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

Sponsor

Energy Development and Power Generation Committee of the IEEE Power Engineering Society

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Abstract: Inspection proceedures 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 the plant owners, designers, and contractors involved in the commissioning of electrical systems of hydroelectric plants.
Keywords: commissioning, hydroelectric power plant

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Introduction

(This introduction is not part of IEEE Std 1248-1998, 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 Powerplant Commissioning of the Hydroelectric Subcommittee of the IEEE Energy Development and Power Generation Committee of the IEEE PowerEngineering 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.

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 is directed to the plant owners, designers, and contractors involved in the commissioning of electrical systems of hydroelectric plants. This guide suggests 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 adaptation may be required for particular corporate structures and philosophies.

1.2 Introduction

This guide was developed to assist engineers involved in the commissioning of electrical equipment in regard to

— Specific electrical equipment tests; and

— The testing program for placing the equipment in operation.

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.

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

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.

3. Definitions and acronyms

3.1 Definitions

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

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

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

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

3.1.5 prestartup testing: All testing required prior to rotating the generating unit under power (hydraulic or electrical) which is unique to the unit and not associated with system testing.

3.1.6 startup testing: All testing of the generating unit from initial-powered rotation to verify suitability for operation.

3.1.7 subsystem verification (system operational testing): Testing to verify that all of the systems required for a main generating unit startup have been tested and are operational.

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

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

EUT: equipment under test

LCI: load commutating inverter

LTE: lead test engineer

MCC: motor control cubicle

NFPA: National Fire Protection Association

O&M: operations and maintenance

OEM: original equipment manufacturer

PCB: polychlorinated biphenyl

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

4. Startup organization

4.1 General

Administrative procedures clarify the roles of all participants in the organization involved in the project test program. Once the role of these parties is identified, a plan for the turnover of equipment/systems from the contractor to the owner should be developed. Schedules of construction completion dates and all testing should be included with the administrative procedures. The 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 Clauses 7, 8, and 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 ensure that each plant system is functional before startup testing of the overall integrated plant commences. The purpose of these procedures is to verify that each system performs in accordance with design requirements.

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.

The typical role of the participants of the startup organization is described 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

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

4.3 Contractor

The contractor typically furnishes, installs, and tests the equipment and systems under the terms and conditions of the contract. Tests performed by the contractor may be witnessed by the engineer or owner. The contractor usually

a) Performs construction and preoperational testing on contractor-furnished equipment and systems in accordance with test requirements contained within the contract;
b) Performs construction testing on owner-furnished equipment in accordance with the contract;

c) Records test data results during construction and preoperational testing, distributes to the engineer, and incorporates into the system turnover package;

d) 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;

e) Schedules completion of construction work and construction test activities to support the overall commissioning program;

f) 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;

g) Provides craft personnel required during construction and preoperational testing by the contractor, and in support of preoperational and operational testing performed by the engineer;

h) Participates in the development of schedules for all phases of the commissioning program;

i) Provides system deficiency list with equipment turnover and resolves all deficiencies; and

j) Notifies the engineer of any engineering or construction deficiencies that will not allow for proper testing and operation of any system.

4.4 Engineer

4.4.1 Project engineering

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

a) Provides all engineering documents and information necessary for completion of construction and testing; and

b) 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) with overall responsibility for the conduct of preoperational and operational testing of owner-furnished equipment and the operational testing of contractor-furnished equipment 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

a) Coordinate the need for vendor representatives during the operational testing phase;

b) Resolve design questions encountered during the commissioning program;

c) Participate in the development of schedules for construction and preoperational testing of contractor-furnished equipment and systems;

d) Develop, in conjunction with the owner, schedules for preoperational and operational testing of contractor-furnished equipment and systems;

e) Accept owner-furnished equipment and systems that have been tested by the contractor in accordance with construction test procedures;

f) Perform preoperational and operational testing of owner-furnished equipment and systems; and

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 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. Typical manufacturer tests include

a) Unit alignment;
b) Rotational runout checks;
c) Rotor diameter measurement;
d) Rotor roundness measurement;
e) Stator bore diameter measurement;
f) Stator roundness measurement;
g) Airgap measurement;
h) Bearing alignment and clearances;
i) Verification of temperature devices;
j) Current transformer polarity checks;
k) Braking system;
l) Bearing oil lubrication system;
m) Stator and rotor winding resistance measurements;
n) Open circuit saturation test;
o) Short-circuit test;
p) Phase sequence test;
q) Heat run;
r) Overspeed tests; and
s) Load rejection tests.

5. Commissioning program

5.1 Commissioning program phases

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

5.1.1 Construction test phase

The construction contractor usually performs required inspections and tests to 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 equipment to the preoperational testing group. Construction testing generally includes

a) Electrical
   1) Insulation resistance testing of electrical equipment and cables;
   2) Continuity tests to verify cable routing;
   3) Initial operation of motors uncoupled (phase rotation check);
   4) Inspection and testing of motor control centers and switchgear; and
   5) Verification of cable terminations in accordance with design documents.
b) Mechanical (including piping)
   1) Hydrostatic testing of piping systems;
   2) Mechanical equipment alignment;
   3) Initial lubrication of mechanical equipment;
   4) Tank cleaning and piping cleaning (flushing);
   5) Inspection of mechanical equipment and piping systems; and
   6) Mechanical test procedures implementation.
c) Instrumentation
   1) Testing of pneumatic instrument lines for leaks;
   2) Verification of proper grounding of shielded cables;
   3) Installation of instrumentation in accordance with design documents;
   4) Continuity tests to verify cable routing;
   5) Verification of cable terminations in accordance with design documents; and
   6) Instrument test procedures implementation.

5.1.2 Preoperational test phase

Preoperational testing generally includes but is not limited to

a) Insulation resistance testing of electrical equipment, to be done prior to terminations (power cables);
b) Checkout of electric motors;
c) Checkout of motor operated valves, dampers and gates;

d) Checkout and verification of electrical control circuitry through functional testing;
e) Calibration of electrical relays and meters;
f) Checkout and trip check tests of switchgear, motor control centers, and molded case breakers;
g) Flushing of mechanical systems/subsystems;
h) Blowdown of station/instrument air lines;
i) Verification of instrument calibration;
j) Loop calibration of all instrument loops;
k) Functional loop checkout of all instrument loops;
l) Preoperational testing in accordance with approved preoperational test procedures;
m) Vendor testing of supplied equipment and systems;
n) Vibration testing of driven equipment;
o) Visual inspection of all systems and equipment; and
p) Verification of polarity and integrity of instrument transformer circuits.

5.1.3 Operational test phase

Operational testing generally includes but is not limited to

a) Hydraulic operation of spiral case shut-off valves and proper setting of closing and opening times;
b) Wicket gate or nozzle alignment and verification of proper opening and closing times;
c) Governor control setting verification;
d) Verification of proper lubrication of generator and turbine bearings;
e) Final check of unit braking system;
f) Initial operation of the turbine-generator and bearing run in;
g) Electrical and mechanical overspeed trip tests;
h) Final setting of vibration shutdown sensors;
i) Voltage regulator and excitation system tests;
j) Verification of proper generator to system synchronization;
k) Testing and verification of electrical protection systems with load;
l) Load rejection tests;
m) Performance runs at prescribed loads;
n) Operation and monitoring via plant control systems (local and remote); and
o) Coordinated testing with all plant units.

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.

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 Construction completion phase

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 should be installed in accordance with design documents. Testing during the construction phase should, at a minimum, include the tests listed in b) of 5.1.1. Final coupling alignment 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.

6.2.4 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 5.1.1. 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 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 piping should be checked out and tested by the construction contractor and should, at a minimum, include those piping system tests listed in 5.1.2.

6.3.4 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 Unit startup and operational phase

The unit startup and operational phase should be accomplished by the LTE, the owner's plant organization, and the vendors' representatives necessary to ensure satisfactory operation of the equipment being commissioned. This phase includes all tests and checks that are necessary to 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.

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:

a) Contractors normally provide craft labor as requested by the LTE in support of construction and preoperational activities.

b) The owner normally provides operations and maintenance (O&M) personnel to support the startup preoperational and operational activities.

c) Construction contractors requiring vendor service support should coordinate their requests with the LTE.

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.

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 Clauses 8 and 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 8.1.17) is used to develop a test schedule and test procedure to commission the new excitation systems. 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 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.

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.

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 briefly describes the test requirements. Supplemental information may be required to completely describe the test requirements. The supplemental information may include the original equipment manufacturer’s (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.

Recommended tests
Static excitation
Systems controls

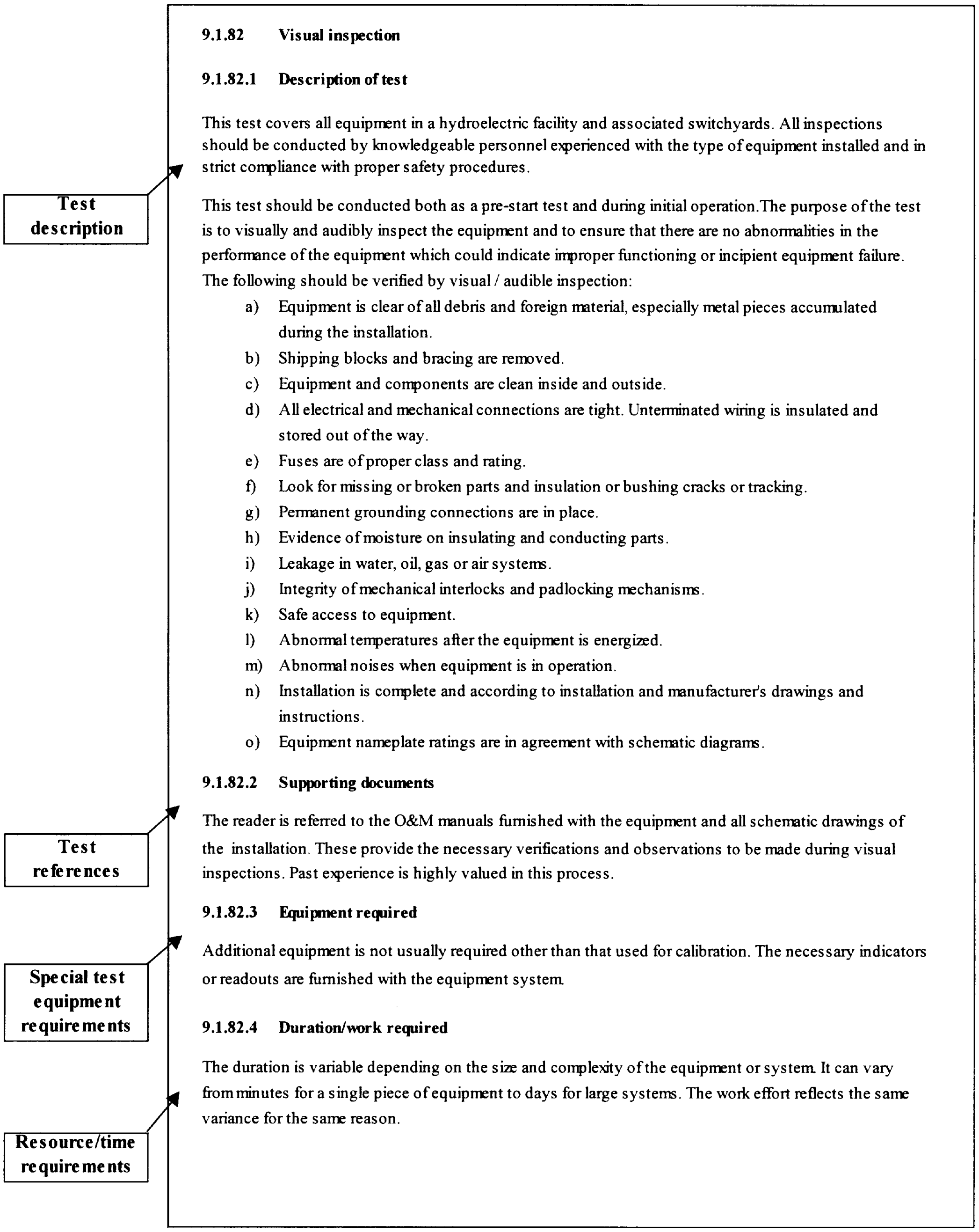
8.1.17 EXCITATION SYSTEMS EQUIPMENT/SYSTEM / Test	Visual Inspection	High potential	Circuitry checkout	Leak testing	Temperature rise	Harmonic distortion	DC winding resistance	Insulation resistance	Functional checks	Initial operation
Rotating excitation system										X
Three-phase ac/dc exciter	X				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
Rectifer 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

Figure 1—Example of equipment test matrix

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. The tests for unit startup are included with the turbine and generator equipment matrices.



9.1.82 Visual inspection

9.1.82.1 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 in strict compliance with proper safety procedures.

This test should be conducted both as a pre-start 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 which 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. Unterminated wiring is insulated and stored out of the way.
e) Fuses are of proper class and rating.
f) Look for missing or broken parts and insulation or bushing cracks or tracking.
g) Permanent grounding connections are in place.
h) Evidence of moisture on insulating and conducting parts.
i) Leakage in water, oil, gas or air systems.
j) Integrity of mechanical interlocks and padlocking mechanisms.
k) Safe access to equipment.
l) Abnormal temperatures after the equipment is energized.
m) Abnormal noises when equipment is in operation.
n) Installation is complete and according to installation and manufacturer's drawings and instructions.
o) Equipment nameplate ratings are in agreement with schematic diagrams.

9.1.82.2 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.

9.1.82.3 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.

9.1.82.4 Duration/work required

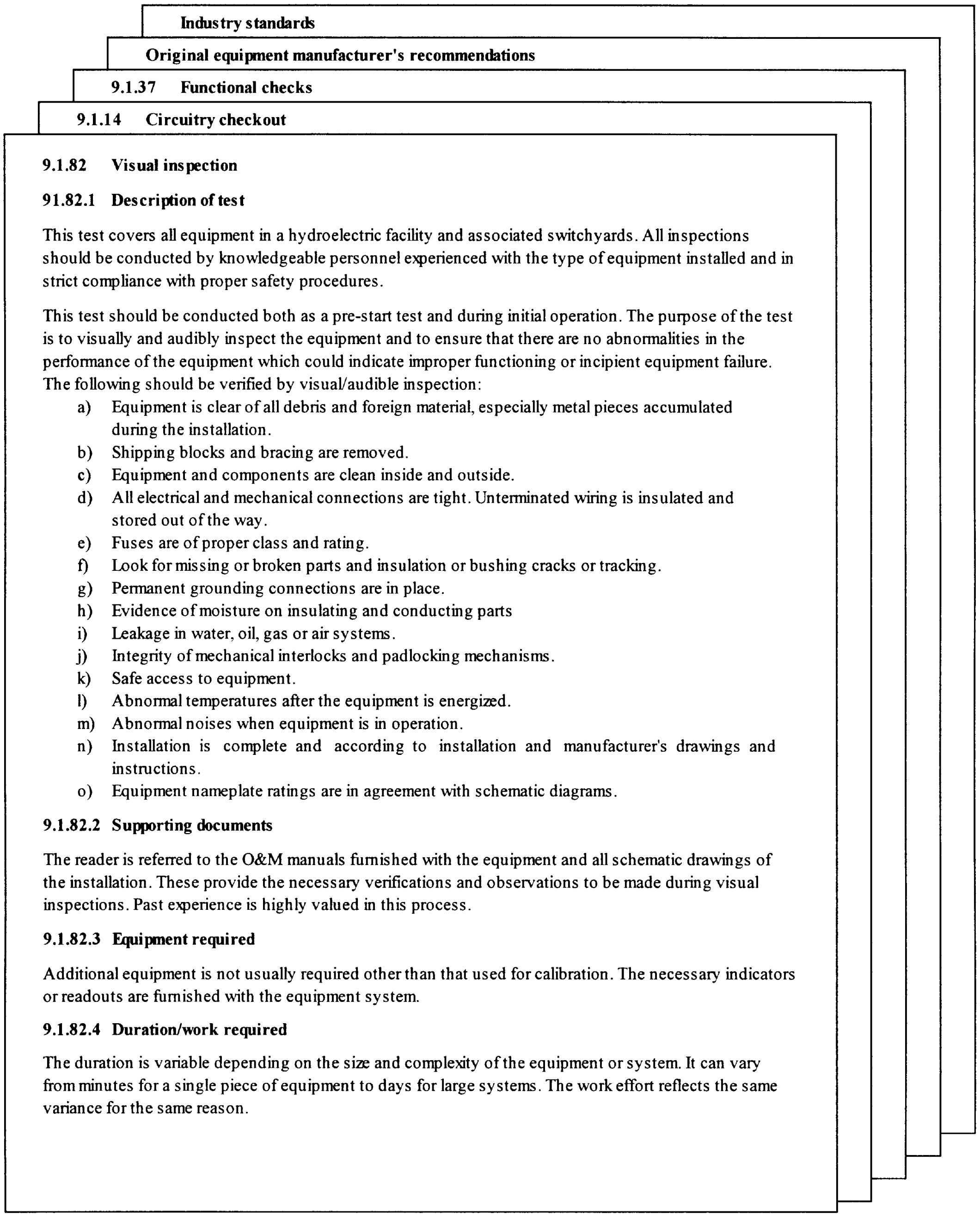
The duration is variable depending on the size and complexity of the equipment or system. It can vary from minutes for a single piece of equipment to days for large systems. The work effort reflects the same variance for the same reason.

Figure 2—Example of a test description

8. Plant equipment

8.1 List of equipment and test matrixes

8.1.1 AC POWER—Low and medium voltage switchgear
8.1.2 AC POWER—Motor control centers (600 V class)



Industry standards

Original equipment manufacturer's recommendations

9.1.37 Functional checks

9.1.14 Circuitry checkout

9.1.82 Visual inspection

91.82.1 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 in strict compliance with proper safety procedures.

This test should be conducted both as a pre-start 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 which 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. Unterminated wiring is insulated and stored out of the way.
e) Fuses are of proper class and rating.
f) Look for missing or broken parts and insulation or bushing cracks or tracking.
g) Permanent grounding connections are in place.
h) Evidence of moisture on insulating and conducting parts
i) Leakage in water, oil, gas or air systems.
j) Integrity of mechanical interlocks and padlocking mechanisms.
k) Safe access to equipment.
l) Abnormal temperatures after the equipment is energized.
m) Abnormal noises when equipment is in operation.
n) Installation is complete and according to installation and manufacturer's drawings and instructions.
o) Equipment nameplate ratings are in agreement with schematic diagrams.

9.1.82.2 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.

9.1.82.3 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.

9.1.82.4 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.

Figure 3—Test package, excitation system control

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 CRANES
8.1.8 DC POWER—Batteries
8.1.9 DC POWER—Chargers
8.1.10 DC POWER—Distribution panel
8.1.11 DRAINAGE/UNWATERING

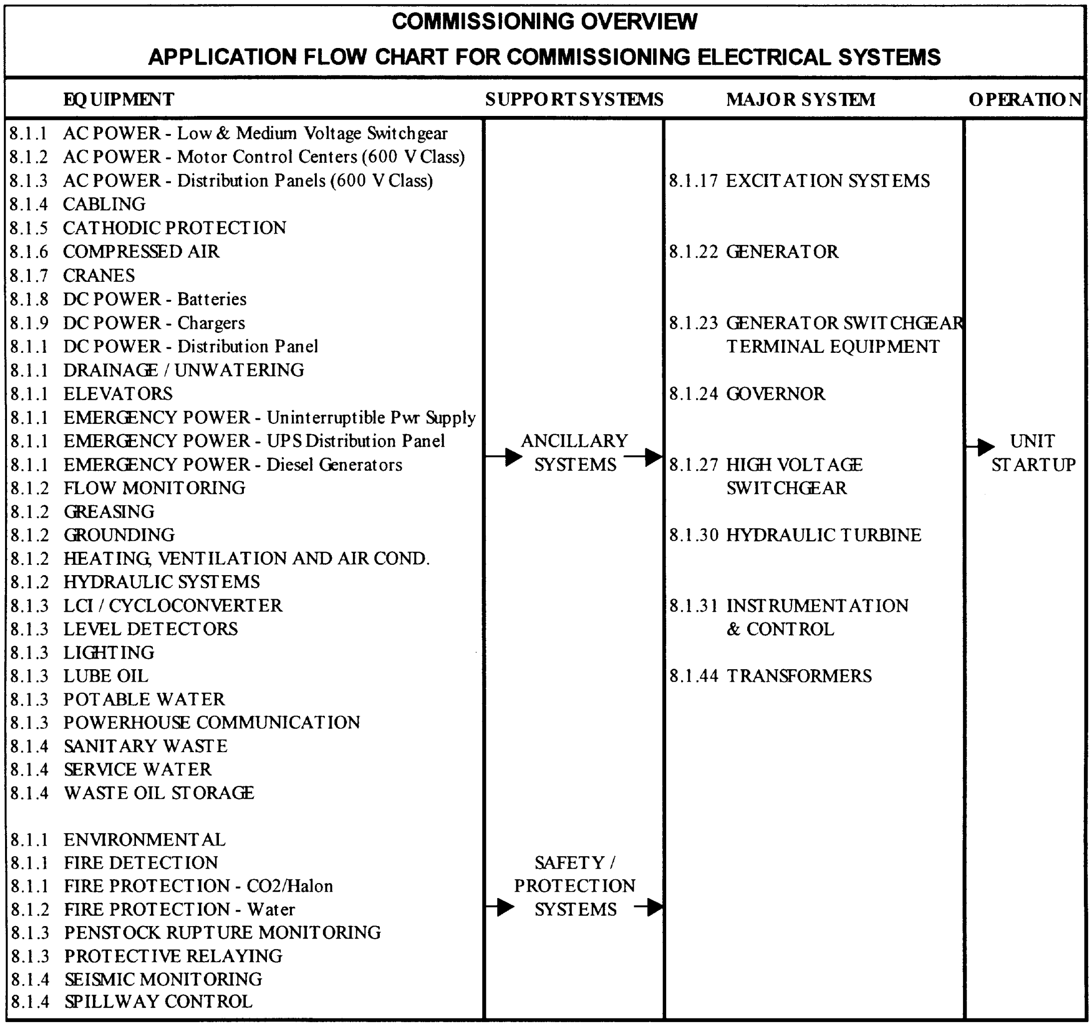


Figure 4—Development of a plant commissioning program

8.1.12 ELEVATORS

8.1.13 EMERGENCY POWER—Uninterruptible power supply (UPS)

8.1.14 EMERGENCY POWER—UPS distribution panel

8.1.15 EMERGENCY POWER—Diesel generators

8.1.16 ENVIRONMENTAL

8.1.17 EXCITATION SYSTEMS

8.1.18 FIRE DETECTION

8.1.19 FIRE PROTECTION—CO_2/Halon

8.1.20 FIRE PROTECTION—Water

8.1.21 FLOW MONITORING

8.1.22 GENERATOR

8.1.23 GENERATOR SWITCHGEAR/TERMINAL EQUIPMENT

8.1.24 GOVERNOR

8.1.25 GREASING

8.1.26 GROUNDING

8.1.27 HIGH-VOLTAGE SWITCHGEAR

8.1.28 HEATING, VENTILATION, AND AIR CONDITIONING

8.1.29 HYDRAULIC SYSTEMS

8.1.30 HYDRAULIC TURBINE
8.1.31 INSTRUMENTATION AND CONTROL
8.1.32 LOAD COMMUTATING INVERTER/CYCLOCONVERTER
8.1.33 LEVEL DETECTORS
8.1.34 LIGHTING
8.1.35 LUBE OIL
8.1.36 PENSTOCK RUPTURE MONITORING
8.1.37 POTABLE WATER
8.1.38 POWERHOUSE COMMUNICATION
8.1.39 PROTECTIVE RELAYING
8.1.40 SANITARY WASTE
8.1.41 SEISMIC MONITORING
8.1.42 SERVICE WATER
8.1.43 SPILLWAY CONTROL
8.1.44 TRANSFORMERS
8.1.45 WASTE OIL STORAGE

