and ventilation clearances for equipment. Verify that field wiring is clear of energized bus. Verify that conductors and cables are secured in accordance with manufacturer instructions to withstand the effects of fault currents. Verify proper separation and clearances of conductors and cables, including primary and secondary conductors for transformers.

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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 contract requirements and in accordance with the NEC. Verify identification of all lighting circuits and branch circuits on panel directories.

Perform a visual and mechanical inspection of equipment, components, conductors, cables, connections, and terminations. Verify that equipment is completely assembled. Verify that equipment and components are clean, dry, and free of tools, debris, and storage of materials. Verify that shipping braces, blocking, brackets, and similar supports have been removed from equipment. Inspect all bus bracing and insulators for contamination, tracking, and broken or missing parts.

Check for physical damage. Inspect doors, panels, and sections of equipment for damage to paint, dents, and scratches, paying particular attention to missing and loose parts and 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 the interior of equipment for missing or loose parts and hardware. Verify that connections and terminations are free of corrosion.

Using a calibrated torque wrench, verify the tightness of accessible bolted electrical connections in accordance with manufacturer published data. Torque all connections in accordance with the manufacturer recommendations and record the results on a tabular form. Alternatively, inspect bolted electrical connections for high resistance using a low-resistance ohmmeter. See Annex A for additional guidance.

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

Verify proper grounding in accordance with contract documents, drawings and specifications, and in accordance with the NEC. 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.

Test all safety devices, fail-safe functions, and all keyed, mechanical, and electrical safety and interlock systems for correct operation and sequencing. 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 that settings for alarm, control, and trip setpoints for adjustable trip circuit breakers, relays, meters, and temperature indicators are adjusted in accordance with contract documents, drawings and specifications, approved submittals, product data and shop drawings, manufacturer instructions, and approved short circuit and coordination studies. Verify that circuit breaker addresses for microprocessor-

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communication packages correspond to contract documents and approved submittals.

Verify the correct level of liquid in liquid-filled devices, such as liquid-filled transformers and bushings, and wet-cell batteries. Check for leaks. Verify the presence of PCB content labeling for liquid-filled equipment, such as transformers, reactors, and capacitors. Verify that positive pressure is maintained on gas-blanketed transformers.

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 initial energization.

Verify the correct operation of all sensing devices, alarms, and indicating devices.

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

Perform infrared scan (thermographic survey) of equipment and components under maximum load conditions. See Annex A for additional information.

Check for unusual sounds after energizing equipment, components, conductors, and systems.

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

Perform acceptance testing on cables, including terminations and joints (tees, taps, and splices), after completing the cable system installation and before the cable system is energized and placed into service, in accordance with ANSI/IEEE 400, ICEA S-93-639/NEMA WC 74, ICEA S-94-649 and ICEA S-97-682.

Ensure that cables are disconnected from equipment and de-energized. *NOTE: 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 terminations specified in ANSI/IEEE 48, IEEE 386, or manufacturer specifications. Disconnect and ground surge arresters, 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 separately. Do not separate permanent joints to test sections of cable. Ground all conductors, 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. Perform testing after terminations and splices using hot dielectric compounds have fully cooled to ambient temperature.

Acceptance testing can be performed by means of direct voltage (DC), alternating voltage (AC), partial discharge (PD), or very low frequency (VLF) AC in accordance with Annex A. Evaluate alternative methods in selecting the appropriate acceptance test for each given cable installation. Do not exceed 80 percent 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 joints that may have lower maximum voltage ratings than the maximum recommended acceptance test voltages for the cable alone.

Perform high-potential testing only on new conductors. Do not perform high-potential testing on conductors that have been in service for more than five (5) years, including testing new conductors spliced or tapped onto existing conductors. Complete high-potential testing on sections of new cable prior to connecting new cable to existing cable. DC high-potential, very low frequency (VLF) AC testing, or any other type of withstand or destructive testing is not recommended as a maintenance test on any medium-voltage cable, especially XLPE cable that has been in service in a wet environment for more than five years, unless approved by the cable manufacturer.

Acceptance testing must be performed on new cable prior to connecting to existing cables. After acceptance testing is completed for the new cable, join the new cable to the existing cable and perform insulation-resistance and shield-continuity testing on the length of new and existing cable including any joints.

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. Terminations must be adequately corona-suppressed by guard ring, field reduction sphere, or other suitable method, as necessary. If acceptance testing is performed by means of direct voltage (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.

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

See NECA 600 for additional guidance.

### *5.5.3 Low Voltage Power Cable (below 600V)*

Perform insulation resistance testing in accordance with Annex A.

### *5.5.4 Electrical Feeders and Branch Circuits (600V or below)*

Make operational checks on all lighting circuits and branch circuits to demonstrate that all circuits perform all functions for which they were designed. In the presence of the CA, field test for correct labeling of circuits and equipment by breaking current and observing loss of power at circuits or equipment. Document, correct, and retest any incorrect equipment circuit identifications found.

### *5.5.5 Liquid-Filled Transformers*

Verify that transformer bushings are clean.

Verify correct primary and secondary fuse sizing for voltage transformers with fusing as overcurrent protection.

Verify correct liquid level in all tanks and bushings.

Where installed, verify that alarm, control and trip settings on temperature and level indicators, pressure

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relief device, and fault pressure relay are as specified.

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

Perform a turns-ratio test on all no-load tap-changer positions and all load tap-changer positions. Verify that the final tap setting is as specified. 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.

Measure resistance of each high-voltage winding in each no-load tap-changer position. Measure resistance of each low-voltage winding in each load tap-changer position, if applicable. Consult the manufacturer if winding-resistance measurements vary more than one percent from adjacent windings.

Perform a core resistance test. If the transformer core ground strap is removable, remove the core ground strap and measure the insulation resistance of the transformer core at 500 volts DC. Core insulation-resistance values should be comparable to factory test results, but not less than 2.0 megohm at 500 volts DC.

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

Where installed, test transformer neutral grounding impedance device. Compare grounding impedance device results to manufacturer published data

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.

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

Remove a sample of insulating liquid in accordance with ASTM D 3613 and perform dissolved-gas analysis (DGA) in accordance with ANSI/IEEE C57.104 or ASTM D3612. Evaluate results of dissolved-gas analysis in accordance with ANSI/IEEE C57.104. Use results as baseline for future tests.

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.
- Parts per million of water in accordance with ASTM D-1533. (Required for all liquid-filled transformer rated 25 kV or higher, and for all silicone-filled transformers.)
- Measure dissipation factor or power factor in accordance with ASTM D-924.

Insulating liquid must comply with manufacturer instructions.

Investigate the presence of oxygen in the nitrogen gas blanket, if applicable.

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See NECA 410 for additional guidance.

### *5.5.6 Dry-Type Transformers*

Verify correct primary and secondary fuse sizing for voltage transformers.

Verify that resilient mounts are free.

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

Perform a turns-ratio test on all no-load tap-changer positions and all load tap-changer positions. Verify that the final tap setting is as specified. 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 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.

Measure excitation-current on each phase. Typical excitation current results for a typical three-legged core transformer are the two outer legs have similar current readings, and the center leg has a lower current reading.

Measure the resistance of each winding at each tap connection. Temperature corrected winding-resistance test results should compare within one percent of previously obtained results.

Perform core 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 500 volts DC. Core insulation-resistance values should be comparable to factory test results, but not less than 1.0 megohm at 500 volts DC.

Verify correct secondary voltage phase to phase and phase to neutral after energization and prior to loading.

See NECA 409 for additional guidance.

### *5.5.7 Instrument Transformers*

Verify correct primary and secondary fuse sizing for voltage transformers.

Perform insulation resistance testing in accordance with Annex A. Perform measurements from winding to winding and from winding to ground.

Measure the transformer turns ratio. Confirm transformer polarity by electrical testing.

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Verify CT secondary connections by driving a low current through the secondary leads and checking for this current at applicable devices.

Verify potential transformer (PT) secondary connections by applying a low voltage to the secondary leads and checking for this voltage at applicable devices. Verify correct secondary voltage by energizing primary winding with system voltage. Measure secondary voltage with the secondary wiring disconnected. Verify correct potential at all devices.

Perform a secondary saturation test of current transformers (CTs) at a minimum of three points below and one point above the knee of the saturation curve.

Measure voltage circuit burdens at transformer terminals. Perform burden tests at the secondary leads of each CT to assure accurate translation of primary current.

Check the PT secondary load with secondary voltage and current measurements. Transformer loading must be less than the volt-ampere capacity of the PT.

Verify that current circuits are grounded and have only one grounding point in accordance with ANSI/IEEE C57.13.3.

Measure the capacitance of coupling-capacitor voltage transformer capacitor sections. Capacitance of capacitor sections of coupling-capacitance voltage transformers must be in accordance with the manufacturer published data.

Perform secondary wiring integrity test. Disconnect the transformer at the secondary terminals and connect the secondary wiring to a rated secondary voltage source. Verify correct potential at each device.

### *5.5.8 Switchgear and Switchboard Assemblies Rated 1200A or Greater*

Perform an insulation resistance test on each bus section, phase-to-phase and phase-to-ground, and on all control wiring in accordance with Annex A. *NOTE: When performing dielectric tests, disconnect all instrument and control transformers, lightning arresters, 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.* Minimum test voltages and insulation resistances are shown in Table 1.

**Table 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 | ~~DC~~ 1000 Megohms |

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| | | |
|---|---|---|
| 5001-15,000V | 2500V DC | ~~DC~~ 5000 Megohms |

Perform a power factor test. For switchgear rated 5 kV and above, power factor should not exceed the values shown in Table 2.

| **Table 2 Switchgear Power Factor Values** | | |
|---|---|---|
| **Power Factor Values** | | |
| **Voltage Rating (volts)** | **Test Voltage (volts)** | **Maximum Reading** |
| 5000 | 5000 | 2% |
| 7000 | 5000 | 2% |
| 15,000 | 10,000 | 2% |
| 35,000 | 10,000 | 2% |

For medium-voltage switchgear, after achieving acceptable insulation resistance test results, perform high-potential testing on each bus section, each phase to ground with phases not under test grounded in accordance with the manufacturer published data (see Annex A for additional guidance). Perform high-potential testing on each bus section, each phase to ground with phases not under test grounded, in accordance with manufacturer published data. Apply test voltage for one minute.

Perform current tests by primary or secondary injection on all metering and relaying circuits in each section of switchgear with a sufficient current magnitude to cause a minimum of 1.0 ampere current flow in the secondary circuit. Verify correct magnitude of current at each device in the circuit.

Verify that the insulating barriers and shutters are properly installed and operating correctly. Inspect all mechanical indicating devices for correct operation. Check indicating lights for proper operation. Replaced burned-out lamps. Verify that filters are in place and/or vents are clear. Verify proper operation of switchgear/switchboard heaters.

Perform a phasing check on switchgear with multiple sources to insure correct bus phasing from each source. Verify the proper operation of control transfer relays located in switchgear with multiple control power sources.

After energization, verify proper voltage with system operating at load conditions. Operate every circuit breaker, switch, and contactor, manually and electrically, if so equipped. Modify tap settings on transformers as needed for actual operating conditions. Measure line amperes with the system operating under load conditions.

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

See NECA 400 and NECA 430 for additional guidance.

