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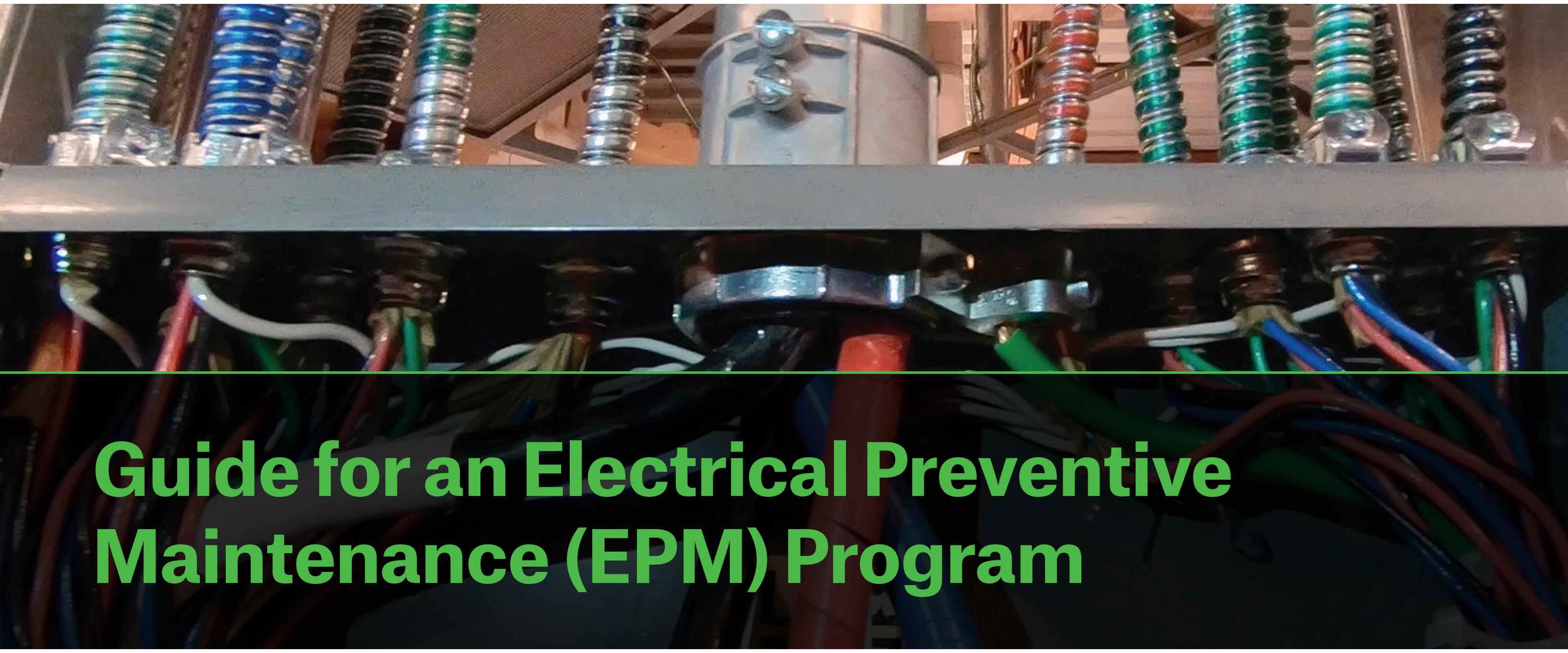

Guide for an Electrical Preventive Maintenance (EPM) Program

HSB, a Munich Re company, is a technology-driven company built on a foundation of specialty insurance, engineering, and technology, all working together to drive innovation in a modern world.

Introduction

Electrical equipment failures account for millions of dollars in damage and lost business every year. As this country's electrical infrastructure continues to age, this problem is only going to worsen unless active steps are taken to counter the trend. Ironically, more than two-thirds of electrical system failures can be prevented by a routine preventive maintenance program. The failure rate of electrical equipment is three times higher for components that are not part of a scheduled preventive maintenance program as compared with those that are. In addition, a planned EPM program allows the equipment owner to schedule the system outage at a time of their choosing rather than having to correct major problems resulting from an always untimely failure.

The purpose of this guide is to provide the insured with typical practices and frequencies that would form the core of a regularly scheduled electrical preventive maintenance program. A preventive maintenance program should be developed, implemented, and completed by properly trained and qualified individuals. Actual maintenance activities and frequencies should be based on the specific operations and conditions of the equipment. Any electrical preventive maintenance program should be performed in accordance with accepted industry standards and safety practices.

