NEWFOUNDLAND POWER
A FORTIS COMPANY

Infrared Thermography Inspection Guidelines

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POLICY STATEMENT

Scheduled infrared thermography inspections shall be undertaken on all major components of the power system to provide safe and reliable operation in a cost effective manner. Regional Managers will be responsible for the required transmission, substation and distribution system inspections. The Manager of Energy Supply will be responsible for the inspections of the generation related equipment.

The results of these inspections and the maintenance work that is completed to correct any deficiencies will be recorded in the Company's computerized maintenance management system.

APPLICABLE INTERNATIONAL STANDARD

ASTM standard E 1934 - 99a (Standard Guide for Examining Electrical and Mechanical Equipment with Infrared Thermography)

INSPECTION PROCEDURES

Inspection Frequency

1. Distribution Feeders

i. Trunk Feeder Primary system

The primary connections, voltage regulators, reclosers, sectionalizers, capacitors, and switches, should be inspected at least once every two years along the trunk feeder section of distribution lines. The trunk feeder system includes at least the primary from the Substation to the first set of fused sectionalizing devices. Trunk feeder should also include the supply to large load centers and critical customers that are beyond fused sectionalizing devices.

Heavily loaded feeders and feeders containing a significant number of sensitive customers may be inspected annually.

ii. Primary system beyond Trunk Feeder

Primary systems beyond the Trunk Feeder, including Pole mounted Transformers and min pad mounted transformers will be inspected as deemed necessary by the Superintendent of Area Operations.

iii. Pad mount and Vaulted Distribution Transformers

All three-phase pad mount and distribution transformers in vaults should be inspected on a two-year cycle.

iv. Secondary system including meter sockets

Individual secondary systems will be inspected as deemed necessary by the Superintendent of Area Operations.

2. Transmission Lines

Individual transmission lines will be inspected as deemed necessary by the Superintendent Area Operations.

3. Substations, and Power Generation Plants

All Substations, and Power Generation Plants should be inspected annually.

4. Commission of Electrical Equipment

All installations of portable substations and portable generation should be inspected as part of the commissioning procedure.

Inspection Process

Infrared inspection provides thermal data about a structure, system, object or process. Determining if the thermal data shows abnormally warm or cool object ("anomaly") that requires repair is often referred to as an art as oppose to a definitive science. The primary factors that are used in assessing the condition of equipment are the equipment's current temperature, ambient conditions, equipment loading (mechanical or electrical), equipment rating, and normal operating condition of the equipment.

Inspections should occur when the electrical loading on equipment is at least 40% of maximum forecast annual demand and when weather conditions are favorable for gathering accurate data.

The process of inspecting equipment is as follows:

1. Measure the ambient temperature.
2. Complete infrared examination of object and record thermal image as required.
3. To the extent necessary, adjust surface temperate measurement to account for electrical loading and wind effects and check object size and distance.
4. Compare thermal image to what is considered normal.
5. Investigate any "anomalies".
6. Assign repair priority.

1. Ambient condition is the temperature of the air surrounding the equipment. This is measured with a thermometer. This information is input into the infrared camera.

2. An infrared examination required the use of infrared imaging tools and must take into account a variety of factors such as, solar gain, surface emissivity, reflection, level and span. When a thermal anomaly is discovered, record the thermal image and a visual photo for further examination. Also, when necessary, a thermal image base line for the object should be captured for comparison to future examinations.

3. When it is necessary to determine the accurate temperature of a specific anomaly it is often necessary to adjust measurements for conductor loading, and wind. Also the object size and the distance to the object will need to be considered. Guidelines to account for electrical loading, wind speed and object size are discussed in appendix A.

4. Comparing the measured temperatures to normal operating conditions depends on the type of object being inspected. Examples of two situations are discussed below:

- Assessing normal conditions for connectors usually involve comparing the temperature to the adjacent conductor. If there is a temperature difference between the connector and the conductor, there is likely some problem with the connection and depending on the extent to the temperature rise, the connection should be repaired or replaced.

  If the connector and the adjacent conductor are both operating at a high temperature, the conductor and connectors may be either overloaded or simply operating under normal conditions. To determine if the conductor and connector are overloaded, current load and estimated maximum load should be checked against conductor ratings. If the conductor load does not explain the heating, a careful physical / visual examination of the conductor should be completed.

- Assessing the normal conditions of major equipment such as transformers, breakers, motors and generators, will require baseline infrared images of the equipment. Comparison of the images will allow assessment of the condition of the equipment.

5. Assessing the temperature anomaly of major equipment will often require a review of the images by engineers and maintenance personnel. Equipment such as transformer bushing may require careful infrared inspections from various angles to fully assess the source of the heat.

