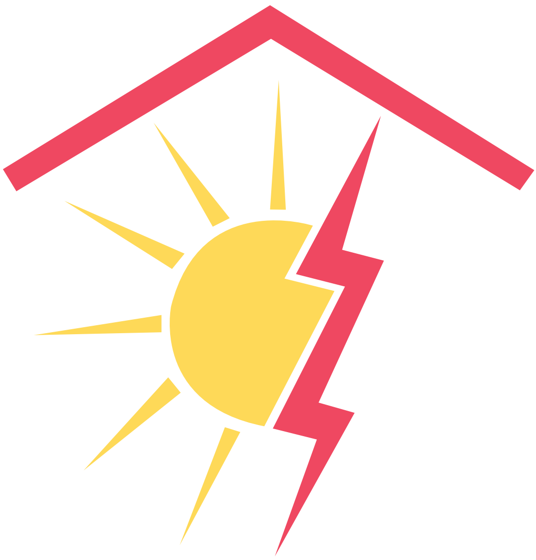
$15.95 CDN

Preventive Maintenance

HANDBOOK



2nd Edition

First Edition, 1992
Second Edition, December 1997

Revised by:

Richard Okrasa, P.Eng., M.B.A.
Ontario Hydro
1997

In-House Energy Efficiency

Energy Savings are Good Business

Printed in Canada.

ELECTRICAL SYSTEMS PREVENTIVE MAINTENANCE

Handbook

2nd Edition

Table of Contents

List of Figures

CHAPTER 1

PREVENTIVE MAINTENANCE: AN EXPLANATION

Reactive maintenance, also referred to as breakdown maintenance, is the most common form of equipment maintenance practiced in industry today. Equipment is neither serviced on a regular scheduled basis, nor is it tested to determine its condition. With this approach, equipment is repaired or replaced when a failure occurs.

Preventative maintenance is a program of routine equipment inspections, maintenance tasks and repairs which are scheduled to ensure that degradation of equipment is minimized. A well-designed preventative maintenance program slightly over-maintains equipment because scheduling is designed for the worst case operating conditions. The overall objective is to prevent operating problems or failures, and ensure reliable operation of a facility.

Predictive maintenance is the technique of regularly monitoring selected parameters of equipment operation to detect and correct a potential problem before it causes a failure. This is done by trending measured parameters which allows a comparison of current parameters to historical data. From this comparison, qualified judgments about the need for corrective action can be made. This approach ensures that the right maintenance activities are performed at the right time.

Chapter 2

Why Maintenance is so Important

For many companies, maintenance is an activity which is carried out reactively, in response to interruptions, breakdowns and other unfortunate events. The ramifications of this kind of approach can be severe, especially at operations such as processing plants, assembly lines and power plants, where the failure of a relatively minor component can disrupt the entire facility. As many companies have found out, the total cost of downtime and emergency around-the-clock repairs can be staggering.

On the other hand, a preventive maintenance program ensures continuity of operation and lessens the danger of unplanned outages. Planned shutdowns take place during periods of inactivity or least usage, and as a result, troubles can be detected in the early stages and corrective action taken before extensive damage is done.

The relationship between maintenance quality and electrical equipment breakdown can be seen in the Following results from a survey conducted by the IEEE Industrial Commercial Power Systems Committee.

Number of Failures Versus Maintenance Quality For All Equipment Classes Combined			
	Number of Failures		
Maintenance Quality	**All Causes**	**Inadequate Maintenance**	**Percent of Failures Due to Inadequate Maintenance**
Excellent	311	36	11.6%
Fair	853	154	18.1%
Poor	67	22	32.8%
Total	1231	212	17.2%

Chapter 3

Causes Of Electrical Failure

There are four principal causes of electrical failure: dust and dirt accumulation; moisture; loose connections; and friction of moving parts. An effective maintenance program should aim to minimize these effects by keeping equipment clean and dry, keeping connections tight and minimizing friction.

Dust And Dirt Accumulation

Lint, chemical dust and the accumulation of oil mist and particles become conductive when combined with moisture on insulation. These can be responsible for degradation of insulation, tracking and flashovers.

Dirt build up on coils, in motors, transformers and relays will obstruct air flow and increase operating temperatures. This results in decreased efficiency and equipment failure.

Contamination cannot be avoided in certain facilities such as steel mills, mines, foundries and aggregate plants. However, contamination in these environments can be minimized with regularly scheduled cleaning of equipment, and the use of properly designed apparatus such as encapsulated coils, totally enclosed self-cooled equipment and separate filtering systems.

Presence of Moisture

Moisture condensation in electrical equipment can cause oxidation, insulation degradation and connection failure. High humidity produces free condensation on the equipment which can result in short circuiting and immediate failure.

Ideally, electrical equipment should be operated in a dry atmosphere, but often this is not possible, so precautions should be taken to minimize the entrance of moisture through the use of proper enclosures and space heaters, where appropriate.

Loose Connections

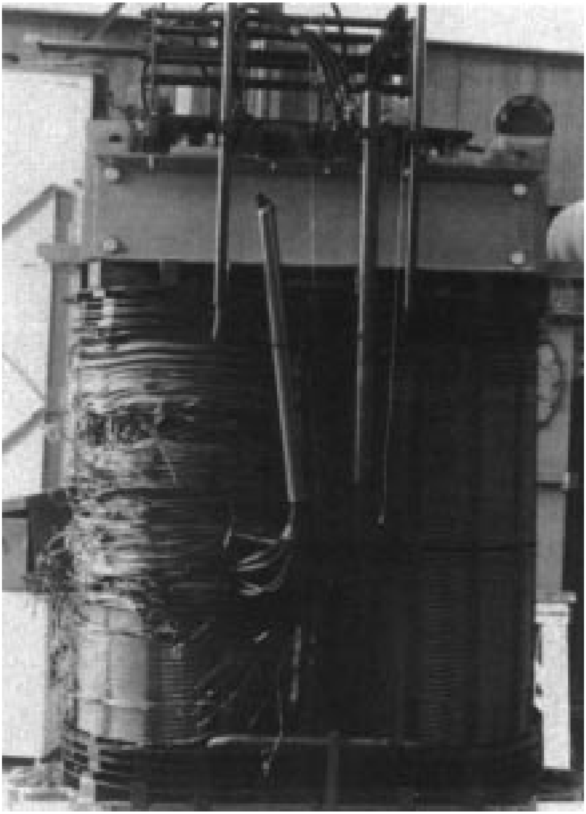
Electrical connections should be kept tight and torqued to recommended values. Creep or cold flow during load cycles is a major cause of joint failure. Hardware on all electrical equipment should be checked for looseness resulting from vibration and normal device operation. Cable connections and fuse clips are common areas where loose connections can be found. Together with contactors and circuit breakers, they should routinely be inspected for tightness.

