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Standard Guide for Examining Electrical Power Distribution Equipment with Infrared Thermography

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1. Scope

1.1 This guide lists the responsibilities of the owner and the infrared thermographer when examining electrical power distribution equipment. Such equipment includes:

1.1.1 Panelboards and equipment control panels, switchboards and equipment control panels with molded case or insulated case circuit breakers; enclosed electrical bus and bus plugs, motor control centers (MCCs), motors, switchgear (with power circuit breakers or fused switches), substations, and other electrical equipment.

1.1.2 While the principles of this Guide apply, additional special techniques and equipment may be required when conducting examinations of electrical equipment out-of-doors in substations and for overhead lines.

1.2 This guide recommends procedures to conduct and document infrared examinations of electrical power distribution equipment.

1.2.1 Examinations of electrical equipment operating at voltages in excess of 600 volts may have special requirements, especially for safe access; some of these are addressed in documents NFPA 70E and NFPA 70B, listed below.

1.3 This guide involves exposure to and the use of equipment in the presence of electrically energized equipment, which presents potential hazards due to electrocution and arc-flash.

1.3.1 This guide recognizes the inherent hazard associated with examining energized electrical equipment. It is the responsibility of the owner to ensure that all personnel are properly trained and qualified and that appropriate safety precautions are observed.

1.3.2 The American Society for Nondestructive Testing (ASNT) standard SNT-TC-1A provides specific and recommended guidance for minimum qualifications and training of personnel involved in infrared thermography. All work should be conducted only by qualified personnel.

1.3.3 The National Fire Protection Association (NFPA) 70E “Standard for Electrical Safety in the Workplace”, provides specific requirements and guidance regarding electrical risk hazard assessment and personal protective equipment requirements when working inside arc flash protection boundaries. This information should guide all examination work.

1.3.4 The National Fire Protection Association (NFPA) 70B ”Recommended Practice for Electrical Equipment Maintenance” provides additional, useful guidance on the maintenance of electrical systems, including the use of infrared examinations for the maintenance process.

1.3.5 This guide does not purport to address all safety concerns, as many safety concerns are specific to the circumstances. As such, it is the responsibility of the owner to ensure that all persons involved in this work are properly trained and qualified to perform this work in the owner's facility.

1.4 While this guide may also be useful when using non-imaging radiometers to conduct examinations, it specifically addresses examinations conducted using infrared *imaging* equipment, either radiometric or non-radiometric.

2. Referenced Documents

2.1 *ASTM Standards*:

2.1.1 E1316 Terminology for Nondestructive Examinations

2.2 Code of Federal Regulations 29

2.2.1 Part 1910 Safety and Health Regulations for General Industry

2.2.2 Part 1926 Safety and Health Regulations for Construction

2.3 National Fire Protection Association: NFPA 70 National Electric Code

2.4 National Fire Protection Association: NFPA 70B

2.5 National Fire Protection Association: NFPA 70E

2.6 American Society for Nondestructive Testing: ASNT SNT-TC-1A

2.7 American Society for Nondestructive Testing: ASNT/ANSI CP-189

3. Terminology

3.1 Anomaly: a system or component that is not functioning within acceptable limits; this may be, but is not always, indicated by a temperature difference.

3.2 Blackbody: the ideal, perfect emitter and absorber of thermal radiation. It emits radiant energy at each wavelength at the maximum rate possible as a consequence of its temperature, and absorbs all incident radiance.

