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Maintenance Scheduling for Electrical Equipment

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This document establishes minimum recommended practices for maintenance of electrical equipment in Bureau of Reclamation hydroelectric power and large pumping plants. Included in this document are recommended maintenance activities, maintenance interval, and references.

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Volume 4-1B

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Acronyms and Abbreviations

AC	alternating current
AEIC	Association of Edison Illuminating Companies
ANSI	American National Standards Institute
AVR	automatic voltage regulator
BIL	basic impulse insulation level
CBM	condition-based maintenance
CCVT	Coupling capacitor/voltage transformers
CFR	Code of Federal Regulations
CIPP	Critical Infrastructure Protection Plans
CO_2	carbon dioxide
DC	direct current
DGA	dissolved gas analysis
EHV	extra high voltage
EPSS	Emergency Power Standby Systems
EPRI	Electric Power Research Institute
FIST	Facilities Instructions, Standards, and Techniques
GPRA	Government Performance and Results Act
GSU	generator step-up
HECP	Hazardous Energy Control Program
hp	horsepower
HVDC	high-voltage direct current
Hipot	high potential tests
IEEE™	Institute of Electrical and Electronics Engineers
IR	infrared
JHA	job hazard analysis
kV	kilovolt
kVA	kilovoltampere
NERC	North American Electric Reliability Council
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
OMB	Office of Management and Budget
O&M	operations and maintenance
OSHA	Occupational Safety and Health Administration
PEB	Power Equipment Bulletin
PO&M	Power Operation and Maintenance
PM	preventive maintenance
PSS	power system stabilizer
RCM	reliability-centered maintenance
Reclamation	Bureau of Reclamation
RSHS	*Reclamation Safety and Health Standards*
SCADA	Supervisory Control and Data Acquisition
SFRA	sweep frequency response analysis
Vac	volts alternating current
Vdc	volts direct current
WAPA	Western Area Power Administration
WECC	Western Electricity Coordinating Council
WG	working group
XLPE	crosslinked polyethylene

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November 2005 Summary of Major Revisions

Note: Added sections are highlighted, and changes are highlighted.

Added:	Section 1.1.5, Combination of Condition-Based and Time-Based Preventive Maintenance
Added	Section 1.5, Job Plan Templates
Added:	Section 1.6, Power O&M Forms
Moved:	Section 26, Potheads and Stresscones to Section 8 (to be with Cables)
Added:	Section 9, Coupling Capacitors and moved all subsequent sections up one number.
Added:	Section 17, Engine Generators (Emergency Standby Power Systems) and moved all subsequent section up one number.
Moved:	Section 22, Meters, to Section 30, and combined with Transducers
Deleted:	Section 24, Insulating Oil; this is covered in sections on specific equipment
Deleted:	Section 27, Voltage Regulator
Added:	Section 32, Transformer Fire Suppression Systems
Updated:	NFPA 70B references to the 2002 Edition
Added	In Appendix A, Operating Time

1. Introduction

1.1 Maintenance

1.1.1 General

This document is intended to establish standard practice as well as to give general advice and guidance in the maintenance of electrical equipment owned and operated by the Bureau of Reclamation. Specific technical details of maintenance are included in other documents which are referenced in this document. Power Equipment Bulletins are available only to Reclamation personnel and may be found on the intranet at http://intranet.usbr.gov/~hydrores/.

Maintenance recommendations are based on industry standards and experience in Reclamation facilities. However, equipment and situations vary greatly, and sound engineering and management judgment must be exercised when applying these recommendations. Other sources of information must be consulted (e.g., manufacturer's recommendations, unusual operating conditions, personal experience with the equipment, etc.) in conjunction with these maintenance recommendations.

1.1.2 Preventive Maintenance

Preventive maintenance (PM) is the practice of maintaining equipment on a regular schedule, based on elapsed time, run-time meter readings, or number of operations. The intent of PM is to "prevent" maintenance problems or failures before they take place by following routine and comprehensive maintenance procedures. The goal is to achieve fewer, shorter, and more predictable outages.

Some advantages of preventive maintenance are:

- It is predictable, making budgeting, planning, and resource leveling possible.
- When properly practiced, it generally prevents most major problems, thus reducing forced outages, "reactive maintenance," and maintenance costs in general.[1]
- It gives managers a level of assurance that equipment is being maintained.
- It is easily understood and justified.

Preventive maintenance does have some drawbacks:

- It is time consuming and resource intensive.
- It does not consider actual equipment condition when scheduling or performing the maintenance.
- It can cause problems in equipment in addition to solving them (e.g., damaging seals, stripping threads).

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[1] *World Class Maintenance Management*, Terry Wireman, Industrial Press Inc., 1990, pg. 7, 73.

Despite these drawbacks, PM generally has proven to be reliable in the past and is still the core of most maintenance programs.

Traditionally, preventive maintenance has been the standard maintenance practice in Reclamation. The maintenance recommendations in this document are based on a PM philosophy and should be considered as "baseline" practices to be used when managing a maintenance program.

However, care should be taken in applying PM recommendations. Wholesale implementation of PM recommendations without considering equipment criticality or equipment condition may result in a workload that is too large to achieve. This could result in important equipment not receiving needed maintenance, which defeats the purpose of PM.

To mitigate this problem, maintenance managers may choose to apply a ***consciously chosen, effectively implemented, and properly documented*** reliability-centered maintenance (RCM) program or augment PM with condition-based maintenance (CBM) practices.

Whether utilizing a PM, RCM, or CBM, or a combination of these, the primary focus of the in-house maintenance staff should be scheduled maintenance.[2] This will reduce reactive (emergency and corrective) maintenance. Scheduled maintenance should have a higher priority than special projects. Scheduled maintenance should be the number one priority.

1.1.3 Reliability Centered Maintenance

Reliability-centered maintenance programs are gaining in popularity and have been piloted in a few Reclamation power facilities with good results. The goal of these programs is to provide the appropriate amount of maintenance at the right time to prevent forced outages while at the same time eliminating unnecessary maintenance.

Implemented properly, RCM can eliminate some of the drawbacks of preventive maintenance and may result in a more streamlined, efficient maintenance program. RCM seems very attractive in times of diminishing funding, scarcity of skilled maintenance staff, and the pressure to "stay online" due to electric utility industry deregulation.

Some features of RCM are:

- Labor intensive and time consuming to set up initially.
- May require additional monitoring of quantities like temperature and vibration to be effective. This may mean new monitoring equipment with its own PM or more human monitoring with multiple inspections.
- May result in a "run-to-failure" or deferred maintenance philosophy for some equipment with its own PM, which may cause concern for some staff and managers.

[2] *World Class Maintenance Management*, Terry Wireman, Industrial Press Inc., 1990, pg. 32.

- May require initial and later revisions to the maintenance schedule in a "trial-and-error" fashion depending on the success of the initial maintenance schedule and equipment condition.

- Should result in a more manageable maintenance workload focused on the most important equipment.

RCM is not an excuse to move to a "breakdown maintenance" philosophy or to eliminate critical preventive maintenance in the name of reducing maintenance staff/funding. However, to mitigate problems associated with a PM program, maintenance managers may choose to apply a ***consciously chosen, effectively implemented, and properly documented*** RCM program.

For RCM to be a viable program at Reclamation facilities, it must:

- Be chosen as the local maintenance philosophy by management.

- Be implemented according to generally accepted RCM practices.

- Be documented so that maintenance decisions are defensible.

1.1.4 Condition-Based Maintenance

This program relies on knowing the condition of individual pieces of equipment.

Some features of CBM include:

- Monitoring equipment parameters such as temperatures, pressures, vibrations, leakage current, dissolved gas analysis, etc.

- Testing on a periodic basis and/or when problems are suspected such as Doble testing, vibration testing, and infrared scanning.

- Careful monitoring of operator-gathered data.

- Results in knowledgeable maintenance decisions which would reduce overall costs by focusing only on equipment that really needs attention.

Drawbacks to CBM include it being very difficult and expensive to monitor some quantities. It requires knowledgeable and consistent analysis to be effective, and condition monitoring equipment and systems themselves require maintenance. Because of these drawbacks, it is nearly impossible to have an entirely condition-based maintenance program.

1.1.5 Combination of Condition-Based and Preventive Maintenance

A combination of condition-based maintenance and preventive maintenance is perhaps the most practical approach. Monitoring, testing, using historical data, and preventive maintenance schedules may provide the best information on when equipment should be maintained. By keeping accurate records of the "as found" condition of equipment when it is torn down for maintenance, one can determine what maintenance was really necessary. In this manner, maintenance schedules can be lengthened or perhaps shortened, based on experience and monitoring.

1.2 Standards and References

1.2.1 Reclamation Standards

Electrical maintenance recommended practices for some equipment are contained in other Facilities, Instructions, Standards, and Techniques (FIST) volumes that will be referenced in this volume. For equipment not covered by other FIST volumes, requirements defined in this document are the recommended practices. Manufacturer's maintenance requirements, as defined in instruction books, also must be incorporated into a complete maintenance program. Other recommended maintenance practices are defined in Power Equipment Bulletins (PEB).

Variance from Reclamation electrical maintenance recommended practices, as defined in FIST volumes, is acceptable provided that proper documentation exists to support the variance. Refer to the *Power Review of O&M Directive and Standard* and *Guidebook* for further information (see section 1.7).

Recommended practices, including recommended intervals defined in FIST volumes, are based on power industry best practices, published standards, and Reclamation's experience maintaining equipment in hydroelectric powerplants. This FIST volume includes references to published standards produced by the Institute of Electrical and Electronics Engineers (IEEE™), National Fire Protection Association (NFPA), and other professional organizations, where they exist. Additional references to published standards may be found in other FIST volumes.

To access Reclamation's FIST volumes:

- Printed FIST volumes:

  Regional and Area Offices – via Form DI-1 or 7-702 to D-7913, telephone (303) 445-3655. Denver Office via form MS-810 to D-7913. All others - contact National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161.

- Intranet access to FIST volumes: http://intra.usbr.gov
  Select: Quicklist; Power O&M.

- Access to Internet FIST volumes: www.usbr.gov
  Select: Programs & Activities, Power Program, Reports & Data; FIST Manuals.

This FIST volume supersedes, in part, *Power Operation and Maintenance (O&M) Bulletin No. 19 - Maintenance Schedules and Records*. Mechanical maintenance portions of *Power O&M Bulletin No. 19* are included in *FIST Volume 4-1A, Maintenance Scheduling for Mechanical Equipment*.

1.2.2 Recommended Standards and References

Current editions of the following published standards and references should be maintained locally for use by electrical engineers, electrical foremen, electrical supervisors, and other O&M personnel:

- FIST Volume 1-1, Hazardous Energy Control Program

- Copies of all Electrical Maintenance and Safety FIST Volumes
- Copies of all Electrical Power Equipment Bulletins
- Manufacturers' instruction/maintenance manuals for all equipment
- *NFPA 70 - National Electric Code* (The handbook can be more useful than the code because of the included explanations and drawings.)
- *NESC (National Electrical Safety Code) American National Standards Institute (ANSI) C2 and Handbook* - available through IEEE/ANSI
- *NFPA 70B – (2002 Edition) Recommended Practice for Electrical Equipment Maintenance*
- *NFPA 70E – Standard for Electrical Safety in the Work Place*
- *NFPA 101 - Life Safety Code®*
- *Reclamation Safety and Health Standards*
- Occupational Safety and Health Administration (OSHA) Code of Federal Regulations (CFR) 29 Part 1910.310-399 - Electrical Safety Standards and CFR 29 Part 1910.269 – Electric Power Generation, Transmission, and Distribution
- *American Electricians Handbook* available through NFPA
- *Industrial Power Systems Handbook* by Beeman, published by McGraw Hill
- Westinghouse's *Transmission and Distribution Handbook* and *Westinghouse Applied Protective Relaying Handbook* (These are out of print but may be available in personal libraries.)
- *Electric Power Research Institute (EPRI) Electrical Power Reference Series*, Volumes 1 through 13.