Friction

Friction can affect the freedom of movement of electrical devices and can result in serious failure or improper operation. In circuit breakers, friction can reduce speed of operation - a vitally important factor. Dirt on moving parts can cause abrasion and can result in improper operation such as arcing or burning.

Devices should not be lubricated unless specified by the manufacturer. The type and grades of lubricant specified should be strictly adhered to. Oil and grease collect dust and other contaminants, and also attack insulation, particularly rubber.

Checking the mechanical operation of devices and manually or electrically operating any device that seldom operates should be standard practice.



Picture of failed transformer due to loose connections

CHAPTER 4

THE KEY ELEMENTS IN AN EFFECTIVE PREVENTIVE MAINTENANCE PROGRAM

No two companies or industries are alike: Nevertheless, there are four key elements for a preventive maintenance program to work effectively:

- A properly designed system
- Properly installed, appropriate equipment
- Trained operating and maintenance staff
- Proper planning and scheduling

SYSTEM DESIGN

A system that is not properly engineered, designed and constructed will not provide reliable service, regardless of how well or how much maintenance is carried out.

A good system design should:

- Define all load requirements
- Include a complete layout showing locations of all the loads on the system
- Establish a motor list

- Determine critical loads
- Define process line requirements
- Allow flexibility
- Determine lighting, air conditioning, compressor and other non-production load requirements
- Provide for future expansion
- Conform to all applicable codes and standards.

Properly Installed And Appropriate Equipment

Good quality equipment, appropriate for the task and properly installed, are the foundation on which effective preventive maintenance programs are built. Some examples of this are:

- Large exterior bolted covers on switch gear and large motor terminal compartments are not conducive to routine inspections, cleaning and testing. Hinged and gasketed doors with a locking system are much better.
- Space heater installations in switchgear or electric motors are a necessity in high humidity areas because they reduce condensation on critical insulation components.
- Motor insulation temperatures can be monitored by using resistance temperature detectors which provide an alarm indication or trip operation at a pre-selected temperature.
- The distribution system should allow for maintenance work without load interruption, or with only minimal disturbances for critical loads. Tie breakers and isolation switches, combined with additional equipment and/or distribution. will allow routine or emergency maintenance to be done on one circuit while the other supplies the critical load.

- Equipment should be located where sufficient space exists to access all areas requiring maintenance work. Overhead lifting facilities or support beams should be installed for the removal of large motors and circuit breakers.
- Removable, “draw-out” type circuit breakers are often preferred for maintenance operations since one circuit breaker can be removed from the switchboard without shutting down the complete service.
- Non-rotating equipment requiring ventilation should be fitted with filters to prevent unwanted contamination.

Properly Trained Staff

The techniques utilized in the performance of a preventive maintenance program are extremely important. Success or failure is dependent to a large extent on the expertise of the personnel performing the work.

Properly trained and adequately equipped maintenance personnel must have a complete knowledge of the equipment operation to be able to make thorough inspections and repairs. The use of untrained personnel on apparatus is unsafe, and can lead to serious injuries and equipment damage.

Planning and Scheduling

A preventive maintenance program can only be effective if it is both well planned and regularly carried out.

Planning involves understanding the electrical system, identifying and prioritizing equipment maintenance requirements and then establishing a maintenance schedule.

The examination, testing, servicing and repair of equipment are generally scheduled during normal production shutdown periods.

Conclusions from an IEEE failure study indicated that an annual schedule is sufficient for most electrical equipment. Notable exceptions are circuit breakers and motor starters which are in frequent use. These should be inspected every six months.

Many manufacturers specify a maintenance schedule and recommend a spare parts list.

A number of insurance companies specify a maximum interval between inspections and testings in order for policies to remain valid.

CHAPTER 5

IMPLEMENTING A PREVENTIVE MAINTENANCE PROGRAM: GENERAL PROCEDURES

There are a number of elements involved in implementing an effective preventive maintenance program:

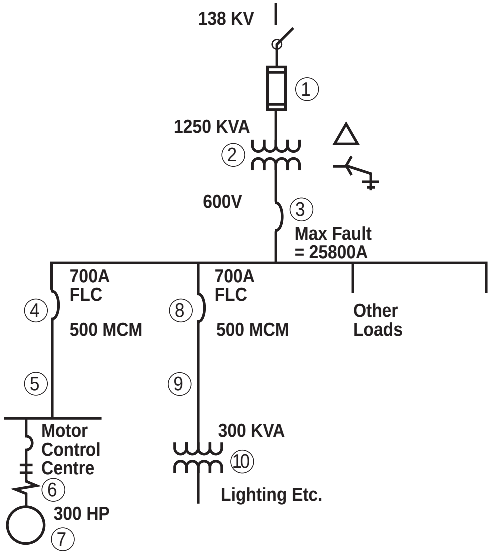
- One-line diagram
- Complete plant inspection
- Equipment service files
- Failure analysis
- Call-up schedule

ONE-LINE DIAGRAM

The one-line diagram is the key reference document for maintenance staff. It is a “road map“ of the electrical system, providing a fast and effective way to trouble shoot the system and uncover operational problems.