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

Confirm the physical orientation of the busway is in accordance with manufacturer labels to insure adequate cooling. Examine outdoor busway to ensure the removal of weep-hole plugs, if applicable, and the correct installation of joint shields.

Measure insulation resistance of each bus, phase-to-phase and each phase-to-ground, for a minimum of one (1) minute in accordance with Annex A, with phases not under test grounded.

Perform high-potential testing of each phase-to-ground with phases not under test grounded, in accordance with manufacturer published data and in accordance with Annex A. 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 guidance.

Perform phasing test on each busway tie section energized by separate sources to insure correct bus phasing from each source. Test with busway energized from permanent sources.

Verify proper operation of busway space heaters.

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

See NECA 408 for additional guidance.

### *5.5.10 Motor Control Centers*

Measure insulation resistance of the line bus, phase-to-phase and phase-to-ground. See Annex A for additional guidance.

Perform operational tests on each starter. Test overload relays by primary current injection and monitor the trip time of each overload relay. Compare against manufacturer published data and either replace or resize relays that are deficient. Measure insulation resistance of motor starters, phase-to-phase and phase-to-ground, with the starter contact closed and overload relays in the “open” position. See Annex A for additional guidance.

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

See NECA 402 for additional guidance.

### *5.5.11 Low-Voltage Motor Starters*

Verify contactor mechanical operation. Inspect that contact gap, wipe, alignment, and pressure are in accordance with manufacturer published data.

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

Perform insulation-resistance tests on all control wiring with respect to ground. For units with solid-state components, follow manufacturer recommendations. See Annex A for additional information.

Test motor protection devices in accordance with manufacturer published data. Verify that the overload element rating is correct for its application. If motor-running protection is provided by fuses, verify correct fuse ratings. Set adjustable or programmable devices according to the protective device coordination study.

### *5.5.12 Medium-Voltage Motor Starters*

Verify racking mechanism operation for removable units.

Verify contactor mechanical operation. Inspect that contact gap, wipe, alignment, and pressure are in accordance with manufacturer published data.

Measure the resistance of power fuses. Resistance values must not deviate by more than 15 percent between identical fuses. Measure blowout coil circuit resistance. Test starting transformers, if applicable. Test starting reactors, if applicable. Verify proper operation of cubicle space heaters, if applicable.

Exercise all active components and confirm correct operation of all indicating devices. Verify correct barrier and shutter installation and operation.

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

Perform insulation-resistance tests on all control wiring with respect to ground. For units with solid-state components, follow manufacturer recommendations. See Annex A for additional information.

Test motor protection devices in accordance with manufacturer published data. Verify that the overload element rating is correct for its application. If motor-running protection is provided by fuses, verify correct fuse ratings. Set adjustable or programmable devices according to the protective device coordination study.

Perform vacuum bottle integrity (high-potential) testing across each vacuum bottle with the contacts in the open position in strict accordance with 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 guidance. Provide adequate barriers and protection against X-radiation during this test. Do not perform this test unless the contact displacement of each interrupter is within manufacturer tolerance. The interrupter must withstand the overpotential test voltage applied.

Energize each contactor using an auxiliary source. Adjust armature to minimize operating vibration

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where applicable.

### 5.5.13 Medium-Voltage Circuit Breakers

Verify racking mechanism operation for removable breakers.

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.

Perform a contact resistance test of each phase and compare results. See Annex A for additional guidance.

Perform an insulation resistance test. Measure insulation resistance phase-to-phase and phase-to-ground and across open poles, using a minimum voltage of 2500V DC. See Annex A for additional guidance.

Perform a power factor/dissipation test with the breaker in the open and closed positions. See Annex A for additional guidance.

Perform high-potential testing in accordance with manufacturer published data. See Annex A for additional guidance.

See NECA 430 for additional guidance.

### 5.5.14 Medium-Voltage Air Circuit Breakers

Perform all mechanical operation tests on the operating mechanism in accordance with manufacturer instructions. Inspect moving and stationary contacts for condition and alignment. Verify that the arc chutes are intact. Inspect puffer operation. Verify cell fit and element alignment. Verify racking mechanism operation for removable breakers.

Perform time-travel analysis. 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. Verify that the contact sequence is in accordance with manufacturer published data. In the absence of manufacturer published data, refer to ANSI/IEEE C37.04.

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

Perform insulation-resistance tests on all control wiring with respect to ground. For units with solid-state components, follow manufacturer recommendations. See Annex A for additional information.

Perform a contact/pole-resistance test. Measure blowout coil circuit resistance.

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

With breaker in the test position, trip and close the breaker with the control switch. Trip each breaker by operating each of its protective relays. Verify trip-free and anti-pump functions.

Perform power-factor or dissipation-factor test with breaker in both the open and closed positions. Compare power-factor or dissipation-factor test results with previous tests of similar breakers or manufacturer published data.

Perform high-potential testing in accordance with manufacturer published data. The insulation must withstand the overpotential test voltage applied.

### *5.5.15 Medium-Voltage Vacuum Circuit Breakers*

Perform all mechanical operation tests on both the circuit breaker and its operating mechanism. Verify racking mechanism operation for removable breakers.

Measure critical distances such as contact gap, as recommended by manufacturer. Contact displacement must be in accordance with factory recorded data marked on the nameplate of each vacuum breaker or bottle.

Perform time-travel analysis. Compare travel and velocity values to manufacturer published data.

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

Perform power-factor or dissipation-factor tests on each pole with the breaker open and each phase with the breaker closed. Compare power-factor or dissipation-factor test results to manufacturer published data. In the absence of manufacturer published data, compare results to similar breakers.

Perform power-factor or dissipation-factor tests on each bushing. Use hot collar procedures if bushings are not equipped with a power-factor tap. Power-factor or dissipation-factor test results and capacitance test results should be within ten percent of nameplate rating for bushings.

Perform insulation-resistance tests on all control wiring with respect to ground. For units with solid-state components, follow manufacturer recommendations. See Annex A for additional information.

Perform a contact/pole-resistance test. Verify trip, close, trip-free, and anti-pump functions. Trip each circuit breaker by operation of each protective device.

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

Perform vacuum bottle integrity (high-potential) testing across each vacuum bottle with the breaker in the open position in strict accordance with 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 guidance. Provide adequate barriers and protection against X-radiation during this test. Do not perform this test unless the contact displacement of each interrupter is within manufacturer tolerance. The interrupter must withstand the overpotential test voltage applied.

### *5.5.16 Medium-Voltage $SF_6$ (Sulfur Hexafluoride) Circuit Breakers*

Verify racking mechanism operation for removable breakers.

Inspect operating mechanism and $SF_6$ gas-insulated system in accordance with the manufacturer published data.

Verify correct operation of alarms and pressure-limit switches for pneumatic, hydraulic, and $SF_6$ gas pressure as recommended by the manufacturer. Test for $SF_6$ gas leaks if temperature-corrected pressure/density alarms or meters indicate a need. Remove a sample of $SF_6$ gas (if provisions are made for sampling) and test.

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 manufacturer published data. In the absence of manufacturer published data, refer to ANSI/IEEE C37.04.

Perform time-travel analysis. Compare travel and velocity values to manufacturer published 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 breakers, perform insulation resistance tests from pole-to-pole. Test voltage must be in accordance with manufacturer published data. See Annex A for additional guidance.

Perform power-factor or dissipation-factor tests on each pole with the breaker open and each phase with the breaker closed. Compare power-factor or dissipation-factor test results to manufacturer published data. In the absence of manufacturer published data, compare results to similar breakers.

Perform power-factor or dissipation-factor tests on each bushing. Use hot collar procedures if bushings are not equipped with a power-factor tap. Power-factor or dissipation-factor test results and capacitance test results should be within ten percent of nameplate rating for bushings.

Perform insulation-resistance tests on all control wiring with respect to ground. For units with solid-state components, follow manufacturer recommendations. See Annex A for additional information.

Perform a contact/pole-resistance test. Verify trip, close, trip-free, and anti-pump functions. Trip each circuit breaker by operation of each protective device.

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

Perform high-potential testing in accordance with manufacturer published data. Perform $SF_6$ bottle integrity test (high-potential) across each $SF_6$ bottle with the contacts in the open position in strict accordance with manufacturer published data. Do not exceed the maximum voltage recommended by the manufacturer for this test. See Annex A for additional guidance. The insulation must withstand the overpotential test voltage applied.

Perform magnetron atmospheric condition (MAC) test on each vacuum interrupter. In the absence of manufacturer's published data, each vacuum interrupter pressure shall not be greater than $1x10^{-2}$ Pa and shall not deviate from adjacent poles by more than two orders of magnitude.

### *5.5.17 Low-Voltage Air-Insulated and Insulated Case Circuit Breakers*

Perform all mechanical operation tests on circuit breakers and the operating mechanism in accordance with the manufacturer published data. Check adjustments on springs, gears, and liners. Check cell fit and element alignment. Inspect arc chutes.

Perform a contact resistance or millivolt drop test on each phase and compare results. See Annex A for additional guidance.

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 a minimum of one minute. Test voltage must be in accordance with the manufacturer published data. See Annex A for additional guidance.

Perform a primary current injection test to determine minimum pickup current and long-time delay (at 300% pickup current), short-time pickup and time delay, instantaneous pickup current, and ground-fault pick up and time delay. *NOTE: Remove or otherwise bypass current-limiting fuses from circuit breakers so equipped prior to applying simulated overload and fault current.* Compare results with the time-current coordination curve for each circuit breaker. Verify trip unit characteristics. Set adjustable or programmable devices according to the protective device coordination study. Replace defective devices, and adjust and retest where necessary.

Verify proper operation of auxiliary functions, such as shunt trip, undervoltage relays, and ground-fault, if applicable, in accordance with manufacturer instructions.

### *5.5.18 Low-Voltage (600V Class) Network Protectors*

Verify trip-free operation. Verify correct operation of the auto-open-close control handle. Verify that the protector closes automatically with the source voltage available on the transformer side only. Verify that the protector opens automatically when the source feeder breaker is opened.

Verify that arc chutes are intact. Inspect moving and stationary contacts for condition and alignment. Verify that primary and secondary contact wipe and other dimensions (vital to the satisfactory operation of the breaker) are correct. Perform mechanical operator and contact alignment tests on both the breaker and its operating mechanism.

Verify cell fit and element alignment. Verify proper racking mechanism operation. Verify appropriate lubrication on moving current-carrying parts. Verify appropriate lubrication on moving and sliding surfaces. Perform a leak test on submersible enclosure in accordance with manufacturer published data.

Verify that maintenance devices are available for servicing and operating the breaker.

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

Verify current transformer ratios.

Perform a contact/pole-resistance test. Measure the resistance of each power fuse for protectors so equipped.

Measure the minimum pickup voltage of the motor control relay. Verify that the motor can charge the closing mechanism at the minimum voltage specified by the manufacturer. Minimum acceptable motor closing voltage must not exceed 75 percent of the rated control circuit voltage.

Measure minimum pickup voltage of the trip actuator. Minimum voltage to operate the trip actuator must not exceed 7.5 percent of rated control circuit voltage. Verify that the actuator resets correctly.

Calibrate the network protector relays in accordance with manufacturer instructions. Adjust relay settings in accordance with the short circuit and coordination study.

Verify phase rotation, phasing, and synchronized operation as required by the application.

