MOTORS AND ADJUSTABLE SPEED DRIVES

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1.0 SCOPE

This data sheet provides operation, testing, maintenance and protection guidelines for large, form wound, alternating current (AC) and direct current (DC) motors. In general, this encompasses motors larger than 1500HP (1.1MW).

1.1 Hazards

Bearing failure and winding insulation failure are the two main equipment breakdown hazards associated with motors. Bearing failure can cause rotating and stationary parts of the motor to rub. This will cause damage to the windings and sometimes the core. Winding insulation failure will result in arcing damage to the windings and sometimes the core.

1.2 Changes

January 2024. Full revision. Major changes were made.

A. Revised the scope of the data sheet to include only motors larger than 1,500 hp.

B. Incorporated condition and performance-based maintenance practice guidance.

C. Removed fire protection requirement for motors.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Protection

2.1.1 Provide an FM Approved, fixed, clean agent fire protection system for adjustable speed motor drives in critical applications. Design the system to flood the drive enclosure or room. Design extinguishing systems in accordance with Data Sheet 4-9, *Halocarbon and Inert Gas (Clean Agent) Fire Extinguish Systems*, as appropriate.

2.1.2 Provide FM Approved wheeled portable carbon dioxide or dry chemical extinguishers at all manned and unmanned locations. Refer to Data Sheet 4-5, *Portable Extinguishers*, to determine effective sizes and locations for the extinguishers. Protect extinguishers located outside against freezing.

2.2 Mechanical

2.2.1 Provide protection for motor bearings in accordance with Table 2.2.1. Arrange these protective devices to alarm first and then to trip the motor if the condition gets worse and no corrective action is taken.

Table 2.2.1. Protection for Motor Bearings with Continuous Lubrication

IEEE Device No	*Protective Relay*	*Purpose*
71	Level	Detects low oil level in reservoir
63	Pressure	Detects low oil pressure supply to bearings
80	Flow	Detects low oil flow to bearings
38	Temperature	Detects high temperature at bearings[1]
n/a	Vibration[2]	Detects bearing deterioration

Note 1. For sleeve bearings, the best place to locate the temperature sensor is in the Babbitt material. Anti-friction bearings do not allow temperature sensors to be installed at the bearing. The sensor can be located in the return oil line of each bearing to detect overheating.

Note 2. For existing locations, having hand-held or fixed instrument for periodic vibration analysis is tolerable.

2.3 Electrical

2.3.1 Electrical Protection

2.3.1.1 Provide electrical protection in accordance with Tables 2.3.1.1-1, 2.3.1.1-2, 2.3.1.1-3, 2.3.1.1-3a, and 2.3.2-3b depending on the type of motor and whether an adjustable speed drive is used.

Tables 2.3.1.1-3a and 2.3.1.1-3b show additional protection for adjustable speed drives. They list protection requirements for the adjustable speed drive and the isolation transformer. Ensure the motor itself is still provided with the protection devices recommended in Tables 2.3.1.1-1, 2.3.2.1-2, and 2.3.2.1-3.

The arrangement of these electrical protective devices is illustrated in Figures 2.3.1.1-1, 2.3.1.1-2, and 2.3.1.1-3.

Table 2.3.1.1-1. Protection for Induction Motors

IEEE Device No	*Protective Relay*	*Purpose*
27	Time Delay Under-Voltage	Prevents nuisance motor trips due to short duration (5–15 cycles) voltage sags. Will trip the motor if the voltage sag is of longer duration (more than 15 cycles).
27	Instantaneous Under-Voltage	Protects the motor from extreme voltage dips, regardless of duration.
46	Phase Balance Current	Protects the motor from current unbalance due to load conditions or single phasing.
47	Phase Sequence	Protects the motor from single phasing, unbalanced phase voltages, and reversed phase sequence.
48	Incomplete Sequence	Applicable to reduced-voltage starters to protect the motor from prolonged operation at subnormal speed when starting.
49	Thermal (RTD/TC or Load Current)	Protects stator winding from overload.
50/51	Instantaneous/Inverse Over-Current	Protects stator winding from overload and short circuits.
50G/51N	Instantaneous/Inverse Ground Fault	Protects the stator winding from ground faults.
50/51R	Instantaneous/Inverse Over-Current	Provides locked rotor protection.
86	Lock-Out	Prevents the motor from being re-started without resetting protection relays. This forces the operator to investigate the cause of tripping instead of attempting to restart the motor with the fault still present and causing additionaldamage.
87	Differential	Protects the stator winding from short circuits and ground faults. This is much more sensitive protection thaninstantaneous/inverse protection.

Table 2.3.1.1-2. Protection for Synchronous Motors

IEEE Device No	*Protective Relay*	*Purpose*
13	Synchronous Speed Device	Protects the motor from out of step operation (when the motor loses synchronism with the system frequency).
26	Overheating Detector	Protects the damper winding from damage when the motor stalls.
27	Time Delay Under-Voltage	Prevents nuisance motor trips due to short duration (5–15 cycles) voltage sags. Will trip the motor if the voltage sag is of longer duration (more than 15 cycles).
27	Instantaneous Under-Voltage	Protects the motor from extreme voltage dips, regardless of duration.
40	Loss of Field	Protects the motor against loss of excitation.
46	Phase Balance Current	Protects the motor from current unbalance due to abnormal load conditions or single phasing.
47	Phase Sequence	Protects the motor from single phasing, unbalanced phase voltages and reversed phase sequence.
48	Incomplete Sequence	Applicable to reduced-voltage starters to protect the motor from prolonged operation at subnormal speed when starting.
49	Thermal (RTD/TC or Load Current)	Protects stator winding from overload.
50/51	Instantaneous/Inverse Over-Current	Protects stator winding from overload and short circuits.
50G/51N	Instantaneous/Inverse Ground Fault	Protects the stator winding from ground faults.
50/51R	Instantaneous/Inverse Over-Current	Provides locked rotor protection.
53	Excitation Check	Protects the motor against loss of excitation.
55	Power Factor	Protects the motor from out of step operation (when the motor loses synchronism with the system frequency).
56	Pull-Out	Protects the motor from out of step operation (when the motor loses synchronism with the system frequency).
86	Lock-out	Prevents the motor from being restarted without resetting tripped protection relays. This forces the operator to investigate the cause of tripping instead of attempting to restart the motor with the fault still present and causingadditional damage.
87	Differential	Protects the stator winding from short circuits and ground faults. Much more sensitive when compared to instantaneous/inverse protection.

Table 2.3.1.1-3. Protection for DC Motors

IEEE Device No	*Protective Relay*	*Purpose*
12	Over-Speed Device	A device that senses over-speed. It is typically used to sense over-speed conditions in series-wound DC motors due to loss of load.
14	Under-Speed Device	An acceleration relay that senses abnormal starting conditions during startup. It acts to adjust the voltage across the armature to maintain the desired starting torque and acceleration.
40	Loss of Field	An electrical device that senses loss of field to prevent over speed in shunt-wound DC motors. This device may beused as an alternative to the over-speed device in shuntwound DC motors
48	Incomplete Sequence	Applicable to reduced-voltage starters to protect the motor from prolonged operation at subnormal speed when starting.
49	Thermal (RTD/TC or Load Current)	Protects the field winding from overtemperature.
76	DC Overcurrent	Detects motor winding faults.

Table 2.3.1.1-3a. Protection for Adjustable Speed Drives (Input Transformer)

IEEE Device No	*Protective Relay*	*Purpose*
26	Overheating Detector	Senses overheating of the transformer liquid; applicable only to liquid-filled transformers.
49	Winding Temperature	Senses overheating of transformer winding.
50/51	Instantaneous/Inverse Over-Current	Protects the transformer against overloads and short circuits.
50G	Instantaneous Ground Fault	Protects the transformer against ground faults.
63	Sudden Pressure	Senses internal faults in liquid-filled transformers.
71	Liquid Level	Senses abnormal liquid levels in liquid-filled transformers.
87	Differential	Protects the transformer from short circuits and ground faults. Much more sensitive when compared to instantaneous/inverse protection.

Table 2.3.1.1-3b. Protection for Adjustable Speed Drives (Power Electronics)

Protective Relay	*Purpose*
Source Reverse-Phase Sequence	Senses problems in the input source that can affect the operation of the drive.
Source Voltage Unbalance	Senses problems in the input source that can affect the operation of the drive.
Source Undervoltage	Senses problems in the input source that can affect the operation of the drive.
Source Thyristor Overcurrent	Protects the thyristors, interconnecting bus and wiring from overheating.
Source Thyristor Overtemperature	Protects the thyristors from overheating due to problems in the cooling system.
DC Overvoltage	Senses drive malfunction and protects the reactor and output converter from overvoltage.
Reactor Overtemperature	Protects the DC link reactor from overheating.
Load Thyristor Overcurrent	Protects the thyristors, interconnecting bus and wiring from overheating.
Load Thyristor Overtemperature	Protects the thyristors from overheating due to problems in the cooling system.
Load Overvoltage	Protects the motor by sensing drive problems that produce overvoltage.
Load Overfrequency	Protects the motor by sensing drive problems that produce overfrequency (or overspeed).
Load Overexcitation [1]	Protects the motor by sensing drive problems that produce overexcitation.

Note 1. Overexcitation protection is not needed if overfrequency and overvoltage protection is already provided.