8.1.1 AC POWER Medium- and low-voltage switchgear **EQUIPMENT/SYSTEM** / **TEST**	Visual inspection	Bolted joint torque	Insulation resistance	Continuity checks	High potential	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					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	X															
Fuses	X								X									
Power cable lugs	X	X	X															
Surge protectors	X		X					X										
Ground sensors	X			X					X				X					
Circuit interrupter	X											X						

8.1.2 AC POWER Motor control centers (MCCs) (600 V class) **EQUIPMENT/SYSTEM** **TEST**	Visual inspection	Bolted joint torque	Insulation resistance	Continuity checks	Polarity (ac)	Ratios	Phase relation	Circuitry checkout	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				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								
Ground cable	X	X	X															
Fuses	X							X										
Overload devices	X							X		X								

8.1.3 AC POWER Distribution panels (600 V class) **EQUIPMENT/SYSTEM** **TEST**	Visual inspection	Insulation resistance	Continuity checks	Phase relation	Circuit-breaker trip	Functional checks	Initial operation										
System							X										
Panel enclosure	X																
Circuit breakers	X	X			X	X											
Power cables	X	X	X	X													
Ground cable	X	X															

8.1.4
CABLING

EQUIPMENT/SYSTEM — **TEST**	Visual inspection	Insulation resistance	High potential	Continuity checks	Circuitry checkout	Initial operation											
System						X											
Conduit	X																
Pull boxes	X																
Cable trays	X																
Duct banks	X																
Man holes	X																
Power cable	X	X	X	X													
Control cable	X	X		X	X												
Splices	X	X	X														
Ground cable	X	X															
Quik connectors	X	X		X	X												
Compression lugs	X	X	X	X													
Bolted lugs	X	X	X	X													

8.1.5
CATHODIC PROTECTION

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Insulation resistance	Voltage measure	Current measure	Functional checks	Initial operation
System						X
Rectifier panel	X					
Ground mat anodes	X					
Circuit breaker	X				X	
Disconnect switches	X	X			X	
Power cable	X	X	X	X		
Ground connectors	X	X				

8.1.6
COMPRESSED AIR

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Pressure testing	Leak testing	Insulation resistance	Continuity checks	High potential	Circuitry checkout	Calibration	Functional checks	Initial operation							
System										X							
Air compressor	X								X								
Air receiver tank	X																
Piping	X	X	X														
Valves	X	X	X						X								
Power cable	X			X	X	X											
Control cable	X			X	X		X										
Instruments	X						X	X	X								
Gauges	X						X	X	X								
Relief valve	X								X								
Quik connection fittings	X																
Blowdown connections	X																
Circuit breaker	X			X		X			X								
Motor starter	X			X					X								
Air dryer	X																
Desiccant heater	X			X	X		X		X								
Cooling water supply	X	X	X														
Relays	X						X	X	X								
Motors	X			X			X		X								
Ground cable	X			X													

8.1.7
CRANES

EQUIPMENT/SYSTEM / TEST	Visual inspection	Insulation resistance	Continuity checks	Phase relation	Calibration	Circuitry checkout	Braking system	Load test	Crane operation	Functional checks	Initial operation						
System								X	X		X						
Power cable	X	X	X	X													
Crane rail busbar	X	X		X													
Power rail shoes	X	X															
Disconnect switches	X	X		X						X							
Deadman safety switch	X					X	X			X							
Circuit breakers	X	X	X	X		X				X							
Gear boxes	X																
Crane rope	X																
Crane hooks	X																
Lifting sheaves	X																
Bumper stops	X																
Limit switches	X		X			X				X							
Runway rail alignment	X																
Alarm bell	X					X				X							
Flashing lights	X					X				X							
Cab controls	X					X				X							
Breaks	X					X	X			X							
Pendant cable	X	X	X			X											
Pendant controls	X					X				X							
Power cable reel	X																
Ground cable	X	X															
Hoist motors	X	X		X						X							
Bridge motor	X	X		X						X							
Trolley motor	X	X		X						X							
Control panel			X		X	X				X							
Relays					X	X				X							
Meters					X	X				X							

8.1.8
DC POWER
Batteries

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Specific gravity	Bolted joint torque	Voltage level	Temperature	Discharge/capacity	Insulation resistance	Ground isolation	Initial operation								
System									X								
Battery cells	X	X		X	X	X											
Intercell bus links	X		X					X									
Bus connectors	X		X														
Power cable	X						X	X									
Battery racks	X																
Safety equipment	X																
Area ventilation	X																

8.1.9
DC POWER
Chargers

EQUIPMENT/SYSTEM **TEST**	Visual inspection	Insulation resistance	Voltage level	Continuity checks	Circuit-breaker trip	Polarity (dc)	Circuitry checkout	Calibration	Equalizing charge	Float charge	Load balance (redundant system)	Functional checks	Initial operation				
System									X	X	X		X				
Charger panel	X																
Circuit breakers	X	X			X							X					
Power cables	X	X	X	X		X											
Control cable	X	X		X				X									
Meters	X							X				X					
Relays	X							X				X					
Instruments	X							X				X					
Control switches	X							X				X					
Timers									X			X					
Fuses	X			X													

8.1.10 DC POWER Distribution panel **EQUIPMENT/SYSTEM** **TEST**	Visual inspection	Insulation resistance	Continuity checks	Polarity (dc)	Circuit-breaker trip	Functional checks	Circuitry checkout	Initial operation
System								X
Panel enclosure	X							
Circuit breakers	X	X			X	X		
Power cables	X	X	X	X				
Ground cable	X	X						
Transfer switches	X	X	X	X		X		
Ground sensors	X					X		
Motor starters	X					X	X	

8.1.11
DRAINAGE/UNWATER-
ING

EQUIPMENT/SYSTEM / TEST	Visual inspection	Pressure testing	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation
System								X
Floor drains	X	X					X	
Piping	X	X						
Valves	X	X					X	
Pumps	X						X	
Motors	X		X		X		X	
Power cable	X		X	X				
Control cable	X		X	X	X			
Level switches	X				X	X	X	
Check valves	X	X					X	
Strainers	X							
Instruments	X				X	X	X	
Gauges	X				X	X	X	
Ground cable	X		X					
Oil separator	X							
Flow sensors	X				X	X	X	
Control switches	X				X		X	
Selector switches	X				X		X	
Motor starters	X		X		X		X	
Control panels	X				X		X	

8.1.12
ELEVATORS

EQUIPMENT/SYSTEM **TEST**	Visual inspection	Insulation resistance	Continuity checks	Circuitry checkout	Load test	Functional checks	Initial operation										
System					X		X										
Elevator control panel	X			X		X											
Power cable	X	X	X														
Floor signal stations	X			X		X											
Control cable	X	X	X	X													
Limit switches	X			X		X											
Emergency devices	X			X		X											
Bypass switches	X			X		X											
Alarm devices	X			X		X											
Door blockage sensor	X			X		X											
Ground cable	X	X															

8.1.13
EMERGENCY POWER
UPS

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Insulation resistance	Continuity checks	Circuit-breaker trip	Polarity (dc)	Ratios	Calibration	Frequency stability	Voltage level	Functional checks	Initial operation						
System								X			X						
Inverter	X		X							X							
Transformer	X	X	X			X											
Circuit breakers	X	X		X						X							
Static transfer switches	X		X							X							
Manual bypass switches	X		X							X							
Power cable	X	X	X		X												
Control cable	X	X	X														
Meters	X						X			X							
Relays	X						X			X							
Ground cable	X	X															
UPS battery charger	X									X	X						
Batteries	X				X				X								
Control switches	X									X							
Control panel	X									X							

8.1.14
EMERGENCY POWER
UPS distribution panel

EQUIPMENT/SYSTEM **TEST**	Visual inspection	Insulation resistance	Circuit-breaker trip	Continuity checks	Functional checks	Initial operation											
System						X											
Panel enclosure	X																
Circuit breakers	X		X		X												
Power cables	X	X		X													
Ground cable	X	X															

8.1.15 EMERGENCY POWER Diesel generators **EQUIPMENT/SYSTEM** / **TEST**	Visual inspection	Pressure testing	Insulation resistance	Continuity checks	High potential	Circuit-breaker trip	Circuitry checkout	Polarity (ac)	Ratios	Phase relation	Calibration	Leak testing	Functional checks	Instrument transformer burden	CT Saturation	Initial operation		
System																X		
Diesel engine	X												X					
Diesel generator	X		X	X	X					X			X					
Fuel oil storage tank	X											X						
Fuel oil day tank	X											X						
Fuel oil pump	X											X	X					
Piping	X	X										X						
Valves	X	X										X	X					
Strainers	X											X						
Exhaust system	X											X						
Diesel panel	X			X			X						X					
Circuit breakers	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					X								
Control cable	X		X	X			X											
Meters	X						X				X		X					
Relays	X						X				X		X					
Instruments	X						X				X		X					
Control switches	X						X						X					
Synchronizing equipment	X						X			X			X					
Ground cable	X		X															
Fuses	X						X											
Motors	X		X										X					
Transfer switch	X												X					
Starting system	X												X					
Control panel	X						X						X					

8.1.16
ENVIRONMENTAL

EQUIPMENT/SYSTEM — **TEST**	Visual inspection	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation
System							X
Fish ladders	X						
Fish weirs	X						
Intake gates	X						
Stop logs	X						
Valves	X					X	
Piping	X						
Level devices	X			X	X	X	
Flow devices	X			X	X	X	
Fish viewing rooms	X						
TV cameras	X					X	
TV sensors	X					X	
Motor operated valves	X			X		X	
Power cable	X	X	X				
Control cable	X	X	X	X			
Ground cable	X	X					
Motors	X	X		X		X	
Motor starters	X			X		X	
Control switches	X			X		X	

8.1.17
EXCITATION SYSTEMS

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	High potential	Circuitry checkout	Leak testing	Temperature rise	Harmonic distortion	DC winding resistance	Insulation resistance	Functional checks	Initial operation							
Rotating excitation system										X							
Permanent magnetic generator (PMG) pilot exciter	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	X				X		X	X									
Sliprings and brushes	X							X		X							

8.1.18
FIRE DETECTION

EQUIPMENT/SYSTEM **TEST**	Visual inspection	Fire zone	Calibration	Insulation resistance	Continuity checks	Circuitry checkout	Polarity (dc)	Functional checks	Initial operation								
System									X								
Fire detection panel	X	X				X		X									
Power cable	X			X	X		X										
Control cable	X	X		X	X	X											
Alarm devices	X	X				X		X									
Ground cable	X	X		X													
Individual detectors	X	X	X		X	X	X	X									

8.1.19
FIRE PROTECTION
CO_2/Halon

EQUIPMENT/SYSTEM / TEST	Visual inspection	Pressure testing	Insulation resistance	Continuity checks	Circuitry checkout	Polarity (dc)	Calibration	Fire code (CO_2 and Halon)	Volumetric (CO_2 only)	Functional checks	Initial operation						
System											X						
Tanks	X							X	X								
Manifold	X	X			X			X	X								
Rupture devices	X				X			X	X	X							
Piping	X	X						X	X								
Valves	X	X						X	X	X							
Nozzles	X							X	X								
Heat detectors	X				X			X		X							
Power cable	X		X	X		X		X									
Control cable	X		X	X	X			X									
Initiating panel	X				X			X		X							
Pressure relief device	X							X	X	X							
Gas detector panel	X			X	X		X	X									
Gas detectors	X				X		X	X	X	X							
Door interlocks	X			X	X			X		X							
Manual operators	X				X			X	X	X							
Instruments	X				X		X	X	X	X							
Gauges	X				X		X	X	X	X							
Alarm devices	X			X	X			X		X							

8.1.20 FIRE PROTECTION Water **EQUIPMENT/SYSTEM** / **TEST**	Visual inspection	Pressure testing	Insulation resistance	Continuity checks	Circuit-breaker trip	Circuitry checkout	Calibration	Fire code (H_2O system)	Functional checks	Initial operation							
System										X							
Penstock valves	X	X						X	X								
Strainer	X	X						X									
Blowdown valve	X	X						X	X								
Head tank	X	X						X									
Piping	X	X						X									
Valves	X	X						X	X								
Sprinkler heads	X	X						X	X								
Deluge valves	X	X				X		X	X								
Hose stations/hydrants	X							X									
Fire detectors	X					X		X	X								
Emergency fire pump	X					X		X	X								
Jockey pump	X					X		X	X								
Motors	X		X			X		X	X								
Circuit breakers	X		X	X	X	X		X	X								
Motor starters	X		X	X		X		X	X								
Power cable	X		X	X				X									
Control cable	X		X	X		X		X									
Instruments	X					X	X	X	X								
Gauges	X					X	X	X	X								
Pressure controller	X	X					X	X	X								
Ground cable	X		X					X									
Alarm devices	X			X		X		X	X								

8.1.21
FLOW MONITORING

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation
System							X
Flow devices	X			X	X	X	
Control cable	X	X	X	X			
Alarm devices	X			X	X	X	
Computer inputs	X			X	X	X	
Radio transmitter	X			X	X		
Telephone lines	X			X			

8.1.22 GENERATOR **EQUIPMENT/ SYSTEM** — **TEST**	Visual inspection	Loop test	DC winding resistance	Insulation resistance	High potential	Turn insulation	Phase rotation	Open circuit saturation	Short-circuit saturation	Insulation power factor	Pressure testing	Shaft runabout	Air gap measurement	Balancing	Temperature rise	Voltage waveform deviation	Telephone influence factor	Bearing insulation	Efficiency	Overspeed	Load rejection	Sudden short circuit	Bearing heat run	Functional checks	Initial operation
Generator																									X
STATOR							X	X	X				X		X	X	X				X	X			
Frame	X																								
Core	X	X																							
Coils	X		X	X	X					X															
Heaters	X																							X	X
Air Housing	X																								
Air coolers	X										X			X											
ROTOR													X	X					X	X					
Field poles	X																								
Field windings	X		X	X	X	X									X										
Spider/rim	X																								
Shaft	X											X													
EXCITATION																									
Rotating	X		X	X											X									X	
Static	X			X																				X	
Field breaker/leads	X			X	X																			X	
Slip rings	X				X																				
BEARING-GUIDE THRUST															X			X					X		
Oil reservoir/piping	X										X														
Oil lift pump	X																							X	
Bearing clearances	X												X												
Cooling water	X										X													X	
Vibration monitoring																								X	
BRAKES/JACKS																									
Brake ring	X												X												
Brake shoes	X												X												
Air system	X																							X	
Oil system	X										X													X	
FIRE PROTECTION																									
CO_2 system	X																							X	
Water	X										X													X	

8.1.23 GENERATOR SWITCHGEAR/ TERMINAL EQUIPMENT **EQUIPMENT/SYSTEM** **TEST**	Visual inspection	Insulation resistance	Continuity checks	Energize auxiliary power	Timing	Operation coil continuity	Contact resistance	High potential	Phase relation	Ground connection	DC winding resistance	Temperature ruse	Ratios	Polarity (ac)	Insulation power factor	Instrument transformer burden	CT saturation	Functional checks	Initial operation
System																			X
SWITCHGEAR CUBICLE	X									X		X							
Circuit breakers	X	X			X	X	X	X				X						X	
Ground switches	X	X			X		X	X		X								X	
Bus bars (cubicle)	X	X									X	X							
Aux. power cables	X	X	X	X															
Control cables	X	X	X	X															
Aux. service equipment (lights/heaters)	X			X														X	
Aux. operation equipment	X			X														X	
Control/prot. devices/systems	X			X														X	
Disconnect switches	X	X			X		X	X				X						X	
MAIN GENERATOR LEADS																			
Isolated phase	X	X	X					X	X		X	X							
Bus duct	X	X	X					X	X		X	X							
Cables	X	X	X					X	X		X	X							
Buswork (open)	X	X	X					X	X		X	X							
Seal-off bushings/barriers												X							
Enclosures/structures										X		X							
NEUTRAL CUBICLE	X									X		X							
Neutral disconnect switch 1pole	X	X					X	X										X	
Neutral transformer	X	X								X									
Reactor/resist	X	X								X									
Resistor (trans. second)	X											X							
Bus bars	X	X						X	X			X							
Aux. power cables	X	X	X	X															
Control cables	X	X	X																
Aux. service equipment (lights/heaters)	X			X														X	
Control protective device	X																	X	
PT/CT/SURGE CUBICLE	X									X									
Potential transformers	X	X							X	X			X	X		X			
P/T fuses	X																		
Carriage	X									X									
Current transformers	X								X				X	X		X	X		
Surge arrestors	X	X								X									
Capacitors	X	X								X					X				
Control cables	X	X	X																

8.1.24 GOVERNOR

EQUIPMENT/SYSTEM — TEST	Visual inspection	Calibration	Load rejection	Polarity (dc)	Continuity checks	Electromagnetic interference/radio frequency interference (EMI/RFI) rejection	Frequency stability	Pressure testing	Servomotor timing	Differential pressure test	Flushing	Leak testing	Clearance measurement	Functional checks	Initial operation				
Governor system															X				
Servo restoring	X	X																	
Servo control valve	X	X				X		X	X	X				X					
Speed switches		X				X								X					
Governor controller		X	X			X	X							X					
Sensors/signal conditioners		X		X	X	X							X	X					
Metering/monitoring				X	X	X								X					
Annunciation				X	X	X								X					
Start/stop control				X	X	X								X					
Overspeed switch	X	X				X								X					
Emergency shutdown		X												X					
Piping systems								X			X	X							

8.1.25
GREASING

EQUIPMENT/SYSTEM / TEST	Visual inspection	Pressure testing	Leak testing	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation
System									X
Grease containers	X	X							
Control panel	X					X			
Selector switches	X					X		X	
Tubing	X	X	X						
Hoses	X	X	X						
Grease fittings	X		X						
Timers	X					X	X	X	
Pressure gauges	X						X	X	
Control switches	X					X		X	
Pumps	X							X	
Motors	X			X				X	
Power cable	X			X	X				
Control cable	X			X	X	X			
Motor starters	X			X	X	X		X	

8.1.26
GROUNDING

EQUIPMENT/SYSTEM — TEST	Visual inspection	Station ground resistance	Earth resistivity
System		X	
Ground cable	X		X
Ground rods	X		X
Ground test cabinet	X		X
Carbon banks	X		X
Ground connectors	X		X

8.1.27 HIGH-VOLTAGE SWITCHGEAR **EQUIPMENT/SYSTEM** — **TEST**	Visual inspection	Insulation resistance	Continuity checks	Energize auxiliary power	Timing	Operation coil continuity	Contact resistance	Phase relation	Ground connection	Temperature rise	Rations	Polarity (ac)	Instrument transformer burden	CT saturation	High potential	Functional checks	Initial operation		
CIRCUIT BREAKERS																			
Air		X			X	X	X	X	X							X			
Oil		X	X		X	X	X	X	X							X			
SF6	X	X			X	X	X	X								X			
DISCONNECT SWITCHES																			
Air		X						X	X		X					X			
SF6	X	X					X	X								X			
GROUND SWITCHES																			
Air		X						X	X	X						X			
SF6	X	X					X	X	X							X			
BUS WORK																			
Air		X							X		X				X				
SF6	X	X						X							X				
Potential transformers	X	X									X	X	X						
Current transformers	X										X	X	X	X					
Surge arrestors	X	X							X										
Aux. power cables	X	X	X																
Control cables	X	X	X																
Aux. service equipment (lights/heaters)	X			X												X			
Aux. operation equipment	X			X												X			
Control/protective device/system	X			X												X			

8.1.28
HEATING, VENTILATION, AND AIR CONDITIONING

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Pressure testing	Insulation resistance	Continuity checks	Circuit-breaker trip	Circuitry checkout	Calibration	Air balance	Functional checks	Initial operation
System								X		X
Air handling unit	X					X				
Air duct	X									
Insulation	X									
Motor operated dampers	X		X	X		X			X	
Manual bypass dampers	X								X	
Thermostats	X			X		X	X			
Circuit breakers	X		X		X	X			X	
Motor contractors	X			X		X			X	
Motors	X		X						X	
Duct heaters	X		X			X				
Heat exchangers	X	X								
Piping	X	X								
Valves	X	X							X	
Fans		X			X		X		X	
Selector switches	X					X			X	
Power cables	X		X	X						
Control cables	X		X	X		X				
Ground cable	X		X							
Fire operated dampers	X					X			X	
Fire detectors	X					X			X	
Fuses	X					X				
Instruments	X					X	X		X	
Gauges	X					X	X		X	
Relays	X					X	X		X	
Filters	X									

8.1.29 HYDRAULIC SYSTEMS

EQUIPMENT/SYSTEM — TEST	Visual inspection	Pressure testing	Leak testing	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation
System									X
Hydraulic storage tank	X	X							
Piping	X	X							
Valves	X	X						X	
Check valves	X	X						X	
Pumps	X	X						X	
Strainers	X	X							
Motors	X			X		X		X	
Motor starters	X			X		X		X	
Power cable	X			X	X				
Control cable	X			X	X	X			
Air compressors	X	X	X					X	
Nitrogen bottles	X		X						
Pressure switches	X					X	X	X	
Solenoid valves	X					X		X	
Pressure relief devices	X	X						X	
Instruments	X					X	X	X	
Gauges	X						X	X	
Relays	X					X	X	X	
Ground cable	X			X					
Air lines	X	X	X						
Position switches	X					X		X	
Float valve								X	