### *5.5.19 Low Voltage Air Switches*

Verify correct blade alignment, blade penetration, travel stops, and mechanical operation. Verify appropriate lubrication on moving current-carrying parts. Verify appropriate lubrication on moving and sliding surfaces.

Measure contact-resistance across each switchblade and fuseholder. Measure fuse resistance. Investigate fuse-resistance values that deviate from each other by more than 15 percent. 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.

Verify correct operation of all indicating and control devices. Test ground-fault protection systems in accordance with Section 5.5.25.

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 manufacturer published data. See Annex A for additional guidance.

Verify cubicle space heater operation, if so equipped.

### *5.5.20 High and Medium-Voltage Air Switches*

Verify correct blade alignment, blade penetration, travel stops, and mechanical operation. Verify that expulsion-limiting devices are in place on all holders having expulsion-type elements. Verify that each fuseholder has adequate mechanical support and contact integrity. Check that fuse clips are tight, secure, and free of corrosion.

Measure contact-resistance across each switchblade and fuseholder. Measure fuse resistance. Investigate fuse-resistance values that deviate from each other by more than 15 percent. 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.

Verify correct operation of all indicating and control devices. Verify appropriate lubrication on moving current-carrying parts. Verify appropriate lubrication on moving and sliding surfaces.

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 manufacturer published data. See Annex A for additional guidance.

After achieving acceptable insulation resistance test results, perform high-potential testing on each pole with the switch closed. Test each pole-to-ground with all other poles not under test grounded in accordance with the manufacturer published data (see Annex A for additional guidance). Apply test voltage for one minute. The insulation must withstand the overpotential test voltage applied.

Verify cubicle space heater operation.

### *5.5.21 Protective Relays and Metering Devices*

Inspect meters, relays, and cases for physical damage, especially where subject to movement or the possibility of pinched wires in doors or access panels, broken parts, and indication of shipping damage. Remove shipping restraint material from protective relays, meters, and cases, if applicable.

Clean relays. If the 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, if applicable, and any evidence of damage with the relay.

Verify meter connections in accordance with single line meter and relay diagrams. Tighten case connections. Verify that mounting hardware and connections are tight. Inspect covers for correct gasket seal. Clean cover glass. Inspect shorting hardware, case-shorting contacts, connection paddles, and/or knife switches. Verify the target reset.

Inspect meters and relays for foreign material, particularly in disk slots of damping and electromagnets. Remove any foreign material from the case.

Verify disk clearances. Verify contact clearance and spring bias. Inspect spiral spring convolutions. Inspect disks and contacts for freedom of movement, end play, alignment of rotating disk(s) and correct travel. Burnish contacts as needed in accordance with manufacturer instructions. Inspect bearings and/or pivots.

Determine the accuracy of all meters and verify watthour meter operation. Verify the accuracy of meters at all cardinal points. Calibrate watthour meters according to manufacturer published data. Calibrate all meters at mid scale. *NOTE: Calibration instrument precision should be 50-percent 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-percent, the precision of the calibration instrument should be plus or minus 5-percent or better.* Calibrate watt-hour meters to 0.50-percent. Verify instrument multipliers.

Set relays and confirm proper fuse sizes and types in accordance with the engineer's specified values indicated in the coordination study report and related material. Test meters and protective relays at the specified settings.

Perform insulation resistance tests in accordance with relay or metering component and test instrument

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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.  Perform insulation resistance tests on protective and control relays, from circuit-to-frame.  Follow manufacturer instructions for allowable testing procedures for solid-state and microprocessor-based relays.

*NOTE:  Do not perform insulation resistance testing or over-potential (high-potential) 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 pickup and dropout of electromechanical targets.  Verify correct operation of all light-emitting diode indicators.  Set the contrast for liquid-crystal display readouts for readability.

Set relays per engineer's specified values, electrically test, and verify functional operation of relays:

- Timing Relay (ANSI Device Number 2 or 62):  Determine the time delay.  Verify proper operation of instantaneous contacts.
- Distance Relay (ANSI Device Number 21):  Determine the maximum reach.  Determine the maximum torque angle.  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 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 sudden application of 120 percent 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 percent of setting.  Determine a second point on the operating curve.  Determine the pickup.

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- 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.
- 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 angle. Determine the time delay.
- Overvoltage Relay (ANSI Device Number 59): Determine the overvoltage pickup. Determine the time delay to close the contact with 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 manufacturer specifications. Verify the operation of the 63 FPX seal-in circuit. Verify the trip circuit to a remote breaker.
- 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 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.
- Multi-function solid-state relays: Perform manufacturer recommended tests and self-testing of relays. Document functional settings of relays using printouts or by scrolling through relay settings. Record 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 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. Check that connections are tight. Verify that the frame is grounded in accordance with manufacturer instructions. Download settings from the relay. Print a copy of the settings for the commissioning report and compare the settings to those specified in the coordination study. 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 for electromechanical and solid-state relays in accordance with each relay function. Check the operation of all active digital inputs. Check all output contacts or SCRs, preferably by operating the controlled device such as circuit breaker, auxiliary relay, or alarm. 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

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each terminal. Upon completion of testing, reset all min/max 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 each set of relay contacts perform its intended function in the control scheme including breaker trip tests, close inhibit tests, 86 lockout tests, and alarm function.

After the equipment is initially energized, measure the magnitude and phase angle of all inputs and compare to expected values.

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.

### *5.5.22 Molded-Case Circuit Breakers*

Operate each circuit breaker to insure smooth operation. Inspect the case, operating mechanism, contacts, and arc chutes for cracks and other defects. Verify proper operation of the circuit breaker charging mechanism, if so equipped. Check trip unit reset operation.

Perform a contact resistance test of each phase and compare results. See Annex A for additional guidance.

Perform an insulation resistance test from each pole-to-pole and each pole-to-ground with the breaker closed and across open contacts of each phase using a test voltage in accordance with manufacturer instructions for a minimum of one minute. See Annex A for additional guidance.

Perform insulation-resistance tests on all control wiring with respect to ground. For units with solid-state components, follow manufacturer recommendations. See Annex A for additional information.

Check circuit breakers for proper mounting, conductor size (ampacity), and feeder designation. Check the tightness of connections with a calibrated torque tool, such as a torque screwdriver or torque wrench, in accordance with manufacturer instructions.

Perform a primary current injection test to determine minimum pickup current and long-time delay (at 300% pickup current), short-time pickup and time delay, instantaneous pickup current, and ground-fault pick up and time delay. Determine the instantaneous pickup current by run-up or pulse method. Clearing times should be within six (6) cycles or less. Record trip times. Compare results with the time-current coordination curve for each circuit breaker. Verify trip unit characteristics. Set adjustable or programmable devices according to the protective device coordination study. Replace defective devices, 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. NOTE: All tripping times should fall within the manufacturer time current coordination tolerance band. Circuit breakers with trip times varying from published tolerance band more than 10% at three hundred percent (300%) current should be replaced.*

Perform minimum operation voltage tests on shunt trip and close coils in accordance with manufacturer

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instructions.

Activate auxiliary protective devices, such as ground fault or under voltage relays, to verify the operation of shunt trip devices. Test ground-fault to ensure activation based on time current coordination curve for the ground fault relay.

Verify correct operation of any auxiliary features such as trip and pickup indicators, zone interlocking, electrical close and trip operation, trip-free, and anti-pump functions.

Test AFCI and GFCI 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 the circuit breaker as the proper test method for AFCI circuit breakers.*

See NECA 407 for additional guidance. Also, see NECA 169 for additional information for GFCI/AFCI circuit breakers.

### *5.5.23 Low-Voltage Power Circuit Breakers*

Perform all mechanical operator and contact alignment tests on both the breaker and its operating mechanism in accordance with manufacturer published data.

Verify that arc chutes are intact. Inspect moving and stationary contacts for condition, wear, and alignment. Verify that primary and secondary contact wipe and other dimensions vital to the satisfactory operation of the breaker are correct. Verify cell fit and element alignment. Verify racking mechanism operation. Verify appropriate lubrication on moving current-carrying parts. Verify appropriate lubrication on moving and sliding surfaces.

Perform an insulation resistance test from each pole-to-pole and each pole-to-ground with the breaker closed and across open contacts of each phase using a test voltage in accordance with manufacturer instructions for a minimum of one minute. See Annex A for additional guidance.

Perform insulation-resistance tests on all control wiring with respect to ground. For units with solid-state components, follow manufacturer recommendations. See Annex A for additional information.

Perform a contact resistance test of each phase and compare results. See Annex A for additional guidance.

Perform a primary current injection test to determine the minimum pickup current and long-time delay (at 300% pickup current), short-time pickup and time delay, instantaneous pickup current, and ground-fault pick up and time delay. Determine the instantaneous pickup current by run-up or pulse method. Clearing times should be within six (6) cycles or less. Record trip times. Compare results with the time-current coordination curve for each circuit breaker. Verify trip unit characteristics. Set adjustable or

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programmable devices according to the protective device coordination study. Replace defective devices, 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. NOTE: All tripping times should fall within the manufacturer time current coordination tolerance band. Circuit breakers with trip times varying from published tolerance band by more than 10% at three hundred percent (300%) current should be replaced.*

Perform minimum operation voltage tests on shunt trip and close coils in accordance with manufacturer instructions.

Verify proper operation of any auxiliary features such as trip and pickup indicators, zone interlocking, electrical close and trip operation, trip-free, anti-pump function, trip unit battery condition, and reset all trip logs and indicators.

Verify proper operation of the circuit breaker charging mechanism.

### *5.5.24 Grounding Systems*

Visually examine grounding conductors and paths, such as raceway couplings, fittings, and connectors. Check the tightness of conductor and raceway connections.

Confirm that the neutral is grounded only at the service equipment. Confirm that the neutral is not grounded on the load side of the service disconnecting means enclosure. *NOTE: It is important to coordinate this testing and follow proper test procedures when performing insulation resistance testing on conductors and equipment.*

Inspect ground conductors, ground buses, and connections for conformance with design specifications and NEC requirements. Verify that the grounding system is in compliance with drawings, specifications, and NEC.

Perform three-point fall-of-potential tests in accordance with IEEE 81, Section 9.04, on the main grounding electrode system. Test each ground rod individually, and test all ground rods interconnected as a system. Resistance values must be no greater than those specified in the contract documents. *NOTE: In general, the maximum resistance to ground should be less~~greater~~ than 5 ohms. In general, if a single electrode has a resistance of 25 ohms or less, a supplemental electrode shall not be required*.

Ground resistance testing should be conducted only 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.

Perform the two-point method test in accordance with IEEE 81 to determine the ground resistance between the main grounding system and all major electrical equipment frames, system neutral, and/or derived neutral points. Resistance values must be no greater than those specified in the contract documents. *NOTE: In general, the maximum resistance to ground should be less~~more~~ than 5 ohms. In general, if a single electrode has a resistance of 25 ohms or less, a supplemental electrode shall not be required*. Alternatively, perform ground continuity test between main grounding 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

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exceed 0.5 ohm.

Verify the equipment grounding path to earth, including ground rods and interconnecting wiring, ground buses on equipment, room and pullbox connections, and associated intermediate copper ground conductors, and structural steel or reinforcing bar connections, rod connection and intermediate conductor in tests, where applicable.

Notify the CA immediately in writing if the specified ground resistance cannot be obtained with the grounding system installed in accordance with the construction documents and in accordance with the NEC.

