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Beyond IR thermography: how continuous thermal monitoring improves performance and equipment protection

by Markus Hirschbold and Dominique Chabert

Executive summary

For many years, scheduled infrared thermography inspections have been the accepted method for reducing the risk of fire by identifying faulty or loose connections in electrical distribution systems. Continuous thermal monitoring offers a safer, more effective way to detect thermal risks on a system-wide, 24/7 basis. The method also delivers up to a 10:1 return on investment due to avoided equipment damage and downtime.

Introduction

In 2017, Atlanta's Hartsfield airport experienced an electrical fire caused by a failure in a piece of switchgear. Located in a tunnel beneath the airport, the fire crippled both the main power system and its backup.[1] Delta Airlines say they lost up to US$50 million in revenue because of the power outage. They had to cancel over 1400 flights.[2]

Every year, electrical fires produce devastating consequences in all kinds of facilities. For critical buildings like hospitals, airports, or data centers, major financial losses, injuries, and even deaths can be the result.

Electrical fires are not uncommon. They account for 22 percent of workplace fires.[3] In hospitals, electrical fires have been identified as the number one cause of fires after cooking-related incidents.[4]

Defects in medium voltage (MV) and low voltage (LV) distribution system wiring and switches, or defects in motors, are often the source of electrical fires.[5] According to the National Electrical Testing Association (NETA), one major insurance carrier estimates that approximately 25 percent of all major electrical failures are due to loose or faulty connections.[6]

Consequently, many insurance companies, the National Fire Protection Administration (NFPA), and many other regulatory bodies require annual thermal surveys to reduce this risk. Driven by these requirements, thermal surveys have become general practice to mitigate the risk of faulty connections in all kinds of buildings.

Thermal inspection standards

In the US, multiple regulatory bodies have set standards for thermal inspections. The NFPA 70B standard is one example.

See the references section at the end of this paper for a selected list of standards.

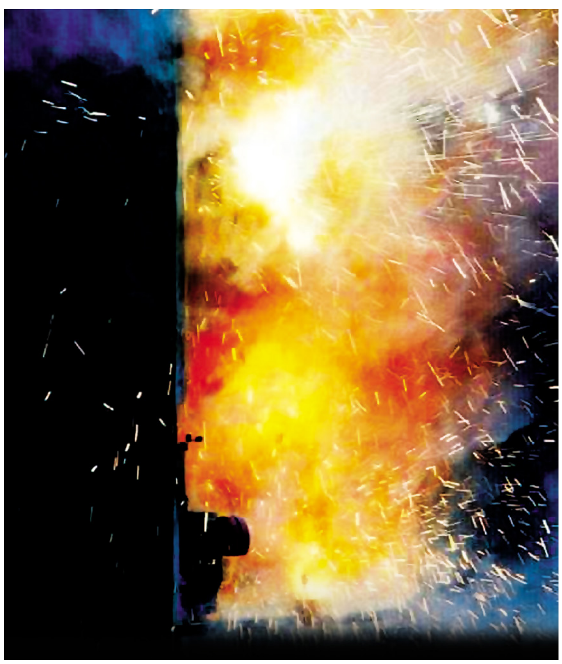


Figure 1

Electrical fires are devastating for critical power facilities, in terms of damages, downtime, injuries, and loss of life.

[1] 'Atlanta airport mess: How does this happen?', CNN Money, December 2017
[2] 'Delta says it lost up to $50 million because of the Atlanta airport power outage', Business Insider, December 2017
[3] Electrical Contractor Magazine, "Fire in the Workplace", 2004
[4] 'Hospital Fires (2012-2014)', NFIRS Data Snapshot, FEMA
[5] 'Fire in the Workplace', EC&M, 2004
[6] 'Top Five Switchgear Failure Causes', NETA World, 2010

Up until now, thermal surveys have been performed using infrared (IR) thermography technology. Though this method is effective when done in compliance with regulations, surveys are performed only on a scheduled basis. And as each test is necessarily performed in close proximity to live electrical equipment, personnel can be put at risk.

This paper will discuss the emergence of *continuous thermal monitoring* technology. Compared to IR thermography, this method offers a safer and more comprehensive way to detect thermal risks across an entire medium and low voltage electrical distribution system.