8.1.30
HYDRAULIC TURBINE

EQUIPMENT/SYSTEM / TEST	Visual inspection	Clearance measurement	Shaft runout	Bearing heat run	Vibration check	Overspeed	Load rejection	Index	Draft tube depression	Pressure testing	Bolted joint torque	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Initial rotation	Bearing insulation	Flushing	Leak testing	Lubrication check	Functional checks	Initial operation
System			X		X	X	X	X	X					X		X						X
Runner	X	X													X							
Blade operation system (if required)	X	X			X										X			X		X	X	
Wicket gates	X	X			X										X					X	X	
Jet deflectors	X	X													X					X	X	
Needle valves	X	X													X			X		X	X	
Shaft		X	X		X																	
Guide bearing	X	X	X	X	X												X	X	X			
Head cover and bottom ring	X																		X			
Shaft seal	X	X																X	X	X		
Servomotors (gates and blade)	X	X								X								X		X	X	
Discharge ring	X	X																		X		
Spiral case and draft tube liner	X	X								X	X											
Electrical controls, alarms, and power	X	X										X	X	X	X						X	
Cooling and seal water flow	X	X			X					X					X			X	X		X	
Oil supply (including pumps, motors)	X			X	X					X		X	X	X	X						X	
Manhole and inspection covers	X										X								X			
Greasing system	X	X			X							X	X	X							X	
Turbine isolation valve (if any)	X									X					X				X		X	
Isolation valve control system	X	X										X	X	X	X						X	
Pressure relief valve (if any)	X	X				X	X			X					X				X		X	
Gen-turbine shaft coupling	X	X									X					X						
Thrust bearing (if part of turbine)	X	X	X	X	X												X	X		X		

8.1.31
INSTRUMENTATION AND CONTROL

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Polarity (dc)	Continuity checks	EMI/RFI rejection	Surge withstand capability	Threshold settings	Calibration	Insulation resistance	Functional checks	Initial operation
Control system	X	X	X	X	X		X		X	X
Metering/monitoring	X	X	X				X		X	
Relaying	X	X	X			X	X		X	
Annunciation	X	X	X						X	
Sensors/signal condition	X	X	X				X		X	
Insulated ground cable	X		X					X		

8.1.32 LOAD COMMUTATING INVERTER/CYCLOCONVERTER

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Circuitry checkout	Leak testing	Temperature rise	Harmonic distortion	Functional checks	Initial operation										
Load commutating inverter (LCI)/ starter	X						X										
Thyristor bridges	X	X		X		X											
Air cooling system		X	X	X		X											
Water cooling circuit	X	X	X	X		X											
DC-reactor	X	X		X													
Controls	X	X				X											
LCI/adjustable speed	X				X	X											
Thyristor bridges	X	X		X		X											
Water cooling circuit	X	X	X	X		X											
DC-reactor	X	X		X													
Controls	X	X				X											
Power factor/harmonic filter	X	X		X	X												
Cycloconverter	X						X										
Thyristor bridges	X	X		X		X											
Water cooling circuit	X	X	X	X		X											
DC-reactor	X	X		X													
Controls	X	X				X											
Power factor/harmonic filter	X	X		X	X												

8.1.33
LEVEL DETECTORS

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation
System							X
Stilling wells	X						
Level detection devices	X			X	X	X	
Control cable	X	X	X	X			
Alarm devices	X			X	X	X	
Computer inputs	X			X		X	

8.1.35
LUBE OIL

EQUIPMENT/SYSTEM — TEST	Visual inspection	Pressure testing	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Flushing	Leak testing	Functional checks	Initial operation
System										X
Storage tank	X	X								
Oil sump	X						X			
Piping	X	X					X	X		
Valves	X	X					X		X	
Check valves	X	X							X	
Level switches	X				X	X			X	
Flow switches	X				X	X			X	
Temperature sensors	X				X	X			X	
Bearings	X									
Pumps	X	X							X	
Motors	X		X		X				X	
Motor starters	X		X	X	X				X	
Pressure switches	X				X	X			X	
Cooling coils	X	X					X			
Water supply	X	X					X	X		
Strainers	X	X								
Filters	X	X								
Power cable	X		X	X						
Control cable	X		X	X	X					
Instrument cable	X		X	X	X					
Ground cable	X		X							
Instruments	X				X	X			X	
Gauges	X					X			X	

8.1.36
PENSTOCK RUPTURE
MONITORING

EQUIPMENT/SYSTEM — TEST	Visual inspection	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation
System							X
Flow sensors	X			X	X	X	
Flow differential monitor	X			X	X	X	
Alarm device	X			X		X	
Control cable	X	X	X	X			

8.1.37
POTABLE WATER

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Pressure testing	Leak testing	Insulation resistance	Continuity checks	High potential	Circuitry checkout	Calibration	Functional checks	Initial operation							
System										X							
Pumps	X								X								
Storage tanks	X		X														
Piping	X	X	X														
Valves	X	X							X								
Back flow preventer	X	X	X						X								
Strainers	X																
Power cable	X			X	X												
Control cable	X			X													
Instruments	X						X		X								
Gauges	X						X		X								
Vent valve	X						X		X								
Reducing valves	X						X		X								
Controllers	X						X		X								
Flow meters	X						X		X								
Circuit breaker	X					X			X								
Motor starter	X								X								
Relays	X						X		X								
Motors	X								X								
Ground cable	X																

8.1.38 POWERHOUSE COMMUNICATION

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation
System							X
Telephone handsets	X			X		X	
Jacks	X		X	X			
Cable	X		X	X			
Paging speakers	X		X	X	X	X	
Telephone terminal box	X		X	X			
Isolation transformers	X			X			
Resistors	X			X	X		
Ground cable	X	X					
Sound-powered headsets	X		X	X		X	
Sound-powered jacks	X		X	X			
Amplifiers	X			X		X	

8.1.39 PROTECTIVE RELAYING

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Calibration	Continuity checks	Insulation resistance	Ratios	Phase relation	Polarity (ac)	Accuracy test	DC winding resistance	Instrument transformer burden	CT saturation	Functional checks	Initial operation				
Overvoltage relays	X	X										X					
Overcurrent relays	X	X										X					
Differential relays	X	X										X					
Stator ground relays	X	X										X					
Field ground relays	X	X										X					
Overexcitation relays	X	X										X					
Backup (impedance) relays	X	X										X					
Reverse power relays	X	X										X					
Out of step relays	X	X										X					
Unbalanced current relays	X	X										X					
Voltage balance relays	X	X										X					
Frequency relays	X	X										X					
Temperature detection relays	X	X										X					
Flow detection relays	X	X										X					
Sudden pressure relays	X	X										X					
Potential transformers	X			X	X	X	X	X	X	X							
Current transformers	X			X	X	X	X	X	X	X	X						
Wiring	X		X	X													

8.1.40
SANITARY WASTE

EQUIPMENT/SYSTEM — TEST	Visual inspection	Pressure testing	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation
System								X
Sewage treatment tank	X	X						
Sewage treatment panel	X			X	X			
Septic tank	X	X						
Dosing tank	X	X						
Leaching piping	X	X						
Leaching field	X							
Sewage lift pumps	X				X		X	
Motors	X		X				X	
Motor contactors	X		X	X	X		X	
Piping	X	X						
Valves	X	X					X	
Power cables	X		X	X				
Control cables	X		X	X	X			
Level switches	X				X	X	X	
Instruments	X				X	X	X	
Gauges	X				X	X	X	

8.1.41
SEISMIC MONITORING

EQUIPMENT/SYSTEM / **TEST**	Visual inspection	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation
System						X
Seismic monitors	X			X	X	
Instrument cable	X	X	X			
Monitor supports	X					
Input/output modules	X	X	X		X	
Computer readouts	X		X		X	
Alarm points	X		X		X	

8.1.42
SERVICE WATER

EQUIPMENT/SYSTEM — TEST	Visual inspection	Pressure testing	Leak testing	Insulation resistance	Continuity checks	High potential	Circuitry checkout	Calibration	Functional checks	Initial operation							
System										X							
Pumps	X								X								
Storage tanks	X																
Piping	X	X															
Valves	X	X							X								
Strainers	X						X										
Power cable	X			X	X	X											
Control cable	X			X	X		X										
Instruments	X						X	X	X								
Gauges	X						X	X	X								
Vent valve	X							X	X								
Controllers	X						X	X	X								
Flow meters	X							X	X								
Air lines	X		X														
Solenoid valves	X						X	X	X								
Circuit breaker	X			X			X		X								
Motor starter	X			X			X		X								
Relays	X						X	X	X								
Motors	X			X			X		X								
Ground cable	X			X													

8.1.43
SPILLWAY CONTROL

EQUIPMENT/SYSTEM — TEST	Visual inspection	Pressure testing	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation
System								X
Spillway gates	X						X	
Hydraulic operators	X	X			X		X	
Storage tank	X	X						
Pumps	X	X					X	
Piping	X	X						
Valves	X	X					X	
Solenoid valves	X	X			X		X	
Motors	X		X		X		X	
Motor starters	X		X	X	X		X	
Control switches	X				X		X	
Position switches	X				X		X	
Power cable	X		X	X				
Control cable	X		X	X	X			
Ground cable	X		X					
TV cameras	X				X		X	
TV monitors	X				X		X	
Selector switch	X				X		X	
Instruments	X				X	X	X	
Gauges	X				X	X	X	
Bulkhead gates	X							
Lifting beam	X							
Mobil crane	X						X	
Bridge crane	X						X	
Level alarms	X				X		X	
Staff gauges	X						X	

8.1.44 TRANSFORMERS

EQUIPMENT/SYSTEM / TEST	Visual inspection	DC winding resistance	Insulation resistance	Insulation power factor	Ratios	Polarity (ac)	Oil dielectric strength	Oil quality	Pressure testing	No load losses	Excitation	Temperature rise	Noise measurement	Calibration	AC impedance	Core ground testing	Gas-in-oil analysis	Instrument transformer burden	CT saturation	Functional checks	Initial operation
HOUSING																					
Tank	X								X												
Coolers/radiators	X								X				X							X	
Conservator	X								X												
Fans/pumps	X												X							X	
Valves	X																			X	
Bushings	X		X	X																	
Ground connections	X																				
WINDINGS																					
High-voltage winding		X	X	X		X															
Low-voltage winding		X	X	X		X															
Tertiary winding		X	X	X		X															
Winding to winding			X	X	X																
OIL							X	X								X					
PROTECTIVE DEVICES																					
Winding temperature devices	X													X						X	
Oil level gauges	X													X						X	
Pressure gauges	X													X						X	
Fault pressure devices	X													X						X	
Surge arrestors	X																				
CTs			X	X	X	X												X	X		
CONTROL CABINET																					
Control switches	X																			X	
Indicating lights/heaters	X																			X	
Starters, relays, wiring	X																			X	
TAP-CHANGER ASSEMBLY	X												X							X	
Taps		X	X	X	X																
NEUTRAL REACTOR	X	X	X	X			X	X							X						
COMPLETE ASSEMBLY	X									X	X	X	X			X					X

8.1.45
WASTE OIL STORAGE

EQUIPMENT/SYSTEM **TEST**	Visual inspection	Pressure testing	Insulation resistance	Continuity checks	Circuitry checkout	Calibration	Functional checks	Initial operation									
System								X									
Oil separator	X																
Waste oil storage tank	X																
Piping	X	X															
Valves	X	X					X										
Check valves	X	X					X										
Air operated pumps	X						X										
Air piping	X																
Level switches	X			X	X		X										
Gauges	X					X	X										
Control cable	X		X	X	X												

9. Systems tests

9.1 List of tests and test descriptions

9.1.1 AC impedance
9.1.2 Accuracy test
9.1.3 Air balance
9.1.4 Air gap measurement
9.1.5 Balancing
9.1.6 Bearing heat run
9.1.7 Bearing insulation
9.1.8 Bolted joint torque
9.1.9 Braking system
9.1.10 Bus transfer
9.1.11 Calibration
9.1.12 Circuit-breaker trip
9.1.13 Circuitry checkout
9.1.14 Clearance measurement
9.1.15 Contact resistance
9.1.16 Continuity checks
9.1.17 Core ground test
9.1.18 Crane operation
9.1.19 CT saturation
9.1.20 Current measure (cathodic protection)
9.1.21 DC winding resistance
9.1.22 Differential pressure test
9.1.23 Discharge/capacity
9.1.24 Draft tube depression
9.1.25 Earth resistivity (grounding)
9.1.26 Efficiency test
9.1.27 EMI/RFI rejection
9.1.28 Energize auxiliary power
9.1.29 Equalizing charge
9.1.30 Excitation
9.1.31 Fire code test (CO_2 and Halon-based systems)
9.1.32 Fire code test (water-based systems)
9.1.33 Fire zone
9.1.34 Float charge
9.1.35 Flushing
9.1.36 Frequency stability
9.1.37 Functional checks
9.1.38 Gas-in-oil analysis
9.1.39 Ground connection
9.1.40 Ground isolation
9.1.41 Harmonic distortion
9.1.42 High potential
9.1.43 Index
9.1.44 Initial operation
9.1.45 Initial rotation
9.1.46 Instrument transformer burden
9.1.47 Insulation power factor
9.1.48 Insulation resistance
9.1.49 Leak testing

9.1.1 AC impedance

9.1.1.1 Description of test

AC impedance of a transformer neutral reactor is measured by circulating rated current and measuring voltage, current, and power. The reactor's resistance, reactance, and losses are computed from the measurements.

9.1.1.2 Supporting documents

[B173] IEEE Std C57.16-1996, IEEE Standard Requirements, Terminology, and Test Code for Dry-Type Air-Core Series-Connected Reactors.

9.1.1.3 Equipment required

The impedance test requires one ammeter, one voltmeter, and one wattmeter. Instrument transformers may be required.

9.1.1.4 Duration/work required

Varies according to size of reactor being tested.

9.1.2 Accuracy test

9.1.2.1 Description of test

Protective relay operation is relatively infrequent. This raises the concern as to whether the relays will operate correctly in the event of a fault. Testing should subject the relays to the actual voltages and currents that would be experienced during a fault, and measurement devices should be capable of determining that the relay operated correctly within the specified time period. Specific test requirements are normally determined from manufacturers' bulletins.

9.1.2.2 Supporting documents

[B67] IEEE Std C37.102-1995, IEEE Guide for AC Generator Protection.

9.1.2.3 Equipment required

General-purpose portable relay test sets are capable of testing most relay types. These test sets include an adjustable, variable-frequency, three-phase power supply along with appropriate timers and measurement devices. Some general-purpose portable relay test sets have computer interfaces that allow the test sequences to be automated.

9.1.2.4 Duration/work required

The tests can be performed by one technician who is experienced in relay testing. Duration depends on the relay types and test equipment capability. A typical relay test session for one generator unit takes about one week, including equipment setup.

9.1.3 Air balance

9.1.3.1 Description of test

The objective in system air balancing is to direct the specified air flows, in the quantities as shown in the plans, to each of the spaces and zones detailed in the plans. The supply system should be set to provide proper quantities and the return system should be adjusted proportionately to achieve an overall balance of supply, return, and outside air.

One of the important factors in evaluating overall flow distribution is duct leakage. A 10% or less leakage is normal. This factor should be considered when setting up branch flow to provide design flow at all outlets.

Velocity within a duct is determined by traversing the duct with a pitot tube. Velocity traverses are quite accurate in the velocity range of 800 fpm and higher. Below 800 fpm a micro-manometer should be employed.

Balancing the air conditioning system requires adjusting the prime air movers. The fan should be operating at or near the design system condition of revolutions per minute (RPM), brake horse power (BHP), and static pressure before beginning duct balance. A 10% increase in fan volume requires a 10% increase in fan speed. To get 10% increase in volume, the fan must generate 21% higher static pressure and the motor must put out 34% more horsepower. Since this is not always possible, try to lessen existing duct losses before increasing fan speed.

9.1.3.2 Supporting documents

ASHRAE transactions and guides.

[B177] SMACNA, Manual on Balancing and Adjustment of Air Distribution Systems.

9.1.3.3 Equipment required

The equipment required for this test includes

— A volt-amp meter;
— A tachometer;
— A pitot tube;
— An inclined manometer, u-tube, or dry type gauge;
— A thermometer;
— Air velocity meters;
— Rotating vane anemometers; and
— Hot wire anemometers.

9.1.3.4 Duration/work required

Varies with size and type of air conditioning system. Small systems can be completed in 8 to 24 h. Some systems may require several days.

9.1.4 Air gap measurement

9.1.4.1 Description of test

The test consists of measurements at a number of different locations around the periphery of the rotor. During a slow rotation type test, the airgap is measured by hand at two locations. One location is a fixed position on the stator that measures rotor shape and the other is a fixed position on the rotor that measures stator shape. When using dedicated air gap measurement instrumentation, the unit is rotated and the measurement system is activated to automatically take the appropriate number of readings.

This test is intended to verify that the rotor-stator air gap is uniform and concentric.

This test applies to the main generator unit and can also be applied to any large rotating electrical machine.

The machine under consideration should be substantially assembled and be able to be rotated slowly for hand measurements. Measurements made by installed and dedicated instrumentation require that the unit be completely assembled and ready to be rotated at appreciable speeds.

9.1.4.2 Supporting documents

There are no applicable IEEE guides or standards, but there is a good reference available in the Canadian *Electrical Association Guide for Erection Tolerance*. In general, air gap non-uniformity should be less than about 5% of the average air gap for new units and 10% for older units. IEEE Std 1095-1989 [B22}[1] also makes reference to this measurement procedure.

9.1.4.3 Equipment required

For the slow rotation check, only a pair of measurement tapered blocks are required at each measurement location. For the test to be performed by dedicated instruments, the full instrumentation system is required to be installed, calibrated, and operational.

9.1.4.4 Duration/work required

Two people with note takers are required for the slow check along with sufficient personnel to rotate the rotor for the slow rotation check. For the automatic process, an operator is needed to rotate the unit (usually using the primer mover) and a trained person is needed to activate the measurement system.

The slow test generally takes about 1 h due to the number of times that the rotor should be turned, positioned, and stopped. The instrument test takes only a few minutes.

9.1.5 Balancing

9.1.5.1 Description of test

The purpose of this test is to determine the amount of dynamic unbalance present in the rotating system due to inherent mechanical unbalance or due to magnetic effects.

The test applies primarily to the main unit shaft system but is applicable to most rotating equipment.

The unit should be ready to be rotated at speeds up to and slightly above normal operating speed. Shaft position measurement equipment should be installed and ready to use.

The test consists of measuring the shaft position versus rotation. The direction of maximum runout on the rotor is related to the location of the unbalance force. Trial weights are added to establish a response on a subsequent test and the test is performed iteratively until a suitably low amount of runout is achieved.

9.1.5.2 Supporting documents

[B22] IEEE Std 1095-1989 (Reaff 1994), IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications.

For large hydroelectric generator units, IEEE Std 1095-1989 [B22] suggests that the run out not exceed 80% of the diametrical bearing clearance.

9.1.5.3 Equipment required

Proximity probes or other equipment suitable for detecting shaft position in two directions at each guide bearing are required to be operational.

9.1.5.4 Duration/work required

The test requires one trained operator for the measurement equipment and one station operator to rotate the unit.

[1]The numbers in brackets preceded by the letter B correspond to those of the bibliography in Annex A.

Each balance run may take up to 2 h in order to allow time for bearing temperatures to stabilize. Depending on the nature of the equipment being balanced, there may be as few as one run or there may be multiple runs to perform the balancing iterations.

9.1.6 Bearing heat run

9.1.6.1 Description of test

The purpose of this test is to ensure that bearing temperatures are stable and in the appropriate range for continued operation or further machine testing.

The test applies to all thrust and guide bearings of hydroelectric units.

The unit should be ready for prolonged operation at rated speed. It is not necessary to energize the unit unless a test is needed with hydraulic turbine loads applied.

The unit is brought to rated speed and held there. All bearing temperatures are recorded on a roughly 30 min basis. The test should continue until either the temperatures are too high or they have stabilized.

9.1.6.2 Supporting documents

[B22] IEEE Std 1095-1989 (Reaff 1994), IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications.

9.1.6.3 Equipment required

Normal bearing temperature devices are sufficient for this test.

9.1.6.4 Duration/work required

One operator and one test person to take records is sufficient. A successful test may require up to 4 h on a large bearing.

9.1.7 Bearing insulation

9.1.7.1 Description of test

The purpose of this test is to ensure that satisfactory bearing insulation is present to prevent shaft voltages from creating damaging current flow through the oil films in thrust and/or guide bearings.

The need for shaft insulation is present in all electric machines, however, it is most important for large hydroelectric units with upper bearings. On hydroelectric units the shaft system is usually grounded at the turbine end of the unit and the opposite bearing or shaft apparatus is insulated.

The unit assembly, including any equipment or parts adjacent to the insulated end of the shaft, should be completely assembled in order to check the insulation of all the appropriate parts.

An ohmmeter is used to measure the resistance across the insulation.

9.1.7.2 Supporting documents

[B5] IEEE Std 43-1974 (Reaff 1991), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

[B22] IEEE 1095-1989 (Reaff 1994), IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications.

9.1.7.3 Equipment required

An ohmmeter capable of reading high resistance (megohms) should be used.

9.1.7.4 Duration/work required

One person can easily perform the test; however, additional personnel may be needed to provide access to the required area.

The test can be performed quite quickly. The actual reading takes only a moment or two.

9.1.8 Bolted joint torque

9.1.8.1 Description of test

Fasteners do not lend themselves well to testing after they are torqued or elongated during the assembly of equipment. The quality and magnitude of the preloading is best determined by the method of preloading, preloading equipment, and procedures used during the act of preloading rather than attempts to test the fasteners after preloading.

The magnitude of fastener preloading should be determined by the OEM. If this is not available, the fasteners should be preloaded to 66% of the material yield strength, unless engineering calculations demonstrate otherwise. Torque or elongating readings of all major bolted connections should be measured and recorded during the equipment assembly.

9.1.8.2 Supporting documents

AISI, Manual of Steel Construction.

Industrial Fastener Institute standards.

OEM, assembly, or maintenance manual.

9.1.8.3 Equipment required

This test requires various fastener preloading equipment, such as manual torque wrenches, hydraulic torque wrenches, hydraulic tensioners, and other power and manual tools used for torquing or elongating fasteners during the assembly of equipment.

9.1.8.4 Duration/work required

Not applicable.

9.1.9 Braking system

9.1.9.1 Description of test

Proper operation of the unit braking system should be verified by standstill tests and simulated start sequences. Once the unit is initially mechanically operated, both the automatic and manual brake activation controls should be checked during the first couple of stops. The test consists of activating the brakes and observing that they have an appropriate effect on rotational speed. Once the unit is stopped, the capability of the brakes to hold the unit against gate leakage flow torque should also be checked by ensuring that the unit is not rotating and that the creep indication relay system is working properly.

9.1.9.2 Supporting documents

OEM assembly and O&M instructions.

9.1.9.3 Equipment required

No special equipment is required, although some sites may wish to record unit deceleration curves of speed versus time for record purposes.

9.1.9.4 Duration/work required

No extra time is needed to perform these tests since they are done as part of the stop sequence during the initial mechanical runs.

9.1.10 Bus transfer

9.1.10.1 Description of test

Bus transfer tests should be included prior to placing station service switchgear in service.

Bus transfer breakers are included to provide a backup or alternate source of station service power. Bus transfer breakers can be designed with interlocks to allow only one transfer breaker to be closed at a time. Other designs provide for both transfer breakers to be momentarily closed to provide a “no-break” transition. Typically, the design provides for automatic closing of the backup breaker if power should be lost on the preferred source breaker.

Bus transfer tests should be conducted prior to energization. When draw-out bus transfer breakers are provided, preliminary tests should be conducted with both breakers in the “test position.”

