Safer Condition Based Maintenance Inspections: Case Study of Implementation at an Ontario Bottling Facility

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Introduction:

Electrical Maintenance Surveillance Device technologies refers to condition based monitoring technology and equipment used every day to inspect electrical distribution assets. These surveillance and inspection systems determine the condition of the individual asset or system being inspected and include but are not limited to: infrared thermography, airborne ultrasound, motor current analysis, partial discharge testing, corona cameras and visual inspections. The implementation challenge is that the inspection and surveillance equipment utilized yield their most valuable results when inspecting electrical distribution equipment that is operating under full load conditions. Doing so while working within the confines of CSA Z462 guidelines can be challenging when the equipment is both most dangerous to maintenance personnel and of the greatest value to the process it is powering. The surveillance equipment implemented normally requires direct access or direct line of sight to the energized components inside the electrical system. This requires panels to be open which is an extremely dangerous condition. In many cases the posted Arc Fault Incident Energy levels are too high and access is prohibited due to internal company rules or lack of appropriate PPE.

This paper will show how EMSD technologies maintain the energized compartment's closed and guarded condition ensuring that personnel are not endangered. Readers will learn how the design allows the required test equipment to be used safely at any time, especially when equipment is under full load conditions which is when the inspection yields its greatest value. A case study at an Ontario beverage bottling facility will be presented demonstrating how these devices can be easily retrofitted on existing electrical distribution equipment to become the nexus for an electrical infrastructure reliability program.

Challenge & Solution:

Every year thousands of electrical workers in the US and Canada are injured or even killed while performing their duties. According to the Bureau of Labor Statistics in the US, there are still over 300 fatalities each year from electrocution with an arc flash component making this the fourth leading cause of occupational fatality. These numbers are nearly half of what they were 20 years ago which is a marked improvement for several reasons. First, personnel have a better understanding of risks due to training. Second, Arc Flash incident energy labeling requirements on equipment that have been implemented provide information to front line personnel as to what Personal Protective Equipment (PPE) they should be employing. Finally, there have been significant improvements in the types and quality of PPE available. Unfortunately, the average number of annual arc flash occurrences has not fallen at the same rate over that period. In fact, there are still 4,000 non-disabling electrical contact injuries each year and 3,600 disabling electrical contact injuries each year which is largely unchanged from 20 years ago.

Awareness and proper use of PPE are clearly saving lives, but if you have ever met someone who was involved in an arc flash accident, you realize that these are life changing events that can cause years of suffering and hardship both to the individual and their family. Fortunately, there are options that can help further reduce the risks to electrical maintenance personnel. However, before we discuss these options, let us examine the equipment failure patterns and types of tools commonly used to measure equipment condition.
Equipment Failure Patterns:

Reliability Centered Maintenance (RCM) are the age-reliability behavior curves which graph the conditional probability of equipment failure with age. The patterns of failure can be broadly split into two categories: Age-related Failures and Random Failures. The lay person often believes that equipment likelihood of failure increases exponentially with age and that the majority of equipment failures are age related. However, any engineer has learned that non-age related or random failures account for nearly 90% of equipment failures. In addition, many understand that it is not necessary the core of the equipment that fails – it has typically been designed with significant forethought, tested to exacting standards and specifications and been manufactured in a controlled process environment. However, then that equipment was dispatched to a customer jobsite and installed by the lowest bidder. As a result, it is quite often the field installation that causes the problem. In some cases, the problem becomes evident shortly after commissioning but in other cases, an issue may not manifest itself for months or even years. Of course, it is possible that you received a factory “lemon” and that the supplier’s inspection and testing processes broke down. However, even in that instance, the failure may occur at some random time in the future.

Given the randomness of equipment failure, it becomes crucial to perform regular and rigorous inspection on electrical equipment. Refer to Figure 1 below – the Electrical Inspection P-F Curve. On the P-F curve, P is the point where a failure starts to occur where an identifiable change in physical condition has begun which will eventually lead to a functional failure. F is the point where the functional failure takes place and the equipment is no longer able to perform the task for which it was designed or where it cannot meet a specified performance standard. There are multiple points along the P-F curve at which different Condition Based Maintenance inspection methodologies would be able to discern that a potential failure is looming.

