



IEEE Guide for the Commissioning of Electrical Systems in Hydroelectric Power Plants

IEEE Power and Energy Society

Developed by the
Energy Development and Power Generation Committee

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of the
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IEEE SA Standards Board

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Abstract: Inspection procedures and tests for use following the completion of the installation of components and systems through to commercial operation are provided. This guide is directed to plant owners, designers, and contractors involved in the commissioning of electrical systems of hydroelectric plants.

Keywords: commissioning, electrical systems, hydroelectric power plant, IEEE 1248, testing

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Introduction

This introduction is not part of IEEE Std 1248-2020, IEEE Guide for the Commissioning of Electrical Systems in Hydroelectric Power Plants.

This document is a guide for the commissioning of electrical equipment in a hydroelectric power plant. The document was prepared by the Working Group on Power Plant Commissioning of the Hydroelectric Subcommittee of the IEEE Energy Development and Power Generation Committee of the IEEE Power Engineering Society (PES).

The group was formed at the 1990 IEEE PES Summer Meeting to provide guidance in the commissioning of electrical equipment in a hydroelectric facility. The commissioning includes the installation of a new power plant, the rehabilitation of an existing power plant, or the upgrading of equipment in an existing power plant.

The group was reformed at the 2013 PES annual meeting to review and revise the guide for current technology and practices.

This guide is intended to be used as a reference document for practicing engineers in the hydroelectric industry.

The guide includes an index of systems, equipment, and tests that provide information on the checkout and commissioning of electrical equipment in a hydroelectric power plant.

Members of the working group represent a cross section of the hydroelectric industry, including power plant owners, designers, and equipment manufacturers.

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IEEE Guide for the Commissioning of

Electrical Systems in Hydroelectric

Power Plants

1. Overview

1.1 Scope

This guide describes tests performed and provides processes to be followed during the commissioning of electrical and control systems in hydroelectric plants. Guidance for methods to be used, organization, and execution of the testing are provided. While the guide does not provide prescriptive procedures that are plant and equipment specific, tests are described along with reference standards for more information. The commissioning of electrical equipment may be for a new hydroelectric plant installation; rehabilitation of an existing hydroelectric plant; or replacement and upgrade of existing electrical equipment.

1.2 Purpose

This guide is directed to hydroelectric ~~the~~ plant owners, operators, designers, and contractors involved in the commissioning of electrical equipment and systems of hydroelectric plants. This guide suggests inspections ~~inspection~~ and tests to be used following the completion of the installation of components and systems through ~~to~~ commercial operation. ~~This guide is influenced by general North American terminology and practice.~~ Minor adapptions ~~adaptation~~ may be required for particular corporate structures and philosophies.

1.3 Organization

1.2 Introduction

This guide was developed to assist engineers involved in the commissioning of electrical equipment in regard to [the following](#):

- Specific electrical equipment tests;~~and~~
- ~~The~~ Testing program for placing the equipment in operation~~;~~

The commissioning of electrical equipment may be for [the following](#):

- A new hydroelectric plant installation;
- Rehabilitation of an existing hydroelectric plant; or
- Replacement and upgrade of existing ~~electrical~~ equipment.

The guide describes the development of a startup organization, followed by a description of the commissioning phases of a hydropower plant. The principal information is contained in matrix format for each major type of electrical equipment, which identifies the various tests that are associated with the equipment. Information is provided for each specific test, including [the following](#):

- a) A brief description~~;~~
- b) Supporting documents~~;~~
- c) Equipment required~~;~~~~and~~
- d) Duration or time required~~;~~

Based on the above information, guidance is provided for planning, developing, and documenting a commissioning program.

This guide addresses conventional hydropower. Portions of the guide are relevant to pumped storage plants, but the unique features of pumped storage plants are not specifically addressed.

The guide also contains a bibliography of industry standards, recommended practices, and guides that may be used as resources by the engineer engaged in the commissioning of electrical equipment. The listing is intended to be an aid in preparing for a hydroelectric plant startup or a particular test. Review of relevant documents is encouraged.

2. References

All testing should be done in accordance with equipment specifications and contracts with reference to and in conjunction with pertinent industry standards. The latest revision of the standards and guides listed in Annex A should be used. A list of supporting documents, which includes both bibliographic items and general documents, is provided for each test in Clause 9 of this guide.

2. Normative references

This guide does not contain normative references. Informative references are listed in Annex A.

3. Definitions, ~~and~~ acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards*

Dictionary Online should be consulted for terms not defined in this clause.¹

commercial operation: The point in time where the equipment, unit, or station is accepted by the user for operation.

IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

construction testing: Performing required ~~inspections and~~ tests to ~~demonstrate~~ ensure that completed installations are in accordance with contract requirements and the latest engineering and design information.

lead test engineer: Engineer that provides overall direction to the commissioning program.

operational testing: All testing required to verify system operation in accordance with design requirements after the major components are ~~component is~~ energized or operated.

performance testing: Testing conducted to evaluate the compliance of a system or component with specified performance.

preoperational testing: All testing required for system components prior to energizing or operating the major system component.

pre-startup testing (dry testing): All testing required prior to rotating the generating unit under power (hydraulic or electrical) which are ~~is~~ unique to the unit and not associated with system testing.

startup testing(wet testing): Operation ~~All~~ testing of the generating unit from initial-powered rotation to verify suitability for operation.

subsystem verification: Verification ~~(system operational testing): Testing to verify~~ that all of the subsystems (i.e., excitation system, governor, protection, high pressure lubrication) ~~systems~~ required for a main generating unit startup have been tested and are ready for operation ~~operational~~.

system testing: Preoperational testing to verify components of the system, and operational testing to verify the coordination of the system components for proper design and operation of the system functions.

unit: The generator or generators, associated prime mover or movers, auxiliaries and energy supply or supplies that are normally operated together as a single source of electric power.

