Infrared & Ultrasound Unite

The Perfect Match for Metal-clad Switchgear Inspections

by James Brady

Infrared technology has revolutionized the electrical maintenance industry by providing a means of non-contact and non-destructive testing to identify eminent failures related to compromised components and connections before they occur. But even with regularly scheduled infrared inspections in place, electrical failures of switchgear above 3500V occur; usually with little advanced warning or understanding about the cause. This leaves maintenance personnel scratching their heads and wondering if their infrared program is missing obvious problems and/or if their predictive maintenance program has deficiencies of which they are not aware.

The likelihood of an infrared inspection missing obvious problems is low as long as the person(s) conducting the survey possesses the proper training and experience. However, if infrared is the only predictive maintenance technology employed to inspect high-voltage switchgear, there is a high probability that potential problems are being missed that can lead to failures.

Electrical discharge in the form of corona and tracking has caused numerous shut-downs and serious damage in metal-clad switchgear. Because corona and tracking conditions are voltage problems that rarely produce heat, they go undetected during a typical infrared inspection. Fortunately, the combined use of ultrasound and infrared when performing a switchgear inspection will provide early detection of both heat and non-heat producing problems.

Several years ago, I was introduced to ultrasound technology at an infrared conference. After realizing the applications and benefits of this predictive maintenance tool, we were soon offering this service as a routine part of our infrared inspection business. That decision has more than paid for itself by finding critical electrical problems for our clients that would have otherwise gone undetected using infrared alone.

This article will attempt to take the mystery out of the occurrence of corona and tracking in metal-clad switchgear by discussing its characteristics, what to look for during an inspection and case studies that have been documented during actual inspections.

What Are Corona and Tracking?

Corona refers to the faint glow surrounding an electrical conductor of 3500 volts or greater, which occurs as a result of the ionization of air as the nitrogen in the air breaks down. When corona occurs, it creates ozone (detrimental to the human lungs, eyes, etc.), ultraviolet light, nitric acid, electromagnetic emissions and sound.

Ozone is a strong odorous gas that deteriorates rubber-based insulation. If moisture or high humidity conditions exist, nitric acids can also be formed that attacks copper and other metals. The electromagnetic emission can be heard as interference on AM radios and the corona sound can sometimes be heard by the human ear and is detectable with ultrasonic scanning devices.

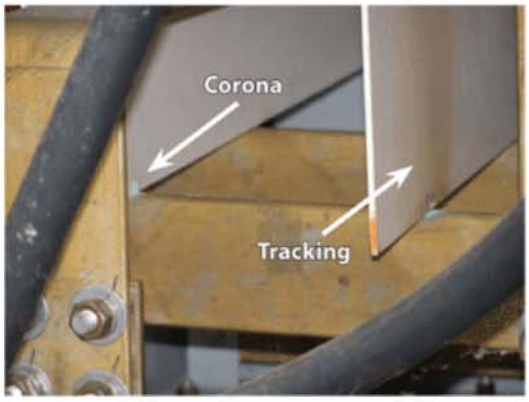


Figure 1 - Corona activity advancing to the tracking stage on insulation board resting on 13kV bus. Notice the carbon deposits and light brown discoloration of the insulation board insulation board on the right.

Corona is a by product of voltage problems and can be present without current flow (i.e. under no load conditions). High potential in the electrical field is the major dictating factor for its presence. Corona activity is at its strongest on the positive (+) and negative (-) peaks of the 60Hz cycle.

Once corona becomes active it leaves behind a conductive "tracking" path on surfaces and also creates a very conductive cloud of air around itself (Figure 1). A flash-over can occur once a "tracking" pathway is completed from phase to phase or phase to ground. It can also occur from the conductive cloud of surrounding air if it finds a path to ground.

What Causes Corona?

Based upon numerous observed conditions of corona, I have concluded that there are three primary causes for its

development: geometric factors, spatial factors, and environmental conditions. Other more subtle conditions may also exist, but the three discussed in detail below are the most common contributors to most problems you will face.

Geometric factors include sharp edges on conductors, connections, and switchgear cabinet components. These features can include sharp or squared surfaces on conductors (Figure 2), tag ends on conductors, sloppy tape wraps, and corners and other sharp edges on cabinet bracing and support shelves.

Figure 2 - A sharp edge on a piece of copper bus provides an excellent spot for corona activity.

Spatial factors include small air gap spaces between, conductors and switchgear cabinet components. Examples of this include: 1) conductors being tie-wrapped together, 2) conductors touching insulators, conduit, and edges of cabinets, 3) non-shielded cables in contact with grounded surfaces, and 4) bus bars in close proximity to insulation board (Figure 3).