After energizing, measure phase-to-phase, phase-to-neutral, and neutral-to-ground voltages to confirm proper neutral-to-ground bonding.

### *5.5.25 Ground-Fault Protection Systems*

Test ground-fault protection systems installed on services when first installed on site. Conduct testing in accordance with manufacturer instructions. Maintain a written record of testing, and make available to the Authority Having Jurisdiction when requested. 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 percent selectivity. See NECA 700 for additional guidance.

Inspect ground-fault protection system components for damage and errors in polarity or conductor routing. Inspect the neutral main bonding connection. Verify that the ground connection is made upstream of the neutral disconnect link and on the line side of any ground fault sensor. Verify that neutral sensors are connected with correct polarity on both the primary and secondary. Verify that all phase conductors and the neutral pass through the sensor in the same direction for zero sequence systems. Verify that grounding conductors do not pass through zero sequence sensors. Verify that the grounded conductor is solidly grounded. Verify correct operation of all functions of the self-test panel. Verify trip operation, no trip test, and non-automatic reset.

For summation type systems utilizing phase and neutral current transformers, verify correct polarities by applying current to each phase-neutral current transformer pair. This test also applies to molded-case breakers utilizing an external neutral current transformer. The relay should operate when the current direction is the same relative to polarity marks in the two current transformers. The relay should not operate when the current direction is opposite relative to polarity marks in the two current transformers.

Disconnect the neutral link and perform neutral insulation resistance testing. See Annex A for additional guidance. Record the insulation resistance, and replace the neutral link. *NOTE: Insulation resistance test results should indicate that no shunt ground paths exist.*

Perform insulation-resistance tests on all control wiring with respect to ground. For units with solid-state components, follow manufacturer recommendations. See Annex A for additional information.

Determine the relay pickup current by primary current injection at the sensor and the circuit interrupting device operated. The relay pickup current must be within ten percent (10%) of the device dial or fixed setting, and in no case greater than twelve hundred (1200) amperes. Verify that the relay does not operate at 90 percent of the pickup setting. Verify that the pickup is less than 125 percent of setting or 1200 amperes, whichever is less.

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Test the relay timing by injecting one hundred fifty percent (150%) and three hundred percent (300%) of the pickup current into the sensor. Electrically monitor and record total trip time. Relay timing must be in accordance with manufacturer published time current characteristics curves but in no case longer than one second at 3000 amperes.

Test system operation at fifty-seven percent (57%) of rated voltage.

Test the zone interlock system by simultaneous sensor current injection and monitor the zone blocking function.

Inspect zero sequence systems for symmetrical alignment of core balance transformers about all current carrying conductors.

Set pick up and time delay settings in accordance with the short circuit and coordination study.

See NECA 400 for additional guidance.

### *5.5.26 Panelboards*

Check all panelboards for proper load balance between phase conductors and adjust the loads as necessary to bring unbalanced phases within 20% of average load. Measure and record current readings on all phase conductors and the neutral conductor. Ensure that the circuit directory for each panel is updated after load balancing, typed, and placed in each panel.

Check torque and tighten all accessible connections to manufacturer specifications.

Perform infrared scan in accordance with Annex A. Perform infrared scan 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. Verify the panelboard does not have a neutral to ground bond unless at the service entrance.

See NECA 407 for additional guidance.

### *5.5.27 Receptacles and Wiring Devices*

Test every installed receptacle and wiring device for proper phasing 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.

Test the retention force of the grounding blade of each receptacle (except pin-and-sleeve and locking-type receptacles). Replace devices with less than 115 g (4 ounces) of retention force.

Test each GFCI receptacle and each GFCI circuit breaker to ensure that the ground-fault circuit interrupter will not operate when subjected to a ground-fault current of less than 4 milliamperes, and will operate when subjected to a ground-fault current exceeding 6 milliamperes. Perform testing with an instrument specifically designed and manufactured for testing ground-fault circuit interrupters. *NOTE: Pushing the receptacle or circuit breaker "TEST" button operation is not acceptable as a substitute for*

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*this test.* Replace GFCI receptacles or circuit breakers that do not shut off power at 5 milliamperes within 1/40th of a second.

Test AFCI receptacles using the test button on the receptacle in accordance with the manufacturer instructions. *NOTE: OSHA does not recognize the use of hand-held test indicators, and receptacle manufacturers only recognize the use of the test button on receptacles as the proper test method for AFCI receptacles.*

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. Correct any deficiencies and retest.

After energizing receptacles and wiring devices and placing under normal loads, check for evidence of thermal damage. Where there is evidence of overheating or failure, perform appropriate thermal evaluation and other tests to determine the extent of damage. Make repairs, rework wiring, and replace damaged devices as needed.

Test receptacle circuits for voltage drop, impedance on phase and neutral conductors, and proper GFCI/AFCI operation at the last receptacle on the branch line. *NOTE: Circuits used for computers or voltage sensitive equipment, at design amperage, should not be less than 6% and for all other circuits less than 10% of design. At all times the voltage at the receptacle should not drop below 111 volts.*

Demonstrate the operation of each switch, timer, and other electrical control wiring device with the systems fully energized and operating. Demonstrate each operation a minimum of three times.

Replace receptacles and devices that are deficient, and retest.

See NECA 130 and NECA 169 for additional guidance.

### *5.5.28 Engine Generators*

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 remaining packing materials, building materials, tools, hardware, 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.

Perform a phase rotation test. Verify that the alternator is connected for the required voltage and phase rotation. Measure the clearance in the generator and exciter air gap. Verify that the air gap is in accordance with manufacturer specifications. Check the alternator for loose items such as shaft keys, and couplings. Tighten or replace loose or damaged components.

Inspect the insulation on all conductors. Replace conductors with damaged insulation. Inspect connections and terminations for damage. Repair or replace damaged connections and terminations. Support all conductors to prevent stress on connections and termination, and to protect conductors from damage from rotating parts and sharp edges.

Check bolts, fasteners, and hardware for tightness. Torque hardware in accordance with manufacturer instructions.

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Measure the winding resistance using a DC bridge and a meter capable of readings in the milli-ohm range. Correct measured values to operating temperature and calculate copper ($I^2R$) losses and efficiency, and compare with manufacturer specifications.

Perform insulation resistance and dielectric tests. Calculate polarization index and dielectric absorption, and perform insulation power factor testing in accordance with IEEE Standard 43. See Annex A for additional guidance. Perform tests on armature and rotating or stationary field windings.

Perform high-potential testing on alternators with ratings greater than 600 Volts. See Annex A for additional guidance. Test each phase separately with the other phases and the winding temperature detectors grounded. Disconnect any capacitors and surge arrestors during the test.

Perform a vibration test for each main bearing cap. Vibration levels must be in accordance with manufacturer published data.

Verify proper operation of the engine governor and alternator voltage regulator systems upon initial start-up in accordance with manufacturer instructions. Verify proper frequency and voltage magnitude at no-load with the engine operating at rated speed.

Verify all generator functions. Functionally test engine shutdown for low oil pressure, over-temperature, over-speed, and other protection features as applicable. Verify all alarms, meters, and auxiliaries and interlocks to the building automation system (BAS). Verify fuel system, fuel storage tank, and level and low fuel indication alarms.

Verify appropriate mechanical system and control system restart functions of all equipment served by the generator. Verify combustion and ventilation air damper functions and pressure drop of exhaust for generators located indoors.

Verify proper operation of multiple generators operating in parallel, including operating sequence, lead-lag generator controls, governors, regulators, speed control, and load sharing, including sharing real power and reactive power (cross-current compensation or VAR control). 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.

Perform load bank testing of each generator in accordance with contract documents. In the absence of contractual requirements, perform the following load test. Apply step (block) loads of 0 percent, 25 percent, 50 percent and 100 percent of full load nameplate rating in 15-minute intervals. Record voltage, current, frequency, and all gaged engine conditions at each step. Operate the generator at 100 percent of full load nameplate real power rating for a minimum of four hours. Record voltage, current, frequency, and all gaged engine conditions every 15 minutes during the full-load test. Verify all generator-running characteristics. Verify starting battery-charging system.

Perform functional testing of generator systems, including automatic transfer switches (ATSs) and uninterruptible power supplies (UPSs). Include power outage simulations, start-up and transfer of power to the generator system, operation of loads connected to the generator system, start-up and shut-down of equipment related to the fire alarm system, electrical power distribution systems, motor control centers and starters, and variable frequency drives, as applicable. Load bank test the UPS if necessary for the UPS to supply load during testing. Using a power line disturbance monitor, measure and record time delays for each power failure to each engine start command, engine start command to engine start (cranking time), engine start to the point where the generator is operating at rated voltage and frequency and total time from power failure until the loads are connected to the generator system.

Verify that each piece of generator control equipment, such as ATSs, can independently start the generator system and transfer its load to generator power.

Verify that adjustable settings are set in accordance with manufacturer instructions and recommendations.

See NECA/EGSA 404 and NECA 406 for additional guidance.

### *5.5.29 Automatic Transfer Switches (ATSs)*

Commission each ATS separately to verify that each ATS starts the generator system and transfers its load to generator power independently of all other ATSs.

Check transfer switches for completeness of assembly. Check switches for proper alignment, and for loose parts and insulation damage. Verify proper grounding.

Verify that manual transfer warnings are attached and visible. Perform manual transfer operation. Verify positive mechanical interlocking between normal and alternate sources.

Perform an insulation resistance test on each pole from phase-to-phase and phase-to-ground with the switch closed and across each open pole in accordance with manufacturer instructions for a minimum of one minute. Perform test with the switch in both the normal and emergency source positions. See Annex A for additional guidance.

Perform insulation-resistance tests on all control wiring with respect to ground. For units with solid-state components, follow manufacturer recommendations. Verify the tightness of all control connections. See Annex A for additional information.

Perform a contact resistance test of each phase and compare results. See Annex A for additional guidance.

Monitor and document ATS settings and timers for manual testing/transfer, normal voltage sensing relays, emergency voltage sensing relays, in-phase monitor, time delay upon transfer, alternate voltage sensing relay, interlocks and limit switch functions, and timing delay and retransfer upon normal power restoration over the course of testing transfer switches. Adjust timer settings in accordance with contract documents and manufacturer instructions for proper operation.

For engine-generator applications, perform system operational testing. Verify that the generator is not running and that the ATS is set for automatic operation~~control switch in the AUTO position~~. Verify that the utility bus is energized, and manually close normal-side feeder breaker to energize the ATS. Verify the position of the transfer switch and indication light statuses. Measure the input (normal) and output (load) voltages of the transfer switch. Check the phase rotation of the normal (utility) bus to the output bus of the transfer switch. Manually open the normal-side feeder breaker to the ATS. Verify that the generation system starts, and that the ATS transfers the load to the generation system. Verify the position of the transfer switch and indication light statuses. Measure the input (emergency) and output (load) voltages of the transfer switch. Check the phase rotation of the emergency (generator) bus to the output bus of the transfer switch. Manually close the normal-side feeder breaker to the ATS. Verify that the ATS transfers the load to the utility, and that generation systems cooldown, stop, and reset for automatic operation. Push the TEST switch to simulate a normal source failure. Verify that the ATS and generation systems operate properly.

Verify appropriate lubrication on moving current-carrying parts. Verify appropriate lubrication on moving and sliding surfaces.

