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# Table of Contents

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrared Safety</td>
<td>1</td>
</tr>
<tr>
<td>Paul Hartman</td>
<td></td>
</tr>
<tr>
<td>Infrared Thermography, Temperature Measurement, and Repair Priorities</td>
<td>4</td>
</tr>
<tr>
<td>John Snell</td>
<td></td>
</tr>
<tr>
<td>Make High-Voltage Electrical Equipment Inspections Safer and Faster</td>
<td>13</td>
</tr>
<tr>
<td>with Infrared Sightglasses</td>
<td></td>
</tr>
<tr>
<td>Antony Holliday</td>
<td></td>
</tr>
<tr>
<td>Infrared Thermography: A Better Tool Than Ever!</td>
<td>16</td>
</tr>
<tr>
<td>John Snell</td>
<td></td>
</tr>
<tr>
<td>Frequent Infrared Inspections of Electrical Cabinets Made Easy and</td>
<td>19</td>
</tr>
<tr>
<td>Inexpensive with Newly Approved UL-Device</td>
<td></td>
</tr>
<tr>
<td>Jon Chynoweth</td>
<td></td>
</tr>
<tr>
<td>Fine Tune Your Infrared Thermography Skills</td>
<td>22</td>
</tr>
<tr>
<td>Bernard R. Lyon Jr. and Robert P. Madding</td>
<td></td>
</tr>
<tr>
<td>Defining the Elements for Successful Infrared Thermography</td>
<td>26</td>
</tr>
<tr>
<td>R. James Seffrin</td>
<td></td>
</tr>
<tr>
<td>Infrared Thermography for Cost-Effective Utility Service Reliability</td>
<td>29</td>
</tr>
<tr>
<td>Travis Curtis</td>
<td></td>
</tr>
<tr>
<td>Infrared Thermography: Yesterday and Today</td>
<td>35</td>
</tr>
<tr>
<td>John Snell</td>
<td></td>
</tr>
<tr>
<td>Infrared Inspections and Applications</td>
<td>38</td>
</tr>
<tr>
<td>Don A. Genitis</td>
<td></td>
</tr>
<tr>
<td>Electrical Inspections with the Use of Infrared, Ultrasound and</td>
<td>42</td>
</tr>
<tr>
<td>Ultraviolet Technology</td>
<td></td>
</tr>
<tr>
<td>Craig Casler</td>
<td></td>
</tr>
</tbody>
</table>

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The intent of this article is to identify the most common hazards associated with performing an infrared survey, particularly safety issues related to equipment operation, electrical hazards, and personal protective equipment.

Infrared Equipment

Foremost, technicians must read the safety instructions provided with each piece of infrared equipment before attempting to operate it.

High on the hazard list for infrared equipment is the use of pressurized argon or liquid nitrogen as a detector coolant.

Often, technology outpaces the learning curve for new equipment. For example, in our shop, we have four types of portable infrared cameras. Each represents the state of the art technology of their time, and each has its own safety concerns.

One camera requires pressurized argon to operate, another requires liquid nitrogen, the others are self contained.

The infrared cameras that require an external source of coolant release nontoxic gases when they are in operation. Even though these gases are nontoxic, they are an asphyxiant that can turn a normal atmosphere into a lethal mixture in a confined space.

High Pressure Argon

The first generation of infrared equipment required small pressurized argon bottles that attached to the bottom of the camera. The pressure in these bottles can be as high as 5,000 PSI at 21°C (70°F).

Great care is required when shipping, handling, and connecting these bottles. The following information was taken from the manufacturer's literature for argon bottle type infrared equipment.

- Do not fill bottles with liquid or precooled argon (excessive pressure could develop).
- Do not dent, drop, or dismantle cylinders.
- Store cylinders within the designed temperature limits of −17°C to +48°C (0°F to 120°F).
- Keep high-pressure cylinders away from heat and flame.
- Do not open valve while opening is pointed toward any person.
- Use infrared equipment with adequate ventilation.
- Use only cylinders designed for the infrared unit.
- Cylinders must be inspected and certified every five years.

Liquid Nitrogen

The next generation of infrared equipment used liquid nitrogen to cool the detector.

Liquid nitrogen is a nontoxic, nonflammable substance with a temperature that hovers around −195°C (real cold °F!). The nitrogen must be handled carefully to prevent personal injury. Frostbite-type burns and blisters can occur if the liquid nitrogen comes in contact with skin while contact with an eye can cause permanent blindness.

The following cautions were taken from the operating manual for a liquid nitrogen filled camera.

- Liquid nitrogen should be stored in a vented, insulated container. A conventional vacuum bottle may be used as a convenient transfer vessel. Storage and transfer vessels should always be vented to prevent pressure build up as the liquid evaporates and expands.
- Make sure the detector reservoir is dry and clean before filling. A cotton swab may be used to remove conden-
sate from the detector reservoir. Failure to do this may result in costly damage to the detector reservoir.

- Protective eyewear should be worn when filling the detector reservoir. Filling should be done slowly to avoid boiling over. Avoid splashing liquid nitrogen on exposed skin surfaces, as prolonged contact will cause severe blistering. Should liquid nitrogen come in contact with skin, brush it off immediately.

Other Infrared Equipment Hazards

Most infrared equipment uses rechargeable batteries. These batteries have their own safety issues. For instance, these batteries may explode if an incorrect charger is used.

To prevent this type of battery damage, use only the charger specifically designed for the equipment. Furthermore, infrared equipment, batteries, and chargers should not be exposed to water (i.e., rain).

As with all portable electric equipment electrical shock hazards can not be ignored. Never use a battery charger with a damaged cover or cord.

Hazards while Performing an Infrared Survey

In addition to infrared equipment safety, the hazards that exist while performing the infrared survey must be considered.

Blast Hazard

The primary safety concern while performing an infrared survey is the electric arc blasts that could be created during a fault. The personal blast hazards are magnified when the covers are removed, exposing energized components. Should an arc blast occur, temperatures in excess of 10,000° F can be created in the first few cycles. Solid materials such as plastic, glass and metal can vaporize. When these solid objects vaporize they can expand as much as 50,000 times, creating excessive pressures inside the electrical equipment. The hot gas vapors created by the electrical fault are capable of delivering first, second, or third degree burns instantaneously.

The majority of electrical arc blasts do not pose a severe safety threat to personnel because they are contained by the equipment’s metal-clad enclosures.

Fault pressure levels inside an electrical enclosure have been known to cause switchboard covers to blow off and transformer tanks to rupture. Unfortunately for the person performing an infrared survey, the most likely place for this pressure to be released is through the opening being used to view the energized components. This means that if an arc blast occurs during an infrared survey, there is a better than average chance that the technician involved will be the recipient of hot vapors and molten metal traveling out the equipment opening at a high rate of speed.

Injury Prevention

As they say in football, the best defense is offence. The same is true for protection against arc blast hazards. The clothing that a technician puts on before stepping in front of a piece of energized equipment can be the difference between life and death in the event of a blast.

As far as blast injury prevention goes let’s first review what types of clothing should never be worn. When a worker is in the area in which an arc blast could occur a technician can not wear any meltalbe or flammable clothing such as, but not limited to, nylon, Gore-Tex, polyester etc.

The minimum personal protective equipment (PPE) a technician should wear while performing an infrared survey is:

- Flame-resistant coveralls (Nomex, treated cotton, etc.)
- Safety glasses (refer to ANSI Z87.1-1979)
- Gloves (leather, or nonflammable material)
- Hard hat
- Leather boots.

Each individual work situation must be evaluated to determine if, and what additional, PPE may be required.

Cover Removal and Replacement

The removal and replacement of covers is another area in which safe work practices must be followed.

Low-voltage (less than 1000 volts) covers will generally require two qualified people to remove. The key phrase is “qualified people.” Any person assisting in the installation and or removal of electrical covers must be qualified. This qualification must include safety training and familiarity with the electrical equipment being disassembled.

There are some covers, such as the front panels on medium-size dry-type transformers, that may not be capable of being safely removed while the equipment is energized. For these transformers, it will be necessary to schedule an outage to gain access.

Where doors or covers are interlocked it may be possible to open them while the equipment is energized, provided the interlocks are designed to be defeated (by passed). For example, 480 volt motor control center door interlocks are intentionally designed to be bypassed and opened while the equipment is energized.

Medium- and high-voltage equipment must be de-energized for cover removal and replacement. The only possible exception for removing medium-voltage covers is where qualified personnel have evaluated the situation and determined how to safely view the energized equipment and where all the following conditions exist:

- The covers are hinged.
- There are no interlocks that must be disassembled to defeat.
• Previous knowledge of the equipment exists so that there is no doubt about the safety of opening the doors with the equipment energized.

Conclusion

Infrared surveys create a situation in which the technician is exposed to energized electrical equipment hazards. Because each infrared project is different each must be evaluated for unique hazards prior to beginning the survey. This means that before the first electrical cover is removed, all personnel involved in the infrared survey shall participate in the prejob safety evaluation. Personnel that must be involved in the evaluation include technicians, maintenance workers, electricians, etc. that may be assisting in the survey.

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Infrared Thermography, Temperature Measurement, and Repair Priorities

PowerTest 2002
(NEA Annual Technical Conference)

John Snell
Snell Infrared

Abstract

Infrared thermography is one of the most valuable tools available for inspecting electrical systems. Too often, however, the use of the technology falls short of its potential full value. Why? A primary reason is our failure to understand the basic heat transfer science involved and, thus, misinterpret the thermal signature of a component possibly headed toward heat-related failure.

Making accurate radiometric measurements of electrical components is not as simple as it first appears; modern infrared cameras make it seem possible to accurately “point and shoot.” In truth the surfaces of many components are difficult to view with any degree of confidence. Shiny metal surfaces do not emit energy efficiently and are also quite thermally reflective of their surroundings. Further, the thermodynamic relationship between radiation given off by the surface and the temperature of subsurface location of high resistance heating is also complex. Changing ambient conditions, especially electrical load, influences both internal and surface temperature, often in ways that are not easy to understand in an across-the-board manner.

Thus, not only is it difficult to accurately measure temperatures using thermography, but it is also difficult to correlate the responsiveness of the internal component temperature as it fluctuates with the surface we are measuring. Compounding the situation further is the fact that generally we often have a poor understanding of the precise nature of heat-related failures in electrical components. While we know the chance of failure increases with increasing temperatures, the trend to failure and the predictability of failure is less knowable.

This paper builds on previous work\(^1\) to discuss how to improve the accuracy of radiometric measurements as well as show the relationship between temperature and the influences resulting in a temperature change. In addition I will discuss the difficulties with prioritizing problems based on temperature alone, for example, as is specified in NETA standards, and suggest alternative approaches that yield more reliable results.

Background

Infrared thermography is a powerful, proven tool that is widely used to evaluate the reliability of and problems in electrical systems. Thermal signatures associated with “hot spots” or abnormally high resistance connection points often precede failures in electrical systems; while it is also possible and useful to find overloads/imbalances, 95% of the problems found will be related to high resistance points of contact. Thermography, with its ability to locate small temperature differences, provides advance warning of impending failure by identifying the location of a suspect component.

When using a radiometric camera (or non-imaging spot radiometer), it is also possible to make a non-contact measurement of the “apparent temperature” of a component surface; as I explain later, this value is inferred from on the radiant power and reflective qualities of the surface rather than its actual temperature. Many thermographers rely on these radiometric temperature measurements of component surfaces as the primary means of understanding the nature of the problem and predicting component failure.
How infrared cameras work

Modern infrared cameras are sophisticated electronic devices with detectors that are sensitive to invisible radiant heat energy given off by all surfaces. This radiation is a form of electromagnetic energy similar to light except we cannot see it with our eyes. Infrared wavelengths are also longer (2-15 microns versus .4-.7 microns). The detector in an infrared camera responds to the radiation with a change in voltage or resistance; that response is processed electronically into a thermal image or, in the case of a spot radiometer, a numerical value.

Today’s systems are remarkably easy to use. In most instances one can simply “point and shoot” and get superb images. These can be colorized and analyzed in the camera, stored as digital files, processed using computer software, and inserted into a report.

Radiometric infrared systems, either imaging or non-imaging, are designed and calibrated to produce a repeatable response that can be quantified. A fundamental assumption is made that the surface being measured produces black body radiation. Because this is never true, an offset or emissivity correction adjustment, is used to correct for the reduced amount of radiation produced by the real surfaces being viewed.

A great deal of cost and effort is typically given to designing and manufacturing a radiometric instrument so that it performs reliably to make repeatable measurements; most will meet a specification of 2% accuracy over a temperature range of –20°F to 500°F. Unfortunately, as I will discuss later, field measurements are much more difficult to make accurately and repeatable than this specification might lead one to believe.

Transfer of heat energy

The temperature of the surface we view with our infrared cameras is determined by a complex thermal relationship with the surroundings. If the component is warmer than its surroundings, as is usually the case, heat is transferred to the surface of the component from the point of high resistance. For most electrical components the primary mode of transfer is conduction, but in cases where components are not solid radiation and convection will play roles.

Being further away thermally from the heat source, the surface will have a lower temperature. Exactly how low depends on the rate at which heat energy is being gained and lost. A balance of energy flow in and out of the surface determines its temperature. The surface loses heat to its surroundings by convection and radiation.

A number of factors affect the transfer rates in both directions and, thus, the surface temperature. The difference between the temperature at the internal point of high-resistance heating and the surface is nearly always significant. If conduction is the primary means by which heat is transferred to the surface, the rate depends on:

- the temperature difference between the internal heating and the surface
- the conductivity of the component
- the area over which transfer occurs

The internal temperature itself also depends on the electrical resistance and rate of current flow.