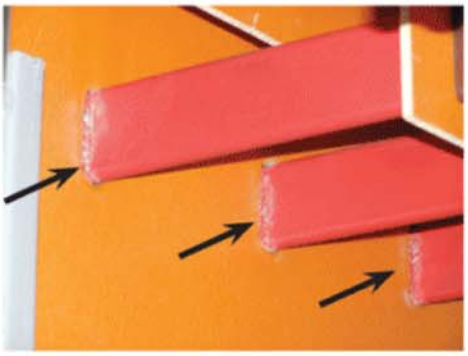


Figure 3 - Corona deposits resulting from small air gap spaces between insulation board and 13kV bus bars.

Finally, **environmental conditions** can also greatly affect the presence of corona and tracking. Contamination in the forms of dust, oils/fluids, and other particulates on conductors and insulators will create corona. Also, switchgear rooms that are hot because of poor air circulation and cabinet enclosures that are subject to wet or humid conditions are more likely to have corona and tracking activity over those cabinets that are kept cool and dry. For these reasons, it is important to make sure that cabinet heaters and fans are working properly.

Signs of Corona and Tracking

There has been much written claiming that the most noticeable sign of corona will be the smell of ozone, since this is, after all, the major by-product of corona. I have not personally smelled ozone in switchgear cabinets, but one important reason for this may be that arc-flash protective hoods and face shields drastically decrease one's ability to smell the outside world. So, please, do not use this as the only criteria to determine if corona is present.

In a great number of cases, corona and tracking problems can be identified by visual inspection. The trained eye usually can pick out problematic areas by using a flashlight and having an unobstructed view of the equipment. Cables,

insulation board and insulators are all prime areas where problems are likely to occur.

Typically, the effects of corona on rubber-based insulators, tape, and insulation board will leave a white powder residue or dust (Figure 4). This white residue is thought to be the combination of the physical breakdown of rubber based insulation and the accumulation of dust attracted to the conductive air surrounding the corona activity.

Figure 4 - White powder/dust residue formed on 13kV powder cables that are tie-wrapped together forming tight air spaces between each other; ideal locations for corona to form.

Other indicators include discoloration and spider cracking on cable insulation. Usually dull finishes and micro-crack stains on cable insulation will be evident. In worst case scenarios, cables will be severely deteriorated (Figure 5).

Figure 5 - 13kV power feed cables showing corona powder and a small but intense area of tracking (shown at arrow).

Unusual weathering patterns on copper bus and conductors are also good indicators of corona (Figure 6). Humid conditions inside of switchgear cabinets will allow nitric acid to form which attacks the copper surface leaving unusual weathering patterns. Cabinets lacking heaters or poor weather seals, and cabinets that are poorly sheltered from wet industrial processes, are especially vulnerable to these conditions.

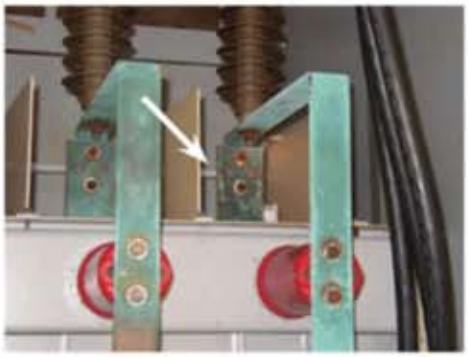
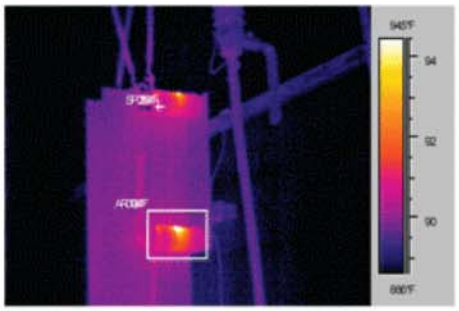


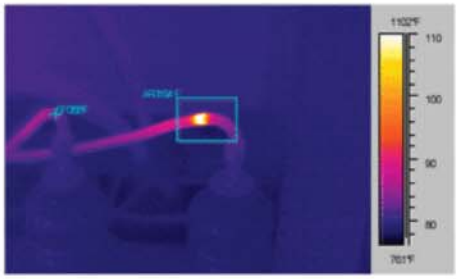
Figure 6 - Unusual weathering pattern on 13kV copper bus under attack by corona produced nitric acid.

As the corona condition advances, carbon tracks will start to develop on conductors and insulators. The distance between the affected phase and a grounded object will ultimately determine the time for a flash-over to occur.

Finally, it should be stated that early stages of corona may not show any visible signs. Mild cases of corona that are caused by metal edges in switchgear cabinets may never be apparent by visual inspection alone.