### *5.5.30 Variable Frequency Drives (VFDs)*

Verify that the VFD rated output current is greater than the motor FLA. *NOTE: VFDs are current rated, not horsepower rated.*

Make sure that the nominal supply voltage, VFD rated voltage, and motor voltage are compatible. Check for proper jumper, screw, or switch settings for the given drive supply voltage parameters, if so equipped.

Ensure that VFDs are installed with an ambient temperature no greater than 40°C (104°F) with a humidity level from 10 to 90% non-condensing. Ensure that there is adequate clearance around VFDs for cooling in accordance with the manufacturer instructions. Verify that vent path openings are free from debris and that heat transfer surfaces are clean.

Verify that there are no power factor improvement capacitors installed on the VFD output between the VFD and the motor. *NOTE: Power factor capacitors connected on the VFD output will cause VFD damage.* Verify that there are no power factor improvement capacitors are installed within a feeder circuit length of 100m (300ft) of the VFD input if there is no line reactor or input filter installed on the VFD input. *NOTE: Upstream capacitors may cause nuisance overvoltage tripping of VFDs that do not have an input line reactor or input filter.*

For 460Vac or 575Vac installations, verify that the motor specification for the cable length and carrier frequency limitations are within recommended limits. *NOTE: A load reactor or an output filter may be needed, if recommended by the manufacturer.*

Verify that all electrical connections are tight. Verify correct connections of circuit boards, wiring, disconnects, and ribbon cables. Make sure that VFDs and all the electrical connections are free of debris.

Verify that the motor and the load rotate freely. Check for damaged bearings, correct belt tension, belt alignment, and/or shaft alignment.

Perform startup of VFDs in accordance with manufacturer instructions. Prior to starting the system, verify that the VFD system can be operated at full speed (60Hz) without causing damage to other equipment or endangering personnel.

*NOTE: VFDs will cause noise on neutral and ground conductors, and voltage fluctuations on phase conductors during normal operation. Additionally, VFDs induce motor bearing currents and shaft voltages that will cause pitting of the shaft and premature motor failure. Check motors for excessive voltages and currents. Install shaft voltage/current eliminators when needed in accordance with manufacturer instructions.*

Without applying power to the VFD, check the supply line phase-to-phase voltages. Phase voltages should be balanced within 3% of each other, and within 10% of the VFD nameplate rating.

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. Calibrate relays and test parameters for input phase loss protection, input overvoltage protection, output phase rotation, over-temperature protection, DC overvoltage protection, over-frequency protection, drive overload protection, and fault alarm outputs. Test the motor overload relay elements by injecting primary current through the overload circuit and monitoring trip time of the overload element.

Calibrate VFDs to the system's minimum and maximum speed control signals. Set adjustable parameters to match the settings provided. Verify that VFD overcurrent setpoints are correct for the application. If a VFD is used to operate multiple motors, verify individual motor overload element ratings are correct for their application. Apply minimum and maximum speed setpoints. Verify that setpoints are within limitations of the load coupled to the motor. Test and record output volts and amps while the drive is at 25%, 50%, and 100% of rated speed and attached load. Observe for balance and performance within manufacturer specifications.

Verify the phase rotation of the VFD output in both VFD mode and the BYPASS mode, if so equipped. Correct incorrect phase rotation in accordance with manufacturer instructions.

Record harmonic distortion at the VFD output, at the VFD input, and at the upstream source that supplies the VFD.

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. *NOTE: Incorrect software programming may result in equipment damage or failure.* Record any changes to the software parameters for future reference.

Perform operational tests 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. Verify proper operation of VFDs from remote start/stop and speed control signals.

Start the motor load with the VFD in BYPASS mode, if so equipped, to ensure that upstream overcurrent protection devices do not trip for motor inrush current with the drive in BYPASS mode.

### *5.5.31 AC Synchronous Motors and Generators*

Check that the installation is complete. Inspect for physical damage. Check for loose items such as shaft keys and couplings. Inspect air baffles, filter media, cooling fans, slip rings, brushes, and brush rigging. Slip ring wear and brushes should be within manufacturer tolerances for continued use. Brush rigging should be intact.

Check all connections for tightness and proper insulation.

Uncouple the motor from the load (drive machinery), and manually rotate to verify that the motor rotates freely and is free from interference.

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Verify the application of appropriate lubrication and lubrication systems.

Measure the resistance of the machine-field winding, exciter-stator winding, exciter-rotor windings, and field discharge resistors.

Prior to energizing, apply voltage to the exciter supply and adjust the exciter-field current to the nameplate value.

Verify that the field application timer and the enable timer for the power-factor relay have been tested and set to the motor drive manufacturer recommended values, if applicable.

Perform phase-to-phase stator resistance testing on machines rated 2300 volts and greater. Perform resistance tests on resistance temperature detector (RTD) circuits, if so equipped. Verify that resistance temperature detector (RTD) circuits conform to drawings.

Perform insulation-resistance test on insulated bearings in accordance with manufacturer instructions.

Perform insulation-resistance tests and dielectric absorption tests (polarization index and 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.

- For motors rated 200 HP and less, and rated 600V and less, perform insulation resistance and dielectric absorption testing.
- For motors rated more than 200 HP, and rated from 600V to 2400 V, perform insulation resistance testing and calculate dielectric absorption ratio and polarization index.
- For motors with ratings more than 200HP and more than 2400V, perform insulation resistance testing and calculate dielectric absorption ratio and polarization index, and perform high-potential testing.

See Annex A for additional guidance. Perform tests on armature and rotating or stationary field windings. Disconnect the neutral connection on the stator, and test each winding with respect to the other windings and ground. Perform high-potential testing on each phase separately with the other phases and the winding temperature detectors grounded, if so equipped. Disconnect any capacitors and surge arrestors during testing.

Momentarily energize (bump) motors to verify proper phase rotation.

Perform vibration monitoring on all rotating equipment greater than 7-1/2 HP (or smaller if highly critical to operations), including motors, pumps, turbines, compressors, engines, bearings, gearboxes, agitators, fans, blowers, and shafts, as applicable. Conduct all tests at normal operating speed at maximum load conditions. The motor must meet the applicable vibration criteria as specified in Tables 3 and 4.

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| Table 3 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 4 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 |

Perform laser alignment on all shaft coupled machines (see Figure 1). All shaft-to-shaft center line alignments should meet the requirements of Table 5 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 illustrates the concept of offset and angular motor alignment.

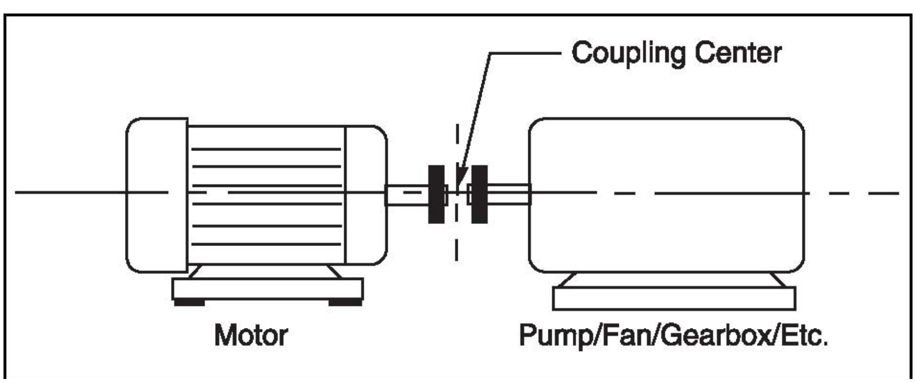


*Figure 1. Coupled Shafts Alignment*

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| Table 5 Coupled Shaft Alignment Tolerance Values | | | |
|---|---|---|---|
| | **RPM** | **Tolerance Specification** | |
| **Soft Foot** | All | <0.0508 mm (0.002 inch) at each foot | |
| | | **Horizontal & Vertical Parallel Offset per 25.4 mm (12 inches) of Spacer Length** | **Angularity/Gap mm/254 mm (1 inch/10 inches) Coupling Diameter** |
| **Short Couplings** | <1000 | 1.2700 mm (0.005 in) | 0.3810 mm (0.015 in) |
| | 1200 | 1.0160 mm (0.004 in) | 0.2540 mm (0.010 in) |
| | 1800 | 0.7620 mm (000.3 in) | 0.1270 mm (0.005 in) |
| | 3600 | 0.5080 mm (0.002 in) | 0.0762 mm (0.003 in) |
| | 7200 | 0.2540 mm (0.001 in) | 0.0635 mm (0.0025 in) |
| | | | |
| **Couplings with Spacers** | <1000 | 0.0508 mm (0.0020 in) | |
| | 1200 | 0.0381 mm (0.0015 in) | |
| | 1800 | 0.0254 mm (0.0010 in) | |
| | 3600 | 0.0127 mm (0.0005 in) | |
| | 7200 | 0.0076 mm (0.0003 in) | |

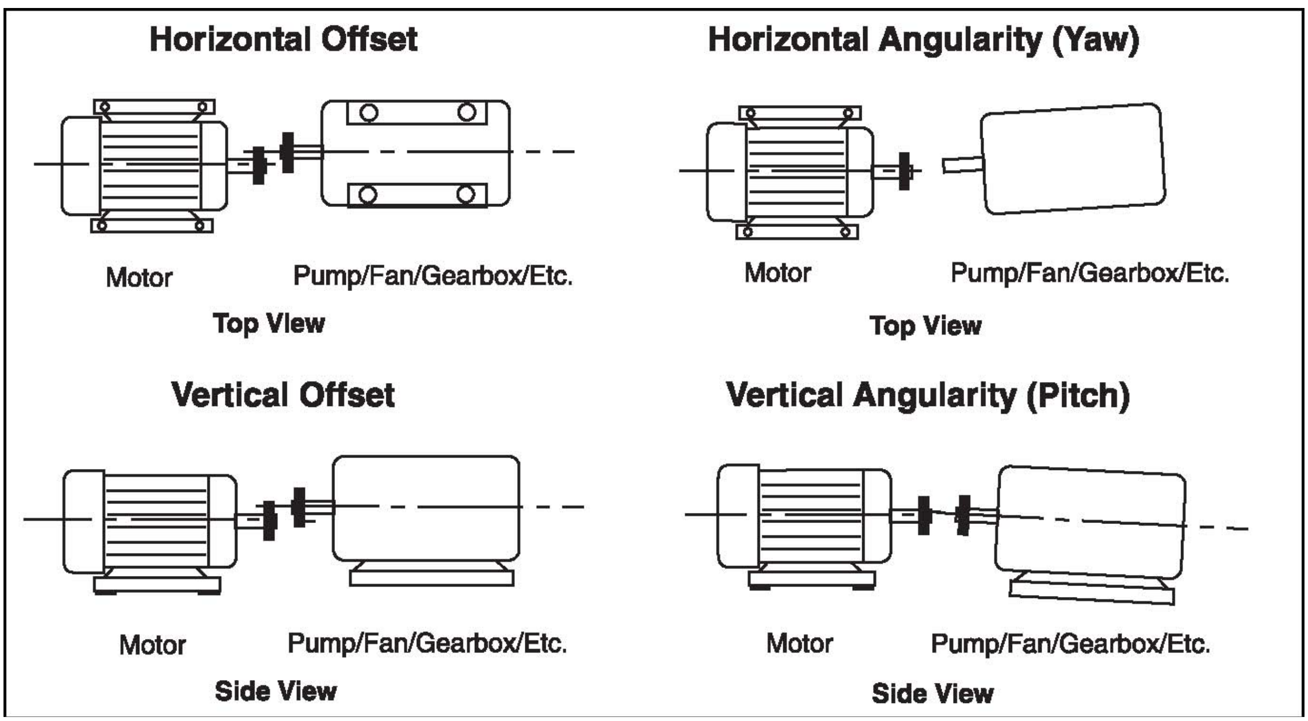


*Figure 2. Offset and Angular Motor Alignment*

Upon startup, verify the absence of unusual mechanical or electrical noise and signs of overheating.