![Electrical Inspection P-F Curve](image)

Figure 1: Electrical Inspection P-F Curve
Technologies to Measure Equipment Condition:

There are several technologies that are broadly used to measure electrical equipment condition. Ultrasonic emissions are caused by electric anomalies such as corona, tracking and arcing. All these emissions produce ionization whereby neutral atoms and molecules gain or lose electrons becoming an ion. Byproducts of this process are Ozone ($O_3$) and nitric acid which is destructive to most dielectric materials and corrosive to certain metals. Each of these anomalies has a distinctive sound characteristic that can be detected using ultrasound detectors that convert sound from 20-100KHz via heterodyning into an audible range for the technician. Detectors also show the intensity of the signal in decibels (dB). Traditionally in electrical applications, it was believed that most ultrasound phenomenon present themselves in medium and high voltage equipment (>1000V) but increasingly, Ultrasound is being used to detect problems in low voltage equipment and as a supplement as part of infrared inspection.

Motor Current Analysis (MCA) involves test equipment connected to measure the motor’s current draw and voltage signature waveform in both the time and frequency domain. MCA can be used to detect bearing faults, drive train problems (alignment), rotor eccentricities, broken rotor end ring faults, broken rotor bar faults and stator inter-turn faults. It should be noted that Ultrasound can also be used to supplement vibration analysis on motor and pump bearings and can sometimes detect early warning signs of bearing wear even earlier than vibration monitoring.

Power Quality Spot monitoring using handheld portable instruments are used to look for potential power quality problems at various locations in the electrical distribution system. It is most common to take measurements on the Low Voltage side of a substation transformer in the associated switchgear using analog metering compartment inputs where possible. However, it is also quite common don appropriate PPE and to use larger split-core or rope type current transformers and voltage probes to hook up directly to the switchgear busbar. Handheld PQ instruments are really only suitable for looking at steady-state power quality phenomenon such as harmonic levels and require the facility's loads to be operating in a normal manner. Spot check of power factor can also be performed with a handheld PQ meter but should always be tempered with a full 12 month utility billing analysis to determine actual power factor correction requirements. Other PQ phenomenon which are not steady-state in nature will likely require permanently installed PQ monitoring hardware and logging software to be captured. This would include transients, flicker, short term voltage sag / swell conditions or longer term over / under voltage conditions.

From an equipment condition based maintenance perspective, harmonics pose the greatest risk of potential premature power quality related equipment failure. Harmonic current is caused by non-linear loads that draw current for only a portion of the voltage waveform. This includes variable speed drives, DC rectifiers, UPS systems and lighting ballasts. In addition, harmonic currents can be magnified by poorly designed power factor correction solutions through a phenomenon known as resonance. The issue with harmonic currents is that they generate significantly higher heating in current carrying components of the distribution network proportional to the square of their harmonic order. For example, 10 Amps of 5th harmonic current (300Hz) on a distribution panel will have the same heating impact as 100 Amps of fundamental 60Hz current. As a result, the current carrying components such as fuses, cables, circuit breakers and terminal blocks can overheat and fail.

Imaging devices can be used as well to measure equipment condition. Imaging is a non-contact method of assessment that keeps the user away from danger and doesn’t intrude upon or affect the target’s operation. Corona cameras work in the UV spectrum and can detect coronal ionization around a conductor or insulator. Of course, Ultrasound can also be used to detect corona but, as this is usually a phenomenon limited to MV and HV applications on distribution substations and overhead transmission lines, a special parabolic attachment with range to 30+ meters is usually required for the Ultrasound detector.