1.3 Maintenance and Test Procedures

1.3.1 General

Electrical maintenance activities fall into three general categories:

- *Routine Maintenance* – Activities that are conducted while equipment and systems are in service. These activities are predictable and can be scheduled, staffed, and budgeted. Generally, these are the activities scheduled on a time-based, run-time-meter-based, or a number of operations schedule. Some examples are visual inspections, infrared scans, cleaning, functional tests, measurement of operating quantities, lubrication, oil tests, governor, and excitation system alignments.
- *Maintenance Testing* – Activities that involve the use of test equipment to assess condition in an offline state. These activities are predictable and can

be scheduled, staffed, and budgeted. They may be scheduled on a time, meter, or number of operations basis but may be planned to coincide with scheduled equipment outages. Since these activities are predictable, some offices consider them "routine maintenance" or "preventive maintenance." Some examples are Doble testing, meggering, relay testing, circuit breaker trip testing, alternating current (AC) high-potential (Hipot) tests, high voltage direct current (HVDC) ramp tests, battery load tests.

- *Diagnostic Testing* – Activities that involve use of test equipment to assess condition of equipment after unusual events such as faults, fires, or equipment failure/repair/replacement or when equipment deterioration is suspected. These activities are not predictable and cannot be scheduled because they are required after a forced outage. Each office must budget contingency funds for these events. Some examples are Doble testing, AC Hipot tests, HVDC ramp tests, partial discharge measurement, wedge tightness, core magnetization tests, pole drop tests, turns ratio, and core ground tests.

This FIST volume addresses scheduling of maintenance activities in the first two categories. It does not address followup work generated by *routine maintenance* or *maintenance testing*, nor does it address *diagnostic testing* (with a few exceptions). Also, maintenance staff may be used for other activities such as improvements and construction, but this guide does not address these activities.

PEB No. 29*, Electrical Testing Synopses*, addresses standard tests for electrical equipment in Reclamation powerplants.

1.3.2 Infrared Scanning

Annual infrared scans of electrical equipment are required by NFPA 70B, 18-17.5. Throughout this FIST volume, infrared (IR) scanning is recommended as a regular maintenance procedure. Infrared scanning and analysis have become an essential diagnostic tool throughout all industries and have been used in Reclamation to detect many serious conditions requiring immediate corrective action. Several forced outages already have been avoided. Infrared scanning is non-intrusive and is accomplished while equipment is in service. It can be used not only for electrical equipment but also to detect mechanical and structural problems. Therefore, infrared scanning is **HIGHLY** recommended as a regularly scheduled maintenance procedure.

Effective infrared scanning and analysis require the following:

- The scanning equipment (IR camera and accessories) must be high quality and correctly maintained and calibrated.

- The IR camera operator must be trained to use the equipment and deal with complicating issues such as differing emissivities of surfaces and reflectivity. Certified Level 1 Thermographer (e.g., Academy of IR Thermography) credentials, or higher, are recommended.

- The IR system operator must be able to analyze results using state-of-the-art software critical to successful interpretation of problems.

- Experiences in the field have shown that technical knowledge of the equipment being scanned is highly desirable.

Field offices with adequate resources may find it possible to achieve professional results by operating a local IR program. Others may find it more cost effective to hire a contractor or use the resources in the Hydroelectric Research and Technical Services Group (D-8450). Call 303-445-2300 for more information.

1.3.3 Fault and Load Flow Studies/Equipment Ratings

Electrical power systems change as new generation and transmission lines are added or modified. Changes also occur as new equipment is added or upgraded inside the powerplant. This may mean that load ratings of various equipment and interrupting ratings of breakers and fuses are no longer adequate. Underrated or misapplied electrical equipment can be hazardous to personnel, to the integrity of the powerplant and power system, and to the equipment itself. Therefore, it is necessary to periodically conduct fault and load studies and to review equipment ratings for adequacy (continuous current, momentary current, momentary voltage, basic impulse insulation level [BIL], current interrupting ratings, etc.) and for coordination of protective relays, circuit breakers, and fuses to ensure safe and reliable operation. *North American Electric Reliability Council (NERC) Planning Standards FAC-009-1* also requires periodic fault and load flow studies.

Requirements for reviewing equipment ratings are indicated where appropriate in the maintenance schedules in this volume. These studies are typically performed by the Electrical Systems Group, D-8440, 303-445-2850.

1.4 Maintenance Schedules and Documentation

Complete, accurate, and current documentation is essential to an effective maintenance program. Whether performing preventive, predictive, or reliability centered maintenance, keeping track of equipment condition and maintenance—performed and planned—is critical.

Maintenance recommendations contained in this volume should be used as the basis for establishing or refining a maintenance schedule. Recommendations can be converted into Job Plans or Work Orders in MAXIMO or another maintenance management system. Once these job plans and work orders are established, implementation of well-executed maintenance is possible.

The maintenance recordkeeping system must be kept current so that a complete maintenance history of each piece of equipment is available at all times. This is important for planning and conducting an ongoing maintenance program and provides documentation needed for the Power O&M Reviews (section 1.7). Regular maintenance and emergency maintenance must be well documented as should special work done during overhauls and replacement.

The availability of up-to-date drawings to management and maintenance staff is extremely important. Accurate drawings are very important to ongoing maintenance, testing, and new construction; but they are essential during emergencies for troubleshooting. In addition, accurate drawings are important to the continued safety of the staff working on the equipment.

1.5 Job Plan Templates

Job plan templates have been created to assist in the development of site-specific MAXIMO Job Plans for electrical and mechanical PM. The electrical job plan templates include all PM activities prescribed in this volume and may be augmented to include manufacturer's maintenance requirements and other site-specific considerations. Local development of complete job plans that match FIST volume requirements can be expedited by adopting these templates. Templates can be accessed on the Reclamation intranet at http://intra.usbr.gov/~hydrores/pomreview/ and selecting "Job Plan Templates" from the menu on the left.

1.6 Power O&M Forms

Power O&M (PO&M) forms have been updated and placed on the intranet for facility use in documenting maintenance. These forms can be filled out online and printed or printed and completed by hand. PO&M forms are available at http://intra.usbr.gov/~hydrores/pomreview/, select "Power O&M Forms" from the menu on the left or from the Reclamation forms Web site http://intra.usbr.gov/forms/.

Word format files of the forms can be acquired from the Hydroelectric Research and Technical Services Group at 303-445-2300, if modification for specific facility use is desired.

1.7 Power O&M Reviews

Electrical maintenance is one area covered in the Power Review of O&M (PRO&M). PRO&M utilizes regularly scheduled Annual (self-assessment), Periodic (regionally conducted), and Comprehensive (Denver conducted) reviews. Each level of review is intended to assess compliance with accepted practices in operation, maintenance, and management. The accepted practices for electrical equipment maintenance are defined in this and other FIST volumes, Power Equipment Bulletins, and in the references cited in this document. As stated in section 1.2.1, above, variance from these practices is acceptable provided that adequate justification is provided to reviewers.

1.8 Limitations

This FIST volume summarizes maintenance recommendations for electrical equipment and directs the reader to related references. It should not be the sole source of information used in conducting maintenance activities. Other references, training, and work experience are also necessary to fully understand and carry out the recommended maintenance.

1.9 Safety During Maintenance

Performing maintenance on electrical equipment can be hazardous. Electrical and mechanical energy can cause injury and death if not managed properly. All maintenance activity must be conducted in accordance with FIST Volume 1-1, *Hazardous Energy Control Program (HECP)*, and *Reclamation Safety and Health Standards* (RSHS). A job hazard analysis (JHA) must be conducted as well. Visitors, contractors, and others working under clearances must be trained in HECP and must follow all JHA and clearance procedures.

ELECTRICAL EQUIPMENT MAINTENANCE SCHEDULES

2. Annunciators

2.1 General

Annunciators provide essential plant condition status information to O&M personnel. Two aspects must be considered: (1) correct operation of the annunciator itself and (2) integrity of the alarm devices and interconnected wiring. Annunciator operation is easily tested using the "Test" button provided on most annunciators and is considered an "operations" activity.

Verifying integrity of the alarm devices and interconnecting wiring requires a "functional test" of these circuits. Functional testing is accomplished by (1) resetting the annunciator, (2) closing (or opening) contacts at the alarm device, and (3) verifying that the correct annunciator window is activated. It is recommended that the alarm device actually be triggered, where possible, for best assurance; however, it may be necessary to simulate contact operation with a "jumper" (or lifted lead) when device activation is not possible.

> **Caution: Operating the alarm device may trigger unwanted control or protection actions as well as annunciation.**

Know what "should happen" by consulting up-to-date drawings before triggering alarms.

Annual functional testing of annunciators is recommended for best assurance of integrity. However, this may be considered too extensive for time and resource limitations. In these cases, functional testing of those alarm points that indicate impending shutdown or failure that could be mitigated by operator action is still recommended.

Functional testing of annunciators also is recommended after a major outage or after modifications that affect wiring and cabling in the plant.

2.2 Maintenance Schedule for Annunciators

Maintenance or Test	Recommended Interval	Reference
Operational test	Each shift – staffed plants Each visit – unstaffed plants	NFPA 70B, 3.3.6; 8.9.6.1; 21.4.11; Annex B.1.22
Functional test	Annually	Reclamation Recommended Practice

3. Arresters

3.1 General

Lightning or surge arresters provide protection for important equipment from high-energy surges. These arresters are static devices which require fairly infrequent maintenance. Most maintenance must take place while the associated circuit is de-energized. However, crucial visual inspections and infrared scans can take place while energized.

3.2 Maintenance Schedule for Arresters

Maintenance or Test	Recommended Interval	Reference
Review equipment rating	5 years	NERC Planning Standard FAC-009-1
Visual inspection with binoculars	Quarterly to semi-annually	NFPA 70B, 8.9.2.1 Annex I Table I.1
Clean insulator and check connections	3-6 years Ambient dependent	Manufacturer's instruction manuals
Doble test (power frequency dielectric loss, direct current [DC] insulation resistance, power factor)	3-6 years Ambient dependent	Doble Test Data Reference Book NFPA 70B, 8.9.2.2 Annex I Table I.1
Replace all silicon carbide arresters with metal oxide varistor type	As soon as possible	PEB No. 12 Manufacturer's recommendation
Infrared scan	Annually	NFPA 70B, 20.17

4. Batteries and Battery Chargers

4.1 General

Battery systems provide "last resort" power for performing communication, alarm, control, and protective functions when other sources of power fail. Battery system maintenance should have highest priority. Computerized, online battery monitoring systems can greatly reduce maintenance required on battery systems and actually improve battery reliability and increase battery life. Reclamation has had positive experience with these systems, and they should be considered to supplement a maintenance program.

Battery chargers, important to the health and readiness of battery systems, require regular maintenance as well.