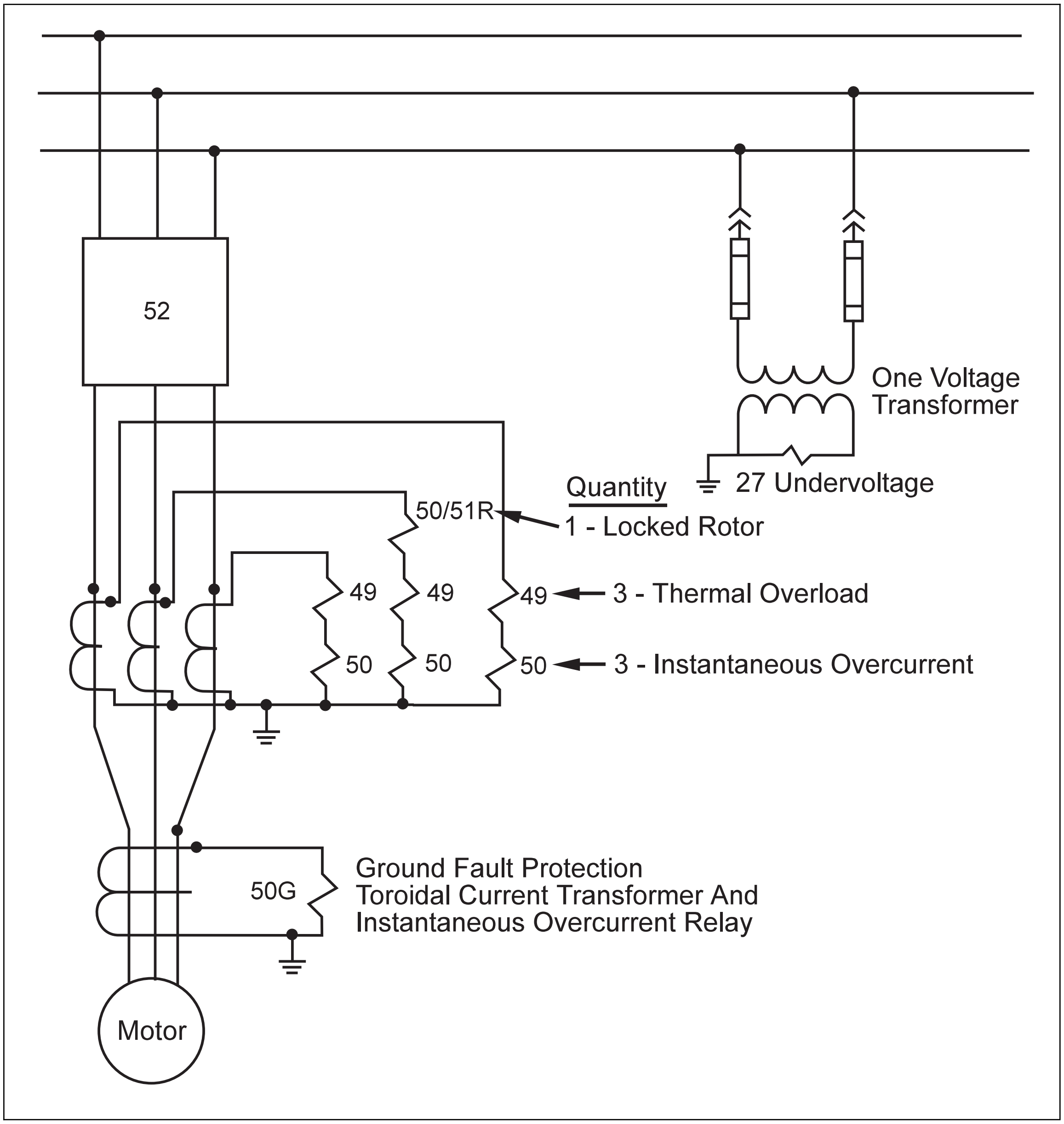

Fig. 2.3.1.1-1. Typical motor protection scheme

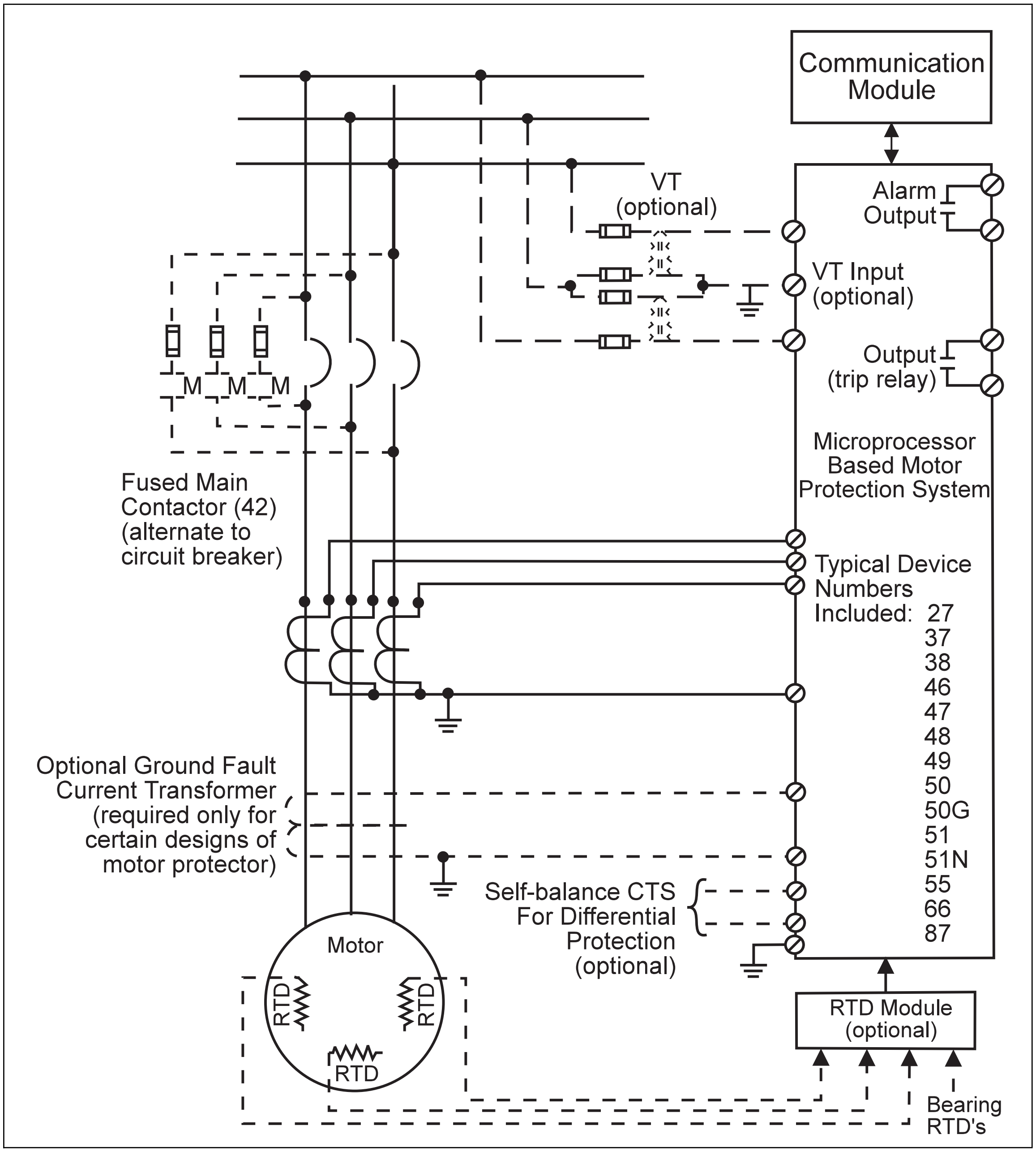

Fig. 2.3.1.1-2. Comprehensive microprocessor based motor protection system

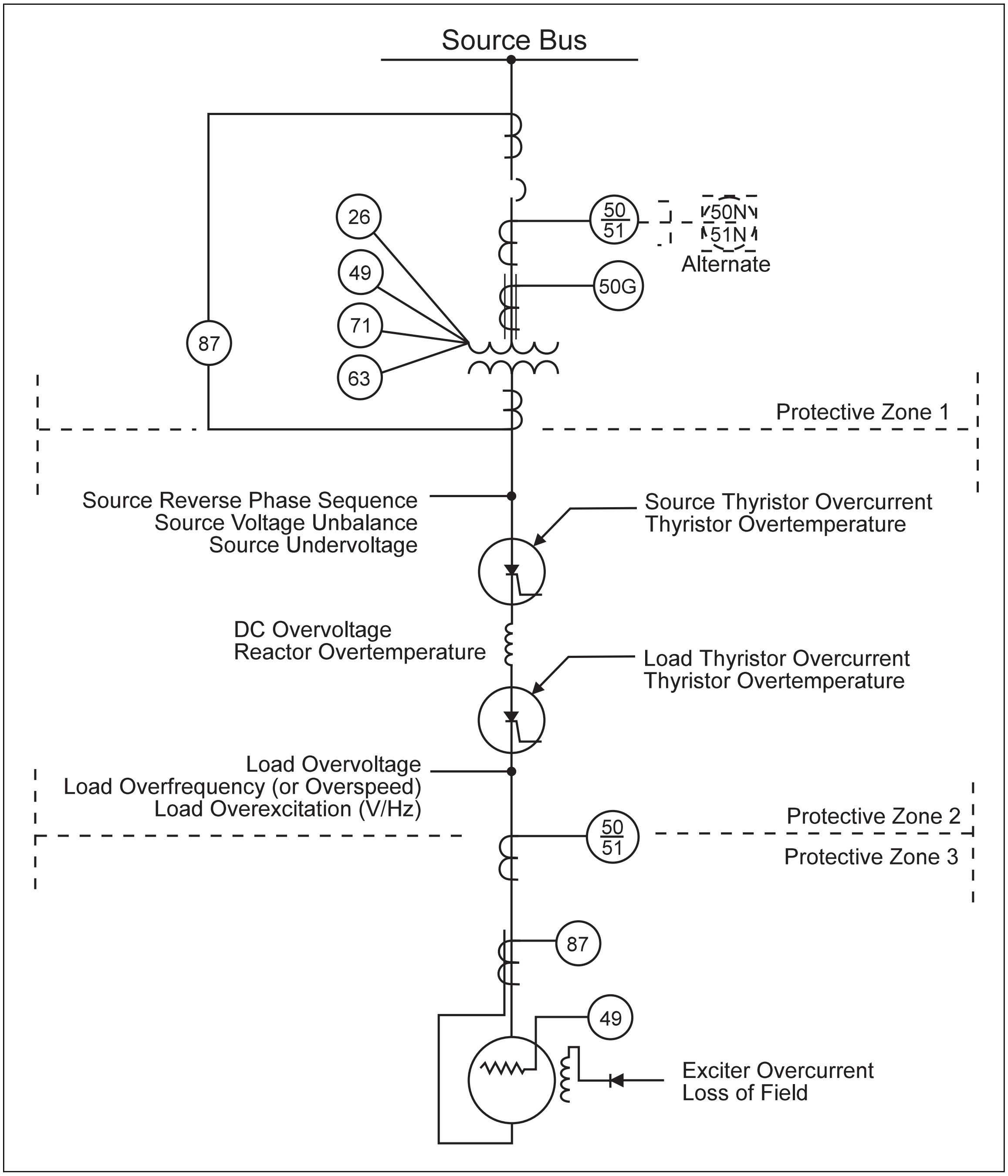

Fig. 2.3.1.1-3. Typical adjustable speed drive protection scheme

2.3.2 Gearless Mill Drives

2.3.2.1 In addition to Table 2.3.2.1, provide the following protection for gearless mill drives (annular synchronous motors or wrap around motors):

Table 2.3.2.1. Additional Protection Relays for Gearless Mill Drivers

Protective Relay	*Purpose*
Air Gap	Measures the air gap at several points around the stator and trips the mill if the air gap is reduced to below the minimum level.
Frozen Charge	Determines at startup whether the mill has a frozen charge and stops the mill to prevent the frozen charge from being dropped.
Mill Weight Overload	Protects against overload damage.

2.3.2.2 Protect the cycloconverter drive supplying the wrap-around motor in accordance with Tables 2.3.1.1-3a and 2.3.1.1-3b.

2.3.2.3 Provide the following monitoring functions for cooling systems in wrap-around motors. Arrange each function to give an alarm warning for low or high limits.

A. Cooling water flow monitors or switches for heat exchangers

B. Cooling air temperature monitors

C. Cooling air humidity monitors to protect against moisture condensation

2.3.2.4 Provide online partial discharge monitoring devices for gearless mill drives. Perform annual partial discharge measurement for diagnostic analysis.

2.3.3 Provide surge protection in accordance with Data Sheet 5-11, *Lightning and Surge Protection for Electrical Systems*.

2.4 Operation and Maintenance

Establish and implement a motor inspection, testing and maintenance program. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program.

2.4.1 General

2.4.1.1 Start, load and operate all motors and drives per manufacturer’s nameplate rating and instructions. Establish and implement an operator training program, including training and retraining on standard operating procedures (SOPs) and emergency operating procedures (EOPs). See Data Sheet 10-8, *Operators*, for guidance on developing operator programs.

2.4.1.2 Provide all motors and drives with the proper enclosure and insulation type for the prevailing condition.

2.4.1.3 Keep motor bearings clean and cool. Lubricate bearings using only the manufacturer’s recommended lubrication.

2.4.1.4 Protect motor bearings against stray or eddy currents using either bearing seat/pedestal insulation or shaft grounding.

2.4.1.5 Operate adjustable speed drives in a cool environment. If this is not practical, provide some means of cooling such as water-cooling or air conditioning. Continuous operation with open cabinet doors is not an acceptable alternative.

2.4.1.6 For gearless mill drives, maintain an alarm log to record any critical events.

2.4.2 Routine Visual Inspection

2.4.2.1 Perform visual inspections at least once a week per the SOPs. Check for unusual noises, unusual vibrations, excessive heat, anchorage, alignment, condition of grounding straps, slip rings, commutator brushes, brush rigging, oil levels, bearing lubrication leaks, cooling water leaks, blocked air inlet vents, combustibles and housekeeping.

2.4.3 In-Service Testing

2.4.3.1 Perform infrared scanning (thermography) annually. Check the bearings, motor frame, motor terminal box, surge capacitors, cables, motor controller and adjustable speed drive for overheating.

2.4.3.2 Perform a complete lubrication oil analysis where applicable according to the recommendations of the OEM regarding point of sampling and reference values for each parameter every six to 12 months.

2.4.3.3 If on-line vibration monitoring is not provided, perform vibration measurements of the shaft and bearings at least once a month.

2.4.4 Performance Monitoring

2.4.4.1 For motors critical to production, provide the following continuous monitoring system to track performance degradation or potential quality issues with the connected electrical system that can cause negative impact to the motor reliability.

- Stator current level at each phase during steady state and acceleration/starting
- Stator voltage level at each phase during steady state and acceleration/starting
- Voltage un-balance level between phases during steady state
- Voltage harmonic level during steady state
- Voltage spiking or transient overvoltage level at the steady state

2.4.5 Condition Monitoring

2.4.5.1 Provide the following condition monitoring systems if a condition-based maintenance strategy is used:

- Vibration monitoring for vibration spectra analysis
- Current monitoring for motor current signature analysis
- Partial discharge monitoring or electromagnetic interference monitoring (for large motors greater than 5,000 hp rated at 4.0kV and above)

The necessary level of condition monitoring depends on factors such as size, type, application, criticality and any pre-existing problems with the motor.

2.4.5.2 When PD on-line condition monitoring is installed, perform annual reading for trending at a minimum. Increase the frequency when abnormal increase of the reading is detected.

2.4.5.3 When motor current monitoring system is installed, perform current signature analysis on an annual basis. The analysis should be performed when the motor operates at 30% of rated capacity or above.