Transfer of heat energy from the internal source of high-resistance heating to the exterior surface seen by the thermographer

Heat is lost from the surface, by convection and radiation, at a rate depending on:

- the temperature difference between the surface and the surroundings
- the area over which transfer occurs
• the emittance of the surface
• the shape, temperature, and emittance of the surroundings
• the shape and orientation of the component to the surroundings
• the velocity and direction of wind flow or air currents

Heat energy may also be gained from the surroundings, even if the ambient air is colder, due to absorption of radiation from the sun or other sources.

Real life heat transfer relationships are extremely complex. While they can be modeled and, to some extent, understood, no single model can be used for all the various situations thermographers find themselves in! It is impossible to make *cart blanche* predictions about what internal temperature drives a given surface temperature.

### Radiometric measurements

Infrared radiation is emitted from a surface in proportion to its temperature. As it becomes warmer, a surface emits more radiation. The amount of energy radiated is a fourth power function of the absolute temperature of the surface. The emitted radiation, however, is only part of the total radiation that the infrared camera detects.

Emissivity, or the efficiency with which the surface radiates, also partially governs the amount of energy a surface emits. Emissivity is a value from zero to one. Most shiny metal surfaces emit energy inefficiently; we would say they have low emissivity values. Most surfaces that are not shiny metals, such as electrical insulation, painted surfaces, and plastics, emit with a high degree of efficiency.

![Figure 3 — The fuse caps are actually the same temperature as the fuse bodies, but, due to their low emissivity and high reflectivity, appear cooler](image)

Low emissivity surfaces are problematic for thermographers on two counts. First, they do not radiate much energy so it is difficult to understand their true temperature. Second, they also reflect the temperature of their surroundings. The result is that whatever information we do see may be confusing or misleading. Figure 2 shows a classic thermal pattern of a set of fuses. The fuse caps do not appear as warm as the fuse bodies. In fact they are the same temperature, or very close. They do not, however, radiate very efficiently and they reflect the cooler surroundings.

It is possible to correct for differences in emissivity in most radiometric cameras. One simply determines an appropriate emissivity value for the surface, inputs the value, and the camera makes the correction automatically. Some systems also allow the operator to input another correction factor, a background temperature value. While both these corrections can, in theory, improve the measurement, their practical value for inspecting typical metal electrical components in the field is extremely limited. Both accuracy and repeatability are poor, even when used by highly qualified thermographers, due to the limited amount of radiation emitted by such surfaces. All we can know is that the component is typically hotter than it appears to be!

### The difficulties of inspecting electrical components

For information to be of value in a decision making process, it must be reliable and timely. One of the benefits of thermography is that inspections can be conducted quickly. If conditions are right, the information may also be very reliable, but this is not always the case. All too often inspections fail to locate components on the verge of failure; sometimes those that are identified as problems are, in fact, operating normally. Some of this may be due to a poorly qualified thermographers. Unfortunately the problem is more widespread; a good deal of the industry’s basic methodologies have been built on shaky scientific ground.

On the foundation of heat transfer and radiometric theory presented above, let's look at the realities of acquiring reliable information from infrared inspections of electrical components. The major difficulties encountered are:

• Low emissivity/high reflectivity
• Load
• Convective cooling
• Thermal gradient
• Ambient air temperature
• Resolution
• Measurement protocol

### Low emissivity and high reflectivity

A significant majority of electrical components are made of shiny metals. Because of their low emissivity, these do not efficiently radiate infrared energy. To understand the impact of this phenomenon, try a simple, but dramatic, experiment. Heat a frying pan on the stove. The pan must be aluminum or stainless steel on one side (low emissivity) and have a non-stick coating (high emissivity) on the other side. When the pan is smoking hot, hold your hand *near* the shiny side (*do not touch it*); notice how warm it feels. Turn the pan over and feel the heat being radiated from the...
coated side: it feels extremely hot compared to the shiny side. Your hand is sensing the same infrared radiation your camera sees. Shiny metals radiate very little energy; we are not able to sense that they are actually hot.

A similar situation exists with electrical components. For example, an aluminum connector (with an emissivity of 0.1) which is at 490°F will radiate .28 watts/in². How will it appear? Its radiometric intensity will be no different than the nearby insulated conductor (with an emissivity of .8) at 100°F. Both radiate .28 watts/in², yet their temperatures are 390°F apart!

If this is not a difficult enough situation, low emissivity components also act as thermal mirrors. Their reflective surfaces will cause them to appear to be the temperature of their surroundings. When conducting an inspection, it is very common to see thermal reflections of yourself on shiny components.

**Figure 4 — This thermal image of the author, reflected by a sheet of aluminum, is a “mirror image,” but one of heat rather than light. The aluminum is actually at ambient air temperature**

What can be done to improve results? When inspecting low emissivity components, it is essential to work slowly, carefully looking for the very subtle temperature differences that may indicate a significant problem. Higher emissivity surfaces, such as conductor insulation, may be nearby and indicate some sign of heating. Holes, cracks and seams also tend to emit better than the surfaces around them; this can be seen in the hex-key holes in many lug connectors.

It is probable that many of these indications will be so subtle as to be misunderstood or missed entirely during a routine inspection. Clearly, missing an abnormally hot connection on low emissivity busbar could have catastrophic consequences. Whenever possible, it is far better to de-energize the equipment and add high-emissivity targets to the surfaces. This can be done by tightly wrapping a loop or two of electrical tape near each joint, on a busbar for instance, or applying a small spot of paint, such as Glyptol®, near any other points of electrical contact.

**Variations in load**

The heat energy output from a resistor varies with the square of the load. An abnormally high-resistance connection behaves in the same manner. Because of increased heat transfer, however, the temperature of the component will increase at less than the square; the rate will also be greater than a linear increase. In other words, if load double, four times the heat is produced. The temperature, however, increases to a level somewhere between two and four times.

This means a seemingly minor problem—with a low temperature rise—on a lightly loaded system may become a “time bomb” as loads approach the maximum rating. Many thermographers use rules of thumb (or even software programs) to predict the point to which temperatures will rise for a given, increased load. These should be used only as guidelines, if at all, since the actual heat transfer is much too complex to predict. The only thing that is clear is that as load increases things will heat up—perhaps dramatically!

What can be done to improve results? The ideal solution is to inspect only with optimum loading conditions. Whenever possible, take time to switch loads to improve test results, and aim for the maximum load the system might see. That will give you the highest degree of assurance of reliability.

When inspecting electrical systems that are under light loads, be aware that any abnormal thermal signature you see may represent a problem that could become very serious if and when loads increase. According to NFPA 70B, Maintenance of Electrical Systems, inspections should be conducted with the highest load the system will normally see. It should not be inspected with less than 40% of design—unless it is always lightly loaded.

**Wind and convective cooling**

Energized electrical components lose heat energy to their cooler surroundings by conduction, radiation, and convection. In many situations, especially outdoors, convection, or wind, is by far the most significant mode of heat transfer. A 10 MPH wind causes leaves to rustle, and a breeze can be felt on your face. That wind will also cool an abnormally hot connection. A 10MPH wind can reduce the temperature rise over ambient by 50% or more. As soon as the wind drops the connection begins to heat up, perhaps catastrophically so. In many parts of the country wind speed is generally 10 MPH or greater so there is little doubt thermographers conducting outdoor inspections will miss some real problems. They will probably also seriously underestimate the severity of those that are found (Fig. 3).

Thermographers must also pay attention to convection when performing electrical inspections inside plants. Electrical components are subject to convective cooling associated with HVAC systems, manufacturing processes, or simply drafts from the outside. I have extensively measured air currents inside plants, frequently finding them in excess of 10MPH. In many instances 20MPH air currents were measured. Like the wind, these are not necessarily continuous, and, therefore, can taint the thermal data being gathered.
What can be done to improve results?

To increase the effectiveness of an inspection, conduct it when convective cooling is minimal. Ideally wind/air currents should be less than 5 MPH. Since this is often not practical, when inspecting with greater convection, work slowly and take careful note of even small thermal abnormalities. Note those for re-inspection when convection is reduced or, if that is not possible, for regular monitoring until their actual condition is understood.

Changes in ambient air temperature

Thermographers who conduct inspections in cool weather will usually underestimate the true severity of problems found. The problems will not appear to be as great (i.e. hot) during cool weather. If left uncorrected until the weather turns warmer, however, you will often see an increase in temperature, making them more susceptible to heat-related failure. While the effects of changes in ambient air temperature are not entirely additive, that is the general trend; for example, all other things being equal, a component at 130°F in 40°F air, will approach 170°F when the air is 80°F. Note that as temperature increases, however, resistance will also increase with the probable result being temperatures of an abnormal component may rise even higher.

Thermal gradient

Radiometric measurements indicate the temperature of the component’s surface only. The surface is almost never the place where electrical energy is being converted into heat energy. Rather, heating occurs at the point of electrical contact, such as along the threads of a bolt, between two connection plates, or, in worst case situations, on contact surfaces that are under dielectric oil. A dramatic thermal gradient can exist between the point of heating and the surface being observed. This fact is clear to anyone who has repaired electrical components and found evidence of melting contact surfaces while the outside surfaces exhibit little damage.

Temperature variations of 1000°F or more over a distance of less than an inch within a component are not unusual. Aluminum components, in particular, diffuse heat with great efficiency. Enclosed bus bars or oil-filled devices may have thermal gradients so great that only a few degrees rise on the surface indicates severe damage on the contact surfaces inside.

A disturbingly common situation that must also be addressed involves thermographers who purport being able to inspect enclosed equipment without opening it. The “reasoning” may involve their claim of being able to see through the enclosure (false) or being able to read the
thermographic resolution, on the other hand, describes the smallest area that can be accurately measured. This is analogous to the smallest type size you can actually read. As it is possible to see type without being able to read it, thermographers often see objects but cannot accurately measure them because they are too small or too far away.

Most modern systems fitted with a “normal” lens have spatial resolutions of approximately 600:1 or better, but their measurement resolution is only 200:1. Thus a warm wire 1/4” in diameter can be seen as far away as 12.5”; to accurately measure it, one would need to be closer than 4’ away. While this is not a severe limitation inside most buildings, it is a constraint for most out-of-doors work where distances to the component are typically greater. Measurements from further away will average the temperature of the component with the temperature of anything behind it. Out-of-doors the clear sky, which appears very cold day or night, is averaged into the measurement commonly resulting in sub-zero values.

What can be done to improve results? It is essential that thermographers understand the working limitations of their system. Work as closely to the equipment as is necessary and safely possible. When that is not possible, use a telephoto lens. When the limitations to measurement resolution are exceeded, temperatures should be reported only with extreme caution as they will typically appear less severe than they actually are.

Measurement protocol

Opening enclosures
Ideally, when inspecting enclosed equipment, the components should be viewed as quickly as is safely possible after opening the enclosure; it is that condition, after all, that represents the ambient environment in which the components are operating (and possibly failing). Many thermographers pay little attention to the fact that the components, including any problems, will begin cooling off as soon as the enclosure is opened, resulting in a misinterpretation of the actual condition that exists.

What can be done to improve results? Develop and use a protocol for opening enclosures that minimizes cool down prior to your inspection.

Defining temperature reference
Many otherwise good thermographers put a great deal of stock in temperature difference (ΔT) measurements, because they know measuring actual temperatures is difficult and often inaccurate. Unfortunately, measuring ΔT is also fraught with problems!

First and foremost is a failure to define the reference precisely. Two different references are typically used, (1) ambient temperature and (2) the temperature of a normal phase or similar, normal component. Both are often used interchangeably with too little regard for their actual meaning or the fact the two values are often dramatically different.

Using ambient air temperature can provide a useful comparison only if the actual air temperature is also reported. Without this key piece of information, it is impossible to say whether the ambient or the component temperature has changed when compared to previous inspections. Even the definition of “ambient” is often unclear. It is best defined as the temperature in which the component is operating. For enclosed equipment it will be the interior air temperature just as the enclosure has been opened. Out-of-doors care should be taken to find a representative indicator that has not been abnormally heated by the sun or that lags behind air temperatures significantly; a piece of white paper waved in the air is a good reference.

Phase to phase temperature differences are also useful, but only if all three phases are under similar conditions, especially load. Accurately correlating temperature differences when loads are uneven will prove risky. As loads increase so will the difference between a normal and problem phase. Without loading information, temperatures, either phase to phase or actual, are of no value.

What can be done to improve results? Consider reporting both phase-to-phase and problem to ambient differences. Along with ambient air temperature and load data. While neither type of measurement is diagnostic by itself, the information will probably prove useful in the final analysis.

Measuring temperature differences (ΔT)
Most phase-to-phase measurements of low emissivity components that are reported are inaccurate. Why? Most thermographers make the measurement using a fundamentally erroneous methodology. If you simply set the emissivity correction value to 1.0, the reported phase-to-phase temperature difference will (nearly always) be less than it actually is. When looking at low emissivity surfaces, in particular, the error may be unbelievably large. Even if the correct emissivity value is used, a technique that in theory will produce accurate measurements, errors can also be expected for shiny metals because of the extreme correction required.

A simple experiment is quite convincing. Obtain two fuses that have shiny aluminum or copper end caps. Heat one to approximately 120°F and look at them with the
Figure 7 — While the difference in temperature, actually radiated energy, is enough to be noticeable on the bodies of the fuses, there is little difference on the fuse caps

A simple explanation reveals a much different story. Normally a component is sized to operate at, or just above, ambient air temperatures. Unlike the abnormally hot component a normal one will not be convectively cooled below surrounding ambient air temperatures regardless of wind speed (unless it is wet). Thus a measurement of $\Delta T$ on a windy day will be much less than on a calm day resulting in the possibility of a serious misinterpretation of the image and, more seriously, a probable failure of the component when convection is reduced.