The causes of electrical fires

A major cause of failure in MV and LV installations is faulty electrical connections, especially connections made on-site.

Cable, busbar, and withdrawable circuit breaker connections can start to deteriorate due to loose connections caused by improper tightening torque or constant vibrations over time. Deterioration can also occur because of damaged surfaces due to corrosion, excessive pressure, or excessive friction.

These conditions can be made worse by two types of conditions:

- **Frequent temperature cycling.** Fluctuations between cold nights and hot days, or low and high current, cause increased and decreased tightness of a connection. This, in turn, contributes to loosening.
- **Frequent on/off switching.** This generates an electromagnetic shock on the busbar and the connection points that can cause those connections to loosen.

Problems due to servicing

In addition, the following service malpractices have been observed in some substations:

- **During cable insulation testing.** To perform these DC current tests, cables must be dismantled. The following problems can occur during re-assembly:
  - The old electrical grease is not cleaned or replaced
  - Improper tightening torque is used
  - Improper positioning of contact washer
- **During draw-in of a withdrawable circuit breaker.** A mechanical problem occurs due to the misalignment of clamps.
- **Installation of a spare circuit breaker.** Problems can occur when contacts have already shown surface deterioration or damage.

Case study: Chemical plant

A major global supplier of lithium products needed to ensure a new chemical processing plant operated with the highest possible reliability.

The MV switchgear was equipped with networked thermal sensors. Thermal monitoring was provided locally at the substation as well as through data integration with the on-site SCADA system.

Thermal monitoring on all connection points is helping the plant's operations team ensure continuity of service, increased safety, and reduced maintenance costs due to minimal on-site testing.

Thermal runaway, connection failure, and fire

In any of the conditions noted above, a critical sequence of events begins to occur:

1. Increasing electrical contact resistance accelerates further deterioration.
2. This increased resistance induces a temperature rise.
3. High temperatures deteriorate the connection surface even more.
4. The further deteriorated surface leads to a further increase in contact re-sistance.
5. The resulting thermal runaway will cause complete connection failure.
6. Fire, flashover, and explosions can occur.
7. In the worst cases, this leads to the destruction of the switchgear and severe injury to the operator.

Early detection of abnormal busbar temperature rises caused by faulty connections will, in most cases, prevent electrical failures and fire. Therefore, insurance companies and regulatory bodies now require thermal inspections to be performed regularly, addressing the highest-risk parts of electrical distribution systems.

Traditional IR thermography

The most common and traditional approach for thermal inspections is carried out using IR thermography. A thermal camera is used to inspect areas of the electrical equipment that represent the highest thermal risks.

IR thermography is usually conducted at regular intervals such as every 6, 12, or 24 months. The potential weakness of this approach is that periodic surveys do not always alert maintenance teams early enough when there is fast deterioration at connection points. Also, restricted access to some electrical rooms due to safety regulations can complicate periodic testing and cause even more thermal risks to be missed.

Figure 2

IR thermography is a manual, scheduled approach that uses a thermal camera to test for temperature increases at high-risk points within MV and LV switchgear. An IR window in the switchgear door provides camera access.

IR thermography also typically requires an IR window installed in the switchgear door to provide adequate camera access for testing of the live equipment. For LV equipment, the operator often has to open door panels to check connections. There can also be limited accessibility and visibility of the contact points, especially with busbars, so positioning the camera can be challenging. For these reasons, there are safety concerns for testing of some types of switchgear and transformers due to the risk of the technician being exposed to an arc flash.

Finally, manually-conducted IR thermography surveys are costly. Even so, the return on investment can be high. According to an article by Cody Jackson, an experienced thermographer with JTI Services in Massachusetts, IR thermography inspections, when followed by timely repairs, can provide a US$4 benefit for every US$1 value of the IR inspection. This is because infrared inspections can catch symptoms of problems before they cause equipment failure.[7]