2.4.5.4 Establish an effective online condition monitoring program and/or performance monitoring program as part of the inspection, testing and maintenance program and include at least the following elements:

1. Establish clear ownership of the system and interpretation of data gathered from sensors. The data should be periodically reviewed and integrated with all available periodic offline testing, in-service testing and operating history for condition assessment.

2. Establish motor-specific criteria (including upper and/or lower absolute values and rate of change/ trending values) using baseline values and trending for each parameter measured to identify results requiring further evaluation of motor or supply system conditions. Take corrective action where required.

3. Perform periodic calibration of the instrument and sensors per OEM guidance

4. Ensure personnel evaluating the monitored variable(s) have proper training and expertise.

5. Repair or replace any non-functional systems or sensors at the next planned outage.

2.4.6 Dismantle/Refurbish and Inspection Intervals

2.4.6.1 Condition based maintenance strategies allow dismantles and inspections to be scheduled based on equipment condition, performance data monitoring outcome, duty, failure history, size and criticality rather than time.

In the absence of a condition based maintenance strategy, dismantle motors every 10-15 years for large synchronous motors such as greater than 5,000 hp or in accordance with manufacturer's recommended dismantle inspection frequency. Perform the tests listed in Tables 2.4.6.1a, 2.4.6.1b or 2.4.6.1c during each dismantle.

In the absence of a condition based maintenance strategy, perform internal visual or borescope inspection and testing for motors at least once every three to five years or in accordance with the manufacturer's recommended inspection frequency. Perform the tests listed in Tables 2.4.6.1a, 2.4.6.1b or 2.4.6.1c during each inspection.

2.4.6.2 Gearless Mill Drives

2.4.6.2.1 Establish a foreign material exclusion (FME) level 3 program in accordance with Data Sheet 9-0 for any gearless mill driver inspection activities.

2.4.6.2.2 Perform inspection and maintenance at least annually. During each inspection, perform the following maintenance activities as applicable in addition to those listed in Table 2.4.6.1b and other OEM recommended activities.

A. Structural

1. Tightness with torque test and visual inspection
2. Foundation for cracks, subsidence and foundation bolt conditions
3. Stator housing inter-connections
4. Stator hold down points and bolted connections
5. Sole plates

B. Mechanical

1. Visual inspection for tightness, leakage and wear
2. Lubrication systems
3. Mill brake
4. Mill motor structure, including critical welds (e.g., core hanger plates)
5. Proper tightness (torque) of stator core bolts
6. Cooling water system
7. Dust sealing system

C. Electrical

1. Instrument calibration and maintenance
2. Tachometer calibration and maintenance
3. Testing of earthquake protection system (if applicable)

D. Other

1. Inspection of alarm logs, data and the entire electrical control and power system
2. Mechanical inspection of the stator and rotor structure
3. Measurements of key bars, holding plates, core bolts and press fingers with adjustment made as needed
4. Recalibration of the air gap monitoring system as needed

Table 2.4.6.1a. AC Induction Motors

Component	*Test*	*Dismantles*	*Inspections*
Stator windings	Insulation Resistance (IR)	×	×
	Polarization Index (PI)	×	×
	DC Conductivity	×	×
	Power Factor (PF) or Tan Delta/Capacitance (Optional)	×	×
	Partial Discharge[1]	×	×
	Polarization/Depolarization (Optional)	x	
Stator Core	Visual Inspection for Hot Spots	×	
	Air Gap Measurement	×	
	EL-CID	× (for >5000 hp motor)	
Rotor Winding	Insulation resistance[2]	×	×
	Polarization index (pi)[2]	×	×
	DC conductivity test[2]	×	×
	Growler Test[3]	x	
	Inspect slip rings, brushes and brush rigging for wear and damage[2]	×	×
Retaining Rings[4]	Visual inspection for corrosion	×	×
	NDE with ring in-situ	×	
Rotor Fans	Visual inspection for cracking	×	×
	NDE of fan blades and vanes for cracking	×	
Rotor Forging	Visual inspection for cracking	×	×
	NDE of forging for cracks and inclusions	×	
	Proper alignment of motors and driven objects	×	
Bearings	Insulation resistance[5]	×	×
	Inspect white metal surfaces of sleeve bearings	×	
	Inspect cage and rolling elements of antifriction bearings	×	
	Inspect shaft surfaces in contact with bearings	×	
Coolers[6]	Inspect air/water heat exchangers for tube erosion or corrosion	×	
	Inspect and clean air filters on air cooled motors	×	×
	Functional testing of water leakage detection system when installed	x	x
RTD or TC	Check condition of RTD	×	
	Measure RTD/TC resistance and continuity	×	
Heater	Check that the motor heater is functioning properly	×	×

Note 1. Only if the motor voltage is 4 kV and higher with no PD monitoring system installed
Note 2. Applicable only to wound rotor induction motors
Note 3. Applicable only to squirrel cage induction motors when MCSA is not tested
Note 4. Only if fitted on wound rotor induction motors
Note 5. Only applicable for insulated bearings
Note 6. Only applicable where an air/water heat changer is provided

Table 2.4.6.1b. AC synchronous motors (round rotor and salient rotor)

Component	*Test*	*Dismantles*	*Inspections*
Stator windings	Insulation resistance (IR)	×	×
	Polarization index (PI)	×	×
	DC conductivity	×	×
	Power Factor (PF), Tan-Delta/Capacitance (Optional for non-GMD motors)	×	×
	Partial discharge[1] (optional for non-GMD motors)	×	×
	Polarization/depolarization (optional)	x	x
	Stator winding wedge tap testing (GMD only)	x	x
Stator Core	Visual inspection for hot spots	×	×
	Air gap measurement	×	
	El-Cid	× (for >5,000 hp motor)	
Rotor Winding[2]	Insulation resistance	×	×
	Polarization index (PI)	×	×
	DC conductivity test	×	×
	Inspect slip rings, brushes and brush rigging for wear and damage	×	×
	DC volt drop test across each pole[3]	×	
	Check inter-pole connections for cracking overheating and damage[3]	×	
	Measure inter-pole connection resistance[3]	×	
	Check inter-pole connection bracing and poles for distortion[3]	×	
	Surge comparison or recurrent surge oscillograph[4]	×	
Retaining Rings[5]	Visual inspection for corrosion	×	×
	NDE with ring in-situ	×	
Rotor Fans	Visual inspection for cracking	×	×
	NDE of fan blades and vanes for cracking	×	
Rotor Forging	Visual inspection for cracking	×	×
	NDE of forging for cracks and inclusions	×	
	Proper alignment of motors and driven objects	×	
Bearings	Insulation resistance[4]	×	×
	Inspect white metal surfaces of sleeve bearings	×	
	Inspect cage and rolling elements of antifriction bearings	×	
	Inspect shaft surfaces in contact with bearings	×	
Coolers[5]	Inspect air/water heat exchangers for tube erosion or corrosion	×	
	Inspect and clean air filters on air cooled motors	×	×
	Functional testing of water leakage detection system when installed	x	x
RTD or TC	Check condition of RTD	×	
	Measure RTD/TC resistance and continuity	×	
Heater	Check that the motor heater is functioning properly	×	×
Static Exciter	Visual inspection for cleanliness and condition	×	
	Check rectifier integrity	×	
Rotating Exciter	Visual inspection for cleanliness and condition	×	×
	Perform IR, PI, DC tests on exciter windings	×	
	Check diode integrity	×	
Brushless Exciter	Visual inspection for cleanliness and condition	×	×
	Perform IR, PI, DC tests on exciter windings	×	
	Check diode integrity	×	

Note 1. Only if the motor voltage is 4 kV and higher. Capacitance tip-up, power factor tip-up tests or on-line PD monitoring are alternate tests that can give an indication of the global partial discharge activity.
Note 2. Include damper (amortisseur) windings.
Note 3. Applicable to salient pole synchronous motors.
Note 4. Only applicable to cylindrical pole synchronous motors.
Note 5. Only applicable where an air/water heat exchanger is provided.

Table 2.4.6.1c. DC Motors

Component	*Test*	*Dismantles*	*Inspections*
Field (Stator) windings[1]	Inspect inter-pole connections for cracking and damaging	×	
	Insulation Resistance (IR)	×	x
	Polarization Index (PI)	×	×
	DC conductivity (DC)	×	×
	DC voltage drop test across each field pole	×	×
	DC polarity check across each field pole	×	×
Core and pole pieces	Visual inspection for hot spots	×	×
	Air gap measurement	×	
Armature (rotor) Winding	Insulation Resistance	×	×
	Polarization Index (PI)	×	×
	DC Conductivity Test	×	×
Commutator	Visual inspection for streaking, unevenness, burning and etching	×	×
	Perform commutator run-out measurement	×	
	Check brushes and brush rigging for wear and damage	×	×
Rotor Fans	Visual Inspection for cracking	×	×
	NDE of fan blades and vanes for cracking	×	
Rotor Forging	Visual inspection for cracking	×	
	NDE of forging for cracks and inclusions	x	
	Proper alignment of motors and driven objects	×	
Bearings	Insulation resistance[2]	×	×
	Inspect white metal surfaces of sleeve bearings	×	
	Inspect cage and rolling elements of antifriction bearings	×	
	Inspect shaft surfaces in contact with bearings	×	
Coolers[3]	Inspect air/water heat exchangers for tube erosion or corrosion	×	
	Inspect and clean air filters on air cooled motors	×	×
	Functional testing of water leakage detection system when installed	x	x
RTD or TC	Check condition of RTD	×	
	Measure RTD/TC resistance and continuity	×	
Heater	Check that the motor heater is functioning properly	×	×

Note 1. Include non-power field windings in the test (interpoles, commutating and compensating windings)
Note 2. Only applicable for insulated bearings
Note 3. Only applicable where an air/water heat exchanger is provided

2.4.7 Testing

2.4.7.1 Tables 2.4.6.1a, 2.4.6.1b and 2.4.6.1c list the electrical and mechanical tests typically performed at motor dismantles and inspections. The number of tests will depend on condition-monitoring data, results of routine inspections, operating experience and failure history.

2.4.7.2 Test and maintain electrical protective devices (surge arrestors, fuses, circuit breakers and relays) in accordance with Data Sheet 5-19, *Switchgear and Circuit Breakers*. Test and maintain batteries that are part of electrical protection systems in accordance with Data Sheet 5-28, *DC Battery Systems*.

2.4.8 Overvoltage (Hipot) Testing

2.4.8.1 Perform a conventional overvoltage test under the following conditions when recommended by OEM:

A. As part of commissioning

B. After a repair. A repair is considered to be any work requiring the removal of stator bars to restack the core, rewind the motor or perform any other work involving the stator bar insulation. Re-wedging, end winding re-bracing and core tightening may also warrant an overvoltage test.

C. After any incident, such as a serious water leak, overheating, or fire exposure, that raises doubts about the integrity of the insulation.

The test voltage under these circumstances may be as high as the factory acceptance test voltage or a lower voltage, depending on the situation. Make the decision regarding an acceptable test voltage after discussions with the repairer or manufacturer.

2.5 Contingency Planning

2.5.1 Equipment Contingency Planning

When a motor breakdown would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop and maintain a documented, viable motor equipment contingency plan (ECP) per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process for developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental and redundant equipment mitigation strategy guidance in that data sheet.

In addition, consider the following elements in the contingency planning process as mitigation strategies for the ECP specific to AC and DC motors:

A. AC Motors (5,000 hp [3,700 kW] and larger):

- A complete stator or complete set of stator coils
- For synchronous motors, a complete rotor, or sufficient rotor coils and field poles as specified by the manufacturer

B. AC motors (less than 5,000 hp)

- A complete spare motor

C. DC Motors (3,000 hp [2,200 kW] and larger):

- A complete armature (including commutator)
- Sufficient field pole windings (e.g., shunt, series, interpole) to replace one quarter of the motor field

D. DC motors (less than 3000 hp)

- A complete spare motor

2.5.2 Gearless Mill Drive Specific Sparing and Equipment Contingency Planning

Sparing can be a mitigation strategy to reduce the downtime caused by gearless mill drive breakdowns (GMD)(also called “wrap-around” or “annular synchronous motors”), depending on the type, compatibility, availability, fitness for the intended service and viability of the sparing. For general sparing guidance, see Data Sheet 9-0, *Asset Integrity*.

2.5.2.1 Routine Spares

2.5.2.1.1 Routine GMD spares are spares that are considered consumables. These spares are expected to be put into service under normal operating conditions over the course of the life of the GMD, but not reduce equipment downtime in the event of a breakdown. It can include sparing recommended by the original equipment manufacturer. See Section 3.5.2 for guidance on routine spares.