Infrared imaging is the other and by far the most common diagnostic tool used to measure equipment condition. Thermal imaging easily compares areas of the target and can give an excellent overview of
asset health. Thermal patterns can be easily analyzed both qualitatively and quantitatively. Qualitative analysis involves comparing components that should theoretically be at the same temperature. For instance, three fuses on a disconnect switch feeding balanced three phase load should all show approximately the same temperature at like locations in the assembly. All three fuse bodies should read generally the same temperature. All three load side connections of the fuse holder should also be at approximately the same temperature. If one of these shows a differential in temperature, but the balanced load condition is confirmed, then that component or connection requires maintenance attention. Figure 2 shows an extreme example of this where someone has replaced a failed fuse with an inappropriate fuse of a different type and rating in a disconnect switch.

![Image](image.png)

Figure 2: Overheating Fused Disconnect captured with Infrared Imaging

If properly calibrated, Thermal Imaging cameras can be used to provide extremely accurate quantitative results as well. Accurate temperature readings can be impacted by many factors including but not limited to the distance to the target, reflectivity of the target surface, geometry of the target, humidity of the air and transmission rate of an Infrared Viewing window. However, Modern IR cameras have the ability to be adjusted for most of these factors and an experienced IR technician can secure very accurate results. NETA publishes guidelines for maximum temperatures that should be observed in different types of electrical equipment to which the actual measurements can then be compared.

**Safety Guidelines while Measuring Equipment Condition:**

Safety concerns for electricians and other maintenance personnel have come to the forefront of health and safety in recent years. Both NFPA70E and the equivalent document in Canada, CSA Z462, call for utilization of the Hierarchy of Control Concept as a framework when considering work on energized equipment. The Hierarchy realizes that in some instances, like when performing condition based inspections of equipment, it is necessary for the equipment to be energized and under load. However, the Hierarchy prioritizes how personnel should think about performing their duties. The stages of the Hierarchy of Risk Control Methods (NFPA 70E, 2018 edition) are:

1. **Elimination** – Eliminate the hazardous energy altogether. Is it necessary to perform the task with the electrical equipment energized or can it be completed with the electrical equipment de-energized? In the case of Condition Based Maintenance (CBM) inspections, most data collection must be performed with the electrical equipment energized and under “normal” load conditions which usually means at least 60% of the normal operating load present. Infrared and Ultrasound inspections must be performed energized and under normal load and, in the case of infrared, thermal stability must be achieved. Most Motor Current Analysis (MCA) tests must be performed with the motor energized while oil sampling can be performed with equipment de-energized. The
fact that taking an equipment shutdown would be inconvenient for the client is not necessarily sufficient cause to bypass Elimination and move to the next control in the hierarchy.

2. **Substitution** – Involves replacing something that produces a hazard with something that does not produce a hazard. To be an effective control, the substitution of process or product must not produce another (new) hazard. If we agree that a given CBM work task must be performed with the electrical equipment energized, is there a way to substitute a way to see or listen inside the equipment or collect a sample without exposing energized conductors or circuit parts? Can we avoid opening hinged doors and removing electrical equipment covers? The use of Electrical Maintenance Safety Devices (EMSD) such as properly sized and located infrared viewing panes or ultrasound ports or sensors may allow the Qualified Person to inspect the electrical equipment and collect data without any exposure to energized conductors or circuit parts. External oil sampling ports can be installed on transformers that allow the Qualified Person to gather a sample without opening the energized terminal chamber. Motor Test Access Panels (MTAP) can be installed to allow safe closed panel testing of motors. Substitution can also be thought of as Design for Maintainability but can be incorporated both on new and retrofitted to existing older equipment. The cost burden of implementing EMSD is not necessarily sufficient defense to move the next control in the hierarchy.

3. **Engineering Controls** – Involves a physical or design changes to the electrical equipment, rather than relying on worker’s behavior or requiring workers to wear protective clothing. There can be some confusion as to when a change is Substitution versus Engineering Controls. My interpretation is that Engineering Controls are to protect the worker from himself (e.g. designing in more insulating, guarding or finger safe components) or implement design changes to reduce hazard levels (e.g. protective devices which reduce the maximum fault clearing time). Engineering Controls might include using high resistant grounding instead of solidly grounded systems to limit the phase to ground fault current or selecting Arc Resistant Switchgear. In this manner, the work task will expose the Qualified Person to reduced electrical hazards and will reduce the resultant potential for injury. With this thinking, other examples of Engineering Controls would be tamper resistant hardware and door interlocks (limit switches) that prevent access into hazardous energized electrical equipment or automatically de-energize the electrical equipment if someone manages to open an access point. Touch proof barriers inside of electrical equipment might also qualify as Engineering Controls – although they often need to be removed to perform Infrared inspections creating a secondary hazard for the thermographer. Engineering Controls should be implemented on electrical equipment before moving to the next control in the Hierarchy. Again, the cost burden of implementing Engineering Controls is not necessarily relevant.