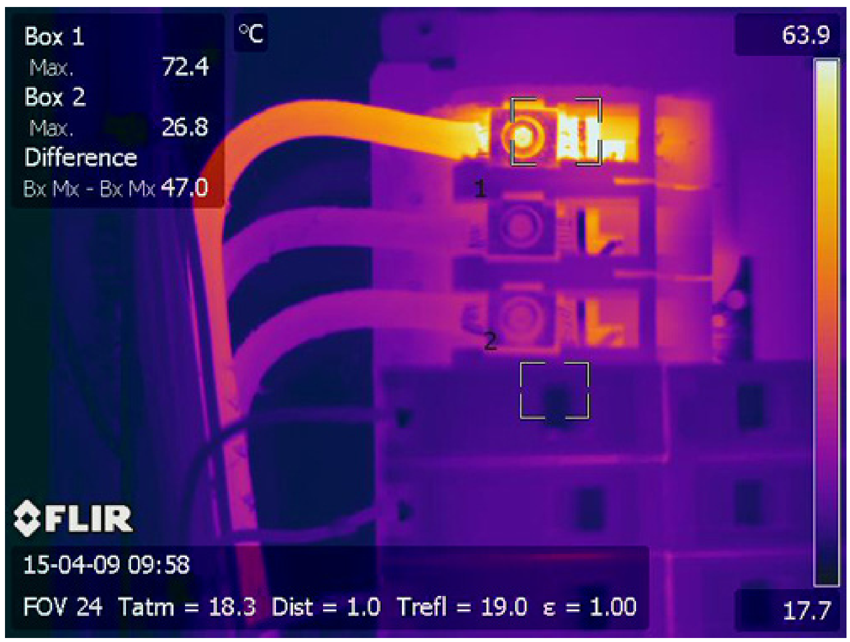


Figure 3

Typical thermographic scan of cable connections inside of electrical switchgear, showing increased heating on one of the three connection points.

Image courtesy of Infrared Imaging Services

Continuous thermal monitoring

Continuous thermal monitoring is a relatively new solution that offers several advantages over IR thermography, with even greater potential ROI.

In contrast to the manual, interval-based approach of IR thermography, thermal monitoring is performed continuously. Abnormal temperature rises or thermal runaways are detected in real-time.

[7] 'Three Ways Infrared Thermography Improves Electrical Maintenance', IRInfo.org

Case study: Facebook data center

An international Facebook data center in Sweden experienced two arc flashes on an overhead 5000 amp busway. Fortunately, the events were limited to one of four power rooms and there were no injuries or downtime as a result.

A post-event analysis revealed that the bolts securing many of the busway joints were not properly torqued during assembly. Over time this created a thermal 'avalanche' effect that eventually caused a joint to fail. The review also identified the inadequacy of IR scans to identify hot spots at busway joints.

After all busway joints were properly torqued, a complete thermal monitoring system was implemented, consisting of 1500 wireless sensors installed on busway runs. Data integrated with the facility's building management system is helping provide early alerts to thermal issues to avoid the risk of arc flash in the future.

Learn more.

Advantages of continuous monitoring

Whereas IR scanning might miss critical conditions if they occur between scheduled scans, they will unlikely be missed by a thermal monitoring system. In addition, thermal monitoring systems will typically include automated alert capabilities. A thermal event will immediately send alarms to operations and maintenance teams, giving them more time to respond before any equipment damage occurs.

An additional benefit of continuous thermal monitoring is the ability to use a current level-based temperature model as a reference. Busbar and connection temperatures fluctuate with the amount of current flowing in the conductor. Therefore, by knowing the current it is possible to better predict the busbar temperature and compare it to the actual temperature. This makes this type of analysis more accurate and provides more finely tuned alarm sensitivity. In other words, abnormal temperature rises can be detected more readily.

Thermal sensor technology for low-density MV and LV connection points

There are two recent innovations to use for continuous thermal monitoring applications:

1. **Thermal sensors**

   This technology relies on permanently installed sensors on individual connection points. This is best suited for low-density applications with few connection points. Thermal sensors are installed on all important connection points and other thermal risk locations throughout the electrical distribution system. This can include:

   - **MV switchgear.** Sensors should be located on incoming cables, busbar, and withdrawable circuit breaker connections.
   - **MV/LV transformer.** Sensors should be located on the transformer MV input, windings, taps, and LV output.
   - **LV busway.** Electrical busways are also made up of many connections to facilitate tap-off points, corners, elbows, or 'joint packs.' The joints are areas where improperly made connections can result in an increased risk of an electrical fire. Fortunately, busways do not require a special window and are often readily accessible for IR scanning. They are also ideally suited for the installation of wireless thermal sensors specifically designed for this application.
   - **LV switchgear.** For large incoming LV cable and busbar connections, thermal sensors can be utilized to obtain the temperatures of individual connection points. For higher-density connections within LV cabinets, the IDD technology described in the next section should be chosen.