4.2 Maintenance Schedule – Flooded, Wet Cell, Lead Acid Batteries

Maintenance or Test	Recommended Interval	Reference
Visual inspection	Monthly	FIST Volume 3-6, Table 1
Battery float voltage	Shift (charger meter) Monthly overall battery voltage with digital meter compare with charger meter	FIST Volume 3-6, Table 1 Record on POM Form 133A
Cell float voltage	Monthly, pilot cells with digital meter Quarterly, all cells	FIST Volume 3-6, Table 1 Record on POM Form 133A
Specific gravity	Monthly, pilot cells Quarterly, 10 percent (%) of cells Annually, all cells	FIST Volume 3-6, Table 1 Record on POM Form 133A
Temperature	Monthly (pilot cell) Quarterly (10% of all cells)	FIST Volume 3-6, Table 1 Record on POM Form 133A
Connection resistance	Annually, all connections	FIST Volume 3-6, Table 1 Record on POM Form 134A
Capacity testing	5 years, annually if capacity less than 90%	FIST Volume 3-6 IEEE 450-1995
Safety equipment inspection	Monthly, test all wash devices and inspect all safety equipment	FIST Volume 3-6 IEEE 450-1995
Infrared scan cells and connections	Annually	NFPA 70B 20.17
Battery monitoring system	According to manufacturer's recommendations	Manufacturer's instruction manual

4.3 Maintenance Schedule – Valve Regulated, Lead Acid (Gel Cel) Batteries

Maintenance or Test	Recommended Interval	Reference
Visual inspection	Monthly	FIST Volume 3-6, Table 3
Battery float voltage	Shift (charger meter) Monthly compare digital voltmeter with charger meter	FIST Volume 3-6, Table 3
Cell float voltage	Monthly pilot cells, Semi-annually, check all individual cells with digital voltmeter	FIST Volume 3-6, Table 3 Record on POM Form 133B
Temperature	Quarterly, all cells with infrared camera	FIST Volume 3-6, Table 3 Record on POM Form 133B
Connection resistance	Quarterly (25%) Annually (100%)	FIST Volume 3-6, Table 3 Record on POM Form 134B
Internal resistance	Quarterly	FIST Volume 3-6, Table 3 Record on POM Form 134B
Capacity testing	Annually and semi-annually If capacity test less than 90%	FIST Volume 3-6, Table 3 IEEE 1188-1996
Safety equipment inspection	Monthly, test all wash devices and inspect all safety equipment	FIST Volume 3-6, Table 3 IEEE 1188-1996
Infrared scan cells and connections	Annually	NFPA 70B 20.17
Battery monitoring system	According to manufacturer's recommendations	Manufacturer's instruction manual

4.4 Maintenance Schedule – Vented Nickel Cadmium Batteries

Maintenance or Test	Recommended Interval	Reference
Visual inspection	Monthly, check fluid levels	FIST Volume 3-6, Table 4
Battery float voltage	Shift, charger meter, Monthly, compare charger meter with digital voltmeter, Quarterly, check pilot cell with digital voltmeter Semi-annually, check each cell with digital voltmeter	FIST Volume 3-6, Table 4
Temperature	Quarterly (pilot cell)	FIST Volume 3-6, Table 4
Intercell connection retorque	Annually, retorque to specifications	FIST Volume 3-6, Table 4
Capacity testing	5 years, annually if capacity less than 90%	FIST Volume 3-6, Table 4 IEEE 1106-1995
Safety equipment inspection	Monthly, test all wash devices and inspect all safety equipment	FIST Volume 3-6, Table 4 IEEE 1106-1995
Infrared scan cells and connections	Annually	NFPA 70B 20.17
Battery monitoring system	According to manufacturer's recommendations	Manufacturer's instruction manual

4.5 Maintenance Schedule – Battery Chargers

Maintenance or Test	Recommended Interval	Reference
Preventive maintenance	Dependent on charger type and manufacturer's recommendations	FIST Volume 3-6 Manufacturer's instruction manual
Infrared scan cables and connections if visible	Annually	NFPA 70B 20.17

5. Bushings

5.1 General

Bushings are critical components of medium and high voltage circuit breakers and transformers. Bushing maintenance is usually conducted at the same time maintenance is performed on the circuit breaker or transformer, or at least during an outage on that equipment.

5.2 Maintenance Schedule for Bushings

Refer to the circuit breaker and transformer maintenance sections of this document for bushing maintenance requirements.

6. Buswork, Enclosures, and Insulators

6.1 General

Buswork conducts current from one part of the powerplant or switchyard to another. Buswork is usually constructed of flat or round copper or aluminum busbar and can be either isolated-phase or nonsegregated. Except for infrared scanning, bus maintenance must be conducted de-energized. Standoff buswork insulators provide isolation of "live" power circuits from ground and other circuits. Failure of insulators will cause a power system fault and a forced outage.

6.2 Maintenance Schedule for Buswork and Enclosures 5-15 Kilovolts (kV)

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
External visual inspection, Check and tighten connections, Check and clean enclosures	Annually	NFPA 70B, 24.5 NFPA 70B, 24.5.2
Hipot (to ground and between phases) or Doble	3-6 years Ambient dependent	NFPA 70B, 20.9.2.3 Table 24.5.6.2 IEEE 27
Infrared scan, while loaded if possible	Annually	NFPA 70B, 24.5.2.2 NFPA 70B, 20.17

6.3 Maintenance Schedule for Buswork Insulators

Maintenance or Test	Recommended Interval	Reference
Doble, Hipot or Megger®, individual insulators	Only when problems detected in 6.2 above	Doble M4000 Instruction Manual
Infrared scan, while system is loaded if possible	Annually	NFPA 70B, 24.5.2.2 NFPA 70B, 20.17

7. Power Cables – Rated 5 kV and Above

7.1 General

High voltage cable conducts power between the powerplant and switchyard. The cable may be solid dielectric or oil-filled. In the case of critical circuits, periodic maintenance tests are justified during the life of the cable to determine whether or not there has been significant insulation deterioration due to operational or environmental conditions.

Direct current Hipot tests effectively reduce inservice failures from faults of the cable or its accessories. When done properly, maintenance tests can detect problems in cables that are approaching failure without accelerating the deterioration process.

Except for infrared scanning, de-energize the cable circuit before maintenance. For assistance in determining appropriate test methods and voltage levels for a specific cable installation, please contact D-8450 at (303) 445-2300.

7.2 Maintenance Schedule for Medium and High Voltage Cables Solid Dielectric and Oil-Filled

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
DC Hipot test (stepped or ramped voltage method)	1-3 years	FIST Volume 3-1 NFPA 70B, 20.9.2.6.1.5 Annex H Table H.2(a) Annex Table I.1 IEEE 400 and 62 NFPA 70B, 10
Oil tests (dissolved gas analysis [DGA], dielectric, acidity, color, interfacial tension, water content, power factor)	Annually for oil-filled cables	Reclamation Recommended Practice
Visual inspection and infrared scan, while loaded	Annually	NFPA 70B, 20.17

8. Potheads and Stress Cones

8.1 General

Potheads and stress cones provide mechanical support and electrical insulation for cables. Insulating capability of these devices is important to prevent a fault and resulting forced outage.

8.2 Maintenance Schedule for Potheads and Stress Cones

Maintenance or Test	Recommended Interval	Reference
Visual inspection for leaks, cracks	Annually	NFPA 70B, 10.2.4 Annex H.2
Doble AC loss measurement (hot collar) or DC ramp with cable	3-6 years	FIST Volume 3-1 Doble Reference Book on Cables and Accessories
Visual inspection and infrared scan, while loaded	Annually	NFPA 70B, 20.17

9. Coupling Capacitors

9.1 General

Coupling capacitor/voltage transformers (CCVTs) are instrument transformers which provide a path for communications (traveling over the transmission line) to reach communication and relaying equipment without allowing power system frequency energy to pass. These are static devices requiring relatively little maintenance. Except for infrared scanning, maintenance must be conducted with equipment de-energized. This equipment normally is oil-filled and must be checked for oil leaks. It is subject to catastrophic explosive failure when not tested on schedule.

9.2 Maintenance Schedule for Coupling Capacitors

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Doble test, oil-filled only	3-6 years	Doble Reference Book on Cables and Accessories Doble Power Factor Test Data Reference Book
Infrared scan, while loaded	Annually	NFPA 70B, 20.17

10. Circuit Breakers

10.1 General

Circuit breakers interrupt electrical current to stop power flow both for switching operations and during fault conditions.

- Molded case circuit breakers are usually located in low voltage distribution panels and in control boards. These are typically 120-volts alternating current (Vac), 125-volts direct current (Vdc), 240-Vac, and 480-Vac breakers for control, protection, and auxiliary power. Molded case breakers in panel boards should not be loaded more than 80% of rating per NFPA 70B, 11-2.

- Low voltage air breakers are usually located in motor starter cabinets, motor control centers, station service switchgear, or similar enclosures. These are typically 480 Vac for auxiliary power.

- Medium voltage circuit breakers are generally located in station-service metal clad switchgear or in separate enclosures as unit breakers. Examples are 4160-Vac station service, 11.95-kV and 13.8-kV unit breakers. These breakers may be air, air blast, vacuum, or SF_6.

- High voltage circuit breakers are located in separate breaker enclosures, either indoors or outdoors. These are oil, air-blast, or SF_6 breakers. Examples are 115-kV and 230-kV breakers located in the switchyard.

- Extra high voltage (EHV) circuit breakers are not addressed in this FIST volume. Reference the manufacturer's instruction books.

Most breaker maintenance (except infrared scanning) must be performed with equipment de-energized.

10.2 Molded Case Breaker Maintenance Schedule, Feeder and Critical Control and Protection Breakers

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Visual inspection	3-6 years	NFPA 70B, 20.10.2.4 Annex H.4F Table I.1
Mechanical operation by hand	2 years	NFPA 70B, 13.10 and Table H.4(f) Annex I, Table I.1
Test critical breakers with current source 300% of rating; test fault trip	3-6 years	NFPA 70B, 20.10 FIST 3-16 Annex I, Table I.1
Infrared scan, while loaded or immediately thereafter	Annually	NFPA 70B, 20.17

10.3 Low Voltage (600 V and Less [480 V] Draw Out Air Breaker Maintenance Schedule

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Preventive maintenance and inspection	Per manufacturer's recommendations, 1-3 years maximum	Manufacturer's Instruction Book NFPA 70B, 8.4 Annex H.4(d)
Insulation testing and overcurrent and fault trip settings and testing	1-3 years per FIST 3 years maximum	FIST Volume 3-16 NFPA 70B, 8.4.6.4 Annex H Table H.4(d) Annex Table I.1
Visual inspection and infrared scan, while loaded or immediately thereafter	Annually	NFPA 70B, 20.17

10.4 Medium Voltage (601-15 kV Rated) Air and Air Blast Breaker Maintenance Schedule

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Inspection and preventive maintenance, lube, clean, adjust, align control mechanism	1-3 years	NFPA 70B, 8.4 Annex H Table H.2(e) Manufacturer's instruction manuals Appendix A, this document
Overcurrent trip settings and testing, test all trips	Annually or 2,000 operations (3-year maximum)	FIST Volume 3-16 NFPA 70B, 20.10 Annex H.2(e) Annex I.1
Contact resistance measurement	Per manufacturer's instructions	Per manufacturer's instructions
Breaker timing (Motion analyzer)	Per manufacturer's instructions	Per manufacturer's instructions
Either Hipot (to ground and between phases) **OR**	3-6 years	NFPA 70B Annex H Table H.2(e)
Doble test	3-6 years	NFPA 70B Doble Field Test Guide
Visual inspection and infrared scan, while loaded or immediately thereafter	Annually	NFPA 70B, 20.17

10.5 Medium Voltage (601-15,000 Vac) Vacuum Breaker Maintenance Schedule

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Preventive maintenance	Per manufacturer's instruction manual	Manufacturer's instruction manual
Record meter readings	Annually	Manufacturer's instruction manuals Western Area Power Administration (WAPA) Standard Maintenance Guidelines, Chapter 13
Record operations counter	Monthly	Manufacturer's instruction manuals
Check foundation, grounds, paint Check external screws, bolts, electrical terminals tight	Annually	Manufacturer's instruction manuals WAPA Standard Maintenance Guidelines, Chapter 13
Contact resistance measurement, motion analyzer, trip test	Per manufacturer's instructions manual	Manufacturer's instruction manuals WAPA Standard Maintenance Guidelines, Chapter 13
Doble test or AC Hipot (including across open contacts[1]) and to ground	5 years	Manufacturer's instruction manuals WAPA Standard Maintenance Guidelines, Chapter 13 NFPA 70B, 8.5.2 Annex Table I.1
Infrared scan and visual inspection, lube, clean, adjust, align control mechanisms	Annually	Manufacturer's instruction manuals WAPA Standard Maintenance Guidelines, Chapter 13

[1] Caution: Refer to manufacturer's instructions regarding safe distances (normally 6 feet or greater) to avoid X-radiation if DC Hipot tests.