~~**3.1.9 turbine/generator testing:** Consists of four testing phases: sub-system verification, prestartup, startup, and performance testing.~~

3.2 Acronyms and abbreviations

~~BHP: brake horse power~~

CT current transformer

EMC electromagnetic compatibility

EMI/RFI electromagnetic interference/radio frequency [interference](#)

EUT equipment under test

LCI load commutating inverter

LTE lead test engineer

MCC motor control [center](#) ~~cubicle~~

NFPA National Fire Protection Association

O&M operations and maintenance

OEM original equipment manufacturer

PCB polychlorinated biphenyl

[PT](#) potential transformer or voltage transformer

~~PMG: permanent magnetic generator~~

~~RF: radio frequency~~

~~RPM: revolutions per minute~~

~~RTD: electronic digital type resistance temperature detector~~

~~SWC: surge withstand capability~~

THF: total harmonic factor

TIF: telephone influence factor

UPS uninterruptible power supply

VT voltage transformer or potential transformer

4. Commissioning planning, roles, and responsibilities

4.1 Planning

A commissioning plan should be prepared that defines the roles and responsibilities of all entities involved, outlines the various test procedures, and documents the commissioning results. The following commissioning plan outline is recommended:

- a) Administrative
- b) Construction testing phase
 - Electrical
 - Mechanical
 - Instrumentation
- c) Preoperational testing phase
- d) Operational testing phase
- e) Performance testing

4. Startup organization

4.1 General

Administrative procedures clarify the roles of all participants in the organization involved in the project commissioning ~~test~~ program. Once the role of these parties is identified, a plan for the turnover of equipment/systems from the construction/erection contractor(s) to the owner should be developed. Schedules of construction completion dates and all testing should be included with the administrative procedures. The commissioning ~~startup~~ organization described herein is based on the owner, engineer, and contractor having an active role in the ~~startup and~~ commissioning activities. The responsibility of the various entities may shift slightly depending on their contractual relationship. In general, the following description is a guide to those responsibilities.

Generic test procedures are typically prepared for ~~the contractors for~~ equipment testing during installation referred to as the construction testing phase. These generic procedures describe electrical, mechanical, and instrumentation verification that are discussed in Clause ~~Clauses~~ 7, Clause 8, and Clause 9. Data sheets should be included in the procedures to record test results and provide baseline data for later use when equipment maintenance is performed by the plant staff.

Preoperational test procedures are used during the preoperational testing phase that follows the construction testing phase. These procedures provide all tests and checks necessary to verify ~~ensure~~ that each plant system is functional before startup testing of the overall integrated plant commences. The purpose of the preoperational ~~these~~ procedures is to verify that each system performs in accordance with design requirements and is complete and safe to energize or operate.

Operational test ~~procedures are used during the final phase of the plant startup. These~~ procedures outline tests to be performed on the major plant systems and components such as turbine-generator, governor and controls, voltage regulator and excitation systems, relays and protection equipment, and the various modes of starting, loading, and stopping each unit. This phase should be coordinated with the vendor's representatives supplying major components and with the operating authority for the plant.

Hydroelectric unit operational testing is made up of pre-startup testing, or dry testing, and startup, or wet testing. Pre-startup testing are those tests to place the unit in service that are performed prior to water up of the unit. Startup testing are those tests after the unit is watered up through placing it in service.

Performance test procedures outline the tests to verify equipment performance meets manufacturer's stated guarantees and to quantify the initial baseline operational performance for future reference.

The typical role of the participants of the startup organization is described [in 4.2 through 4.5 below](#).

4.2 Owner

The owner is usually the operator and provides the operating and maintenance personnel that participate in the commissioning program. The owner's representative usually:

- Reviews administrative, construction, preoperational and operational programs, and schedules;
- Witnesses testing activities, as necessary, in support of the commissioning program;
- Provides coordination with offsite operating, dispatching, or interfacing agencies, as required;
- Conditionally accepts equipment and systems for operation during the preoperational testing phase;
- Accepts equipment, systems and facilities, subsequent to successful testing of these items, and provides final acceptance of the project
- Operates all permanent plant equipment to support the start-up schedule; ~~and~~
- Makes final decisions in areas of disputes relating to test activities performed during the test program

4.3 Contractor

[A](#) ~~The~~ contractor typically furnishes, installs, and tests the equipment and systems under the terms and conditions of the contract. [There may be multiple contractors performing work for different scopes of supply, installation, and testing.](#) Tests performed by [a](#) ~~the~~ contractor may be witnessed by the engineer or owner. The contractor usually:

- Performs construction and preoperational testing on contractor-furnished equipment and systems in accordance with test requirements contained within the contract;
- Performs construction testing on owner-furnished equipment in accordance with the contract;
- Records test data results during construction and preoperational testing, distributes to the engineer, and incorporates into the system turnover package;
- Implements tagging and work clearances on systems and equipment under the jurisdiction of the contractor in accordance with the commissioning program tagging procedure prior to turn over to the owner;
- Schedules completion of construction work and construction test activities to support the overall commissioning program;
- Provides the engineer with status of contractor-furnished equipment and systems deficiency list items; advises the engineer when turnover for preoperational testing will occur on contractor-furnished equipment and owner-furnished equipment;
- Provides [trade \(craft\)](#) personnel required during construction and preoperational testing by the contractor, and in support of preoperational and operational testing performed by the engineer;
- Participates in the development of schedules for all phases of the commissioning program;

- Provides system deficiency list with equipment turnover and resolves all deficiencies;~~and~~
- Notifies the engineer of any engineering or construction deficiencies that will not allow for proper testing and operation of any system~~;~~

4.4 Engineer

The engineer could be associated with the owner, contractor, or third party engineering firm. The roles described in 4.4.1 and 4.4.2 may be filled by one or more engineers.

4.4.1 Project design engineering

The project design engineer typically provides the design documents to install and test the equipment~~based on the manufacturer's recommendations~~. The engineer usually:

- Provides all engineering documents and information necessary for completion of construction and testing;~~and~~
- Furnishes engineers on-site to provide assistance on design and engineering problems~~;~~

4.4.2 Lead test engineer

The ~~engineer typically provides a~~ lead test engineer (LTE) has the ~~with~~ overall responsibility for coordinating and ensuring that construction, ~~the conduct of~~ pre-operational and operational testing of owner and/or contractor furnished equipment, and the operational testing of contractor furnished equipment are performed ~~under coordination of the owner~~.