It is essential that one-line diagrams are updated regularly. A typical one-line diagram will include:

- Upstream utility supply, including voltage and current ratings, short circuit levels, relay settings and grounding methods
- Available short circuit currents through the distribution

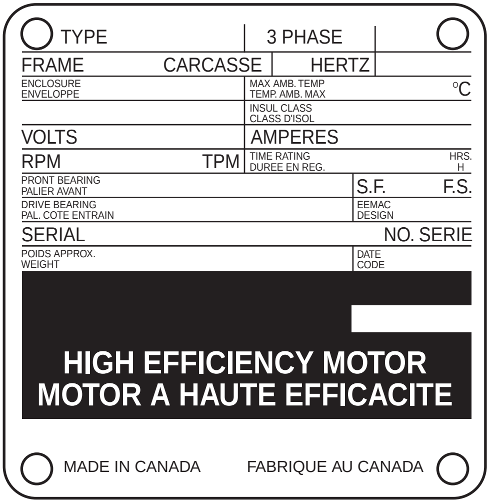


Typical One-Line Diagram

- Location and rating of lightning arrestors
- Rating, reactances, connections and grounding methods of transformers
- Size, type and number of conductors for all loads
- Circuit breaker and fuse ratings, continuous and interrupting capacity
- All current and potential transformer locations and ratings
- Size, type and setting of all protective devices such as relays, circuit breakers and fuses.

Complete Plant Inspection

This should include a close look at all motors, transformers, protective devices, etc. to record nameplate data and perform any necessary inspection and/or maintenance work.



Typical Motor Nameplate

Mechanical components such as conduits, underground cable locations, ground connections, bearings, belt drives and filters should also be recorded.

In some cases, on/off exercising or a simple visual inspection may be all that is required. In other situations, dedicated equipment may be needed along with the assistance of outside specialists.

The following inspections should take place:

- Supply and distribution rooms to ensure they are clean, uncluttered, well ventilated and, if required, heated.

- All indicator lights and instruments for proper operation.
- An analysis of the power circuits telling whether the loads are properly identified. An improperly-labeled circuit breaker or switching device is very dangerous for anyone doing preventive maintenance.
- All circuits for current levels to identify those which are loaded and those which have spare capacity.
- Current on each phase in a 3-phase system should be checked for balanced conditions. Neutral currents should be near zero. Redistribution of single phase loads may be necessary to maintain balanced currents .
- Overload device settings and fuses for proper current and interrupting ratings.
- All feeds to motors for proper load vs. name plate rating, and correct overload heater ratings/settings.
- in some cases, a coordination study may be necessary, especially for recent expansions or new distributions.

Equipment Service Files

Another important ingredient in an effective preventive maintenance program is an accurate and up-to-date file of information on every important piece of electrical equipment.

Often, information on equipment is lost, misplaced, misfiled or discarded and it is not until a crisis occurs that staff discover that the information is missing.

This data is essential for the proper management of a preventive maintenance program, as well as for the training of new staff and as a reference for existing staff.

The following information should be in the equipment files:

- One-line diagram(s)
- Manufacturers' information such as instruction bulletins, schematics, parts lists and manuals
- Repair and failure reports

The most important section in the files should be a record system showing all repairs required by the electrical equipment over time. The records should also contain information on the availability of spare parts, quality of service from equipment manufacturers and time required for repairs. This combined body of information will not only serve to be helpful in planning and scheduling preventive maintenance work, but will also be useful in evaluating equipment for future purchases.

Failure Analysis

Every equipment failure should be thoroughly investigated and the root cause determined and documented. Generally, it will be found that timely and adequate preventive maintenance could have prevented the failure. If correctable by preventive maintenance, the corrective action should be included on the work list. If the failure was caused by a weak component or improper/infrequent maintenance, then all like equipment should be investigated as soon as possible.

Call-Up Schedule

The optimal time interval between scheduled maintenance is a function of a number of factors which vary from one piece of equipment to another such as running hours, number of starts, loading and operating environment.

Probably the best technique to determine frequency of overhaul is to keep maintenance and failure records for each piece of equipment, and base call-ups on a combination of your own experience and manufacturers' recommendations.

Motor Data Sheet

Motor Maintenance Record

Description

Equipment: ______________________________ Fruequency of Overhaul ____________ Years

HP: ____________ Rated Volts: ______ S/N: __________ RPM __________ Maint. Priority: __________

History

Precious Locations: ______________________________

Replaced with Spare? S/N of spare

Previous Number of Rewinds ______________

Reason for Maintenance? P.M.

Work Order # ______________________ Other

Condition

1. Bearings Bearing Type: Inboard ____________

   Outboard ____________

Bearings Replaced Inboard Yes

No

Outboard Yes

No

2. Rotor ______________________________
3. Stator ______________________________
4. Commutator ______________________________

Tests:

1. Meggered __________ Ohms at: __________ Volts: __________ Temperature: __________
2. Phase Resistance OK? ______________________________
3. Test Run OK? ______________________________
4. Qualitative Noise and Vibration OK? ______________________________

Post Repair Status

Installed in Location ______________________

or

Stored as Spare ______________________

General Comments

____

____

____

____

Maintenance ______________________ Date: ______________________

P.M.#: ____________ Labour Cost ____________ Material Cost ____________

Keeping track of routine inspection records allows one to recognize if any trends are developing. Records of past failures, inspections and repairs are excellent indicators of problem areas needing attention.

CHAPTER 6

EQUIPMENT AND SAFETY PROCEDURES

TEST AND MAINTENANCE EQUIPMENT

Basic “make or buy” choices are involved in deciding on the test and maintenance equipment for a preventive maintenance program.

Much of the test equipment is highly specialize,. has limited applications and tends to be expensive. The cost and usefulness of this equipment should be carefully weighed against the cost of having the services performed by outside contractors.