6. Repair priorities are determined through a variety of factors.

- Visually observable deterioration of object and presence of questionable noise or smells.
- Difference in the temperature of object from what would be considered normal.
- Likelihood of component failure
- Potential Impact failure would have on customers.
- The cost and risk to overall system if the component fails
- The costs associated with the repair

Assigning repair priorities is a very critical step in ensuring the efficiency and effectiveness of the thermography program (See Appendix B). To best develop experience in assigning priorities, the inspector should, from time to time, review repair priories with operating and maintenance staff, and physically examine objects during and after repairs is made.

Appendix B provides some guidelines that can assist in determining repair priority.

MAINTENANCE PROCEDURES

Upon completion of an inspection, scheduled preventative maintenance shall ensure the system maintains a high degree of integrity and reliability. This section establishes guidelines for maintenance procedures.

Regional Managers will be responsible for the required transmission, substation and distribution system repairs. The Manager of Energy Supply will be responsible for the repairs of the Generation related equipment.

Maintenance Classification

Abnormally warm or cool connectors, conductors or other objects ("anomaly") identified through inspection process will be given one of four classifications based on the nature of the abnormal condition. Unless otherwise stated or directed, the response times should be as shown in Table 1.

Table 1: Repair Priorities

CLASSIFICATION	RESPONSE TIME
Emergency Immediate security of the line / equipment is at risk	Immediate
Priority 1 Defects which if left could result in an interruption	One Month (approximately)
Priority 2 Defects of less consequence	Within 12 months
Priority 3 Defects of minor concern: no repairs necessary	Continue to monitor condition for possible upgrading of classification

Defects defined, as emergency shall be reviewed within 24 hours of identification for the purpose of initiating repairs immediately or downgrading the reported condition. This review may require a second visit by designated operating personnel.

WORK METHODS

Infrared inspection requires the inspector to take pictures of equipment while energized and operating under normal conditions. This may expose the inspector to risks from rotating machines, pressurized pipes and energized conductors. These risks are compounded by potential loss of depth perception that may occur while operating a camera. As such the worker must be fully aware of the risks associated with his surroundings and be fully knowledgeable of the Company's health and safety standards. When necessary an assistant will be assigned to ensure the safety of the camera operator.

REPORTING and TRACKING

The recording of infrared images will be through standard report formats. The standard reports will contain all information required for baseline thermal images of major equipment and sufficient information for facilitating the repairs.

Each Region and the Energy Supply Department will be responsible for maintaining database / listing of images for future reference.

Each Region and the Energy Supply Department will be responsible for logging and tracking repairs in the Company's computerized maintenance system.

INSPECTOR TRAINING QUALIFICATIONS

Personnel selected for completing infrared inspections will normally be required to complete a formal Level 1 Infrared Inspection Training Course. The only exception is inspectors selected to complete distribution line inspections only. They can complete inspections after training by a Company Specialist.

It is preferred that all inspectors obtain and maintain Level 1 Infrared Inspection Certification. Any inspector who does not have or maintain certification will need to have their images periodically reviewed by Company Specialists.

The Company will maintain at least one Specialist that will obtain and maintain a Level 2 Infrared Inspection certification. The Specialist(s) will be responsible for ensuring the quality of the inspector images, the maintenance and calibration of cameras, the development of standard reporting templates, and the purchasing of new infrared thermography equipment.

EQUIPMENT MAINTENANCE

All infrared thermal imaging equipment shall be maintained and calibrated according to manufacturer instructions.

Appendix A: Compensation Factors

I. Compensating for Electrical Loading

When evaluating an infrared image of electrical equipment the effect of electrical load can be taken into account with the following equation. Normally, it is not recommended to conduct thermographic inspections when the electrical system load is below 40 percent of expected Full Load.

Load Corrected Delta T = (Delta T) / (percent of Full Load) ²

Where: Delta T is the measured temperature rise above ambient

II. Compensating for Wind Effects

During outdoor inspections the cooling effect of wind must be taken into account. Normally, it is not recommended to conduct thermographic inspections with winds in excess of 8 m/sec (approx. 28 km ph or 18 mph).

Wind Corrected Delta T = Delta T * Correction Factor

Where: Delta T is the measured temperature rise above ambient

The table below shows the correction factor for wind speeds from 1 to 8 m/s.

WIND SPEED			
m/s	**mph**	**km ph**	**CORRECTION FACTOR**
<1	**<2.24**	**3.6**	**1.00**
2	**4.48**	**7.2**	**1.36**
3	**6.72**	**10.8**	**1.64**
4	**8.96**	**14.4**	**1.86**
5	**11.2**	**18.0**	**2.06**
6	**13.4**	**21.6**	**2.23**
7	**15.7**	**25.3**	**2.40**
8	**17.9**	**28.8**	**2.50**
9	**20.1**	**32.3**	**2.61**

(OR MORE) - MEASUREMENT NOT RECOMMENDED

Example:

An anomaly of 5^{o}C (Delta T) is identified on a Nema Pad, the load is approximately 40% of anticipated peak for the winter and the wind, at the time of the inspection is approximately 15 kmph.