The LTE should prepare the procedures required to implement the program and give final approval to these procedures prior to owner review and approval. These procedures should be incorporated into a commissioning manual. In addition, the LTE should

- Coordinate the need for vendor representatives during the operational testing phase~~;~~
- Work with the engineers and manufacturers to resolve design questions encountered during the commissioning program~~;~~

- Participate in the development of schedules for construction and preoperational testing of contractor-furnished equipment and systems;
- Develop, in conjunction with the owner, schedules for preoperational and operational testing of contractor-furnished equipment and systems;
- Review and accept ~~owner-furnished~~ equipment and systems that have been tested by the contractor in accordance with construction test procedures
- Verify ~~Perform~~ preoperational and operational testing of all ~~owner-furnished~~ equipment and systems are performed; ~~and~~
- Verify performance testing requirements are scheduled and performed

~~g) Perform operational testing of contractor-furnished equipment and systems.~~

The following test procedures are recommended:

~~—Administrative~~

~~—Electrical~~

~~—Mechanical~~

~~—Instrument~~

~~—Preoperational~~

~~—Operational~~

The LTE usually directs all activities to help ensure a smooth, effective commissioning program and is typically responsible for the overall conduct of the commissioning program for all project equipment and systems. The LTE usually has primary responsibility for scheduling and directing the efforts of those assigned to the performance of the commissioning activities. The LTE typically coordinates the interface activities of the contractor for construction and the owner's personnel required to accomplish the commissioning program.

4.5 Manufacturer/vendor

In addition to factory tests to be performed on manufacturer-furnished equipment, tests are typically performed during the installation phase in accordance with the contract. These tests are performed in support of the commissioning program and in keeping with the schedules for preoperational and operational testing.

Manufacturer/vendor representatives are involved during installation and testing to verify the equipment is properly installed and meets design and contract requirements. They may be involved in all four phases of the commissioning program. The responsibilities in each phase should be clearly identified in the contract. For example, during the construction phase their role may be to inspect or supervise the work of others. During the pre-operational and operational phases, they may be responsible for conducting certain tests on their own equipment.

Typical manufacturer tests include the following:

- Unit alignment;
- Rotational runout-checks;
- Rotor diameter measurement;
- Rotor roundness measurement;
- Stator bore diameter measurement;
- Stator roundness measurement;
- Airgap measurement;
- Bearing alignment and clearances;
- Verification of temperature devices;
- Current transformer polarity-checks;

- Braking system;
- Bearing oil lubrication system;
- Stator and rotor winding resistance measurements;
- Open circuit saturation test;
- Short-circuit test;
- Phase sequence test;
- Heat run;
- Overspeed tests; ~~and~~
- Load rejection tests.

5. Commissioning program phases

~~5.1 Commissioning program phases~~

The commissioning program is usually divided into the following four ~~three~~ phases: ~~the construction phase, the preoperational test phase, and the operational test phase.~~

- 1) Construction test phase
- 2) Preoperational test phase
- 3) Operational or startup test phase
- 4) Performance testing

5.1 Construction test phase

The construction contractor usually performs required inspections and tests to ~~demonstrate~~ ensure that completed installations are in accordance with contract requirements and the latest engineering and design information. The results of construction testing should be documented by the construction contractor and turned over with release of ~~the~~ equipment ~~for to the~~ preoperational testing ~~group~~. Construction testing generally includes electrical, mechanical, and instrumentation aspects as listed in 5.1.1 through 5.1.3.

5.1.1 Electrical

Examples of electrical aspects are as follows:

- Insulation resistance, partial discharge and high potential testing of electrical equipment and cables;
- Continuity tests to verify cable routing;
- Initial operation of motors uncoupled (phase rotation check);
- Inspection and testing of electrical equipment (transformers, motor control centers, ~~and~~ switchgear, etc.); ~~and~~
- ~~5) Verification of cable terminations in accordance with design documents.~~
- Insulation resistance testing of electrical equipment, to be done prior to terminations (power cables)
- Verification of cable terminations in accordance with design documents; ~~and~~
- Equipment grounding verification
- Tests to verify plant communications system and networks

5.1.2 Mechanical ~~(including piping)~~

Examples of mechanical aspects are as follows:

- Pressure ~~Hydrostatic~~ testing of piping systems;
- Mechanical equipment alignment;
- Initial lubrication of mechanical equipment;
- Tank, cleaning and pipe, tube and duct ~~piping~~ cleaning (flushing);
- Inspection of mechanical equipment and piping systems; ~~and~~

~~6) —Mechanical test procedures implementation.~~

5.1.3 Instrumentation

Examples of instrumentation aspects are as follows:

- Testing of pneumatic instrument lines for leaks;
- Verification of proper grounding of shielded cables;
- Inspection of instrumentation and installation of instrumentation in accordance with design documents;
- Calibration and setting of instruments and dedicated controllers
- Continuity tests to verify cable routing;
- Verification of cable terminations in accordance with design documents

~~6) —Instrument test procedures implementation.~~

5.2 Preoperational test phase

Preoperational testing generally includes, but is not limited to, [the following](#):

- [Final](#) checkout of electric motors;
- Checkout of motor operated valves, dampers, and gates;
- Checkout and verification of electrical control circuitry [and software](#), through functional testing;
- Calibration of electrical relays and meters;
- [Verification of operator interface, control system programming, function and input/outputs](#)
- Checkout and trip check tests of switchgear, motor control centers, and molded case breakers;
- Flushing of mechanical systems/subsystems;
- Blow down of station/instrument air lines;
- [Verification of proper lubrication of generator and turbine bearings](#)
- Verification of instrument calibration;
- Loop calibration of all instrument loops;
- Functional loop checkout of all instrument loops;
- Preoperational testing in accordance with approved preoperational test procedures;
- Vendor testing of supplied equipment and systems;
- Vibration testing of driven equipment;
- Visual inspection of all systems and equipment; ~~and~~
- Verification of polarity and integrity of instrument transformer [circuit](#) ~~circuits~~.

- Functional tests of auxiliary systems and equipment

5.3 Operational test phase

Operational testing is of complete systems to ensure systems and subsystems work together as intended.

5.3.1 Electrical system operational testing

Operational testing of electrical systems generally consists of energization and placing the equipment in service. It may include tests for breaker and protection coordination, operating temperature, and power quality.

5.3.2 Unit operational testing

Operational testing of the turbine-generator unit generally includes, but is not limited to, the following:

~~Operational testing generally includes but is not limited to~~

- Hydraulic operation of spiral case shut-off valves and proper setting of closing and opening times;
- Wicket gate or nozzle alignment and verification of proper opening and closing times;
- Governor control setting verification;
- Verification of proper lubrication and cooling of generator and turbine bearings;
- Final check of unit braking system;
- Initial operation of the turbine-generator and bearing run in;
- Electrical and mechanical overspeed trip tests;
- Final setting of vibration shutdown sensors;

- Voltage regulator and excitation system tests;
- Verification of proper generator to system phase rotation and synchronization;
- Testing and verification of electrical protection systems with load;
- Load rejection tests;

~~m) Performance runs at prescribed loads;~~

- Operation and monitoring via plant control systems (local and remote); ~~and~~

Coordinated testing with all plant units.