10.6 Medium and High Voltage SF_6 Breaker Maintenance Schedule

NOTE: Manufacturer should be contracted to do this maintenance if specifically trained personnel are not available.

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Preventive maintenance	Per manufacturer's instruction manuals	Manufacturer's instruction manuals
Record gas pressure and temperature, compare with tolerances	Monthly	Manufacturer's instruction manuals
Record operations counter	Monthly	Manufacturer's instruction manuals
Visual inspection	Monthly, annually, 5 years	Manufacturer's instruction manuals
Check foundation, grounds, paint	5 years	Manufacturer's instruction manuals WAPA Standard Maintenance Guidelines, Chapter 13
Check external screws, bolts, electrical terminals tight	Annually	Manufacturer's instruction manuals
Contact resistance test, power factor insulation test, motion analyzer, trip test, moisture test on gas	5 years, if required by manufacturer	WAPA Standard Maintenance Guidelines, Chapter 13 Manufacturer's instruction manuals
Verify operation and calibration of temperature and pressure switches and gauges	5 years	WAPA Standard Maintenance Guidelines, Chapter 13
Check lube points, heater operation, tightness of terminals, linkages, screws, bolts; latch, linkage, operating mechanism adjustments	5 years	Manufacturer's instruction manuals
Overhaul breaker with new seals, contacts, nozzles	10 to 15 years or 4,000 to 10,000 operations (more frequent if high current operation)	Manufacturer's instruction manuals
Overhaul disconnect, grounding, and breaking switches	15 years or 5,000 to 10,000 operations	Manufacturer's instruction manuals
Gas cart maintenance	Per manufacturer's instruction manuals	Manufacturer's instruction manuals FIST 5-9, 15 EPRI Guidelines Section 5.1.1 and Section 5.2

10.7 High Voltage (Greater Than [>] 15,000 Vac) Oil Circuit Breaker Maintenance Schedule

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Preventive maintenance	Per manufacturer's recommendations, FIST Volume 3-16, and Appendix A	Manufacturer's instruction manuals FIST Volume 3-16 FIST Volume 4-1B, Appendix A
Visual inspection Breaker and bushings	2 years, per manufacturer's instructions	FIST Volume 3-16 Doble Reference Book on High Voltage Circuit Breakers NFPA 70B, 8.6 Doble Bushing Field Test Guide IEEE P62-1995
Breaker and bushings Doble test	3-5 years (6 months to 1 year for suspect bushings)	FIST Volume 3-2 FIST Volume 3-16 Doble Reference Book on High Voltage Circuit Breakers
Contact resistance	Per manufacturer's recommendations	Manufacturer's instruction manuals
Breaker timing (Motion analyzer)	Per manufacturer's instructions	FIST Volume 3-16 Manufacturer's instruction manuals
Bushing - Doble with hot collar	3-5 years, more often if ambient condition requires	Doble Bushing Field Test Guide
Bushing - cleaning	3-5 years, more often if ambient condition requires	Reclamation Recommended Practice
Infrared scan	Annually	NFPA 70B, 20.17
Insulating oil - Doble test (power factor and dielectric strength) and dissolved gas analysis	3-5 years	Doble Reference Book on Insulating Liquids and Gasses ANSI C57.104
Test tripping circuits	3-5 years	NFPA 70B FIST 4-1b

11. Communication Equipment

This document does not define maintenance of communication equipment used in power system operation.

Refer to communication system operation and maintenance requirements included in these documents:

- Bureau of Reclamation Radio Communication Systems - Management and Use - *Guidelines 07-01*. Maintenance requirements are given in section 14.
- Department of the Interior - *Departmental Manual - Radio Communications Handbook (DM377)*

Information regarding operation and maintenance of Reclamation communication systems may be found at the Reclamation intranet site: http://intra.usbr.gov/telecom.

12. Control Circuits

12.1 General

Control circuits (usually 125 Vdc, 250 Vdc, or 120 Vac) provide the path for all control functions for major equipment in the powerplant. Reliability of these circuits is paramount. Although tested during commissioning, these circuits can become compromised over time through various means:

- Modifications and construction work which unintentionally break circuit integrity or introduce wiring errors.
- Age and deterioration of wiring rendering the system nonfunctional.
- Connections that become loose.
- Failure of individual control and protection devices due to misuse, old age, or inadvertent damage.

Verifying the integrity of the control devices and interconnecting wiring requires a "functional test" of these circuits. Functional testing of control circuits may be considered completed in the course of normal plant operation. However, control circuits that rarely are used should be functionally tested on a periodic basis.

12.2 Maintenance Schedule for Control Circuits

Maintenance or Test	Recommended Interval	Reference
Functional test control circuits	3-6 years	NFPA 70B under specific equipment and Appendix H

13. CO_2 Systems

13.1 General

Carbon dioxide (CO_2) systems provide fire suppression for generator and large motor windings. These systems consist of CO_2 storage bottles or tanks, piping and valves, and electrical control systems.

13.2 Maintenance Schedule for CO_2 Systems

Caution: CO_2 is dangerous and costly to replace. Take care to avoid inadvertent CO_2 discharge during maintenance and testing.

Note: Mechanical maintenance recommendations are included in this report but may be moved to FIST Volume 4-1A, *Maintenance Scheduling for Mechanical Equipment*, when that FIST volume is revised.

Maintenance or Test	Recommended Interval	Reference
Visual inspection and check gauges	Weekly	NFPA 12, 1-11.3.6
Weigh CO_2 bottles	Semi-annually	FIST Volume 5-2, 6.4.3 NFPA 12, 1-11.3.5 FIST Volume 5-12, 12.2
Function check electrical controls	Annually	FIST Volume 5-2, 6.4.3 NFPA 12, 1-11.3.2 FIST 5-12, 15, Table 2
Operate routing valves	Annually and after painting	FIST Volume 5-2, 6.4.3 FIST Volume 5-12, 15, Table 2
Overall CO_2 system functional test	Annually	FIST Volume 5-2, 6.4.3 NFPA 12, 1-11.3.5
Cylinder discharge and hydrostatic test	12 years Any discharged cylinder not hydrostatically tested in past 5 years must be tested prior to refill.	FIST Volume 5-2, 6.4.3 FIST Volume 5-12, 15, Table 2
Visually inspect and functional test CO_2 discharge warning beacons and alarms	Annually	NFPA 72, 7-3.1 NFPA 72, 7-3.2 and Table 10.4.3 FIST Volume 5-12, 15, Table 2
Test heat, smoke, flame detectors	Annually	NFPA 72, Table 10.4.3

14. Cranes, Hoists, and Elevators

14.1 General

Cranes, hoists, and elevators are important to operation and maintenance of the facility. Proper maintenance of cranes and hoists will ensure they are ready for service which will reduce time and cost of maintaining other equipment. Maintaining elevators is important to the convenience and safety of staff, visitors, and the public. Also, elevators must be inspected periodically by a certified elevator inspector. Maintenance of these types of equipment is important to the safety of everyone. Elevators must be certified by a State-licensed inspector annually in most States.

14.2 Maintenance Schedule for Cranes, Hoists, and Elevators

Mechanical maintenance of cranes, hoists, and elevators is covered in FIST Volume 4-1A, *Maintenance Scheduling of Mechanical Equipment*. Only the electrical components are covered here.

Maintenance or Test	Recommended Interval	Reference
Inspect motors, controls, wiring	Annually	FIST Volume 2-10 FIST Volume 4-1A

15. Electrical Drawings

15.1 General

Electrical drawings, especially 1-lines, switching diagrams, control and protection schematics, and wiring diagrams, are the most important references for safety and O&M of a facility. Ideally, these drawings will be kept current with all modifications and replacements to plant equipment. Every effort must be made to keep key electrical drawings up to date to avoid risk to equipment and staff. Key electrical drawings should be accessible to all O&M personnel.

15.2 Maintenance Schedule for Electrical Drawings

Maintenance or Test	Recommended Interval
Key control and protection schematics	Current and available
Key wiring diagrams	Current and available
1-line, 3-lines, tripping, switching diagrams	Current and available
Relay data sheets	Current and available

16. Emergency Lighting

16.1 General

Reliable plant emergency lighting is essential for personnel safety.

16.2 Maintenance Schedule for Emergency Lighting

Maintenance or Test	Recommended Interval	Reference
Preventive maintenance	Per manufacturer's recommendation	Manufacturer's instruction manuals
Functional test	Monthly (30 seconds)	NFPA 101, 5.9.3
Functional test	Annually (1½ hours)	NFPA 101, 5.9.3

17. Engine Generators

17.1 General

Engine generators are critical systems at powerplants, dams, and other water-related facilities. They must be maintained and tested regularly to ensure they will perform as expected. Manufacturer and NFPA standards should be followed.

Engine generators provide essential power to supply critical loads in the event of loss of normal power source. Spillway or outlet gates/valves may need to be operated for water release purposes with engine generator power. Powerplant critical loads such as sump pumps, fire pumps, and battery chargers also are dependent on reliable power. Engine generators also may be used to power unit auxiliaries and the generator excitation system for blackstart generators assigned to restore the power system after a blackout.

17.2 Maintenance Schedule for Engine Generators

Component	Requirement	Frequency	NFPA 110 Reference
All Emergency Power Standby Systems (EPSS) components	Inspect	Weekly	8.4.1 POM Form 400
EPSS	Operated at available load for assigned class duration or minimum of 4 hours.	At least once every 36-48 months	8.4.8 and 4.2 Table 4.1(a)
Generator sets	Exercised for a minimum of 30 minutes[1] (including automatic cold start) by: (1) Running at operating temperature conditions and at not less than 30% of the nameplate kilowatt rating; or (2) Loading that maintains the minimum exhaust gas temperatures as recommended by the manufacturer.	At least monthly[2]	8.4.2
Generator set battery	Inspected and maintained in full compliance with manufacturer's recommendations.	Weekly	8.3.6
Transfer switch	Operated electrically, both directions	Monthly	8.4.5
Circuit breakers	Exercised manually	Annually	8.4.6

[1] Load exercising at normal operating temperature is important because it prevents accumulation of carbon particles, unburned fuel, lube oil, condensed water and acids in the exhaust system, and other engine problems that can occur with unloaded exercising.

[2] In addition, per manufacturers' recommendations, many facilities start and run the engine generator weekly.