   A typical thermal sensor can be approximately 4 x 4 cm in size. These are installed directly on MV and LV connection points, typically with some form of strapping system (see **Figure 4**). Sensors can be used on new or existing installations. For LV busways, installation can typically be done keeping the circuit live, as long as proper safety precautions are followed.

   Sensors can be designed for dedicated thermal monitoring. Some may offer additional capabilities, such as humidity monitoring.

Many thermal sensors take advantage of advances in wireless connectivity. This greatly simplifies the installation of sensors, especially in retrofit scenarios. It also eliminates any isolation or insulation issues caused by the sensing wires.

Sensors can be designed to be bus-powered or powered by a battery. This further simplifies installation.

2. **Insulation decomposition detection: for high-density LV cabinets**

While thermal sensors are well-suited to lower-density connection points, thermal monitoring for smaller conductors and high-density wiring within LV cabinets is more challenging.

Emerging insulation decomposition detection (IDD) technology offers an effective solution by detecting cable thermal decomposition in a range of temperatures that provides early warning of an imminent risk of fire. IDD offers a simple and reliable way to preventively detect cable connection issues for the great majority of LV cable types on the market while providing unique benefits versus other established fire detection systems.

IDD requires only a single smart sensor to be located at the top of each column or cabinet. The sensor analyzes gas and particles, taking advantage of the behavior of cable insulation decomposition during a thermal runaway situation, detecting this abnormal condition before any smoke or insulator browning occurs. The sensor detects an overheating problem with any cable inside that column of the cabinet, enabling a solution that is more simple and quicker to install and integrate.

Note that thermal sensors can be a good complement to IDD technology, with the former used on all larger lower-density connection points, and the latter used for smaller high-density cable connections within LV cabinets.

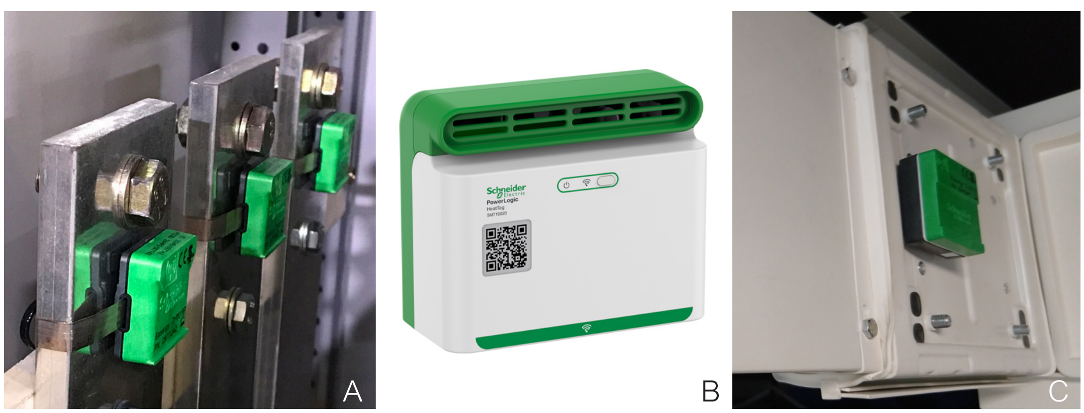


Figure 4

Typical installation of thermal sensors on (A) busbars, (B) IDD, and (C) busway

Communications architecture

It would simply not be practical to manually check the temperature readings of each permanently mounted sensor regularly. Wireless connectivity enables 24/7 monitoring, with constant scanning of all sensors to detect abnormal temperatures.