Verify proper operation of machine space heaters, if applicable.

Perform a vibration test.

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### *5.5.32 AC Induction Motors and Generators (Alternators)*

Inspect air baffles, filter media, cooling fans, slip rings, brushes, and brush rigging. Verify that resistance temperature detector (RTD) circuits conform to drawings, if so equipped. Verify that metering or relaying devices utilizing RTDs have the correct rating.

Verify the correct application of appropriate lubrication and lubrication systems.

Verify the absence of unusual mechanical or electrical noise and signs of overheating during initial test run.

Perform insulation-resistance tests and dielectric absorption tests (polarization index and 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.

- For motors rated 200 HP and less, perform insulation resistance testing and calculate the dielectric absorption ratio.
- For motors rated more than 200 HP, perform insulation resistance testing and calculate polarization index.
- For motors rated more than 1000HP and more than 4000V, perform insulation resistance and dielectric absorption testing, calculate polarization index, and perform high-potential testing.

See Annex A for additional guidance. Perform tests on armature and rotating or stationary field windings. Disconnect the neutral connection on the stator, and test each winding with respect to the other windings and ground. Perform high-potential testing on each phase separately with the other phases and the winding temperature detectors grounded, if so equipped. Disconnect any capacitors and surge arrestors during testing.

Perform phase-to-phase stator resistance testing.

Perform insulation-resistance testing on the bearing pedestal in accordance with manufacturer instructions.

Perform resistance tests on RTDs, if so equipped.

Verify proper operation of the motor space heater, if applicable.

Momentarily energize (bump) motors to verify proper phase rotation.

Measure the running current and evaluate relative to load conditions and nameplate full-load amperes.

### *5.5.33 DC Motors and Generators*

Inspect baffles, filter media, cooling fans, slip rings, brushes, and brush rigging.

Verify the correct application of appropriate lubrication and lubrication systems.

Inspect the commutator and tachometer generator.

Verify the absence of unusual mechanical or electrical noise and signs of overheating during initial test

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run.

Verify that resistance temperature detector (RTD) circuits conform to drawings, if so equipped. Verify that metering or relaying devices utilizing RTDs have the correct rating.

Perform insulation-resistance and dielectric absorption tests (polarization index and 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 guidance.

- For motors rated 200 HP and less, perform insulation resistance testing and calculate the dielectric absorption ratio.
- For motors rated more than 200 HP, perform insulation resistance testing and calculate polarization index.

Perform an insulation-resistance test on the bearing pedestal in accordance with manufacturer instructions. Pedestal bearing insulation resistance must not be less than 1.0 megohm at 500 volts DC.

Perform resistance tests on RTDs, if so equipped.

Verify proper operation of the motor space heater, if applicable.

Measure armature running current and field current or voltage. Compare to nameplate.

### *5.5.34 Battery Systems*

Torque battery rack connections in accordance with manufacturer instructions. Inspect battery racks and insulating covers for physical damage, loose connections, cracking, dielectric leaks, dirt, corrosion, and seismic parts and spacers.

Check DC power, control power, and battery connections including cell-to-cell, tier-to-tier, rack-to-rack, and UPS to battery module connections, if applicable, for correct polarity.

Check battery jars and covers for cracking, distortion, dielectric leaks, dirt, and corrosion. Inspect jar and post seals. Check electrolyte levels, if applicable. Check vented lead-acid batteries and vented nickel-cadmium batteries for clogged flame arresters. Inspect vented lead-acid battery cells, and check plates for cracks, sulfate, and hydration.

Measure and record the cell-to-cell and terminal connection resistance with a digital low-resistance ohmmeter. Remake connections having a resistance of more than 10 percent above the average.

Inspect terminals for loose or broken connections, and burned insulation. Check for liquid contamination (battery electrolyte and oil from capacitors). De-energize equipment and make corrections or repairs for any abnormal operating conditions in accordance with manufacturer recommendations.

Verify the presence of flame arresters, adequacy of battery support racks, mounting, anchorage, grounding, and clearances, ventilation of battery room enclosure, and existence and proximity of suitable eyewash equipment.

Measure the voltage drop across all battery cells and across all DC connections with a digital voltage meter. Set the voltage range of the meter to the maximum open-circuit voltage range of the connection. Investigate readings that deviate from other readings by 25 percent or more.

Perform a battery impedance test and record the results.

Energize and test batteries in accordance with contract documents and manufacturer instructions. Inspect all parts for evidence of overheating and evidence of physical damage, including warn insulation and corrosion, at each step during energization. Close the battery circuit breaker, and measure and record the battery charging voltage and current. Allow the batteries to charge for a minimum of 24 hours, or until the batteries are fully charged, whichever is less. Record the time. Measure and record the battery float voltage and current and rectifier/battery charger output voltage and current every 4 hours while charging.

After charging, check batteries for signs of vibration, and check vented lead-acid batteries for signs of excessive gassing. For vented (flooded) batteries, add electrolyte to batteries as required to fill cells up to the bottom of the high-level line using manufacturer recommended materials and methods. Equalize non-valve regulated batteries in accordance with manufacturer instructions.

Verify that the batteries are fully charged and are on float charge. Measure and record the float voltage and charging current.

After charging batteries, measure each cell voltage and total battery voltage with the charger in the float mode of operation. Measure ripple current, specific gravity, electrolyte temperature, electrolyte fill level, overall float voltage measured at the battery terminals, charger output current and voltage, ambient temperature, condition of ventilation and monitoring equipment, and temperature of the negative terminal of each cell of the battery.

Load test batteries in accordance with manufacturer instructions. The values for discharge time and end point voltage should be selected from the battery manufacturer published ratings, and the values used for the acceptance test should be approximately the same as that of the intended application. The discharge rate should be at a constant current or constant power load equal to the selected manufacturer rating of the battery. Set up a load suitable for the test along with the necessary instrumentation to maintain the test discharge rate as determined above. Disconnect the charging source, connect the load to the battery to begin the test, and track the time, continuing to maintain the selected discharge rate. If the charging source cannot be disconnected, decrease the current being drawn by the load to compensate for the current being supplied to the battery by the charging source. Read and record the individual cell voltages and the battery terminal voltage with the load applied at the beginning and at the completion of the test and at intervals specified in contract documents or as recommended by the manufacturer. Take a minimum of three sets of readings. Take individual cell voltage readings between respective posts of like polarity of adjacent cells so as to include the voltage drop of the intercell connectors. Maintain the discharge rate and record the elapsed time at the point when the battery terminal voltage decreases to a value equal to the minimum average voltage per cell as specified by the design of the installation times the number of cells. Upon completion of testing, inspect bus bar bolts, repair and re-torque to specifications as necessary. Replace any failed batteries or bus bars and note on the record of the test.

Remove and dispose of empty, partially full, and excess acid drums, including shipping containers and obsolete batteries, in accordance with local laws and regulations regarding disposal of hazardous material. Do not dispose of batteries in a fire.

### *5.5.35 Battery Chargers*

Verify that the battery charger is compatible with the type and configuration of the battery plant. Check the settings of the charger and calibrate in accordance with manufacturer instructions to match the float and equalizing levels required by the batteries.

Inspect filter and tank capacitors.

Verify proper operation of cooling fans. Clean filters if provided.

Before connecting the battery charger to the battery, measure and record the battery charger output voltage. Verify proper operation of all charger functions and alarms. Verify proper polarity of the battery charger and the battery plant.

Upon energizing the battery charger, verify float voltage, equalization voltage, and high voltage shutdown settings. Verify the current limit. Verify correct load sharing of parallel battery chargers. Verify the calibration of meters. Verify the proper operation of alarms. Measure and record the input and output voltage and current. Measure and record AC ripple current and/or the voltage imposed on the battery. Perform full load testing of the charger.

### *5.5.36 Flooded Lead Acid Batteries*

Verify that the battery room/area ventilation system is operable. Verify the existence and proximity of suitable eyewash equipment. Verify electrolyte levels. Measure electrolyte specific gravity and temperature levels. Verify the presence of flame arresters. Verify the adequacy of battery support racks, mounting, anchorage, seismic supports, if applicable, and clearances. Inspect the spill containment installation, if applicable. Verify the application of an oxide inhibitor on battery terminal connections.

Measure the charger float and equalizing voltage levels. Adjust charger settings to the battery manufacturer recommended settings. Verify all charger functions and alarms. Measure each cell voltage and total battery voltage with the charger energized and in the float mode of operation. Measure intercell connection resistances. Measure the battery system voltage from positive to ground and negative to ground.

### *5.5.37 VRLA Batteries*

Verify that the battery room/enclosure ventilation system is operable. Verify existence and proximity of suitable eyewash equipment. Verify adequacy of battery support racks or cabinets, mounting, anchorage, seismic supports, if applicable, and clearances. Verify the application of an oxide inhibitor on battery terminal connections.

Measure negative post temperatures. Measure the charger float and equalizing voltage levels. Verify all charger functions and alarms. Measure each monoblock/cell voltage and total battery voltage with the charger energized and in the float mode of operation. Measure intercell connection resistances. Perform internal ohmic measurement tests.

### *5.5.38 Uninterruptible Power Supply (UPS) Systems*

Coordinate UPS testing with generator/transfer switch testing, if applicable.

Verify electrical connections using the wiring schematic to ensure proper phasing and voltage connections. Check that the battery charger connections to the battery and the battery connections to the inverter have the correct polarity. Verify the proper operation of forced ventilation. Verify that the vents are clear, air inlets are not obstructed, and filters are in place.

Adjust programmable parameters in accordance with manufacturer instructions. Set the free running frequency of the oscillator.

Simulate critical malfunctions to test all warnings, alarms, and shut downs and to verify annunciation and protective device functions. Test alarm circuits. Test all electrical and mechanical interlock systems for correct operation and sequencing.

Verify synchronizing indicators for static switch and bypass switches, if so equipped. Test the static transfer from the inverter to bypass and back. Use the actual UPS load if possible without interrupting critical loads. Test DC undervoltage trip level on the inverter input breaker.

Measure and record the battery voltage. Measure and record the inverter output voltage and current.

Perform an infrared scan in accordance with Annex A.

See NECA 411 for additional guidance.

### *5.5.39 Lighting*

Perform operational tests on completed lighting systems, including testing all switches, controls, and emergency lights, switching ballasts, and batteries. Test the operation of lighting controls and integral components to ensure they respond appropriately to changing conditions and parameters, as specified.

Measure lighting levels in all areas to assure they meet the requirements specified in the contract documents. Demonstrate lighting levels at desk level after dark to ensure that they are not affected by daylight, and record readings.