4. **Awareness** – A stage that is not typically part of the Hierarchy you will find for other hazard control methodologies outside of the electrical realm. Awareness basically is ensuring that the personnel involved in a work task have a documented Job Safety Plan that was created by a Qualified Person and includes:
   a. A description of the job and individual work tasks.
   b. Identification of the electrical hazards associated with each work task.
   c. A documented shock risk assessment.
   d. A documented arc flash risk assessment.
   e. Use of work procedures involved as well as any special precautions and energy source controls.

Awareness is basically making sure you have a plan and have considered all the potential risks of doing energized open panel CBM work. Until the plan is complete and documented, you cannot proceed to the next control in the Hierarchy. Additional Awareness controls would be ensuring signage is installed on electrical equipment including identification and arc flash and shock Equipment Labels.
5. Administrative Controls – Includes using electrical safe work procedures and employee training. Specific training for Qualified Persons would include Electrical Safety Training, Lockout Tagout Training, Emergency Response Training, First Aid / CPR (based on Jurisdictional requirements) and PPE training. Training must be documented and retraining / certification must be performed at proper intervals. Even Unqualified Persons who will not be working on electrical equipment need to be trained on basic electrical safety practices. With the Awareness and the Administrative Controls in place, only then can you move to the final control in the Hierarchy.

6. PPE – Personal Protective Equipment includes rubber insulating gloves with leather protectors, using insulated hand tools, arc-rated clothing, arc-rated faceshields, arc flash suits etc. PPE is the least effective means of controlling hazards because of the high potential for PPE to be damaged, worn improperly or selected incorrectly for the level of hazard that exists. PPE increases the physiological effort required to perform a work task. Frequent breaks and dress downs may be required to prevent heat stroke or fatigue leading to human error. Furthermore, even choosing the appropriate level of PPE will only limit, in the event of an arc flash, the burn injuries to only 1st and 2nd degree. Burn injuries along with contusions, lacerations, concussion and broken bones can all still occur due to the arc blast pressure wave that emanates out of an arcing fault event. Open panel CBM data collection is inherently high risk work without controls and should only be done as a last resort.

With electrical equipment, maintenance personnel typically interact in a variety of ways to perform inspection tasks including opening and closing doors, removing or replacing covers, reaching into or
leaning into equipment, removing or replacing internal barriers, operating switches or circuit breakers, racking circuit breakers and using tools and test equipment. All of these task present a potential arc flash hazard and many of these hazardous tasks can be eliminated altogether with the proper implementation of EMSD technologies.

Types of Electrical Maintenance Safety Devices:

EMSD broadly fall into three categories: Windows, Ports and Online Monitoring. Windows allow inspection in the visual, ultraviolet and/or infrared spectrum and must be properly sized and located to allow the inspector to “see” the target inspection points which are typically cable terminations, bus bar joints and critical current carrying components that are equipment specific. For instance, on an inverter for power conversion you might want to be able to inspect the DC bus capacitors for early signs of overheating while on a power factor correction capacitor bank it might be the individual stage fuses that would be of most interest. By using a properly sized and located IR window, the technician avoids having to remove cover and/or open equipment doors eliminating the risk of arc flash and/or electrocution and meaning that he does not have to put on special PPE to perform his inspection task.

Traditionally, the bulk of windows were small round units usable only in the infrared spectrum and were made from an IR transmissive crystal. Although these round crystal windows were also transparent in the visual spectrum, it was much more common for visual inspection windows, used to see device open/closed status, to be made from Lexan or a similar clear thick polymer material. Unfortunately, Lexan and most other thick rigid polymer materials as well as regular silica glass are not transparent in the IR spectrum and therefore cannot be used to perform thermography.