Question:

What would be the expected Delta T when the peak load occurs? What would the temperature be if peak load occurred on a calm day.

Answer:

i. Correction for Loading:

Delta T = measured delta T / (per cent of full load)^2
= 5 / (0.4)^2
= 31.25^{0}C

ii. Correction for Wind Speed

Delta T = Delta T X correction factor at 15 kph
= 31.25 X 1.86
= 58.13^{0}C

The temperature under calm conditions at peak load would be 58.13^{0}C

III. Checking Object Size and Distance

To accurately measure the temperature of an object, the object must be larger than the size of a single detector element as superimposed on the object (spatial resolution). The extent to which the object must be larger than the spatial resolution is related to many factors including optics, and the electronics of the camera for which data from manufacturers is not readily available. The environment between the camera and the object also impacts the measurement.

Spatial Resolution is often defined as the Instantaneous Field of View (IFOV) and is expressed as an angular measurement expressed in milliradians (mrad) (one thousandths of a radian). The following equation can be used to determine the maximum distance from which a hot spot of a particular size can be viewed.

Maximum Distance from Object
= Object size / TAN(IFOV) / Misc. Factor

Where	Object Size	- approx width or height of object (which ever is less)
	TAN()	- Tangent Function
	IFOV	- Supplied by Manufacturer, (Varies between Camera Lenses)
	Misc. Factor	- Use 1.3 to account for aiming errors and instrument imperfections

Example: Determine how close you need to be to a 1cm hot spot to get a reasonable accurate measurement. The IFOV for a 24 deg lens on an Agema 695 camera is 1.3 mrad.

Maximum Distance to Object
= Object size / TAN(IFOV) / Misc Factor
= 1 / TAN(.0013) / 1.3
= 5.9m

Appendix B: Guidelines for Classifying Anomolies[1]

Table 1 provides guidelines for determining the repair priorities for connection related problems only. All anomalies associated with major pieces of equipment should be considered a high priority and the appropriate engineering / maintenance staff should be alerted to the anomaly as soon as it is found. The priority for the repair will then be set by the subsequent investigation.

Table 1: Repair Priorities for connection related hot spots

ITEM	EMERGENCY	PRIORITY 1	PRIORITY 2	PRIORITY 3
Bare bolted, crimped or soldered connection	△T > 100°C	100°C >△T > 50°C	50°C >△T > 25°C	25°C >△T > 10°C
Taped or Insulated connection	△T > 50°C	50°C >△T > 25°C	25°C >△T > 15°C	15°C >△T > 10°C
Conductor – Candy Striping		Candy Striping indicates welding has occurred		
Hot Line Clamps		△T > 5°C		

Table 2 provides information on normal equipment thermal signatures. This table can be used to assist thermographers in identifying anomalies.

Table 2: Normal Thermal Signatures for Electrical Equipment

ITEM	NORMAL THERMAL SIGNATURE	NOTES
Bushing	Operates at ambient	Any heating suggests a poor connection of fault inside bushing
Capacitors	Operates above ambient	Should compare capacitors to check for anomalies.
Circuit Breakers	Operate at ambient except at CTs within bushings	CTs in each bushings should be equally warm. Any other temperature rise should be treated seriously.
Conductors	Operates above ambient	Extent of normal heating is dependant on load, conductor size and wind speed. Constant non-unitform heating may indicate broken or deteriorated strands
Lightning arrester	Operating at ambient	Any heating suggest arrester is conducting electricity. This indicates unit is deteriorating and should be replaced.

1 – Ranking of Anomalies is dependent on many factors and as such relies heavily on experience for inspector. As the Company gains more experience these guidelines will need to be updated. Ranking anomalies for large equipment often requires comparison between pieces of equipment or comparison with previous inspections of same piece of equipment.

Table 2 Normal Thermal Signatures for Electrical Equipment (cont'd)

ITEM	NORMAL THERMAL SIGNATURE	NOTES
On-Load Tap Changer	Slightly below temperature of transformer	Tap changer should be investigated if compartment at higher temperature than transformer.
Transformer	Operates above ambient temperature	Temperatures to be compared to manufacturers rating. Baseline images will assist in assessing transformers. Inspection should look for blocked radiators.
Current Transformers	Will operate between 0 and 15^{o}C above ambient	Compare to other equally loaded CTs to assess condition
Potential Transformers	Slightly above ambient	Compare to other PTs.