Required maintenance tools might include wrenches, socket sets, rubber mallets, screwdrivers, torque wrench, callipers and micrometers, lubrication equipment, specialized mirrors, auxiliary light sources, portable generators, portable blowers, vacuum cleaners, paint brushes and rags to remove dirt, files and burnishing pads to clean contacts and manufacturers’ recommended cleaning solvents.

Basic test equipment could consist of full-range multimeters to cover all system voltage ranges, 1000 volt megohmeters, clip-on ammeters, thermometers, phase sequence indicators, power factor meters and ground detectors. Sometimes specialized test equipment is required. These include circuit breaker and relay testers, transformer turns ratio testers, capacitance bridges, high potential test sets, industrial analyzers, vibration analyzers and infrared cameras.

Testing of Protective Relays using a Relay Test Unit

SAFETY PRECAUTIONS

Use of safety equipment and adherence to safety procedures are mandatory and must be enforced in any operation where electricity and mechanical energy is (or potentially) present.

Some of the procedures which should not be forgotten are:

- A well-defined switching, isolation, testing, grounding and lock-out procedure that must be in place prior to the commencement of any electrical work. The electrical utility should be notified so that proper arrangements can be made prior to starting any work in the incoming substation.

- All safety equipment should be tested and inspected before and after each use.
- Warning signs and barricades must be in place, and all unauthorized personnel excluded from the area.
- Toxic vapours from solvents must be avoided. A means of exhausting vapours or other personnel protection must be provided to avoid inhalation of toxic vapours from solvents.
- Personnel should be trained in first aid treatment and know all the safety precautions to be used.
- An approved fire extinguisher should be nearby, and personnel must know how to use it.
- The use of metallic ladders must be avoided around electrical equipment.
- Assess and protect from mechanical as well as electrical hazards.

Among the safety equipment that should be available are:

- Voltage detectors (for use at the proper voltage level) along with voltage test devices
- Rubber insulating gloves with leather protectors, rubber insulating mats and blankets
- Approved safety grounds
- Insulated hot sticks
- Approved hard hats, safety glasses, and/or goggles, and safety shoes with insulated toes
- Approved fall arrest equipment for working on above ground.

CHAPTER 7

EQUIPMENT-SPECIFIC PROCEDURES

LUBRICATION

Proper lubrication of bearings is essential for optimum performance. Many bearing failures are due to a lack of lubrication, but more commonly, bearings fail because of over-lubrication. Motor bearings should be lubricated according to the manufacturer's instructions, using the specified lubricant. When regreasing, the motor should be shut down and the grease drain plugs removed. Grease should be added using a hand operated grease gun until grease appears at the drain plug. Run the motor for at least ten minutes before reinstalling the drain plugs to allow excess grease to be expelled from the bearing housing.

Where the manufacturer does not provide a recommendation on bearing lubrication, the following table can be used as a guide for motors operating under usual service conditions.

Speed RPM	HP	8 hr/day Operation	24 hr/day Operation
3600	1 - 25 30 - 40 > 40	5 years* 6 months 4 months	2 years 2 months 2 months
1800	1 - 20 25 - 50 60 - 75 > 75	5 years* 4 years 1 year 9 months	2 years 1 1/2 years 4 months 3 months
1200 & Below	1 - 10 15 - 30 > 40	5 years* 4 years 1 year	2 years 1 1/2 years 4 months

*These motors often have sealed bearings and should be replaced at these intervals

Insulation Resistance Testing

Insulation resistance testing, commonly referred to as "Megger" testing, gives a good indication of problems such as grounds, moisture, contamination and damaged windings. To be effective as a predictive maintenance tool, insulation resistance testing should be done on a regular basis and the results trended as a single test reading are of little value. Insulation resistance is measured between the windings and the motor's frame. For motors rated at 600V or less, a 500 volt megger should be used. This reading should be temperature corrected to 40˚C using the following equation:

$R_{40} = R_t \times K_t$

Where:

R_{40} = Insulation Resistance corrected to 40˚C.

R_t = Insulation resistance at measured temperature.

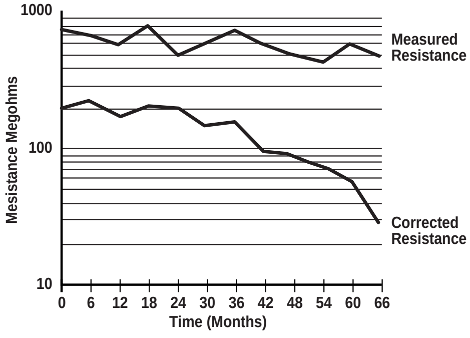
K_t = Temperature correction coefficient.

The temperature correction coefficient can be obtained from the following table:

Temp °	K_t	Temp °	K_t
0°	0.06	30°	0.5
5°	0.09	40°	1.0
10°	0.13	50°	2.0
15°	0.18	60°	4.0
20°	0.25	70°	8.0

Caution! After completion of the insulation resistance test, the windings must be discharged to prevent serious personal injury. The winding lead must be shorted to the motor frame to ensure that any residual charge is dissipated.

Results of the insulation resistance tests are then trended over time. By doing this, it is easy to see if the insulation is degrading as shown in the following graph of insulation resistance, taken every six months.



Motor insulation Resistance Trended

It can be seen that the insulation resistance is degrading after month 24. It would be appropriate to remove the motor from service and send it to a motor service center. The stator windings can be cleaned and dried.

Polarization Index Testing

A polarization index test is used to determine the slope of the insulation dielectric absorption curve. It is useful for evaluating windings for absorbed moisture and overall suitability for an over-potential, or Hipot, test. The polarization index, or P.I., is the ratio of the insulation resistance values taken at two time intervals. The typical P.I. test used the insulation resistance value at ten minutes, compared with the value obtained at one minute.

$P.I. = R_{10} / R_{1}$

Where:

R_{10} = 10 minute resistance value

R_{1} = 1 minute resistance value

A polarization index of 2 or more indicates that the windings are in acceptable condition. If the value is less than this, the windings should be cleaned and dried. On motors smaller than 200 hp, it may be difficult to obtain readings greater than 1.5, even with good windings. In this case, the test duration should be reduced to one minute.