5.4 Performance testing

Performance testing are those tests done to demonstrate the performance of a system or equipment.

- Unit, and generator efficiency
- Power-gate relationship
- Performance runs at prescribed loads
- Turbine index testing
- Testing to develop and validate electrical system models for the following:
 - 1) Turbine governor
 - 2) Exciter
 - 3) Power system stabilizer
- Generator temperature rise test

6. Commissioning implementation

6.1 General

Throughout the construction and installation of the plant systems, construction supervisors and engineers should perform the necessary inspections to ensure that completed installations are in accordance with the latest engineering and design information.

6.2 Construction completion phase

During the construction phase, the construction contractor usually performs required inspections and tests. The results of construction testing should be documented by the construction contractor and turned over with release of equipment to the preoperational test group.

6.2.1 Electrical

All electrical equipment should be installed in accordance with design documents. Testing during the construction phase should, at a minimum, include the tests listed in ~~a) of~~ 5.1.1.

6.2.2 Mechanical

All mechanical equipment and piping should be installed in accordance with design documents. Testing during the construction phase should, at a minimum, include the tests listed in ~~b) of~~ 5.1.2 ~~1~~. Final coupling alignment of rotating equipment should be performed after startup engineers have operated the associated equipment satisfactorily. All equipment lubrication should be done during this construction phase before turnover. The lubrication and alignment forms attached to this procedure should be used to record the applicable data. Rotating equipment operational problem corrective actions should be the responsibility of the construction group.

6.2.3 Piping

~~All piping should be installed in accordance with design documents. Testing during the construction phase should, at a minimum, include the piping system tests listed in b) of 5.1.1. Piping changes that are required should be completed by the contractor.~~

6.2.3 Instrumentation

All instrumentation devices and piping should be installed in accordance with design documents. Testing during the construction phase should, at a minimum, include those instrumentation system tests listed in ~~c) of 5.1.3~~ 4. Instrumentation changes that are required should be completed by the contractor.

6.3 Preoperational testing phase

The LTE and staff should supervise the checkout and testing during this phase. They should ensure that tests performed during this phase of the commissioning are conducted in accordance with approved procedures prior to commencing with the next phase, which is operational testing.

6.3.1 Electrical

All system preoperational testing should be done during this phase by the construction contractor and should include, at a minimum, those electrical system tests listed in ~~5.1.2~~. During verification of the control system and control circuitry, drawings should be marked to indicate checkout is complete.

6.3.2 Mechanical

~~All mechanical equipment should be checked and tested by the construction contractor and should, at a minimum, include those mechanical system tests listed in 5.1.2.~~

6.3.3 Piping

All [mechanical equipment and](#) piping should be checked ~~out~~ and tested by the construction contractor and should, at a minimum, include those [mechanical piping](#) system tests listed in 5.1.2.

6.3.3 Instrumentation

All final instrument calibration and testing should be done during this phase and should, at a minimum, include those instrumentation system tests listed in 5.1.2. Loop checkout includes checking each loop from the field device to the control board or final control device. This is normally done by the startup group's instrument test technician.

6.4 [Operational testing phase and](#) unit startup ~~and operational phase~~

The operational [testing phase and](#) ~~The unit startup and operational phase~~ should be accomplished by the LTE, the owner's plant organization, and the vendors' representatives necessary to [demonstrate](#) ~~ensure~~ satisfactory operation of the equipment being [commissioned](#) ~~commissioned~~. This phase includes all tests and checks that are necessary to [facilitate](#) ~~ensure~~ satisfactory station commercial operation ~~(see 5.1.3)~~. This phase should include placing all systems in operation and ultimately operating the unit being commissioned at full load. [Operational testing also includes tests performed to demonstrate the operational performance of the turbine-generator unit.](#)

The unit startup and operational phase should be coordinated by the LTE and the owner's representative. Support services are normally arranged according to the following procedures:

- Contractors normally provide [trade](#) ~~craft~~ labor as requested by the LTE in support of construction and pre-operational activities.
- The owner normally provides operations and maintenance (O&M) personnel to support the startup preoperational and operational activities.
- Construction contractors requiring vendor service support should coordinate their requests with the LTE.

- The LTE should help ensure operational testing of contractor-furnished equipment and systems are performed.

The LTE usually directs all activities to ensure a smooth, effective commissioning program and is typically responsible for the overall conduct of the commissioning program for all project equipment and systems. The LTE usually has primary responsibility for scheduling and directing the efforts of those assigned to the performance of the commissioning activities. The LTE typically coordinates the interface activities of the contractor for construction and the owner's personnel required to accomplish the commissioning program.

- ~~d) The LTE normally has responsibility for determining vendor service support required for startup.~~

~~Results of operational testing are reviewed by the owner's representative, and if acceptable, the unit is declared commercially operational and turned over for normal operation. The warranty period for the major plant components usually begins at this time.~~

6.5 Performance testing

Performance testing should be accomplished by the LTE, the owner's plant organization, and the vendors' representatives necessary to demonstrate performance of the equipment, systems, and unit.

The performance tests should be coordinated by the LTE, plant operations and the owner's representative. Support services are normally arranged according to the following procedures:

- The owner or contractors normally provide trade labor in support of performance testing.
- The owner normally provides operations and maintenance (O&M) personnel to support the startup preoperational and operational activities.

7. Application of this guide

7.1 General

This clause provides a method for preparing and executing the commissioning of electrical and other major systems in a hydroelectric plant.

Clause 8 identifies the equipment and systems in a hydroelectric facility in a matrix format. Each matrix lists all tests that are typically performed on a particular piece of equipment or system to verify its readiness for operation. This information along with Clause 9, which provides a brief description of each test, are the keys for planning commissioning activities. Using the matrices and test descriptions, an engineer should be able to identify and schedule the required tests for installing, checking, and verifying operational status of electrical equipment in the plant.

Typically, the LTE and contractors develop a schedule for the design, delivery, and installation of equipment that will ultimately be commissioned in the plant. When the design is completed and the equipment purchased, necessary information becomes available for developing test procedures used for the installation checkout and operational verification. An equipment test schedule should be developed in conjunction with the construction schedule for equipment and system installation. Once the equipment and systems are identified, the matrices in Clause 8 list suggested tests to be performed on various systems and equipment.