Frequency of EPM

In general, HSB recommends a frequency of once every three years for conducting regular preventive maintenance on electrical equipment. However, frequency is highly dependent on equipment conditions and operations. The frequency of the activities should be based on actual conditions. Where applicable, this guide will note components that require a more frequent EPM program to help ensure reliability and operation.

Individual locations may require more frequent maintenance due to the physical environment or operational nature of the equipment. For example, harsh environments where excessive moisture or dust may be present should have a more frequent EPM program. Similarly, equipment that is used intermittently or equipment critical to a key process should be considered for a more frequent program. Sound engineering judgment should be used in determining if more frequent maintenance is appropriate.

Recommended maintenance practices

The following sections are segmented by equipment type. For each component, a recommended minimum practice for preventive maintenance is provided. Where applicable, additional suggested practices are presented for a more thorough EPM program.

3.1 Switchgear

3.1.1 Enclosures—Ensure that all enclosure panels, doors, and structures are well-maintained in accordance with the manufacturer's specifications. During de-energized maintenance, enclosures are to be vacuum cleaned of all loose dirt and debris — use of compressed air is not recommended since this may cause foreign particles to become embedded in the insulation or damage insulators. Any buildup of dirt or other contaminants that will not come off with vacuuming should be cleaned with lint-free rags using cleaning solvents recommended by the manufacturer.

All vents and fan grills are to be cleaned of all dust and/or dirt accumulations. Ensure that ventilation openings are not obstructed. Where seals and/or gaskets are installed, these should be examined and repaired or replaced as necessary. All doors and access panels should be properly secured during operation. Where heater elements are installed, these should be cleaned, examined for damage and/or deterioration, and tested. Repair or replace heater elements as necessary.

In environments where there is an extreme exposure to adverse conditions, the frequency of maintenance for enclosures should be increased as conditions warrant.

Electrical equipment rooms or vaults should be kept cleaned of dirt and/or dust accumulations on a regular basis. Doors and windows should be maintained in proper working order and kept closed during routine operation. Access doors should be clearly marked to alert personnel that live electrical equipment is in use. Where ventilation and/or air conditioning is used, all fan motors should be cleaned and examined for signs of wear and deterioration. Fan blades should be cleaned of dirt and dust and bearings should be properly lubricated. Vent openings should be cleaned of all dust and dirt accumulations. Filters should be cleaned and/or changed as recommended by the manufacturer, or more often if conditions warrant. Electrical equipment rooms should never be used as storage areas.

Electrical equipment rooms or vaults should be examined for evidence of water seepage. The tops of electrical equipment enclosures should be examined for evidence of water since this is a common entryway that often goes undetected until a failure occurs. The source of the water should be immediately identified and corrective measures taken to permanently correct the condition.

3.1.2 Insulators, supports, and connectors—Inspect insulators and conductor supports for signs of cracking, broken pieces, and other physical damage or deterioration. Clean all loose dirt with lint-free rags. For contaminates that will not remove easily, solvents approved by the manufacturer may be used. Examine for evidence of moisture that may lead to tracking or flashover while in operation. Examine surrounding areas for signs of tracking, arcing, or overheating. Repair or replace damaged insulators and supports as necessary.

Examine all bolts and connecting devices for signs of deterioration, corrosion, or overheating. Ensure that bolts and connecting devices are tight, according to manufacturer's specifications. Be careful not to over-torque bolts and connecting devices since insulators are easy to damage and difficult to replace. Where copper and aluminum conductors and/or connectors are used together, examine connections for signs of galvanic action. Ensure that the connectors are properly used and installed in accordance with manufacturer's specifications. Apply an antioxidant compound to all aluminum-to-copper connections.

3.1.3 Conductors—Examine insulation for signs of deterioration, cracking, flaking, or overheating. Examine all connections for signs of overheating, cracked or broken connectors, and signs of tracking or arcing. Ensure that conductors are clean and dry. Examine and clean all connections, and torque to manufacturer's recommendations.

3.2 Air circuit breakers

3.2.1 Insulation—Remove and clean inter-phase barriers. Clean all insulating materials with vacuum and/or clean, lint-free rags. If it is necessary to use cleaning solvents, use only solvents recommended by the manufacturer. Inspect for signs of corona, tracking, arcing, or thermal or physical damage. Ensure that insulation is left clean and dry.