Prerequisite tests include

- Transfer time, if applicable;
- Visual inspection;
- Mechanical operation;
- Phase rotation;
- Phase relationships;
- Trip test; and
- Trip and close coil continuity.

9.1.10.2 Supporting documents

Control sequence schematic drawings.

Manufacturer’s O&M manuals.

Plant design criteria documents.

9.1.10.3 Equipment required

Once prerequisite tests are completed, a hand-held multimeter is the only test equipment required to diagnose any malfunction.

9.1.10.4 Duration/work required

If no circuitry problems are encountered, bus transfer tests typically can be completed in 2 h.

9.1.11 Calibration

9.1.11.1 Description of test

In a hydroelectric powerhouse there is an assortment of meters, instruments, detectors, and switches used to measure, detect, and control voltage, rotation, current, flow, motion, pressure, level, position, heat, light, quality, quantity, operation, failure, and protection. These devices will typically require some sort of calibration to ensure accurate readings and signals are transmitted. The calibration generally requires a test instrument to measure the known quantity. The device is connected to another test instrument to measure the output of the device. The calibration procedure is a process of adjusting the device until its output correctly represents the known input quantify.

9.1.11.2 Supporting documents

Instruments, detectors, and switches are usually supplied with instructions on the calibration techniques and adjustment procedures. Since the number and variety of these devices is great, it is not possible to list all the possible calibration references available, but the reader is referred to the O&M manuals that are typically furnished with the equipment being installed.

9.1.11.3 Equipment required

Again, because of the great variety of detectors and devices that require calibration, it is not possible to list the full complement of test equipment required. Usually a commissioning person can accomplish a majority of the calibration needed for hydroplant commissioning with a multimeter capable of reading voltages in wide ranges and continuity. Previously calibrated bridges may be necessary for other critical devices. Protective relays require special test setups and equipment. All test equipment should be calibrated by a recognized test facility and be traceable to the calibration test.

9.1.11.4 Duration/work required

The time necessary can vary from less than an hour for a single individual to a day for two or three individuals, depending on the equipment being calibrated. Generator switchboards instrument circuits takes days to check since it involves the verification of each circuit of continuity and also includes the calibration of all meters. An individual level switch may take minutes to adjust to a specific level. Position detectors may take days to calibrate and adjust on large gate operators.

9.1.12 Circuit-breaker trip

9.1.12.1 Description of test

Circuit-breaker trip tests are required prior to energizing and placing the circuit breaker in service. The purpose of this test is to ensure the breaker will trip upon closure of control switch or relay contacts. When draw-out type circuit breakers are provided, preliminary tests should be conducted with breaker in the “test position.”

Prerequisite tests include

- — Visual inspection
- — Mechanical operation
- — Phase relationship
- — Trip coil continuity
- — Circuitry tests

9.1.12.2 Supporting documents

Manufacturer's O&M manual control sequence schematic drawings.

9.1.12.3 Equipment required

Circuit breakers with integral trip devices require a breaker test set. Breakers with over-current and other protective relays require the trip contacts be mechanically pushed closed or the trip output contacts jumpered and control switches be operated.

Once the prerequisite tests are completed, only a hand-held multimeter is required to diagnose any malfunctions.

9.1.12.4 Duration/work required

Duration of trip test for any given breaker depends entirely on the complexity and number of trip sources. Approximately 15 min will be required for each trip source unless there are problems to be traced.

9.1.13 Circuitry checkout

9.1.13.1 Description of test

This is more of a process than strictly a test procedure. It involves working directly from a schematic diagram of the full circuit being checked. The checkout confirms that the circuit is in accordance with the schematic diagram. Each element in the schematic is verified to be in place and properly wired. Visual inspection is used to verify equipment nameplates, location, and quality of the wiring. Continuity testing is employed to verify proper wiring. Calibration and timing of the individual circuit elements is completed during this phase of the project. This circuitry checkout is a complete verification of the circuit, as designed, up to the operational test of the equipment. These tests should not only include testing to insure operation as designed but also include testing to verify that they cannot be inadvertently defeated (e.g., a sneak circuit).

9.1.13.2 Supporting documents

The schematic diagram of the circuit being checked out. See also visual inspection, continuity check, calibration, and timing.

9.1.13.3 Equipment required

Any equipment required for supportive tasks such as continuity checks and calibration.

9.1.13.4 Duration/work required

Dependent upon size and complexity of circuit being checked out. Full start-stop circuitry of large hydro units can take up to two weeks for two people. Simpler circuits such as governor pump circuits can be completed in one day by one individual.

9.1.14 Clearance measurement

9.1.14.1 Description of test

This test covers clearance and run out measurements of all critical hydroelectric turbine components. All measurement should be conducted by knowledgeable personnel experienced with the type of turbine to be tested. This test should be conducted both as a prestart test and during performance testing. The purpose of the test is to obtain measurements to ensure that there are no abnormalities in the condition or performance of the turbine components that could indicate improper functioning, efficiency, or incipient component failures. The following clearance measurements should be obtained:

a) Runner seal or blade tip clearance and the surface roughness;
b) Blade operating system if required;
c) Wicket gate heel-to-toe clearances, wicket gate top and bottom clearances, and wicket gate bearing diametric clearances;
d) Shaft clearance and runout;
e) Guide bearing clearance and runout;
f) Shaft seal;
g) Servomotor (gate and blade);
h) Discharge ring;
i) Spiral case and draft tube liner;
j) Cooling and seal water flow;
k) Greasing system;
l) Isolation valve control system;
m) Pressure relief valve (if any);
n) Generator-turbine shaft coupling;
o) Thrust bearing; and
p) Shaft speed sensors (governor).

9.1.14.2 Supporting documents

Turbine Manufacturer’s Instruction Book.

[B168] IEC 60041 (1992-02), Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines.

[B21] IEEE Std 810-1987 (Reaff 1994), IEEE Standard for Hydraulic Turbine and Generator Integrally Forged Shaft Couplings and Shaft Runout Tolerances.

[B22] IEEE Std 1095-1989 (Reaff 1994), IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications.

9.1.14.3 Equipment required

Because of the great variety of equipment required for the clearance measurement, it is not possible to list all the test equipment. Some of the equipment required are dial indicators, straight edges, feeler gages, plumb bobs, measuring tapes, and levels.

9.1.14.4 Duration/work required

Generally, up to four people are required for a calibration measurement. An operator is needed to check the automatic process measuring items such as wicket gates, servomotor, etc. The time can vary from 1 to 8 h.

9.1.15 Contact resistance

9.1.15.1 Description of test

Contact resistance tests for circuit breakers of all voltage classes and current ratings will ensure that contacts are firmly seated and that the breaker has not been damaged in shipping or handling.

Contact resistance tests should be conducted prior to energizing and placing breakers in service.

When draw-out type circuit breakers are provided, contact resistance measurements should be conducted with the breaker in the “test position,” otherwise, the breaker should be de-energized and disconnected from any live primary circuits. The breaker should be cycled opened and closed a few times to verify the repeatability of contact resistance.

Prerequisite tests include

— Visual inspection
— Mechanical operation
— Trip and close coil continuity

9.1.15.2 Supporting documents

[B172] IEEE Std 118-1978 (Reaff 1992), IEEE Standard Test Code for Resistance Measurements.

Manufacturer’s O&M Manuals.

9.1.15.3 Equipment required

Instrumentation should be suitable for the level of precision required. A high-current breaker should have contact resistance in the order of microhms or less. See IEEE Std 118-1978 [B172] for various test methods.

A good quality hand-held multimeter should be satisfactory for measuring contact resistance of station service and distribution breakers rated 600 A or less.

9.1.15.4 Duration/work required

A large power breaker requiring precision instruments will require approximately 4 h for each breaker.

Contact resistance measurements for distribution breakers, where the test is intended only to demonstrate functionality and where contact pressure is not adjustable can be conducted in a few minutes for each breaker.

9.1.16 Continuity checks

9.1.16.1 Description of test

This test consists of verifying conductor integrity and proper identification. All individual conductors in a circuit shown on a schematic are verified before circuitry checkout is initiated. The continuity test is usually combined with a visual inspection. A test instrument is used to measure or verify the proper conductor path for the circuit shown on the schematic. Both ends of the conductor are unterminated and one end is grounded. The other end is tested with the instrument for a path to ground, indicating full continuity from one end of the conductor to the other. An alternate method of continuity checking is to energize the circuit and see if it works, but this can lead to precipitous failure in equipment and conductors.

9.1.16.2 Supporting documents

General electrician manuals and aids are available to aid in performing the continuity test. Manuals or documents explaining the procedure may exist in the project owner's records.

9.1.16.3 Equipment required

A volt-ohm meter or "continuity checker" in the form of a battery-driven buzzer or light can be used. It is cautioned that this testing is done with all circuitry de-energized.

9.1.16.4 Duration/work required

This depends upon the experience of the individuals testing the conductors and the complexity and size of the circuitry being checked. For example, it would take two individuals about one week to complete all necessary continuity checks on the control circuitry of a medium-sized hydro generator.

9.1.17 Core ground test

9.1.17.1 Description of test

A transformer core has a single point ground to prevent voltage rise during operation. Should an inadvertent ground occur while the transformer is in service, circulating current may be generated in the core. The heat produced by this condition may produce ethylene and acetylene gas. Under extreme conditions winding insulation can be destroyed, thus causing the transformer to fail.

The core ground test requires the grounding strap to be removed and resistance measured between the core and ground with a high resistance meter.

9.1.17.2 Supporting documents

[B82] IEEE Std 62-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus—Part 1: Oil Filled Power Transformers, Regulators, and Reactors.

9.1.17.3 Equipment required

The core ground test requires a dc high resistance meter.

9.1.17.4 Duration/work required

The duration of the test depends on how easily the core ground strap is removed. On some transformers the connection is through a small bushing external to the tank. Others have internal connections that may require a manufacturer's representative or consultant. The time required to actually measure ground resistance is minimal.

9.1.18 Crane operation

9.1.18.1 Description of test

Prior to initial use, all new, reinstalled, altered, and extensively repaired or modified cranes should be tested by a qualified person to ensure compliance with referenced standards and to verify proper operation. Specific functions to be tested include the following:

Hoist lift. In an unloaded condition, the hook should be raised and lowered through a full range of travel and operating speeds. Micro drive controls, if applicable, should be tested to both upper and lower limits of travel. The limit switches at the upper and lower limits of travel will be activated at each travel cycle.

Braking system. The braking system including trolleys, trucks, and hoist/hook components should be tested in an unloaded condition. The tested components are subjected to various travel speeds with the brakes subsequently applied and stopping distance and performance observed.

Bridge and trolley traverse. The bridge and the trolley should be individually and concurrently operated over the entire travel distance.

Travel limits. During the bridge and trolley traverse test, the limit switches at each end of travel should be engaged to stop the travel of pretested component.

9.1.18.2 Supporting documents

[B157] ASME B30.2-1996, Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist).

9.1.18.3 Equipment required

There are no specific equipment requirements for the non-load tests.

9.1.18.4 Duration/work required

Setup time is minimal and actual test time is based on the size of the crane and travel distance. Tests are usually performed concurrently. A minimum of three complete test cycles are recommended for each test referenced above.

9.1.19 CT saturation

9.1.19.1 Description of test

The purpose of this test is to verify CT saturation curves furnished by the manufacturer. The test consists of applying a variable ac test voltage to the secondary winding with the primary winding open circuited and measuring secondary current. The values of applied secondary voltage and measured secondary current are usually plotted on log-log paper to match the factory data. Also, the test can be performed by energizing the primary winding from a variable ac high-current source and measuring current in the short-circuited secondary winding. However, this method is generally not used due to difficulties in obtaining a variable high ac current source.

9.1.19.2 Supporting documents

[B69] IEEE Std C57.13.1-1981 (Reaff 1992), IEEE Guide for Field Testing of Relaying Current Transformers.

Saturation curves provided by the manufacturer.

9.1.19.3 Equipment required

A variable ac test voltage source of adequate capacity. An average reading voltmeter and an rms ammeter.

9.1.19.4 Duration/work required

Setup time depends on where the CT is located and the work required to disconnect the primary circuit from the equipment in which the CT is located. The test itself requires only a few minutes.

9.1.20 Current measure (cathodic protection)

9.1.20.1 Description of test

For the purpose of commissioning, current requirements for cathodic protection systems have been previously determined during the design phase. The commissioning test verifies that the design current can be achieved and maintained by the installed system.

9.1.20.2 Supporting documents

The current requirements, both galvanic and impressed, are covered in the design documents for the cathodic protection system.

9.1.20.3 Equipment required

If the system is an impressed current type, the electrical equipment contains the appropriate meters from which to read the impressed current. If the system is a galvanic current type, it may not be necessary to measure the current for the purposes of design verification. If it is felt necessary, specific test points should be selected and the appropriate scale of a meter inserted.

9.1.20.4 Duration/work required

For an impressed current system, the effort is minimal and consists of reading a meter and checking the reading against the design requirement. A galvanic system could take approximately two people one day to determine the test points, make the meter insertion, and take the required number of readings.

9.1.21 DC winding resistance

9.1.21.1 Description of test

This test is used to locate high-resistance connections within the stator winding, main field of the rotor, and transformers. For ac windings, the resistance from phase to neutral should be recorded. Since the resistance of copper is affected by temperature, the data should be corrected to a constant temperature for trending purposes. Due to the dielectric characteristics of the insulation, the resistance reading will steadily change when the low voltage of the test equipment is applied. Sufficient time should be allowed to permit the reading to stabilize before recording the data.

9.1.21.2 Supporting documents

[B5] IEEE Std 43-1974 (Reaff 1991), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

[B6] IEEE Std 56-1977 (Reaff 1991), IEEE Guide for Insulation Maintenance of Large Alternating-Current Rotating Machinery (10 000 kVA and Larger).

[B82] IEEE Std 62-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus—Part 1: Oil Filled Power Transformers, Regulators, and Reactors.

[B84] IEEE Std 943-1986 (Reaff 1992), IEEE Guide for Aging Mechanisms and Diagnostic Procedures in Evaluating Electrical Insulation Systems.

9.1.21.3 Equipment required

A low-resistance ohmmeter or a Kelvin bridge will be required.

9.1.21.4 Duration/work required

The time required to prepare for the test is dependent upon the equipment to be tested. It can vary from a few minutes to several hours if phase isolation is required. The test itself requires only a few minutes, but following the test, the energized specimen should be allowed to discharge directly to ground until all residual charge has dissipated.

9.1.22 Differential pressure test

9.1.22.1 Description of test

The turbine servomotor differential pressure measurement is made with the servomotor moving in one direction at a slow controlled rate. The differential pressure across the effective piston area of the servomotor times the stroke of the servomotor is the required work to either open or close the turbine's gates or blades. Since the hydrodynamic forces on the turbine parts and forces generated from losses in the turbine's various mechanical components vary with the direction of the servomotor's movement, this test should be conducted in each direction. A servomotor differential pressure test provides information to confirm the adequacy of the servomotor's capacity at the governor's rated oil system pressure. Since the turbine runner design effects the test results, this test is most often conducted at or near the rated net head across the turbine.

In the simplest form for this test, each end of the turbine servomotor is instrumented with a calibrated pressure gauge and a scale is used to identify the position at every 10% of the servomotor's stroke. It is necessary to have good communications between an operator controlling the servomotor position at the governor control cabinet and the personnel monitoring and recording the data at the turbine servomotor.

9.1.22.2 Supporting documents

[B48] ASME PTC 29-1980 (R1895), Speed Governing Systems for Hydraulic Turbine-Generator Units.

9.1.22.3 Equipment required

The most basic test requires two pressure gauges and a calibrated scale located at the servomotor. More elaborate testing can be made using calibrated pressure and position feedback transducers with a chart recorder.

9.1.22.4 Duration/work required

At a minimum, two people for 1/2 day would be required to conduct the test. Note that the operating head across the turbine will limit when the test can be conducted at rated conditions.

9.1.23 Discharge/capacity

9.1.23.1 Description of test

A capacity test, usually referred to as an acceptance or a performance test, should be performed to demonstrate that the battery meets its performance specification and also to establish a baseline for comparison of the results of future periodic tests. Although many specifications call for a factory acceptance test prior to shipment, it is still a good idea to repeat the test at the owner's site before placing the battery in service. The purpose of this test is twofold:

a) To ascertain that the battery was not damaged during packaging, shipping, handling, storage, and installation; and

b) To cycle, or exercise, the battery one more time before placing it in long-term float service, as will be the case in many hydroelectric plant applications.

The performance test is designed to verify that the battery meets the manufacturer's published (or quoted) discharge characteristics with the defined initial and final conditions. It is very important to record all test parameters, both measured and calculated, and to include them in the test documentation. These parameters should include initial electrolyte specific gravity (for lead-acid types) and open circuit cell voltages, average temperature and temperature correction factor, calculated discharge current, test duration, and acceptance criteria.

9.1.23.2 Supporting documents

Manufacturer's O&M manual.

[B86] IEEE Std 450-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead-Acid Storage Batteries for Stationary Applications.

[B88] IEEE Std 485-1997, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications (BCI).

[B90] IEEE Std 1106-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Nickel-Cadmium Storage Batteries for Generating Stations and Substations.

9.1.23.3 Equipment required

This test requires a battery discharge test set, including recorder.

9.1.23.4 Duration/work required

Setup time is dependent upon the number of individual cells undergoing testing, since each cell voltage is to be recorded by the test set. The test duration can be from a few minutes to several hours. Usually, the test duration is selected to be the same as the design duty cycle that was used in sizing the battery.

9.1.24 Draft tube depression

9.1.24.1 Description of test

The test is intended to check the draft tube water depression system and its design. This performance testing should be conducted during the initial operation. Normally, the system can be initiated manually by an operator or automatically whenever the unit is motoring with the wicket gates closed. The following tests should be performed:

a) *Manual control by an operator*. Initiate the draft tube depression system with the unit not running. Observe the system air injection valve open and close within the design time. Observe the station air pressure supplying the depression system. Verify that the pressure is above the minimum system operating pressure. Observe that the system make-up air valve operates due to leakage of air through the shaft gland and leakage through the wicket gates.

b) *Automatic control (if equipped)*. Set the system control to automatic mode upon satisfactory manual system test. Start-up the unit and place the unit on-line. Close the wicket gates and motor the unit. At that point, observe the system air injection valve open and close within the design time. Observe that the unit power consumption decreases as the draft tube water level is depressed below bottom of the turbine runner. Check the station air pressure adequacy. Observe that the system make-up air valve operates on demand.

9.1.24.2 Supporting documents

[B124] IEEE Std 1010-1987 (Reaff 1992), IEEE Guide for Control of Hydroelectric Power Plants.

9.1.24.3 Equipment required

No special equipment is required.

9.1.24.4 Duration/work required

One person is normally sufficient to observe the system operation while an operator sets up the unit.

9.1.25 Earth resistivity (grounding)

9.1.25.1 Description of test

Earth resistance measurements are typically done during the preliminary design phase to support:

a) The design of the station or substation grounding system;

b) Estimating potential gradients including step and touch voltages; and

c) Design of cathodic protection systems.

This test is described here in case commissioning verification of the grounding system is warranted. The most accurate method of measuring the average resistivity of large volumes of undisturbed earth is the four-point method. Small electrodes are buried in four small holes in the earth, all at a depth of *b* and spaced (in a straight line) at intervals of *a*. A test current *I* is passed between the two outer electrodes and the potential *V* between the two inner electrodes is measured with a potentiometer or high impedance voltmeter. This procedure is repeated at several locations within the area. IEEE Std 81-1983 [B128] describes the test and calculation methodology in detail.

9.1.25.2 Supporting documents

[B128] IEEE Std 81-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System (Part 1).

9.1.25.3 Equipment required

An instrument capable of measuring the earth resistivity either by the two-, three-, or four-electrode method.

9.1.25.4 Duration/work required

The time for setting up the instrumentation and collecting the data should be approximately 4–6 h.

9.1.26 Efficiency test

9.1.26.1 Description of test

The purpose of these tests is to determine the losses present in the generator at various loads.

This test can be applied to most hydroelectric generators. However, there can be measurement or logistical difficulties where units are designed without their own bearings.

The two main methods of doing efficiency testing on hydroelectric generators are the retardation and calorimetric methods. In the former, the unit is repeatedly driven to speeds just above the normal rated speed and allowed to coast down under the appropriate conditions of current and voltage. Repeated runs are made to establish the losses at several short-circuit current levels and several open-circuit voltage levels in order to establish a relationship of loss at rated speed for each case. In calorimetric testing, several heat runs are done at specific loading conditions in order to establish the heat loss through the cooling systems and enclosure.

The unit should be ready in all respects for normal operation. A test procedure covering steps and all relevant settings and connections should be in place to ensure that correct testing steps are followed. Protection and control device settings need to be in place for each phase of the test.

9.1.26.2 Supporting documents

[B167] IEC 60034-2 (1972-01), Rotating electrical machines. Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles).

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

9.1.26.3 Equipment required

Extensive equipment is required. The test should be planned, set up, and executed by experienced personnel. One or more additional units may be required to provide back to back starting, reacceleration, and excitation supply.

9.1.26.4 Duration/work required

Tests are usually performed by one or two people, however, several electricians or mechanics may be needed to set up for the tests.

Efficiency tests can be accomplished in three to ten days depending on the complexity of the setup.

9.1.27 EMI/RFI rejection

9.1.27.1 Description of test

Equipment being commissioned for use in hydroelectric plants (new or refurbished) should be evaluated for rejection of EMI/RFI or for meeting requirements of electromagnetic compatibility (EMC). The EMC of electrical equipment in the proximity of other electrical equipment should not be compromised. Tests should be performed to evaluate the susceptibility of electrical equipment to both radiated and conducted emissions of equipment under test (EUT). Additionally, particular emphasis should be taken when known frequencies of hand-held transceivers will be used or which may be affected by the operation of the EUT. Frequencies of hand-held transceivers utilized for voice communication by plant personnel should be carefully monitored for adverse operational effects on the EUT. Conversely, the EUT should not adversely affect operation of other equipment by creation of spurious emissions. A typical test consists of operating a hand-held radio transmitter at a distance of 1 m from the equipment being tested. To pass the test, the equipment must continue to operate without a significant change (< 1%) in its operating point. This test subjects the equipment to electromagnetic radiation that is representative of the type of radiation that is likely to be present during operation of the generating station. EMC is particularly significant when a hydro plant is being commissioned as a remotely operated site. While EMC evaluations may be performed at the plant site, most of these tests should be performed by the equipment supplier at the manufacturing facility or by a testing laboratory specializing in EMI/RFI rejection testing. However, tests for compatibility from radiated emissions may be required at the plant site in the presence of existing equipment. Because of the complexity of this topic, a through review of the following references is recommended.

9.1.27.2 Supporting documents

[B160] ANSI C63.12-1987, Recommended Practice for Electromagnetic Compatibility Limits.

[B50] IEEE Std 125-1988 (Reaff 1996), IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators.

[B62] IEEE Std C37.90.2-1995, IEEE Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

[B175] MIL-STD-461D, Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference.