2.5.2.2 Equipment Breakdown Spares

2.5.2.2.1 Equipment breakdown spares for GMDs are spares intended to be used in the event of an unplanned outage of a GMD to reduce downtime and restore operations. Provide the following equipment breakdown spares for GMDs:

A. Spare stator coils in accordance with OEM recommendations. Store a sufficient number of spare stator coils and slot wedging kits, assuming one stator bar fails to ground. For double-stacked stator coils, assume a bottom stator bar has shorted to ground.

B. Beyond spare stator coils, ensure the following additional spares are stored and are available from the OEM on short notice:

- Two rotor poles. For designs with both left- and right-hand poles, provide one left-hand and one right-hand spare pole.

2.5.2.2.2 Maintain the GMD equipment breakdown spare viability per Data Sheet 9-0.

2.5.2.3 Develop a viable equipment contingency planning for the following equipment critical to operation of GMD, in accordance with Data Sheet 5-4, *Transformers*.

• Cyclo-converter transformer
• Excitation transformer

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Visual Indications

Table 3.1 describes visual indications and their likely causes. It illustrates the value of having visual inspections performed by a knowledgeable person. Visual inspections can be carried out during a dismantle with the rotor removed or while the motor is assembled using borescope, fiberscopes, robotic cameras and other similar equipment. Limited visual inspections can also be carried out with the motor in service.

Table 3.1. Visual Indications and Likely Causes

Component	*Visual Indication*	*Likely Cause*
Frame	Loose motor frame footing bolts	Foundation problems
	Cracked grouting around motor footings	Foundation problems
	Internal Corrosion of Motor Casing	Faulty space heaters
	Paint Discoloration and/or Blistering on the Stator Frame, Casing, and Core	Overload operation or improper cooling
Stator	Nonmagnetic dust or greasing (mixture of oil and dust)	Loose stator bars within the stator slot leading to abrasive wear of groundwall insulation
	Magnetic dust or greasing	Fretting of core laminations or loose stator winding wedges
	Carbon dust in air cooled machines	Poor sealing between motor and exciter
	Red iron oxide powder in stator bore	Loose core
	Blocked cooling vents	Dirty or faulty air filters.
	Damaged tops of stator core teeth	FOD from pieces of core plate, space blocks, and foreign material in stator bore
	Bent or broken laminations	Careless rotor removal
	Back of core burning	Excessive current transfer between core laminations and stator frame keybars
	Bulging or deformation of stator barInsulation[1]	Asphalt migration due to excessive temperatures
	Soft spots on stator bar insulation[1]	Asphalt migration due to excessive temperatures
	Tape separation (separation of stator insulation due to friction between stator slot and stator bar as the bar expands and contracts)	Excessive thermal cycling
	Girth cracking (stator insulation cracks completely around the girth of the stator bar and separates from the bar, forming a neck)	Excessive thermal cycling, high temperature operation
	Dry and brittle insulation, discolored insulation, powder accumulations in the stator core slot	Thermal aging due to operation at excessive temperature
	Burn marks, whitish or brownish powder on stator bars	Corona activity
	Pinpoints of lights during blackout inspection	Slot partial discharge activity
	Strong ozone smell in air cooled machines	Slot partial discharge activity
	Hollow sound when stator wedges are tapped	Loose stator bars
	Stator wedges migrating axially beyond core ends	Loose stator bars
	Side packing filler strips migrating up from core slots	Loose stator bars

Table 3.1. Visual Indications and Likely Causes (continued)

Component	*Visual Indication*	*Likely Cause*
Cylindrical Rotor	Copper dust in vent holes	Shorted rotor turns
	Copper dust at rotor end windings	Deteriorated end winding blocking
	Blocked or vent holes	Possible rotor thermal sensitivity
	Cracking of ends of rotor body flex slots	Operation under abnormal conditions (e.g., out of step)
	Discolored or distorted wedges	Operation under abnormal conditions (loss of field, motoring, underfrequency)
	Oxidation and pitting of retaining ring external surfaces	Poor operating environment (high moisture or corrosive contaminants)
	Fretting marks on shrink fit areas of retaining ring	Excessive overheating during operation or mechanical movement due to severe load changes.
	Rotor tooth top cracking	Poor design
	Rotor tooth cracks due to fretting	Excessive start/stop operations, excessive turning gear operations and cyclic loading (only with steel wedges)
Squirrel Cage Rotor	Cracked or broken rotor bars and short circuit rings	Frequent starts, loose bars or poor bar-to-short circuit ring welds
	Melted rotor bars (die-cast aluminum rotor bars)	Frequent starts
	Burnt rotor core laminations	Broken rotor bars allowing current to circulate in the core
Salient Pole Rotor	Signs of overheating at inter-pole connections	Overload operation or loose boltedconnections
	Mechanical damage (cracking) at inter-pole connections	Fatigue, thermal cycling, excessive mechanical force or inadequate bracing
	Overheating of pole windings	Overload operation or loose boltedconnections
	Distortion and bowing of pole windings	Inadequate coil bracing between poles. More likely to occur in motors with long poles.
	Movement and damage to pole collars	Fatigue, thermal cycling or excessive mechanical force
	Movement of damper windings out of pole face	Thermal cycling
Bearings	Imbedded foreign material in babbitt	Contamination of lubrication oil
	Pitting of bearing or shaft surfaces	Poor shaft grounding or faulty bearing insulation
Fan	Cracks at roots or welds of cooling fan	Fatigue
Lubrication Oil	Discoloration, dirt and metal particles in lubrication oil	Bearing damage or contamination oflubrication system
Excitation System	Accelerated wear of slip ring brushes	Possible high harmonic problem with field current or high machine vibration
	Discoloration of brush springs	Overheating of brushes or poor brush pressure
Commutator	Streaking or threading of commutator surface	Low current density in the brushes, contaminants, improper brush, low humidity
	Burning or etching of commutator surface	High mica, dirty commutator, incorrect brush pressure, brushes located off electricalneutral position, shorted commutator bars
Brushes and Rigging	Arcing at slip rings or commutator surface	Inadequate brush contact, brush rigging touches the slip rings or commutator
	Excessive brush wear	Loss of spring pressure, incorrect brush
	Discoloration of brush springs, holders or pigtails	High brush resistance, high pigtail resistance, poor brush pressure or excessive current

Note 1. Applicable to asphalt–mica insulation systems only.

3.2 Motor Tests

This section contains a table with a list of motor tests. It includes the failure mode each test is capable of detecting and the acceptance criteria for each test.

Table 3.2. Motor Tests

Test	*Test Method*	*Tested Component*	*Detected Failure Mode*	*Acceptance Criteria*
Insulation Resistance	Apply DC voltage for 1 minute and measure leakage current.	Stator, rotor, field, armature and damper windings	Contamination, defects, and deterioration ofground insulation	For pre-1970 vintage machines, minimum resistance should be about (E +1) MΩ, where E is the rated phase-to-phase voltagein kV for AC windings, or the rated DC voltagein kV for DC windings. For post-1970 vintage machines, minimum resistance should be about 100 MΩ.
PolarizationIndex	Ratio of the 10 minute and 1 minute insulation resistances	Stator, rotor, field, armature and damper windings	Contamination, defects, water ingress and deterioration of ground insulation	A polarization index (PI) equal to or greater than two is an indication the insulation is clean and dry. When the insulation resistance reading at 1 minute is above 5,000 MΩ, the calculated PI can be disregarded.
DC Conductivity	Pass a DC current through the winding and measure thevoltage across the winding to determine resistance (i.e., use a low-resistance ohmmeter or a Kelvin bridge to measure resistance).	Stator, rotor, field, armature and damper windings	Broken and cracked windings, poor connections, shorted turns in rotor winding	Compare the DC resistance of eachwinding. The resistances must be within one of each other.
Power Factor	Apply an AC voltage and measure the power factor of each winding (one phase at a time with the other two phases grounded).	Stator windings	Ground wall insulation deterioration due to thermal degradation or water ingress	Epoxy mica –maximum power factor of 0.5% Asphaltic mica – maximum power factor of three to five. A one percentage increase in trended power factor is serious. Increasing power factor with decreasing capacitance indicates thermal deterioration. Increasing power factor with increasing capacitance indicates water absorption.

Table 3.2. Motor Tests (continued)

Test	*Test Method*	*Tested Component*	*Detected Failure Mode*	*Acceptance Criteria*
Power Factor Tip-Up	Measure the power factor of each stator winding phase at about 20 line- to-ground voltage and then again at 100 line- to-ground voltage. The tip-up is the difference between the two power factors.	Stator windings	Partial discharge activity due to ground wall insulation deterioration from thermal degradation or load cycling	Trend tip-up values. An increasing trend indicates increasing partial discharge activity.
Partial Discharge	Apply line to ground AC voltage to one phase at a time and hold for 10 to 15 minutes. Then measure partial discharge activity at the machine terminals.	Stator windings rated 4 kV and higher	Ground wall insulation deterioration	Trend peak partial discharge magnitude. Doubling of partial discharge activity every six months indicates serious deterioration.
Surge Comparison	Apply a surge voltage with a rise time of 100 ns at the machine terminals for each phase. Increase the surge voltage gradually until 2.6 times line to ground voltage. Measure the wave form on an oscilloscope.	Stator windings	Turn-to-turn insulation deterioration	Changes in the waveform indicate a puncture of the turn insulation. This is a pass/fail test.
Recurrent Surge Oscillograph	Use a reflectometer to apply 100 V, high-frequency voltage pulses at both ends of the stator winding, and measure the voltage at the injection point as a function of time, using an oscilloscope.	Stator windings	Shorted turns, ground faults and high-resistance connections in the stator winding	Compare the waveforms from both ends of the winding. Differences in the waveforms indicate the presence of a defect in the stator winding. The location of the defect can also be determined from the shape of the waveform.
Loop Test	Excite the core to produce 100 back-of-core flux and allow the core to soak for at least 30 minutes (up totwo hours for large machines). Take temperature readings every 15 minutes toensure the excited core does not undergo thermal runaway from lack of cooling.	Stator core	Shorted or damaged core laminations	Hot spots with a temperature difference of between 5°C and10°C indicate core defects.

Table 3.2. Motor Tests (continued)

Test	*Test Method*	*Tested Component*	*Detected Failure Mode*	*Acceptance Criteria*
Growler	A typical growler consists of a U-shaped core that is excited by a 120 V AC coil. The U-shaped core is placed so it straddles arotor bar and is moved axially along the length of the rotor bar.	Squirrel cage rotor bars	Broken rotor bars	A metal plate placed on top of the rotor bar will vibrate (growl) when the growler passes across a break in therotor bar.
RTD and TC Insulation	Only applicable to ungrounded RTDs and TCs. Tie RTD/TC lead wires together and apply a DC voltage for 1 minute and measure the resistance. (Use the RTD or TC manufacturer's recommended test voltage.)	RTD (resistance temperature detector) or TC (thermocouple)	Damage to RTD or TC due to corrosion, contamination, excessive heat, excessive current or mechanical stress	Insulation resistance of not less than 1 MΩ.
RTD and TC Continuity	Use a low-voltage ohmmeter to measure circuit continuity.	RTD (resistance temperature detector) or TC (thermocouple)	Damage to RTD or TC due to corrosion, contamination, excessive heat, excessive current or mechanical stress	No open circuits are present.
Pole drop	Apply an AC or DC voltage across a field pole and measure the voltage drop across the field pole.	Synchronous machines with salient poles and DC machine field poles	Shorted turns in field poles	The minimum volt drop across any pole must be 10, or less than the average volt drop across all the poles
Inter-Pole Connection	Use a low-resistance ohmmeter or a Kelvin bridge to measure the resistance of the inter-pole connections.	Synchronous machines with salient poles and DC machine field poles	Broken and cracked conductors, poor connections	Compare the DC resistance of each connection to the previous one as well as to past tests. The difference must not be larger than one between test results
Bearing Insulation	Apply a 500 V DC voltage to the bearings and measure the resistance to ground.	Insulated bearings	Circulating currents can damage the shaft and bearing surfaces.	Minimum insulation resistance of 50 MΩ for individual bearings tested with the motor disassembled. Minimum insulation resistance of 5 MΩ for bearings tested while motor is assembled.
Commutator Run-Out	Use a run-out indicator and measure total indicated run-out (TIR) while the shaft is turned slowly.	Commutator	Uneven commutator surface leading to poor brush performance	TIR is not over 0.025 mm for a speed greater than 1,525 m/min and not over 0.075 mm for a speed less than 1,525 m/min.