7.2 Using this guide to develop a test program

After the equipment and systems that are to be commissioned are identified, the material in [Clause 8](#) and [Clause 9](#) is then applied to develop the test program. An example of a simple application is used to illustrate the process.

The example assumes that the existing unit exciters in the plant have been replaced with new bus fed static excitation systems. The test matrix for a static excitation system (~~see 8.1. 18 17~~) is used to develop a test schedule and test procedure to commission the new excitation systems. [An example](#) ~~The test matrix from 8.1.17~~ is reproduced in Figure 1 with key components of the matrix highlighted. An examination of the matrix shows major components of the static excitation system listed under the column titled "Equipment/system." The major components for the static excitation system include the air cooling system, the rectifier bridge, the water cooling system (if employed), the field breaker/leads, the controls, and the excitation transformer. Also included on the matrix are a number of specialized tests used for verifying the readiness of the component or subsystem for operation. For example, the [control](#) ~~controls~~ system is highlighted in Figure 1 and shows marks that are placed in the test columns for visual inspection, circuitry checkout, and functional checks indicating that these tests are recommended for verifying that the controls of the excitation system are ready for operation. Descriptions of the specific tests listed for checkout of the controls of the excitation systems are contained in Clause 9.

8.1.18 EXCITATION SYSTEMS		Recommended Tests for Static Excitation System											
TEST	Visual inspection	High potential	Circuitry checkout	Load testing	Temperature rise	Harmonic distortion	DC winding resistance	Insulation resistance	Functional checks	Initial operation			
Rotating excitation system										X			
Permanent magnetic generator (PMG) pilot	X			X		X	X	X					
Rotating dc shunt exciter	X			X		X	X	X					
Commutator and brushes	X						X		X				
Three-phase ac/dc exciter	X			X		X	X	X					
Rectifier bridge	X			X				X					
Air cooling system	X	X	X	X				X					
Water cooling circuits	X	X	X	X				X					
Field breaker/leads	X	X	X					X					
Controls	X		X					X					
Static excitation system					X				X				
Rectifier bridge	X			X				X					
Air cooling system	X	X	X	X				X					
Water cooling system	X	X	X	X				X					
Field breaker/leads	X	X	X					X					
Controls	X		X					X					
Excitation transformer ¹	X			X		X	X						
Sliprings and brushes	X						X		X				

(New)

Recommended tests
Static excitation
Systems controls

**8.1.17
EXCITATION SYSTEMS**

EQUIPMENT/SYSTEM	Test	Visual inspection	High potential	Circuit checkout	Leak testing	Temperature rise	Harmonic distortion	DC winding resistance	Insulation resistance	Functional checks	Initial operation
Rotating excitation system											X
Three-phase ac/dc exciter		X				X		X	X	X	
Rectifier bridge		X				X				X	
Air cooling system		X		X	X	X				X	
Water cooling circuits		X		X	X	X				X	
Field breaker/leads		X	X	X						X	
Controls		X		X						X	
Static excitation system							X				X
Rectifier bridge		X				X				X	
Air cooling system		X		X	X	X				X	
Water cooling system		X		X	X	X				X	
Field breaker/leads		X	X	X						X	
Controls		X		X						X	
Excitation transformer		X				X		X	X		

Equipment components, static excitation system
"X" means recommended test for component

(Deleted)

Figure 1—Example of equipment test matrix

One of the specific tests to be performed on the control system for the static excitation system, the visual inspection test ~~(see 9.1.82)~~ is reproduced in Figure 2 with key elements of the test highlighted.

9.2.36 Visual inspection – All Equipment

9.2.36.1 Description of test

This test covers all equipment in a hydroelectric facility and associated switchyards. All inspections should be conducted by knowledgeable personnel experienced with the type of equipment installed and conducted in strict compliance with proper safety procedures.

Test
Description

This test should be conducted both as a prestart test and during initial operation. The purpose of the test is to visually and audibly inspect the equipment and to ensure that there are no abnormalities in the performance of the equipment that could indicate improper functioning or incipient equipment failure. The following should be verified by visual/audible inspection:

- a) Equipment is clear of all debris and foreign material, especially metal pieces accumulated during the installation.
- b) Shipping blocks and bracing are removed.
- c) Equipment and components are clean inside and outside.
- d) All electrical and mechanical connections are tight.
- e) Unterminated wiring is insulated and stored out of the way.
- f) Fuses are of proper class and rating.
- g) Look for missing or broken parts and insulation or bushing cracks or tracking.
- h) Check wiring for insulation cracks, bushings for cracks or tracking.
- i) Permanent grounding connections are in place.
- j) Evidence of moisture on insulating and conducting parts.
- k) Leakage in water, oil, gas, or air systems.
- l) Integrity of mechanical interlocks and padlocking mechanisms.
- m) Safe access to equipment.
- n) Abnormal temperatures after the equipment is energized.
- o) Abnormal noises when equipment is in operation.
- p) Installation is complete according to installation and manufacturer's drawings and instructions.
- q) Equipment nameplate ratings are in agreement with schematic diagrams.

9.2.36.2 Supporting documents

Test
References

The reader is referred to the Q&M manuals furnished with the equipment and all schematic drawings of the installation. These provide the necessary verifications and observations to be made during visual inspections. Past experience is highly valued in this process.

9.2.36.3 Equipment required

Special Test
Equipment
Required

Additional equipment is not usually required other than that used for calibration. The necessary indicators or readouts are furnished with the equipment system.

9.2.36.4 Duration/work required

Resource/time
requirements

The duration is variable depending on the size and complexity of the equipment or system. It can vary from minutes for a single piece of equipment to days for large systems. The work effort reflects the same variance for the same reason.