3.3 Blackbody reference: a calibrated, traceable device used to check the calibration of an infrared imaging radiometer or spot radiometer

3.4 Finding: a component or system, whether anomalous or normal, that has been documented with a thermal image

3.5 Infrared system: an electronic camera used to detect emitted thermal energy; also called a thermal imaging system

3.6 Owner: the party responsible for the operation of the electrical systems and components

3.7 Qualified escort: the person assisting the thermographer, typically by locating equipment, opening enclosures, making load readings, and securing the equipment after the examination, among other activities

3.8 Qualitative infrared examination: an examination that does not include radiometric temperature data but does provide thermograms showing thermal relationships

3.9 Quantitative infrared examination: an examination that records radiometric temperature data provided by a thermal imaging system

3.10 Radiometric temperature measurement: the measurements made using an infrared system by correlating the radiation emitted by a surface with its temperature; such data must be corrected for emissivity, transmissivity and reflected background temperature

3.11 Spot radiometer: a non-imaging device that detects infrared radiation

3.12 Thermogram: the image produced by a thermal imaging system showing the thermal relationships of the equipment being examined.

3.13 Thermographer: a person who is qualified to conduct an examination using a thermal imaging system.

4. Summary of Practice

4.1 There are two primary benefits of conducting an infrared examination of an electrical system:

4.1.1 To validate that the electrical systems and components are operating within acceptable limits as determined by owner.

4.1.2 To detect thermal anomalies associated with abnormal conditions in the electrical system and/or components that might result in adverse operations, equipment damage, system failures or unscheduled outages.

4.2 In some cases, quantitative radiometric temperatures of components may provide useful data. Special care must be exercised when examining low emissivity (for example, reflective metal) surfaces.

4.3 The infrared examination is conducted typically on energized, exposed electrical components; appropriate safe work practices must be used at all times.

4.4 It is essential that certain conditions exist for the results to be considered valid, including, among others, having the system energized and loaded, having a clear line of sight of the components, and ensuring that the effect of ambient conditions on heat transfer relationships is fully understood.

5. Significance and Use

5.1 This guide can be used by an owner to specify how an infrared examination of electrical equipment shall be conducted and who is qualified as an infrared thermographer (ref 1.3.2) to perform such examinations.

5.2 The purpose of infrared examinations of electrical equipment is to document the "as-found" condition of the equipment. When this involves the identification of anomalous components or systems, further measures or testing are generally required to fully understand the root cause of the anomaly, or to correct problems before failures occur, or when appropriate to "run to failure," to minimize consequences.

5.3 Anomalies in electrical components can be generally grouped in one of two categories:

5.3.1 Abnormal electrical resistance at points of electrical contact, such as connectors and switch mechanisms, which is typically caused by loose or deteriorated connections, improperly installed components, corrosion, and metal fatigue.

5.3.1.1 Thermal signatures for these types of anomalies will typically be warmer than normal at the high-resistance contact point with diminished temperatures as distance increases from that point.

5.3.2 Overloads on undersized conductors or circuits and abnormal load imbalances.

5.3.2.1 Thermal signatures for these types of anomalies will typically be equally warmer (or occasionally equally cooler) than normal throughout the entire circuit, phases or portion of the system affected by the anomalous condition.

5.3.3 In addition, equipment may be located that is anomalous but cooler than normal as a result of failed or inoperable components.

5.4 Mechanical failures, such as misalignment, unbalanced loads, improper lubrication, corrosion or excessive wear of parts and components, may also have an impact on the electrical systems associated with them.

5.5 System or component failures often result in substantially higher repair costs compared to identifying the anomaly prior to failure and remedying the condition on scheduled downtime rather than incurring unexpected breakdowns.

5.6 These failures can also result in increased risk of substantially greater loss of plant equipment and production capabilities as well as putting personnel at risk.

6. Personnel Responsibilities

6.1 The Owner shall

6.1.1 Establish an inventory list of the equipment to be examined.

6.1.2 Provide a qualified escort to accompany the thermographer, for the purpose of, among other duties:

6.1.2.1 Locating equipment and ensuring its safe examination

6.1.2.2 Opening/Closing electrical panels

6.1.2.3 Removing/replacing protective covers

6.1.2.4 Measuring electrical loads

6.1.2.5 Assisting in assessing the presence and criticality of anomalies and recommended remedial actions

6.1.3 Meet with the thermographer and the qualified escort assigned to the thermographer, to review the equipment scheduled for examination and ensure that all required safety practices have been met and required personal protective equipment is provided.