3.2.2 Contacts—Ensure that all contacts are clean, smooth, and in proper alignment. Ensure that spring pressures are maintained according to manufacturer's specifications. On silver contacts, discoloration is not usually harmful unless caused by insulating deposits. Clean silver contacts with alcohol or silver cleaner using non-abrasive cloths.

Manually close breaker to check for proper wipe, contact pressure, contact alignment, and to ensure that all contacts make at approximately the same time. If possible, a contact resistance test should be performed to determine the quality of the contacts.

Older breakers equipped with carbon contactors generally require very little maintenance. Examine for proper pressure, deterioration, or excessive dressing which may interfere with their proper operation.

Draw-out contacts on the circuit breaker, and the stationary contacts in the cubicle should be cleaned and inspected for overheating, alignment, and broken or weak springs. Coat contact surfaces with contact lubricant to ease mating (see manufacturer's recommendations).

3.2.3 Arc interrupters—Clean all ceramic materials of loose dirt and examine for signs of moisture, and make sure the assemblies are clean and dry. Examine for cracked or broken pieces. Dirt and arcing deposits may be removed by light sanding — do not use emery cloth or wire brushes which may leave conductive residue behind. Repair or replace as necessary.

Examine arc chutes for dirt and/or dust accumulations and clean as necessary. Dielectric testing of arc shields may be recommended by the manufacturer. Check air puffer for proper operation.

3.2.4 Operating mechanism—Inspect for loose, broken, worn, or missing parts (consult manufacturer's schematics for required parts). Examine for excessive wear of moving parts. Observe that operating mechanisms function properly without binding, hanging, or without delayed action. Ensure any lubrication is done according to the manufacturer's specifications. Ensure mechanisms are clean, properly lubricated, and all bolts and screws are properly secured. Repair or replace as necessary.

3.2.5 Auxiliary devices—Inspect operating devices for proper operation and general condition. Ensure all indicating devices are fully functional and properly set. Protective relays and circuit breaker trip devices should be inspected and tested according to manufacturers' specifications and applicable industry standards such as those issued by the Institute of Electrical and Electronics Engineers (IEEE) and the National Fire Protection Association (NFPA).

3.3 Vacuum circuit breakers

All maintenance is similar to that performed on air circuit breakers. As always, it is recommended that the manufacturer be consulted for specific maintenance and testing procedures.

The integrity of the vacuum chamber is often tested by applying a test voltage across the open contacts of the breaker. However, this can be a destructive test and is therefore not recommended by HSB.

Caution: This procedure can produce X-ray emissions, so personnel should maintain a safe distance from the breaker if this test is performed. It is important to closely follow manufacturer's recommended procedures if conducting this test in order to ensure that proper results are obtained. The breaker vapor shield can accumulate an electrostatic charge during this test. Ensure that it is discharged immediately following the test.

3.4 Air disconnect switches

Inspect and clean insulators and conductors as with circuit breakers. Tighten connections in accordance with manufacturer's specifications. Do not over-tighten as this may result in damage to connectors.

If cleaning solvents are used, ensure that they are used as recommended by the manufacturer. Where abnormal environmental conditions exist, more frequent inspection and cleaning may be required.

Check the operation of the arc blades, if applicable, and ensure proper wipe of the main contacts. Inter-phase linkages and operating rods should be inspected to make sure that the linkage has not been bent or distorted and that all fastenings are secure. The position of the toggle latch to the switch operating linkage should be observed on all closed switches to verify the switch is mechanically locked in a closed position. Operate switch manually several times to ensure proper operation, and then by motor if power-operated. Ensure that all moving parts are properly secured and lubricated as specified by the manufacturer.

Contact resistance testing of each phase contact should be performed. The results should be recorded and analyzed to ensure proper contact is being made. If the contact resistance of the switch exceeds recommended minimums, repair or replace the switch immediately.

3.5 Oil circuit breakers

3.5.1 External—Inspect the enclosure for signs of oil leakage. Clean external bushings assemblies and examine for signs of deterioration, tracking, and loose or broken parts. Observe oil gauge to ensure device is operating properly and measuring the oil level accurately.

3.5.2 Insulating oil test—Conduct a dielectric screen test of the insulating fluid. Based on the results of this test, filter or replace oil as required. Heavy carbon content can indicate potential contact wear and should be investigated further.