$P.I. = R_{60} / R_{30}$

Where:

R_{60} = 60 second resistance value

R_{30} = 30 second resistance value

Caution! After completion of the P.I. test, the windings must be discharged to prevent serious personal injury. The winding leads must be shorted to the motor frame to ensure that any residual charge is dissipated.

As with any motor diagnostic test, it is useful to trend the test results on a regular basis.

Hipot Testing

The Hipot test is an overvoltage test which determines if a winding has a certain level of insulation strength. Good insulation can withstand voltage levels much higher than the voltages used in Hipot testing, so test failures mean that the insulation would be unsuitable for service.

DC Hipot testing

DC Hipot testing is a good, non-destructive routine test to ensure insulation strength. The voltage level applied for one minute for DC Hipot testing of motors operating at 600V or less can be determined as follows:

$V_{test} = 1.7 \times (2E + 1000)$ for new motors

$V_{test} = 2E + 1000$ for motors which have been in service

Where:

V_{test} =   DC Hipot test voltage

E =   Rated voltage of the motor

Caution! After completion of the DC Hipot test, the windings must be discharged to prevent serious personal injury. The winding leads must be shorted to the motor frame for at least four times the test duration to ensure that any residual charge is dissipated.

AC Hipot Testing

AC Hipot testing is used by motor manufacturers and motor repair centers as a pass/fail type of test to determine if there is any weakness in the insulation system. Due to the currents involved in AC Hipot testing, a breakdown of insulation causes permanent damage, so it is considered a destructive test. While AC Hipot testing can be used to test new and newly rewound motors, it does not lend itself to routine maintenance programs.

Test voltages used for AC Hipot testing are:

$V_{test} = 2E + 1000$ for motors which have been in service

Where

V_{test} =   AC Hipot test voltage

E =   Rated voltage of the motor

Surge Comparison Testing

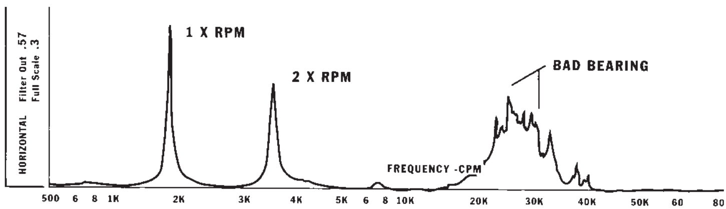
Insulation tests, such as the megger test and the hipot test, help determine the integrity of the winding insulation to ground. These tests, however, do not give an indication of the interturn insulation. When a motor is used with an adjustable speed drive, or when lightning strokes hit the electrical disribution system, extremely high voltage surges are experienced, especially on the first few turns of a stator coil.

Surge comparison testing is a widely used method of testing the interturn dielectric strength. The surge test applies a brief high-voltage impulse to two identical coils, windings or phases. This impulse causes a damped oscillation in the test coil which is displayed on a dual-channel ocilloscope. A stable waveform indicates no breakdown of insulation. The test also makes a qualitative comparison of the two coils. If the waveshape of the two coils is identical, this indicates that the coils have identical impedance. This comparison test can identify shorted turns in a coil.

Vibration

Gradual increases in vibration may not be noticeable to operators or maintenance personnel unless test devices are used to measure the degree of vibrational displacement.

Vibration analyzers are available which can determine the levels and causes of vibrations. For example, a vibration occurring at the running speed is an indication of imbalance or misalignment. Also, vibration levels at several times the rotating speed, are signs of pending bearing problems.



Motor Vibration Signature

Vibrations should be checked with a portable vibrometer during routine inspections. For 20 to 200HP EEMAC motors, the following table can be used as a guide for the maximum total ampli tude of vibrations:

Standard Balance	
Frame Size	**Total Amplitude of Vibration (Inches)**
Up to 220 (approx. 1 - 15 HP)	0.0010
Over 220 to 320 (approx. 15 - 75 HP)	0.0015
Over 320 through 500 (approx. 75 - 200 HP)	0.0020

Dirt

It is important to keep motors clean in order to avoid the overheating and insulation failure which can result from the accumulation of dirt on screens and filters. Dirt in the motor will create higher temperatures, which will decrease the operating efficiency.

Techniques which can be used include:

- Wiping with lint-free cloths
- Using suction to draw out dust
- Using dry compressed air, being careful not to drive dirt further into the motor. Recommended pressure is between 20-30 PSI.

Only solvents recommended by the motor manufacturer should be used. Extensive rinsing and drying is necessary after solvent cleaning and before motors are re-started.

Looseness

All electrical connections should be tightened to proper values. All winding end spacers, slot fillers and coil packing materials should be tight and secure.

Moisture

Water vapour can condense in totally enclosed machines, and will gradually collect and reach windings. Motors should be warmer than the surrounding air when not running, through the use of space heaters or solid state winding heaters.

A.C. Motor Starter Circuits

Visual Inspection and Cleaning

Check for any signs of moisture, overheating or loose connections. Motor starters are particularly prone to loose connections due to vibration from contactor operation.

A standard paint brush is very effective in cleaning dust and debris form motor starter circuits. Compressed air should be avoided because it can blow dust into hidden and inaccessible areas.

Contactors

The contactor assemblies should be operated manually by pushing in the contact assembly and checking for binding and friction. Be sure all electrical equipment is de-energized.

The contacts on the contactor assembly should be checked for excessive carbon deposits, arcing, overheating, welding or any appreciable loss of metal.

There is no need to replace contacts if they are discoloured, which is normal and expected. They should be replaced if only 25 percent of the contact material remains.

Carbon on contacts can be removed by using non-abrasive burnishing tools.

Separating and filing of welded or damaged contacts is not recommended because it leads to poor contact interface afterwards. Some manufacturers recommend that all springs and screws be replaced along with the contacts.