Sensors form a complete, facility-wide thermal monitoring network. Using wireless data concentrators and other communication interfaces, as necessary, thermal data is uploaded automatically and continuously to local and cloud-based analytic applications. Thermal monitoring may be offered as a core function or modular add-on to a power and energy management system solution.

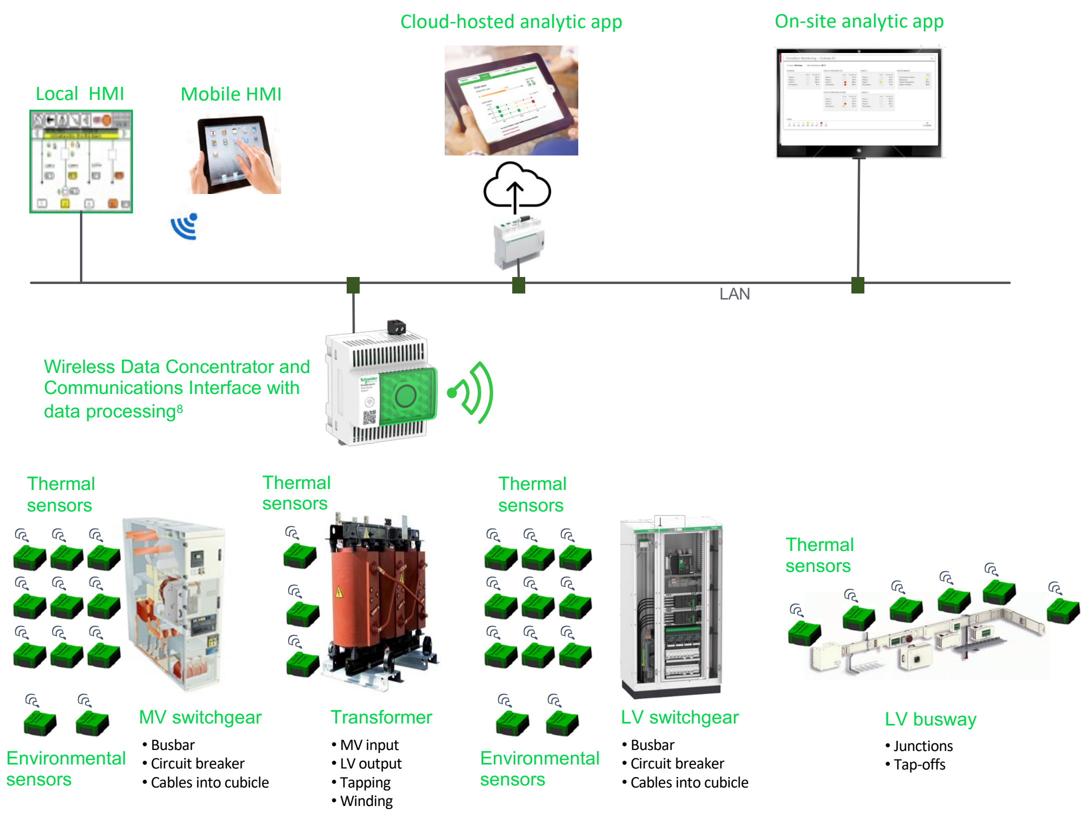


Figure 5

Typical thermal monitoring system showing wireless sensors feeding data to cloud-hosted and on-site analytic applications

Alarming and analytics

One of the key benefits of continuous thermal monitoring is near real-time alarming. If a sensor reading shows an abnormal temperature rise at any connection point or in the insulation of any cable, an alarm will be generated at the software level. The software can be configured to immediately send a notification to the mobile devices of local operation and maintenance teams.

Local or cloud-based applications should allow temperature and, if available, humidity to be visualized by area, equipment, and individual sensor. Applications that also provide long-term trending of thermal data can help personnel detect slow deterioration, addressing issues well before they cause a problem.

[8] One data concentrator can monitor one or more equipment depending on their physical separation.