Figure 3: Failed Crystal Windows

Round crystal IR windows suffer from several other shortcomings that make them of questionable value in industrial applications. Crystal windows are very thin (2-4mm typically), fragile and susceptible to failure due to mechanical shock and vibration. When they fail, they often do not fail in a “safe” manner, leaving a 2”-4” hole in the face of the equipment through which personnel could be exposed to energized components. Crystals are also hygroscopic in nature meaning that they will absorb moisture and airborne contaminants over time and their transmission rate will change making it impossible for even an experienced thermographer to get accurate quantitative results. None of these modes of failure are covered under warranty by the crystal window manufacturers. Crystals also have very limited Field of View (FoV) as the largest crystals are only 4” in diameter meaning that it is often necessary to install three or more round windows to “see” the three phases of a target device like connections on a circuit breaker or transformer. Finally, some equipment standards for MV equipment and the newest CSA standard (C22.2 No.14-10) have static load and impact test requirements that cannot be passed by crystal IR windows.
By contrast, polymer reinforced windows do not suffer from any of these shortcomings. Special thin film IR transmissive polymers have been discovered and designed into reinforced housings of virtually any shape and size. While the polymer is fragile by itself, the reinforcing body creates an IR window of superior strength that can pass all static load and impact testing requirements. The polymers are stable over time and transmission rates do not change and manufacturers of these types of windows offer a lifetime warranty. The flexible nature of the polymer means that entire custom replacement panels can be designed and even curved surfaces like isophase busbar can implement an IR window into the design.

![Figure 4: Inspection through a Polymer IR Window](image)

Ports are the second type of EMSD and involve ultrasound ports strategically located to allow an ultrasound technician to listen for arcing and tracking problems in electrical equipment. Most recently, IR window with embedded ultrasound ports or even built-in 40kHz Ultrasound sensors are available in the market. Voltage indicators are also in this category and are usually deployed as an extra safety step as part of a Lock-Out Tag-Out (LOTO) process. Voltage ports and CT shorting blocks are welcomed by Power Quality technicians as a way to keep them out of harms way by allowing them to gain access to voltage and current information without having to change the equipment from a closed and guarded condition. Finally, MCA ports allow the MCA technician to easily access the motor voltage and current without having to open the terminal chamber.

**Online Monitoring:**

Online Monitoring is the final type of EMSD and is sometimes also referred to as Critical Asset Surveillance Technologies (CAST). Online monitoring includes permanently installed versions of Power Quality and Partial Discharge (PD) monitoring. PQ monitoring, with permanently installed hardware and sensitive software, can be used to detect transients and other fleeting PQ that often come down from the utility and impact sensitive equipment within the end users facility. Without the PQ monitoring in place, it is often impossible to prove that the utility was the cause of damage or production outage. PD monitoring is basically monitoring the ultrasound signature of equipment and is primarily used in HV utility substation applications. For industrial and commercial buildings and especially on hyper critical equipment or equipment where IR window installation is impractical due to equipment design, temperature monitoring may hold the most promise as a surveillance technique to catch problems early in the P-F curve.

**Summary:**

Electrical Maintenance Safety Device (EMSD) technologies should be used as part of a Condition Based Maintenance program to ensure personnel are kept as safe as possible while performing critical
inspection work on electrical assets under normal load conditions. The Hierarchy of Control concept encourages us to employ a “safety by design” approach as the next best protocol in instances where it is not possible to perform the necessary work with the equipment de-energized. Permanently installed online monitoring technologies can provide significant additional value to determine when it may be prudent to conduct in depth inspection and proactive maintenance. However, they can be even more valuable when they tell us nothing is wrong and allow us to use our limited maintenance man-hours on more productive tasks than pure calendar based maintenance activities.

