Developing an IEEE Continuous Thermal Monitoring Standard and a Major Company's Protection of Their Electrical Assets

EXPLORING CONTINUOUS THERMAL MONITORING FOR ELECTRICAL CONNECTIONS AND COMPONENTS

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THE PROCESS OF INITIATING AN IEEE STANDARD IS NOT well understood by many. The objective of this paper is to follow the development of an IEEE Standard Working Group (WG) and the initial efforts to develop an IEEE Standard for continuous thermal monitoring (CTM). This also investigates methods to monitor the operating condition of equipment connections as an alternative to infrared (IR) thermography surveys. It includes a review of methods that can capture data for analysis, trending,

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and predictive maintenance for personnel safety and extended equipment reliability. Maintenance of electrical switchgear and motor control centers (MCCs) is critical to elevating safety and assuring facilities' uptime in all industries. Key concerns in every company's electrical distribution system include the connections and terminations of electrical equipment.

In an increasingly arc-flash conscious world, personnel exposure to energized equipment is elevating costs and concerns for worker safety. So, the shift from labor-intensive maintenance and inspection practices to safer, more efficient, less costly data collection with options for automated data collection is increasingly valuable. During prolonged operation, electrical connections, splices, and cable terminations are subject to thermal expansion and contraction that could loosen connections. Vibration and corrosion will also impact their condition and subsequently their operating temperatures. Poor terminations will increase heat generation and higher operating temperatures. Deteriorating terminations left unchecked may overheat and fail. The result can be equipment failure, downtime, and higher risks for personnel safety.

This article also explores a specific corporation's efforts to elevate reliability of electrical distribution throughout their operations by applying CTM. This not only includes manufacturing and mill operations but considers their end-product distribution and other business operations. (When this article was presented at the IEEE/IAS Pulp and Paper Industry Conference in June 2022, only independent drafts of proposed sections and annexes of the Guide had started. There was no draft of the proposed Standard.)

Introduction

Though not always applied in the same fashion, IEEE standards are globally recognized, widely used, and accepted across multiple industries. There are three distinct categories of IEEE Standards including the following:

- *IEEE Standards*: documents with mandatory requirements.
- *IEEE Recommended Practices*: documents in which procedures and positions preferred by subject matter experts and IEEE are represented.
- *IEEE Guides*: documents in which alternative approaches to accepted practices are suggested but no clear-cut recommendations are made.

Through the initiation of a study group and support of IEEE Technical Committee(s) to sponsor a project authorization request (PAR), a WG does not exist until the project is recognized by the IEEE Standards Board "New Standards Committee" (aka NESCOM). At that time, it is confirmed whether the WG project is developing a "Guide," a "Recommended Practice," or a "Standard."

In 2021, a new IEEE-Standards Association PAR was initiated to address CTM for switchgear and MCCs. The initial study group was sponsored by the IEEE Industry Applications Society–Petroleum and Chemical Industry Committee (IAS-PCIC) and consisted of six members. But the interest generated beyond IAS resulted in a jointly sponsored IEEE Standard in conjunction with the IEEE/PES (Power & Energy Society) Switchgear Committee (SWG).

The PAR was approved as IEEE P2969 "Guide for Continuous Thermal Monitoring of Switchgear and Motor Control Centers Below 52 kV" to address low-voltage (LV) and medium-voltage (MV) equipment. After the PAR approval, the initial "Study Group" grew to more than 50 WG members. At the time of the paper's presentation almost half of the WG members were from various MCC and switchgear manufacturers and continues with six different user companies. As with many IEEE Standards Working Groups, the commitment of participants varies. Attendance establishes the voting membership for consensus approval to circulate a draft of the proposed standard for balloting among the sponsor(s) membership and others.

In the case of the "Continuous Thermal Monitoring" effort, the PAR was sponsored by both the IEEE/IAS-PCIC Standards Subcommittee and the IEEE/PES-SWG (Switchgear Committee). Although this was originally proposed as a "Recommended Practice," it was approved as a "Guide." This was in consideration of new applications and technologies of various temperature sensors for monitoring electrically energized connections.

Annual thermographic IR surveys for switchgear and MCCs are an accepted practice to determine the condition of electrical distribution equipment for personnel and equipment safety. This practice, covered under the National Electrical Testing Association (NETA) Standard for Maintenance Testing, is recognized by National Fire Protection Association (NFPA) 70E but is not universally nor consistently applied in industrial or commercial facilities.