17.3 Maintenance

See Manufacturer's instruction books, NFPA 110, PEB No. 28, and form POM-400 for complete inspection, testing, and maintenance requirements.

Testing and maintenance records for engine generators should be maintained on site.

18. Exciters and Voltage Regulators

18.1 General

Exciters and voltage regulators comprise excitation systems which provide appropriate DC excitation for the field of generators and synchronous motors. Excitation systems may be rotating or static.

18.2 Maintenance Schedule for Exciters and Voltage Regulators

Some components of excitation systems (e.g., transformers, circuit breakers, protective relays, annunciators, and buswork) may require maintenance similar to that described in like sections of this document. However, excitation system manufacturer maintenance requirements supersede requirements specified in these sections.

Automatic voltage regulator performance testing ("alignment") is a specialty, requiring specialized training and unique equipment as well as knowledge of current power system stability requirements. It is recommended that qualified staff in the Hydroelectric Research and Technical Services Group (D-8450) perform these tests.

Maintenance or Test	Recommended Interval	Reference
Preventive maintenance	Per manufacturer's recommendations	Manufacturer's instruction manuals
Automatic voltage regulator (AVR) and power system stabilizer (PSS) performance testing Contact the Controls Team of the Hydroelectric Research and Technical Services Group, D-8450, 303-445-2309	5 years	Western Electricity Coordinating Council Controls Working Group (WG) Recommendations Policy
Infrared scan	Annually	Reclamation Recommended Practice

19. Fire Detection, Fire Fighting Equipment, and Alarm Systems

19.1 General

Fire detection and alarm systems provide indication and warning of fire in the facility. They are crucial to safety of personnel and the public. Correct operation may also minimize damage to equipment by an early response. Regular maintenance of systems in unstaffed facilities is particularly important because O&M staff are not usually present to detect problems.

19.2 Maintenance Schedule for Fire Detection, Fire Fighting Equipment, and Alarm Systems

Maintenance or Test	Recommended Interval	Reference
All circuits - functional test	Annually - staffed facility Quarterly - unstaffed facility	NFPA 72, 7-3.1
Visual inspection of detection and control equipment (fuses, interfaces, lamps, light emitting diodes, primary power supply)	Annually - staffed facility Weekly - unstaffed facility	NFPA 72, 7-3.1
Visual inspection - batteries	Monthly	NFPA 72, 7-3.1
Lead acid battery 30-minute discharge and load voltage test	Monthly	NFPA 72, 7-3.1
Ni Cad battery 30-minute discharge and load voltage test	Annually	NFPA 72, 7-3.1
Other maintenance[1]	Per NFPA recommendations	NFPA 72, 7
Fire hoses	Annually unrolled and inspected	NFPA 72, 7-3.1
Fire extinguisher maintenance	Annually (site specific)	NFPA 72

[1] NFPA 72 7 is revised regularly, and requirements change frequently. Reference the latest version of the standard for the latest requirements.

20. Fuses

20.1 General

Fuses provide power and control circuit protection by interrupting current under certain overload and fault conditions.

20.2 Maintenance Schedule for Fuses

Some fuse failures are self evident. Loss of meter indication or control circuit operation may indicate a blown (open) fuse. Other fuses that are critical to equipment operation may be monitored and their opening alarmed. However, some fuse operation cannot be detected remotely and should be assessed by regular maintenance. It may be as simple as looking for the "fuse operated" indicator on the fuse, or it may require checking with an ohmmeter. Failure to do so may result in more significant failure leading to an outage.

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Remove, inspect, and check Check fuse mounting clips, etc.	3-6 years	NFPA 70B, 15.2.3 Annex H.2j Annex I.1
Visual inspection and infrared scan, while loaded or immediately thereafter.	Annually	NFPA 70B, 15 NFPA 70B, 20.17 Annex H

21. Generators and Large Motors

21.1 General

Generators produce electrical energy from mechanical power transmitted from the turbine. Large motors drive pumps to move water. Generators and large motors included in this section are synchronous machines performing the primary function of the power or pumping plant. Small motors are covered in section 24, "Motors."

21.2 References and Standards

Maintenance references and standards from which the recommendations are drawn are numerous:

- Manufacturers instruction books
- FIST Volume 3-1, *Testing Solid Insulation of Electrical Equipment*
- Power O&M Bulletin No. 19 - *Maintenance Schedules and Records*
- IEEE Standard (Std.) 432-1992, *Guide for Insulation Maintenance for Rotating Electric Machinery (5 horsepower [hp] to 10,000 hp)*

- IEEE Std. 95-1997, *Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage*
- IEEE Std. 43-2000, *Recommended Practice for Testing Insulation Resistance of Rotating Machinery*
- *Conditions Rating Procedures/Condition Indicator for Hydropower Equipment*, U.S. Army Corps of Engineers
- *Handbook to Assess the Insulation Condition of Large Rotating Machines*, Volume 16, Electric Power Research Institute
- *Electric Generators*, Power Plant Electrical Reference Series, Volume 1, EPRI
- *Inspection of Large Synchronous Machines*, I. Kerszenbaum
- *Test Procedure for Synchronous Machines*, IEEE 115-1983
- *Guide for Operation and Maintenance of Hydrogenerators*, IEEE Std. 492-1974

21.3 Maintenance Schedule for Generators and Large Motors

Note: See Appendix B in this document.

Maintenance or Test	Recommended Interval
Preventive maintenance and inspections	No standard recommended interval. Machine specific PM according to site operating conditions. Also, see Appendix B.
Stator winding - physical inspection	During 1-, 2½-, and 5-year warranty inspections; thereafter, during major maintenance outages but not to exceed 5 years.
Stator winding - high voltage DC ramp test	3 to 5 years and after prolonged maintenance outage.
Stator winding - insulation resistance polarization index (Megger®)	Performed in lieu of HVDC ramp test
Stator winding - AC Hipot test	At factory and as an acceptance test. Non-routine thereafter but may be used to verify insulation integrity before and/or after stator winding repair.
Stator winding - partial discharge measurements (on line monitoring with partial discharge equipment)	Nonroutine. Performed if problems are suspected.

Continued

Stator winding - black out test	Nonroutine. Performed when deterioration is suspected.
Stator winding - ozone measurement	Nonroutine. Performed when deterioration detected.
Stator winding - wedge tightness measurements	During 1-, 2½-, and 5-year warranty inspections; thereafter, performed after rotor is removed (particularly if unit in operation for 20-25 years without rewedging).
Stator winding - power factor measurements (Doble)	Nonroutine. May be performed in conjunction with other generator condition tests.
Stator core - physical inspection	During 1-, 2½-, and 5-year warranty inspections; thereafter, during major maintenance outages but not to exceed 5 years.
Stator core - core magnetizing test	Nonroutine. Should be performed prior to rewind or if core has been damaged.
Rotor - physical inspection	During major maintenance outages but not to exceed 5 years.
Rotor - insulation resistance polarization (Megger®)	Nonroutine. Performed when deterioration is suspected.
Rotor - AC pole drop test	Nonroutine. Performed when deterioration is suspected.
Thrust and upper guide bearing insulation test	Annually per FIST Volume 5-11.

22. Governors

22.1 General

Governors control generator power and frequency output by regulating water flow to the turbine. Governors may be mechanical type or electrohydraulic type having electronic controls. New digital governors substitute digital control circuits for analog electronic controls of older electrohydraulic governors.

Mechanical governor maintenance is fully described in FIST Volume 2-3, *Mechanical Governors for Hydraulic Units*. Mechanical maintenance requirements for all types of governors are identified in FIST Volume 4-1A, *Maintenance Scheduling for Mechanical Equipment*. The electrical maintenance schedule below supplements these mechanical maintenance requirements.

22.2 Maintenance Schedule for Governors

Maintenance or Test	Recommended Interval	Reference
Preventive maintenance	Per manufacturer's recommendations	Manufacturer's instruction manuals
Control system alignment	5 years	Reclamation Recommended Practice

23. Ground Connections

23.1 General

Equipment grounding is an essential part of protecting staff and equipment from high potential caused by electrical faults. Equipment grounding conductors are subject to failure due to corrosion, loose connections, and mechanical damage. Grounding may also be compromised during equipment addition and removal or other construction-type activities. Periodically verifying grounding system integrity is an important maintenance activity.

23.2 Maintenance Schedule for Ground Connections in Substations/Switchyards

Maintenance or Test	Recommended Interval	Reference
Visual inspection, tighten connectors	Annually	PEB No. 26

24. Motors (< 500 hp)

24.1 General

Motors of this type drive pumps, valves, gates, and fans. They are usually induction motors and are generally less than 500 hp but may be somewhat larger. Critical motors should routinely be tested.

24.2 Maintenance Schedule for Motors

Maintenance or Test	Recommended Interval	Reference
Insulation resistance (Megger®)	Annually	FIST Volume 3-4, 2.2
Infrared scan	Annually	NFPA 70B, 20-17.5

25. Personal Protective Equipment

25.1 General

Personal protective equipment is used by maintenance workers to provide protection from hazardous electrical energy. Integrity of this equipment is paramount, so maintenance should be scheduled and accomplished similar to equipment maintenance.

25.2 Maintenance Schedule for Personal Protective Equipment Hot Line Tools

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Safety ground - visual inspection	Annually and before each use	NFPA 70E, 130.7 FIST Volume 5-1
Safety ground - millivolt drop test	Annually	FIST Volume 5-1
Hot stick cleaning, inspection, and electrical test	Inspect before each use; test every 2 years	OSHA 1910.269J(iii) IEEE Std. 978
Gloves, sleeves, blankets tests	Annually	Manufacturer's instruction manuals NFPA 70E, 130.7 IEEE 978

26. Relays and Protection Circuits

26.1 General

Section 11.4 of the Western Electricity Coordinating Council (WECC) *Minimum Operating Reliability Criteria* requires that: "Each system shall provide for periodic testing of protective systems and remedial action schemes which impact the reliability and security of the interconnected system operation."

Protective relays monitor critical electrical and mechanical quantities and initiate emergency shutdown whenever they detect out-of-limits conditions.

Protective relays must operate correctly when abnormal conditions require and must not operate at any other time.

Electrical protective relays are calibrated with settings derived from system fault and load studies. Initial settings are provided when relays are installed or replaced. However, electrical power systems change as new generation and transmission lines are added or modified. This may mean that relay settings are no longer appropriate. Outdated relay settings can be hazardous to personnel, to the integrity of the powerplant and power system, and to the equipment itself. Therefore, it is necessary to periodically conduct a fault and load study and review protective relay settings to ensure safe and reliable operation.

Fault and load studies and relay settings are provided by the Electrical Design Group (D-8440) at 303-445-2850. Field-initiated changes to relay settings should be verified by this group.

Protective relays currently in use in Reclamation include electro-mechanical, solid-state, and microprocessor-based packages. Calibration and maintenance recommendations differ from type to type because of their different design and operating features.

Calibration: This process usually includes removal of the relay from service to a test environment. Injecting current and/or voltage into the relay and observing the response according to the manufacturer's test procedure verifies the recommended settings. Calibration of electro-mechanical relays is recommended frequently since operating mechanisms can wear and get out of adjustment. Calibration of solid-state and microprocessor-based relays is recommended less frequently since there are fewer ways for them to get out of calibration.

Relay Functional Test: This process verifies that the protective outputs of the relay (e.g., contact closures) actually operate as intended. This can be accomplished as part of the calibration procedure in most cases, but relay functional testing should be verified according to the maintenance schedule.