6.1.4 Shall issue an "Energized Electrical Work Permit" in accordance with the recommendations of NFPA 70E when working on energized electrical equipment.

6.1.5 The owner shall assume full responsibility for consequences resulting from actions taken, or not taken, as a result of data provided by an infrared examination.

6.2 The infrared thermographer shall:

6.2.1 Possess certification of adequate knowledge and training in the practice of infrared thermography, as defined in ASNT SNT-TC-1A, for the duties they are assigned:

6.2.1.1 Level I thermographers may perform examinations, collect data, and, as appropriate, make evaluations based on specific, written "pass/fail" criteria.

6.2.1.2 Level II thermographers may perform examinations, collect data, analyze data and prepare reports. Level II competency is recommended for determination of emissivity and most radiometric temperature measurements.

6.2.2 Possess certification of adequate knowledge and training in safety practices associated with working on energized electrical equipment (NFPA 70E), and adequate knowledge and training as required by the owner for necessary familiarity with their facility, operations and equipment.

6.2.3 Verify the owner's designation of the flash protection boundary and if the boundary is to be crossed, use appropriate personal protective equipment.

6.3 Unless the thermographer is qualified, the thermographer shall not:

6.3.1 Cross the restricted approach boundary

6.3.2 Remove or replace panel covers or open or close electrical cabinets containing energized electrical components

6.3.3 Measure electrical loads

7. Procedure

7.1 Equipment to be examined shall be under adequate load; ideally this is "normal operating" load or, when appropriate for validation testing, under "worst-case" loading.

7.2 If loading is light and likely to increase in the future, particular care should be given to documenting any abnormalities; in these conditions, some abnormalities may be below the threshold of detection.

7.3 Equipment shall be externally examined before removing any protective covers to determine the possible presence of internal heating. If abnormal heating is suspected, the owner or qualified escort should take appropriate remedial action.

7.4 Enclosures of electrical equipment shall be opened for direct examination wherever practical and safe.

7.5 As an alternative, consideration may be given to conducting the examination through "windows" that are transparent to detected infrared radiation or to "ports." Safety procedures should be modified to accommodate this task. Care must be taken to insure that all equipment can be seen and special lenses may be required.

7.6 Thermographic examinations shall be made using an infrared imaging system, producing a thermogram for documenting, ideally, *any* components or systems that are not operating normally.

7.6.1 Every effort shall be made to ensure the thermal image is in sharp focus; failure to do so can render further analysis difficult and may mean radiometric temperatures, if measured, are inaccurate.

7.6.2 Thermal images shall be stored, preferably at bit depths of 12-bit or greater, on electronic media.

7.6.3 When appropriate, corresponding visual images shall also be recorded, either with a visual camera integral to the infrared system or on a separate visual camera

7.6.3.1 Visual images shall be properly exposed to ensure adequate detail is available. Particular attention should be given to perspective, focus, contrast, resolution and lighting

7.6.3.2 Visual images shall align with the thermal image as closely as possible

7.7 Thermograms shall be recorded of all anomalies, and, when deemed necessary, of normally operating equipment or components as well.

7.8 Spot radiometers are not recommended for locating anomalies but, when properly used, they may sometimes be employed to measure radiometric temperatures.

7.9 All findings shall be documented by appropriate nameplate data, equipment location, a visual photograph of the equipment and a corresponding thermogram of the anomaly.

7.9.1 The date and time of the observation shall be recorded, preferably as part of the thermal image.

7.9.2 Where possible or practical, the rated and measured electrical load associated with an observed finding should be recorded.