3.5.3 Internal—Since the contacts for oil circuit breakers are not readily accessible for inspection, the contact resistance should be tested as a minimum.

More extensive maintenance on the contacts might require draining the oil and dropping the tank, and is therefore performed less frequently. Follow manufacturer's recommended schedule for examination of internal components such as contact inspections. Open breaker and examine contacts for wear and/or excessive deterioration. Examine linkages for loose, broken, or missing parts; repair or replace as necessary.

3.5.4 Auxiliary services—Operating mechanisms should be maintained as with air circuit breakers. Where applicable, examine oil level indicators, sight glasses, oil lines, gaskets, and tank lifters for proper conditions. Repair or replace as necessary and in accordance with manufacturer's recommendations.

Examine arc-quenching assemblies for carbon deposits or other contaminates. Follow manufacturer's recommendations for cleaning.

3.6 Molded-case circuit breakers

Molded-case circuit breakers should be kept clean for proper ventilation of the breakers. These types of breakers are usually tripped by a thermal element that senses an increase in temperature due to excessive current draw. However, if dirt accumulates on the surrounding edge of the breaker, the heat build-up may not be permitted to dissipate properly and result in nuisance tripping.

Clean the breaker housing and inspect it for cracks or signs of overheating. Tighten all connections. Exercise the breaker several times to ensure the mechanism has freedom of movement and to allow contact wiping.

In addition, larger duty circuit breakers (225 amps or above) should be electrically trip tested to ensure proper operation of the trip elements and trip linkages. Refer to the latest edition of the National Electrical Manufacturers Association (NEMA) Standard AB4, Procedures for Verifying Field Inspections and Performance Verification of Molded-Case Circuit Breakers. If possible, test contact resistance to ensure quality of breaker contacts.

All molded-case circuit breaker panels should be cleaned of all dirt, dust, and debris using a vacuum.

3.7 Battery stations/chargers

3.7.1 Batteries—Thoroughly clean all battery surfaces of dust and/or dirt accumulations. Clean and tighten all terminal connections. Remove any corrosion on battery terminals with bicarbonate of soda.

Clean battery studs and cable ends. On stranded cable, if ends are corroded, cut off ends or separate strands and clean internally.

Check electrolyte levels and specific gravity. Variations of more than fifty (50) points between cells may indicate a bad cell.

3.7.2 Charger—Clean all dust and/or dirt accumulations from charger. Clean all vent openings and ensure that they are free from obstructions.

Check terminals and connections for tightness. Check all relays, lights, and other indicating devices for proper operation.

If all cells consistently read low, check charger for proper operation. If electrolyte levels are low, check charger rate settings against the manufacturer's specifications. Consistently low levels may indicate the charge rate is too fast.

3.7.3 Safety—While charging, batteries emit explosive gases. Allow no open flames or sparks permitted near charging batteries. Battery rooms should be well-ventilated and smoking should not be permitted.

3.8 Cables and bus

De-energize cables if they are to be touched or moved during maintenance.

3.8.1 Cables in manholes—*Caution: Check for dangerous gases using a properly calibrated test meter before entering any confined space such as a manhole.*

Inspect for sharp bends, physical damage, excessive tension, oil leaks, pits, cable movement, soft spots, cracked jackets, damaged fireproofing, poor ground connections, deteriorated, and corroded or weakened cable supports. Inspect for wear at entrance point and at supports. Inspect manhole for spalled concrete, proper ventilation, and excessive moisture. Inspect potheads for oil or compound leakage and for cracked/chipped porcelain.

Examine the manhole and cable grounding system to ensure its integrity. If cathodic protection has been installed in the manhole, it too should be evaluated. Corrective action should be taken as appropriate to maintain the integrity of these systems.

3.8.2 Aerial cables—Check supports for excessive wear or deterioration, check cables for wear at support points, and inspect for mechanical damage from vibration. At dead-ends, check cable for worn insulation, sharp bends, or cracks.

3.8.3 Raceways—Check raceways for proper mechanical support of raceway and cables as well as check insulation for abrasion or cracks at support points. Examine raceway joints for clean and tight connections.

3.8.4 Bus duct—Bus duct joint covers should be removed to allow access for a thermographic survey of the energized bus under load. After de-energizing and grounding the bus duct, connections should be checked for proper tightness as well as evidence of overheating, corrosion, arcing, or other forms of deterioration. All loose or dirty connections should be cleaned and properly torqued — be careful not to over-torque the bolts. Consult the manufacturer for recommended maintenance practices and torque values. The tops of the bus duct enclosure should be inspected for evidence of water or other foreign matter that may contaminate the bus duct.