Note 1. This is not applicable to VPI motors. If the 1-minute insulation test result is higher than 1000 MΩ, then it is highly likely that the PI result will be much higher than 2. This does not indicate that the insulation is dry and brittle.

3.3 Failure Modes

On the reliability of large motors, the Institute of Electrical and Electronics Engineers (IEEE) indicates that bearing failure and winding-insulation failure are the two leading causes of motor failures. The IEEE found that bearing failures account for 44% of all motor failures, and winding insulation failures account for 26% of all motor failures. The key underlying contributing factor to these failures is lack of maintenance and the use of improper components.

3.3.1 Bearing Failure

The main cause of bearing failure is improper or lack of lubrication; specifically, over- or under-lubricating or applying the wrong lubricant.

Bearing failure due to fatigue can also result from excessive loads or failure to replace bearings when they have reached the end of their lives.

Shaft currents can also cause damage to the bearings. Shaft currents flow to ground through the bearing. This creates arcing at the bearing surface. The bearing surface becomes pitted and this affects the oil flow, eventually leading to overheating and failure of the bearing.

Shaft currents are created by harmonics, poor shaft grounding and faulty bearing pedestal grounding.

Misalignment between the motor and driven object can also cause bearing damage. Excessive vibration is one common cause of bearing failures.

Bearing failure can cause rubbing damage to the rotating and stationary parts of the motor. Fortunately, bearing failures tend to develop slowly and will provide several indications that failure is imminent. These indications include an increase in bearing noise, vibration or temperature. Bearing lubrication oil analysis will also provide early warning of bearing problems.

3.3.2 Winding Insulation Failure

Form-wound motors have the same insulating systems as generators. Stator windings on induction and synchronous motors, and field windings on DC motors consist of three components: groundwall insulation, which provides the main insulation between the stator bar and the grounded core; turn insulation, which provides insulation between individual turns within each stator bar; and strand insulation, which provides insulation between individual strands in each turn.

In general, windings are typically designed for a life of 20 years if properly maintained and operated. Stator winding failures happen when either the groundwall or turn insulation fails, allowing a short circuit to occur.

Failure of strand insulation does not result in immediate winding failure, but it will give rise to circulating currents within the stator bar and cause local temperatures to rise. This will accelerate localized thermal aging of the stator insulation and eventually lead to failure.

Failure of groundwall and turn insulation can occur due to the following causes:

A. Thermal deterioration. This is an oxidative process that occurs when insulation is overheated. The chemical bonds in the organic components of the insulation break down and cause the insulation system to deteriorate. Overheating of the motor occurs due to overload, poor cooling, poor design, harmonics, excessive starts and abnormal operating conditions such as overexcited or underexcited operation of synchronous generators and voltage imbalance.

B. Partial discharge. This is electrical arcing that occurs in gas-filled voids within the stator groundwall insulation as well as within the interface between the stator copper conductor and the groundwall insulation, and within the interface between the groundwall insulation and the stator slot. Partial discharge is an erosive process that will eventually erode away enough insulation to cause a failure.

C. Corona. This occurs in motors rated 4 kV and higher and is typically found at the stator end windings due to insufficient separation between the stator bars.

D. Load cycling. Frequent load cycling causes insulation failure due to the difference in thermal expansion between the copper stator bar and the groundwall insulation. Girth cracking and tape separation are some of the results of load cycling. Girth cracking occurs in thermoplastic insulation, and tape separation occurs in thermoset insulation.

E. Loose stator bars. Insulation shrinkage and loose wedges can cause the stator bars to become loose in the slot. This enables the stator bar to move and cause the insulation to become abraded. This failure mode does not occur in motors manufactured using the global VPI (vacuum pressure impregnated) method or with motors using thermoplastic insulation.

F. Faulty semiconductive coating. Some motors greater than 6 kV will be provided with a semiconductive coating to reduce partial discharge activity. Deterioration of this coating will allow partial discharge to occur and eventually fail the insulation.

G. Overvoltage transients. Lightning, electrical faults, circuit breakers switching transients, power factor correction capacitor switching and adjustable speed drives will introduce transient overvoltages that stress the insulation. If the transient overvoltages are high enough or extreme repetitive frequencies (such as thousands of impulses per second above two per unit), these transients can deteriorate healthy insulation somewhat quickly. These failures typically occur in the first few coils of a phase group. The insulation will fail. Surge arresters limit the magnitude of the transient voltage spike. The arrester conducts transient voltage to ground when the voltage reaches a given value to provide this protection. The purpose of the surge capacitors is to limit the rate of rise of the voltage or turn-to-turn voltage stress. This is achieved by the capacitor momentarily absorbing the initial energy, thereby slowing down the steep wave front of the transient.

H. Contamination. Motors operating in environments with fly ash, coal dust, solvents, acids, cement dust, oil, and other contaminants will be susceptible to electrical tracking, erosion and chemical attack. This is especially true for open ventilated machines where cooling air is taken directly from the surrounding environment.

I. End winding vibration. Stator end windings hang outside the core and need to be properly supported; otherwise, they can vibrate and abrade the insulation, eventually resulting in failure.

3.3.3 Overheating

Overheating was discussed in the previous section as a cause of thermal deterioration of winding insulation. The following is additional detail on the causes of overheating:

A. Operating at lower than rated voltage produces higher currents and increased heat losses (I2R) in the motor winding. This generates heat beyond the motor’s cooling capacity.

B. Mechanical failures such as jammed impellers on driven pumps or fans, damaged seals on driven pumps, misalignment and bearing failure can interfere with the rotation of motors. This can cause the motor to draw more current. In the worst case, locked rotor conditions can result, which will quickly overheat the motor.

C. Poor brush pressure, improper brush material or improper brush contact with the commutator or slip ring can cause the brush to overheat. Overheating can lead to commutator or slip ring damage, resulting in a short circuit or an open circuit in the armature winding of DC motors or the field winding of synchronous motors.

D. Operating motors at higher than rated load results in higher currents and increased losses in the winding. If the overload is large enough, the motor may fail to start or accelerate; or it may stall.

E. Lack of adequate time between starts can overheat the windings and reduce their insulation life. In addition, this heat may crack the rotor bars in squirrel-cage motors and the damper windings in synchronous motors.

F. Duty cycles involving rapid repetitive starting, plugging, jogging and reversal will cause cumulative heating of the motor.

G. Loss of ventilation prevents heat removal from the motor. Ventilation loss is commonly caused by restricted air ventilation paths. High ambient (room) temperature, above 104°F (40°C), can also lead to overheating.

3.4 Condition Monitoring

3.4.1 An effective condition monitoring program is essential to the successful implementation of a condition-based or predictive-maintenance strategy.

3.4.2 Condition monitoring is also useful for a time-based, preventive-maintenance strategy. Depending on the level of condition monitoring, the number of tests that need to be carried out at each dismantle or inspection may be reduced.

Condition monitoring can also be used to target the maintenance and inspection activities that need to be carried out at each dismantle.

3.4.3 The following condition-monitoring systems for electric motors are commercially available. A brief description and their typical application is provided.

3.4.3.1 Online Vibration Analysis

Vibration analysis is a proven and established method of monitoring the condition of motor bearings. It can detect misalignment, bearing wear, poor lubrication, foundation problems and even broken or cracked rotor bars. Motors with sleeve type bearings usually have vibration sensors mounted on the shaft. Motors with antifriction bearings have vibration sensors mounted on the motor housing. Permanently mounted vibration sensors providing continuous vibration monitoring or handheld vibration monitors are used.

3.4.3.2 Lubrication Oil Analysis

Lubrication oil analysis is applied to motors with oil lubricated bearings. It can detect bearing wear, overloaded bearings, overheated bearings, foreign matter in lubrication oil and deteriorated or contaminated lubrication oil.

3.4.3.3 Thermography

Thermography can be applied to monitor the condition of all types of motors. It can detect problems such as overheated windings, poor electrical connections in the motor terminal box, overheated bearings and overheated motor couplings (indicating misalignment problems). The best results are achieved using an infrared camera. However, temperature measurement using non-contact thermometers or contact thermocouples applied to bearing housings and the motor housing can also provide valuable information about overheated bearings and general motor overheating.

3.4.3.4 Motor Current Signature Analysis

This is a widely used condition-monitoring tool for induction motors. It involves the measurement of the motor line currents and the use of a spectrum analyzer to examine the line currents. A benchmark spectrum is first collected and then subsequent measurements compare the current spectrum against the benchmark. Changes in the spectrum can indicate problems such as partial discharge activity, broken squirrel-cage rotor bars, air gap eccentricity, rotor imbalance, misalignment and high-resistance sections in the rotor bars (i.e., cracked bars).

3.4.3.5 Partial-Discharge Monitoring

Partial-discharge monitoring senses partial discharge or corona activity in stator insulation. Partial discharge activity is caused by defects in the insulation, overheating, movement of the stator bars, loose stator bars, inadequately spaced stator end windings, excessive operating thermal and electrical stresses, poor semi-conductive coating, and contamination.

Early partial-discharge detectors consisted of high-frequency current transformers placed at the generator neutral or between the terminal surge capacitors and ground. Modern partial-discharge detectors consist of capacitors installed at the motor phase terminals. Partial-discharge monitoring is typically applied to large form-wound motors rated 4.0 kV and above.

Stator slot couplers also are used on large motors to provide more accurate detection and location of partial-discharge activity. These sensors consist of strip antennae installed under the wedge or between the top and bottom coils of the stator bar. Sometimes, RTD's wiring is used as stator slot couplers; but this method is not preferred.

Interpretation of partial-discharge tests is carried out by measuring the peak partial-discharge magnitude, MΩ and comparing this to a database of MΩ readings from similar machines to see if the value of MΩ falls within the expected range for these machines.

Important information is also obtained from trending the value of MΩ. Analysis of the partial-discharge pattern, as well as how partial discharge activity varies with changes in load, humidity, and temperature, allows more detailed fault diagnosis to be performed. For example, discriminating between partial-discharge activity due to contamination, loose stator bars, poor semi-conductive coating, insulation defects, or end winding is possible.

3.4.3.6 Electromagnetic Interference Monitoring

Electromagnetic-interference monitoring involves the measurement of the radio frequency noise generated by electrical equipment. The radio frequency noise is measured using high-frequency current transformers (or radio frequency current transformers) attached to the motor neutral ground lead. A radio receiver and spectrum analyzer are used to evaluate the radio frequency spectrum generated by the motor.

All electrical faults generate noise or electromagnetic interference. An experienced operator can detect problems by examining the radio frequency spectrum and comparing it to what is expected for a similar machine. However, trending the spectrum and looking for changes that would indicate a developing problem is more typical. The analysis is based on pattern recognition as well as trending. A skilled operator is key to the proper evaluation of the results.

Electromagnetic-interference testing is a complementary technique to partial-discharge testing. Both detect partial-discharge activity inthe motor. Electromagnetic interference testing is also able to detectpartial discharge activity beyond the motor (e.g., in connected cables,ground leads and buses). However, because electromagnetic interference testing requires access to the motor ground lead, this test may not beconducted on all motors.

3.4.3.7 Air Gap Flux Probes

Air gap flux probes are applied in large synchronous motors. The probes are small search coils permanently installed in the air gap of the motors to measure rotor slot leakage flux. The waveform from the flux probes is used to identify shorted turns in the rotor winding. Readings from the air gap flux probes are taken approximately once a year to monitor rotor winding deterioration. Readings are also taken whenever bearing vibrations increase to determine if the cause of the increased vibration is from shorted rotor turns.

3.4.3.8 Performance Monitoring

A motor performance monitoring program can track stator voltage and current under different loading conditions to identify deficiencies associated with motors or the supply power systems to which the motor is connected. The following are critical parameters commonly included in the motor performance monitoring program.

1. Stator current at steady state: It is a function of load and supply voltage. Voltage levels below name plate or overload will result in higher current, leading to increased heat damage to machine.

2. Stator current at starting: It can be divided into two stages. The first stage, often referred to as in-rush current, involves the magnetization current and normally lasts less than half second. The second stage, commonly referred to as starting current, is the elevated current drawn immediately following the in-rush current and lasting to steady state condition. A significant change in the in-rush or starting current from normal values may indicate a possible problem in stator or rotor cage. Significant increases in starting current duration may indicate open parallel winding in the stator, multiple broken rotor bars in a cage winding on the rotor, or binding of rotating parts or load problems.

3. Supply voltage level: A motor is generally able to operate within +/- 10% of rated machine voltage. Supply voltage lower than the normal range can cause elevated operating current, leading to overheating damage. Operating above the normal range can increase starting current, overexcitation and overheating.