How hot is too hot?

Given the numerous difficulties encountered by thermographers, as detailed above, it is a wonder we have had any success! Even when radiometric measurements are accurate, the information must be used intelligently to evaluate the repair priority of a finding. We know that components have heat-related failure mechanisms. Unfortunately, the answer to “how hot is too hot?” is often not a simple one! This is reflected in the fact that the three most widely used temperature-based prioritization systems are quite different:

<table>
<thead>
<tr>
<th>Action</th>
<th>Navy</th>
<th>NETA/NFPA</th>
<th>NMAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate</td>
<td>70°C+</td>
<td>16°C+</td>
<td>56°C+</td>
</tr>
<tr>
<td>Serious</td>
<td>40-69°C</td>
<td>NA</td>
<td>29-56°C</td>
</tr>
<tr>
<td>Intermediate</td>
<td>25-39°C</td>
<td>4-15°C</td>
<td>9-28°C</td>
</tr>
<tr>
<td>Advisory</td>
<td>10-24°C</td>
<td>1-3°C</td>
<td>5-8°C</td>
</tr>
</tbody>
</table>

A closer reading of the three systems reveals the disturbing fact that load, emissivity, thermal gradient, convection, and ambient air temperature, are not meaningfully addressed. It is also not clear whether the temperature differences listed are rise over ambient or rise over a normal phase.

While detailed information and manufacturing standards are available regarding the temperature limits of various materials and components, they typically are based on a “not-to-exceed” temperature; this is very different than the “hot-spot” temperature that will be found in a component with a high-resistance connection point. The high-resistance hot spot may reach temperatures high enough to cause significant damage—far in excess of the specified threshold—long before the thermographer can see the component itself approaching that limit.

In fact few meaningful alarm limits exist for thermographers to rely on. The most reliable limits are probably the materials’ annealing and melting temperatures. Of course, these are much too high to be particularly useful as alarms, except perhaps to say generically that a system that is predominantly aluminum, rather than copper or alloy, should be considered more conservatively. The failure temperature of the insulation may also be useful.

Many thermographers marvel that a problem can exist for so long without failing. This is not surprising when one looks closely at the mechanics of failure; in many instances, microscopic anomalies are present from the beginning resulting in slow oxidation and slight heating. Annealing of spring metals, i.e. switches or contacts, begins to occur after a month at 200°F (at the contact surface), after which there is often an acceleration to functional failure. This, in turn, results in increased resistance and oxidation. As resistance increases so does heating which, in turn, results in even higher resistance. An increase in component temperature of 18°F results in a 4% increase in resistance.

Convective cooling and measuring temperature differences ($\Delta T$)

Another fundamental error many thermographers make is believing that phase to phase temperature difference measurements will “neutralize” the cooling effects of convection. This is simply not the case as shown by the table below:

<table>
<thead>
<tr>
<th>Wind speed</th>
<th>Air temperature</th>
<th>Normal component temperature</th>
<th>Abnormal component temperature</th>
<th>$\Delta T$ Phase to phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>70°F</td>
<td>73°F</td>
<td>303°F</td>
<td>230°F</td>
</tr>
<tr>
<td>5</td>
<td>70°F</td>
<td>72°F</td>
<td>160°F</td>
<td>88°F</td>
</tr>
<tr>
<td>10</td>
<td>70°F</td>
<td>72°F</td>
<td>122°F</td>
<td>50°F</td>
</tr>
</tbody>
</table>

Where is showing this phenomenon but non-radiometrically, i.e. without temperature values.

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As indicated in the previous discussions, thermographers encounter numerous situations where extremely serious problems are not indicated by a thermal signature that is obvious. If certain components (such as a lightly loaded, low-emissivity one with a large thermal gradient that is being cooled convectively with low ambient air) appear even slightly warm, it probably represents a situation that is very close to heat-related failure when conditions change. When components heat to the point that metals melt, re-welding occurs and resistance, and thus temperature, can actually drop for a period of time, as shown in the “saw tooth” graph below.

Perhaps the most insidious example of where heating fails to correlate with the actual problem is on double- or parallel-fed circuits; here current flows through the path of least resistance, meaning the abnormal, high-resistance problem will be cooler than the normal portion of the circuit. Misreading such a situation can quickly result in disaster.

Prioritizing based on all relevant factors:

In all cases the root cause of abnormal heating should be fully understood; to not do so puts a great deal at peril. Clearly not all found situations represent problems, and not all that represent actual problems need be fixed immediately. In a world where maintenance resources are always limited by circumstances, the repair priority should be determined based not on temperature alone, but rather on a matrix of all relevant factors. In the end isn’t our job simply to help optimize the return on an investment of available resources?

Even when temperature is accurately measured and its relevancy clearly understood, it is only one of many factors to be considered. Others may include:

- Personnel safety
- Possible change in load and convective cooling
- Criticality of the equipment
- Reliability of the radiometric measurement
- Indications of other test methods

A simple matrix, such as the one shown below, can be used to guide the prioritization process in a manner that is much more useful than basing the decision temperature alone:

<table>
<thead>
<tr>
<th>Prioritization Matrix</th>
<th>Increasing probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factors to be considered:</td>
<td>1  2  3  X</td>
</tr>
<tr>
<td>Will a failure injure people?</td>
<td>* 3</td>
</tr>
<tr>
<td>Is component critical?</td>
<td>3</td>
</tr>
<tr>
<td>Will loads increase?</td>
<td>2</td>
</tr>
<tr>
<td>Will convective cooling decrease?</td>
<td>2</td>
</tr>
<tr>
<td>Is measurement unreliable?</td>
<td>2</td>
</tr>
<tr>
<td>Is thermal gradient large?</td>
<td>2</td>
</tr>
<tr>
<td>Given gradient, is delta-T great?</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Repair priorities based on total score:</th>
</tr>
</thead>
<tbody>
<tr>
<td>*immediate action required</td>
</tr>
<tr>
<td>32+ Repair immediately</td>
</tr>
<tr>
<td>27-31 Repair at next opportunity</td>
</tr>
<tr>
<td>22-26 Schedule repair</td>
</tr>
<tr>
<td>17-21 Monitor</td>
</tr>
</tbody>
</table>

How does the matrix work? A series of questions are asked to get at the relevant issues involved. The answers are scored as either one, two or three with that value then being multiplied to best reflect its “weight” in the decision making process. The total score is used to determine the actual repair priority based on the resources available. Certain aspects, such as safety, can be given overriding weight, as represented by the asterisk, when deemed vital.

The exact questions asked, as well as the multipliers and scores used to designate priorities, can all be modified to reflect the actual circumstances involved. For instance, if safety is not a priority, as might be the case for a remote, unmanned pumping station, it would be given less weight. If repair budgets are very tight, the scoring can be made more conservative. If inspections will be done under extreme ambient conditions, it may be useful to add a factor about air temperature.

Success requires all who use the matrix to do so uniformly and consistently. Any errors in evaluation, such as an unanticipated failure or a false positive, should be used to feed changes back into the system (either into the matrix itself or to those who are using it) to make it more accurate. The more it is used in this manner, the greater the probability of accurate predictions.

A more complex system could possibly prove more accurate, unless, like some that have been proposed, it becomes so complex it cannot actually be used. Simplicity has great merit if the system is otherwise accurately reflects the actual condition of the component, its likelihood of failure, and the repercussions of such a failure if it did occur. Simple systems similar to that shown above have been used extensively with excellent correlation to reality.

Conclusions:

The primary benefit of infrared thermography for the maintenance of electrical systems is locating components with abnormally high-resistance prior to their failure. It may also be possible to give a radiometric temperature of
the component. In both cases surface temperature will vary widely depending on a number of factors, including load, ambient air temperature, convective cooling, and thermal gradient. The radiometric measurement is also affected by surface emissivity and background temperature.

All too often problems are missed or misunderstood or the measurements are unreliable; in some cases blame can be laid on a poorly qualified thermographer; such problems are minimized when certification is based on nationally recognized standards such as the American Society for Nondestructive Testing (ASNT) SNT-TC-1A. In other instances, however, we must face the fact that the reliability of thermography is inherently low. For that reason it is paramount that we also understand the variables, work within the limitations of both science and the technology and, where possible, enhance the conditions for an inspection to increase the reliability of the inspection data.

Even with the best possible thermographic data in hand, determining a priority for repair should be based on all relevant factors, not just temperature. It is clear many serious problems are simply not indicated by high temperatures. Existing methodologies based on temperature alone are not valid and should be avoided. Only by considering all relevant factors can the true seriousness of a found problem be determined. A simple, flexible methodology utilizing a weighted matrix is proposed to address some of the inadequacies of previous systems and yield more accurate predictions of repair priorities.

References:

Make High-Voltage Electrical Equipment Inspections Safer and Faster with Infrared Sightglasses

NETA World, Spring 2004 Issue
by Antony Holliday
Hawk IR International, Ltd.

The installation of IR sightglasses and ports into high-voltage cabinet doors and access panels makes IR scanning safer and faster by eliminating the need to remove panels or doors. Installing crystalline sightglasses or metal mesh inspection ports into panels or doors provides a cost-effective solution to the electrical arc flash and shock hazards faced by thermographers when performing IR surveys of high- or low-voltage electrical equipment cabinets. Retracted to cabinet doors or panels, inspection ports provide a direct line-of-sight to targets within, preserving the protection provided by the doors and panels and providing a physical safety barrier to protect the thermographer against arc hazards.

IR sightglasses and metal mesh inspection portals enable thermographers to quickly and safely inspect live components inside protective cabinets. They save time and money by eliminating the need to remove and replace doors and panels for inspection, resulting in dramatic increases in safety as well as inspection speed and total area coverage. (“IEEE 1584, Guide for Performing Arc Flash Hazard Calculations,” provides test methods designers and facility operators can use to determine the arc flash hazard distance and incident energy from electrical equipment to which workers may be exposed. This standard addresses arc flash hazards for arcs-in-a-box and arcs-in-open-air.)

Without the use of these inspection ports, the doors must be removed to expose the components inside — thereby raising the inherent risk of arc flash. If the thermographer is not qualified to remove the doors, the infrared survey will, therefore, require twice as many people, significantly more time and more cost, while also opening the possibility for arc flash when the doors are removed.

The risk, especially with high-voltage, high-amperage equipment, is very real. When cabinet covers and doors are removed or opened — especially during the removal or replacement operations — a dynamic element is introduced into what was previously a static system. Dropped tools, a bad grip on the panel, accidental contact, cabinet failure, and even induced airflow can all contribute to the manifestation of an electrical arc flash and even the risk of electrocution. IR sightglasses and ports help eliminate these possibilities.

With IR sightglasses or ports installed, the static conditions within the cabinet remain virtually unchanged during inspection. The thermographer simply removes a protective security cover, carries out the IR survey, replaces the cover, and moves on to the next cabinet — all without requiring the services of a qualified electrician.

What to look for in a sightglass or port

When selecting a sightglass solution, as for any other electrical component, the prudent maintenance professional should insist on a robust, quality design that has earned listings and ratings from authoritative sources, such as UL and switchgear manufacturers. The products illustrated in this article, Hawk IR C-Range (crystalline) and M-Range (mesh) devices from FLIR Systems, are UL recognized and approved for installation on new equipment at the factory and for field installation (retrofitting) into NEMA 3/12 equipment or below. These products are also rated IP65 (weatherproof) with the protective cover open (crystalline)
or closed (mesh) by Sira Test and Certification, a member of the globally-respected Sira Group, a leading conformity assessment services organization in the UK.

Another key design consideration is the elimination of any mounting fittings inside the cabinet. For example, Hawk IR Sightglasses are designed to be adhered onto the cabinet door or panel permanently, framing a hole that is quickly punched into the panel (which must be removed for this process) with a special electrohydraulic mounting tool. A permanent, front gasket forms part of the sealing system. With the absence of any penetrating mounting hardware, Hawk IR portals can also be installed safely in the horizontal plane, without fear of bolts shaking loose and falling into the live equipment. After installation of the IR sightglasses or ports, the plant safety officer should re-evaluate the required personal protective equipment.

To prevent access to the cabinet interior by unauthorized personnel, the sightglass or port should have a robust, tamperproof cover. Hawk IR devices have metal covers that are locked in place with a proprietary design fastener. To remove the protective cover requires a specific access key. This or similar tamperproof security must always be used on equipment that is located in generally accessible areas.

Types of IR inspection portals

Crystalline IR sightglasses

The portal material is transparent to IR and visible light but presents a physical barrier to the entry of objects into the high-voltage environment.

Metal mesh IR ports

Designed primarily for indoor, low-voltage (<500 V) applications, this design can provide a significant level of protection. However, not all products on the market adhere to IEE and IEEE guidelines for hole sizes in electrical equipment, which advise NO holes greater than one-half inch, are permitted in metal-clad switchgear. These metal mesh IR ports are UL recognized and approved for fitting to both new equipment at the factory and for field installation (retrofitting) into NEMA 1 equipment.

Understanding “arc-rating”

There is a lot of speculation about the performance of IR sightglasses under arc-fault conditions. The question of “arc-rating” is asked time and again, especially when IR sightglasses are proposed for retrofitting to existing equipment. Some manufacturers of IR windows in the past have claimed that their products are “arc-rated” and, as such, are suitable for retrofitting onto existing arc-rated equipment with no effect on the mechanical integrity of the equipment.

Do not be fooled! It is simply not possible to arc-rate an accessory or component such as an IR sightglass or port and then apply the rating to every possible scenario faced under arc-fault conditions in every possible location on every possible combination of equipment. When a piece of equipment is subjected to an internal arc-fault type test,
the results are applicable only to that type of equipment in that specific layout for that specified energy level. If the equipment in its entirety passes the arc-fault test, then it is the equipment as a whole that can be classed as arc-rated. What this does not mean is that any component part of this package is subsequently arc-rated for use on any equipment certified to that energy level or less.