3.8.5 Testing—Suggested cable or bus tests include insulation resistance testing and polarization index testing. These tests should be recorded to track trends that may indicate a deterioration of the cable's insulation.

3.9 Transformers

Transformer data (such as voltage, current, and temperature readings) should be recorded on a regular basis in order to determine operating conditions of the transformer. Peak, or redline, indicators should be recorded and reset. Readings taken on a weekly basis can provide important information about the loading of the transformer that is needed before additional loads can be added to the transformer.

3.9.1 Dry type transformers—After de-energizing and grounding the transformer, clean all coils, connections, and insulators of loose dust or dirt deposits with a vacuum cleaner. Examine the transformer for signs of overheating, deterioration, arcing, loose or broken parts, or other abnormal conditions. Ensure all connections are tightened according to manufacturer's specifications. Clean enclosure of any dust and dirt accumulations and ensure that vent openings are free from obstruction. If cooling fans are installed, examine for proper operations and lubricate as necessary.

Additional suggested testing includes an insulation resistance test, a dielectric absorption test, and a power factor test. These are non-destructive tests which can be performed to track the condition of the insulation over time. Detailed records should be maintained and analyzed to identify undesirable trends that may indicate the onset of an insulation failure.

3.9.2 Liquid-filled transformer—Insulating liquid samples should be taken annually and screen tested for dielectric breakdown, acidity, color, power factor, and interfacial tension. A fault gas analysis or adissolved gas analysis (DGA) test conducted by a qualified testing laboratory should be performed annually. The results should be trended to track conditions and schedule maintenance as necessary.

Examine the transformer tank and bushings for evidence of leakage. Inspect the bushings, insulators, and surge arrestors for broken or damaged parts, signs of overheating or arcing, or tracking. Clean all bushings, insulators, and surge arrestors of any dirt or dust accumulation. Tighten all conductor connections in accordance with manufacturer's recommendations.

If applicable, perform a ground resistance test to ensure a value of 25 ohms or less.

3.10 Surge arrestors

Clean and inspect porcelain for signs of damage or deterioration. Repair or replace as necessary.

Examine arrestor leads for damage and/or deterioration.

Other suggested tests are 60 cycle spark over and hold tests, watts-loss and leakage current tests, insulation resistance tests, and grounding electrode circuit resistance tests. These should be conducted according to manufacturer's recommendations.

3.11 Protective relays

Inspection, maintenance, and testing of protective relays should be done on an annual basis in order to ensure proper and reliable operation. All necessary precautions should be taken while working with protective devices to ensure personnel safety and to avoid any unplanned interruption of service. In particular, when working on control circuits, all current transformer (CT) secondaries should be shorted to ground and never left open-circuited in order to avoid serious injury to maintenance personnel.

3.11.1 Visual and mechanical inspection—Inspect relays for physical damage and deterioration. Inspect gaskets and covers for damage and/or excessive wear, and repair or replace as necessary. Examine and clean the relay and enclosure of foreign materials, such as dust, dirt, and moisture contamination. Examine the condition of the spiral spring, disc clearances, contacts, and case shorting contacts (if present). Check mechanism for freedom of movement, proper travel and alignment, and tightness of mounting hardware and plugs.

3.11.2 Electrical testing—Using an appropriate testing instrument, suitable for the relays being tested, conduct electrical testing of the relays in accordance with manufacturer's recommendations and IEEE testing standards. For overcurrent relays, test the following functions of the relay at the established settings specified by the system engineer or manufacturer:

- Pickup contacts should close when a current equal to the relay tap setting is applied to the induction coil. Adjust the spring as needed to allow for proper operation.
- Timing tests should be performed corresponding to two (2) or more points on the relay's time current curves. One of the tests should be done at the specified time dial setting.
- Instantaneous pickup test should be performed for the specified instantaneous setting, if applicable.
- Seal-in units should be tested to ensure that the contacts hold closed with the minimum specified current applied.
- Relay target should indicate when the relay has operated.
- If possible, the relays should be tested to ensure that operation of the relay will in fact cause a tripping action of the respective circuit breaker. Relays that do not test satisfactorily or are found to be defective should be replaced immediately to maintain the integrity of the protection systems.