Walk-test areas equipped with occupancy sensors to ensure that lights turn on and off automatically. Adjust time delay and sensitivity settings as needed. Verify proper occupant override operation, if applicable. Record blind spots or issues with occupancy sensors not performing properly.

For lighting control relay panels, verify that the time clock, if so equipped, has been programmed with correct lighting zones and correct on/off controls. Simulate time-changes to witness automatic light controls. Verify proper occupant override operation, if applicable. Record any issues observed during testing.

For daylight harvesting systems, test dimming controls during daylight hours when controls should automatically dim lighting. Verify that amperage changes in light fixtures are proportional to external light changes. Verify that light levels at the specified work plane remain within specified limits using a combination of daylight and dimmable lighting. Measure and record light levels in each room. Verify that all (and only) specified light fixtures are controlled by the system. Verify that dimming delays and ramp times are set and functioning so that changes in light fixture output are gradual, do not bother

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occupants, and comply with the specifications. Verify that dimming does not cause lower-than-specified lighting levels in spaces with daylight harvesting. Verify that the controls and sensors are tamper-resistant and not easily overridden or disabled by occupants. Verify that photo sensors are in appropriate locations for the lights being controlled and are not affected by direct sunlight or obstructions (shadows). Adjust system and component settings as needed in accordance with contract documents, drawings and specifications, and in accordance with manufacturer instructions.

See NECA/IESNA 500, NECA/IESNA 501, and NECA/IESNA 502 for additional guidance.

### *5.5.40 System Testing*

Perform system functional testing upon completion of the acceptance tests on individual equipment and components. Develop test parameters and perform tests for the purpose of evaluating the performance of all related components and equipment, and their functioning as an integrated system within design requirements and in accordance with manufacturer instructions.

Test interconnections of the electrical equipment with other systems, such as mechanical, security, and fire alarm systems. If a building automation system (BAS) is installed, verify the overall system functions, monitoring and control, including data points derived from or delivered to the electrical system.

Verify the proper operation of electrical equipment and devices under load. Coordinate testing as needed to allow for testing the electrical system while mechanical systems are running.

### *5.5.41 Medium and High-Voltage Surge Arresters~~Protective Devices (SPDs)~~*

Inspect ~~SPDs~~ arresters for correct mounting and adequate clearances. Verify that arresters are clean. Verify that the ground lead on each device is individually attached to a ground bus or grounding electrode. Verify that the stroke counter, if present, is correctly mounted and electrically connected.

Test the ground connection for continuity. Measure the resistance of the ground connection. The resistance between the arrester ground terminal and the grounding system should be less than 0.5 Ohm.

Perform insulation-resistance testing at voltage levels in accordance with the manufacturer instructions. See Annex A for additional guidance.

### *5.5.42 Low-Voltage Surge Protective Devices (SPDs)*

Inspect SPDs ~~for correct mounting and adequate clearances~~to ensure conductor length from the SPD to the bonding location is as short as possible and does not exceed the SPD's manufacturer's maximum length requirement. If manufacturer's requirements are unknown, ensure length does not exceed 36 inches with no sharp bends or coils. If present, ~~V~~verify ~~that~~ the SPD's ground lead ~~on each device~~ is ~~individually attached~~bonded to a grounded bus or ground electrode. ~~Verify that the stroke counter, if present, is correctly mounted and electrically connected.~~ *NOTE: When SPDs are not connected directly to equipment bus work but have lead wires, excessive length and sharp bending of those wires can reduce the SPD effectiveness. Where practicable, keep length of leads less than 24-inches.*

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If present, ~~T~~test the SPD's ground connection for continuity~~. M~~ by measuring~~e~~ the resistance ~~of the ground connection~~between the SPD's ground terminal (if accessible) and the grounding system. The resistance ~~between the arrester ground terminal and the grounding system~~ should be less than 0.5 Ohm.
*NOTE: Not all SPD's utilize a common ground conductor (common mode).*

~~Perform insulation-resistance testing in accordance with manufacturer instructions. Perform an insulation power factor test. Power factor tests should indicate similar dielectric loss between similar arrests. See Annex A for additional guidance.~~

### *5.5.43 Capacitors*

Inspect capacitors for correct mounting and required clearances in accordance with NEC requirements and in accordance with the manufacturer instructions. Verify that capacitors are electrically connected in their specified configuration and in accordance with their nameplate ratings.

Measure the capacitance of all terminal combinations and compare with the manufacturer published data. Measure the resistance of internal discharge resistors and compare with the manufacturer published data.

Perform insulation-resistance tests from the terminals to the case for one minute on capacitors with more than one bushing. Test voltage and minimum resistance must be in accordance with manufacturer instructions. See Annex A for additional guidance.

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

Perform infrared scan. See Annex A for additional guidance.

### *5.5.44 Dry-Type Reactors (Shunt and Current-Limiting)*

Verify that tap connections are as specified, if applicable.

Perform winding-to-ground insulation-resistance tests. Apply voltage in accordance with manufacturer published data. See Annex A for additional guidance.

Measure winding resistance. See Annex A for additional guidance. Consult the manufacturer for recommendations if winding-resistance test results vary more than one percent from factory tests.

### *5.5.45 Liquid-Filled Reactors (Shunt and Current-Limiting)*

Verify the settings and operation of all temperature devices, if applicable. Verify that cooling fans and pump motors have correct overcurrent protection, if applicable. Verify proper operation of all alarm, control, and trip circuits from temperature and level indicators, pressure relief devices, and fault pressure relays, if applicable. Verify correct liquid level in all tanks and bushings. Verify that positive pressure is maintained on nitrogen-blanketed reactors. Verify that tap connections are as specified, if applicable.

Perform winding-to-ground insulation-resistance tests. Apply voltage in accordance with manufacturer published data. See Annex A for additional guidance. Calculate the polarization index. Perform insulation power-factor or dissipation-factor tests on windings in accordance with the test equipment manufacturer published data. Perform power-factor or dissipation-factor or hot collar watts-loss tests on bushings in accordance with the test equipment manufacturer published data. Measure winding resistance. Measure the percentage of oxygen in the nitrogen gas blanket, if applicable.

Remove a sample of insulating liquid in accordance with ASTM D-923. Test the sample for:

- Dielectric breakdown voltage: ASTM D-877 and/or ASTM D-1816.
- Acid neutralization number: ASTM D-974.
- Specific gravity: ASTM D-1298.
- Interfacial tension: ASTM D-971 or ASTM D-2285.
- Color: ASTM D-1500.
- Visual Condition: ASTM D-1524.
- Water in insulating liquids: ASTM D-1533. (Required on equipment rated 25 kV or higher, and on all silicone-filled units.)
- Measure power-factor or dissipation-factor in accordance with ASTM D-924.
- Remove a sample of insulating liquid in accordance with ASTM D-3613 and perform dissolved-gas-analysis in accordance with ANSI/IEEE C57.104 or ASTM D-3612.

### 5.6 Deferred and Seasonal Testing

If any check or test cannot be completed due to the need for seasonal testing, weather conditions, building structure, required occupancy levels, or other testing factor where system loadings are closer to the system design criteria, or other deficiency, the execution of checklists and functional testing may be delayed until after Substantial Completion, but before the expiration of the warranty period, upon approval of the CA and owner. Perform these tests and checks as soon as conditions permit adequate testing.

Perform and document the specified testing and the results. Correct deficiencies identified during deferred and seasonal testing. Update record documents, O&M manuals, as-build drawings, and other commissioning documents as needed for any modifications made during deferred or seasonal testing.

## 6. Recording and Documenting Performance

Documentation is an essential component of the commissioning process. Record and collect all formal and informal communications during the commissioning process. Document all pre-functional and functional performance checks and tests. Submit documentation in the format(s) as required in contract documents.

### 6.1 Documentation

*NOTE: Commissioning, including start-up testing, acceptance testing, integrated system testing, and operational tune-ups and adjustments, is the process by which the proper operation and sequence of operation of electrical equipment is validated, in addition to developing baseline criteria by which future trend analysis can identify equipment deterioration. These baseline tests are compared with later tests and the results of routine maintenance to identify any downward trend in equipment and system*

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*performance. As such, it is vital to maintain complete and accurate records of commissioning and maintenance activities.*

Commissioning documentation includes, but is not limited to:

- Approved submittals, testing, balancing, and calibration reports for the equipment, sub-systems, and systems being commissioned.
- All approved shop drawings of electrical equipment. Fold full-size sheets as required to fit in binders.
- All pre-functional performance test checklists, signed by the responsible personnel, organized by system and sub-system.
- All verification and functional performance test checklists/results, signed by the responsible personnel, organized by system and sub-system.
- Completed as-built drawings signed by the contractor.
- Copies of the operation and maintenance (O&M) manuals.

### 6.2 Non-Conformance Items

*NOTE: In general, the A/E is the final interpretive authority regarding technical non-compliance issues or deficiencies (compared with Design Intent or Basis of Design (BOD) documents) and their resolution (in accordance with the Design Intent or Basis of Design (BOD) documents).*

*NOTE: In general, the owner is the ultimate decision authority in resolving deficiencies or issues of non-conformance. The owner may decide whether modifications are required to correct deficiencies, or whether tests will be accepted as submitted. If corrective work is performed, the owner may determine whether tests will be repeated and a revised report submitted.*

Non-conformance items or deficiencies may be identified at any point during the commissioning process. All deficiencies should be recorded in a comprehensive log that is maintained by the CA, is continuously updated, and is periodically reviewed by the entire commissioning team.

Deficiencies identified during commissioning should be documented on standardized forms and/or checklists used to document that particular phase of commissioning for the specific equipment or system. Minor deficiencies that can be corrected during the normal course of performing testing and commissioning procedures should be corrected at that time with appropriate notations made on the forms and/or checklists.

Deficiencies or non-conformance items that cannot be corrected during the normal course of performing testing and commissioning procedures should be documented on a standardized Resolution Tracking Form or Non-Conformance Form that summarizes each deficiency and outlines possible options for resolving the deficiency, along with recommending a preferred option for resolution, that is submitted to the A/E for review. *NOTE: The Resolution Tracking Form or Non-Compliance Form should contain a Statement of Correction that is signed after resolution of the deficiency, and to certify that the equipment or system is ready for retesting.*

# 7. Operating and Maintenance (O&M) Manuals

Operating and Maintenance (O&M Manuals) typically include, but are not limited to, the following:

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- System descriptions, including narratives of the theory of operation, overall system layout, description of major components, interconnections with utilities and other systems, description of control system layout and operation, identification of unusual features or functions, and major safety precautions.
- Manufacturer installation, start-up, and operating instructions.
- Control sequences describing start-up, all modes of operation, and shut down.
- Troubleshooting procedures.
- References to drawings, schematics, sequences of operation, and other information included as part of the construction contract drawings and specifications that show the system configuration and layout and equipment arrangements and items of control, as appropriate.
- Spare parts lists.
- Manufacturer, vendor, supplier, and sub-contractor 24-hour contact information.
- Approved and corrected shop drawings, such as wiring, control, and one-line diagrams, and marked-up catalog data.
- Owner-contracted tests, if any.
- Factory testing reports, if any.
- Field test reports, checklists, and forms.
- Full warranty information, including clearly identifying all responsibilities of the Owner to keep the warranty in force.
- Copies of the installation, start-up, and checkout materials that are supplied with and shipped inside equipment, if any.
- Forms and checklists completed in the field by factory or field technicians.
- Preventive maintenance procedures including recommended frequency for each preventive maintenance task, such as cleaning, inspection, lubrication, and scheduled overhauls. Group tasks and sort by frequency, such as daily, weekly, quarterly, and annually.