Special application needs
IR inspection portals used in typical plant environments on motor lead boxes, air circuit breakers, transformer terminal boxes, and motor control centers should be equipped with temperature-resistant gaskets and seals that are classified as low smoke and fume (LSF) type. For applications in semiconductor fabrication and other clean-room environments, all components, including the mounting and sealing gaskets, should meet much more stringent Class 1 clean room specifications.

Ease of installation
IR inspection portal system design should include installation tools. Some designs utilize an O-ring sealing method with fittings that require two people to install. Advanced designs include self-adhesive gaskets that allow one person to do the installation by providing temporary positioning of the mounting flange while the permanent fittings are tightened. Hawk IR provides an installation kit that features a very effective battery-operated electrohydraulic punch and all the dies, drill-bits, drivers, and accessories required. Using the kit, the whole process takes less than ten minutes.

Antony “Tony” Holliday is an engineer and thermographer with experience in many areas of power control and distribution in the telecommunications industry. This article is a reflection of his responses to numerous thermographers and end-users who have requested assistance from Hawk IR International Ltd. to increase coverage of their electrical infrared (IR) program into previously inaccessible areas. 1-800-464-6372, or go to: www.flirthermography.com/accessories.
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Infrared Thermography: A Better Tool Than Ever!

NETA World, Summer 2005 Issue

by John Snell
Snell Infrared

All of a sudden everyone seems to be talking about or using infrared thermography! Fueled by plummeting camera prices and systems that are easier than ever to use, the technology is being applied widely for countless new and old applications. As NETA World readers are well aware, smaller commercial and industrial companies, previously cut off from the day-to-day benefits of having the technology in-house, are finding the returns on an investment in equipment — and personnel to use it — great enough that many are jumping in successfully.

The insurance industry, long a proponent of using infrared, continues to rely on the technology for managing loss-control. One major industrial insurer documented average electrical equipment losses of $150,000 per incident for 125 typical claims. This did not include production losses! Nearly 80 percent of the incidents were caused by connection failures of one kind or another. Attributed savings from another primary industrial insurer were reported to be several billions of dollars for 2004. After last year’s devastating hurricane season, damage assessment using thermography was big business, not only for electrical and mechanical equipment, but also for buildings, roofs, and boats. Infrared clearly is helping insurers successfully manage their risk, and its use will only continue to increase.

The flip side of this rosy picture is that in many cases the technology is still not producing the full and consistent returns of which it is capable. Several contributing factors are obvious. First and foremost, thermographers are often poorly qualified. In addition very few companies have certification programs to document qualifications and ensure that high-quality results can be obtained safely and consistently.

Second, many in maintenance expect thermography to be a miracle cure rather than one of several tools that can help improve machine asset management. There is a failure to acknowledge the very real limitations of the technology, even when using high-end infrared cameras. This, along with a lack of standards and written procedures, results in too many missed opportunities.

When used properly, as part of a well-planned maintenance or testing program, thermography can play several vital roles. Probably its best and most frequent use is as a tool to locate potential problems before those problems become dangerously degraded. Secondarily, it can be used to validate the integrity of new installations or repairs to equipment. Both are essential to assuring that manufacturing and utility systems will continue to function reliably and safely.

To be successful, inspections must be conducted under conditions that allow us to see any existing problems. Without this protocol, problems may go undetected, leaving the customer with a false sense of security. Essential conditions include the following key points:

This substation disconnect switch shows at least one problem, and possibly two. Diagnosing such problems is not always simple and should be attempted only with a full understanding of the existing loading and environmental conditions.

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• Equipment must be under load, preferably at worst-case conditions. For electrical equipment, NFPA 70B suggests a 40 percent or greater load. Our experience indicates this is the absolute minimum needed for successful work.

• As direct a view as possible of the equipment or component is required. This means the enclosure covers must be open or access must be gained through an infrared window or port. In cases where access is limited, such as bus ducts or motor terminal boxes, thermal indications of a problem — even an advanced one — may be undetectable or only very subtly so.

• When winds (or air currents inside) are greater than approximately 10 miles per hour, some hot spots will not be detectable and others will be cooled, often significantly enough that they will probably be misinterpreted.

• Radiometric measurements should be attempted only on high emissivity components such as electrical insulation or very heavily oxidized metals. Despite popular belief, if a metal surface appears metallic, measurements will be unreliable.

• Some components are not well-connected thermally to the surfaces we see with the infrared cameras. An example of this is heating occurring on contacts inside a large breaker. In such cases, surface indications may be quite subtle or, in worst-case conditions, undetectable.

• Ambient air temperature, direct sunshine, and precipitation all may influence what a hot spot looks like and whether or not we will see it. Generally, we can work successfully under a wide variety of climatic conditions only if their influence is fully understood and accounted for.

Qualified thermographers understand that success depends on most or all of these conditions being favorable at one time. When this is not the case — an all too common situation — thermal indications may be very subtle or below the threshold of detection.

Some would cast the technology as a predictive tool, relying heavily on the radiometric temperatures provided by most systems. Only rarely does the technology fulfill such a role, and even then it most often does poorly. These unreliable results are due primarily to three factors:

• The precise relationship between component heating and failure is typically not well understood. We know, for instance, that high resistance heating in an electrical connection is a problem, but there are no simple answers to questions like “How long will it last?” or “When should it be fixed?”

• Surface temperatures measured by infrared cameras are influenced by a number of factors other than the friction or electrical resistance associated with a machine failure. To isolate and construct trends for these causal influences and understand their impact on failure is nearly always difficult and often not practically possible.

• Radiometric temperature measurement for bare metal surfaces, i.e., electrical connections, are highly unreliable. Corrections for emissivity, while based on physics, are simply inadequate for accurate and repeatable field work.

Unfortunately, many thermographers, and even more of their customers, delude themselves into believing components can be trended as they approach the failure point. In fact several temperature-based systems for prioritizing problems are frequently used and misused in the industry. Clear-thinking and some simple experimentation quickly demonstrate that these may not accurately portray the severity of a finding. Working within the right conditions, however, will allow us to verify asset health or document exceptions. The severity of these findings can then be determined using additional test methods such as a voltage drop or dissolved gas analysis along with other input about the consequences of a failure should it occur.

Despite the claims of some equipment sales people to the contrary, buying more costly infrared cameras will not change any of the basic physics discussed above! While some consultants or companies may still need the power of a high-end system, a large crop of lower-cost systems offers incredible value for many end users.

A handful of choices of low-cost infrared cameras currently exist, although more will be available soon. These cameras are priced under $10,000, are simple to use, and when used properly are perfect for quality assurance and problem detection inspections. Several are nonradiometric (meaning only temperature relationships are seen, as opposed to specific temperature values) or have only a center-spot temperature readout. These are part of basic feature
sets that reduce camera costs while still proving more than adequate for most electrical inspections.

Another reason camera prices have tumbled is that detectors are now mass-produced in smaller pixel densities. In the recent past all detectors measured 320x240 pixels. Now detectors with a quarter that number of pixels (160x120) are common, and soon we will see systems with detectors measuring 80x60. Does this mean resolution is sacrificed? Interestingly, in most cases it does not! Instead, the result is an image of a smaller area, usually with resolution that is very acceptable, if not indistinguishable from higher-priced cameras. One situation where having more densely populated detectors is critical is when moving closer is not an option, such as inspections of outdoor substations.

So, do not dismiss lower cost systems! They can help consultants capture or keep customers who are looking elsewhere for service providers. If customers decide to get into the technology on their own, it may be appropriate, as a way to keep them close, to assist them in doing it safely and effectively. Consultants are often best qualified to provide inspections of specialized equipment and continue to provide the expertise many customers will never gain, but by buying into the technology, customers will have access to its power on a day-to-day basis. If data from insurance companies is representative, the returns will be extremely attractive — probably in the vicinity of 20 or 30 to one!

Thermography, when used correctly, is one of the most powerful quality assurance tools in our maintenance toolbox. As powerful as it is, however, even the most modern cameras are unable to think for themselves. Success requires that the system be used by a qualified thermographer conducting the inspection under correct conditions so that any potential problem can be detected. While measuring radiometric temperatures may be useful, those measurements are often unreliable. Furthermore, too many people try to make them more meaningful than is appropriate, especially with regard to prioritizing findings.

The bottom line is this: use thermography to assure asset health and, when a system is not up to par, to locate the problems. Use other tools and reasoning to determine solutions and to plan when to fix the problems in a cost-effective manner. If you are wondering whether or not you should jump into thermography, there is no better time for your company — and your customers — than now.

John Snell is founder and President of Snell Infrared, a leading training company in the industry. He has been active professionally for his entire 22-year career, twice serving as Conference Chair for Thermosense and Chair of an ASNT Topical Conference on Thermography. He also sits on the standards committees of ASNT, ASTM, and ANSI/ISO and has worked with standards committees at EPRI, BINDT and NETA. In 1994, Mr. Snell had the honor of becoming the first thermographer in the world to pass the ASNT Level III exam for the thermal/infrared method. He is a graduate of Michigan State University. (800-636-9820. www.snellinfrared.com)
Frequent Infrared Inspections of Electrical Cabinets Made Easy and Inexpensive with Newly Approved UL-Device

Is the cause of your next production stoppage behind door number one, door number two, or door number three? If you’re a plant manager concerned about the condition of electrical hardware, that can be a frustrating question. Today’s higher equipment utilization rates call for an aggressive infrared (IR) inspection program for electrical panels to head off disaster, but that has traditionally been a tough goal. One graphic example of how frequent IR inspections can save significant expense occurred recently at a gas enrichment plant in the western United States. Using a new lens and port technology that facilitates closed-door IR inspections, the plant’s maintenance team discovered overheated, failing connection leads to two 4,500-horsepower, methane compressor motors critical to the 24/7 operation. A similar electrical connection problem at the plant previously had caused an unscheduled outage that resulted in one million dollars in lost production. The timely finding enabled plant managers to correct the problems on a controlled basis, avoiding costly unscheduled downtime and damaged equipment.

Two Inspection Options, Neither Appealing

Up to now, the methods and options for performing a safe IR scan have not been appealing. Removing or opening electrical panels always poses a risk when high energy is involved. Human error, particularly for an inspector suited up in heavy personal protective equipment (PPE), equipment failure, and other factors can transform stable conditions in the cabinet into a dangerous environment for the inspector and anyone nearby. Preferably, an arc flash assessment per NFPA 70E will be done first to determine safe boundaries. Certainly, the correct level of PPE should be worn. Regrettably, the heavy protective suits, gloves, hoods, and face shields that are sometimes required make this an arduous task, even in a cool environment, thus discouraging frequent inspections.

Closed-door inspection is safer and a better use of manpower, allowing the thermographer to work without the help of an electrician and with a greatly reduced level of PPE. Traditionally, this has required installation of costly and fragile IR-transparent windows (or sight glasses) which allow a small portion of a cabinet interior to be viewed through a camera. Metal mesh ports are also available.

From a thermographer’s standpoint, IR-transparent windows transmit only varying percentages of IR in different wavelengths, depending on the material. The resulting temperature measurements cannot be considered accurate.

IR-transparent windows used in sight glasses for electrical cabinets are made of various crystalline materials that allow light in the wavelength of 0.13 to 10 microns to pass through. However, the range sensed by uncooled microbolometer cameras are 8-14 microns. If the sight glass only transmits up to 10.0 microns then the camera is NOT “seeing” 71.5% of the energy from the target. This reduction of signal/energy on the detector results in lower image quality and severely compromises temperature values based on camera algorithms established for energy from 8-14 microns. IR transparent windows are also expensive — hundreds of dollars for just a few square inches. They scratch and shatter easily if pressure is applied, so they are easily vandalized and a camera can’t be pressed against them.

Because only a limited area of the cabinet interior can be viewed through a sight glass even with a wide angle lens, it may take four or more sight glasses (at a cost of about $200 to $300 each) to make the interior of a typical panel viewable from outside. Sight glasses also require a relatively...
large hole in the cabinet door, which can be a safety hazard if the window breaks.

Metal screens can compromise safety if they fall into the cabinet or become bent or broken. They easily skew thermography by acting as both reflectors and emitters of IR radiation while obstructing an unknown percentage of radiation from the target of interest.

UL-Approved Device for Closed-Door Inspections

Another alternative has recently been developed for closed-door inspections that requires no IR-transparent window or metal mesh. It allows a thermographer to scan a panel looking through a tiny 0.50-inch opening in the door. This new system (Figure 1 and Figure 2) combines a viewport with a fisheye lens known as a SpyGlass™. The cone-shaped tip of the lens docks in the socket-shaped opening of the viewport to maintain a comfortable, steady position for the camera to reduce operator fatigue.

This combination of window-free port and fisheye lens makes company-wide standardization feasible and affordable because the less than $50 cost of the ports decreases as quantity increases. Industry leaders such as GE, Exxon Mobil, Boeing, DuPont and Cargill already have thousands of these ports installed. The patented viewports have received UL approval in the United States and in Canada, leading to a high level of confidence by early adopters.

The fisheye/viewport system enables closed-door thermal inspections of connected electrical switchgear, while maintaining the original safety rating of the cabinet. This applies to cabinets energized with 480 to 13,200 volts as well as motor junction boxes with 4,160 volts.

No IR Attenuation or Obstruction

The fisheye lens and viewport provide the clearest possible view and most accurate temperature measurement of electrical switchgear under load because the tiny port opening requires no IR-transparent window or metal mesh.