Figure 6

Thermal monitoring screen showing status of networked thermal and environmental sensors, with alarm conditions highlighted in red

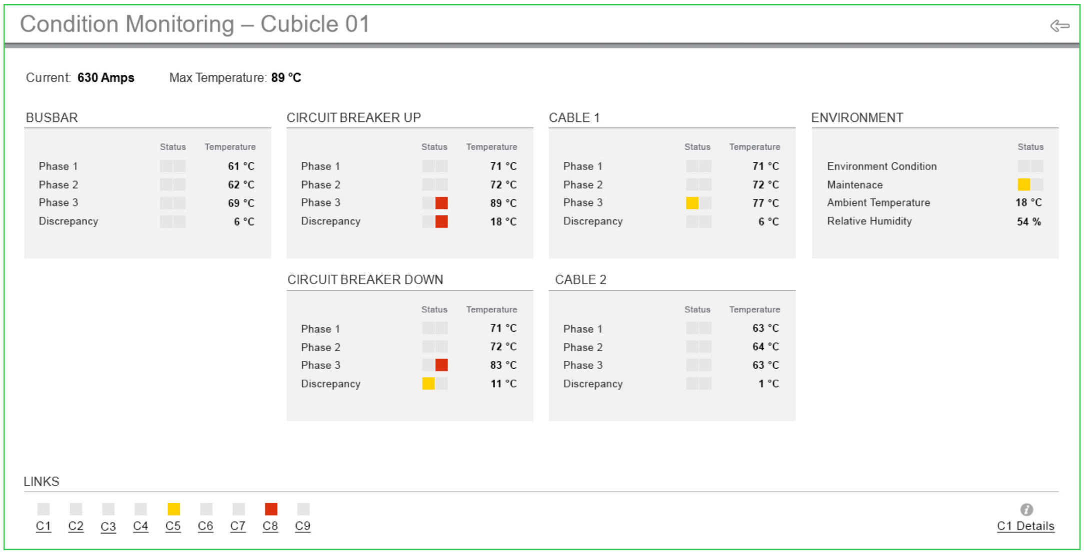
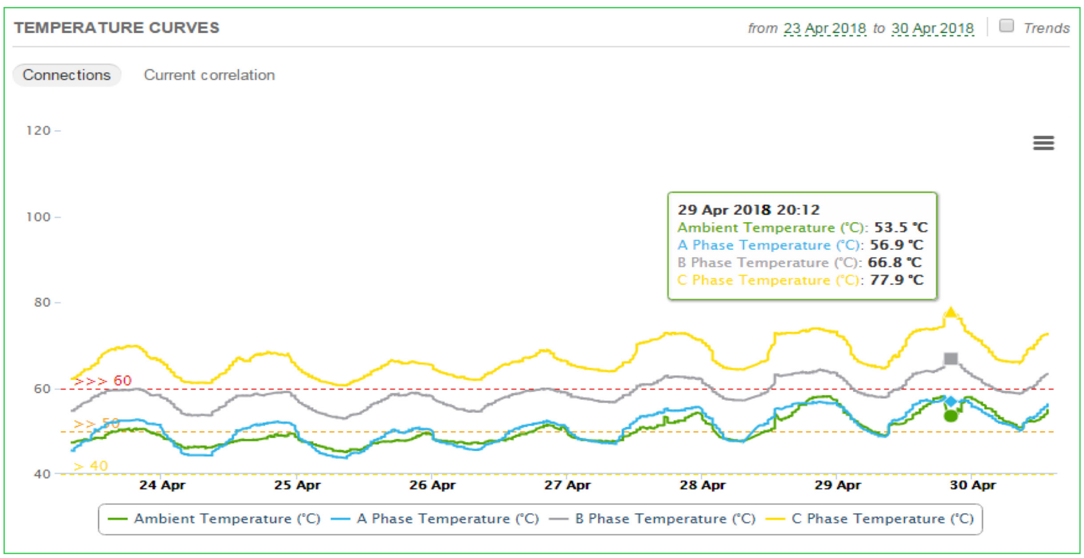


Figure 7

Thermal trend graph showing an abnormal temperature rise on one phase of a transformer.



Case study: Harbor terminal

One of the largest shipping terminals in the western Mediterranean needed the highest safety and reliability for two secondary power distribution substations.

A complete power management system was installed, featuring thermal monitoring on cable connections, with data integrated with the SCADA and asset management systems.

The solution helps predict potential failures to maintain uptime and increase safety while improving asset management efficiency.