Motor Protection Devices

Protective devices for motors should accomplish the following: closely simulate the motor's operating characteristics; permit non-damaging and temporary overload currents; protect against voltage imbalance and single phasing; provide current limiting to protect components for present and future fault currents.

Thermal type overload relays are used in most installations to protect the motor against overload currents or a sustained overload during normal operation. Initial inspection/maintenance should check for the following:

- Compensation for ambient temperature
- Proper size overload heater for the motor
- Service factor of motor
- Installation of power factor correction capacitors
- Type of reset - automatic or manual
- Setting of adjustable tripping range.

Protection is also necessary for unbalanced and single phasing of the three phase voltage supply. A few simple steps can be taken to ensure a well-balanced system:

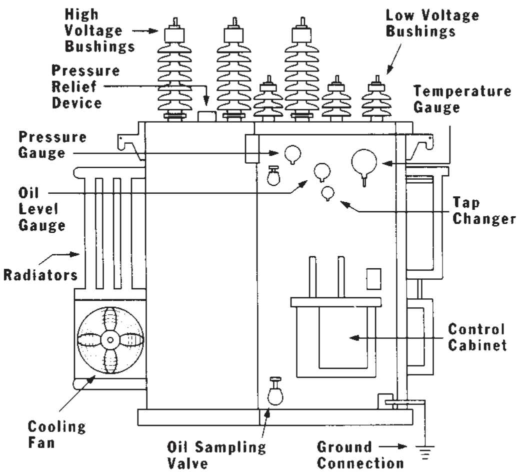
- Check the one-line diagram to see if single phase loads are distributed evenly
- Regularly check the voltages on each of the three phases to verify that minimum variation exists
- Check to see if a ground fault indicator should be installed

TRANSFORMERS

Transformer maintenance can be carried out either in-house or by an outside specialized service.

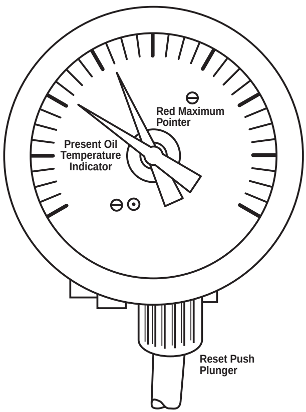
In-house inspection/maintenance should be done on at least a monthly basis. Things to look for are:

- ***Condition of the Transformer Surface:*** Rust and corrosion should be corrected; presence of oil may indicate gasket problems; radiator fins should be checked for defects.
- ***Oil levels:*** These may be shown by sight glasses or gauges; oil levels will rise as temperatures go up, so temperatures should be considered when readings are taken; the oil itself should be tested on a yearly basis (see Insulating Oil Analyses).



Transformer Layout

- ***Breathers:*** Silica gel types should be checked for pink or white discoloration, which indicates moisture saturation, and then dried out in an oven or replaced if necessary; conversion kits should be used on units without silica gel breathers to keep moisture out of the transformer.
- ***Pressure Relief Vent:*** A ruptured diaphragm or a popped-out indicator is a warning that the transformer has seen higher than normal internal pressures: caution must be taken during inspection because these devices tend to be close to high or low voltage bushings.
- ***Temperature Gauges:*** The oil temperature reading should be regularly recorded and compared against transformer loading. Large transformers sometimes have an additional winding temperature gauge mounted next to the temperature gauge. Usually the winding temperature should be higher than the oil temperature. Peak temperature indicators should be reset after value has been recorded.



Temperature Gauge

Temperature Gauge

- ***Pressure and Vacuum:*** A "zero" reading for an extended time on the pressure/vacuum gauge is an indication of leak in the system which should be corrected. The gauge should always show positive pressure. Moisture and dirt can be pulled into the oil if a vacuum develops.
- ***Tap Changers:*** The off-load changer handle should be locked at all times; if not seated properly on a position and energized, extensive damage can result; experienced maintenance personnel should be called upon to change voltage tap position. Off load tap changers should never be operated until the transformer is totally de-energized. On-load tap changers should only be adjusted by specialists, as the cam and limit settings are critical. It is important that tap changers be exercised regularly to prevent carbon build up on the contact surfaces.
- ***Bushings:*** If the bushings are equipped with sight glasses or level gauges, the oil level should be checked from ground level. Personnel should not attempt to get near the bushings to check the level.
- ***Cooling Fans:*** These should be operated in the manual mode to ensure all units are operating smoothly. If moisture or rust is present inside the fan control cabinet, the heater resistors inside should be checked for proper operation. All gaskets around the fan control cabinet should be in place and in good condition.
- ***Dry Transformers:*** Visual inspection of the core, coils and temperature gauge should be carried out; units in areas of high dust accumulation should be vacuumed and blown dry annually using dry compressed air (less than 30 PSI). Excessive dirt on the windings will encourage higher temperatures and also reduce efficiency. All work should be done when the equipment is de-energized and grounded.

- ***Insulating Oil Analysis:*** Transformer oil should be checked periodically to ensure it meets all specifications for dielectrics. acidity and free of water; if the oil tests poorly, specialized services are available for filtering, reconditioning or replacement. No oil samples should be taken from a transformer if the pressure gauge indicates a negative pressure (vacuum), as air could be drawn up into the coils.
- ***Gas in Oil Analysis:*** Certain gases are generated by common transformer problems, and as a result this kind of analysis is very popular because it provides an early indication of trouble; the analysis is conducted by laboratories which specialize in this area.
- ***PCB Content:*** Local environmental laws require that transformers with polychlorinated biphenyl (PCB) concentrations above certain levels be classified and protected by proper methods. More information on this is available from the provincial government. Testing for PCB content should be carried out prior to any other oil sampling or work on the transformer.
- ***Other Insulating Liquids:*** Includes specialized types such as silicon and fluids with very high levels of PCBs known by trade names such as Askerels, Inerteen and Pyranol. All require special fluid handling by outside specialists.
- ***Specialized Testing:*** Transformers must be de-energized and isolated. Dedicated equipment is required and experienced maintenance personnel should carry out these tests. The tests include:

  Megger Testing - Similar to that described under “A.C. Motors”, except readings are adjusted to 20@C, as indicated in the following table:

Temperature Correction Factors For Insulation Resistance (Corrected For 20˚C)			
Temp. ˚C	**Correction Factor**	**Temp. ˚C**	**Correction Factor**
0˚	0.25	40˚	3.95
5˚	0.36	45˚	5.60
10˚	0.50	50˚	7.85
15˚	0.74	55˚	11.20
20˚	1.00	60˚	15.85
25˚	1.40	65˚	22.40
30˚	1.98	70˚	31.75
35˚	2.80	75˚	44.70

Dielectric Absorption and Polarization Index Tests Similar to those described under "A.C. Motor". Oil-filled transformers should usually have a polarization index greater than 2.0.