The Commissioning Authority (CA) should review the O&M manuals early in the commissioning process to become familiar with the equipment, sub-systems, and systems being tested, and to use in developing commissioning and test procedures.

Organize O&M Manuals by each major system. Submit O&M Manuals in digital formats when permitted. For hard copies, submit O&M Manuals in three-ring binders.

All information included in the final O&M Manuals, including equipment schedules, manufacturer literature, and drawings, must represent the as-built condition of systems and equipment. Include all data concerning changes made during construction.

Each section must include the information required in the appropriate section of the specifications plus any additional information necessary for the owner’s personnel to successfully operate and maintain the systems and equipment covered in that section.

# 8. Training

Conduct comprehensive training for the owner’s operating and maintenance (O&M) personnel in the operation, maintenance, and troubleshooting of all commissioned systems and equipment. Ensure that training meets any requirements listed in the contract documents. Provide video/audio recording of the training as a record document and for use for future training.

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Interview the owner's O&M personnel to determine any special training needs, to verify areas in which training will be most valuable, and to determine how rigorous training should be for each piece of commissioned equipment.

In general, vendors should be responsible for providing training on their respective equipment.  Vendors should submit a written training plan for review and approval by the owner's representative and the CA prior to training.

Use approved O&M manuals as training resources whenever possible.

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*(This Annex is not a part of the Standard)*

# Annex A: Electrical Testing Procedures

## A.1 General

Perform electrical testing in accordance with test equipment manufacturer instructions. Use test equipment of suitable ratings and sensitivity. Follow 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 joints (tees, taps and 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 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.

## A.2 Vibration Monitoring

Use a vibration data collector with the following minimum requirements:

- 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 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.

## A.3 Contact Resistance

Inspect bolted electrical connections for high resistance using a low-resistance ohmmeter. Compare bolted connection resistances to values of similar connections. Microhm or millivolt drop values should not exceed the high levels of the normal range as indicated in manufacturer-published data. If manufacturer data is not available, investigate any values which deviate from similar connections by more than 50 percent of the lowest value.

## A.4 Infrared Scan

Perform infrared scanning in accordance with test equipment manufacturer instructions. Use an infrared scanning device designed to measure actual operating temperatures, or designed to detect significant deviations from surrounding conditions. Provide documentation of device calibration.

Provide supplemental barriers and safety precautions during infrared scanning to prevent accidental contact with exposed energized components. Use appropriate personal protective equipment (PPE).

De-energize equipment and conductors in accordance with established safety procedures. Remove accessible covers, plates, panels, weathershields, and doors of equipment, junction boxes, and pull boxes to reveal busing, conductors, terminations, joints, and other internal current-carrying components.

Energize equipment and conductors, and turn on all normal loads. Allow equipment and conductor to reach normal operating temperature.

Perform infrared scanning of all accessible current-carrying electrical components while conductors and equipment are energized and operating under normal to maximum load conditions, but not less than 40 percent of the rated capacity of the electrical equipment being inspected. *NOTE: Infrared scan results could be inconclusive if equipment and conductors are lightly loaded.*

Inspect distribution systems, equipment, and conductors with imaging equipment capable of detecting a minimum temperature difference of 1°C at 30°C. 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 scan. Include notations of deficiencies detected, causes of temperature differences, remedial actions taken, results from retesting after remedial actions, and inaccessible or unobservable areas and equipment. Maintain a permanent record of all infrared scan results to track electrical characteristics of equipment, conductors, terminations, and joints over time.

Temperature differences of 1°C to 3°C indicate possible deficiency and warrant investigation. Temperature differences of 4°C to 15°C indicate a deficiency; repair as time permits. Temperature differences of 16°C and above indicate a major deficiency that must be repaired immediately.

Consult equipment, conductor, termination, connector, accessories, and component manufacturers for repair or replacement recommendations if infrared scan results indicate overheating of components.

## A.5 Insulation Power 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.

Perform an insulation power factor test on each winding of transformers in accordance with the transformer manufacturer published data or the test equipment manufacturer published data. Correct results to 20°C in accordance with test equipment manufacturer instructions. Compare results obtained to manufacturer factory test results. If manufacturer data is not available, acceptance tests results will serve as the baseline data for future reference. Investigate power factor test values more than 3-percent for dry-type transformers.

Perform a power factor test on transformer bushings that are equipped with power factor taps, and perform hot collar watts-loss test on filled 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 transformers corrected to 20°C must be in accordance with transformer manufacturer published data. Compare with test equipment manufacturer published data. Investigate bushing power factors and capacitances that vary from nameplate values by more than ten percent. Investigate any bushing hot collar watts-loss results that exceed the test equipment manufacturer published data.

## A.6 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

## A.7 Breaker Timing

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

## A.8 Insulation Resistance Testing

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 5~~00~~,000V DC
- A short-circuit terminal current of a minimum of 2.5 milliamps

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 16ºC (60ºF) with a relative humidity of less than 60-percent. Do not perform insulation resistance tests during times of high relative humidity. When insulation resistance measurements are taken at other than 16ºC (60ºF), convert quantities to equivalent values at 16ºC (60ºF).

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 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.

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 300 V 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.

Measure insulation resistance at one minute 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 previous test results and with 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 previous test results under similar conditions by more than 50 percent of the lowest value.

Insulation resistance should not be less than 2 megohms for circuits under 115V, 6 megohms between conductor and ground for 115V to 600V circuits 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 low-voltage, air-insulated and insulated case circuit breakers, insulation resistance should not be less than fifty (50) megohms.

When insulation resistance measurements fall below the specified minimum values at 16ºC (60ºF), apply heat and dry equipment and conductors in accordance with manufacturer instructions, subject to the approval of the CA. If drying is to be done by applying an electric potential to the equipment, do not exceed the continuous voltage or current ratings of the equipment being dried, either directly or by induction.

### *A.8.1 Dielectric Absorption and Polarization Index*

Perform a dielectric absorption test for rotating machinery, motors and alternators, and dry-type transformers from winding to winding and winding to ground for ten minutes. Apply test voltage for 10

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minutes or more to develop the dielectric-absorption characteristic.

Plot insulation resistance against time to determine 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.

If facilities are not available for a 10-minute test, calculate the polarization index by taking insulation resistance readings at 30 and 60 seconds. The ratio of the 60-to-30-second or the 10-to-l-minute ratio will serve as an indication of the winding condition.

The dielectric absorption ratio or polarization index should be greater than 1.0 and should be recorded and maintained for future reference. For DC 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.

### A.9 High-Potential Acceptance Testing (DC High-Potential and Very Low Frequency (VLF) AC High-Potential Testing)

*NOTE: DC high-potential or overpotential testing can cause insulation failure and should be used with caution. Complete all insulation resistance testing prior to high-potential testing. Review insulation resistance test results to determine the suitability for high-potential testing. Do not perform DC high-potential tests until insulation-resistance levels are raised above minimum levels.*

Provide supplemental barriers and safety precautions during high-potential testing to prevent accidental contact with exposed energized components. Clean and dry equipment found in a wet or dirty condition before performing high-potential testing.

Humidity, wind, and surface conditions strongly affect the results of DC high-potential testing. Do not perform high-potential tests during times of high relative humidity. Follow manufacturer instructions for performing high-potential testing of equipment and conductors. Follow the test equipment manufacturer instructions. Use the lowest possible test voltages as recommended by the equipment or conductor manufacturer and the test equipment manufacturer.

Check the high-potential test set for proper operation. Ensure that the input voltage to the test set is regulated. Ensure that DC high-potential 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 equipment 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 high-potential testing. Repair or replace equipment and conductors that fail high-potential testing in accordance with manufacturer instructions. Repeat high-potential testing in its entirety for equipment and conductors that are repaired or replaced.

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### *A.9.1 DC High-Potential Testing*

Apply the test voltage slowly in a minimum of five equal increments until 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 1 to 2 minutes. See Table A.9.1 for the maximum recommended DC high-potential 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.

**Table A.9.1 Recommended Maximum Voltages for DC High-Potential Testing**

| 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 |

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 testing 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 high-potential test failures on cables with elastomeric insulation.*

At any step where the calculated leakage resistance decreases approximately 50 percent 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 high-potential tests to assure complete discharge, but not less than 30 minutes.

### *A.9.2 Very Low Frequency (VLF) AC High-Potential Testing*

Apply the test voltage for a minimum of 30 minutes. See Table A.9.2 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.

**Table A.9.2 Recommended Maximum Voltages for VLF AC High-Potential Testing**

| 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 |

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.

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 withstand tested is considered to have good insulation when no failure is detected during the withstand test and the percent standard deviation of Tan-Delta measurements at all test voltages is less than 0.02 (See Section A.10). Cable with a percent standard deviation of Tan-Delta measurements ~~is~~ greater than 0.02 should be tested further to determine the cause.

## A.10 Tan-Delta (Dissipation Factor) Testing Using Very Low Frequency (VLF) Test Set

*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.*

Perform Tan-Delta testing only on shielded cables. *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. Disconnect parallel conductors.

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-*

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*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 90º 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 90º.*

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 cable degradation of the overall cable.

Maintain a record of Tan-Delta measurements to track cable electrical characteristics over time.

### A.11 Partial Discharge Testing

Partial Discharge (PD) testing is used to detect physical damage of cables, terminations, and joints, 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 PD in the cable 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.

When partial discharges are identified, measure and record the Partial Discharge Inception Voltage (PDIV), or the voltage at which point the PD is initiated, and the PD Extinction Voltage (PDEV), or the lower voltage at which point the PD is extinguished, which will help in evaluating the overall condition of the cable, which is a subjective process open to interpretation.

*NOTE: One drawback to partial discharge testing is that one location of significant partial discharge can mask areas of lesser PD.*

Maintain a record of Partial Discharge test results to track cable electrical characteristics over time.

*(This Annex is not a 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 commissioning building electrical systems. The following publications may also provide useful information:

National Fire Protection Association
1 Batterymarch Park
Quincy, MA 021697471
(617) 7703000 tel
(617) 7703500 fax
*www.nfpa.org*

NFPA 702020, *National Electrical Code* (ANSI)

Institute of Electrical and Electronics Engineers
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 088551331
(732) 9810060 tel
(732) 9819667 fax
*www.ieee.org*

IEEE 432013, *Recommended Practice for Testing Insulation Resistance of Rotating Machinery*

InterNational Electrical Testing Association
3050 Old Centre Ave., Suite 102
Portage, MI 49024
(888) 300638 tel
(269) 8886382 tel
(269) 4886383 fax
*www.netaworld.org*

NETA ATS, Standard for Acceptance Testing Specification for Electric Power and Systems (ANSI)
NETA ECS, Standard for Electrical Commissioning Specifications for Electric Power Equipment and Systems
NETA ETT~~2018~~, *Standard for ~~the~~ Certification of Electrical Testing Technicians*
~~NETA ATS2013, *Standard for Acceptance Testing Specification for Electric Power and Systems (ANSI)*~~

National Electrical Contractors Association
3 Bethesda Metro Center, Suite 1100
Bethesda, MD 20814
(301) 6573110 tel
(301) 2154500 fax

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*www.necanet.org*

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