Beyond the improved accuracy offered by the current level-based temperature modeling noted above, thermal analytics may also provide a phase-to-phase comparison. This can help further differentiate and isolate a problem, for example, if one phase of a 3-phase transformer starts to exhibit a thermal runaway condition. In this particular example, if the transformer has not completely failed, load shedding could be implemented to reduce the load on that phase to a safer level until a transformer replacement can be scheduled.

Outsourced services

Many of the newest cloud-based power and energy management solutions allow for data sharing with outsourced expert services. As part of this strategy, facility teams can outsource thermal monitoring tasks. A contracted third-party maintenance service that provides analytic and advisory services can monitor multiple facilities from a central operations center.

These services enable predictive, condition-based maintenance, ensuring maintenance is focused where it is needed, the right maintenance is performed at the right time, and maintenance spend is optimized.

Increased ROI

When compared to IR thermography, continuous thermal monitoring offers a significant increase in return on investment over time. The following is a cost comparison example for ten MV switchgear cubicles.

Table 1

Cost comparison for IR thermography versus a continuous thermal monitoring system

	Price		
Example: 10 MV cubicles	CAPEX	OPEX	TOTAL
Periodic thermographic survey*	€2800	€10,000	€12,800
Thermal monitoring hardware and connection to locally-hosted app	€5000	€0	€5000

** Based on 1 visit every 2 years, €1000 per switchboard per visit, over a 20 year lifetime.*

In this example, IR thermography costs approximately 2.5 times more than thermal monitoring over a 20-year lifetime. Based on the 4:1 cost-benefit analysis of thermal surveys by JTI above, the resulting ROI for continuous thermal monitoring would be approximately 10:1. Therefore:

For every euro/dollar invested in thermal monitoring, 10 euros/dollars in potential equipment damage is avoided.

This, of course assumes that any identified issues are followed up with timely repairs.

As previously noted, the recent Atlanta Hartsfield airport incident resulted in close to US$50 million in losses for Delta Airlines. Adding in all other airlines, the overall damages were most likely well over US$100 million. This makes it easy to justify many millions in a thermal monitoring solution to avoid a similar incident in the future.

Conclusion

Wireless continuous thermal monitoring is the best way to detect abnormal temperature rises in any electrical distribution infrastructure before they lead to equipment failure, major financial losses or worse, loss of human life.

Over the typical 20-year lifetime of most switchgear, continuous thermal monitoring is estimated to be 2.5 times more cost-effective than IR thermography. It is also a safer alternative, as it avoids the need to expose personnel to live equipment and the risk of arc flash.

In terms of improving reliability and uptime, a thermal monitoring system identifies thermal issues that arise faster than the typical IR scanning intervals. It also provides higher accuracy in identifying thermal risks when offering current level-based temperature modeling and phase-to-phase comparisons. And near real-time alarming enables service teams to respond quickly to risks before downtime and damage can occur.

We recognize that in many jurisdictions, infrared scanning is required by codes and standards. In this case, continuous thermal monitoring still makes sense to complement IR scanning. And, IR scanning intervals could be reduced to the maximum allowable intervals.

About the authors

Markus Hirschbold (P.Eng., CEM, PMP)
Markus is responsible for offer creation of EcoStruxure Power, the IoT-connected solutions of Schneider Electric, designed to improve every aspect of power distribution systems. He has held various key positions in R&D, Services, Power Quality, Project Management, and Offer Marketing in over two decades of tenure at Schneider Electric.

Dominique Chabert
Dominique is in charge of offer creation for medium voltage products and MV/LV transformers including integration with the EcoStruxure Power program. He has held various positions in R&D, Marketing, and Project Management for the Contracting and Medium Voltage departments for Schneider Electric.

Resources

IR standards, specifications, and guidelines

For an extensive list of organizations that publish infrared standards, infrared specifications, and infrared guidelines for performing infrared inspections and/or related testing, please refer to this page at IRINFO.org.

White papers

‘Using Infrared (IR) Thermography to Improve Electrical Preventive Maintenance Programs’

New gas and particle sensing technology detects cables overheating in LV equipment

Continuous thermal monitoring solutions

Easergy smart sensors

Continuous Thermal Monitoring for Power Distribution Explained

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