9.1.27.3 Equipment required

Equipment required for this test includes

- A spectrum analyzer
- A radio frequency (RF) generator
- Hand-held transceivers (if utilized for plant operation)

Additionally, suitable instrumentation should be provided at the equipment being tested in order to determine if it remains within acceptable limits of operation while being exposed to the electromagnetic radiation.

9.1.27.4 Duration/work required

The duration of these tests will depend on the number of devices and systems that will be analyzed. A typical test requires one person to observe the operation of the equipment being tested and one person to operate the EMI/RFI source equipment. Depending upon the size of the equipment being tested and the number of different EMI/RFI sources specified for the test, the duration of this test could range from less than 1 h up to approximately 2 days.

9.1.28 Energize auxiliary power

9.1.28.1 Description of test

Energizing the auxiliary power supply should take place after the station service switchgear tests are complete. This test does not include tests of the prime mover.

Prerequisite tests include

a) Engine generator (prime mover is not addressed in this guide)
    1) Visual and mechanical inspection
    2) Electrical and mechanical tests
        i) Insulation-resistance test on generator winding with respect to ground in accordance with IEEE Std 43-1974 [B5]. Determine polarization index.
        ii) Protective relay devices tested in accordance with applicable sections of this guide.
        iii) Phase relationship.
        iv) Functionally test engine shutdown for low oil pressure, overtemperature, overspeed, and other features as applicable.
        v) Vibration base-line test. Plot amplitude versus frequency for each main bearing cap.
        vi) Load bank test performed in accordance with the following schedule:

            25% rated for 30 min

            50% rated for 30 min

            75% rated for 30 min

            100% rated for 3 h
        vii) Record voltage, frequency, load current, oil pressure, and coolant temperature at periodic intervals during test.

b) Automatic transfer switches
    1) Visual and mechanical inspection
        i) Inspect for physical damage.
        ii) Compare nameplate information and connections to drawings and specifications.
        iii) Check tightness of all control and power connections.
        iv) Perform manual transfer operation.
        v) Confirm proper lubrication.

vi) Check switch to ensure positive mechanical interlock between normal and alternate sources.

vii) Ensure manual transfer warnings are attached and visible.

viii) Check that all covers, barriers, and doors are secure.

2) Electrical tests

i) Insulation-resistance tests phase-to-phase and phase-to-ground with switch in both source positions.

ii) Contact-resistance test across all main contacts.

iii) Verify settings and operation of control devices in accordance with design criteria and drawings.

iv) Calibrate and test all relays and timers including voltage and frequency-sensing relays, in-phase monitor (synchronism check), engine start and cooldown timers, transfer and retransfer timers, etc.

3) Automatic transfer tests

i) Simulate loss of normal power.

ii) Return to normal power.

iii) Simulate loss of emergency power.

iv) Simulate all forms of single-phase conditions.

9.1.28.2 Supporting documents

Acceptance testing specifications.

Design criteria documents.

Equipment drawings.

[B5] IEEE Std 43-1974 (Reaff 1991), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

NETA acceptance testing specifications.

9.1.28.3 Equipment required

Once prerequisite tests are completed, a hand-held multimeter is usually the only test equipment required to diagnose malfunction.

9.1.28.4 Duration/work required

Approximately two days will be required to energize auxiliary power and complete the prerequisite tests.

9.1.29 Equalizing charge

9.1.29.1 Description of test

An equalizing charge, sometimes called a *freshening charge* in the case of a newly installed battery, should be included in preparations for placing a battery in service. Implementation schedules will often require a battery to be stored for some time before installation and connection to the charger. Most battery manufacturers allow a limited storage period without any charging and a somewhat longer period if a trickle charger is connected. In either case it is likely that some energy has been lost from the battery through self-discharge. It is therefore very important to follow the manufacturer's instructions carefully in determining storage requirements as well as the need for an equalizing charge.

When scheduling an equalizing charge, be sure to consider the float charge duration required as a prerequisite in most performance test procedures. After an equalizing charge, batteries are usually required to float for three to seven days before the start of any performance or acceptance test.

9.1.29.2 Supporting documents

[B86] IEEE Std 450-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.

[B90] IEEE Std 1106-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Nickel-Cadmium Storage Batteries for Generating Stations and Substations.

OEM O&M manual.

9.1.29.3 Equipment required

The equipment required for this test includes a battery charger (permanent or temporary), and a digital voltmeter.

9.1.29.4 Duration/work required

Setup time is minimal if the permanent charger is installed and calibrated. Switch the charger to equalize mode, and set the equalize timer (if provided) to return the charger to float mode after a predetermined duration. If a temporary charger is to be used, the connections should be made, and the charger float and equalize voltage levels should be calibrated using a digital voltmeter. In addition, some installations require special ventilation to prevent accumulation of hydrogen during equalize charging.

9.1.30 Excitation

9.1.30.1 Description of test

The excitation current of a transformer is the current the transformer draws when rated voltage is applied to its primary terminals with the secondary terminals open. This test is one of the means used to verify that the core design and its performance is satisfactory. It provides means of detection of short-circuited turns, core bolt insulation breakdown, poor joints or contacts, core problems, etc.

The test is normally done in conjunction with the no-load loss test, with wattmeter, voltmeter, and ammeter readings being observed and recorded at each voltage level over the range of 70%–110% rated voltage. The test voltages should not exceed the rated line-to-line voltage for delta-connected windings or rated line-to-line neutral voltage for wye-connected windings. The test voltages should be the same for each phase. The excitation current can be recorded as an rms value using the average-voltage voltmeter method and expressed in per unit or in percent of the rated line current of the winding in which it is measured. Winding terminals that are normally grounded in-service should be grounded during the excitation test, except for the winding being energized. Excitation current readings taken in the field for each winding should be recorded for comparison with factory readings and with future test results.

9.1.30.2 Supporting documents

[B40] IEEE Std C57.12.90-1993, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and Guide for Short-Circuit Testing of Distribution and Power Transformers.

9.1.30.3 Equipment required

For a single-phase transformer, one ammeter, one voltmeter, one wattmeter and a single-phase voltage supply are required per test setup. Three-phase metering and supply voltage are needed for a three-phase transformer.

9.1.30.4 Duration/work required

The duration and work required varies according to type of transformer being tested (single- or three-phase). All loads should be disconnected and transformer deenergized prior to the test. Meter setup time is minimal.

9.1.31 Fire code test (CO_2 and Halon-based systems)

9.1.31.1 Description of test

The purpose of this test is to perform a National Fire Protection Association (NFPA) code or equivalent acceptance test on CO_2 or Halon-based fire protection systems. The manufacturer of the system normally supplies a recommended acceptance test procedure for the system. The acceptance test typically covers a physical check of the installed system including piping, nozzles, and extinguishing agent containers to ensure proper installation of system components, tests of supervised circuits (both electric and pneumatic), functional tests of the system's control panel, electrical and pneumatic systems, alarm systems, valves, and equipment shutdown features, and a full discharge test.

For a total flooding application, the full discharge test should measure the system discharge time, verify achievement of the specified duration of soaking concentration, and confirm that the protected area's ventilation system is properly interlocked to shut down upon detection of fire.

For a normal maintenance functional test, the system should be "puff tested" and put back into service as soon as the inspection is complete. A puff test requires flowing just enough gas to ensure discharge from all nozzles then closing the supply valves so as not to exhaust the remaining supply.

9.1.31.2 Supporting documents

[B144] NFPA 12, Carbon Dioxide Extinguishing Systems.

[B145] NFPA 12A, Halon 1301 Fire Extinguishing Systems.

[B146] NFPA 12B, Halon 1211 Fire Extinguishing Systems.

O&M, Manufacturer's Operation and Maintenance Manual for the fire detection system.

9.1.31.3 Equipment required

The following equipment is required for the discharge test:

— An accurate concentration meter capable of providing both direct readout and printout. Multiple recorders may be required for large installations;
— A stopwatch;
— Portable exhaust fan, if needed for post-test ventilation.

9.1.31.4 Duration/work required

The duration of the code test varies with the size and type of fire protection system. A small system test can be completed in 8–24 h. Larger systems may require several days.

9.1.32 Fire code test (water-based systems)

9.1.32.1 Description of test

The purpose of this test is to perform a NFPA code or equivalent acceptance test on a water-based fire protection system following installation or refurbishment of the system. These are four NFPA recognized variations of a water-based fire protection system including:

— Sprinkler systems
— Standpipe and hose systems
— Water spray fixed systems
— Foam-water sprinkler systems

In addition, the system may have a fire pump and/or a water storage tank. Applicable references for each of the NFPA recognized water-based protection systems are listed in 9.1.32.2.

In general, the NFPA code acceptance test, regardless of system type, requires a piping flushing test, a piping (and pump) hydrostatic test, a flow test, and operational tests of any water flow detection devices, remotely controlled valves, and water level alarm devices in the system. In the case of a foam-water sprinkler system, a foam discharge test and measurement of foam concentration is also required. The specific test procedures for each system variation are listed in the referenced NFPA documents. Pumps (if employed in the system) require tests verifying flow rates, system operating pressures, measurements of operating voltages, and currents and operational checks of any associated pump controllers and their accompanying control devices.

All operating parts of the system should be fully tested to assure they are in operating condition.

The operating test should also include a test of automatic detection equipment.

9.1.32.2 Supporting documents

[B147] NFPA 13, Installation of Sprinkler Systems.

[B148] NFPA 14, Standpipe and Hose Systems.

[B149] NFPA 15, Water Spray Fixed Systems.

[B150] NFPA 16, Deluge Foam-Water Sprinkler and Foam-Water Spray Systems.

[B151] NFPA 20, Centrifugal Fire Pumps.

[B152] NFPA 22, Water Tanks for Private Fire Protection.

[B153] NFPA 25, Inspection, Testing, and Maintenance of Water-Based Extinguishing Systems.

9.1.32.3 Equipment required

Depending upon the type of system some or all of the following testing equipment may be required:

— Pressure gages
— Flowmeters
— Voltmeter
— Ammeter
— Timing device

9.1.32.4 Duration/work required

The duration will vary with the size and type of the fire protection system. A small system can be completed in 8–24 h. Larger systems may require several days.

9.1.33 Fire zone

9.1.33.1 Description of test

The purpose of this test is to provide a systematic means of verifying the proper operation of all elements comprising the fire detection system within a defined zone of the entire fire detection system. These elements include detection and signaling devices in the zone, the signaling and control wiring associated with these devices, and those elements supervising or controlling the detection and signaling devices.

The test sequence requires testing and verifying that

a) Stray voltages capable of causing erroneous operation do not exist in the zone's wiring system;
b) All conductors in the zone's wiring system are isolated from ground (other than those intentionally grounded); and
c) All conductors of the system have been tested for conductor to conductor isolation.

In addition, conductor loop resistances are measured to verify that values do not exceed the manufacturer's specified limits. Other elements of the test sequence involve

— Verifying that each initiating device and associated signaling line circuit is properly monitored in regard to circuit integrity; and
— Testing these same elements together with associated supervisory elements to ensure proper alarm response.

All apparatus should be restored to normal as soon as possible after each test or alarm and kept in normal condition for operation. This includes rewiring, resetting, or replacement of equipment as necessary.

A complete record of the tests and verification of each successful zone test should be kept and be available for examination by the authorized representative(s).

9.1.33.2 Supporting documents

Manufacturer's O&M manual for the fire detection system.

[B154] NFPA 72, National Fire Alarm Code.

[B155] NFPA 72H, Testing Procedures for Local, Auxiliary, Remote Station, and Proprietary Protective Signaling Systems.

9.1.33.3 Equipment required

A volt-ohm meter or “continuity checker” in the form of a battery-driven buzzer or light can be used. It is cautioned that this testing is done with all circuitry de-energized.

9.1.33.4 Duration/work required

The duration of a fire zone test is dependent upon the number of initiating or signaling devices within the protected zone and the complexity of the wiring comprising the signaling and control circuits in the zone. As a conservative estimate, a test for a single zone should be able to be completed in less than an hour. The duration of tests on all zones comprising a complete fire detection system is in turn dependent upon the number of zones in the system.

9.1.34 Float charge

9.1.34.1 Description of test

All batteries, especially the lead-acid types, will benefit if placed on float charge as soon after delivery as possible. Implementation schedules will often require a battery to be stored for some time before installation and connection to the charger. Most battery manufacturers allow a limited storage period for wet cells without any charging and a somewhat longer period if a trickle charger is connected. It is important not to exceed the manufacturer’s recommendations on duration of storage before placing the battery on float charge.

It is also necessary to schedule the float charge duration required as a prerequisite in most battery performance test procedures. After an equalizing charge, batteries are usually required to float for three to seven days before the start of any performance or acceptance test.

9.1.34.2 Supporting documents

[B86] IEEE Std 450-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.

[B90] IEEE Std 1106-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Nickel-Cadmium Storage Batteries for Generating Stations and Substations.

OEM O&M manual.

9.1.34.3 Equipment required

This test requires the use of a battery charger (permanent or temporary), and a digital voltmeter.

9.1.34.4 Duration/work required

Setup time is minimal if the permanent charger is installed and calibrated. Verify that the charger is set to float mode. If a temporary charger is to be used, the connections should be made and the charger float and equalize voltage levels should be calibrated using a digital voltmeter.

9.1.35 Flushing

9.1.35.1 Description of test

Prior to flushing of powerhouse piping systems, all piping needs to be pressure and leak tested. Pressure testing of power plant piping systems is commonly conducted at one and one-half times the design pressure. Both the oil lubrication and governor piping systems should have a recommended cleanliness level that needs to be verified by taking a sample of the flushing solution while the flushing is in progress to verify that the proper cleanliness level has been reached.

Because of the small clearances employed in oil hydraulic valves and logic elements, the cleanliness level of the oil lubrication and governor piping systems needs to be greater and requires additional effort as compared to cleanliness levels required for water piping systems. Water systems can usually be cleaned with a fast flush using water where the fluid velocities achieved are at least three times the design levels and are maintained until the water shows no discoloration.

Oil system piping needs to be flushed with the flushing solution's flow rates at or above a Reynolds Number of 3000. Flow rates at these velocities produce turbulent flow rates in the piping system and help in transporting of the contaminates to the filtering cart or skid assembly. By using a solution flow rate with high Reynold Numbers, the time required to flush an oil piping system is reduced. Since the surface tension of the oil decreases with an increase in the flushing solution's temperature, it is common to perform a fast flush with the fluids temperature at approximately 50 °C.

9.1.35.2 Supporting documents

[B158] ANSI/SAE J1165-MAR86, Reporting Cleanliness Levels of Hydraulic Fluids.

[B164] ASME B31.1-1998, Power Piping.

OEM instruction manual.

9.1.35.3 Equipment required

This test requires filter cart assemblies or skids with properly sized pump, electric motor and heater, and flushing oil or solvents as recommended by the equipment manufacturer. For oil piping systems, oil sampling kits or contamination particle counter sensors can be used to determine when the piping cleanliness level has been achieved.

9.1.35.4 Duration/work required

For water systems the flushing times can be as short as several hours, and for oil systems the flushing time varies from several days to two weeks.

9.1.36 Frequency stability

9.1.36.1 Description of test

Electrical loads that require uninterruptible power are also, typically, the loads most affected by amplitude and frequency fluctuations in the supply voltage waveform. It is no accident that manufacturers of modern uninterruptible power supplies have developed highly stable inverter circuitry to meet the demands of critical plant equipment. Most systems employ phase-locking to ensure that the inverter output remains matched in both frequency and phase to the auxiliary source under all specified loading conditions.

Many of the systems built today require no routine field adjustments to the oscillator or gate driving circuitry. The manufacturer's instruction manual should be reviewed to determine the need for adjustments in specific installations.

9.1.36.2 Supporting documents

OEM O&M manual.

9.1.36.3 Equipment required

This test requires a frequency meter or an oscilloscope.

9.1.36.4 Duration/work required

Reference the manufacturer's instruction manual if testing or adjustments are required.

9.1.37 Functional checks

9.1.37.1 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 in strict compliance with proper safety procedures.

This test is conducted after all calibration, continuity, and circuit checkout work is completed, but prior to initial operation. It is the verification that equipment properly opens, closes, starts, stops, rotates, tilts, etc., when commanded. For example, a contact closure on a protective relay should lead to the correct action of a circuit breaker. Control and speed switches need to initiate the expected operation of brakes, turbine blades, and wicket gates.

9.1.37.2 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 a test of functional operation.

9.1.37.3 Equipment required

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

9.1.37.4 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.

9.1.38 Gas-in-oil analysis

9.1.38.1 Description of test

This is a gas chromatic lab test performed under strict procedures in the lab using a sample of oil that has been drawn into an air-tight stainless steel sampling vessel design for dissolved gas-in-oil testing. The results of the test reveal percentage of dissolved hydrocarbons, hydrogen, oxygen, and products of combustion (for utilization of used equipment, ASTM D4059-96 can be used if the polychlorinated biphenyl (PCB) content is questioned).

9.1.38.2 Supporting documents

[B35] ASTM D3612-96, Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography.

[B36] ASTM D4059-96, Standard Test Method for Analysis of Polychlorinated Biphenyls in Insulating Liquids by Gas Chromatography.

[B79] IEEE Std C57.106-1991 (Withdrawn), IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.

9.1.38.3 Equipment required

These tests are lab tests and the sampling methods and equipment are covered in the ASTM standards.

9.1.38.4 Duration/work required

The sampling process takes about 1 h for one person. Lab results can be received in one day if the owner is willing to pay for expedited service.

9.1.39 Ground connection

9.1.39.1 Description of test

Ground testing consists of verifying the absence or presence of grounds in electrical circuits. This test involves systematically searching for unintentional grounds in “ungrounded” circuits and verifying the presence of the appropriate number and locations of intentional grounds in “grounded” circuits.

9.1.39.2 Supporting documents

[B70] IEEE Std C57.13.3-1983 (Reaff 1990), IEEE Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases.

9.1.39.3 Equipment required

A volt-ohm meter is required for this test.

9.1.39.4 Duration/work required

9.1.39.5 Notes

Control and annunciator-system circuits are generally dc and operated ungrounded on both the positive and negative poles. During construction, inadvertent grounds may occur in the wiring and cabling process. These grounds must be eliminated prior to further tests.

Prior to closing control circuit breakers and energizing control circuits, the positive and negative conductor at each control circuit breaker (load side) should be tested for shorts to ground and to each other.

9.1.40 Ground isolation

9.1.40.1 Description of test

With the increasing complexity of control and backup systems in modern hydroelectric plants, the supporting station dc systems are growing both in stored energy and in total numbers of circuits. As a result, the occurrences of ground faults are seen to increase in proportion to the number of connected devices. It is therefore imperative that the dc power system is cleared of all ground faults before any of the supported system loads are connected.

The manufacturer's instruction manual for the battery charger should contain startup procedures, including measurement of output voltage balance with respect to ground. Depending on charger design, this test is done either before or after connection to the battery. The battery manufacturer's instructions should be followed for installation of intercell connection hardware, cleaning, and preparing the battery for service. The dc distribution centers and main power cables should be tested for insulation resistance before connection of the battery and charger. Once all of the main power interconnections are made, the complete system should be checked for voltage balance with respect to ground. This ensures that the dc power system is properly isolated from ground before the branch circuits are energized.

Most plant dc systems employ some method of ground detection and annunciation. Depending upon system design, it is often helpful if circuits feeding those systems are among the first to be energized. The annunciator can then be used in the identification of grounded circuits as the connections are made to the dc distribution centers.

9.1.40.2 Supporting documents

OEM O&M manuals for battery and charger.

9.1.40.3 Equipment required

Equipment required for this test includes

- A digital voltmeter;
- A ground detection relay; and
- An annunciator (if available).

9.1.40.4 Duration/work required

The amount of work involved in isolating grounds will vary in proportion to the total number of circuits. Checkout of the battery, charger, and distribution center should take no more than a couple of days. Ground isolation testing for the supported systems should be spread throughout the plant preoperational testing phase as the individual systems are energized.

9.1.41 Harmonic distortion

9.1.41.1 Description of test

The characteristic harmonics produced by converters, excitation systems, etc., require balanced impedances in the ac system and equal firing of the thyristors. If the firing circuits do not operate symmetrically so that the commutation of each device is not correct, non-characteristic harmonics are produced. These normally are small, but with a parallel resonance at one of them, they can be amplified to a value that could cause problems.

A harmonic measurement should be performed as an acceptance test, to demonstrate that the equipment and the system's converter meets the performance specification.

The purposes of current and voltage harmonic measurements are

a) To measure existing values of harmonics and comparison with recommended levels.
b) To diagnose and trouble-shoot situations in which the equipment performance is unacceptable to the utility or the user.

c) To observe existing background levels and tracking the trends in time of voltage and current harmonics.

d) To measure harmonic voltages and current with their respective phase angle to determine the harmonic driving point impedance at a given location.

9.1.41.2 Supporting documents

[B72] IEC 61000-4-7 (1991-08), Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 7: General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto.

[B76] IEEE Std 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.

9.1.41.3 Equipment required

For the measurement and analysis of harmonics, the following equipment can be used:

— *Spectrum analyzer.* A range of frequencies are scanned, and all the components, harmonics, and interharmonics are displayed.

— *Harmonic analyses or wave analyses.* The amplitude and depending on the equipment, the phase angle of a periodic function is measured.

— *Distortion analyses.* The total harmonic distortion is measured.

— *Digital harmonics measuring equipment.* The frequency range and the band width is measured.

9.1.41.4 Duration/work required

The measured and duration of these tests will depend on the number of devices and/or systems that will be analyzed. A typical test requires one person to perform the tests. Depending upon the equipment and/or system tested and the number of measurements/analyses specified, the duration could range from less than 1 h up to a few days. Additionally, the extensiveness of testing will determine the time required to perform the test.

9.1.42 High potential

9.1.42.1 Description of test

High potential testing refers to the application of a voltage to ground on the windings or voltage carrying parts of electrical apparatus. It is generally considered a “proof” test, not a diagnostic test, and is usually destructive if the insulation breaks down. There are many test variations that include using voltages that are dc stepped dc, ac normal frequency, ac very low frequency, etc. None of the variations can exactly duplicate the electrical voltage stress distribution on the insulation with the equipment in service with power flowing. Theoretically, weakened insulation will puncture when subjected to the test voltage. It is presumed if the insulation does fail during the test, it would have soon failed in service if not at initial energization. For at least some voltages and insulation types, high potential testing may be considered to degrade the insulation or decrease remaining life. Test voltages that do not significantly exceed equivalent normal operating voltages are considered by most experts to have negligible effect on insulation life.

9.1.42.2 Supporting documents

[B100] ANSI C37.85-1989 (R1995), Interrupters Used in Power Switchgear, X-Radiation Limits for AC High-Voltage Power Vacuum.

[B1] ANSI C50.10-1990, Rotating Electrical Machinery—Synchronous Machines.

[B51] ICEA S-66-524, Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (NEMA WC7-1988).

[B52] ICEA S-68-516, Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of electrical Energy (NEMA WC 8-1988).

[B81] IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing.

[B82] IEEE Std 62-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus—Part 1: Oil Filled Power Transformers, Regulators, and Reactors.