Figures 7a & 7b: A temperature rise of 8 F-degrees is observed on active corona on a 13kV stand-off bushing for a disconnect switch.



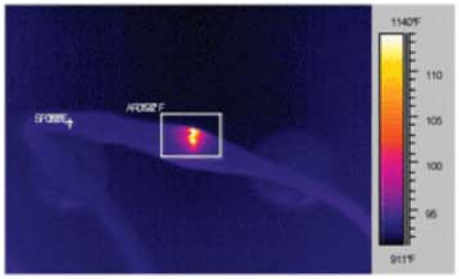


Figure 8a & 8b - Delta temperatures of over 30F-degrees are seen on conductor cables that having tracking problems.

Heating Patterns Associated With Corona

It has been my experience that most cases of corona produce very little, if any, heat. Very faint heating patterns may result from the molecular disturbance of electrons associated with the ionization of air. Depending upon air movement and the intensity of the corona, the delta temperature may or may not be detectable with infrared technology (Figures 7a and 7b). This can be deceiving for the infrared thermographer who is unfamiliar with corona, as this serious condition may only receive a minor severity rating if evaluated solely on temperature rise criteria.

In advanced stages where corona has become destructive or is advancing into tracking, I have seen very noticeable delta-temperatures, especially on conductors. Figures 8a and 8b show examples of such cases.

Ultrasound Technology

Sounds above the normal range of human hearing, 20 to 20 kilo-Hertz (kHz), is typically thought of as ultrasonic. A frequency range between 20 kHz to 40 kHz generally covers all of the ultrasonic applications used for predictive maintenance applications; leak detection, stream traps, bearings and lubrication, and electrical discharge.

Ultrasound equipment includes a receiver unit, headphones, and various modular listening devices that attach to the receiver for both airborne and structure-borne scanning. Airborne devices include cone-shaped collectors that capture ultrasonic wave traveling through air. Structure-borne devices include magnetic base collectors and rod attachments used to contact the surface of equipment.

Through a process of 'heterodyning" the ultrasound signal is converted by the receiver unit to a low frequency audible signal that can be heard trough the headphones. There is also a read-out display that shows the intensity of the received signal.

Using Ultrasound to Detect Corona and Tracking

While most corona and tracking problems can be seen, I am a die-hard proponent of using ultrasound technology during a switchgear inspection. Three of the most obvious reasons are 1) ultrasound will verify the corona and tracking you see, 2) ultrasound allows you to qualify the severity of corona and tracking since they have distinct sound patterns that change with increasing stages of development, and 3) ultrasound will detect problems that you visually cannot see (Figures 9a and 9b).

Because corona and tracking problems occur and propagate in air, airborne ultrasound is the right choice to detect these problems. Ultrasonic waves are directional in their movement, which makes it relatively easy to track these problems back to their source. However, ultrasound wave will rebound off of surfaces and can be partially and completely blocked by components in the switchgear cabinet. By following the unit's strongest received signal the operator can usually find the source of the problem. The operator can also use blocking techniques to filter out competing ultrasound noises, if necessary.

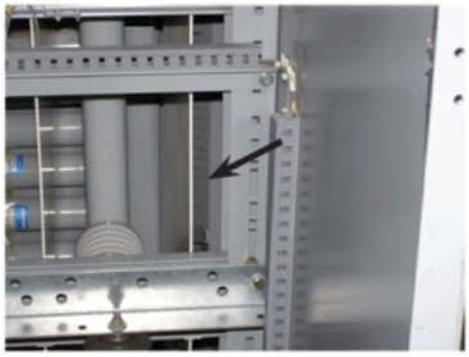


Figure 9a - Ultrasound was used to find tracking on blind side of insulation board (see arrow).

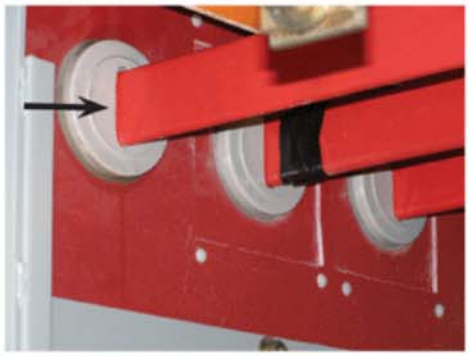


Figure 9b: Ultrasound was used to find corona on ceramic collars surrounding 13kV bus, no visible signs of corona are present.

Corona problems will be heard as a continuous buzzing or frying noise. The intensity of this sound will be directly related to the severity of the problem. Tracking problems will sound much like corona problems but will have pauses and possible drops and increases in intensity.