The viewport uses only a 0.50-inch aperture covered by a sealed, screw-on cap to maintain the integrity and safety rating of the cabinet when not in use. To prevent unauthorized access to the cabinet, a locking device for the viewport cap is available as well. Allowing an unobstructed view of a cabinet’s entire interior, the viewport is unaffected by moisture, dirt, UV, and corrosive environments that can degrade IR windows or penetrate metal mesh covers. It never needs cleaning or replacement.

The viewport is designed to dock with the cone-shaped tip of the lens barrel (Figure 3). The plastic-tipped barrel protects the lens elements from contact with the port or cabinet and provides a layer of insulation to eliminate path-to-ground hazards. By contrast, a camera lens with a metal rim in contact with an IR window can damage the window easily.

Figure 1 — Maintenance monitoring of high-voltage electrical connections, looking through a 0.50" viewport with SpyGlass™ equipped IR camera.
In addition to the wide field of view provided by the lens, its tip works with the viewport like a ball-and-socket joint, allowing the camera to be rocked at different angles to look up, down, and to the sides as well as straight ahead.

The viewport is UL approved for installation at the OEM level or as a retrofit in the field on NEMA Type 1, 2, 3, 3R, 4, 5, 12, 12K, and 13 enclosures. Suitable for both low- and high-voltage applications, it can be installed on cabinets indoors or outdoors in either vertical or horizontal position.

A Broad Field of View

The fisheye lens, with its wide field of view (53° horizontal by 40° vertical, or 66° diagonal) allows easy scanning of the interior of the electrical cabinet through the viewport while providing a temperature measurement accuracy of ±3°C (Figures 4 and 5). Focusing from four inches to infinity (100 mm to infinity) and providing great depth of field, the fisheye lens reduces the need to refocus for different electrical cabinet depths. It is worth noting that it could easily take up to four IR sight glasses to cover this same area for inspection with a typical wide angle lens.

20-Minute Installation

The viewport can be installed by one person in 20 minutes or less. The electrical equipment should be de-energized before installation. To install, simply open or remove the cabinet door, use a Greenlee punch to create the aperture, drill the screw mounting holes, affix the viewport, and reinstall the door.

Versatile Applications

The viewport can be installed on any application where an expansive and unobstructed view behind a panel or door is desired, including mechanical rooms. Motor control centers, transformer terminal boxes, air circuit breakers, motor lead boxes, and a wide range of mechanical equipment can be outfitted with viewports.

Figure 3 — Locking style viewport with cap open.

Figure 4 — Typical image of an electric motor lead taken with SpyGlass lens and IR camera.

Figure 5 — A hot fuse clip, photographed with SpyGlass-equipped IR camera.

Jon Chynoweth has been involved in the development and marketing of thermal imaging cameras and related software for 20 years. He began developing imaging software needed for process control and utility applications, leading to a position at Raytheon as manager of sales and marketing for uncooled cameras in North America. He later formed a business, acquired by Mikron Infrared, to develop thermal cameras and software. Certified as an ASNT Level I thermographer, he is currently Vice President of Mikron’s Thermal Imaging Division.
Fine Tune Your Infrared Thermography Skills

NETA World, Summer 2005 Issue

by Bernard R. Lyon Jr. and Robert P. Madding
FLIR Systems, Inc.

What is it that separates the rookies from the superstars, the novices from the experts, and the amateurs from the professionals? It is training and experience. This applies to many endeavors, not only thermography. While training and experience may not guarantee success, lack of these will certainly increase the odds of impending failure. We have had the fortunate opportunity to see many thermographers advance in their careers. This article explores some of the areas considered vital to their success.

Safety

On the back of our ASNT Membership cards is the phrase "creating a safer world." With that in mind, it is fitting that we begin by including a few words about safety.

Electric power appears harmless. It is not snarling, roaring, or displaying claws or canines, all prehistoric danger signals we humans have learned to recognize and avoid for our survival. Electricity is just there, not obviously dangerous. It may crackle, hiss, buzz, or hum, but it does not appear to pose an obvious threat. Therefore, we must learn through training how to stay alive in this seemingly benign but potentially deadly environment. High voltage is unforgiving. You do not get second chances.

For electrical work, never enter an unknown or dangerous environment without being accompanied by qualified personnel. Always have a tailgate meeting before starting your IR survey. Learn and follow the client’s rules and guidelines with respect to safety equipment, clothing, restrictions, lockouts, etc.

Focus on Focus

The focus of a thermogram, or thermal image, can be critical for two reasons. First, it is a poor reflection on the thermographer to provide a blurry image to the client. Secondly, the temperature measurements and temperature difference measurements will be incorrect for an improperly focused image, especially when trying to measure small hot spots, and you cannot refocus after you freeze and save the image!

Take a look at the images below. The unfocused image shows a lower temperature and a lower temperature difference than the correctly focused image. Always focus carefully!

Figure 1 — Out-of-focus thermograms lead to incorrect measurements. Simulated hot spot problem from the Infrared Training Center IR camera laboratory.

Figure 2 — Correct focus produces good measurements and looks professional. Simulated hot spot problem from the Infrared Training Center IR camera laboratory.
Temperature Range

While many infrared cameras claim to be able to detect and measure objects somewhere from 4°F to 2732°F (–20°C to 1500°C), they cannot do it within the temperature span of a single image. Most modern infrared cameras break up the total temperature measurement specification into a number of defined temperature ranges.

Let us say that you are operating an infrared camera on Range 1 (–40°F to 248°F or –40°C to 120°C) and you capture a thermogram where the temperatures of the objects vary between 68°F and 392°F (20°C and 200°C). The hot objects above 248°F (120°C) will show up as white, but you cannot tell how hot they are because the data was captured on too low a range.

When analyzing thermograms, changing the emissivity or the reflected apparent temperature (Background, Tamb, or Trefl – terminology used depends on your camera) can push the reading out of range. Not all software can correct for this. If you are unsure about the emissivity of the target, save at least one image on a range where the lowest emissivity value does not cause an out-of-range condition. If the temperature difference cannot be reconciled on one thermogram within a given range, take two thermograms that will allow calculating the temperature difference later. If you are not familiar with the terms emissivity and reflected apparent temperature, do not expect to get temperature measurements with an infrared camera with any confidence. Get trained!

Finally, there can be occasions where the IR image details are important but are lost due to the range setting required to capture a hot spot. In these cases take two thermograms, one that will give IR details and one that will give proper temperature measurement of the hot spot. It is much easier to take too many thermograms than not enough.

Distance and Spot-Size Ratio

Thermal image data is dependent on distance due to spatial resolution and atmospheric interference of the infrared energy from an object. The effects of optical resolution far outweigh the atmospheric effects for most condition monitoring thermography.

Can you read a newspaper from across a room? Of course not. You need to get closer to the paper or view it through a good set of binoculars. Infrared cameras are no different! Just because you see a “hot spot” in the image does not necessarily mean that you will be able to read a good temperature. Knowledge of your camera’s optical resolution is imperative in determining the correct distance to object relationship before you save a thermogram.

The figure below illustrates this. Two thermograms of the same problem show two very different readings. One is taken with normal optics, the other just minutes later with a 3X telescope. For the set of severity criteria used by the thermographer, the temperature rise went from a minor problem without a telescope to a critical problem with the telescope. The thermographer knew the spot size ratio was much too small to get a good reading without the telescope. Had he not known this, he would have made an incorrect evaluation of the severity of the problem.

Knowledge of the “Spot Size Ratio” is necessary to properly assess the maximum distance you can be from your target and still get a good reading. Some camera manufacturers make it easy by designing a cursor that allows you to find the correct distance easily. All you have to do is move close enough (or use a telephoto lens) so that your hot spot fills the interior of the cross hairs and your measurement will be correct.
Figure 5 — Thermogram of a connector using a standard lens at 25 feet distance. Note the maximum temperature is 117° F (47 °C).

Figure 6 — A 3X telescope was placed on the camera at the same distance and now the maximum temperature has jumped to almost 572° F (300° C)!

If your target is too small to properly resolve, then your temperature reading will be lower (assuming a hot target with cooler surroundings) than the actual temperature. Don’t be fooled into thinking that if you are only performing temperature difference measurements that you are okay. Unfortunately the same thing is true for differentials. If you are too far away, the delta T’s are too low!

Thermal Tuning

We have often seen thermographers with their infrared cameras pointed at components surrounded by a clear sky—not unusual for substations or power distribution. Usually they press the auto-adjust key. This will set the level and span to some typical values from minus 40° F to plus 120° F (-40° C to 49° C), in many cases close to the entire dynamic range of many IR cameras. This greatly reduces the contrast and washes out the components so much, they cannot find any problems, where problems indeed existed.

You do not want to have the sky as part of the dynamic range. You need to have the level and span adjusted to give the best view of the components. If you are going to use auto-adjust, aim the camera away from the sky, so only ambient targets are viewed. This is such an issue that some newer cameras actually have a low offset the user can set so the auto-adjust does not go below a preset value. You want your span across the temperature range of the good and bad targets.

The goal is to have the minimum span set so you can see the targets in their ambient environment, and the problem targets are readily apparent. Figures 7 and 8 give an idea of what we are talking about. On a sunny day in the field, it is much more difficult to find problems with the level and span settings shown in Figure 7. The thermographer probably would have missed this critical problem completely.

Further adjustment and analysis can be made in the field and also on the report. Here, we are just trying to spot the problems.

Figure 7 — Poorly thermally tuned for finding problems.

Figure 8 — Properly thermally tuned for finding problems.

Solar Loading Effects

The figure below gives an example of how solar loading masks a thermal anomaly. Returning in the early morning when solar loading is minimal, one sees the problem clearly.
Some closing remarks

Compare, compare, compare. If there was ever a diagnostic technology that succeeds by comparison, IR thermography is it. This is especially true for electrical systems, as you normally have three phases at which to look.

Collectively, we have over 50 years experience in infrared thermography. One thing we have learned is that it is essential to keep active and informed. We strongly recommend that serious thermographers attend and participate in conferences, take advantage of free newsletters and internet posts, and sharpen their skills through training, seminars, and continuous experience. When asked to give advice to new thermographers, Dana Curtis, a skilled and experienced thermographer, without hesitation said, “Never let your infrared camera collect dust.”

Mr. Lyon holds a BSc degree in secondary education, Earth Sciences major. With nearly twenty years experience in the infrared industry, he has been teaching and consulting in IR Thermography since 1986, both in-house and at customer sites, in the U.S. and internationally. He had conducted ten courses in Brussels, addressing the needs of the European training demands, prior to the construction of the Infrared Training Center in Sweden. On occasion he has been a guest speaker for General Motors, Delaware Valley Power Quality Group and other organizations. Additionally, he has over five years experience in servicing, calibrating, customizing, and operating infrared imaging systems. He is an active member of ASNT, serving on two committees and has also conducted a short course on thermography for the organization.

Dr. Madding is a graduate of the University of Missouri with a BS in Physics, and a Masters and Ph. in Physics from the University of Wisconsin-Madison. He began the first infrared thermography seminar at the University of Wisconsin Extension in 1978. He co-founded the Thermosense Conference in 1978 with two other colleagues from the UW. In 2000 he founded the InfraMation Conference, the largest annual IR conference for thermographers. He has published numerous technical papers on infrared thermography applications, as well as contributing chapters to textbooks such as Applied Thermal Design and the Encyclopedia of Optical Engineering. Bob has over 30 years experience in infrared thermography applications and training.
The Anatomy of a Shermco Field Service Engineer

Odds are, you won’t find a job anywhere that a Shermco Field Service Engineer can’t handle. As one of the world’s most respected electrical maintenance and testing companies, Shermco delivers A+ service from utility transmission to low-voltage distribution.

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Successful thermography begins long before the actual field work begins. The final results for any project depend upon understanding the task to be performed, selection of equipment, operator skills, inspection techniques, and documentation of findings. Failure to understand how these factors contribute to the final conclusions can lead to serious errors. To ensure optimum results, a thermographer needs to understand the nature and reason for the inspection, all equipment and operator limitations, site conditions, and the proper documentation of findings.

**Introduction**

The use of infrared thermography as a preventive and diagnostic inspection technique is now widely recognized. The benefits of infrared thermography have led to a greater public awareness of common applications. Research continues to broaden the applications of thermography. Advances in equipment now allow thermographers to routinely perform tasks that could only be dreamed of as little as ten years ago.

Common applications of infrared thermography now include electrical and mechanical systems, structures, petrochemical, transportation and medicine. Regardless of the application, the final results depend upon understanding the task to be performed, selection of equipment, operator skills, inspection technique, and documentation of findings. Before embarking upon a project, a thermographer needs to consider and understand how these factors will influence the final results. The purpose of this paper is to define the basic elements that a thermographer needs to consider for a successful project.

**Methodology**

**Defining the Task:** Perhaps the most important and often most overlooked part of thermography is defining the project. Before any successful task can begin, the thermographer needs to determine exactly what is to be done and what is expected of the final results. This usually entails meeting with the client to discuss the subject of the inspection, any recent problems and history related to the project, and what is expected of the results. In the case of a manufacturing facility’s electrical system, a client might ask a thermographer to “conduct an infrared scan to locate hot spots.” While this might seem to be a straightforward request, it does not adequately define the task. From this request it is unclear when the work is to be performed, what type of imager is to be used, who will open/close panels covers, what verification tests are to be included, or what type of documentation is required.

Regardless of project type, it is always desirable for the thermographer to work with the client so that all aspects of the project can be defined. If the project requires skills beyond thermography such as additional electrical testing, the thermographer may elect to perform these tasks if he/she is qualified or work with others who are qualified. Once the exact nature of the task has been determined, a scope of work can be developed to define the project in a written format.