Protective relays operate into protection circuits to accomplish the desired protective action. Similar to control circuits, protection circuit integrity may be compromised by construction, modifications, deterioration, or inadvertent damage. A compromised protection circuit may not provide the system and plant protection desired. Periodic functional testing is recommended to ensure the integrity of protection circuits.

Protection Circuit Functional Testing: This process verifies that the entire protective "trip path" from protective relay through circuit breakers (or other protective equipment) is intact and functional. This requires actually operating the entire circuit to verify correct operation of all components.

Protective circuit functional testing is accomplished as follows:

- Conduct a Job Hazard Analysis.
- Verify that testing will not disrupt normal operation or endanger staff or equipment.
- With lockout relays reset, initiate lockout relay trip with the protective device contact.[3]
- Verify the lockout relay actually tripped from the protective relay action. Verify that circuit breakers actually tripped (or other protective action occurred) from the lockout relay action.
- Activate the lockout relay from each protective device. After the first full test of lockout relay and breakers, it may be desirable to lift the trip bus from the lockout relay so as not to repeatedly trigger the lockout—a meter may be substituted to verify contact initiation.

  Caution: Do not forget to reconnect the trip bus to the lockout relay when testing is complete.

Where functional testing of ALL protection circuits is unfeasible, testing of the most critical protection circuits and devices is still recommended.

Reclamation standard design for lockout relay and circuit breaker control circuits includes the use of the red position/coil status indicator light to monitor the continuity of the circuit through the trip coil. These lights should be lit when the lockout relay is in the "Reset" position or when the breaker is closed. If the light is not lit, this may indicate a problem with the coil integrity which should be addressed immediately.

[3] It is recommended that the protective device actually be operated where possible for best assurance. The ideal functional test is to actually change input quantities (e.g., instrument transformer secondary injection) to the protective device to thoroughly test the entire protection path. However, it may be necessary to simulate contact operation with a "jumper" when device activation is not possible.

26.2 Maintenance Schedule for Relays and Protection Circuits

Maintenance or Test	Recommended Interval	Reference
Fault/load study and recalculate settings	5 years	Reclamation Recommended Practice NERC FAC-009-1
Electro-mechanical relays Calibration and functional testing	Upon commissioning and every 2 years	NFPA 70B, 8.9.7 and 20.10.3 Annex Table I.1 Per manufacturer's instructions Fist 3-8 WECC Std. 11.4
Solid-state relays Calibration and functional testing	Upon commissioning 1 year after commissioning and every 3 years	NFPA 70B, 8.9.7 and 20.10.3 Annex Table I.1 Per manufacturer's instructions Fist 3-8 WECC Std. 11.4
Microprocessor relays Calibration and functional testing	Upon commissioning 1 year after commissioning and every 8-10 years	Reclamation Recommended Practice Per manufacturer's instructions Fist 3-8 WECC Std. 11.4
Protection circuit functional test, including lockout relays	Immediately upon installation and/or upon any changes in wiring and every 3-6 years	FIST Volume 3-8 NFPA 70B Annex Table H.4(c) Manufacturer's instruction manuals PEB No. 6
Check red light lit for lockout relay and circuit breaker coil continuity	Daily[1]	Reclamation Recommended Practice
Lockout relays Cleaning and lubrication	5 years	Power Equipment Bulletin No. 6 and Manufacturer's instructions

[1] In staffed plants, in conjunction with daily operator control board checks. Otherwise, check each visit to the plant.

27. SCADA Systems

27.1 General

Supervisory Control and Data Acquisition (SCADA) systems are computer-based, real-time control systems for power and water operations. Since these systems are in operation continuously and are in many ways self-diagnosing, regular maintenance and testing is not necessary except as recommended by the manufacturer. However, circuits that are infrequently used may require periodic functional testing to ensure they will be operational when the need arises.

Security requirements affecting SCADA are dictated by documents such as Presidential Decision Directive 63: Critical Infrastructure Protection, May 22, 1998, and Office of Management and Budget (OMB) Circular A-130, Appendix III, Security of Federal Automated Resources, February 8, 1996. Periodic audits, Critical Infrastructure Protection Plans (CIPP), and regularly scheduled security training are important requirements of SCADA security.

27.2 Maintenance Schedule for SCADA Systems

Maintenance or Test	Recommended Interval	Reference
Preventive maintenance	Per manufacturer's recommendations	Manufacturer's instruction manuals
Functional test circuits	3-6 years	Reclamation Recommended Practice
Failure mode tests	Annually	Reclamation Recommended Practice
Security - audit	3 years	OMB Circular A-130, Appendix III
Security - CIPP updated	2 years	Presidential Decision Directive 63
Security - training	Annually	Public Law (P.L.) 100-235, Computer Security Act of 1987
Uninterruptible power supply test	Annually	Reclamation Recommended Practice

28. Security Systems

28.1 General

Security systems at powerplants are critical for protection of Reclamation personnel, the public, and facility equipment. Most security systems are site specific including many different manufacturers of cameras, receivers, card key systems, gates, gate controls, and other types of equipment.

Therefore, it is imperative that personnel at each plant understand and follow manufacturers' instructions for maintenance and testing the particular equipment installed.

29. Switches, Disconnect – Medium and High Voltage

29.1 General

When open, disconnect switches permit isolation of other power system components, thus, facilitating safety during maintenance procedures. Disconnect switches may be manually or motor operated and, in some cases, may integrate fuse protection. (See section 20 on fuses).

29.2 Maintenance Schedule for Disconnect Switches

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Preventive maintenance	Per manufacturer's recommendations and per Appendix C	Manufacturer's instruction manuals Appendix C
Visual inspection	Semi-annual	NFPA 70B, 8.7 Annex H.2(f) FIST Volume 4-1B, Appendix C
Infrared scan, while loaded	Annually	NFPA 70B, 20.17

30. Transducers/Meters

30.1 General

Transducers convert data collected in one format into electrical signals used by meters and computerized monitoring and control systems. Accuracy of transduced signals is important to alarm and control functions. Examples of transduced data include:

- Bearing oil level or temperature read by a meter or scanning equipment
- Megawatt or megavars as input to the SCADA system

30.2 Maintenance Schedule for Transducers

Maintenance or Test	Recommended Interval	Reference:
Calibration	3-5 years	NFPA 70B, 12.4

30.3 Maintenance Schedule for Meters

Meters indicate, and sometimes record, electrical and mechanical quantities for operator information. Some meters also transmit stored data to Supervisory Control and Data Acquisition (SCADA) or other systems. Accuracy of meter indication is important to ensure correct power and water systems operation.

Maintenance or Test	Recommended Interval	Reference
Calibration/inspection	3-5 years with transducers and when problems are suspected	NFPA 70 B, 8.9.7

31. Transformers

31.1 General

Transformers convert electrical power from one voltage level to another. Transformer reliability is essential to the continued delivery of the facility's services.

31.2 References and Standards

Maintenance references and standards from which the recommendations are drawn are numerous:

- Manufacturers' instruction books
- *Doble Transformer Maintenance and Test Guide*
- IEEE Std. 62-1995
- FIST Volume 3-30, *Transformer Maintenance*
- FIST Volume 3-31, *Transformer Diagnostics*
- NFPA 70B - *Recommended Practices for Electrical Equipment Maintenance*
- *Transformers: Basics, Maintenance, and Diagnostics* (Reclamation manual)

31.3 Station/Distribution Transformers Under 500 kVA[4]

31.3.1 General

Station and distribution transformers generally operate at relatively low voltages and power ratings. They provide step-down power to supply plant auxiliary loads—for example, a 480 - 240/120-Vac transformer that supplies power to auxiliary lighting panels.

31.3.2 Maintenance Schedule for Station and Distribution Transformers

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Infrared scan, while loaded	Annually	NFPA 70B, 20.17
Doble test if oil-filled	3-6 years	FIST Volume 3-30
Dissolved gas analysis if oil-filled	Annually	Reclamation Recommended Practice FIST Volume 3-30 NFPA 70B, 9.2.8

31.4 Instrument Transformers

31.4.1 General

Instrument transformers convert power system level voltages and current to levels safe to feed meters and other low voltage and current devices. Voltage or potential transformers generally have output in the 240/120-Vac range, while current transformers have output in the 2.5- to 5-ampere range. Voltage transformers may be integral to other equipment or stand alone. Typically, current transformers are integral to other equipment (circuit breakers, transformers) but occasionally may be stand alone (e.g., 500-kV switchyard at Grand Coulee).

Over the course of time, instrument transformers (particularly current transformers) may become overburdened with the addition of more devices in the secondary circuit. This may lead to saturation during a fault which may cause the relay to misoperate. Periodically, measuring secondary burden and comparing it to the transformer rating will indicate if this is a problem.

Instrument transformer secondary wiring always should be checked for integrity after any work that may have disrupted these circuits.

Instrument transformers that are oil-filled will fail catastrophically and cause hazards to workers if not maintained properly. Any oil leak should trigger immediate Doble testing and replacement planning.

[4] kVA = kilovoltampere.

31.4.2 Maintenance Schedule for Instrument Transformers

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard
Burden measurements	5 years	FIST Volume 3-8
Doble test if oil-filled	5 years	Reclamation Recommended Practice
Visual inspection	Annually	Reclamation Recommended Practice
Infrared scan	Annually	NFPA 70B, 20.17

31.5 Dry-Type Power Transformers – 500 kVA and Larger

31.5.1 General

Dry-type power transformers are air cooled, having no liquid insulation. Typical applications include station service and excitation system transformers.

31.5.2 Maintenance Schedule for Dry-Type Power Transformers

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Infrared scan	Annually	NFPA 70B, 20.17 FIST Volume 3-30
Temperature alarm check	Annually	NFPA 70B, 9.3 Annex H.2(c) FIST Volume 3-30
Visual inspection/cleaning	Annually	NFPA 70B, 9.3 Annex H.2(c) FIST Volume 3-30
Check fan operation	Annually	NFPA 70B, 9.3 Annex H.2(c) FIST Volume 3-30
Clean fans and filters	Annually	NFPA 70B, 9.3 Annex H.2(c) FIST Volume 3-30
Turns ratio test	3-6 years or if problems are suspected	NFPA 70B, 9.3 Annex H.2(c) NFPA 70B, 20.11
Megger® windings or Hipot	3-6 years or when problem is suspected	NFPA 70B Annex H.2(c) NFPA 70B, 9.2.9 and 20.9

31.6 Oil-Filled Power Transformers

31.6.1 General

Oil-filled transformers generally deliver power to and from the main units of the facility—for example, generator step-up transformers. These transformers are generally located outside the building in a transformer bay or in a switchyard. These transformers may be two-winding or more and include autotransformers.