From the beginning of IR thermography and the use of infrared cameras for this application, there have been limitations. The high costs of cameras in the early 2000s (reports as high as US$25,000 each) limited the application of IR cameras for many companies. Additionally, training maintenance personnel to achieve thermography

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FIGURE 1. A thermographer conducting an IR Scan of a low-voltage MCC unit. Note the door interlock has been defeated to allow the equipment to remain energized with the door open. (This image predates protective clothing requirements for energized work.)

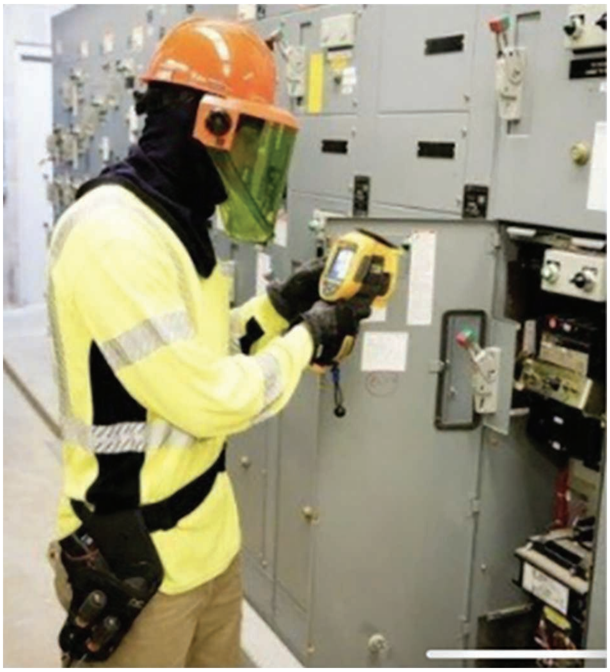

FIGURE 2. A hand-held IR device inspecting electrically energized equipment to allow meaningful operating data to be captured.

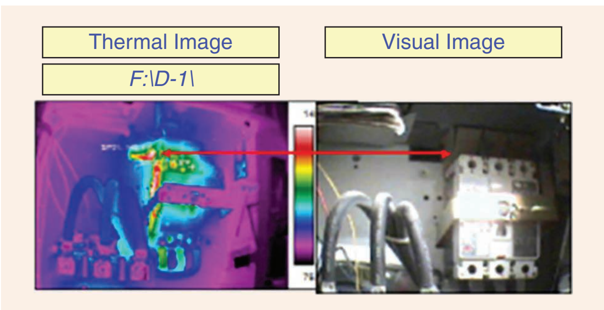

FIGURE 3. An IR Image comparison with a visual image to call attention to the specific area where the hot spot was detected.

certification to operate their IR cameras and measure thermal anomalies can be costly. Also, third-party certification is considered necessary to ensure data for reports is accurate but may not actually be required.

Since that time, the practice has continued to be under scrutiny because of the limited data points infrequently collected for analysis. At times, data was collected when equipment was not energized yielding information of no value. There are known limitations in capturing meaningful thermographic images during a plant's annual inspections. Continuous monitoring can supplant or complement traditional periodic IR imaging surveys as well as other maintenance practices. A thorough thermographic survey on energized electrical equipment could disrupt equipment operation and manufacturing processes. The potential for such outages, even when planned, can sometimes postpone such surveys from taking place at all (Figure 1).

Some companies acknowledge a lack of strict scheduling and adherence to these surveys. Based on admittedly irregular inspections and poorly captured data, these surveys are obviously not a priority to every company (Figure 2). Other companies conduct inspections as frequently as once a month, depending on the criticality of the connected equipment. Then, each year third-party inspection services are contracted for data collection, calibrating IR cameras, and updating personnel training.

Capturing a visual image of electrical connections and components along with a thermal image is a customary practice to help recognize more clearly where a point or region of concern exists. Camera resolution adjustments for clarity sometimes seem to satisfy personal color preferences versus achieving meaningful images. Hence, the ongoing need for thermographer training and certifications (Figure 3).

Safety Versus Accuracy

Most companies recognize that the equipment must be energized for the data to be meaningful. Otherwise, the I^2R heat generation isn't present, and any troublesome connections don't reveal their higher operating temperatures. Even with scheduled and well-planned thermographic surveys of energized equipment, the operator may not capture true and accurate temperature survey data under varying load conditions (Figure 4).