7.9.3 Environmental and ambient conditions associated with the finding shall be measured and recorded. Environmental conditions include:

7.9.3.1 Correction values for surface emissivity and reflected background temperature

7.9.3.2 Ambient air temperature

7.9.3.3 Wind speed and direction, solar loading and other external radiant heat sources

7.9.3.4 Care should be taken to work within the limits of both spatial and measurement resolution for the infrared system being used. Supplemental telephoto lenses may be required for some kinds of work, such as out door substations or overhead lines.

7.10 A method to determine a repair priority should be agreed upon by the thermographer and owner. Prioritization of findings should take into account any observed thermal differences and should also consider the impact on personnel safety, the criticality of the equipment, present and future thermal relationships, and productive operation of the equipment and/or the facility.

7.11 An example approach to prioritizing findings for repair is to ask the following questions. If any of them are answered in the affirmative, the finding is categorized as a Priority 1, requiring immediate action; this might include such actions as repair, schedule for repair, reduction of temperature by increased cooling or load reduction, or further testing to determine root cause, etc.

7.11.1 Is the phase-to-phase temperature difference greater than 24C (43F)[1]?

7.11.2 Is the absolute temperature greater than 100C (212F)[1]?

7.11.3 Is convection greater than 24kph (15mph)? [2]

7.11.4 Is physical damage, such as melting or discoloration, evident?

7.11.5 Is component shiny flat or tubular bus?

7.11.6 Thermal gradients are large or moderate[3]

7.11.7 Are loads likely to increase by 3X or more prior to repairs?

7.11.8 Notes:

7.11.8.1 [1]For measurements that are reliable, i.e. high emissivity surfaces

7.11.8.2 [2]Convection measured at the component surface

7.11.8.3 [3]Massive, solid connector, indirect connections such as bus stabs, or any oil-filled or gas-filled equipment

7.12 If none of these questions are answered "yes," component should be scheduled for further investigation and/or more frequent thermographic inspection cycle.

8. Report

8.1 The infrared thermographer shall provide a detailed report of the thermographic examinations. This report shall include:

8.1.1 Complete identification of the equipment examined and its location information.

8.1.2 A comprehensive report for each observed anomaly, including the information collected in Section 7.

8.1.3 When relevant, the history of any previously found anomalies associated with the particular component or system (NFPA 70B). Trending of an anomaly over time, while useful, must be done only with great care as many factors can cause thermal patterns to change.

8.1.4 Suggestions for repairs and corrective actions, as appropriate. An infrared examination displays the current condition of equipment, usually indicating the presence of an anomaly, but is not diagnostic and therefore does not indicate the specific cause of the anomaly. Suggested corrective actions shall not be construed to be a diagnosis, as the actual cause is often discovered later during the repair.

8.2 Anomalies should be re-examined following completion of corrective actions to verify that operations are within acceptable limits. The component condition should be documented with a new thermogram and incorporated into a written report in accordance with the requirements of Sections 7 and 8.

8.3 Equipment scheduled for examination but not available should be noted and re-scheduled for later examination rather than being passed over until the next inspection cycle occurs.

9. Precision and Bias

9.1 The infrared thermographer shall perform a calibration check on a regular basis, depending on needs.

9.1.1 For many circumstances daily calibration checks of some type are warranted

9.1.1.1 A simple equipment functionality check can be made by measuring the temperature of a known, high-emissivity reference.

9.1.1.2 A more rigorous calibration check is often warranted using a calibrated, traceable black body reference standard.

9.1.1.2.1 Records of calibration checks should be kept

9.1.1.2.2 When the infrared system fails to comply with manufacturer's specifications for calibration, consideration should be given to having the manufacturer perform a re-calibration. Calibration shall include all lenses and filters being used.

9.1.1.2.3 The functionality of infrared systems being returned to service after re-calibration by the manufacturer shall be checked prior to being used for an examination.

9.1.1.3 Annual calibration by the manufacturer *may* be warranted, but should not be considered as a substitute for regular functionality checks.

10. Keywords

10.1 Electrical, infrared, thermography, heat, radiometric, non-radiometric, spot radiometer, calibration, safety, maintenance, condition monitoring