31.6.2 Maintenance Schedule for Oil-Filled Power Transformers

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Preventive maintenance	Per manufacturer's recommendations	Manufacturer's instruction manuals FIST Volume 3-30
Transformer physical inspection	Annually	NFPA 70B, 9.2 Annex H FIST Volume 3-30
Bushings - visual inspection	Quarterly and 3-5 years	Doble Bushing Field Test Guide IEEE P62-1995 FIST Volume 3-30
Bushings - check oil level	Weekly	FIST Volume 3-30
Bushings - cleaning	3-5 years	FIST Volume 3-30
Transformer and bushings - Doble test	3-5 years (6 months to 1 year for suspect bushings)	FIST Volume 3-2 Doble Bushing Field Test Guide IEEE P62-1995, 6.2 FIST Volume 3-30
Transformer and bushings - infrared scan	Annually	NFPA 70B, 20.17 FIST Volume 3-30
Insulating oil - DGA, physical, and chemical tests	Annually after first year of operation	NFPA 70B, 9.2.9.4 FIST Volume 3-5 FIST Volume 3-30
Core - Megger® test	If DGA indicates	IEEE P62-1995, 6.1.5 NFPA 70B, 9.2 Annex H.2(b) FIST Volume 3-30
Leakage reactance, Turns Ratio tests, SFRA test	If problems are indicated by other tests	FIST Volume 3-30 FIST Volume 3-31
Cooling fans - inspect and test	Annually	FIST Volume 3-30
Oil pumps and motors - inspect and test	Annually	FIST Volume 3-30

Continued

Heat exchangers - inspect	Annually	FIST Volume 3-30
Conservator and bladder - inspect	3-5 years	FIST Volume 3-30
Top oil and winding thermometers	Annually inspect and infrared scan 3-5 years calibrate	FIST Volume 3-30
Oil level indicator operation	3-5 years	FIST Volume 3-30
Pressure relief device	Annually inspect and perform function test 3-5 years check oil leaks	FIST Volume 3-30
Sudden pressure relay	Annually inspect and perform function test 3-5 years test per manufacturer's recommendations	Manufacturer's instructions FIST Volume 3-30
Buchholz relay	Annually inspect and perform function test	Manufacturer's instructions FIST Volume 3-30
Inspect foundation, rails, trucks	3-5 years	FIST Volume 3-30 POM 19

32. Transformer Fire Suppression Systems

32.1 General

Reclamation generator step-up (GSU) transformers normally contain thousands of gallons of flammable transformer oil. Based on Reclamation's past practice, on NFPA 851 "Fire Protection for Hydroelectric Generating Plants," and Edison Electric Institute's "Fire Protection for Transformers," Reclamation requires fire suppression for mineral oil-filled GSU transformers.

32.2 Maintenance Schedule for Transformer Fire Suppression Systems

Maintenance or Test	Recommended Interval	Reference
Fire pumps	Annually run pump with water flow	NFPA 25, 8.3.3 FIST Volume 3-32
	Maintenance	See manufacturer's instruction

Continued

All systems Circuit breakers	Manually operate Monthly and visual inspection	NFPA 25, Table 8.5.3 FIST Volume 3-32
All systems Test alarms and automatic starting	6 months	NFPA 25, Table 8.5.3 NFPA 72-10 FIST Volume 3-32
All systems Visual inspection of electrical system	Annually	NFPA table 8.5.3.4 FIST 3-32
Water spray fixed system (nozzles fixed)	See NFPA 25 Table 10.1	NFPA 25 FIST Volume 3-32
Valves and valve components	See NFPA 25 Table 12.1	NFPA 25 FIST Volume 3-32
Water mist system	See NFPA 750, Table 13.2.2 and Table 13.3.4	NFPA 750 FIST Volume 3-32
Manually operate breakers and test all circuit breaker trips according to section 10, "Circuit Breakers"	See section 10, "Circuit Breakers"	See section 10, "Circuit Breakers"

33. Transmission Lines

33.1 General

Transmission lines carry electrical power between the facility and the power system. Reclamation maintains relatively few transmission lines. However, inspection of transmission line segments entering switchyards is recommended.

33.2 Maintenance Schedule for Transmission Lines

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Visual inspection with binoculars	Semi-annually	NFPA 70B Annex H.3
Infrared scan	Annually	NFPA 70B, 20.17

34. Blackstart Generators

34.1 General

Upon complete loss of the power system (blackout), it will be necessary to establish initial generation and begin system restoration at select powerplants. Initiating (main unit) generators are referred to as system blackstart generators and are designated as such in system blackstart restoration plans. They must be able to self-start without any source of offsite electrical power and maintain adequate voltage and frequency while energizing isolated transmission facilities and auxiliary loads of other generators.

34.2 Testing Schedule for Blackstart Generators

Maintenance or Test	Recommended Interval	Reference
Review equipment ratings	5 years	NERC Planning Standard FAC-009-1
Demonstrate through simulation or test that the unit can perform its intended function as required by the system restoration plan	5 years	WECC and NERC Combined Planning Standard IV Part A WECC Policy dated April 23, 2004 Reclamation Policy Memo dated April 28, 2005
Each unit tested to verify it can start and operate without being connected to the system	Annually	WECC Policy dated April 23, 2004 Reclamation Policy Memo dated April 28, 2005 See POM Form 401

Appendix A

AIR AND OIL CIRCUIT BREAKER PREVENTIVE MAINTENANCE

Appendix A

AIR AND OIL CIRCUIT BREAKER PREVENTIVE MAINTENANCE

Adapted from Power O&M Bulletin No. 19 –
Maintenance Schedules and Records – October 1965, Section 10

NOTE: *Unless the maintenance interval is specified, conduct preventive maintenance annually (indicated by •) or as the equipment becomes available during an outage. For other maintenance requirements, see section 10, "Circuit Breakers," in the body of this FIST volume.*

Foundation

- Check foundation for cracks and settling. A shift of the breaker tanks may break bushings or cause misalignment of contacts or binding of operating mechanism.

Frame and Tanks

Daily or Weekly – Check for oil leaks and note tank temperature by touch.

Oil Valves and Plugs

- Check condition of paint and repaint as necessary. Inspect oil valves and plugs and stop oil leaks. See that oil drain valves that can be operated without wrenches are plugged or locked to prevent unauthorized opening. Tighten bolts. Clean exterior of tanks. Inspect underside of cover for moisture and rust, and clean and repaint as necessary. Check tank liners and interphase barriers.

Oil Levels and Gauges

Daily or Weekly – Check oil level in gauges of the tanks and oil-filled bushings. Replenish oil if below normal.

- Clean dirty gauge glasses and connections into tank. Drain out and replace bushing oil if dirty or discolored.

Breathers and Vents

Daily or Weekly – Check for external obstructions to breakers and vents.

- Check to see that screens and baffles in vents or breathers are not obstructed or broken.

Panels and Cabinets

- Check air circuit breaker or other panels of insulation material for cracks and cleanliness. Check condition of enclosing cabinets including hinges, latches, locks, door gaskets, and paint.

Bushings or Insulators

Quarterly – Check for chipped or broken porcelain, excessive dirt film, oil level and oil or compound leaks.

- Clean porcelain with water, liquid turtle wax, or other suitable cleaner. Repair chipped spots by painting with lacquer such as 1201 glyptal. Inspect gaskets for leaks. Tighten bolts. Check insulation resistance with contacts closed with Doble test set, Megger®, or Hipot. Check oil sample from bottom of bushing for dielectric strength and dissolved gas analysis (DGA) and presence of water and dirt which may be entering at top. Replace or replenish oil if necessary. Check and clean interior at least once every 5 years.

Bushing Current Transformers and Potential Devices

- Check tap settings and adjustments at terminal board to see that they agree with diagrams. Check insulation resistance of wiring with devices connected. Check ratio and phase-angle adjustments of potential transformers if changes have been made in secondary connections or burden. Tighten connections, including tap connections into bushing.

Main Terminals and Ground Connections

Daily or Weekly – Check for presence of foreign materials, birds' nests, etc. in or near connecting buswork; loose or overheating connections; and loose or broken frame ground connections.

- Tighten all bus and ground connections and inspect for heating. Refinish contact surfaces if they have been overheating. Inspect ground cable to see that it is not loose or broken.

Main Contacts

- Remove the tanks or drain out oil so that the contacts can be inspected. Dress contacts, if rough, with a fine file. It is necessary to carefully remove only the projecting beads. Pits in a flat, smooth surface are not objectionable. Check contact drop with "ducter" or by direct current millivolt drop with a micro-ohm meter. Frequency of breaker contact maintenance should be based on number and severity of faults interrupted rather than a definite time period. Experience will tell how many faults can be interrupted before contact repairs are necessary. Data should be kept on each breaker to guide future maintenance. Inspection schedules might be extended further as oil handling methods, methods for determining oil condition, and other improvements are made. The following factors should be established before intervals between inspections can be extended:

A. All new breakers must have a complete inspection at the end of 1 year.

B. Only after breakers have field experience should the inspection periods be extended.

C. Breakers used on special applications, such as capacitor and reactor switching, should be considered separately.

D. If recurring troubles are found on a certain type of breaker, the inspection schedules should be shortened until trouble is eliminated.

E. Breakers interrupting a large number of faults should be given special attention to determine whether or not early internal inspection is required.

F. When oscillographs indicate abnormal breaker operation, an immediate inspection of the breaker should be made.

Contact Pressure Springs

- Check springs for loss of temper, breaks, or rust deterioration.

Flexible Shunts

- Check flexible shunts at contact hinges for overheating and fraying. Tighten connections.

Magnetic, Air, or Oil Blowout Devices

- Check arc-rupturing blowout coils, magnetic circuit, arc chutes, de-ion grids, oil blast, or other interrupters for proper operation.

Crosshead

- Check contact crosshead for misalignment, breaks, bends, or looseness on lift rod.

Lift Rods and Guides

- Check contact lift rods for breaks, weakening, or warping, and pulling out at ends. Check adequacy of guides.

Operating Rods, Shafts, and Bell Cranks

- Check for loose locknuts, setscrews, keys, bearings, bent rods, or twisted shafts, etc. Clean moving parts of rust, dirt, and accumulated grease and oil. Wash out bearings, pivots, and gears with a suitable cleaner; and operate breaker several times to work out dirt and old lubricant. Lubricate with new grease or oil. In cold climates, it is important to use lubricant that will not stiffen with cold. Wipe off excess oil. Enclosed dust-tight bearings should require less servicing.

Operating Time

- A 2-cycle breaker with dirty or dried out grease in the operating mechanisms, bearings, and gears will act more like a 6- to 12-cycle breaker the first time it is operated or exercised. After that, the operating time will be closer to normal until it has again "rested," at which time, it will again have unacceptable operating times.

Closing Solenoid Air Cylinder, Motor, or Spring

Weekly – Visual inspection to see that equipment is in operating condition. Drain condensation from air cylinder.

- Observe mechanism during several closing operations to see that everything is in proper working order. Check solenoid plunger for sticking in guides.

Annually – Check coil resistance and insulation resistance.

- Dismantle air cylinder and clean and relubricate. Check motor. Check closing springs for proper tension and closing energy.

Manual Operating Device

- See that manual operating lever or jack is kept on hand and in usable condition. See that breaker will close with it.

Latch and Trip Mechanism

Weekly – Visual inspection to see that mechanism is in operating condition.

- Observe mechanism during several tripping operations to see that everything is in working order.

Annually – Check pins, bearings, and latches for wear, binding, and misalignment.

- Clean and relubricate. Check latch carefully to see that it is not becoming worn so that it would unlatch from vibration or stick and fail to trip. Tighten bolts and screws.

Tripping Solenoid

Weekly – Visual inspection to see that solenoid trip device is in operating condition.

- Observe operation during electrical tripping. See that full energy, snappy action of plunger is obtained. Check plunger for sticking in guides.

Annually – Check coil and insulation resistance.

Solenoid Valves

Annually – Check for condition of valve seat and refit as necessary.

- See that moving parts are free to operate. Check resistance and insulation resistance of solenoid coil.

Auxiliary Switches

Annually – Check condition of contacts and refinish with fine file if burned or corroded.

- Check contact springs, operating rods, and levers. Check closing and opening position with respect to main contacts while breaker is being slowly closed and opened manually. Certain auxiliary contacts used for special purposes may require close adjustment in this respect.

Operation Counter

Monthly – Observe and record reading of operation counter.

- See that the operations counter is properly registering the operations.

Position Indicator

- See that position indicator or semaphore is properly indicating the breaker position. Check operating rods or levers for loose parts.