Transformer Turns Ratio (TTR) Test - Determines the ratio of the transformer and can detect an open winding or a short-circuited winding. The ratio between phases of the same tap should be within 0.5 percent.

Insulation Power Factor Test - Detects problems in the quality of the insulating system that can lead to failures.

Other Tests - Include the following - Winding resistance; gas relay; core to ground test; polarity; pressure test; alarm; control and protection tests.

Substations and Switchgear

The substation and switchgear are critical components of an electrical system. The following preventive procedures are recommended:

Air Break Switches and Circuit Breakers

All air break switches and circuit breakers should be inspected, cleaned and exercised annually, and lubricated as recommended by the manufacturer.

An IEEE study showed that 75 percent of circuit breakers fail due to mechanical reasons.

Since the outdoor substation disconnects are exposed to the harsh environment, exercising annually is especially important.

In addition:

- All safety locks should be exercised and tested for proper operation
- Contact resistance should be tested with a low resistance micro-ohmmeter
- Electric tripping functions should be tested through selector switches and protective relays
- Outdoor substation ground connections should be inspected and ground resistance testing should be considered, especially in new or very old substations

Substations that utilize battery power supply for tripping circuits should have batteries and chargers serviced to ensure proper operation in the event of an overload or short circuit.

Low resistance test units capable of measuring micro-ohms, should be used to conduct resistance tests on circuit breakers.

Insulation resistance should be tested using a meg-ohmmeter.

Only flexible type burnishing tools should be used to clean contacts.

Insulators

All insulators on high voltage structures, and metal enclosed and metal clad switchgear assemblies, should be cleaned and inspected for tracking. Tracking develops in the form of streamers on the surface of the insulator that has an appearance similar to tree branches. If these marks can be removed by cleaning and no damage results to the porcelain, then the insulator can be re-used.

Conductive dust, found in some industries, will reduce creepage distance and can combine with water to cause arcing. This should be removed using approved cleaners, or can be washed while energized using a special water spray. In some areas of conductive dust, the insulators can be coated with a silicon gel.

Electrical Connections

All electrical connections on bus bars, cables and control circuits should be checked. All bolts should be torqued to their proper values. Extreme caution should be taken when tightening brass, copper or aluminum hardware.

Cell (Compartment) Heaters

All cell heaters should be checked for proper operation to prevent condensation. Ammeters can be installed in the circuit to provide personnel with convenient and visual confirmation of cell heater operation.

Lightning Arrestors and Surge Protectors

Lightning arrestors should be situated as close as possible to the equipment they are designed to protect. Ground and line connections should be tight, short and direct.

Lightning arrestors and surge protectors should be inspected periodically for overheating, and cracked or broken insulators. They should be kept free of dirt and other Foreign matter. Cracks or chips in the porcelain glaze can allow moisture to enter. When this moisture freezes and expands, it will produce breakage. Small cracks and chips can be repaired temporarily with epoxy.

Lightning arrestors must be disconnected from the power line and any stored capacitance must be discharged to ground prior to cleaning or any other work.

Cables and Bus Ducts

Periodic testing of cables should be carried out to check insulation levels. The testing should be done by experienced maintenance personnel to make sure that the insulation is not over-stressed.

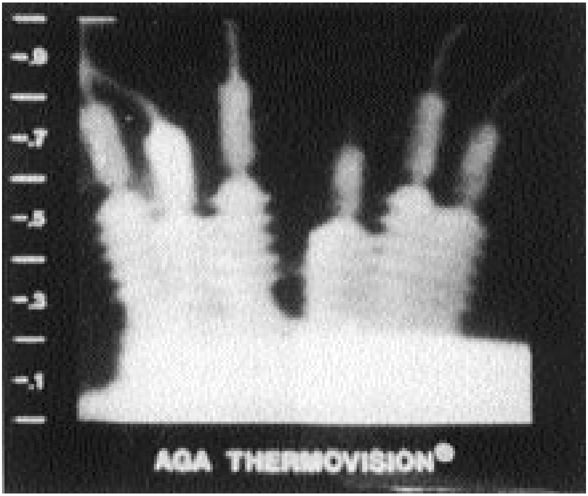
All associated stress cones and potheads on high voltage cables should be inspected for heating, leakage and proper ground connections.

Breaker Panels

Breaker panels, distribution panels, and service entrance equipment should be visually inspected and cleaned as common problems include airborne contamination by dust, dirt, chemicals and oil mist due to the surrounding environment and condensation. Inspect enclosure condition for signs of moisture, corrosion, damage or overheating. Check for missing knock out fillers or breaker filler plates. Inspect wiring and connections for signs of heating or damage. Clean and vacuum interior and exterior breaker panels and torque all connections. Maintain molded breakers by exercising them several times.

Thermographic Inspection

Infrared scanning is an excellent tool for troubleshooting the complete electrical system, especially the serious problems that can result from poor contacts, improper connections, blown fuses, overloading or any other higher than normal temperature situations.



Thermographic Picture

It allows maintenance personnel to actually see and photograph hot spots - an obvious benefit since many electrical problems are initially characterized by rising temperatures.