A proper scope of work serves as the blueprint for all aspects of the project. It defines what is to be done and why, and it describes which published standards are to be followed. It also describes when and where the project is to be conducted as well as who will perform the work. In short, a proper scope of work ensures that all parties know what is to be done and what can be expected at the completion of the project.
Applicable Laws and Codes: Before accepting a project, a thermographer must determine whether any part of the scope of work is governed by local laws and/or codes. In some locations, thermographers are not legally permitted to perform electrical voltage and ammeter readings since this is considered electrical work and persons must be licensed to perform electrical work. In such cases, a thermographer could elect to work with a qualified professional in order to jointly complete the project. Regardless of the type of infrared inspection, it is the thermographer’s responsibility to comply with all applicable laws and codes.

Thermographer Qualifications: Perhaps the greatest limiting factor in thermography is the thermographer. Although thermal imagers each have their limitations, thermographers can overcome this by selecting the proper equipment. This will be discussed later.

Since the thermographer is the most important factor in thermography, knowledge is of utmost importance. Unless otherwise specified in the scope of work, it is usually not enough for a thermographer to understand only how to operate a thermal imager to produce thermograms. The professional thermographer needs to have a thorough understanding of infrared theory and heat transfer principles and how site conditions and weather can influence results. At a minimum, a thermographer must also have a basic understanding of the equipment to be inspected. When a thermographer is unfamiliar with the components to be inspected, it is his/her responsibility to gain the knowledge necessary to properly conduct the infrared inspection.

A thermographer must always be an expert in his/her field and be able to honestly recognize personal limitations. Anything less compromises the final results of a project before the inspection begins.

Equipment Selection: Perhaps the second greatest limiting factor in thermography is the thermal imaging equipment. Even the best thermographer cannot compensate for equipment that is not capable of producing the desired information. Fortunately, today’s wide selection of equipment provides many choices for accomplishing the task. Modern thermal imagers offer features that not only make thermal imaging easier but provide more capabilities to the thermographer. Unfortunately, the wider selection of equipment tends to make the selection of equipment more difficult due to the large number of choices.

Unless a scope of work states the equipment to be used, the thermographer needs to select the proper equipment for the task. Some of the more important criteria for the selection are the spectral response of the imager, color options, visual and measurement fields of view, radiometric capabilities, operating limitations and image recording. The use of accessories such as filters, heat shields, and special lenses might also be required. Other important considerations include operating temperature, sensitivity to magnetic fields, and atmospheric attenuation.

A thermographer must always be aware of the capabilities and limitations of his/her equipment. Equipment should be maintained in good working order and calibrated in accordance with manufacturer’s recommendations. A thermographer must also be able to honestly recognize limitations of his/her hardware. Failure to do so compromises the final results of the project before the inspection begins.

Site Conditions: Prior to the actual performance of the infrared inspection, all pertinent site conditions must be considered. Limitations such as imager size or certain display types might preclude the use of certain equipment. Other site conditions which need to be addressed are the accessibility of the equipment to be inspected, radiation levels, airborne particles, sterile requirements, and the presence of hazardous or explosive areas.

It is the responsibility of the thermographer to speak with site personnel prior to a project to discuss all pertinent site conditions and determine how these conditions will affect the work to be performed.

Weather Limitations: Anyone who has worked outdoors can appreciate the effect weather can have on an infrared inspection. Intense summer sunlight during electrical substation inspections can make work more than a little difficult. High wind can completely obscure thermal data during an inspection while precipitation usually cancels any plans to work outdoors.

Even when weather conditions are less than extreme, weather still plays a role in outdoor thermography. In the case of an infrared inspection of an outdoor substation, the amount of daytime solar loading will have a direct effect on a thermographer’s ability to detect anomalies from midday until several hours after sunset.

In order to ensure optimum results, a thermographer needs to understand and consider how weather conditions will affect final results. When weather is less than optimum, a work postponement may be the wisest decision.

Figure 1 — Inspecting at night can help to eliminate errors caused by solar loading and solar reflections.
Additional Responsibilities: Due to client requirements or the type of project, many infrared inspections include responsibilities outside of thermography. Some common examples include:

- Recommendations for repair of electrical system exceptions
- Removal/replacement of electrical panel covers
- Ammeter/voltmeter readings

These types of requests are often coupled with an infrared inspection. In some cases, additional responsibilities are necessary in order to properly complete a project. As long as a thermographer is qualified and not prohibited by local laws and codes, he/she might consider performing this work directly. When a thermographer is not qualified to handle additional responsibilities, working with another qualified professional may be the best choice.

Documentation: The final documentation is the formal record of a project. Proper documentation details how and when an inspection was performed, who performed the work, weather conditions, any special procedures followed, the results of the work, and conclusions. The report should also include all pertinent graphics, photographs, and thermograms.

With the advent of more sophisticated imaging equipment and advances in computers, thermograms are no longer limited to black and white photographs. Color thermograms, video tapes, and flash cards are now more common than ever. Laptop computers and powerful software enable the thermographer to prepare reports while in the field.

Since the possibilities are so varied, the thermographer should consult with the client before the project begins to determine which type of documentation is best suited to the client’s needs. Above all, the report should be clear and easy to understand.

Limiting Liability: Whenever thermographers make recommendations in their reports, they accept a certain amount of liability which goes beyond the basic infrared inspection and subsequent documentation. Before offering recommendations in a report, a thermographer needs to carefully consider how much liability he/she is willing to accept. Depending upon location, providing recommendations often qualifies as professional engineering.

Professional engineering requires special insurance for professional liability. An experienced insurance agent can help to determine what type of insurance coverage amounts are appropriate for a thermographer. Your insurance agent should also be able to outline what type of recommendations are covered by your insurance. Depending on the type of information offered in a thermographer’s report, professional liability insurance may not be necessary.

Expert Witness: The ability of thermography to serve as evidence in legal cases has gained a wider acceptance in the last few years. Properly documented infrared inspections make compelling evidence with their ability to graphically present information the average person can not see.

With today’s litigious society, chances are good that a thermographer will be called to testify in a legal case. Thermographers do not always appear in court by choice. Often thermographers are subpoenaed with little or no warning. At other times, a rather insignificant inspection is suddenly the centerpiece of a legal action.

By always properly preparing, executing, and documenting an infrared inspection, the likelihood that a thermographer’s work will be allowed in court increases greatly. At the same time, the embarrassment that accompanies a substandard report is avoided.

R. James Seffrin is a Level III Certified Infrared Thermographer™ and Director of Infraspection Institute located in Burlington, NJ. He has over 21 years experience in performing infrared inspections for a wide variety of commercial, industrial, and residential applications. During his career, Mr. Seffrin has trained and certified thousands of students in the use of infrared thermography for a wide variety of applications.

Mr. Seffrin has authored dozens of technical articles on the subject of thermography and is publisher of the content-based website, IRINFO.ORG. He is also coauthor of several industry standards and is qualified as an expert witness on the subject of thermography.

Figure 2 — A properly documented report includes imagery and all pertinent data required for analysis.
Infrared Thermography for Cost-Effective Utility Service Reliability

PowerTest 2006
(NTA Annual Technical Conference)

Travis Curtis
FLIR Systems, Inc.

For utilities reliability is key. Equipment failure, and subsequent service interruptions, must be avoided if at all possible. To ensure continuity and save money, thousands of utilities have turned to infrared thermography for ongoing equipment inspection and predictive maintenance, providing benefits including:

- Delivering Uninterrupted Power
- Inspecting Equipment Under Load
- Averting Unscheduled Shutdowns
- Improving Equipment Reliability
- Maximizing Equipment Life by Making Timely Repairs
- Creating a Safer Work Environment
- Saving Thousands of Dollars for quick ROI

This presentation will highlight, through working examples, the benefits of an infrared predictive maintenance implementation.

I. Introduction*

As utilities move forward into the new millennium and a deregulated environment, market share has become increasingly more important to the survival of the organization. To achieve an acceptable market share, utilities need to provide enhanced services and/or a superior product.

One way for a utility to deliver a superior product is for it to use infrared thermography (IR) as a predictive maintenance (PdM) tool in its generating stations and on its transmission / distribution (T&D) system. Infrared thermography is a well known and highly utilized tool in many applications from building envelope and roof surveys, to medical diagnoses. As utilities increase the use of this technology and its applications within the industry, many benefits can be achieved.

By using infrared thermography, utilities can perform fast and efficient PdM over a broad area and a large number of items. Routine IR scans of critical equipment can help avoid unscheduled outages by identifying anomalies prior to failure, and allow for the scheduling of maintenance during normal working hours. By scheduling IR surveys prior to routine maintenance, anomalies can be identified, parts obtained, and manpower requirements more accurately estimated to address all aspects of a component's functionality. By identifying anomalies at an early stage of development, component deterioration can be minimized, resulting in less expensive maintenance and increased life expectancy.

Finally, IR surveys can be used to verify the integrity of work performed and help identify poor work practices.

The results of performing IR surveys in the delivery of a superior product are:

- Increased utility system reliability
- Increased safety for both utility employees and the general public
- Reduced environmental contamination—a burning transformer or oil filled circuit breaker can produce significant environmental hazards.
- Reduced maintenance costs for the utility by reducing the amount of maintenance work and parts required, and reducing the number of emergency restoration calls
- Reduced customer lost production and downtime due to fewer outages, resulting in increased customer pro-
duction and revenues, and therefore increased utility revenues through increased electricity sales
• Increased utility customer retention and acquisition due to higher customer satisfaction

II. Predictive Maintenance Assessment Program**

The mission of a PdM assessment program is to improve and optimize grid reliability through the deployment of a multidisciplinary diagnostic program of equipment monitoring.

Typical elements of this program are:
• PdM technical lead
• Maintenance initiatives
• Infrared diagnostics
• Acoustical diagnostics
• Vibration analysis
• Technical reporting
• Technical recommendations

With all these elements in place, and by means of Predictive Maintenance Assessment reports consistently demonstrated and documented failure avoidance and cost avoidance may be achieved. An Infrared Thermography Inspection program in particular can have the most dramatic effect on results in this regard, as shall be demonstrated by examples given later in this paper. Management support and “buy-in” is crucial to any program of this kind.

The importance of “selling” the program to PdM team members as well as to Management cannot be emphasized enough. While Management’s major concerns involve meeting business goals and maintaining profitability, the goals of the team members revolve more around job satisfaction, recognition of contribution by Management and personal enrichment and advancement. Both want a safe working environment. Working with one of the most modern and powerful technologies, such as infrared thermography, goes a long way toward achieving these goals.

Field personnel also benefit by the success of the program. Frequent systematic inspections, meaningful findings and timely maintenance and repair optimize personnel and facility safety, minimize down time and enhance the job satisfaction of field operating personnel.

Another critical element to the program is emphasizing the concept of a “team effort”. Effective communications among team members is essential. The need to “close the loop” on any finding must remain foremost in the minds of all team members.

III. IR Inspection Plan Development & Sample Implementation***

Planning is the first step in successful electrical substation inspection. One simple to follow method is: Start at the top and work down! This may seem elementary, but it works well. To ensure that nothing is overlooked, inspect all high voltage structure equipment first – structure mounted potential and current transformers, air break switches, bus connections, and substation line terminations.

![Figure 1a](image1.png)

![Figure 1b](image2.png)

![Figure 1c](image3.png)

Figure 1a-1c: 69KV Potential Transformers. Empty Bushing on Left

Be very careful with camera settings. Figures 1a and 1c show the same components. If slight thermal variations are present and go undetected, extremely dangerous situations may be overlooked! Thermal tuning is crucial!

For more information: sale@nhatha-electric.com
Figures 3a-3b: 69KV Line Connections supporting substation

After high voltage structure inspection is complete, evaluate distribution equipment, including main substation transformers, regulators, circuit breakers, and low voltage disconnect switch structures.

Figures 4a-4c: 25MVA Transformer

A quick scan of the high voltage structure easily detects these types of problems.
Thermal levels in load tap-changer tanks should be lower than in the main tank. The images above indicate a critical condition within this tap-changer! We recommend taking an oil sample and analysis to verify the problem, as removing the transformer from service and opening the tank is a major task.

All three images above show conditions thermographers may encounter. Figure 5a shows connection problems on secondary bushings. Figure 5b indicates a secondary core ground that allows iron of the winding structure to become a current path. Figure 5c shows malfunctioning radiators. All three conditions may cause premature unit deterioration.

When evaluating transformers and regulators, it is important to view from many different angles. From Figure 6a, one might assume this regulator has an adequate oil level for proper radiator function. Figure 6c indicates differently!
Figures 7a-7c: 14.4KV Vacuum Circuit Breakers

Not all elevated readings indicate abnormal situations. An inspector might think an internal control wiring problem exists in the breaker shown in Figure 7a, but that is not the case. In fact, that image is normal. The control cabinets of outdoor switchgear are heated. The heater of the circuit breaker control cabinet in Figure 7c is inoperative, and in danger of moisture encroachment, one of leading causes of switchgear failure.

Figures 8a-8c: 15 KV Disconnect Switches: Before & After Replacement

The problem most frequently encountered will be overheated disconnect switches. Usually, only cleaning, adjustment and lubrication, are necessary to eliminate that condition, but not always! When extreme cases are documented, it is important to re-evaluate after maintenance is performed. If the condition persists, replacement may be required.

In our example, all outside inspections are now complete. Briefly examine the entire station yard visually to ensure that nothing was overlooked, as structure-mounted equipment is often hard to locate, making this will be time well spent.

Then move indoors. Most substations have control houses, but not all. In either case, protected areas are established where the controls and monitoring systems are located.