De-energizing a cabinet prior to inspection allows opening the door safely. Then, with the door open and the maintenance worker in appropriate personal protective equipment (PPE), reenergizing the cabinet with the IR camera prepared allows capturing of thermal images with the switchgear fully powered. Hot spots are more easily recognized with multiple perspectives and views when the panel door is open. However, safety risks then increase. This method of detecting deteriorating electrical connections might prevent equipment failure and costly downtime if the survey is early enough to detect pending problem(s).

In an increasingly "arc-flash conscious" world, any exposure to energized distribution and control equipment elevates concerns for worker safety and maintenance costs. As such, the levels of PPE required for inspecting energized equipment can extend the time for the inspection. If the connected equipment is out of service, it may be safe but hot spots are no longer present. So, *operating* temperature can't be measured. A representative from an offshore oil company relates to expensive third-party inspections on production platforms. In addition to the thermography certification of the inspector, there must be additional safety training for helicopter shuttles and "life on the rig" for weeks at a time.

Continuous monitoring can supplant or complement traditional periodic IR imaging surveys as well as other maintenance practices.

IR Windows Avert Exposure to Energized Electrical Equipment

As an alternative to opening an energized electrical cabinet, installing IR windows allows thermal images without de-energizing the equipment for more meaningful inspections and data collection while the equipment is operating. The introduction and implementation of IR windows allows energized equipment inspection but also introduces new challenges on the collection of the temperature data sought. This includes an impact on the accuracy of any thermographic camera readings/images captured through the window (Figure 5).

Often the thermographer does not have a clear line of sight through a window, so the points to be inspected may not be visible due to the camera angle or equipment isolating barriers. To complicate this challenge, new internal arc classified switchgear assemblies to address arc-flash concerns for personnel safety further limit line of sight access necessary for the IR cameras to "see" electrical connections in question. Significant advancements in capturing thermal data and temperature profiles of energized equipment continue to be developed.

Temperature Sensors and Temperature Measurements

The shift from labor intensive maintenance practices to safer, more efficient surveys and inspections continue to gain momentum. Thermistors, thermocouples, resistance temperature detectors, fiber optics, noncontact IR, and other sensors are all used as alternatives to hand-held IR cameras (Figure 6). At least one globally recognized insurance underwriter/equipment approval agency has recognized that CTM is an acceptable alternative to handheld IR cameras for periodic inspections. Increasing the number of users of CTM systems suggests that this will become adopted based on increased data collection and its availability for transmittal and analysis (Figure 7).

In most applications, the temperature of the conductor(s) and connection(s) change their thermal profiles over an extended period. This is as opposed to a catastrophic failure mode where an abnormally elevated temperature develops very quickly. Discrete temperature sensors themselves, no matter how accurate, should be given careful consideration as to what points they're monitoring and how. Measuring temperatures of connections and components without consideration of the operating conditions inside that cabinet can be misleading. In addition to the heat generated by the resistive losses

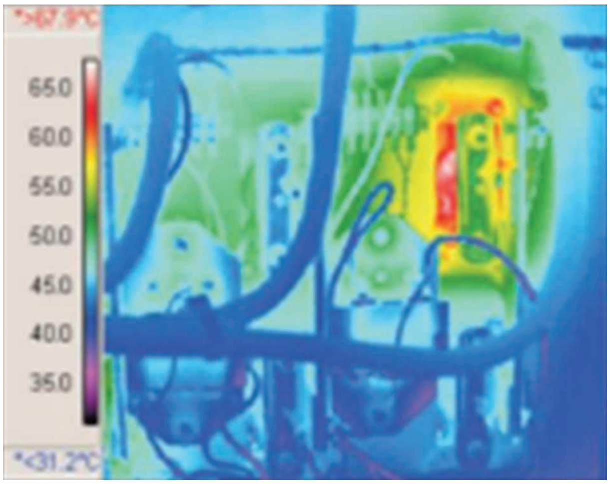

FIGURE 4. An IR Image with a temperature scale as part of inspection data captured during an IR inspection.

FIGURE 5. IR windows are available in various sizes and geometries to capture a broader view for thermographic images without exposing personnel to energized equipment.

(converted into thermal energy), the operating temperature inside a cabinet is impacted by its environment. [i.e., in a cabinet without ventilation in the sun or in extreme ambient conditions like the Middle East versus the Arctic, and so on (Figure 8).

In other cases, such as monitoring MCC drawers (aka buckets) installed in a controlled environment, CTM focuses more on comparisons between the line- side and load-side terminations. Along with detecting unacceptable temperature rise(s) at monitored connection(s), this "Delta T" approach also monitors unbalanced loads that could reduce the life of equipment within a process system (Figures 9 and 10).