[B7] IEEE Std 95-1977 (Reaff 1991), IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage.

[B8] IEEE Std 112-1996, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

[B18] IEEE Std 433-1974 (Reaff 1991), IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Voltage at Very Low Frequency.

[B102] IEEE Std C37.09-1979 (Reaff 1988), IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

[B103] IEEE Std C37.010-1979 (Reaff 1988), IEEE Standard Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

[B105] IEEE Std C37.013-1997, IEEE Standard for AC High-Voltage Generator Circuit Breaker Rated on a Symmetrical Current Basis.

[B108] IEEE Std C37.20.1-1993 (Reaff 1998), IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

[B109] IEEE Std C37.20.2-1993, IEEE Standard for Metal-Clad and Station-Type Cubicle Switchgear.

[B111] IEEE Std C37.21-1985 (Reaff 1991), IEEE Standard for Control Switchboards.

[B37] IEEE Std C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

[B23] NEMA MG 1-1993, Motors and Generators.

9.1.42.3 Equipment required

High potential test set (with sufficient voltage output capability and type required—ac, dc, very low frequency, etc.). For extra high voltage, compressed gas insulated switchgear special gas handling and resonant type testing equipment is often required.

9.1.42.4 Duration/work required

The test averages 2 h per piece of equipment, but may vary significantly depending on equipment type and setup time. Normally requires two electricians or electrical test specialists.

9.1.42.5 Notes

Switchgear. The operating dielectric (oil, air, SF6, etc.) should be checked for moisture, contamination, etc., before high potential test.

Outdoor large oil filled transformers. On-site commissioning high potential test is not recommended.

Generators. Separate phases should be tested individually if possible.

Cables. Usually test after delivered and again after installation. Test according to manufacturer's recommendation for special insulations.

Motors. Test should be performed from switchgear.

9.1.43 Index

9.1.43.1 Description of test

An index test identifies relative turbine performance characteristics. The test requires calibration of a differential pressure system to measure relative flow through the turbine, usually Winter-Kennedy taps, either by utilizing stepped up data from a scale model test or an absolute efficiency test performed on the prototype. A turbine characteristic curve can be developed utilizing relative flow data and power measurements from the generator at incremental loads at a given head. The relative efficiency is computed at each test point from head, relative flow, and generator power. The test can be repeated at various heads to obtain the complete family of curves, or an existing family of curves can be proportionately adjusted based on a test at a single head.

While the index test provides only relative and not absolute efficiency, an index test can indicate the absolute change of efficiency if a previous test has been performed on the turbine.

9.1.43.2 Supporting documents

[B47] ASME PTC 18-1992, Hydraulic Turbines.

9.1.43.3 Equipment Required

The type of equipment required varies with the type of test instrumentation selected as follows:

a) Classical index tests utilize manometers for flow, floats for head, governor instruments for gate and blade position and a power meter. Each test station's data is recorded by a person with an instrument or measuring device.

b) Semiautomatic index tests utilize manometers or differential pressure transducers for flow, floats, or pressure transducers for head, governor instrumentation, or position transducers for gate and blade position and a power meter or transducer. Some data are recorded by personnel and some data are taken by automatic devices.

c) Automatic index tests utilize a differential pressure transducer for flow, pressure transducers for head, position transducers for gate and blade position, a power transducer, and electronic data recording equipment. A computer can also be utilized to collect and analyze the data.

9.1.43.4 Duration/work required

Numbers of personnel and test duration varies with type of test instrumentation and methodology selected. Generally, a classical test can be performed in 4 h on non-Kaplan units, excluding instrumentation installation and setup.

9.1.44 Initial operation

9.1.44.1 Description of test

This test is usually thought of as the energization and first operation of powerhouse equipment. The process started with the simpler tests of system components and now has culminated in the actual operation of the equipment itself. Individual circuits are energized sequentially and component operation is verified along with proper adjustments and indications (see calibration). After this process is completed on the auxiliary circuits, the final and full operation of the equipment or system is initiated. Usually, the equipment is brought up to a level below full operating condition and observations are made for proper operation. Then, in gradual steps, the equipment is brought up to full and complete operation. Again, verification is made for the proper control action, indication, and response to specific conditions. The final initial operation test is to observe the proper shutdown sequence of the equipment.

9.1.44.2 Supporting documents

Since the variety of equipment and systems is so great, it is impossible to list all the references necessary for this test. The reader is referred to the O&M manuals furnished with the equipment that usually cover the necessary verifications and observations to be made for initial operation. Some complex systems that consist of a multitude of subsystems, such as a hydroelectric generator, require a startup individual.

9.1.44.3 Equipment required

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

9.1.44.4 Duration/work required

The duration varies depending on the size and complexity of the equipment or system. It can vary from several hours for a battery charger to several days for a hydroelectric generator. The work effort reflects the same variance for the same reasons. For the larger systems, it is probably not practical to perform the initial test with a single individual. Starting a hydroelectric generator, for example, requires several individuals for the entire test period.

9.1.45 Initial rotation

9.1.45.1 Description of test

This test is intended to ensure that there are no mechanical obstructions preventing free rotation of the turbine or generator.

The test applies to all rotating apparatus such as pumps, motors, generators, and turbines.

The unit should be ready in all respects for rotation. It should be inspected for loose or inappropriate hardware, and any bearing forced lubrication should be operative.

The unit is slowly rotated using small amounts of force such as turning by hand for small machines or turning utilizing a few people or ropes on larger units.

9.1.45.2 Supporting documents

[B22] IEEE Std 1095-1989 (Reaff 1994), IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications.

9.1.45.3 Equipment required

No special equipment is required.

9.1.45.4 Duration/work required

One person is enough for small machines, while larger units may require several people to turn the unit and several people stationed in various parts of the unit to listen for obstructions.

A simple rotation test will take only about 2 h to set up and execute.

9.1.46 Instrument transformer burden

9.1.46.1 Description of test

Instrument transformer secondary circuit burden tests are performed to

a) Verify design calculations;
b) Help confirm circuit wiring;
c) Satisfactory contact resistances of terminal blocks and test devices; and
d) Insure that the transformer is not overloaded.

The external burden can either be calculated or measured.

Current transformers. To determine the external connected burden in volt-amperes, disconnect the burden from the transformer and measure the voltage required to drive rated current through the connected burden. If both resistive and reactive components of the burden are desired, a suitable phase angle meter can be connected.

Potential transformers. To determine the external connected burden in volt-amperes, amperes disconnect the burden from the transformer and apply rated voltage and measure the current flowing in the connected burden. If both resistive and reactive components of the burden are desired, a suitable phase angle meter can be connected.

9.1.46.2 Supporting documents

[B69] IEEE Std C57.13.1-1981 (Reaff 1992), IEEE Guide for Field Testing of Relaying Current Transformers.

9.1.46.3 Equipment required

— Three-phase power supply
— Voltmeter
— Ammeter
— Phase angle meter

9.1.46.4 Duration/work required

If the transformers are equipped with test blocks close to the transformer to quickly disconnect the secondary circuit, it should be possible to measure the burden in approximately 1 h per transformer set. If the secondary circuit must be unwired to disconnect the burden for the measurement, the duration will be dependent on the location of the transformer and its accessibility.

9.1.47 Insulation power factor

9.1.47.1 Description of test

Insulation power factor and dissipation factor are the cosine and tangent respectively of the applied test voltage and the resulting current through the insulation. For most insulations, these factors fall in the 0–0.1 (or 0 –10%) range. In this range the two factors are often used interchangeably since they differ by less than 0.005 (0.5%).

Power factor tests should be performed on each phase with the breaker in both the open and the closed position. Power factor tests should be performed on each bushing of oil-filled breakers. Use conductive straps and the hot collar procedure if bushings are not equipped with a power factor tap. The power factor of an insulation should remain constant with increasing test voltage if no discharges are present.

Insulation power factor tests are optional for medium voltage breakers with non-hygroscopic insulation.

Prerequisite tests include

a) Insulation power factor tests should be the final test prior to energization after all other tests are completed and the switchgear has been thoroughly cleaned to remove all construction dust and debris. Use only fluids or solvents specifically approved by the manufacturer.
b) Visual inspection.
c) Mechanical operation.
d) Trip and close coil continuity.
e) Phase relationship.

9.1.47.2 Supporting documents

[B82] IEEE Std 62-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus—Part 1: Oil Filled Power transformers, Regulators, and Reactors.

Manufacturer’s O&M manuals.

9.1.47.3 Equipment required

The equipment required for this test includes

— Adjustable voltage source at power frequency.
— Precision bridge for volt, amps, and watts measurement.

9.1.47.4 Duration/work required

Insulation power factor tests will require about 4 h for each breaker.

9.1.48 Insulation resistance

9.1.48.1 Description of test

This test covers all equipment in a hydroelectric facility and associated switchyards that have high-voltage insulation systems. All tests should be conducted by knowledgeable personnel experienced with the type of equipment installed and in strict compliance with proper safety procedures. Upon completion of this test the test specimen should be grounded properly and long enough to dissipate any residual charge.

This test should be conducted prior to the application of high voltage to detect any contamination or moisture on the exposed insulation surfaces. This test may also locate cracks or fissures in the insulation. The insulation resistance is the ratio of voltage to current measured with a voltmeter in conjunction with an ammeter or by a single cross-coil instrument that indicates resistance directly. The amount of applied dc voltage depends on the normal operating voltage of the test specimen. Typical applied voltages range from 500–5000 Vdc.

The insulation resistance test measures the dielectric, charging, and leakage-to-ground currents of the insulation. The test specimen is isolated from the ground and all other equipment. The high-voltage lead is connected to the test specimen. Note that when testing a three-phase winding, different values will be obtained when testing all three phases simultaneously versus each isolated phase. If testing isolated phases while the non-tested phases are grounded, the resistance values will be approximately twice that of all three phases together. If the non-tested phases are guarded, the results will be three times the result with the phases tied together.

Due to the dielectric absorption characteristics of high-voltage insulation, the resistance appears to increase from the time the voltage is applied until the test is concluded. In practice, the insulation resistance value is recorded after the voltage has been applied for 1 min. The absolute minimum for returning equipment to service is for the 1 min insulation reading to be in excess of

$$(\mathrm{VLL} + 1)\ \mathrm{M\Omega}$$

where

VLL is the line-to-line rated voltage (kV).

The insulation resistance is highly dependent upon the type of insulation and the test conditions. Resistance is inversely proportional to the temperature of the specimen and directly proportional to the relative humidity. Unless the tests are repeated under similar conditions, trending the data is ambiguous at best. Some trending value may be obtained by compensating for the temperature differences, by correcting the data to an approximate value at a specified temperature, e.g., 40 °C (see IEEE Std 43-1974 [B5]).

9.1.48.2 Supporting documents

The reader is referred to the O&M manuals furnished with the equipment and all schematic drawings of the installation.

[B5] IEEE Std 43-1974 (Reaff 1991), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

[B6] IEEE Std 56-1977 (Reaff 1991), IEEE Guide for Insulation Maintenance of Large Alternating-Current Rotating Machinery (10 000 kVA and Larger).

[B82] IEEE Std 62-1995, IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus—Part 1: Oil Filled Power transformers, Regulators, and Reactors.

[B84] IEEE Std 943-1986 (Reaff 1992), IEEE Guide for Aging Mechanisms and Diagnostic Procedures in Evaluating Electrical Insulation Systems.

9.1.48.3 Equipment required

This test requires an insulation resistance meter that can provide test voltages of 500 V– 5000 Vdc. Since the dielectric characteristics of high-voltage insulation is dependent upon the applied voltage, it is important that the dc voltage supply be regulated for a constant output, otherwise, the test results will be affected by the drift in the applied voltages.

9.1.48.4 Duration/work required

The time required to prepare for the test is dependent upon the equipment to be tested. It can take as little as few minutes, but it may take several hours if phase isolation is required. The test itself requires only a few minutes, but following the test the energized specimen should be allowed to discharge directly to ground for at least 1 h before the ground can be removed.

9.1.49 Leak testing

9.1.49.1 Description

This test is to be used as a guide to properly test an air, oil, or water system to validate that the system is capable of safe and efficient operation at its designed maximum operating pressure with no detectable leaks.

The test of an air, oil, or water system should include subjecting the equipment to a static pressure of its maximum designed operations pressure for a period specified by the OEM, or if this is not available, for a period of not less than 1 h without showing any detectable leaks or drop in pressure.

9.1.49.2 Supporting documents

[B163] ASME 1995 ASME Boiler and Pressure Vessel Code, Section V Code, Article 10, Leak Testing.

[B162] ASNT-1982, Nondestructive Testing Handbook, Volume 1—Leak Testing.

[B165] ASTM E432-91, Standard Guide for Selection of a Leak Testing Method.

[B166] ASTM E479-91, Standard Guide for Preparation of a Leak Testing Specification.

OEM, assembly or maintenance manual.

9.1.49.3 Equipment required

This test requires an appropriate system capable of supplying the required maximum desired test pressure. Any test other than basic visual inspection will require leak detection equipment, such as bubble, sonic, chemical, infrared, mass spectrometer, flow measurement, etc.

9.1.49.4 Duration/work required

The duration of the test is 4–8 h, but it may vary according to the size and complexity of the system being tested.

9.1.50 Load balance

9.1.50.1 Description of test

Occasionally, plant dc systems become so large that a single charger cannot supply the current necessary for operating loads and battery charging. Charger manufacturers have, therefore, developed control interconnection means that should allow two or more identical chargers to be connected to share the load. At time of commissioning, load sharing chargers should be adjusted to ensure that each charger will contribute its share of the load current under all system loading and charging conditions. This is generally referred to as a *load sharing* or *load balance test*.

If the battery charger is designed for load sharing operation, the manufacturer's instruction manual should contain procedures for testing and adjusting load balance. Recommendations should be given for determining the current load to be applied during adjustment as well as the acceptable level of current imbalance for the equipment under test.

9.1.50.2 Supporting documents

OEM O&M manuals for battery and charger.

9.1.50.3 Equipment required

The equipment required for this test includes

— Two digital voltmeters
— A dc load bank

9.1.50.4 Duration/work required

The load bank should be connected close to the electrical center between the chargers. In some installations this may require considerable setup time. Once the load bank is properly connected, the test usually proceeds quickly, probably no more than a couple of hours.

9.1.51 Load rejection

9.1.51.1 Description of test

The load rejection test is a unit overspeed test on load rejection. The test is performed to verify design specifications of the following systems:

a) The governor system should meet the requirements of 4.1.2 of IEEE Std 125-1988 [B50]. Following the load rejection, the speed should be returned to the set point as influenced by the speed droop/speed regulation setting.

b) The synchronous generator overspeed test should be made according to 3.13 of IEEE Std 115-1995 [B11].

c) Some hydraulic turbine systems are equipped with a pressure relief valve to minimize penstock pressure rises when the wicket gates close rapidly on load rejection. Verify the valve operates as designed, if so equipped.

d) The test should also verify the excitation system's response to the overspeed.

e) The test may also be used to document transient penstock and draft tube pressures, headcover deflection, and vertical movement of the rotating components.

9.1.51.2 Supporting documents

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

[B50] IEEE Std 125-1988 (Reaff 1996), IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators.

Original equipment instruction manuals.

9.1.51.3 Equipment required

The equipment required for this test includes

— Multi-channel strip chart recorder
— Peak holding voltmeter
— Pressure gauges
— Dial indicators
— Vibration analyzers
— Transducers for speed and gate position

9.1.51.4 Duration/work required

The testing generally require three to four people and an operator to set up the unit. The actual test time depends on the number of load rejections and the time needed to coordinate with power system requirements.

9.1.52 Load test

9.1.52.1 Description of test

Prior to initial use, all new, reinstalled, altered, extensively repaired, or modified cranes should be tested by a qualified person to ensure compliance with referenced standards and to verify proper operation. Specific functions to be tested are explained below.

The crane and appurtenant components should be tested in a loaded configuration. The test should be supervised by a designated or authorized person and a written report provided by the supervising person. The report should confirm the load rating of the crane and be placed in a file that is readily accessible to designated personnel.

The load rating should not be more than 80% of the maximum load suspended during the test. Also, test loads are not more than 125% of the rated load, unless the manufacturer recommends otherwise.

The following operations are part of the rated load test:

a) Hoist the test load a distance to assure that the load is supported by the crane and held by the hoist brake(s).
b) Transport the test load by means of the trolley for the full length of the bridge.

c) Transport the test load by means of the bridge for the full length of the runway in one direction with the trolley as close to the extreme right hand end of the crane as practical, and in the other direction with the trolley as close to the extreme left hand end of the crane as practical.

d) Lower the test load, and hold the load with the brakes(s).

9.1.52.2 Supporting documents

[B157] ASME B30.2-1996, Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist).

9.1.52.3 Equipment required

Equipment required for the load test are calibrated weights with identification showing weight. These weights could be concrete, billet steel, or water bags.

9.1.52.4 Duration/work required

Setup time is minimal and actual test time is based on the size of crane and travel distance. A minimum of three complete test cycles are recommended for all tests referenced above, except the load test. The 125% load test is generally performed only once.

9.1.53 Loop test

9.1.53.1 Description of test

The loop test can have two purposes. It may be used to energize a magnetic core to allow it to settle enough for reclamping to be established, or it may be used to energize the core to allow detection of core insulation problems.

The test is applicable to any magnetic core but is commonly applied only to the cores of larger hydrogenerators.

The core should be ready in all respects to be wound. It should be completely piled and clamped. Suitable barriers and noise warnings should be posted to prevent hearing damage.

The test consists of winding a toroidal coil around the core and energizing it with single phase ac power to establish an alternating flux in the core. If used for "shakedown" purposes, the flux density is kept to about 1/2 of normal levels and is left applied for a couple of hours. The core clamping structure is retightened afterward. If used for detection of core imperfections, the core may be energized at rated flux levels and the core overall average temperature should rise about 15 °C–20 °C. Older cores may show hot spots of up to about 10 °C while new cores would normally not have spot temperatures in excess of 5 °C above the average core temperature.

9.1.53.2 Supporting documents

There are no applicable standards; however, the calculation of test values is described in IEEE Std 56-1977 [B6].

[B6] IEEE Std 56-1977 (Reaff 1991), IEEE Guide for Insulation Maintenance of Large Alternating-Current Rotating Machinery (10 000 kVA and Larger).

9.1.53.3 Equipment required

A suitably sized single-phase power supply and the appropriate voltage and current rated cable are needed. A smaller coil of wire is wound independently on the core to measure the flux voltage directly. Hearing protection is required for all people in the test area. A means of measuring core local temperatures is also needed.

9.1.53.4 Duration/work required

A large unit may require about four to six people to wind the core and make the appropriate connections. Once underway, the test needs to be monitored by at least two people. One of these should watch the core temperature while the second monitors the power supply and flux voltage measurement.

The setup time for such a test may take a day, the test itself may take from 4–6 h if low flux levels are used, and the disassembly may take another day.

9.1.54 Lubricating/hydraulic oil check

9.1.54.1 Description of test

The following turbine/generator components require either turbine lubricating oil or hydraulic oil for proper operation. The testing of these systems is to ensure that the proper flow rates of oil exists in each of the following components:

a) Turbine oil head for Kaplan turbines (with adjustable blades);

b) Guide and thrust bearings;

c) Turbine shaft seal or packing box; and

d) Gate and blade servomotors.

This testing of the various lubricating systems can be conducted only after pressure testing, flushing and leak testing of the associated piping systems has been first completed. Additional sensors supplied in the hydraulic systems such as flow, pressure, and level switches need to be checked out and confirm the main control annunciation operates correctly. Proper checkout of the pump electric motor lead/lag controls is also required. Prior to spinning the unit it is essential that all temperature sensors used in the system have also been checked out.

The cooling water flow to the turbine shaft seal is necessary to provide proper lubrication to the rotating members of the seal.

9.1.54.2 Supporting documents

OEM instruction manual.

9.1.54.3 Equipment required

No special equipment is required.

9.1.54.4 Duration/work required

The time for the static test with the unit stationary will take approximately 2 h. However, 3–4 h will be needed when the bearing tests are being conducted and as the unit is first rotated. One person is stationed at each device and an operator is to be at the unit controls. Additional personnel should be located at the pump control panel to energize/deenergize the pump motors as required.

9.1.55 Noise measurement

9.1.55.1 Description of test

This test consists of recording noise levels at intervals of 1.0 m around the transformer tank, starting at a point in front of the main drain valve and proceeding in a clockwise direction with no fewer than four microphone locations. Noise levels should be recorded at one-third and two-thirds tank height with the transformer energized at rated voltage and frequency with no load. For transformers having an overall tank height of less than 2.4 m, measurements should be made at half height. Microphones should be 0.3 m from the major sound-producing surfaces except where fans are in operation, where the microphones should be 2.0 m away from any portion of the transformer radiators, coolers, or cooling tubes.

For reference and correction purposes, levels should be recorded of the ambient noise level with the transformer unexcited before and after the test. Noise readings should be taken with 100% and 50% of the coolers in operation.

9.1.55.2 Supporting documents

[B161] ANSI S1.4-1983 (R1997), Specification for Sound Level Meters.

[B40] IEEE Std C57.12.90-1993, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers.

9.1.55.3 Equipment required

A noise meter with a response curve.

9.1.55.4 Duration/work required

Setup time is minimal. A taut string stretched around the periphery of the transformer should be utilized to locate microphone positions.

9.1.56 No-load losses

9.1.56.1 Description of test

No-load losses are those losses that result from excitation of the transformer. They include core loss, dielectric loss, and conductor loss in the winding due to excitation current. This test is one of the means used to verify that the core design and its performance is satisfactory.

The no-load loss test is conducted with rated voltage and frequency of the transformer. The source is to be a sine-wave voltage unless a different waveform is inherent in the operation of the transformer. Losses are particularly sensitive to differences in waveform. It is therefore necessary to correct measured results to a sine-wave basis. The average-voltage voltmeter method is the recommended method for correcting measured no-load losses.

Readings taken in the field should be recorded for comparison with factory readings and with future test results.

9.1.56.2 Supporting documents

[B40] IEEE Std C57.12.90-1993, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers.

9.1.56.3 Equipment required

For a single-phase transformer, one ammeter, one RMS-responding voltmeter, one average responding voltmeter, one wattmeter, and a single-phase voltage supply are required per test setup. Three-phase metering and supply voltage are needed for a three-phase transformer.

9.1.56.4 Duration/work required

The duration and work required varies according to type of transformer being tested (single- or three-phase). All loads should be disconnected and transformer de-energized prior to the test. Meter setup time is minimal.

9.1.57 Oil dielectric strength

9.1.57.1 Description of test

This test is commonly done on insulating oils of electrical equipment such as transformers and circuit breakers. The test is a measure of the insulating quality of the oil and can be done either in the field or in a laboratory. It is a good test for the commissioning of new equipment as well as a tool for maintenance. A sample of oil is drawn under a prescribed procedure into either a test container or a shipping container. If the test is done in the field, the test container is connected to a high-voltage power supply and the specific test for dielectric strength is performed. If the test is to be performed in a lab, the shipping containers are sent to the lab.