(New)

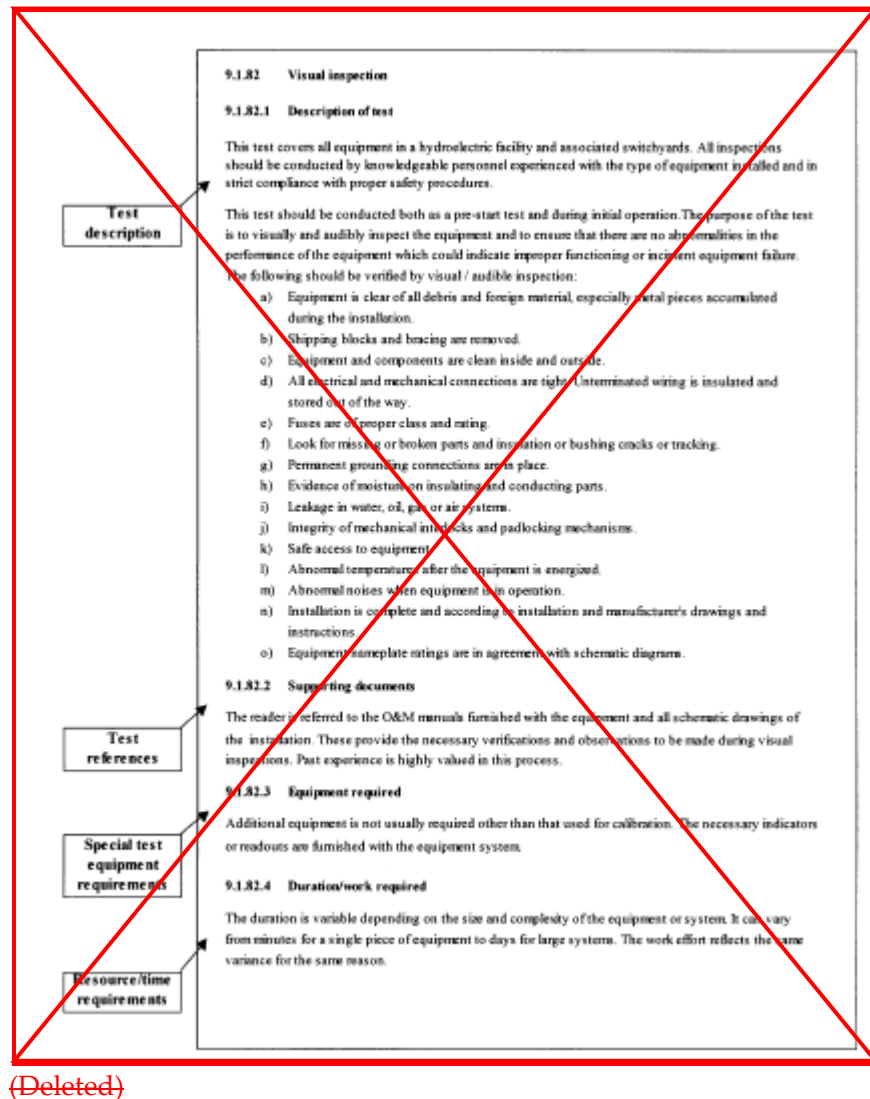


Figure 2— Example of a test description

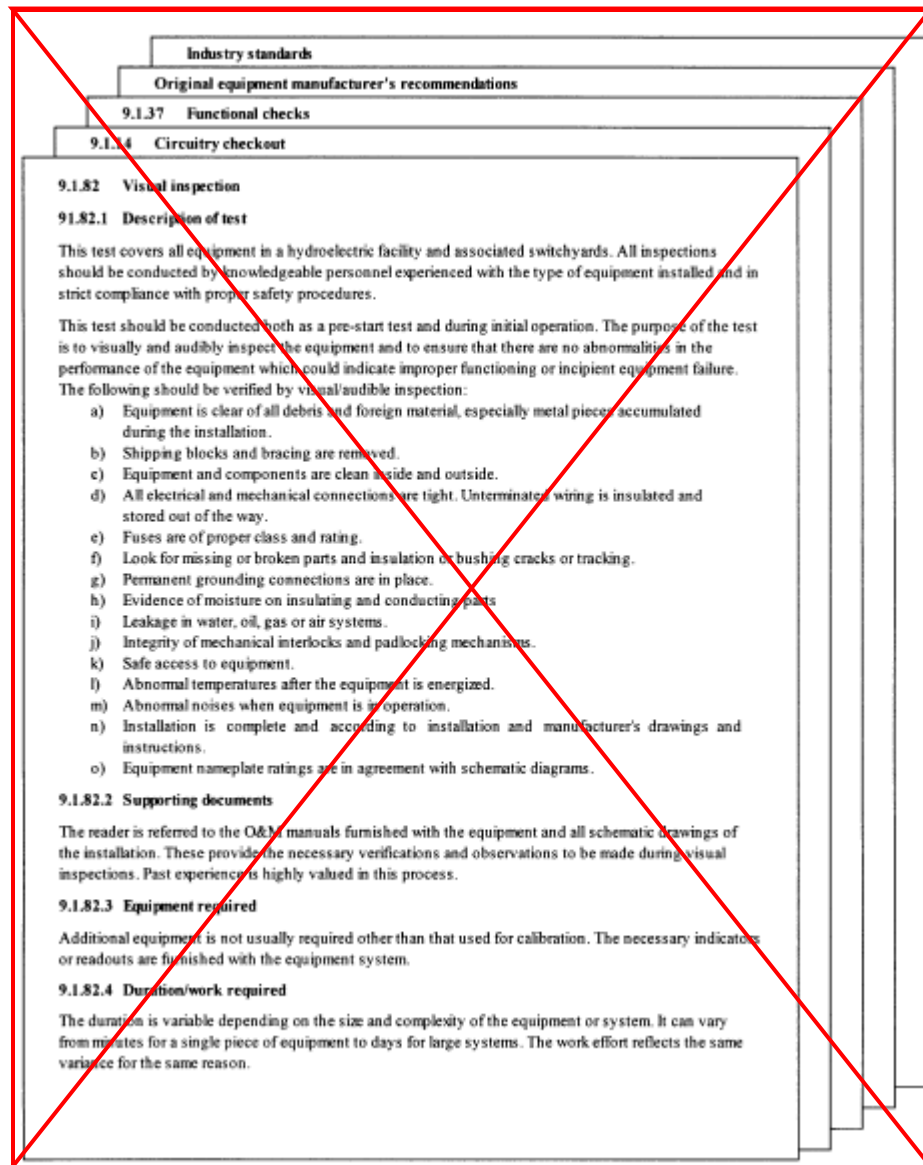
As can be seen, information about the test provides specifics on the description of the test, test references, equipment required, and the time required to perform the test. It was compiled by extracting the test descriptions from Clause 9 that correspond to the specific tests noted on the equipment matrix and appending any equipment supplier recommendations and industry standard procedures associated with the specific equipment.