Thermistors, thermocouples, resistance temperature detectors, fiber optics, noncontact IR, and other sensors are all used as alternatives to handheld IR cameras.

Newer Technologies for IIoT

CTM is important in the implementation of overall condition-based maintenance practices as it can reduce risks and lower costs during active operation. It can also improve facility safety and reduce maintenance costs while simultaneously improving reliability and up time by reducing needs for personnel working on (or near) energized equipment.

Digitization and Industrial Internet of Things (IIoT) needs of the future are driving demands for more data, and CTM now provides data with analytical tools for predictive maintenance. The ability to have more complete data regularly collected for analysis allows temperature trending for every point monitored and can highlight specific connections that need attention during planned maintenance or outages (Figure 11).

Implementation for a Major Company's Future… Now

The Weyerhaeuser Corporation was known for paper products in past decades. Its use of process automation technologies for their mills helped the company advance techniques and technologies routinely implemented across different industries. Changing the company's focus in the new millennium, Weyerhaeuser divested its pulp and paper mills and increased its emphasis on the wood products industry, including engineered products and dimension lumber for residential and commercial construction. Today, the company operates 19 sawmills, seven panel mills, seven engineered wood products mills, and other operations for support of its wood products business. This includes nursery operations and distribution centers, all dependent on reliable electrical equipment performance.

From 2004 to 2007, voltage presence indicators for MCCs were evaluated and implemented for new construction. These confirmed the availability of voltage at the bucket but provided no temperature information. So, there were no warnings of rising temperatures or other internal fault conditions. CTM has since gained attention and implementation for present and future projects.

There are CTM installations in place and/or presently being installed that implement different technologies. There are presently hundreds of sensors already installed from different manufacturers of this type of equipment. Among these, Weyerhaeuser is also addressing various levels of communications to integrate with

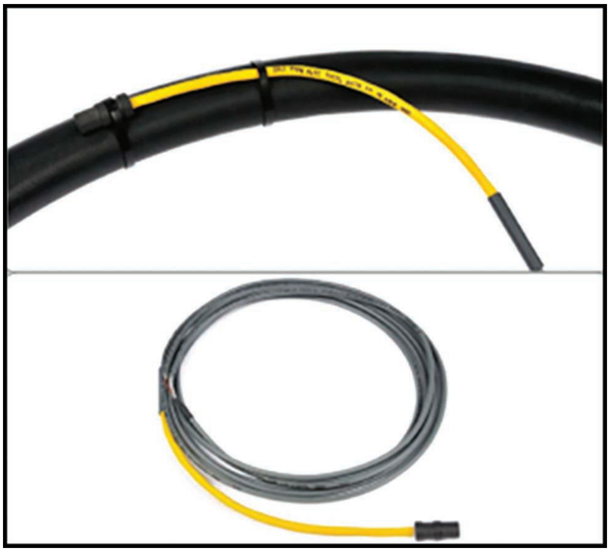

FIGURE 6. An example of an insulated cable temperature sensor for LV applications. Note there is a secondary sensor depicted here for measuring cabinet ambient temperature.

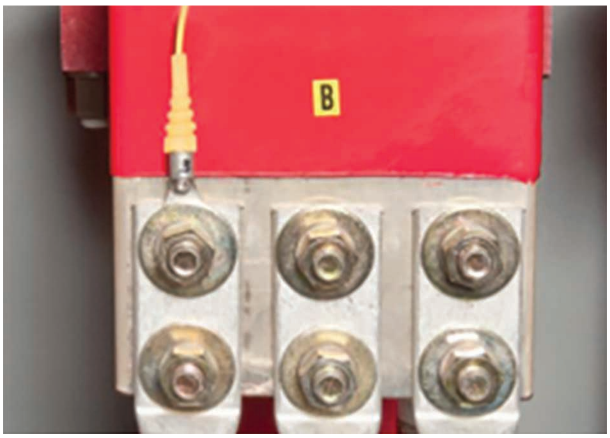

FIGURE 7. A fiber-optic sensor secured under a bolted electrical connection.

overall condition-based monitoring systems for their critical electrical distribution equipment.

One of the largest sawmills in Weyerhaeuser's Wood Products operations is in the southern United States. This specific mill was selected for digitization and elevated process automation before being brought online in 2018. This included investments into CTM systems for a 4160-Vac switchgear lineup which feeds all of the MV power distribution and eight 480-Vac switchgear lineups that feed all of the low-voltage switchgear and MCCs at that site. These systems are expected to be networked for future IIoT operation of this plant.