Thermographic surveys are made with portable equipment capable of scanning considerable areas rapidly and taking stop-action photographs (thermographs) to provide records and identification. The equipment usually consists of a handheld camera (scanner) and a video display.

The best time to make a thermographic survey is during regular operations and under full load conditions. Using the survey to make the diagnosis of maintenance problems will enormously increase the effectiveness of the maintenance program.

Thermographic surveys should be carried out by an outside company which specializes in this area and has had relevant experience in the electrical field.

Relay Protection and Fuse Protection

Maintenance of a relay system should include an annual operational check, calibration and cleaning. Dirt in the relay, either on the disc or between the contacts, will cause the relay to slow down or not function at all. This in turn could cause the next relay in the protective system to cause a much larger shutdown than necessary.

Electronic relays are usually less likely to go out of calibration and less susceptible to dirt. They normally need only be checked every other year.

Fuses in substations, switchboards, panel boards and motor control centres should be checked for proper size, application and interrupting ability. Code-type fuses, such as "one-time" or "renewable", should be used only if the fault levels have been calculated and are less than the fuses' interrupting rating.

Loose fuseclips are a major source of hot connections and should be checked. Outdoor fuseholders should be checked annually for proper freedom of movement.

Coordination and Short Circuit Studies

It is essential that the tripping sequence of an operation's electrical protection system be coordinated to ensure that the preferred relay sends a trip signal when a fault occurs.

A thorough coordination study should include a review of the short circuit ratings of the electrical equipment at all locations.

Capacitors

Capacitors used in power factor correction applications normally require very little maintenance. Basically, all that is required is the following:

- Check current ratings with a clip-on ammeter to determine whether they are operating at the proper level. If not, look under the cover for blown fuses. Harmonics generated by solid state rectification can blow protective fuses.
- Check all power connection leads and safety ground connections for tightness.
- Look for signs of leaking fluid in liquid-filled units.
- Keep ceramic bushings and other insulators clean.

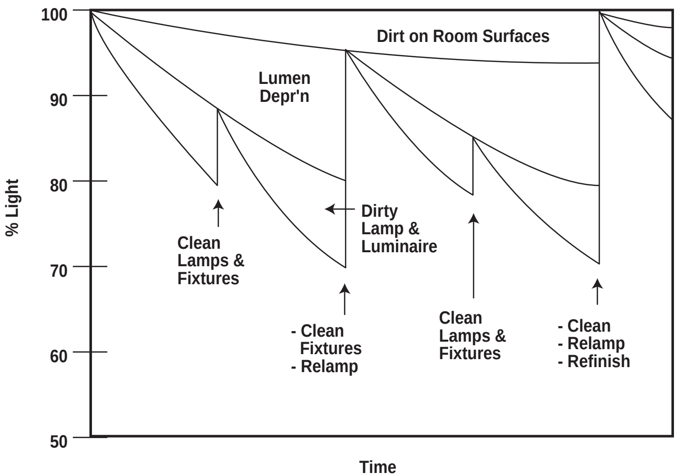
Extreme care should be taken to ensure capacitors are discharged prior to starting any work. Capacitors are capable of storing large charges - even when not in use or disconnected.

Some older capacitors are liquid-filled and may contain polychlorinated biphenyls (PCBs).

LIGHTING

Lighting is often overlooked in preventive maintenance programs, even though it accounts for anywhere from 12 percent to 40 percent of industrial load.

Regular maintenance of lighting consisting of regular cleaning of fixtures and lamps, and proper relamping should be an element in any preventive maintenance program. The result of an effective maintenance program can be seen in the chart.



Light Emitted During Effective Maintenance

Regular cleaning of lamps and fixtures is necessary to keep illumination at an acceptable level. Cleaning once every two years in an air conditioned office is usually sufficient, as is once a year for general assembly and machine shops. In dirty locations such as foundries, cleaning intervals of three or four times a year in necessary to maintain good lighting efficiency.

Relamping is important because the light output of most lamps decreases as they burn, and as a consequence they should be replaced at the point where they begin to experience the steepest deterioration. Information of lamp light depreciation rates is available from manufactures.

Solid State Control Equipment

An increasing number of companies are making use of programmable logic controllers (PLCs), computers, digital control equipment, variable speed electronic drives, numerical control machines, and other solid state control equipment.

Preventive maintenance for this kind of equipment includes the following:

- Maintenance software and on-line diagnostics to run tests on all parts of the system
- Replacement circuit boards, numbered or colour-coded for easy replacement
- Inspection of cooling fans for proper operation
- Cleaning of filters when necessary
- Installation of flow switches on fans to alarm when air flow stops
- Special maintenance on the cooling circuit and water treatment in water-cooled systems
- Checking all connections and groundings to eliminate breakdown problems

Other Vulnerable Areas

The following pieces of apparatus are often overlooked during routine maintenance procedures:

- Stand by generators, including the electrical transfer switch
- Stand by fire pumps and their associated controller
- Battery banks and chargers
- Alarm systems

OTHER IN-HOUSE REFERENCE GUIDES:

- Adjustable Speed Drives
- Fans
- Energy Monitoring & Control Systems
- Lighting
- Lighting Substitution
- Motors
- Power Quality
- Power Quality Mitigation

COMMENTS:

For any changes, additions and/or comments call or write to:

Scott Rouse
Project Manager
Ontario Hydro
700 University Avenue, H10-F18
Toronto, Ontario
M5G 1X6
Telephone **(416) 592-8044**
Fax (416) 592-4841
E-Mail srouse@hydro.on.ca

In-House Energy Efficiency

Energy Savings are Good Business

"The sun represents sustained life
while the lightning bolt depicts energy. The integration represents the perfect partnership of energy utilization and the environment that encourages wise use and respect for all natural resources. The roof represents the in-house aspect of energy efficiency throughout Ontario Hydro."

Marcel Gauthier
Georgian Bay Region - Retail

Printed on recycled papers

Ontario Hydro