Case Study – Ontario Bottling Facility

One of the North America’s leading bottled water companies dedicated to providing customers with healthy hydration options and equally committed to keeping their people safe, recently approached IRISS for assistance in optimizing their asset life cycles. Their primary goal was defining cost-effective, consistent maintenance processes by adopting the technologies to support and sustain these processes throughout the U.S. and Canada. As part of this multisite initiative, Scott Thornton of DTM Consulting Services, was engaged to provide recommendations for placement, sizing, and type of IR windows to be installed at their Ontario, Canada facility. After initial site survey, DTM recommended the IRISS CAP-CT series in various sizes to complete this project. CAP-CT series is a NEMA 4 / IP65 rated IR window and ideal for indoor applications.

The company developed a reliability and maintenance policy that includes a 3-5 year improvement plan. This policy was then communicated to all employees. The company outlined all essential reliability and maintenance elements, their key performance indicators, why these are important and the importance of a Reliability Centered Maintenance (RCM) and Reliability Based Maintenance (RBM) program for overall plant safety.

The company had done the necessary research and determined that they would retrofit using the IRISS transparent patented polymer Infrared Windows as safer method of conducting standards-compliant inspections. It was decided by the reliability team to implement the large format infrared polymer windows for Main Switchgear Bus connections; Main Breaker connections and Fused Switches to help eliminate the hazard of live work by finding hot spots through the IR windows.

As a result, more frequent inspections of energized equipment could be performed by retrofitting with Infrared Windows for routine inspections. The closed panel inspections with the windows in place did not require the elevated levels of Personal Protective Equipment (PPE) mandated in NFPA 70E and Z462, thus reducing time and maintenance costs. Thermal imaging was not new to the maintenance and reliability team as they had previously retrofitted some equipment with traditional round calcium fluoride windows. However, it was determined that a transparent polymer Infrared Window available in various large formatted sizes would provide both visual and thermal inspection with fewer units needing to be installed.

With the infrared windows installed, there was no need to remove panels or wear increased levels of PPE. Inspections could now be performed more often and on electrical equipment that had previously been considered “uninspectable” due to high levels of Arc Flash incident energy.

The installation process proceeded smoothly and included:

1. Preplanning to identify the equipment and obtain approval to shut down
2. De-energizing the equipment with two electricians to make sure it was safely isolated, locked out and tagged out
3. Once de-energized, the two electricians removed all covers on the equipment in question
4. The IR windows were installed using supplied drill/cut templates in the appropriate location and the covers were replaced
5. Appropriate PPE was put on by the electricians and the equipment was reenergized
6. Together with operations, the electricians confirmed the equipment was operating at normal load levels and allowed sufficient time for the equipment to become thermally stable.

7. Thermographer electrician then performed the infrared inspection on the equipment to secure baseline temperature data.

8. Personnel completed the inspection by taking notes of any problems discovered.

Installation Requirements:
- Main Breaker Buss: CAP-CT-24
- Main Breaker Load: CAP-CT-24
- Fused Breakers: CAP-CT-24

Main Breaker Buss - Cabinet A

SWGR 96-SWG-01
Cabinet A, B, C
The bottled water company has recognized a huge savings in time and money with the implementation of infrared windows into their condition based monitoring program. The use of polymer infrared windows allows more convenient and frequent inspections resulting the ability to catch and fix potential problems long before they turn into unexpected outages. In this way, the bottled water locations will see increased Mean Time Between Failure (MTBF) on their critical electrical infrastructure. Most large facilities with large distribution power systems find that their insurance provider requires annual infrared (IR) inspections of their electrical systems. This mandate is a direct result of verbiage found in NFPA 70B and
Z463 standards but retrofitting IR windows enables the facility to perform these inspections in a fraction of the time and in a much safer way.

Savings to justify the enhanced electrical reliability program are generally broken down into three categories.

- Manpower labour savings from performing closed panel (no PPE) inspections
- Return on Safety from reducing at risk behaviours
- Annual Failure Rate amortization savings by increasing inspection frequency

Experience has shown that sites are able to validate the program viability with a 1.5 year or shorter return on investment which is easily achievable when all three categories are added together. Based on the results at the first sites, the bottled water company has now proceeded with implementation of the IRISS IR window solutions at twenty-nine (29) of their sites around North America.