> **At least one globally recognized insurance underwriter/equipment approval agency has recognized that CTM is an acceptable alternative to handheld IR cameras for periodic inspections.**

In 2019, another southern mill was upgraded with new electrical distribution equipment and all eight 480-Vac LV switchgear include CTM. These systems will also be networked for data collection and analysis for future IIoT automation. Presently, a third facility in the southern United States is being upgraded to include seven 480-Vac LV switchgear line-ups to include CTM that will also be networked for data collection and analysis from anywhere in the Weyerhaeuser network.

As determined in this article and elsewhere in the references, elevated operating temperatures could create problematic conditions and/or cause equipment outages. Weyerhaeuser is considering CTM of all main bus-to-bus splices and critical equipment connections on LV and MV switchgear. However, it is important to note that they are not discontinuing their practice of thermographic surveys.

Weyerhaeuser's monthly inspection schedules are still being maintained and new electrical equipment enclosures include IR windows for capturing thermographic data as they have done for decades. This allows validation of new data from CTM systems to be compared with IR thermographic data collected and maintained for decades.

Looking ahead it is expected that the roles of these different technologies may be reversed. That is, the CTM systems will provide the primary data and IR thermographic data would be taken for additional analysis

FIGURE 8. Noncontact IR sensors targeting bus connections for continuous thermal monitoring.

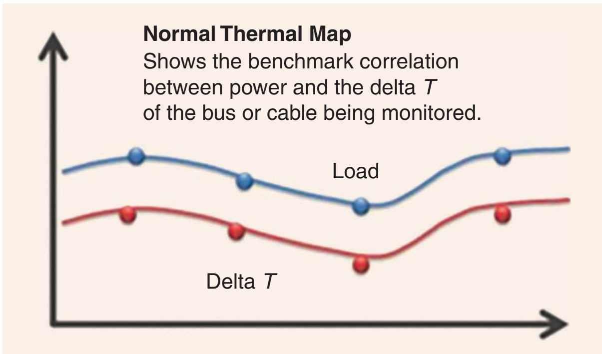

FIGURE 9. Tracking Delta-T temperature data against electrical load information.

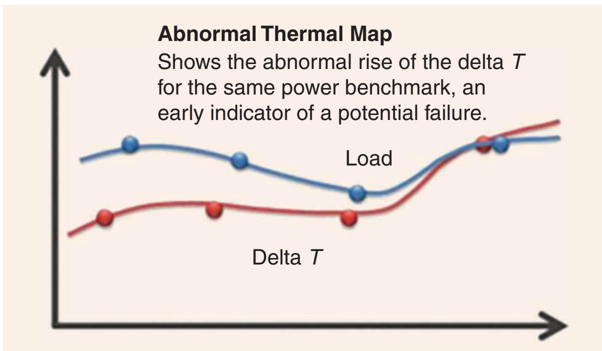

FIGURE 10. Note a rise in Delta-T without an accompanying change in load.

of any areas of interest or concern. During the transition, the time *not* invested in periodic inspections using thermal imaging cameras will be compiled for evaluation to demonstrate maintenance and inspection savings. As data identifies conditions where arcing fault risks and conditions may exist, any quantified costs due to outages and down time may also be compiled.

IEEE CTM Standard Development

Continuous thermal monitoring has been successfully used to complement traditional periodic IR thermographic surveys for switchgear and MCCs for many years. As this practice continues to gain recognition for elevating personnel and equipment safety, it's also recognized for elevating equipment and system reliability. It is expected that there will be more conversions to this technology throughout industry in the future. Not only in the process industries but wherever electrical service is considered critical.

Continuous thermal monitoring has been successfully used to complement traditional periodic IR thermographic surveys for switchgear and MCCs for many years.

The development of the IEEE P2969™ Guide for Continuous Thermal Monitoring of Switchgear and Motor Control Centers up to 52 kV continues and is to be balloted within the WG for presentation to the IEEE/IAS-PCIC Standards Chair in 2023. From there, the circulation of the Guide to Ballot Groups among the Sponsoring Committee(s) (and potentially beyond) will be scheduled. Ultimately, every proposed IEEE Standard must be presented to the IEEE Review Committee (aka REVCOM) for approval and release to the Standards Board (SB) for publication and distribution.

FIGURE 11. A collection of data cards for collecting and transferring temperature data to a host system for trending analyses.

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