4. Voltage drop at the starting: The high inrush current for an across-the-line started motor normally causes a significant and sudden voltage drop at the motor terminals. A significant change in the voltage drop at starting compared to its normal value is a possible sign of either machine or supply system problems.

5. Voltage unbalance: The current unbalance that results from voltage unbalance between phases can create overheating damage to the motor. Adjustable speed drives can be even more vulnerable than standard motors. A thorough investigation by the facility can often resolve the origin of excessive voltage unbalance.

6. Harmonic component of the supply voltage: Excessive harmonic content of the supply voltage above specified maximal permissible level can create excessive heat damage to the machine.

7. Voltage spikes or transient overvoltage: Voltage spikes can cause failure of stator insulation. Monitoring these spikes at the connected system can help identify the minimum insulation level needed for the machine or possible corrective action at the system level.

3.4.4 Condition-monitoring systems are not able to detect all failure modes. Therefore, taking the opportunity to inspect the machine any time it is opened for other purposes and not relying wholly on condition-monitoring data is important. Routine offline motor testing to complement condition-monitoring results is also important.

3.5 Gearless Mill Drives (GMDs)

Gearless mill drives (GMDs), also referred to as “annular synchronous motors” or “wrap-around motors,” were first developed for small rotating kilns in the cement industry in the 1960s but are now used extensively in the mining industry to drive large, high-speed, rotating, ore-grinding mills. GMDs are used to improve mechanical efficiencies in driving larger and heavier grinding mills (some are now over 40 ft [12 m] in diameter and are rated at 23,500 kW). They replace conventional side-mounted AC motors with pinion and ring gears.

The GMD is essentially a salient-pole synchronous motor. The rotor poles are mounted on the shell-to-head flange of the mill body, and the stator windings are housed in an external frame surrounding the mill flange. The rotor and stator are typically located at the feed end of the mill. A typical 12 MW, 30 ft (10 m) diameter gearless mill drive has 540 stator coils and 72 rotor poles. The poles are mounted on a support flange, which in turn is bolted to a mounting flange that is part of the SAG mill shell. The pole pieces are laminated. A rotor cover is attached to the pole support flange that protects the pole, stator and air gap from dust.

Like any other synchronous motor, DC excitation current is supplied to the rotor poles via slip rings and brushes. The slip rings are also mounted on the shell-to-head flange. Slip rings carry DC excitation power to the rotor circuit, including the rotor poles mounted on the rim of the SAG mill shell and the pole crossovers that connect each pole to the next. The concept of left- and right-hand poles arises from the way the pole crossovers are arranged. Physically they are not identical. Each pole (right or left hand) has a plus and a minus connection. One type (right or left hand) has the plus terminal closer to the motor/mill axis (mill) and the minus terminalcloser to the stator core. The other type has the connection terminalsthe opposite way.

The stator is built in four segments. Each segment is built with the stator coils inside the stator core. The frame behind the stator core forms an air box where cooling air is circulated to cool the stator.

The air gap between stator and rotor is very small. For example, it is normally about 0.6 in. (16 mm) for a 20 MW motor. The air gap is not uniform around the stator because the SAG mill shell sags under its own weight and forms an elliptical shape. The stator frame and shell also flex under the operating stress of the mill as well as the magnetic forces in the air gap. Air gap monitoring is very critical for these machines. A rigid foundation is also critical, and the mill foundation should be treated as an integral part of the SAG mill and included in the overall design process.

The stator windings of a GMD are supplied by cycloconverters (see Figure 3.5). The cycloconverter is a 12-pulse converter. It uses water-cooled thyristors to convert 50 Hz or 60 Hz incoming power to a variable, low-frequency, three-phase supply. Most gearless mill drives operate at a rated frequency between 5 Hz and 10 Hz. By varying the output supply frequency from 0% to about 120% of the rated frequency, the cycloconverter is able to drive the mill over a wide speed range from standstill to around 1 rpm. The cycloconverter also acts as an electrical brake to bring the motor smoothly and quickly to a stop with minimal rocking. It also allows the mill to be driven in a clockwise or counter-clockwise direction.

Special transformers with multiple secondary windings are used to supply the cycloconverter. The cycloconverter typically is housed in an air-conditioned room away from the mill that is called “E-house.” It supplies the stator via cables. Busbars inside the stator frame distribute power to the three-phase stator winding.

Because the GMD is used in a dusty environment, a dust shield with a metal to Teflon seal is provided between the rotating mill body and the stator frame to keep dust and water out of the motor windings.

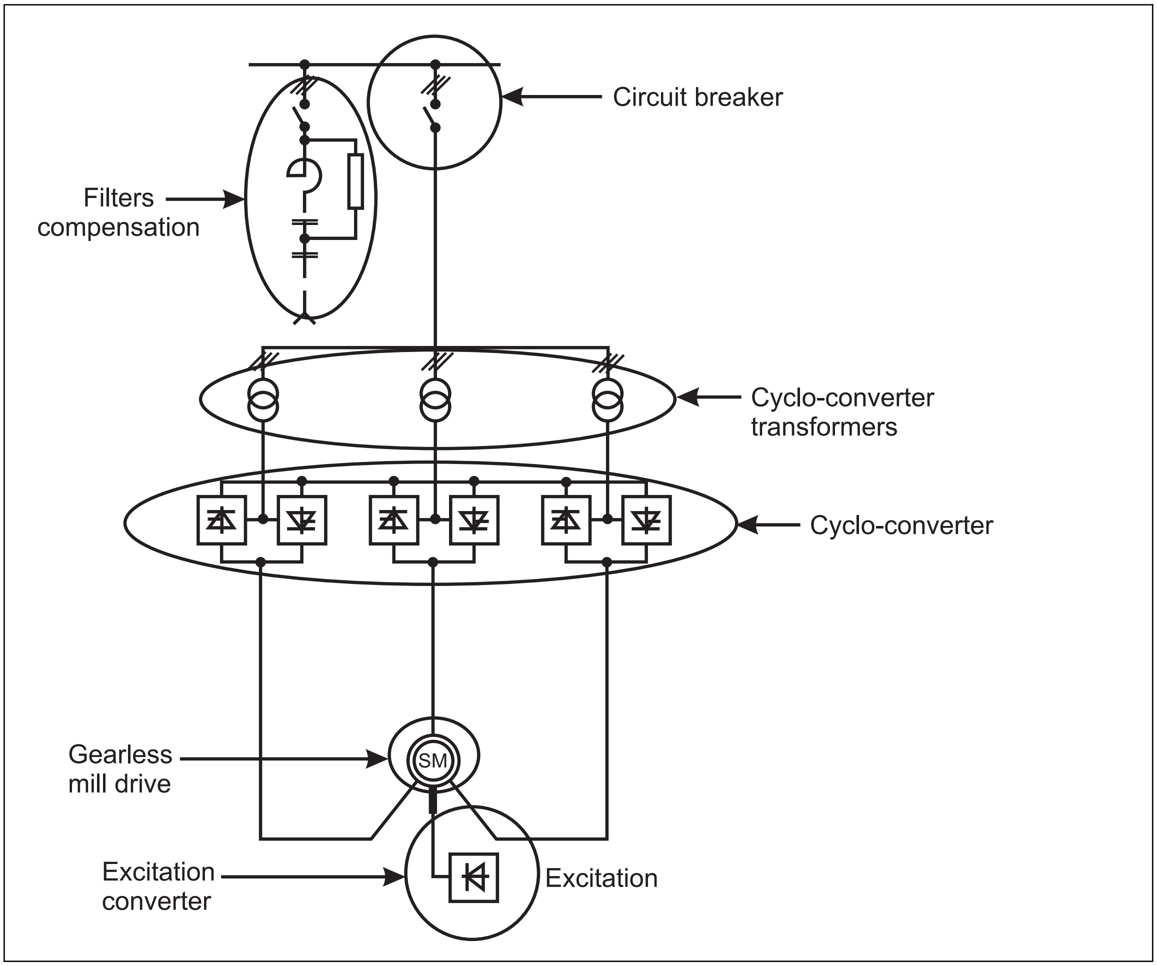

Fig. 3.5. Simplified diagram of the electrical system for a GMD motor (not showing excitation transformer)

3.5.1 Unique Hazards Associated with the Gearless Mill Drive

The GMD is exposed to the same electrical and mechanical hazards associated with conventional salient-pole synchronous motors. However, some unique hazards are associated with this type of motor.

3.5.1.1 Air Gap

Gearless mill drives have a small air gap between stator and rotor. Maintaining this air gap within the manufacturer's recommended minimum and maximum range is critical. If the air gap is too large, the rotor will draw more excitation current; and this could lead to overheating of the rotor poles. If the air gap is too small, unacceptable deflection of the stator frame will occur. Because of the strong nonlinear relationship between air gap variation and deflection, small changes in the air gap will lead to large deflections. This could reduce the air gap until the rotating andstationary parts of the motor rub and cause damage to the windings and poles.

3.5.1.2 Frozen Charge

When a mill is shut down over a long period of time with a charge inside the mill, the charge may solidify. This solid mass is known as a “frozen charge.”

The charge in a SAG mill consists of rough ore, steel balls and water. The charge is usually loose and cascades within the mill as it is turned. If the mill is allowed to come to a standstill with partially ground ore inside the mill, the water in the charge will evaporate and, over time, the ground ore will act as a binder to cement the charge into a solid mass. When the mill is started with a frozen charge, the charge will stick to the mill shell and will not cascade when it reaches the critical angle. In the worst case, the charge will stick to the shell and be carried to the 180 degree angle and fall as a solid block. Several hundred tons of frozen charge dropping 33 ft (10 m) will cause significant damage to the mill body and bearings.

Although this hazard is not unique to gearless mill drives, the critical need to maintain a minimum air gap, as well as the large diameter of these mills, means dropping a frozen charge has more effect on a gearless mill drive than on a conventional mill.

By monitoring the motor torque during startup, the presence of a frozen charge in the mill can be detected and the mill stopped before the charge is allowed to drop.

3.5.2 Routine Spares

3.5.2.1 The following are common routine spares for a GMD. Store and maintain the routine spares per original equipment manufacturer recommendations to maintain viability. Refer to Data Sheet 9-0, *Asset Integrity*, for additional guidance.

- Power electronics (thyristor and other components)
- Consumables (resins), managed on a time-stamp replenishment basis
- Heat exchanger
- Airflow fan

4.0 REFERENCES

4.1 FM

Data Sheet 4-0, *Special Protection Systems*
Data Sheet 4-11N, *Carbon Dioxide Extinguishing Systems*
Data Sheet 5-11, *Lightning and Surge Protection for Electrical Systems*
Data Sheet 5-19, *Switchgear and Circuit Breakers*
Data Sheet 5-20, *Electrical Testing*
Data Sheet 5-31, *Cables and Bus Bars*

4.2 Others

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Institute of Electrical and Electronics Engineers (IEEE). *Guide for Diagnostic Field Testing of Electric Power Apparatus - Electrical Machinery*. IEEE 62.2.

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Electric Power Research Institute (EPRI), *Electric Motor Predictive and Preventive Maintenance Guide* (EPRI-NP-7502))

APPENDIX A GLOSSARY OF TERMS

FM Approved: Reference to FM Approved in this data sheet means the product or service has satisfied the criteria for Approval by FM Approvals. Refer to the *Approval Guide*, a publication of FM Approvals, for a complete listing of products and services that are FM Approved.

A.1 Motor Glossary: Terms Defined in Accordance with National Electric Manufacturers Association (NEMA) Standard MG-1

Adjustable-Speed Motor: Speed can be varied gradually over a considerable range, but once adjusted remains practically unaffected by the load (e.g., a shunt motor with field resistance control designed for a considerable range of speed adjustment).

Armature: Part of a motor or generator that includes the main current-carrying winding that carries the load current. In direct-current motors the armature winding (rotor) is connected to the commutator and the armature is the rotating member. In alternating-current machines, the armature (stator) is the stationary member and is the current carrying device.

Brush: Conductor serving to maintain electric contact between stationary and moving parts of a motor. Brushes must be replaced periodically.

Collector Rings (Slip Rings): Metal rings mounted on the rotor of the motor that, through the stationary brushes bearing on them, conduct current into or out of the rotating windings.

Commutator: Cylindrical ring or disk assembly of conducting bars mounted on the rotor (armature) of direct-current motors. The conducting bars are each insulated with an exposed surface for contact with current-collecting brushes.

Compound-Wound Motor: Direct-current motor with two field windings: one, usually the predominating field, is connected in parallel with the armature circuit; the other is connected in series with the armature circuit.