3.12 UPS systems

This section provides general recommended maintenance guidelines for uninterruptible power supply (UPS) systems. Since there is a wide variety of systems and equipment available, the manufacturer's instructions and recommendations should be consulted for more complete and detailed maintenance requirements.

UPS systems are categorized in two basic ways: static and rotary. For the purposes of this guide, only static systems will be addressed.

When performing any maintenance and/or testing of UPS systems, follow all recommended safety procedures as indicated by the manufacturer and required by OSHA. Only fully trained and qualified persons with proper test equipment should perform UPS maintenance.

Clean interior and exterior of cabinets and enclosures, ensuring that any areas of corrosion and/or deterioration are repaired as necessary. Clean all vent and air circulation openings and ensure freedom from obstructions. If installed, clean cooling fan blades and motor housings. Ensure that motor bearings are properly lubricated and that fan blades are properly secured to drive shafts. Examine for signs of moisture contamination and correct if necessary.

Clean and examine all electrical connections for signs of corrosion or deterioration, and repair or replace as necessary. Ensure all connections are tightened according to manufacturer's specifications. As applicable, clean and test all breakers, disconnects, and relays as prescribed elsewhere in these standards and as specified by the manufacturer. Check all system alarms and indicating lights for proper operation.

Check inverters for fluid leaks from wave-forming capacitors. Check capacitors for signs of bulging or discoloration. Examine transformers and heat sinks for signs of overheating. Maintain batteries as prescribed in Section 3.7 of this guide and as specified by the manufacturer.

3.13 Electric motors

A maintenance program for electric motors should utilize proven and well-understood testing and inspecting methods performed by qualified knowledgeable personnel to identify and evaluate conditions.

Recommended maintenance practices and frequencies

- **Installed and running** – Actions typically performed with the motor installed and coupled to the driven load.
- **Installed and offline** – Actions which require the motor to be electrically disconnected but can be performed with the motor installed and coupled.
- **Overhaul** – Actions typically completed during a routine overhaul. Additional testing/activities may be required based on the individual situation.
- **Post overhaul** – After completion of maintenance, the insured should review work report, ensure all parts sent with the motor (i.e., terminal box, couplings) were returned, and perform basic testing of the motor before placing it in the stock system.

There are several methods of acceptable cleaning. These include water spray, low pressure steam cleaning, and cryogenic (CO_2 pellets) cleaning. The intent of cleaning is to remove all dirt and contamination, including any grease or oil film on the windings. Cleaning methods should not utilize high pressure flow or any abrasive methods that could cause damage to the windings.

Maintenance activity	Location	Performance characteristics	Frequency
Visual inspection	Installed and running	– Inspection should look for: • Evidence of damage caused by dirt, loose parts, or foreign objects • Verification that air inlets are not blocked • Evidence of moisture and/or dirt build-up • Unusual noises, leaking oil seals, or high vibration • Oil level gages (if present) should be checked • Evidence of degradation of foundation, bed plates, and anchor bolts • Evidence of oil rings turning (if applicable) • Evidence of leaking oil and water piping and connections	6 months
Temperature monitoring of bearings and windings	Installed and running	– If motor is not equipped with installed sensors: • Record bearing temperatures and stator temperature using thermographic imaging. This data should be trended. The monitoring should be completed at similar motor loading and ambient temperature to allow for accurate trending.	6 months
Vibration	Installed and running	– Record and trend vibration levels. – This should be done by a trained and experienced technician, preferably a qualified level II technician.	6 months
Oil analysis	Installed	– Sample and analyze. Look at overall conditions and check for foreign matter, additive depletion, varnish precursors, and metallic elements. – **Motor should be shut down when taking sample.**	12 months
Running current	Installed and running	– Record and trend all three phase currents and verify the currents are balanced and do not exceed nameplate rating. – Each phase should be within +/- 5% of the average of all three phases.	12 months
Insulation resistance (IR)	Installed and off line	– Perform IR check between motor leads and ground. This determines condition of the ground insulation. Record, temperature correct, and trend. **Motor voltage** / **Test voltage(VDC)** / **Acceptable reading** < 1000 / 500 / > 5 1000-2500 / 1000 / > 100 megohm 2501-5000 / 2500 / > 100 megohm > 5000 / 5000 / > 100 megohm	– 12 months for > 600-volt motors – 24 months for < 600-volt motors
Polarization index (PI)	Installed and off line	– Ratio of the 10-minute IR to the 1-minute IR – (10-min IR/1-min IR) – Determines condition of ground insulation – Test voltages similar to the IR test voltages – Acceptance criteria ratio > 2	– 12 months for > 600-volt motors – 24 months for < 600-volt motors