9.1.57.2 Supporting documents

[B28] ASTM D877-87 (1995), Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes.

[B33] ASTM D1816-97, Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes.

[B79] IEEE Std C57.106-1991 (Withdrawn), IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.

9.1.57.3 Equipment required

An insulating oil dielectric strength test apparatus as described in the ASTM standards, appropriate cabling, and oil test cup (ASTM cell D877) are needed for on site testing. An oil sample may be sent to a lab for analysis if access to on site test equipment is not an option.

9.1.57.4 Duration/work required

If the oil is tested on site, approximately one individual can do the test with the proper equipment in around 1 h. Samples can be taken from the equipment in 1 h and shipped to an off site lab if the test is not done on site. Lab results can be received in one day if the owner is willing to pay for expedited service.

9.1.58 Oil quality

9.1.58.1 Description of test

This is a screening test to determine the capability of the insulating oil to perform the insulating and operating functions that are intended. The screening test is a series of tests that examine the physical properties of the oil such as dielectric strength, color, neutralization number, interfacial tension, power factor, and water content.

9.1.58.2 Supporting documents

[B28] ASTM D877-87 (1995), Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes.

[B29] ASTM D924-92, Standard Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids.

[B30] ASTM D974-97, Standard Test Method for Acid and Base Number by Color-Indicator Titration.

[B31] ASTM D1500-96, Standard Test Method for ASTM Color of Petroleum Products (ASTM Color Scale).

{B32] ASTM D1533-96, Standard Test Methods Water in Insulating Liquids (Karl Fischer Reaction Method).

[B33] ASTM D1816-97, Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origion Using VDE Electrodes.

[B34] ASTM D2285-97, Standard Test Method for Interfacial Tension Electrical Insulating Oils of Petroleum Origion Against Water by the Drop-Weight Method.

9.1.58.3 Equipment required

These tests are lab tests and the sampling methods and equipment are covered in the ASTM standards.

9.1.58.4 Duration/work required

The sampling process takes about 1 h for one person. Lab results can be received in one day if the owner is willing to pay for expedited service.

9.1.59 Open circuit saturation

9.1.59.1 Description of test

The purpose of this test is to ensure that the stator voltage characteristic curve is close to the calculated values. Sufficient agreement ensures that there are no errors in the winding connection configuration.

The test is usually applied to large hydroelectric generators as an initial check of predicted characteristics.

The generator should be fully assembled and ready to operate. The terminal voltage measurement equipment should be ready to use. The excitation system must be ready to use and placed in manual control operation.

The test consists of bringing the unit to it normal speed then slowly increasing excitation while measuring terminal voltage.

9.1.59.2 Supporting documents

[B4] IEC 60034-4 (1985-01), Rotating electrical machines—Part 4: Methods for determining synchronous machine quantities from tests.

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

9.1.59.3 Equipment required

Voltmeters and potential transformers are needed to measure the terminal voltage, and ammeters or shunts are needed to measure the field excitation current.

9.1.59.4 Duration/work required

The test can generally be done by one operator and one test person. Once set up, the test can be accomplished in about 1 h.

9.1.60 Operating coil continuity

9.1.60.1 Description of test

The purpose of this test is to verify that a complete unbroken circuit exists for the closing and trip coils of electrically operated circuit breakers and switches.

Prerequisite tests are to check operating coil nameplate voltage against trip and close voltages actually used.

9.1.60.2 Supporting documents

Manufacturer’s O&M data.

9.1.60.3 Equipment required

This test requires a good-quality multimeter.

9.1.60.4 Duration/work required

Each coil can be expected to require about 15 min depending on accessibility.

9.1.61 Overspeed

9.1.61.1 Description of test

This test consists of mechanically operating the unit using the prime mover at its maximum operating speed. The test is basically intended to check the mechanical integrity of the unit, its bearings, and its design. The unit should be thoroughly visually inspected before the test to ensure that there are no loose hardware or loose parts, especially on the rotor.

The unit is run without excitation and the speed is increased up to the agreed upon limits of turbine gate position, speed, or vibration. After shutdown the unit is reinspected to see if any effects are noticeable.

9.1.61.2 Supporting documents

[B3] IEC 60034-1 (1996-12), Rotating electrical machines—Part 1: Rating and performance.

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

9.1.61.3 Equipment required

No special equipment is required, although safety precautions should be taken to avoid personnel hazard in case of equipment failure.

9.1.61.4 Duration/work required

The duration of the test will generally be short even with time taken to stabilize bearing temperatures at rated speed and then a controlled excursion to the overspeed. The time required at overspeed is generally agreed upon by the supplier and purchaser.

9.1.62 Phase relation

9.1.62.1 Description of test

The phase relation tests are intended to ensure that phase relationships are consistent throughout the plant.

The standard phase arrangement on three-phase assembled switchgear buses and primary connections should be 1, 2, 3 or A, B, C from front to back, top to bottom, or left to right, as viewed from the main switching device operating mechanism side. Certain types of equipment may require other phasing arrangements and a neutral conductor. In these cases the phasing should be suitably indicated.

Panel mounting devices should be mounted in the same arrangement as described above as viewed from the front of the panel.

The phase sequence on connection diagrams should be such that, when considering voltage to neutral on a polyphase system with respect to the element of time, the voltage of phase 1 should reach a maximum ahead of the voltage of phase 2, phase 3, etc. This sequence should be designated as phase sequence in the order 1, 2, 3 unless otherwise suitably indicated.

The phase relationship should be verified prior to energizing any equipment at system voltage.

Given that the phase relationships are identified at the plant terminals, all three-phase equipment including auxiliary motors, motor control equipment, station service switchgear, and transformers and generators, must be phased consistently.

In some cases the phase relationship can be verified by visually tracing bus duct and tray cable.

Where cables are run in conduit, a test setup as shown in Figure 3 of IEEE Std 115-1995 [B11] should be used.

A fused single-phase low voltage source is preferred for initial phase relationship tests. Connect across phases 1-2 at source, and identify at end, then 2-3, then 3-1. With this method each phase at end can then be identified.

As a prerequisite test, check that the 3-line drawings employ consistent phase relationships.

9.1.62.2 Supporting documents

[B108] IEEE Std C37.20.1-1993 (Reaff 1998), IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

[B110] IEEE Std C37.20.3-1987 (Reaff 1992), IEEE Standard for Metal-Enclosed Interrupter Switchgear.

9.1.62.3 Equipment required

This test requires a low-voltage single-phase power source and a multimeter.

9.1.62.4 Duration/work required

Duration of phase relationship depends entirely on access and visibility. If the conductors can be visually traced back to plant terminals, approximately 1 h per piece of equipment would be required for two people to remove covers and visually trace. If tests must be set up, approximately 4 h per piece of equipment would be required.

9.1.63 Phase rotation

9.1.63.1 Description of test

The purpose of this test is to ensure proper voltage relationship between the electrical equipment and the power system.

The test applies to any large rotating electrical machine.

The unit should be ready in all respects for rotation and should also be ready to be energized.

The test consists of bringing the unit to rated speed and energizing the field until rated voltage appears across the terminals. The voltage difference between the terminals and their associated phases of the power system is measured before any attempt is made to connect the machine to the system.

9.1.63.2 Supporting documents

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

9.1.63.3 Equipment required

Two sets of voltmeters and potential transformers are required.

9.1.63.4 Duration/work required

One person is sufficient to take readings while an operator sets up the unit. The actual test should require only a few minutes. Equipment set up may take a day if the system is not arranged with appropriate potential transformers.

9.1.64 Polarity (ac)

9.1.64.1 Description of test

The purpose of this test is to verify the polarity of current and potential transformers.

The polarity of a transformer is a designation of the relative instantaneous directions of currents in the leads. Primary and secondary leads are said to have the same polarity when, at a given instant, the current enters the primary lead in question and leaves the secondary lead in question in the same direction as though the two leads formed a continuous circuit.

Polarity can be determined using a dc kick test with a dc ammeter or voltmeter and a battery. The dc voltmeter may be used for both current and potential transformers, but better results are usually obtained using a dc ammeter when testing current transformers. The instrument is connected to the secondary terminals of the transformer with the marked terminal connected to the positive terminal of the instrument. Connect the negative terminal of the battery to the primary unmarked terminal of the transformer and then sharply connect the positive terminal of the battery to the marked terminal of the transformer.

If the polarity is correctly marked for the two windings, the instrument should show a positive or upscale "kick" when the contact is made and a negative or downscale "kick" when it is broken. When testing potential transformers it is often necessary to connect the dc voltmeter across the primary terminals and the battery across the secondary terminals in order to obtain a good "kick." Some transformers are subtractive by design and will have opposite polarity from the conventional or additive transformers.

9.1.64.2 Supporting documents

Manufacturer's O&M manuals.

Three-line diagram and electrical schematics.

9.1.64.3 Equipment required

Equipment required for this test includes

— A dc voltmeter/ammeter
— Battery supply

9.1.64.4 Duration/work required

This is dependent upon the experience of the individuals testing and how much work is required in isolating the transformer for testing.

9.1.65 Polarity (dc)

9.1.65.1 Description of test

The purpose of this test is to field verify the polarity designations of dc equipment and cables.

DC equipment is usually polarity sensitive so it is imperative that all dc cables and devices be tested for verification of correct polarity prior to energizing. This is done by measuring the potential using a dc voltmeter with the positive terminal of the voltmeter connected to the positive terminal of the device.

9.1.65.2 Supporting documents

Manufacturer's O&M manuals.

Three-line diagram and electrical schematics.

9.1.65.3 Equipment required

Equipment required for this test includes

— A dc voltmeter/ammeter
— Battery supply

9.1.65.4 Duration/work required

This is dependent upon the experience of the individuals testing and how much work is required in isolating the device for testing.

9.1.66 Pressure testing

9.1.66.1 Description of Test

a) All piping should be tested at 150% of design pressure for a length of time sufficient to determine tightness (not less than 1 h). Air lines tested with water should be thoroughly dried after testing and before connecting to equipment.

b) Water supply and hydraulic systems are generally subjected to a static pressure test above the nominal system pressure.

c) Spiral case and spiral case extension are hydraulically tested when units require field welding. The test should be performed at 150% of design head including water hammer.

9.1.66.2 Supporting documents

[B156] ANSI A 40-1993, Safety Requirement for Plumbing.

[B164] ASME B31.1-1998, Power Piping.

[B147] NFPA 13, Installation of Sprinkler Systems.

9.1.66.3 Equipment required

A test pump is required on some of the tests. Additional equipment is not usually required other than that required for calibration.

9.1.66.4 Duration/work required

The duration is variable depending on the size and complexity of the equipment or system. It can vary from several hours for an emergency power diesel generator fuel oil pump piping to several days for spiral case hydrostatic test.

9.1.67 Ratios

9.1.67.1 Description of test

The purpose of this test is to field verify current transformer and potential transformer ratios. This test is not intended to certify instrument transformer accuracy or phase angle. Ratio tests should be conducted prior to energization of equipment.

Preferably ratio tests for potential transformers are conducted initially with primary leads disconnected from equipment.

Current transformers ratios should be checked with low voltage current injection and all primary sources disconnected.

If a standard transformer (one having a known polarity and ratio) is available, then a comparison test by connecting a wattmeter first to one transformer and then the other in the same circuitry can quickly establish the polarity and ratio. Alternatively, connect the primary winding of the standard and test transformers in series and the secondary windings in a series loop with the ammeter as a balance bridge across them. If the ammeter reads zero, the CTs have the same polarity and ratio.

For wound CTs where the ratio is not too large, the polarity and ratio can be established by connecting the primary and secondary windings in series with the polarity marked on the open ends and applying a convenient voltage (5 V) to the secondary winding. If the total voltage across both windings is lower than the same test with the secondary winding connected reversed, the polarity is correct. The ratio can be established by

$$E\ (\text{total}) = E\ (\text{secondary}) - M\ (\text{turn ratio}) \times E\ (\text{secondary})$$

Prerequisite tests are to check instrument transformer nameplate ratings against drawings and check connections and polarity against drawings.

9.1.67.2 Supporting documents

[B69] IEEE Std C57.13.1-1981 (Reaff 1992), IEEE Guide for Field Testing of Relaying Current Transformers.

Manufacturer’s assembly drawings.

[B176] NETA, 1995 Acceptance Testing Specifications.

Three-line diagrams.

9.1.67.3 Equipment required

This test requires a turns-ratio test set, or

— Voltage source equal to system voltage
— Current source
— Voltmeters
— Ammeters

9.1.67.4 Duration/work required

Each set of instrument transformers, potential or current, can be expected to require about 4 h depending on accessibility.

9.1.68 Servomotor timing

9.1.68.1 Description of test

This test verifies the maximum rate timing of the turbine control servomotors. These servomotors are typically operated by hydraulic pressure from a dedicated hydraulic pressure system. Other types of turbine control actuators, such as electromechanical actuators, may also be used. The principles of measuring the servomotor timing are the same, regardless of the method of actuation.

For servomotors controlling water flow through the turbine, the servomotor timing is particularly important to prevent the water hammer effect from causing the penstock to fail. A penstock failure can cause loss of life and severe damage to the surrounding area.

The timing of all turbine control servomotors contribute to the performance of the governing system, including the limitation of overspeed upon load rejection. Limitation of overspeed is important to prevent damage to the turbine and generator.

A typical timing test consists of setting the governing system to operate the servomotor at its maximum rate through its full stroke. This is done in both directions of travel, and may be done several times to verify the consistency of timing. The timing is generally tested before watering up the unit, and again after watering up. Necessary adjustments may be made to the servomotor timing during the testing process in order to achieve the desired results. Certain applications may include more than one rate limiter in each direction to be employed under various operating conditions. In these cases, the servomotor timing should be tested for each distinct timing limiter.

9.1.68.2 Supporting documents

[B48] ASME PTC 29-1980 (R1985), Speed-Governing Systems for Hydraulic Turbine-Generator Units.

[B49] IEC 60308 (1970-01), International code for testing of speed governing systems for hydraulic turbines.

[B50] IEEE Std 125-1988 (Reaff 1996), IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators.

[B124] IEEE Std 1010-1987 (Reaff 1992), IEEE Guide for Control of Hydroelectric Power Plants.

[B125] IEEE Std 1020-1988 (Reaff 1994), IEEE Guide for Control of Small Hydroelectric Power Plants.

9.1.68.3 Equipment required

An indication of servomotor position and a method of measuring time are required. This may consist of using a stop watch while watching the servomotor position indicator, or it may consist of using an oscillographic recorder connected to a servomotor position transducer. The method used to test the servomotor depends upon the degree of accuracy required along with the level of data documentation required for the installation.

9.1.68.4 Duration/work required

The setup time can vary greatly, depending upon the type of instrumentation chosen for the test. The testing generally requires one person to operate the unit and one person to make the measurements. The duration of the actual testing can vary from less than 1 h to several hours, depending upon the speed of the servomotor and the number of different timing settings. Other operational constraints may increase the time required for the test.

9.1.69 Shaft runout

9.1.69.1 Description of test

The purpose of this test is to determine the amount of runout that is present in the assembly of the shaft system.

The test applies to any shaft line assembly, but especially to large hydroelectric turbine generator units.

The shaft system is rotated slowly to a number of positions, and readings are taken from fixed datum points that are axially aligned. Four plumb wires are commonly used. The amount of shaft sideways motion and the amount of play in the system are measured.

The shaft system should be fully assembled and the bearings should be ready for slow rotation.

9.1.69.2 Supporting documents

[B21] IEEE Std 810-1987 (Reaff 1994), IEEE Standard for Hydraulic Turbine and Generator Integrally Forged Shaft Couplings and Shaft Runout Tolerances.

[B22] IEEE Std 1095-1989 (Reaff 1994), IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications.

9.1.69.3 Equipment required

Plumb wires with oil damping pots or other vertically aligned measurement equipment accurate to about .00254 cm (1/1000 in).

9.1.69.4 Duration/work required

A small number of people are needed to rotate the unit and about two people are needed at each bearing to record measurements. Once the rotation is able to be made, a full set of readings can usually be made in under half a day.

9.1.70 Short-circuit saturation

9.1.70.1 Description of test

The purpose of the test is to ensure that electromagnetic design parameters have been satisfied and the test may also serve to proof test high-current connections.

The test is normally applied to most hydroelectric generators.

The unit should be fully capable of operation in all regards.

The test consists of installation of a solid three-phase short circuit on the main terminals, followed by operation at rated speed with sufficient excitation gradually applied. The excitation level is increased until rated load stator current is circulating. Values of field current and stator current are compared to design predictions. The unit is inspected after the test of any evidence of local overheating.

9.1.70.2 Supporting documents

[B4] IEC 60034-4 (1985-01), Rotating electrical machines—Part 4: Methods for determining synchronous machine quantities from tests.

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

9.1.70.3 Equipment required

A set of connections designed for installation on the main leads in order to form the three-phase short is required. Appropriate current transformers and shunts are required to read the stator and field currents respectively. A separate source of field excitation is also needed if the exciter is the potential source type that is fed from the generator terminals.

9.1.70.4 Duration/work required

A small crew may be required to install the connections; the test can be accomplished by one instrument reader and an operator. A total of two days should be allowed for set up, test, and tear-down.

9.1.71 Specific gravity

9.1.71.1 Description of test

Specific gravity readings are recommended to be recorded on a periodic basis once a lead-acid battery is placed in service. These readings indicate not only the state of charge, but also the general condition of the battery when evaluated over time. Specific gravity readings are not recommended for nickel-cadmium batteries since the electrolyte is passive in the chemical reaction and, therefore, provides no useful information as to the state of charge or battery condition.

Recommended procedures for reading specific gravity may vary among battery manufactures, so the instruction manual should be followed in developing site-specific procedures. Generally, specific gravity measurements are meaningful only after the battery has been allowed to float for some period of time following addition of water to the cells. Lead-calcium cells may require several weeks on float charge for the electrolyte to become thoroughly “stirred.” Lead-antimony cells, on the other hand, should be stirred in just a few days because of the higher float current typical for this type battery.

Most batteries come with an O&M manual that includes instructions for reading specific gravity using a syringe type hydrometer. Electronic digital hydrometers are also available today, some with recording capabilities, that will provide enhanced accuracy and speed recording of measurements. During the commissioning phase it is highly recommended that the initial specific gravity readings be taken and recorded by the personnel responsible for periodic surveillance of the battery once it is placed in service. The reason for this is consistency of readings—changes in gravity readings over a period of time are more meaningful in the evaluation of battery condition than the absolute readings at a particular time, so it is important to achieve consistency right away. Furthermore, the format for recording battery data should be developed during this phase to ensure that the data are recorded in a consistent manner from the outset.

9.1.71.2 Supporting documents

[B86] IEEE Std 450-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.

O&M manual.

9.1.71.3 Equipment required

The equipment required for this test includes

— A hydrometer, either a syringe type or an electronic digital type.
— Safety equipment as recommended by manufacturer and as required by the facility owner.

9.1.71.4 Duration/work required

An experienced battery technician may read the specific gravity of as many as 240 cells in an hour with a recording digital hydrometer. Similar efficiency may be achieved with a non-recording hydrometer if an assistant is available to record the readings. It is best to schedule the time for these readings based on the experience level of those taking the measurements.

9.1.72 Station ground resistance

9.1.72.1 Description of test

This test is to measure the true resistance to earth of the station ground grid, irrespective of the earth's resistance and condition. The purpose of this test is to

a) Determine the actual impedance of the ground grid;

b) Provide a check on the ground calculation;

c) Determine the rise in ground potential and its variation throughout an area that may result from ground fault currents in a power system; and

d) Determine resistance between station ground grid and a remote point.

This information should provide data for verifying the adequacy of the station ground grid for providing electrical fault protection.

9.1.72.2 Supporting documents

[B128] IEEE Std 81-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System (Part 1).

[B129] IEEE Std 81.2-1991, IEEE Guide for Measurement of Impedance and Safety Characteristics of Large, Extended or Interconnected Grounding Systems (Part 2).

9.1.72.3 Equipment required

The following instruments may be used for measuring ground resistance connections:

a) Ratio ohmmeter;

b) Double balanced bridge;

c) Single balance bridge; and

d) Direct-reading ohmmeter.

9.1.72.4 Duration/work required

The time for setting up the instrumentation and collecting the data should be approximately 4–6 h. The time depends on the size of the station ground grid which determines the distance of the remote electrode from the ground electrode.

9.1.73 Sudden short circuit

9.1.73.1 Description of test

The sudden short-circuit test may be used as a proof test for winding construction and as a means of measuring various synchronous machine parameters.

The unit should be fully assembled and ready for normal operation. A thorough visual inspection should be performed before and after the test to identify changes in condition.

A high-current three-phase switch or breaker is installed on the main leads. The switch is initially open with a solid three-phase short installed on the non-machine side. The unit is brought to rated speed and an appropriate voltage level then the switch is closed. Field and stator currents are recorded along with a reference speed signal.

9.1.73.2 Supporting documents

[B4] IEC 60034-4 (1985-01), Rotating electrical machines—Part 4: Methods for determining synchronous machine quantities from tests.

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

9.1.73.3 Equipment required

High-speed data recording instruments and a large capacity shorting switch are required.

9.1.73.4 Duration/work required

A small crew will be needed to install the test equipment. A test person and an operator will be needed to perform the test. Test set up, performance, and tear down should take about 3 days.

9.1.74 Surge withstand capability

9.1.74.1 Description of test

This test subjects the equipment to electrical impulses that are representative of the type of induced voltages likely to be present during operation of the generating station. The test consists of connecting the surge withstand capability (SWC) source to all of the external wiring connections on the equipment being tested. The operation of the equipment being tested is observed to verify that its operation does not deviate beyond acceptable limits when subjected to the output of the SWC source.

9.1.74.2 Supporting documents

[B61] IEEE Std C37.90.1-1989 (Reaff 1994), IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems.

9.1.74.3 Equipment required

A suitable SWC source is needed. Typically, this will consist of an impulse generator capable of producing repetitive bursts of high voltage that can be coupled into the equipment wiring. Suitable instrumentation should be provided at the equipment being tested in order to determine if it remains within acceptable limits of operation while being exposed to the SWC pulse generator output.

9.1.74.4 Duration/work required

A typical test requires one person to observe the operation of the equipment being tested and one person to operate the SWC source equipment. Depending upon the size of the equipment being tested and the number of wiring connection points specified for the test, the duration of this test could range from less than 1 h up to approximately 2 days.

9.1.75 Telephone influence factor (TIF)

9.1.75.1 Description of test

The purpose of this test is to measure the harmonic content of the stator voltage waveform, especially in frequencies of interest to telephone communication interference.

The test is normally applied to any large salient pole synchronous machine.

The machine should be ready for operation at rated speed and rated voltage.

Once at rated speed and voltage, a full cycle of voltage waveform is recorded and analyzed for harmonic content. The various harmonic contents are tabulated with either IEC or IEEE weighing factors to arrive at balanced and residual TIF or total harmonic factor (THF).

9.1.75.2 Supporting documents

[B4] IEC 60034-4 (1985-01), Rotating electrical machines—Part 4: Methods for determining synchronous machine quantities from tests.