Damper Winding Amortisseur Winding): A winding consisting of several conducting bars that are short-circuited at the ends with a conducting end ring or plates. These conductors are distributed on the field poles of a synchronous machine to suppress pulsating changes in magnitude or position of the magnetic field linking the poles.

Duty: Requirement of electrical service defining the degree of regularity of the load. Heavy duty is often used to denote an application requiring high locked-rotor torque and having high intermittent overloads. Similarly, light duty often describes an application requiring very little locked-rotor torque and little overload capacity.

Duty, Continuous: Requirement of service that demands operation at a substantially constant load for an indefinite period of time.

Duty, Intermittent: Load changes regularly or irregularly with time.

Efficiency: Ratio of useful power output to the total power input.

Electrically Reversible Motor: Can be reversed by changing the external connections even while the motor is running. If, while the motor is running at full speed in one direction, the connections suddenly change to the opposite direction of rotation, the motor will stop, reverse, and resume full speed in the opposite direction. A class of service where the motor is expected to perform this duty is often known as plugging service.

Field Coil (DC and AC Salient Pole): Suitably insulated winding to be mounted on a field pole to magnetize it.

Field Winding (Cylindrical Rotor): Produces the main electromagnetic field of the motor.

Form Wound: As opposed to random-wound motors where the winding consists of round insulated magnet wire randomly wound into the stator slot to form a coil, form-wound motors have pre-formed insulated stator bars consisting of multiple conductor strands that are inserted into the stator slot to form a coil.

Frame: Supporting structure for the stator parts. In a DC motor it usually is part of the magnetic circuit; it includes the poles only when they are an integral part of the frame.

Frozen Charge: When an ore grinding mill is shut down over a long period with a charge inside the mill, the charge may solidify into a single mass. When the mill is started with a frozen charge, the charge will stick to the mill shell and not cascade when it reaches the critical angle. In the worst case, the charge will stick to the shell and be carried to the 180° angle and fall as a solid block.

IEEE Device Number: The number used to identify protection relays. Refer to ANSI/IEEE C37.2 “IEEE Standard Electrical Power System Device Function Numbers” for additional detail.

Induction Motor: Converts electric power at the primary circuit into a mechanical power. The secondary circuit short-circuits or closes through a suitable circuit and carries induced current.

Rotor: Rotating member of a machine.

Salient Pole: Type of field pole that projects toward the armature.

Series-Wound Motor: Direct-current motor in which the field and armature circuits are connected in series.

Service Factor: Multiplier that, when applied to the rated power, indicates a permissible power loading that may be carried under the conditions specified for the service factor.

Shunt-Wound Motor: A direct-current motor in which the field circuit and armature circuit are connected in parallel.

Squirrel-Cage Induction Motor: Involves a secondary circuit consisting of a squirrel-cage winding suitably portioned in slots in the secondary core.

Squirrel-Cage Winding: Permanently short-circuited winding, usually uninsulated (chiefly used in induction machines), having its conductors uniformly distributed around the periphery of the machine and joined by continuous end rings.

Stator: The stator is the portion of a machine that contains the stationary parts of the magnetic circuit with their associated windings.

Synchronous Motor: Average speed of normal motor operation is exactly proportional to the frequency of the system to which it is connected. It transforms electric power from an AC system into mechanical power. Synchronous motors usually have DC field excitation.

Wound-Rotor Induction Motor: Secondary circuit of the motor consists of a polyphase winding or coils whose terminals are either short-circuited or closed through an adjustable resistance.

A.2 Adjustable Speed Drive Glossary: Terms Defined in Accordance with IEEE P958

Adjustable Speed Drive: An electric drive system designed to adjust speed of a motor and its driven equipment across a specified speed range.

Commutation: The transfer of the current from one converter switching branch to another.

Converter: An operative unit for electronic power conversion, comprising one or more electronic switching devices and any associated components, such as transformers, filters, commutation aids, controls and auxiliaries.

Current Limiting: An overload protection mechanism that limits the maximum output current to a preset value and automatically restores the output when the overload is removed.

Drive System: Combination of the power converter (controller), motor, and any motor mounted auxiliary devices; also, equipment for converting available power into mechanical power suitable to operate a machine.

Efficiency: The ratio of load power to the total line power, including the contribution of all harmonics.

Harmonics: A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.

Inverter: A machine, device or system that changes DC power to AC power.

Power System: The electric power sources, conductors, and equipment required to supply electric power.

Source: The electrical network to which a drive is connected.

Speed Range: All the speeds that can be obtained in a stable manner by action of a part (or parts) of the control equipment covering the performance of the motor. The speed range is generally expressed as the ratio of the maximum to the minimum operating speed.

Stability: The ability of a drive to operate a motor at constant speed (under varying load), without “hunting” (alternately speeding up and slowing down). It is related to both the characteristics of the load being driven and electrical time constants in drive regulator circuits.

Synchronous Speed: The speed of rotation of the magnetic flux, produced by or linking the primary winding.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

January 2024. Full revision. Major changes were made.

A. Revised the scope of the data sheet to include only motors larger than 1,500 hp.

B. Incorporated condition and performance-based maintenance practice guidance.

C. Removed fire protection requirement for motors.

July 2022. Interim revision. Minor editorial changes were made.

July 2020. Interim revision. Updated routine spare guidance for gearless mill drives and provided additional clarification on sparing in Section 2 and 3.

April 2020. Interim revision. Contingency planning and sparing guidance was added.

April 2014. Updated recommendations for gearless mill drives (GMD) and fire protection of motors.

January 2007. The data sheet has been completely revised.

September 1998. Revised.

December 1982. Data Sheet 5-13, *Synchronous Motors*, first issued.

June 1976. Data Sheet 5-17, *Large Electric Motors*, first issued.

APPENDIX C MOTOR PROTECTION

Proper installation and use of protective devices for motors involves many variables, including motor type (induction, synchronous, DC), motor rating (hp [kW], voltage, starting current), motor application and motor importance.

Tables 2.3.1.1-1, 2.3.1.1-2, and 2.3.1.1-3 list protective relays that may be used to protect DC, induction, and synchronous motors. Table 2.3.1.1-2 lists protection for DC motors. Tables 2.3.1.1-3a and 2.3.1.1-3b list protection functions for adjustable speed drives. Adjustable speed drive protection may be provided by a combination of internal drive functions and external protection.

C.1 AC Motor Protection

C.1.1 Undervoltage Protection, Device 27

Undervoltage relays are applied to motors to prevent automatic restart for the following reasons when voltage returns after a power system disturbance:

A. To prevent a possible safety hazard that could result if a motor automatically restarted

B. To avoid excessive inrush current to the motor load and the corresponding voltage drop on the power system

C. To avoid catastrophic shaft torque impulses on a turning motor

Induction disk undervoltage relays are normally used; and their time delay setting is coordinated with fault relays, so tripping due to low voltage accompanying external faults will be avoided. Instantaneous undervoltage relays are used to protect synchronous motors that have starters with AC-held contactors from restarting out of step. Instantaneous relays also are applied to large induction motors where the internal voltage does not decay rapidly enough. Excessive inrush current and damage to the motor winding, shaft and foundation can occur due to the motor’s internal voltage being out of phase with the reclosed system voltage.

C.1.2 Bearing Temperature Protection, Device 38

Bearing-protection devices activate during excessive bearing temperatures or other abnormal conditions, such as undue wear, which may eventually result in excessive bearing temperature. Bearing-temperature protection is difficult to apply effectively. Excessive temperature can cause bearing damage before bearing-temperature protection devices operate. More serious mechanical damage to the journal, the rotor and the stator will be prevented by operation of the protective device to shut down the motor. The bearing temperature sensor should be a fast-responding type and located either in the bearing Babbitt or in the lubricating oil flowing from thebearing.

C.1.3 Phase Current Balance Protection, Device 46

Phase unbalance relays are used to prevent rotor overheating due to negative-sequence currents. Negative-sequence currents are caused byunbalanced voltages produced by phase-to-ground and phase-to-phasefaults, an open phase, and unbalanced loads on a three-phase system.These negative-sequence currents induce double-line frequency currents(120 Hz) that flow in the damper winding and/or rotor parts. A 5%voltage unbalance produces a 20% to 30% current unbalance. An openphase to a three-phase motor is commonly called single phasing of themotor, since only single-phase power is available to the motor. If onephase to a three-phase motor opens while it is running, the motor maycontinue to run, but as a single-phase unit. The motor itself tends tomaintain the voltage in all three phases, but current in the two soundphases theoretically will be 1.73 times normal load current and zerocurrent in the open phase. When a motor bus is supplied from adelta-wye or wye-delta transformer, single phasing on the supply sideof the transformer results in currents to two phases of the motorslightly greater than normal motor load current, and the third phasebeing approximately twice normal current. Phase unbalance relays shouldbe provided where single phasing is a strong possibility due to thepresence of fuses or where overhead conductors are subject to physicaldamage or impedance unbalance with untransposed lines. Unbalance relaysshould have enough time delay to permit system faults to be cleared.

C.1.4 Phase Sequence Voltage Protection, Device 47

Phase-sequence voltage relay responds to the positive- and negative-sequence components of the three phase quantities of the applied voltage. The relay can protect the motor from starting in reverse due to incorrect phase rotation. If the phase rotation is not correct (100% negative sequence), or if all three phase voltages are not present; if the applied voltages are sufficiently unbalanced (partial negative sequence), or if an undervoltage occurs (no negative sequence), the relay will operate. Phase-sequence voltage relays are recommended for all important busses supplying motor loads. The relay can detect single phasing of the upstream supply to a single lightly loaded motor; it cannot detect single phasing between the relay and the motor. The negative-sequence voltage produced on the source side of an open phase is minimal, and the relay will not respond. The relay only responds to the voltage unbalance on the load side of an open phase.Phase-current balance relay (Device 46) should be used to detect amotor feeder circuit open phase.

C.1.5 Incomplete Sequence Protection, Device 48

The incomplete sequence relay locks a motor out if the normal starting, operating or stopping sequence is not completed within a predetermined time. Incomplete sequence protection would be applied to reduced-voltage started motors, wye-delta starting control, wound-rotor induction motors and other sequential start arrangements. This protection also is applied to synchronous motors to block tripping of the loss of field (Device 40) and pullout (Device 56) protection schemes during startup.

C.1.6 Thermal Overload Relay, Device 49

Thermally sustained overload protection limits the motor winding temperature and current to predetermined values during abnormal motor operating conditions. This protection prevents motor insulation from breaking down prematurely. Any of the following may cause thermal overload:

- Overcurrent
- Stalling the motor
- Failure to start
- High ambient temperature
- Inadequate motor ventilation
- Reduced speed
- Frequent starting or jogging

- Low voltage or frequency
- Mechanical failure of the driven load
- Improper application or installation
- Unbalanced line voltage
- Single phasing

Current sensing alone will not detect conditions such as restricted ventilation, nor will temperature sensing alone adequatelydetect conditions such as overcurrent. Although not required by industry standards, for complete thermal protection, both temperature and current sensing are needed.

Thermal overload protection falls into three classes:

1. Thermal induction, eutectic, bimetallic or electronic thermal-overload relay responding to motor current
2. Temperature relays operating from resistance temperature detectors (RTD) or search coils built into the motor
3. Thermal overload relays that respond to a combination of motor current and temperature from RTDs

The National Electric Code (NEC) requires one thermal overload relay per phase to protect all three phase motors unless they are protected by other approved means. Three devices are required to protect against single phasing, because only one phase may have high enough current to operate the overload device. The overload device must be selected to trip at no more than (a) 125% of rated full load current for motors with a service factor not less than 1.15, and (b)115% of full load current for all other motors.

C.1.7 Instantaneous Phase Overcurrent Protection, Device 50

Instantaneous phase overcurrent relays detect motor phase faults with no intentional time delay. Fast clearing of phase faults accomplishes the following:

- Limits damage at the fault location
- Limits the duration of the voltage dip accompanying the fault
- Limits the possibility of the fault spreading, and of fire or damage

Instantaneous overcurrent relays must be set above induction motor starting inrush currents or synchronous motor contribution to an external fault. Recommended pickup setting is 175% of the motor starting inrush current or external motor fault contribution. Automatic transfer systems might require higher settings, due to the combined motor starting inrush and substation full load current.