Maintenance activity	Location	Performance characteristics	Frequency
Winding resistance	Installed and off line	– A comparison of the line-to-line resistances of the motor's winding. This test should be done at the motor terminals using a meter capable of measuring low resistance (milliohms). A typical ohm meter does not have adequate accuracy. Record, temperate correct, and trend. – Each phase should be within +/- (3% to 5%) of the average of all three phases.	– 12 months for > 600-volt motors – 24 months for < 600-volt motors
Bearing insulation resistance check (if applicable)	Overhaul	– Completed similar to other IR (megger) test. Used to verify condition of insulation on a bearing. • Test voltage: 500 VDC • Acceptance criteria: 1 megohm	60 months
Shaft total indicated run out (TIR)	Overhaul	– Measure the trueness of the shaft extension. A high value can cause vibration issues. – Acceptance criteria: 3600 rpm max .001 in < 3600 rpm max .003 in	60 months
Inspection and measurements of bearing journals and housing fits	Overhaul	– Diameters of the fits should be measured and compared to bearing industry standards. – Bearing journals and housing bores should be visually inspected for finish, pitting, rubbing, and corrosion.	60 months
Stator visual Inspection	Overhaul	– Inspection should look for: • Coil movement • Plugged vent holes • Soft or degraded insulation • Coil bracing adequate and intact • Lamination damage • Partial discharge activity • Tightness of wedges	60 months
Rotor/Shaft visual inspection	Overhaul	– Inspection should look for: • Cracks in rotor bars • Balance weights properly secured • Signs of bar movement • Signs of rotor/stator rub or lamination damage • Cooling ducts clear • Rubbing marks on shaft • Keyway distortion	60 months
Clean, bake dry, and varnish (as needed)	Overhaul	– All parts should be cleaned and baked dry to remove all dirt and contamination. The windings should be reinsulated as appropriate.	60 months
Insulation resistance	Overhaul and post overhaul	– Perform IR check between motor leads and ground. This determines condition of the ground insulation. Record, temperature correct, and trend. **Motor voltage** / **Test voltage(VDC)** / **Acceptable reading** < 1000 / 500 / > 5 1000-2500 / 1000 / > 100 megohm 2501-5000 / 2500 / > 100 megohm > 5000 / 5000 / > 100 megohm	60 months
Polarization index (PI)	Overhaul and post overhaul	– Ratio of the 1-minute IR to the 10-minute IR. Determines condition of ground insulation. • (10-min IR/1-min IR) • Test voltages similar to the IR test voltages – Acceptance criteria ratio > 2.	60 months
Winding resistance	Overhaul and post overhaul	– A comparison of the line-to-line resistances of the motor's winding. This test should be done at the motor terminals using a meter capable of measuring low resistance (milliohms). A typical ohm meter does not have adequate accuracy. Record, temperate correct, and trend. – Each phase should be within +/- (3% to 5%) of the average of all three phases.	60 months

Maintenance activity	Location	Performance characteristics	Frequency
Surge test	Overhaul	– The test verifies the insulation condition between the turns of a motor's winding. It can be a destructive test. This test should only be done after the visual inspection, the other electrical checks, and the clean and drying process. Test voltage (overhaul): 2 x rated voltage +1000. – Acceptance criteria: steady and duplicate patterns.	60 months
Rotor balance	Overhaul	– Balance process minimizes the out of balance of the rotor. Acceptable levels are based on speed and application of the machine.	60 months
Core loss	Overhaul	– This test is completed on both the rotor and stator. This test excites the core to determine overall core loss levels and locate any shorted laminations. Any hotspots or high core loss found should be investigated and corrected.	60 months
Broken rotor bar checks	Overhaul	– Methods to check for cracked rotor bars include visual, audible, hotspot check, growler, magnetic paper, and single phase rotation.	60 months
No load run test with vibration measurements	Overhaul	– This test is performed after all work has been completed. Test should verify acceptable current balance, bearing temperatures, vibration levels, and that there is no unusual or rubbing or noises present.	60 months

An industry-accepted, pass/fail test that is ideally suited for new or recently rewound motors is an AC or DC high potential test (hipot). An AC voltage is applied to the windings at twice the operating voltage plus 1000v (A 4160v motor is tested at 9000 volts!) or a DC voltage is applied to the windings at 1.7 x (twice the operating voltage plus 1000v). Both the AC and DC "hipot" tests are considered destructive tests because marginal equipment can fail prematurely while undergoing this test. Because of its destructive nature, HSB does not recommend this test as a maintenance test.