Dashpots or Snubbers

- Check for proper setting and adjust as necessary. Clean out and replenish liquid in liquid dashpots.

Mechanism Cabinet

- Check condition of metal and hardware. Repaint as necessary. See that door gaskets are tight and properly exclude dust and dirt.

Cabinet Lights and Heaters

Weekly – Check cabinet heaters and see that they are in service in cold weather. Replace burnt-out lamps.

- Check heating elements and replace, if in poor condition.

Power Supplies and Wiring

Weekly – See that all power and control circuit switches are closed and fuses are in place.

Annually – Inspect fuses or circuit breakers in all power and control supply circuits.

- Check and tighten wiring connections at terminal points. Inspect wiring for open circuits, short circuits, and damaged insulation. Check insulation resistance of wiring with devices connected.

Oil DGA and Dielectric Tests

Annually – Check dielectric strength of the insulating oil in the main tanks and oil-filled bushings.

Filter Oil

- The necessity for filtering the insulating oil will depend on the results obtained from the oil tests and the amount of carbon in the oil. The oil should be filtered if the dielectric strength is below 25 kilovolts or if there is a noticeable amount of carbon in suspension or in the bottom of the tanks.

Operation

- Some breakers, particularly those carrying high values of current, have a tendency to develop contact heating if left closed for long periods. Opening and closing breakers several times at intervals, as system operation permits, may reduce contact resistance and heating by wiping the oxide from the contact surfaces. This method also demonstrates that the breaker is in operating condition.

References

How to Maintain Electric Equipment, GET-1125, General Electric Company

FIST Volume 3-1, *Testing of Solid Insulation of Electrical Equipment*

FIST Volume 3-2, *Testing and Maintenance of High Voltage Bushings*

FIST Volume 3-7, *Painting of Transformers and Oil Circuit Breakers*

FIST Volume 3-16, *Maintenance of Power Circuit Breakers*

FIST Volume 3-17, *Power Circuit Breaker Problems*

FIST Volume 3-18, *Replacing Glaze Burned Insulators*

Appendix B

GENERATIOR AND LARGE MOTOR PREVENTIVE MAINTENANCE

Appendix B

GENERATOR AND LARGE MOTOR PREVENTIVE MAINTENANCE

Adapted from Power O&M Bulletin No. 19 –
Maintenance Schedules and Records – October 1965, Section 10

NOTE: *Unless the maintenance interval is specified, conduct preventive maintenance annually (indicated by •) or as the equipment becomes available during an outage.*

Foundation, Base, or Support

- Check concrete foundation for cracks. Check base or support for broken, loose, or weakened parts. Check and tighten anchor bolts. Check sound-absorbing base for adequacy.

Frame

- Check for cracks and loose or broken parts. Clean and repaint as necessary. Check frame ground connection.

Laminations and Pole Pieces

- Check for loose laminations and tighten clamping bolts. If laminations vibrate and cannot be stopped by tightening clamping bolts, force some quick-drying varnish or shellac between the loose laminations while the machine is out of service. Check for damaged laminations at airgap due to rubbing or objects caught in airgap. Check and tighten field pole piece clamping bolts. (Refer to manufacturer's instructions or contact the Hydroelectric Research and Technical Services Group at 303-445-2300 for proper torque values.)

Armature or Rotor

- Check squirrel-cage rotor bars or amortisseur windings for loose or broken bars or end connections. Check field circuit connections and tighten if necessary. Check voltage drop across each pole by applying alternating current at the collector rings. This method will show a turn-to-turn short better than using direct current. Check pole keys for tightness. Rebalance armature or rotor if vibration is objectionable. (See FIST Volume 2-2, *Field Balancing of Large Rotating Machinery*.)

- Check overall rotor resistance or impedance.

Airgap

- Check airgap at four quadrature positions and recenter rotor if necessary. On horizontal machines, the bearings may need replacing if the bottom airgap is appreciably smaller than the top.

Air Fans

- Check rotor air fans for fatigue cracks. Check and tighten holding bolts and screws.

Windings

- Inspect for damaged insulation, dirt, oil, or moisture. Blow out dust with clean, dry air at pressure not exceeding 40 pounds per square inch. Clean exposed parts of windings thoroughly with a nonflammable solvent using suitable brushes for hard-to-reach places. The use of carbon tetrachloride is not recommended because of the toxic hazard. Revarnish windings if insulation is becoming hard, brittle, or dull. Check for insulation deterioration such as tape separation, cracking, brittleness, or evidence of corona. Check insulation with high voltage direct current method. (See FIST Volume 3-1, *Testing Solid Insulation of Electrical Equipment*.)

Banding and Lashing

- Check wire and string banding on direct current armature windings. Check end-turn lashing of alternating current stator coils. Apply lashing if end turns vibrate excessively.

Slot Wedges

- Check slot wedges and replace loose ones. Tighten coils in slots by rewedging, if necessary.

Commutator or Collector Rings

- **Daily** – Check commutator or collection rings and brush operation. Wipe commutator or rings if needed. Have brushes replaced if worn too short.

Brushes and Brush Rigging

- Turn down, stone, or polish commutator or collector rings if grooved, rough, or eccentric. Undercut mica if high. If commutator or rings have a good polish, they should not be disturbed. Check brush spring tension and brush fit. Tighten bolts, screws, and connections. Reset brush holders if not properly spaced. Check brush neutral position. Replace and sand in new brushes if needed. Clean up carbon or metallic dust.

Shaft and Bearings

Daily – Check bearing temperature, lubrication, and oil level. (See FIST Volume 2-4, *Lubrication of Powerplant Equipment*.)

During Shutdown/Inspection – Check bearing clearances. Check oil for dirt, sludge, and acidity, and filter or replace as necessary. Check end play on horizontal machines. Replace or refinish rough bearings. Inspect bearing oil piping and cooling water piping for leaks. Check shaft for wobble and alignment. Check for shaft currents through bearings on larger machines. Check insulation of insulated bearings. Check oil film resistance occasionally with machine in operation with ohmmeter of 6 volts or less on thrust bearings provided with test terminals.

Couplings, Gears, and Pulleys

- See that keys, setscrews, and coupling bolts are tight. Check parts of flexible couplings for wear or fatigue. Adjust belt or silent chain tension. Flush out and renew grease in gearboxes. Inspect belts, chains, or gears. Check alignment between driving and driven machine.

Cooling Coils and Air Coolers

- Check for water leaks in bearing cooling coils and surface air coolers. Check cooling water flow. Check external supply and piping for leaks. Flush out cooling coils with air and water. Test bearing cooling coils for leaks by applying air pressure to coils. Observe for air bubbles rising in oil and drop in air pressure with supply valve closed or use hydrostatic pressure test. Use hydrostatic pressure test on air coolers. If water scale is present, circulate a solution of 25% hydrochloric acid and water through the coils until clean. Then flush out thoroughly. Clean external surfaces of coils if practical. A pressure of 75 pounds per square inch is recommended.

Temperature Indicators and Relays, Water and Oil Flow, and Pressure Gauges and Relays

- Check indicators, gauges, and relays for correct operation and sticking, dirty contacts. Check calibration if in doubt.

Recordkeeping

Maintain detailed records, tracking armature temperature against generator load. If temperature readings begin to rise over 5 degrees Centigrade for the same loading conditions, this may indicate a problem that should be investigated.

References

How to Maintain Electric Equipment, GET-1125, General Electric Company

FIST Volume 1-4, *Permissible Loading of Generators and Large Motors*

FIST Volume 2-2, *Field Balancing of Large Rotating Equipment*

FIST Volume 2-4, *Lubrication of Powerplant Equipment*

FIST Volume 3-1, *Testing Solid Insulation of Electrical Equipment*

FIST Volume 3-3, *Electrical Connections for Power Circuits*

FIST Volume 3-11, *Generator Thrust-Bearing Insulation and Oil Film Resistance*

Appendix C

DISCONNECT SWITCH
PREVENTIVE MAINTENANCE

Appendix C

DISCONNECT SWITCH PREVENTIVE MAINTENANCE

Adapted from Power O&M Bulletin No. 19 –
Maintenance Schedules and Records – October 1965, Section 10

NOTE: *Unless the maintenance interval is specified, conduct preventive maintenance annually (indicated by •) or as the equipment becomes available during an outage. For other maintenance requirements, see section 10, "Circuit Breakers," in the body of this FIST volume.*

Inspection

Semi-Annual – Observe components visible through inspection windows: switch contacts, auxiliary devices, wiring, terminal blocks, fuse clips and fuses, insulators and insulating materials, space heater operation, cable terminations, adequate grounding, cleanliness, evidence of water leaks, and overheating of parts. Observe stress cones and leakage sections for cleanliness and tracking. Record loads if equipped with meters.

Weekly – Note whether multiple-shot reclosing fuse has operated. Replace as needed. Check fuse latching and tripping mechanism for proper operation.

Major Maintenance or Overhaul

Depending on ambient, 3 to 6 years.

Major Maintenance or Overhaul	Maintenance to Perform
Structure and enclosure	Repair rust spots and paint.
Base and mounting	Check for loose bolts and insecure or inadequate supporting structure.
Ventilating louvers and air filters	Clean and replace as needed.
Buses, splices, and bolts	Check bolts for manufacturer's recommended torque.
Insulators	Check for chipped or broken porcelain, excessive dirt film, and tracking; clean as necessary; replace broken insulators; tighten base and cap bolts.
Space heaters	Verify operation or operate continuously to overcome thermostat malfunction.
Main switch blades and contacts	See that blades are properly seated in the contacts; operate the switch several times and see that blades are properly aligned to engage contacts; clean contact surfaces if corroded; lubricate; tighten bolts and screws.

Continued

Contact and hinge spring and shunts	Check pressure springs in contact and hinge and replace, if not adequate; replace flexible shunts, if frayed.
Blade latches and stops	See that blade latches, where provided, are engaged; check latches for proper engaging and holding blade against opening force. See that stops are in place and tight.
Arcing switch blades and contacts	Do not lubricate.
Arc chutes or interrupter device	Check for condition, alignment, and proper operation.
Switch operating mechanism and linkage	Adjust for adequate contact closure and over travel; lubricate.
Operating rods, levers, and cranks	Check and tighten bolts, screws, and locknuts; see that rods, levers, and cranks are in serviceable condition and repair as necessary; lubricate pivot points and bearings.
Gearboxes	Check gears and bearings; flush out oil or grease and relubricate.
Operating motor and mechanism	Check motor operation and Megger®; check adjustment of brake.
Auxiliary and limit switches	Check condition of contacts and refinish with fine file if burned or corroded; check contact springs, operating rods, and levers; check closing and opening positions with respect to main switch contacts, travel, or motor mechanism.
Door and other interlocks	Functional test for proper sequence.
Switch disconnect studs and finger clusters (if drawout type)	Lubricate unless manufacturer's instruction says not.
Cable terminations and connections	Clean and inspect for surface tracking; check connections for correct tightness.
Meters	Check calibration.
Fuse clips and fuses	Check clips for adequate spring pressure and proper fuse rating.
Grounding	Check base and operating handle ground connections; see that ground cable is not broken.
Potential, current, and control transformers	Evaluate and make necessary repairs.
Switch operating hot sticks	See that switch operating hot sticks are in good condition and are kept in a dry place; inspect hot sticks for damage and deterioration; discard suspect switch operating hot sticks; test hot sticks per requirements under FIST Volume 4-1B, section 25, "Personal Protective Equipment."

References

FIST Volume 3-18, *Replacing Glaze Burned Insulators*