C.1.8 Instantaneous Ground Overcurrent Protection, Device 50N/50G

Instantaneous ground-overcurrent relays protect the motor against high level ground faults. Either a toroidal (window) type current transformer (CT) that encircles all three phase conductors, or the residual connection from three CTs (one per phase) can feed the relay. Both methods have their drawbacks. The window CT requires taking physical mounting precautions to prevent a current unbalance in the CT. On the other hand, high starting currents and feedback for external faults may saturate the three phase CTs unequally, causing a false residual current that trips the ground relay. Medium voltage, solidly grounded systems have historically used residually connected ground fault relays (Device 50 N) where large ground fault currents exist. The instantaneous ground-fault relay must be set above the false residual current. Typical pickup would be 10 to 40 Amperes. The common practice on medium voltage, low-resistance grounded systems is to use thetoroidal-connected, instantaneous ground overcurrent relay (ground sensor, Device 50 G). Primary current pickup values of the instantaneous ground-sensor relay range from 4 to 12 Amperes.

C.1.9 Time Delay Ground-Overcurrent Protection, Device 51N/51G

Time delay ground overcurrent relays detect low level ground faults. The relay can be connected in either method described above with the same precautions. Time delay on the residually-connected relay (Device 51 N) is set longer than the motor starting time to prevent undesired tripping with sensitive settings. Time delay for the ground sensor relay (Device 51 G) must be used if a more sensitive pickup than the instantaneous ground sensor relay (Device 50 G) setting is desired. The 51 G time delay prevents operation due to zero sequence cable capacitance current flow during external ground faults. Short time or extremely inverse time induction disk overcurrent relays are used with a typical setting of 1A tap and 1/2 time dial. The overall system (relays and current transformers) normally must be tested and set in the field.

C.1.10 Time Delay Phase-Overcurrent Protection, Device 51

Time delay phase-overcurrent relays protect the motor against overloads, low level faults, locked rotor and failure to accelerate to rated speed within the starting time. Inverse long time induction disk relays have the preferred characteristics for motor protection.

Extremely inverse relays are sometimes used for better time-current coordination with feeder relays and faster operation. Care must be taken that the extremely inverse relay does not trip from starting current.

Locked rotor protection can be provided by the induction overcurrent relay only if the allowable locked rotor time exceeds the motor acceleration time. For this case, the overcurrent relay is set to pick up at 150% to 175% of motor full load current. Select the time setting to be greater than the startup time at rated inrush current, but less than the locked rotor limiting time. The motor is protected for both locked rotor and failure to accelerate to rated speed within the starting time. On some modern large motors allowable locked-rotor current time is less than the starting time. During a normal start the active input power is utilized for the driven load. During a locked rotor condition all of the active input power to themotor is dissipated as heat loss occurs in the motor. A relay with atime delay selected to be greater than the startup time would notprotect the motor for a locked rotor condition. If accelerating timeexceeds locked rotor time then locked rotor protection must be providedusing one of the following methods:

A. One overcurrent relay for failure to accelerate to rated speed protection, and a second overcurrent relay supervised by a zero speed switch to provide locked rotor protection. During startup, the speed switch disengages the locked rotor protection, leaving protection to the failure to accelerate relay. After the motor is up to speed, the locked rotor protection is engaged.

B. A relay with independent adjustments for failure-to-accelerate and locked-rotor characteristics.

C. A distance relay and a timer.

C.1.11 Differential Protection, Device 87

A differential relay detects three-phase, phase-to-phase and phase-to-ground faults that develop within the motor differential zone. Differential relays cannot detect turn-to-turn faults within the same winding, nor can they detect motor ground faults on high resistance or ungrounded systems. Differential relays have limited sensitivity for motor ground faults on low resistance grounded systems. Differential relays recommended for motors with 1,500 hp and greater are required on smaller motors for sensitive fault detection if the motor horsepower is greater than one half the supply transformer kVA.

C.2 Additional Synchronous Motor Protection

Synchronous motors require the following protective devices in addition to those already described.

C.2.1 Damper Winding Thermal Protection, Device 26

Damper winding relays protect a synchronous motor’s short-time rated squirrel-cage winding during startup. When the synchronous motor is started, high currents are induced in the damper winding. Should the motor fail to start and accelerate, Device 26 will operate to trip the motor off-line.

C.2.2 Loss of Field Protection, Device 40

Loss of field protection detects an abnormally low level of field current. Either a DC undercurrent relay with a timer connected in the field, or a conventional generator type loss-of-excitation relay on the motor leads can be provided. The system must provide the required excitation current to the motor when a loss of field occurs. The excitation current drawn from the power system by large motors may cause a voltage drop and endanger continuity to service of other loads. Heavily loaded motors will probably pull out of step and stall. Lightly loaded motors will not be capable of accepting load when necessary. The relay should trip the motor off the line.

C.2.3 Power Factor Relay, Device 55

A power relay protects the motor from operating at sub-synchronous speed with its field applied. This loss of synchronism or out-of-step operation with the system can be caused by increased loading, decreased excitation, or low system voltage. Out-of-step operation produces oscillations in the motor stator current and possible physical damage to the motor. The power-factor relay operates when the current to the motor becomes extremely lagging and the motor loses synchronism (reactive power [var] flows into it) or when the synchronous motor field is lost.

C.2.4 Field Application Relay, Device 56

A field application relay automatically controls field excitation to an AC motor. It also removes the field during an out-of-step condition and then automatically reapplies the field at the proper time and condition. Device 56 is commonly referred to as pull-out protection because it provides loss of synchronism protection. The system conditions and effects of out-of-step operation or loss of synchronism are described under power-factor relay, Device 55. Protection for pulling out-of-step can also be provided by a power-factor relay (Device 55) and a loss-of-field relay (Device 40).

C.3 DC Motor Protection

Direct current motors require the following protective devices in addition to those already described.

C.3.1 Overspeed Protection, Device 12

Overspeed protection usually is provided by a directly connected speed switch that functions on motor overspeed. It applies to DC motors that may reach excessive speed because of loss of load or excitation. Series wound DC motors overspeed as a result of a loss of mechanical load and are protected by a speed switch. Shunt-wound DC motors overspeed due to loss of field and may be protected from this condition by a speed switch or a loss-of-field relay (Device 40). The overspeed protection should be arranged to trip the motor supply.

C.3.2 Acceleration Protection, Device 14

An acceleration-protection relay is an underspeed device that functions when the speed of the motor falls below a predetermined value. Acceleration relays automatically control the voltage across the DC motor armature during startup. Uniform starting current, starting torque and acceleration are maintained.

C.3.3 Loss of Field Protection, Device 40

A loss-of-field relay prevents excessive overspeed on a DC shunt wound motor due to a loss or open field. Loss-of-field protection is provided by a DC undercurrent relay with a timer connected in the field circuit. Loss-of-field protection should be arranged to trip the motor supply.

C.3.4 DC Overcurrent Relay, Device 76

DC overcurrent relays are provided to detect motor faults. The DC overcurrent relay must be set above the motor inrush current.

C.4 AC Adjustable Speed Drive Protection

C.4.1 Source Converter Overcurrent

This protection provides thermal overload protection for the input converter thyristors and interconnecting bus or wiring.

C.4.2 Source Converter Overtemperature

This function protects the input converters from overtemperature, and can be used to shut down the drive for this condition.

C.4.3 Source Voltage Unbalance

This function checks for unbalanced source voltage to the drive.

C.4.4 Source Undervoltage

This function monitors voltage levels of the source. Typical alarm setting is 30 seconds at 90%; trip setting is 30 seconds at 70%.

C.4.5 Source Reverse Phase Sequence

This function protects the drive from being incorrectly connected.

C.4.6 DC Link Overvoltage

The overvoltage function protects the DC link between the source and output converters. Typically, the setting is in the range of 110% to 120%.

C.4.7 DC Link Overtemperature

This function protects the link reactor insulation from thermal damage.

C.4.8 Load Converter Overcurrent

This function provides thermal overload protection for the output converter thyristors and interconnecting bus or wiring.

C.4.9 Load Converter Overtemperature

This function protects the input converters from overtemperature and can be used to shut down the drive for this condition.

C.4.10 Load Overvoltage

This function protects the load converters from overvoltage.

C.4.11 Load Overfrequency (Overspeed)

This function provides overfrequency (overspeed) protection for the motor.

C.4.12 Load Overexcitation

This function provides overexcitation protection for the motor. It may not be necessary if both overvoltage and overfrequency protection are already provided.

C.5 ASD Isolation Transformer (If Applicable)

C.5.1 Transformer Overtemperature, Device 26

This function provides overtemperature protection for the transformer oil.

C.5.2 Transformer Winding Overtemperature, Device 49

This function protects the transformer winding from overheating.

C.5.3 Transformer Instantaneous/Time Overcurrent, Device 50/51

The overcurrent functions protect the transformer and associated equipment from phase faults and overloads.

C.5.4 Transformer Ground Fault Instantaneous/Time Overcurrent, Device 50N/51N or 50G

These overcurrent functions protect the transformer and associated equipment from ground faults.

C.5.5 Gas Pressure Relay, Device 63

This device detects excessive pressure in an oil-filled transformer.

C.5.6 Liquid or Gas Level, Device 71

This device detects high liquid or gas levels in an oil-filled transformer.

C.5.7 Phase Differential, Device 87

This function provides high speed protection against phase faults for the transformer and any other equipment within the zone of protection.

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APPENDIX E EQUIPMENT FACTORS

E.1 Maintenance

- A documented inspection, testing and maintenance program as part of asset integrity is in place to maintain motor integrity and reliability.
- Electrical and mechanical testing (including in-service testing) are completed and meet or exceed OEM guidelines and/or FM standards.
- Structural inspections for GMDs meet OEM guidelines and/or FM standards.
- A Foreign Material Exclusion (FME) program is in place during outages for GMDs.
- Adequate pre-outage planning is in place, and/or outage service reports are maintained for review and trending after the outage.
- Deficiencies identified during inspection, testing and maintenance activities are tracked, documented and adequately managed.
- Inspection, testing and maintenance programs are updated when required due to process and/or equipment changes.
- No other conditions of concern are present that impact motor maintenance.

E.2 Operating Conditions

- Condition and performance monitoring where required to monitor operating parameters is favorable.
- Vibration
  - Monitoring results are within acceptable parameters/design limits.
  - Records show no unexplained step changes.
  - Trending analysis is in place.
  - No unfavorable trends reported.
- Motor is operating within rated capacity.
- No other conditions of concern are present that impact motor operating conditions.

E.3 Environment

- Enclosures, including air intakes, are in good condition; and no water or oil leaks are present.
- Motor is suitable for the environmental conditions in service.
- No other conditions of concern are present that impact the motor environment.

E.4 Operators

- Alarms
  - Procedures are in place to alert operators of upset conditions that require immediate response or which could result in confusion or delay.
  - Documentation\logging and/or evaluation is in place. Operators are informed on alarm status at shift changes.

- Operators
  - Training and retraining of operators, including the scope of operator responsibilities as part of standard and emergency operating procedures (i.e., safe start up, normal operation, upset conditions, emergency scenarios, shutdown) is in place
  - Standard and emergency operating procedures are in place. Operating procedures are clear, easy to understand, up to date, motor specific and/or clearly define emergency actions for motor upset conditions.
  - Direct communication with key personnel to raise issues or concerns to management is in place.
  - Review and revision of emergency operating procedures is in place as needed, and operators are informed at shift changes.
  - Routine operator rounds/visual inspections to assess operating conditions are completed and documented per the SOP's.
- Process controls, alarm set points and jumpers are properly managed.
- No other conditions of concern present that impact motor operators.

E.5 History

- Motor has a favorable fleet history.
- Adequate documentation and trending of operating and inspection, testing and maintenance history is maintained.
- No history of operating the motor outside the OEM's design limits without proper approval documentation.
- Qualified contractors complete major repairs, replacements or updates.
- Appropriate mitigating actions impacting motor service aging and remaining useful life have been implemented where required.
- Motor remaining useful life is evaluated where required, using a condition-based approach, with corrective action taken as needed before a breakdown/failure in service.
- No other conditions of concern are present that impact motor history.

E.6 Safety Devices

- Electrical protective relays, monitoring (including vibration), trouble signals and alarms for the stator, rotor and exciter, and battery systems when applicable are:
  - Properly installed, functional and are reliable.
  - Inspected, tested and maintained to existing procedures that meet ANSI/IEEE and FM standards.
  - No other conditions of concern are present that impact motor safety devices.

E.7 Contingency Planning

- A viable equipment contingency plan and/or equipment breakdown sparing is in place where needed to reduce motor downtime in the event of a breakdown.
- The scope and implementation of the equipment contingency plan addresses recovery options/mitigation strategies to respond to and recover from a motor breakdown.
- Equipment breakdown spares, where provided, are properly stored and maintained viable.
- No other conditions of concern are present that impact motor contingency planning.