Prior to opening a switchgear cabinet, it should be scanned ultrasonically using screened ventilation ports, seams around the cabinet doors, and the cabinet bolt holes once a few are removed. Typically, advanced cases of corona and tracking will be heard using this "initial"

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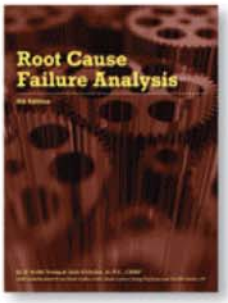

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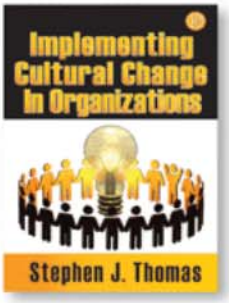

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Airborne Ultrasound Level 1 by Jim Hall, Independent Ultrasound Expert

This 23 part course combines basic knowledge of airborne ultrasound theory, leak detection, bearing analysis, acoustic lubrication, steam trap troubleshooting and electrical scanning. This workshop series will also acquaint participants with the process of interfacing vibration analyzers with ultrasound instruments.

Infrared Thermography Level 1 by Wayne Ruddock, Independent Infrared Expert

This 23 part course follows the recommended training requirements of ASNT for Level I Thermal/Infrared Certification. The hands-on workshops ensure that the participants should have mastered the skills necessary to not only operate their infrared system but to perform various inspections and report on their findings.

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scan technique. If you have any question about the safety of opening a switchgear cabinet, do not open it until an outage can be secured.

If no noise is heard during the initial scan, do not assume that a problem does not exist. The interior geometric design of the cabinet may not allow the signal to reach the ultrasound collector or may allow a partial and weak signal to be heard. Likewise, mild cases of corona may have a very weak discharge signal that cannot be heard until the cabinet is open.

Other problems that may affect the initial scan are competing ultrasonic noises generated by 60Hz electrical cycle generated by transformers, moving air from cabinet and overhead fans, and mechanical vibration from inside switchgear cabinets.

Mechanical vibration signals can sound similar to electrical discharge. If you are in doubt, apply light pressure on the side of the cabinet and/or door to see if you can reduce or eliminate the ultrasound signal. The noise will dissipate or change if you are picking up mechanical vibration. This technique will quickly rule out any confusion between mechanical vibration and electrical discharge.

Performing a Switchgear Inspection

Working around energized high-voltage switchgear should only be performed by a qualified person wearing the appropriate arc-flash personal protection equipment (PPE) as prescribed by NFPA 70-E guidelines. As these guidelines continue to move front and center in our industry, it is becoming easier to find qualified switchgear professionals that are familiar with, and more importantly wear, the necessary PPE when opening and closing cabinets.

There are some things that you can do to reduce the risk of arch-flash. If you are an "in-house" technician with high-voltage switchgear, consider installing hinges on panels and modifying bolts that can be easily handled while wearing gloves.

Once a cabinet is open, the inspector should slowly scan the entire interior of the cabinet with the ultrasound listener. Both front a back compartments, if accessible, should be scanned on rack-in breakers and load interrupter switches. Never should the ultrasound instrument or any body parts break the plane of the cabinet or exceed the approach distance for the given voltage class.

Although I'm not a huge fan of LCD screens on infrared cameras, they do have their place when conducting this type of inspection. The arch-flash face shields make it next to impossible to use an eyepiece viewer, but the LCD screen can be easily viewed while wearing a face shield. Keep in mind that small delta-temperature rises on cables and bushing may be indicators of larger problems.

Once a problem is detected, it should be described and photographed. Because of the dangers involved with getting too close to the equipment, having a telephoto lens on your visual camera will help get a closer look at a problem and see details that may otherwise be missed. Also, a bright flashlight will help overcome reduced vision caused by face shield tinting and will also illuminate dark and tight areas where corona and tracking may be hiding.

If there is any doubt, or you lack the expertise in-house, contracting these specialized services to a qualified consultant is the best choice. However, if you are considering this type of inspection program in-house, receiving the proper training is always to best way to assure that you are not only receiving the best return on your investment and efforts, but keeping your personnel safe.

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Jim Brady of Brady Infrared, Liane Harris with ECS2 Group and Jim Hall with Ultra-Sound Technologies work together in a limited partnership to bring together the use of Airborne Ultrasound, Vibration and Infrared. This group is committed to teaching others how to use and integrate these technologies. You can contact Jim Hall, Ultra-Sound Technologies for any questions or comments. As well, any request for training or services. Jim Hall, Ultra-Sound Technologies, (770) 517-8747 or jim.hall@ultra-soundtech.com or www.Ultra-SoundTech.com