Loose connections and overloaded circuits are the most common control system problems. Also check heating systems’ operation to maintain an environment suitable for relay and control systems.
Figures 9a-9c: Common Control System Problems

Often, tightening a terminal screw is all that is needed. Even if this is the case, allow time for cooling to ensure that the problem is resolved. Other conditions that may cause this abnormal thermal signature include improperly pressed crimp connections, broken terminal screws, and deteriorated control wire. The problem source must be positively identified and eliminated, or system protection may be jeopardized.

Figures 10a-10c: Overloaded Circuits

Inspect all control wiring for overloaded circuits. Under-sized wire or excessive current levels can cause this condition. In either case, this condition poses an extremely dangerous situation. Control system failure can have catastrophic consequences!

IV. Conclusion*

IR is an extremely useful PdM tool that can help identify problems in utility generating stations and on its transmission and distribution system. Its use in a PdM program can help avoid emergency restorations, help identify additional issues to be addressed during routine maintenance, minimize component deterioration which extends component life cycle, and verify work performed and bad work practices. All these benefits lead to reduce utility maintenance costs and parts stock, increased system reliability, increased utility and customer revenues, and increased utility customer retention.

When a program is developed, it is important that each phase be thought out and developed carefully, and allowed to change, improve and mature with experience so that the program becomes an efficient, cost saving, and irreplaceable tool for the company. This will help to insure the highest reliability on the transmission and distribution system, while minimizing repair cost to the company. In this way, the company will be able to deliver a superior product to its customers and increase its share of the market place.

IV. References


**Excerpts from “How Infrared Thermography helps Southern California Edison Improve Grid Reliability”, Bob Turnbull and Steve McConnell, Southern California Edison, from InfraMation 2000 Proceedings


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Infrared Thermography: Yesterday and Today

NETA World, Summer 2006 Issue

by John Snell
Snell Infrared

As the workforce ages it becomes more and more important to record—for posterity if nothing else—what things used to be like. “When I was…” or “Remember when…” are both common lead lines for many water cooler discussions in shops around the country. Often the “olden” ways were actually better! In other cases, we’ve just forgotten how bad they really were or we are too “crusty” to admit the new ways are, in fact, better.

As many NETA members are graying—and even retiring—infrared cameras are turning younger and even more “red hot” than ever before. They are also getting smaller, cheaper, and easier than ever to use, and the trend is definitely going to continue. Today’s thermographers can’t really appreciate how good they have it. That’s not all bad because they are already pushing today for an even better tomorrow.

That said, real men (and a few real women too) remember earning their stripes in the “good old days.” Maybe we should just think of it as an early form of “seat-of-the-pants certification.”

Perhaps you recognize yourself in one of the following scenarios:

• Do you remember waiting ten minutes for a single image to be created by this amazing “new and modern” infrared scanner (1968)? Thankfully, cameras today operate in “real time,” at anywhere from 9-2000 frames per second.

• Don’t you miss lugging 30-50 pounds of camera, processor, batteries, coolant, cables, and other assorted stuff around?

No need to become an “infrared body-builder” anymore! Nearly all cameras on the market today weigh less than two pounds.

• It is hard to believe, but we had to use “gray scale step levels” and a programmable scientific calculator to determine temperature from the thermal image. Today? Most cameras are actually powerful handheld computers that are fully radiometric allowing for very sophisticated temperature analysis to be done with just the push of a button or two.

• Probably the single most dramatic change over time, however, has been price. Even five years ago nearly all the systems on the market were priced at $40,000 or more.

For more information: sale@nhatha-electric.com
Thanks to competition and manufacturing innovations, today there are many excellent choices for cameras under $20,000 and even a few very good systems for under $10,000.

In the “good old days” only a few of us were in this business. It was a big deal to buy the camera and learn what we were doing. Training was not easy to get and, honestly, sometimes I wondered how much any of us, students or instructors, really knew about the very complex subjects (heat transfer and machine failure) we were dealing with.

Nowadays? Anyone can buy an infrared camera on eBay and even more people are jumping into the market to buy brand new cameras. Some of them know what they are doing and many, many others do not. I predict it will get worse before it gets better. Unfortunately in the rush to market, the label “certification” has lost almost all of its real meaning. There are few, if any, regulations on who can use thermography or how they use it. NETA members should be protective of their credentials in a market where differentiation is critical to success.

Has our vision of how to use infrared changed as much as the equipment? Too many who are involved in maintenance still perceive this as an expensive technology best used to measure temperatures of hot spots during an annual inspection. Others have progressed beyond this thinking. The bottom line is they are using the technology to get new customers and to keep their existing customers happy! There are few tools better at either than these.

Infrared cameras are now so accessible that many use them on a daily basis. One day they may provide baseline thermal data about a new installation or a repair of electrical equipment, either for the customer or the contractor. The next day a technician may be troubleshooting a machine with a variety of tools and the infrared camera helps show the “big—thermal—picture” with details filled in by other tools. Regular inspections are still a part of how thermography is being used, but they are no longer done only on an annual basis to find problems. Inspection statistics and return-on-investment calculations drive the frequency of inspection to ensure the availability of reliable electrical assets at all times.

A commonly used inspection protocol in “days of old” was to open up a long line of enclosures put your tools down and come back to inspect all of them with the infrared camera. No more!! Safety alone has caused us to open only one at a time, and then only after we have looked at the outside and, perhaps, listened to it with airborne ultrasound to detect possible problems. We also discovered that the equipment cooled off waiting for us with the doors open! By the time we looked at the thermal image, many problems had cooled below the threshold of detection and others that we did find were cooler than they had been before we came along. We now get much more accurate and representative inspections than in the past, and, of course, all done with a much higher level of safety.

While all of us hope to not find “hot spots” during our work, when we do, we now think of them in a different manner than we did in the past. First, we know thermography can help us determine the root cause of a problem. For instance, a large number of problems found in a particular brand of fused disconnect switch caused one large company to go back to the manufacturer about it. They worked together to find the root cause (dried grease) and better routine preventive maintenance strategies (cleaning and regreasing) that drastically reduced future occurrences.

When we find a hotspot nowadays, we don’t just quickly look at the temperature, classify it in a temperature-based category, and move on. First we ask ourselves “Are conditions such that if a problem exists, I’ll see it?” If the answer is “yes,” we can continue with confidence. But if not, for instance if loads will be getting much heavier in the near future, then we know some problems may not be detectable at this time. We can either proceed cautiously or reschedule the work to a time when loads are higher and any problems can be detected. This remarkable technology, it turns out, is best used as one of many tools rather than an end to itself! And it certainly is not a substitute for good, critical thinking, a skill essential to the work of electrical specialists.
Reporting has gotten much easier since the days of Polaroid pictures and typing reports on the old IBM Selectric! Digital images can be adjusted and analyzed in the computer and then quickly dropped into a report template and “PDFed” (that did not even used to be a word) and emailed to the customer, often before you leave the jobsite. The time savings is stunning!

Another huge change in the way we use thermography is around personnel safety. I’m embarrassed to remember standing around with a bunch of people looking at a transformer bushing — so hot you could smell it! — talking about what we thought the problem might be. Of course, we wore no flash protection to speak of and had no idea about flash boundaries.

Today I would not even think of working without proper PPE. Some activities require such a burdensome level of PPE that we’ve changed our entire inspection procedure so that we can work safely. That may include powering down or using airborne ultrasound instead of infrared. Regardless of the situation, we get in, get the image and get out of the flash zone to do our analysis so that we stay out of harm’s way as much as possible.

In more and more cases we see customers installing and using view ports and/or infrared transparent windows. I remember hours spent helping remove the covers of enclosures before we could even begin the infrared inspection. It was both dangerous and time consuming. Ports and windows, properly installed and used, make inspections much easier, faster, and safer.

We also used to think we could measure the temperature of anything if we just set our emissivity correction properly. We now know that is not true. When we are looking at any metal surface that is as shiny as the dirtiest coin in your pocket, accurate temperatures are hopeless! Of even greater concern than measuring the temperature is whether or not we’ll even see the hotspot in such a case. Although standard procedures do not yet exist for it, we are seeing more and more customers apply some sort of high-emissivity target material to low-emissivity surfaces. This allows for a much higher certainty of detection and measurements accurate to within a few degrees.

So much has changed both with the tool we use and with how we use the tool. I suggest if you are still using old tools, check out the new ones. While your old system may still “work just fine,” you will probably get much better results upgrading to one of the new systems. And if you are still using this technology the old way, think again! Sometimes I still catch myself writing 19—on a check or a letter (yes, I still hand write some letters!) and then I remind myself the way we do many things has changed, including writing and using infrared. Welcome to 2006—a great New Age for thermography and thermographers!

John Snell of Snell Infrared, Montpelier, VT has trained thousands of people to use this remarkable technology in the past 20 years. His company works with all the major suppliers of IR systems to provide their customers with training, while remaining 100 percent independent of the sale of any particular product. To learn more about IR cameras, call them at 800-636-9820 or visit their website at www.snellinfrared.com, to view links to suppliers as well as a very active messageboard.

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Infrared Inspections and Applications

NETA World, Winter 2006-2007 Issue

by Don A. Genuts
Group CBS

Instrumentation

Infrared equipment used for electrical inspections range anywhere from handheld spot thermometers to sophisticated imaging devices with high-resolution thermal and visual color displays. The popularity of infrared technology is apparent today by the wide price range and variety of instruments available. For the successful service provider, instrument cost is secondary to having equipment that provides high-resolution images and allows for accurate and efficient report writing. Features such as user-friendly software can automate the process of collecting, reporting, and archiving infrared images and thermal data. Sophisticated features such as Blue Tooth voice comment recording, built-in auxiliary laser target-pointing devices, and visual (conventional camera-type) imaging can add to the instrument cost but can greatly assist report accuracy and efficiency. When choosing an infrared instrument, one must consider these features along with their associated costs.

Personnel Qualifications

The following statement obtained directly from the NETA Maintenance Testing Specifications summarizes the need to have Infrared Technicians possess a broad range of both electrical and thermography experience. “It is a necessary and valid requirement that the person performing the electrical inspection be thoroughly trained and experienced concerning the apparatus and systems being evaluated as well as knowledgeable of thermographic methodology.” Without extensive experience and training in both disciplines, improper diagnostics may result in unnecessary repairs, or leaving the customer with misinformation that results in reduced electrical reliability.

Typical Applications

For electrical systems, infrared instruments are generally used to identify current-carrying conductor anomalies. Over time, connections become loose from cycling temperature variations due to loading fluctuations and vibration associated with electrical equipment operation along with many other factors. Higher resistances occur across these problem connections, and heat is created based on the associated I2R losses. Heat is indirectly measured by the objects emissivity using the infrared instrument. Left unattended, these problem connections worsen over time and eventually lead to complete failure. Infrared technology is capable of identifying these problems and should be incorporated into annual maintenance plans. Other conductor problems that generate heat and can be detected by infrared instruments include overloaded circuits and circuits with substantial harmonic content. Dirty, corroded, and damaged connections or faulty contacts can also be detected.

Benefits

A major insurance carrier estimates that approximately 25 percent of all electrical failures are attributed to faulty electrical connections. Therefore, many insurance firms are the driving force behind requiring facilities to conduct annual infrared surveys. Infrared technology has evolved into one of the best overall technologies for preventing failures and has the added benefit of not requiring an outage to perform, as it can be done on line. Several additional benefits of infrared technology are listed below:

The testing is nondestructive.

Infrared technology allows you to “see” the thermal image.

The results can be trended and compared to previous results.

Pictures taken of the problems can provide a record of the problem.

The results may be used for prioritizing repairs.

The infrared survey is relatively economical.
The technology helps increase reliability.

The technology is predictive in that it identifies problems before complete failure or damage occurs, thus allowing for a proactive maintenance approach or program.

When Is It a Problem?

It is not necessarily easy to properly detect and diagnose an electrical problem with infrared technology. This is why having a technician with the right combination of electrical and thermography experience is so important. Technical knowledge and field experience in electrical testing are mandatory prerequisites for nonroutine problem identification and for recommending corrective actions. However, the following guideline taken from NETA Maintenance Testing Specifications provides a good general reference in regards to temperature differences and their associated severity level.

<table>
<thead>
<tr>
<th>Temperature difference (ΔT) based on comparisons between similar components under similar loading</th>
<th>Temperature difference (ΔT) based upon comparisons between component and ambient air temperatures</th>
<th>Recommended Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1ºC - 3ºC</td>
<td>1ºC - 10ºC</td>
<td>Possible deficiency; warrants investigation</td>
</tr>
<tr>
<td>4ºC - 15ºC</td>
<td>11ºC - 20ºC</td>
<td>Indicates probable deficiency; repair as time permits</td>
</tr>
<tr>
<td>- - - - -</td>
<td>21ºC - 40ºC</td>
<td>Monitor until corrective measures can be accomplished</td>
</tr>
<tr>
<td>&gt;15ºC</td>
<td>&gt;40ºC</td>
<td>Major discrepancy; repair immediately</td>
</tr>
</tbody>
</table>

Another infrared application for fluid-filled transformers is to compare the temperature of the load tap-changer (LTC), if so equipped, to that of the main tank. Generally, the main tank temperature should be warmer than the isolated LTC tank. Similar temperatures can indicate dangerous leaks between the two tanks or severe “coking” or arc debris buildup on the LTC contacts.

Overheating of dry type transformer core assemblies can provide indication of serious core delamination problems which can allow eddy currents that are responsible for inefficiencies resulting in increased thermal and electrical losses. This abnormal heating also causes winding insulation deterioration and reduces the life of the transformer. Associated follow-up electrical tests should include checking for proper operating voltages, individual phase loading and balance, and an analysis of harmonic content of the load.
Switchgear

A great deal of investment is presently being made in the installation of thermal viewing ports for switchgear. These ports allow infrared inspections to be performed without removing switchgear covers, thus significantly reducing or eliminating worker arc flash exposure. The installation of permanent infrared sensors and continuous infrared monitors are also viable methods for recognizing potential thermal failures of critical equipment.