An industry accepted test to verify the integrity of the turn-to-turn insulation in an electric motor is a surge or impulse test. This test uses a charged capacitor to pulse a voltage into two windings of a motor simultaneously. The voltage is set low to begin and raised slowly while the operator watches the wave forms on an oscilloscope. The voltage pulse is eventually raised to twice the operating voltage, plus 1000 volts. Since the windings are supposed to be identical, the wave forms should be identical — a difference in wave forms indicates a problem. A skilled operator can determine the exact type of fault (turn to turn, phase to phase, etc.) by studying the wave form patterns. This test can be considered a potentially destructive test because marginal motors can fail under test. This test should only be performed during an overhaul period, after the visual inspection, the other electrical checks, and the clean and drying process have been completed.

Motor Current Signature Analysis is a relatively new test that can help detect rotor and stator issues based on the current waveform of the motor. This test evaluates the condition of the motor by analyzing the frequency spectrum of the line current. This test is still considered in the developmental stage by HSB. Industry guides for test procedures or acceptance criteria have not been established.

There are additional tests which can be completed on motors at voltage levels 4160 volts and higher. These tests include power factor (or dissipation factor), capacitance, and partial discharge test. These tests can be very beneficial but they are highly specialized. They should be evaluated on a case-by-case basis to determine their suitability.

Infrared inspection

An infrared, or thermographic, inspection should be performed at least once every three years on all switchgear, distribution panels, cable and bus connections, motor control centers and starters, and other critical equipment. Infrared inspections are extremely beneficial in reducing electrical failures by identifying potentially dangerous conditions; eg., loose or dirty connections, overloaded or imbalanced circuits, or improperly installed equipment. By measuring the heat imbalance relative to the environment and to surrounding equipment, abnormal or adverse conditions can be uncovered that if left unattended would worsen to the point of failure.

Infrared (IR) surveys are very helpful in planning the work scope of an upcoming scheduled outage. Prior to the planned maintenance, an IR survey should be conducted to help identify areas that need specific and immediate attention. Resources can then be allocated to address these specific problems during the de-energized period.

Infrared surveys are done on energized equipment and should be conducted during peak demand periods if possible. This will reveal the most serious problems and those that would otherwise go undetected. At a minimum, the loading should be at least 40% of the rated load of the equipment being inspected.

Effective infrared surveys require specialized equipment and should be performed only by qualified technicians. Experience and training is required to accurately identify problem conditions and possible causes so that specific recommendations can be made to correct the situation. It is imperative that these recommendations be implemented in a timely manner to benefit from an infrared inspection. Knowing a problem exists does not help avoid an electrical failure unless corrective actions are employed.

Record keeping

The electrical preventive maintenance program should be well-documented as to scope and frequency of maintenance. Record all routine maintenance activities and the results of routine testing for trending purposes. Document all repair and/or replacement of electrical components. When changes are made to the electrical distribution system, update all applicable drawings and maintenance schedules to reflect the changes. Ensure that spare parts inventories are updated for any new equipment added based on the manufacturer's recommendations.

Standards

Any electrical preventive maintenance program should be performed in accordance with accepted industry standards and work/safety practices. This includes, but is not limited to, the latest releases of the following:

- National Fire Protection Association (NFPA) 70B, Recommended Practice for Electrical Equipment Maintenance
- National Fire Protection Association (NFPA) 70, National Electrical Code
- National Electrical Manufacturers Association (NEMA) Standard AB4, Procedures for Verifying Field Inspections and Performance Verification of Molded-Case Circuit Breakers
- International Electrical Testing Association (NETA), Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems
- IEEE STD P1415 Motor Maintenance and Failure Analysis (draft)
- National Electrical Manufacturers Association (NEMA) Standard MG1
- International Electrical Testing Association (NETA), Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems
- OSHA Applicable Standards
- IEEE STD 1415, IEEE Guide to Introduction Machinery Maintenance Testing and Failure Analysis
- EEE STD 43, IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery

Note: Upgrades or expansion of electrical systems should be designed by a qualified professional engineer and installed by licensed electricians.

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