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

9.1.75.3 Equipment required

The exciter will generally be fed from the alternative source to avoid possible harmonic content due to exciter electronics. A suitable high speed voltage waveform recording or analyzing device is required.

9.1.75.4 Duration/work required

An operator and test technician are required. Once the machine is running the test takes a very short time.

9.1.76 Temperature

9.1.76.1 Description of test

Electrolyte temperature readings are recommended to be recorded on a periodic basis once a battery is placed in service. These readings are used in evaluating the battery state of charge as well as the general condition of the battery over a period of time. Usually, temperatures are measured and recorded for one or more representative, or “pilot,” cells rather than every cell in the battery. This is acceptable for long term surveillance. However, initial measurements need to be taken for all cells within a few weeks after the battery has been placed on float charge. In addition to establishing a baseline for future comparison, these readings should be used to verify the installation design with respect to ventilation and heating. Some battery manufacturers recommend a maximum temperature differential among connected cells of 3 °C. If greater differentials are measured among the cells of a battery, there exists a need for corrective action.

9.1.76.2 Supporting documents

[B86] IEEE Std 450-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.

[B90] IEEE Std 1106-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Nickel-Cadmium Storage Batteries for Generating Stations and Substations.

OEM O&M Manual.

9.1.76.3 Equipment required

Equipment for this test includes

— An alcohol type thermometer or an electronic digital type resistance temperature detector (RTD);

— Safety equipment as recommended by manufacturer and as required by facility owner.

9.1.76.4 Duration/work required

Alcohol type thermometers may require at least 15 min to provide an accurate reading, while digital types usually stabilize more rapidly. Adjust the planned test duration accordingly.

9.1.77 Temperature rise

9.1.77.1 Description of test

This test determines the operating temperature characteristics of various parts of the unit. The unit is operated at a steady load point and the relevant temperatures are recorded periodically until steady state is reached.

9.1.77.2 Supporting documents

[B3] IEC 60034-1 (1996-12), Rotating electrical machines—Part 1: Rating and performance.

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

9.1.77.3 Equipment required

The desired accuracy of the test results should determine the level of extra instrumentation required. For a simple recommissioning of an older unmodified unit, station equipment may suffice to ensure that nothing has changed significantly. Tests intended for performance characterization of new units or parts may be made with separate calibrated instruments and more careful loading procedures.

9.1.77.4 Duration/work required

A single load test of a small unit may be done in 3–6 h while a set of four to six runs at various loads with detailed instrumentation on larger units may take 3–4 days.

9.1.78 Threshold settings

9.1.78.1 Description of test

Threshold setting testing consists of establishing operating levels for settable control and protective devices. The testing involves testing settable devices for present settings, adjusting the settings to the desired level, and then verifying the setting.

9.1.78.2 Supporting documents

Calculated settings.

Device instruction books.

9.1.78.3 Equipment required

Calibration equipment is needed for setting mechanical devices. Relay test sets are needed for setting protective relays.

9.1.78.4 Duration/work required

9.1.78.5 Notes

Initial settings on mechanical devices should be made and verified using "bench" testing, simulation, or actual mechanical conditions where possible. Settings may have to be adjusted later when the devices are actually operating in the plant. Settings of electrical devices can usually be made "in-situ," although protective relays are usually disconnected from normal circuity via test switches.

Threshold settings should be carefully documented for later reference.

9.1.79 Timing

9.1.79.1 Description of test

Circuit breaker timing tests should be included in preparation for placing a circuit breaker in service. Verification of breaker timing compared to design requirements and manufacturer's specifications is important in order to ensure that the circuit breaker under test will play its role in the relay coordination scheme.

Timing tests are made to determine the time required for circuit breakers or components to operate during open, close, and close-open operations, and to compare circuit breaker travel and velocity values to manufacturer's acceptable limits.

All three contacts of three-phase equipment should operate at the same time within the design criteria and the manufacturer's tolerances. Uniformity between phases is especially important for circuit breakers that isolate interconnected sources such as tie breakers and generator breakers.

Circuit breaker timing tests should be conducted prior to energization. Timing trip tests, and trip coil continuity tests for non draw-out equipment should be conducted after permanent installation. Draw-out breaker elements may be tested in place or in test fixtures.

Prerequisite tests include

— Trip tests;
— Trip and close coil continuity; and
— Mechanical operation.

9.1.79.2 Supporting documents

[B105] IEEE Std C37.013-1997, IEEE Standard for AC High-Voltage Generator Circuit Breaker Rated on a Symmetrical Current Basis.

OEM O&M manuals.

Plant design criteria documents.

9.1.79.3 Equipment required

Timing tests may be made by any of the following methods:

a) An oscillograph with suitable travel indicators connected to an appropriate point or points of the circuit breaker linkage or contacts;
b) A cycle counter or interval timer to determine the time interval after the energizing of the closing or tripping circuit to the closing or parting of contacts; or
c) A time travel recorder to record graphically, as a function of time, the position of the part to which it is mechanically attached.

An oscillograph with travel indicators and time travel recorders can produce records from which the speed of the part can be calculated.

9.1.79.4 Duration/work required

High-voltage breakers and generator breakers typically require two technicians 4 h to set up and record timing data for all three phases.

9.1.80 Turn insulation

9.1.80.1 Description of test

The purpose of this test is to detect shorted turns in either stator or rotor coils.

The test may be applied to any coil consisting of two or more turns that has been electrically isolated from the rest of the unit.

The test coil is electrically isolated and a suitable waveform generating device is available.

Test description—an impulse voltage is applied to the coil leads and the voltage response to the impulse is recorded.

9.1.80.2 Supporting documents

[B83] IEEE Std 522-1992, IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating-Current Rotating Electric Machines.

9.1.80.3 Equipment required

An impulse tester capable of producing a 0.2 ms front with a voltage up to 5000 V per coil turn is required.

9.1.80.4 Duration/work required

A test technician can perform this test. Coil isolation may take up to a day and the test can be done in minutes. Coil reconnection or extraction may take significantly longer.

9.1.81 Vibration check

9.1.81.1 Description of test

The following turbine components should be checked for abnormal vibration to assure that the components are in satisfactory operating condition:

— Blade operating system (if required);

— Wicket gates;
— Guide bearing;
— Cooling and seal water flow system;
— Oil supply system including pumps and motors;
— Greasing system; and
— Thrust bearing (if part of turbine).

9.1.81.2 Supporting documents

[B174] ISO PT1, International Standard Mechanical Vibration.

Turbine manufacturer's instruction book.

9.1.81.3 Equipment required

The vibration level can be monitored with accelerometers or proximity transducers.

9.1.81.4 Duration/work required

Generally, up to two people are required for the vibration checks. The time necessary can vary up to 8 h.

9.1.82 Visual inspection

9.1.82.1 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. Unterminated wiring is insulated and stored out of the way.
e) Fuses are of proper class and rating.
f) Look for missing or broken parts and insulation or bushing cracks or tracking.
g) Check wiring for insulation cracks, bushings for cracks or tracking
h) Permanent grounding connections are in place.
i) Evidence of moisture on insulating and conducting parts.
j) Leakage in water, oil, gas, or air systems.
k) Integrity of mechanical interlocks and padlocking mechanisms.

l) Safe access to equipment.

m) Abnormal temperatures after the equipment is energized.

n) Abnormal noises when equipment is in operation.

o) Installation is complete according to installation and manufacturer's drawings and instructions.

p) Equipment nameplate ratings are in agreement with schematic diagrams.

9.1.82.2 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.

9.1.82.3 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.

9.1.82.4 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.

9.1.83 Voltage level

9.1.83.1 Description of test

Overall battery voltage should be recorded on a periodic basis once a battery is placed in service. The charger output voltmeter may be used for daily or weekly readings, provided it is checked on a regular basis for calibration. A better method would be to use a calibrated digital voltmeter to take these measurements. In addition to total voltage, the individual cell voltages should be recorded periodically, though not as often. The readings are used in evaluating the general condition of the battery over a period of time. The owner should be looking for differences in individual cell voltages among all the connected cells of a battery. The manufacturers provide details on how to evaluate voltage differentials when detected under float charge conditions as well as the proper corrective actions when they occur.

The baseline data for future comparison is normally collected during commissioning. Once a battery has been on float charge for a period long enough to assure stability, usually not more than three weeks, the baseline voltage readings may be taken. The manufacturer's recommendations should be followed to record the measurements to ensure that all accompanying readings required for meaningful evaluation are included.

9.1.83.2 Supporting documents

[B86] IEEE Std 450-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.

[B90] IEEE Std 1106-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Nickel-Cadmium Storage Batteries for Generating Stations and Substations.

OEM O&M manual.

9.1.83.3 Equipment required

Equipment required for this test includes

- A digital voltmeter
- Safety equipment as recommended by manufacturer and as required by facility owner

9.1.83.4 Duration/work required

The readings should take only a matter of minutes for a typical 60 cell battery if an assistant is available to record the cell voltage readings or if a recording voltmeter with sufficient storage capability is used.

9.1.84 Voltage measure

9.1.84.1 Description of test

Prior to energization of an impressed current cathodic protection system, several structure-to-reference potential readings should be taken at different points. The existing potential between the protected structure and the reference source should be noted. The potential difference between the protected surface and the reference source should then be brought into design specifications by energizing the rectifier and adjusting its output.

9.1.84.2 Supporting documents

The installation professional should refer to the design criteria for the specific cathodic protection system. Since these systems are unique and project specific, generic instructions do not exist.

9.1.84.3 Equipment required

A reference electrode, such as a copper-copper sulfate electrode, and a high-resistance digital voltmeter will be required.

9.1.84.4 Duration/work required

The duration depends on the size of the cathodic protection system. Time can vary between one to three days for the complete checkout of the system. The voltage measurements would typically take two people one day to perform.

9.1.85 Voltage waveform deviation

9.1.85.1 Description of Test

The purpose of this test is to determine the amount of deviation of the sinusoidal voltage waveform of the generator from the ideal sinusoid.

The test is commonly applied to any large salient pole synchronous machine.

The unit is capable of running at rated speed and rated voltage.

The unit is run at rated speed and rated voltage and a cycle of voltage waveform is recorded. The harmonics are analyzed and the deviation between the actual voltage waveform and the fundamental alone should be less than a prescribed amount.

9.1.85.2 Supporting documents

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

[B4] IEC 60034-4 (1985-01), Rotating electrical machines—Part 4: Methods for determining synchronous machine quantities from tests.

9.1.85.3 Equipment required

A high-speed scope or wave analyzer is required to get a good waveform and to analyze the fundamental magnitude.

9.1.85.4 Duration/work required

The test can be performed with a test technician and an operator. The test should take moments once the unit is running at the required condition.

9.1.86 Volumetric

9.1.86.1 Description of test

This test is performed on CO_2-based fire protection systems and is part of the NFPA code acceptance test (described in 9.1.52) used with these type of protection systems. The purpose of the test is to verify that the calculated design volumes of CO_2 required for a particular system effectively cover the fire hazard for the full period of time required by the design specifications and that all pressure operated devices function as intended. The test requires discharge of the design quantity of CO_2 for volumetric verification.

9.1.86.2 Supporting documents

Manufacturer’s O&M manual for the fire detection system.

[B144] NFPA 12, Carbon Dioxide Extinguishing Systems.

9.1.86.3 Equipment required

The following equipment is required for the volumetric test:

— An accurate concentration meter capable of providing both direct readout and printout. Multiple recorders may be required for large installations;
— Equipment for measuring weights of CO_2 cylinders;
— A stopwatch; and
— Portable exhaust fan, if needed for post-test ventilation.

9.1.86.4 Duration/work required

The duration of the volumetric test varies with the size and type of fire protection system. A test on a small system can be completed in several hours. Larger systems should require more mobilization and demobilization time.

10. Documentation

10.1 Record keeping

Construction and commissioning of a hydroelectric power plant produces a wide variety of documentation. Early in the project design phase it is necessary to develop a record-keeping system where information can be efficiently cataloged, stored, and updated. The record-keeping system should be capable of handling documentation ranging from data stored on electronic media to full-sized reproducible drawings.

Record keeping during construction and commissioning should be a precursor to an information management system that can maintain plant records after the project is declared operational. It should incorporate a distribution system that ensures the availability of all information necessary for efficient operation.

10.2 Engineering documentation

Documentation typically produced by the engineer during design and construction includes

a) Permits and licenses;
b) Equipment specifications and bidding documents;
c) Logic and flow diagrams;
d) Design and construction drawings; and
e) Progress reports.

10.3 Factory documentation

Information that is provided by the equipment manufacturers and the material suppliers includes

a) Name and address of equipment and sub-equipment suppliers;
b) Equipment manuals;
c) Equipment specifications and recommended settings;
d) Manufacturer’s drawings;
e) Recommended operating procedures;
f) Recommended maintenance procedures;
g) Factory test reports;
h) Turbine model test report;
i) Material safety data sheets;
j) Lubricant specifications;
k) Software documentation;
l) Spare parts list; and
m) Recommended commissioning tests.

10.3.1 Factory testing of equipment

Factory testing is not covered by this guide; however, the results of this testing should be reviewed prior to performing tests of the equipment in the field to ensure that the equipment is not subjected to stresses beyond what industry standards require. An example is high potential testing, which should be conducted in accordance with IEEE standards.

10.4 On-site documentation

Documentation produced during on-site commissioning and project completion includes

a) “As-built” drawings;

b) Acceptance test procedures;
c) Protective relay and instrument settings;
d) Unit commissioning reports;
e) Unit performance tests;
f) Index tests;
g) Maintenance procedures;
h) Operating procedures;
i) Inventory and spare parts lists;
j) Safety standards and procedures;
k) Signed copy of test reports;
l) Exception reports;
m) Punch lists; and
n) A final project report.

Annex A

(informative)

Bibliography

The following listing of industry standards, recommended practices, and guides are provided as a helpful resource to the engineer engaged in hydroelectric power plant rehabilitation. The engineer is encouraged to review documents that apply to the desired commissioning test.

A.1 Generators and motors

[B1] ANSI C50.10-1990, Rotating Electrical Machinery—Synchronous Machines.

[B2] ANSI C50.12-1982, Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications.

[B3] IEC 60034-1 (1996-12), Rotating electrical machines—Part 1: Rating and performance.

[B4] IEC 60034-4 (1985-01), Rotating electrical machines—Part 4: Methods for determining synchronous machine quantities from tests.

[B5] IEEE Std 43-1974 (Reaff 1991), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

[B6] IEEE Std 56-1977 (Reaff 1991), IEEE Guide for Insulation Maintenance of Large Alternating-Current Rotating Machinery (10 000 kVA and Larger).

[B7] IEEE Std 95-1977 (Reaff 1991), IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage.

[B8] IEEE Std 112-1996, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.

[B9] IEEE Std 113-1985 (Withdrawn), IEEE Guide: Test Procedures for Direct Current Machines.

[B10] IEEE Std 114-1982, IEEE Standard Test Procedure for Single-Phase Induction Motors.

[B11] IEEE Std 115-1995, IEEE Guide: Test Procedures for Synchronous Machines, Part I—Acceptance and Performance Testing, Part II—Test Procedures and Parameter Determination for Dynamic Analysis.

[B12] IEEE Std 117-1974, IEEE Standard Test Procedure for Evaluation of Systems of Insulating Materials for Random-Wound AC Electric Machinery.

[B13] IEEE Std 275-1992, IEEE Recommended Practice for Thermal Evaluation of Insulation Systems for Alternating-Current Electric Machinery Employing Form-Wound Preinsulated Stator Coils for Machines Rated 6900 V and Below.

[B14] IEEE Std 304-1977 (Reaff 1991), IEEE Standard Test Procedure for Evaluation and Classification of Insulation Systems for Direct-Current Machines.

[B15] IEEE Std 399-1990, IEEE Recommended Practice for Industrial and Commercial Power System Analysis.

[B16] IEEE Std 429-1994, IEEE Recommended Practice for Thermal Evaluation of Sealed Insulation Systems for AC Electric Machinery Employing Form-Wound Preinsulated Stator Coils for Machines Rated 6900V and Below.

[B17] IEEE Std 432-1992, IEEE Guide for Insulation Maintenance for Rotating Electric Machinery (5 hp to less than 10 000 hp).

[B18] IEEE Std 433-1974 (Reaff 1991), IEEE Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Voltage at Very Low Frequency.

[B19] IEEE Std 434-1973 (Reaff 1991), IEEE Guide for Functional Evaluation of Insulation Systems for Large High-Voltage Machines.

[B20] IEEE Std 492-1974 (Reaff 1986) (Withdrawn), IEEE Guide for Operation and Maintenance of Hydrogenerators.

[B21] IEEE Std 810-1987 (Reaff 1994), IEEE Standard for Hydraulic Turbine and Generator Integrally Forged Shaft Couplings and Shaft Runout Tolerances.

[B22] IEEE Std 1095-1989 (Reaff 1994), IEEE Guide for Installation of Vertical Generators and Generator/Motors for Hydroelectric Applications.

[B23] NEMA MG 1-1993, Motors and Generators.

[B24] NEMA MG 2-1989, Safety Standard for Construction and Guide for Selection, Installation, and Use of Electric Motors and Generators.

[B25] NEMA MG 10-1994, Energy Management Guide for Selection and Use of Polyphase Motors.

[B26] UL 547-1991, Thermal Protectors for Motors.

[B27] UL 1004-1994, Electric Motors.

A.2 Transformers

[B28] ASTM D877-87 (1995), Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes.

[B29] ASTM D924-92, Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids.

[B30] ASTM D974-97, Standard Test Method for Acid and Base Number by Color-Indicator Titration.

[B31] ASTM D1500-96, Standard Test Method for ASTM Color of Petroleum Products (ASTM Color Scale).

[B32] ASTM D1533-96, Water in Insulating Liquids (Karl Fischer Reaction Method).

[B33] ASTM D1816-9, Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes.

[B34] ASTM D2285-97, Standard Test Method for Interfacial Tension of Electrical Insulating Oils of Petroleum Origin Against Water by the Drop-Weight Method.

[B35] ASTM D3612-96, Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography.

[B36] ASTM D4059-96, Standard Test Method for Analysis of Polychlorinated Biphenyls in Insulating Liquids by Gas Chromatography.

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[B38] IEEE Std C57.12.01-1989 (Withdrawn), IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those with Solid Cast and/or Resin-Encapsulated Windings.

[B39] IEEE Std C57.12.56-1986 (Reaff 1993), IEEE Standard Test Procedure for Thermal Evaluation of Insulation Systems for Ventilated Dry-Type Power and Distribution Transformers.

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[B41] IEEE Std C57.12.91-1995, IEEE Test Code for Dry-Type Distribution and Power Transformers.

[B42] IEEE Std C57.92-1981 (Reaff 1991), IEEE Guide for Loading Mineral-Oil-Immersed Power Transformers up to and Including 100 MVA with 55 C or 65 C Average Winding Rise.

[B43] IEEE Std C57.94-1982 (Reaff 1987), IEEE Recommended Practice for Installation, Application, Operation, and Maintenance of Dry-Type General Purpose Distribution and Power Transformers.

[B44] IEEE Std C57.98-1993, IEEE Guide for Transformer Impulse Tests.

[B45] IEEE Std 799-1987 (Reaff 1992), IEEE Guide for Handling and Disposal of Transformer Grade Insulating Liquids Containing PCBs.

[B46] UL 1561-1994, Dry-Type General Purpose and Power Transformers.

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[B48] ASME PTC 29-1980 (R1985), Speed Governing Systems for Hydraulic Turbine Generator Units.

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[B50] IEEE Std 125-1988 (Reaff 1996), IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators.

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[B52] ICEA S-68-516, Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy (NEMA WC 8-1988).

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[B54] IEEE Std 400-1991, IEEE Guide for Making High-Direct-Voltage Tests on Power Cable Systems in the Field.

[B55] NEMA VE 1-1991, Metal Cable Tray Systems.

[B56] NEMA WC 50-1976 (R1993), Ampacities, Including Effect of Shield Losses for Single-Conductor Solid-Dielectric Power Cable 15 kV Through 69 kV.

[B57] NEMA WC 51-1986 (R1991), Ampacities of Cables in Open-Top Cable Trays.

[B58] UL 1072-1995, Medium-Voltage Power Cables.

[B59] UL 1277-1996, Electrical Power and Control Tray Cables with Optional Optical-Fiber Members.

[B60] UL 1569-1995, Metal-Clad Cables.

A.5 Protection and relaying

[B61] IEEE Std C37.90.1-1989 (Reaff 1994), IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems

[B62] IEEE Std C37.90.2-1995, IEEE Standard Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

[B63] IEEE Std C37.91-1985 (Reaff 1990), IEEE Guide for Protective Relay Applications to Power Transformers.

[B64] IEEE Std C37.96-1988 (Withdrawn), IEEE Guide for AC Motor Protection.

[B65] IEEE Std C37.97-1979 (Reaff 1990), IEEE Guide for Protective Relay Applications to Power Systems Buses.

[B66] IEEE Std C37.101-1993, IEEE Guide for Generator Ground Protection.

[B67] IEEE Std C37.102-1995, IEEE Guide for AC Generator Protection.

[B68] IEEE Std C37.106-1987 (Reaff 1992), IEEE Guide for Abnormal Frequency Protection for Power Generating Plants.

[B69] IEEE Std C57.13.1-1981 (Reaff 1992), IEEE Guide for Field Testing of Relaying Current Transformers.

[B70] IEEE Std C57.13.3-1983 (Reaff 1990), IEEE Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases.

[B71] IEEE Std 242-1986 (Reaff 1991), IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.

A.6 Excitation

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[B74] IEEE Std 421.2-1990, IEEE Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control Systems.

[B75] IEEE Std 421.3 (Draft 1995), High-Potential Test Requirements for Excitation Systems for Synchronous Machines.

[B76] IEEE Std 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.

A.7 Insulation

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[B78] IEEE Std C37.90-1989 (Reaff 1994), IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus.

[B79] IEEE Std C57.106-1991 (Withdrawn), IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.

[B80] IEEE Std 1-1986 (Reaff 1992), IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.

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A.8 Batteries, ups, and standby power systems

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[B87] IEEE Std 484-1987, IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations.

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[B92] NEMA PE 5-1985 (Reaff 1991), Utility Type Battery Chargers.

[B93] UL 1236-1994, Battery Chargers for Charging Engine-Starter Batteries.

[B94] UL 1564-1993, Industrial Battery Chargers.

A.9 Breakers, switchgear, panelboards, and motor control centers

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[B96] ANSI C37.12-1991, Specification Guide for AC High-Voltage Circuit Breakers Based on a Symmetrical Current Basis.

[B97] ANSI C37.16-1988, Low Voltage Power Circuit Breakers and AC Power Circuit Protectors, Preferred Ratings, Related Requirements, and Application Recommendations.

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[B149] NFPA 15, Water Spray Fixed Systems.

[B150] NFPA 16, Deluge Foam-Water Sprinkler and Foam-Water Spray Systems.

[B151] NFPA 20, Centrifugal Fire Pumps.

[B152] NFPA 22, Water Tanks for Private Fire Protection.

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