The integrity of outdoor switchgear assemblies is often compromised by defective strip heaters. The strip heaters increase the switchgear temperature slightly above ambient in order to prevent condensation during daily or seasonal temperature changes. The functionality of these strip heaters and their effectiveness to perform this duty can be determined by performing thermal imaging of the switchgear enclosures. In other words, and once again, the absence of heating identifies a potential problem.

Medium-Voltage Splices and Terminations

Although many problems associated with splice and termination components are related to insulation failure that can be identified by on-line partial discharge surveys, still many problems are associated with conductor integrity. Several utilities require infrared scanning of underground vault splice assemblies before personnel are allowed into these areas. In this capacity, infrared is used as both a safety and a reliability tool. Additional infrared applications include the inspection of pad-mounted transformer premolded elbow assemblies. One utility estimated that approximately 30 percent of its elbows had been found with thermal problems due to connection, probe, or crimp deficiencies.

Low-Voltage Bus Duct

Low-voltage bus duct assemblies are popular for facility applications that require distributing high currents for long distances due to their lower installation cost compared to conduit and cable. Although very reliable, these assemblies are very difficult to test by conventional methods due to limited access caused by their construction. Infrared inspections are one of the few technologies that can help identify bus segment contact problems at joints. Infrared inspections must generally be performed by scanning the outside bus duct enclosure. Although significant air gaps exist between the bus and enclosure, this technique has been successful in detecting connection problems. Without detailed internal bus construction information available, the technician should investigate even slight temperature differences occurring at the enclosure near bus segment connection points or coupling joints.

Additionally, bus-plugs or bus-taps depend on a very limited amount of contact area. These points of contact are further dependant on spring tension and are, therefore, especially vulnerable to overheating conditions. Many times this is caused by conducted heat from failing contacts or terminations within the bus-plug assembly.

Heat run tests, also known as continuous-current, temperature-rise tests, are generally conducted by the manufacturer in order to verify adequate conductor size for the application. However, occasionally applying high currents to bus or circuit breakers in the field can reveal problems that may not be apparent during normal operation. The cost of performing this test generally limits its use to problem troubleshooting when other testing avenues have been exhausted.

Noncurrent-Carrying Items

Many times other problems can be spotted with ancillary items which normally do not carry current and, therefore, (mistakenly) are not part of the normal infrared survey. Thermographers, experienced in the vastness of potential problems, will many times glance around in their field of view and spot other items radiating heat (or not radiating heat), which will raise their curiosity level to the point of a closer look. Many times a metallic structural support, cable-way, or cable tray assembly, none of which should be carrying current, will indicate heating that is apparently from electrical current flowing. Field measurements of hundreds of amperes have been seen numerous times and are most commonly the result of excessive eddy currents caused by inductive heating. This heating effect can cause the surface temperature to rise well beyond the boiling point of water, potentially presenting a burn hazard to personnel or the deterioration of other substances in close proximity.

Grounding connections normally do not carry continuous current; therefore, a ground connection showing any increase in temperature can indicate a possible problem. Further investigations of these types of problems have uncovered a variety of issues, such as ground loops, broken or disconnected grounds, and high impedance faults.

Conclusion

The infrared survey is a great initial screening or detection tool for potential problems, but additional electrical tests should be performed in order to confirm initial conclusions. It is extremely easy to have a false positive thermal image; therefore, other measurements such as millivolt drop tests, current readings, harmonic analysis, power factor, and others should be performed on suspect observations. These additional tests are mandatory as certifiable test results may be necessary or required for investigative or litigation purposes.

Deluxe or premium camera systems can fix many field errors after the image has been stored, but basic fundamental errors such as focus, range, or distance cannot be corrected after the survey. Additional common mistakes are incorrect emissivity settings or assumptions and reflected or indirect contributions.

Lastly, the infrared survey remains one of the best overall tools for detecting potential electrical problems. The popularity of the technology and the low cost of equipment have allowed nonexperts to implement infrared survey programs.
However, the additional cost associated with upper-end equipment and experienced technicians with certified training may very well be worth every penny when important decisions are made based upon infrared survey results.

Other Acknowledgements:

The author would like to thank Harold Orum of Halco Service in Los Angeles, CA for his valuable assistance with this article. Harold is a NETA Affiliate and has accumulated more decades of electrical experience than he will admit to.

Mr. Genutis received his BSEE from Carnegie Mellon University, has been a NETA Certified Technician for 15 years, and is a Certified Corona Technician. Don has nearly twenty-five years of practical field and laboratory electrical testing experience. He is presently serving as Vice President of the Group CBS Eastern U.S. Operations and acts as Technical Manager for their subsidiary, Circuit Breaker Sales & Service located in Central Florida.
Electrical Inspections with the Use of Infrared, Ultrasound and Ultraviolet Technology

PowerTest 2008  
(NETA Annual Technical Conference)

Craig Casler  
Absolute Infrared Inspection Services

Abstract

The purpose of this paper is to show how thermography, ultrasound & ultraviolet equipment compliment each other for electrical inspections providing a more valuable use of the inspection service.

While performing an electrical inspection some anomalies may be detected with the infrared camera and not the ultrasound as well as with the detection of corona and vise versa. The infrared inspection will detect resistance and current related anomalies along with some corona. The ultrasound can detect high frequency noises associated with corona and arcing. The ultraviolet or corona camera can produce images of corona locating the anomaly for repair. All of these anomalies can be harmful to electrical components if gone undetected.

Providing all of these services increases the potential for detecting harmful and destructive problems.

Infrared, Ultrasound and Ultraviolet

There isn't much more depressing to a customer when an infrared inspection was performed and a hot bushing on the low voltage side of a transformer was detected as an area of concern and repaired then the transformer fails due to an unknown problem on the high voltage side H3 arrestor and the customer wants to know why after he assumed the infrared inspection would solve those types of problems. Educating the customer is the first priority on what will be found during an infrared inspection and what other potential problems exist.

Providing both of these services at the same time increases the chances of detecting potentially harmful problems, broadens the service provided and lessens the chances of a potential failure.

Independently each of these tools is a great asset to predictive & preventative maintenance programs and in many cases having a second opinion is a luxury when both of these tools can detect and anomaly normally gone undetected.

Most components have their own thermal signature during normal operating conditions. Being able to recognize out of place temperature patterns with the infrared camera is a valuable aid in monitoring the operating condition of...
this and other types of equipment. In normal operating oil filled transformers, the higher concentration of heat is more toward the top (not the bottom) and understanding the oil is vital to aid in keeping the coil in transformers cool. Further investigation revealed 150 gallons of sludge in a 528 gallon tank in this particular transformer.

In many case the thermal image will reveal good looking components but the ultrasound produces potentially hazardous results. A high voltage discharge was detected at the top of the H 3 arrestor. Once the report is turned over to the customer a closer look will likely reveal the source of the problem. In this case the electrician could not find the source of the discharge. One year later at the annual inspection the sound of the discharge was greater and a burn mark was easily visible on the top ring of the arrestor. Because it was not easily visible the first go around the electrician moved on. The conditions were favorable for the ultrasound both times and the electrician learned to look harder and I left this experience with the confidence of the customer in the services provided.

In some cases the concentration of heat may be higher but oil circulation may not be good with in the cooling fins still maintaining a higher than normal oil temperature.
A return visit was scheduled in the evening when the transformer could be shut down to remove the arrestor’s plastic cap. This arrestor had a corona discharge on the end of the wire. Corona video enabled the electrician to understand the cause of the arching and make repairs.

The following year this transformer was re inspected during the annual inspection of electrical equipment. Another location of discharge was detected with the ultrasound and corona video was captured with the corona camera. The arching was coming from the top of the pistol grip near the base of the connection.

This newer transformer belonged to the power company. The customer and the power company where reluctant to open the doors or even include it in the inspection. The customer thought it may be a waste of time because the transformer was only a year old. The discharge was strong enough to be heard through the doors. Once the customer had a listen, the customer gave it a second thought. When the door was opened, it only took a second or two for the black marks on the metal next to the wire and the burn marks on the wire to drop jaws realizing maybe it wasn't a waste of time. Fortunately the plant was scheduled for a power shut down that afternoon and the repair was made.
During a routine inspection of 35 Kv distribution equipment a discharge was detected with the ultrasound. Further investigation with the ultraviolet camera revealed corona discharge at the right cut out. Once the cut out was replaced a large crack in the insulator was visible. The crack could not be seen from a distance but was easily seen once the cut out was in hand.

This corona was detected during a routine inspection of power distribution equipment as well. Visibly a potential problem existed. Two separate phases in close contact with each other raised suspicion. The ultrasound picked up on the corona discharge and the corona camera was used to capture the corona image and video to show what needed to be done to correct this potential hazard. Simply enough separating these wires with enough distance the field of energy between the two wires dissipated.
High voltage components may or may not be insulated. The most important part is that they stay within the confines of the insulation value they have or do not have maintaining a distance that complies with that field of energy given off by the component. When two fields of energy such as this comes in close contact it produces the corona seen here. In some cases a nick or crack or wear mark or some type of damage in the insulation of wires or components will bring these fields of energy in close contact when there distance may have been good to begin with. This close contact may be phase to phase or phase to ground.
In advanced stages the corona will generate heat that can be detected with the infrared camera. The heat is slight in some cases not easily detectable and in very advanced stages more pronounced temperatures are detected.

Commonly electrical distribution components exposed to road dust, salt from winter time, elevated road conditions higher than electrical components, or near salt water or sea water, are more prone to corona build up. In some cases a fresh rain after a long winter will wash deposits from electrical components reducing corona activity.

The more destructive and shorter lived corona activity will come from damaged or improperly installed components while the nuisance corona can last for months even years before becoming destructive it may still be damaging over time.

Some corona can also be seen visibly if the conditions are right. Damp or rainy nights are ideal conditions for corona.
Lightening Arrestors – are lightening arrestors supposed to generate heat?
Technically they can and will, is it a sign of a problem, it can be but will require more investigation work.
Typically found in the MOV arrestor.

Conclusion:

Bringing all three of these technologies together can make great difference in predictive & preventative maintenance of high voltage components.

- Infrared will pick up on resistive or current related anomalies and well as some corona activity in advanced stages.
- The ultrasound is a great tool for detecting tracking or arcing as well as corona activity.
- The ultraviolet camera brings the corona activity to light so proper corrective action can be taken.
- All three of these tools have multiple capabilities and will easily earn their keep if put to good use.

There are no fancy high profile people, standards or references written into this paper just a whole lot of experiences to pass on and I hope it has been helpful and useful information.

Craig Casler, CDT is the owner of Absolute Infrared Inspection Services. He is a Level III Thermographer, Level II ASNT, and Level I Ultrasound. Craig has presented at several conferences including the thermal solutions Infrared Conference in January of 2006 and 2007, and the Reliability PDM conference in September of 2007. He presents Infrared to Apprentice Electricians, Roofer, and Technical Trade Students and was published in the American Concrete Institute's Concrete International Magazine in August 2006.
The following is a listing of all NETA Accredited Companies as of August 2011. Please visit the NETA website at www.netaworld.org for the most current list.

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Advanced Testing Systems ................................................................. Patrick MacCarthy
American Electrical Testing Co., Inc. ................................................ Scott Blizard
Apparatus Testing and Engineering ................................................ James Lawler
Applied Engineering Concepts ........................................................ Michel Castonguay
Burlington Electrical Testing Company, Inc. ........................................ Walter Cleary
C.E. Testing, Inc. ............................................................................... Mark Chapman
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About NETA

NETA (InterNational Electrical Testing Association) is an association of leading electrical testing companies; visionaries, committed to advancing the industry’s standards for power system installation and maintenance to ensure the highest level of reliability and safety.

NETA is an accredited standards developer for the American National Standards Institute (ANSI) and defines the standards by which electrical equipment is deemed safe and reliable.

NETA is also the leading source of specifications, procedures, testing, and requirements, not only for commissioning new equipment but for testing the reliability and performance of existing equipment.

QUALIFICATIONS OF THE TESTING ORGANIZATION

An independent overview is the only method of determining the long-term usage of electrical apparatus and its suitability for the intended purpose. NETA Accredited Companies best support the interest of the owner, as the objectivity and competency of the testing firm is as important as the competency of the individual technician. NETA Accredited Companies are part of an independent, third-party electrical testing association dedicated to setting world standards in electrical maintenance and acceptance testing.

Hiring a NETA Accredited Company assures the customer that:

• The NETA Technician has broad-based knowledge — this person is trained to inspect, test, maintain, and calibrate all types of electrical equipment in all types of industries.

• NETA Technicians meet stringent educational and experience requirements in accordance with ANSI/NETA Standard for Certification of Electrical Testing Technicians, (ANSI/NETA ETT).

• A registered Professional Engineer will review all engineering reports.

• All tests will be performed objectively, according to NETA specifications, using calibrated instruments traceable to the National Institute of Science and Technology (NIST).

• The firm is a well-established, full-service electrical testing business.

CERTIFICATION

NETA Certified Technicians conduct the tests that ensure that electrical power equipment meets the ANSI/NETA standards’ stringent specifications.

Certification of competency is particularly important in the electrical testing industry. Inherent in the determination of the equipment’s serviceability is the prerequisite that individuals performing the tests be capable of conducting the tests in a safe manner and with complete knowledge of the hazards involved. They must also evaluate the test data and make an informed judgment on the continued serviceability, deterioration, or nonserviceability of the specific equipment. NETA, a nationally-recognized certification agency, provides recognition of four levels of competency within the electrical testing industry in accordance with ANSI/NETA Standard for Certification of Electrical Testing Technicians, (ANSI/NETA ETT).