The information in ~~Clause~~[9.2.36.1](#) briefly describes the test requirements. Supplemental information may be required to completely describe the test requirements. The supplemental information may include the original equipment manufacturers' (OEM) recommendations or other industry standards. All tests checked in the test matrix should be performed to verify the readiness of the controls of the excitation system for operation.

A set of tests or a "test package" as shown in Figure 3 is recommended for use by test personnel to verify operational readiness of the controls of the excitation system. Similarly, "test packages" are developed for each of the other elements comprising the static excitation system. By combining the requirements of each of these test packages for the various elements of the static excitation system, the engineer should be able to develop a comprehensive test procedure for the entire system, have knowledge of special test equipment and resources required for the entire checkout, and be able to develop an accurate estimate of the time required to conduct the excitation system checkout.

Industry standards
Original manufacturers' recommendations
9.2.16 Functional checks - Equipment
9.2.6 Circuitry checkout - Control Circuits
9.2.36 Visual inspection - All Equipment 9.2.36.1 Description of test This test covers all equipment in a hydroelectric facility and associated switchyards. All inspections should be conducted by knowledgeable personnel experienced with the type of equipment installed and conducted in strict compliance with proper safety procedures. This test should be conducted both as a prestart test and during initial operation. The purpose of the test is to visually and audibly inspect the equipment and to ensure that there are no abnormalities in the performance of the equipment that could indicate improper functioning or incipient equipment failure. The following should be verified by visual/audible inspection: a) Equipment is clear of all debris and foreign material, especially metal pieces accumulated during the installation. b) Shipping blocks and bracing are removed. c) Equipment and components are clean inside and outside. d) All electrical and mechanical connections are tight. e) Unterminated wiring is insulated and stored out of the way. f) Fuses are of proper class and rating. g) Look for missing or broken parts and insulation or bushing cracks or tracking. h) Check wiring for insulation cracks, bushings for cracks or tracking. i) Permanent grounding connections are in place. j) Evidence of moisture on insulating and conducting parts. k) Leakage in water, oil, gas, or air systems. l) Integrity of mechanical interlocks and padlocking mechanisms. m) Safe access to equipment. n) Abnormal temperatures after the equipment is energized. o) Abnormal noises when equipment is in operation. p) Installation is complete according to installation and manufacturer's drawings and instructions. q) Equipment nameplate ratings are in agreement with schematic diagrams. 9.2.36.2 Supporting documents The reader is referred to the O&M manuals furnished with the equipment and all schematic drawings of the installation. These provide the necessary verifications and observations to be made during visual inspections. Past experience is highly valued in this process. 9.2.36.3 Equipment required Additional equipment is not usually required other than that used for calibration. The necessary indicators or readouts are furnished with the equipment system. 9.2.36.4 Duration/work required The duration is variable depending on the size and complexity of the equipment or system. It can vary from minutes for a single piece of equipment to days for large systems. The work effort reflects the same variance for the same reason.

(New)



(Deleted)

Figure 3—Test package, excitation system control

7.3 Coordinating commissioning tests of systems and units

Using all of the appropriate test descriptions, a complete testing program can be developed to commission the electrical systems. Once the station and unit systems are tested and verified for operation, the commissioning of a unit may begin. Refer to Figure 4 as a guide for developing a plant-specific commissioning program. A hydroelectric unit includes the turbine/generator and all support equipment for operating the units and delivering the electrical power to the utility system. [Unit testing follows the sequence of four testing phases: sub-system verification, pre-startup, startup, and performance testing.](#) The tests for unit startup are included with the turbine and generator equipment matrices.

Commissioning overview			
Application table for commissioning electrical systems			
Equipment testing leads to Support Ssystem Testing to Major System Testing to Unit Operation			
Equipment	Support Systems	Major System	Operation
AC POWER-Low and medium voltage	ANCILLARY SYSTEMS	EXCITATION SYSTEMS CONVERTERS GENERATOR GENERATOR SWITCHGEAR TERMINAL EQUIPMENT GOVERNOR HIGH VOLTAGE SWITCHGEAR HYDRAULIC TURBINE INSTRUMENTATION & CONTROL TRANSFORMERS	UNIT STARTUP
AC POWER-Motor control centers (600 V class)			
AC POWER-Distribution panels (600 V class)			
CABLING			
CATHODIC PROTECTION			
COMPRESSED AIR			
CONTROL SYSTEM - DIGITAL			
CRANES			
DC POWER—Batteries			
DC POWER—Chargers			
DC POWER—Distribution panel			
DRAINAGE/UNWATERING			
ELEVATORS			
EMERGENCY POWER—UPS			
EMERGENCY POWER—UPS distribution panel			
EMERGENCY POWER—Diesel generators			
FLOW MONITORING			
GREASING			
GROUNDING			
HEATING, VENTILATION, AND AIR CONDITIONING			
HYDRAULIC SYSTEMS			
LCI/CYCLOCONVERTER/AC Exit			
LEVEL DETECTORS			
LIGHTING			
LUBE OIL			
POTABLE WATER			
POWERHOUSE COMMUNICATION			
SANITARY WASTE			
SERVICE WATER			
WASTE OIL STORAGE			
ENVIRONMENTAL	SAFETY/ PROTECTION SYSTEMS		
FIRE DETECTION			
FIRE PROTECTION—CO ₂ /Gasses			
FIRE PROTECTION—Water			
PENSTOCK RUPTURE MONITORING			
PROTECTIVE RELAYING			
SEISMIC MONITORING			
SPILLWAY CONTROL			

(New)

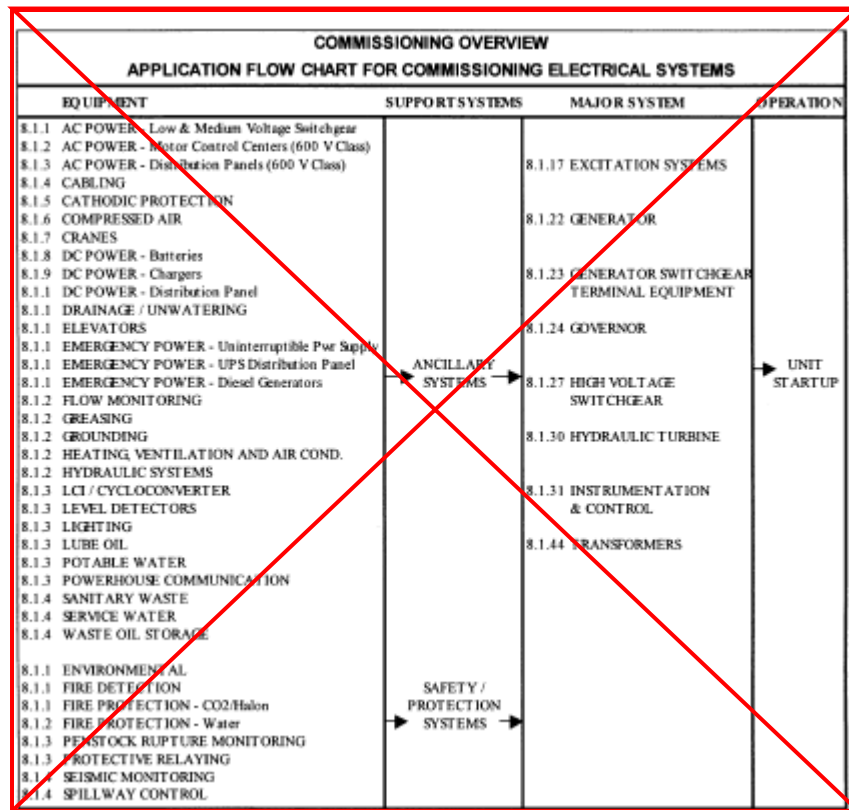


Figure 4—Development of a plant commissioning program

8. Plant equipment

8.1 List of equipment and test matrixes

[This subclause contains the tables for testing discussed in Clause 7.](#)

- 8.1.1. AC POWER-Low and medium voltage switchgear
- 8.1.2. AC POWER-Motor control centers (600 V class)
- 8.1.3. AC POWER-Distribution panels (600 V class)
- 8.1.4. CABLING

8.1.5. CATHODIC PROTECTION

8.1.6. COMPRESSED AIR

8.1.7. CONTROL SYSTEM

8.1.8. CRANES

8.1.9. DC POWER—Batteries

8.1.10. DC POWER—Chargers

8.1.11. DC POWER—Distribution panel

8.1.12. DRAINAGE/UNWATERING

8.1.13. ELEVATORS

8.1.14. EMERGENCY POWER—Uninterruptible power supply (UPS)

8.1.15. EMERGENCY POWER—UPS distribution panel

8.1.16. EMERGENCY POWER—Diesel generators

8.1.17. ENVIRONMENTAL

8.1.18. EXCITATION SYSTEMS

8.1.19. FIRE DETECTION

8.1.20. FIRE PROTECTION—CO₂/[Gasses](#) ~~Halon~~

8.1.21. FIRE PROTECTION—Water

8.1.22. FLOW MONITORING

8.1.23. GENERATOR

8.1.24. GENERATOR SWITCHGEAR/TERMINAL EQUIPMENT

- 8.1.25. GOVERNOR
- 8.1.26. GREASING
- 8.1.27. GROUNDING
- 8.1.28. HIGH-VOLTAGE SWITCHGEAR
- 8.1.29. HEATING, VENTILATION, AND AIR CONDITIONING
- 8.1.30. HYDRAULIC SYSTEMS
- 8.1.31. HYDRAULIC TURBINE
- 8.1.32. INSTRUMENTATION AND CONTROL
- 8.1.33. LOAD COMMUTATING INVERTER/CYCLOCONVERTER
- 8.1.34. LEVEL DETECTORS
- 8.1.35. LIGHTING
- 8.1.36. LUBE OIL
- [8.1.37. PARTIAL DISCHARGE MONITORING](#)
- 8.1.38. PENSTOCK RUPTURE MONITORING
- 8.1.39. POTABLE WATER
- 8.1.40. POWERHOUSE COMMUNICATION
- 8.1.41. PROTECTIVE RELAYING
- 8.1.42. SANITARY WASTE
- [8.1.43. SECURITY, PHYSICAL](#)
- 8.1.44. SEISMIC MONITORING

- 8.1.45. SERVICE WATER
- 8.1.46. SPILLWAY CONTROL
- 8.1.47. TRANSFORMERS
- 8.1.48. WASTE OIL STORAGE

^aFor transformer refer to the table in 8.1.44.

^aThe telephone influence factor test is no longer relevant for use with modern telephone systems.

8.1.1 AC POWER Medium- and low-voltage switchgear																
TEST	Visual inspection	Bolted joint torque	Insulation resistance	Continuity checks	High potential/VLF	Polarity (ac)	Ratios	Phase relation	Circuitry checkout	Calibration	Bus transfer	Contact resistance	Functional checks	Instrument transformer burden	Current transformer (CT) saturation	Initial operation
System											X				X	
Switchgear cubicle	X															
Circuit breakers	X		X									X	X			
Vacuum interrupter	X				X											
SF6 interrupter	X				X											
Arc chutes	X															
Current transformers	X		X	X		X	X	X	X					X	X	
Potential transformers	X		X	X		X	X	X	X					X		
Power cable	X		X	X	X			X								
Control cable	X		X	X												
Bus bar	X	X	X	X	X			X								
Meters	X								X	X			X			
Relays	X								X	X			X			
Instruments	X								X	X			X			
Control switches	X								X				X			
Selector switches	X							X	X				X			
Synchronizing panel	X							X	X				X			
Ground cable	X	X														
Fuses	X			X					X							
Power cable lugs	X	X	X													
Surge protectors	X		X					X								
Ground sensors	X			X					X				X			
Circuit interrupter	X											X				

(New)

~~(Deleted)~~

8.1.2 AC POWER Motor control centers (MCCs) (600 V class)													
TEST	Visual inspection	Bolted joint torque	Insulation resistance	Continuity checks	Polarity (ac)	Ratios	Phase relation	Circuitry check out	Calibration	Functional checks	Instrument transformer burden	CT saturation	Initial operation
System													X
MCC cubicle	X												
Circuit breakers	X		X							X			
Disconnect switches	X		X				X			X			
Transfer switches	X		X	X			X	X		X			
Current transformers	X		X	X	X	X	X	X			X	X	
Potential transformers	X		X	X	X	X	X	X			X		
Power cable	X		X	X			X						
Control cable	X		X	X									
Bus bar	X	X		X			X						
Meters	X							X	X	X			
Relays	X							X	X	X			
Ground sensors	X			X			X	X		X			
Motor starters	X						X	X		X			
Ground cable	X	X											
Fuses	X							X					
Overload devices	X							X		X			

(New)