Automated Substation Monitoring with Thermal Imaging

by **Richard Harada**

Introduction

Infrared technology is widely used by utilities to find heat related anomalies in the electrical system that could indicate potential problems. Portable infrared cameras have been typically used by thermographers to periodically inspect substations and other key areas of the grid. Early detection of excessive heat in the electrical system, or the absence of it in some cases, allows the utility to schedule maintenance and correct issues before an expensive failure occurs. While periodic scanning is useful, it is subject to many changing variabilities including changing environmental and load conditions.

Automating thermal inspections can greatly reduce the costs to utilities through reduction of travel while increasing employee safety and the amount and quality of data that is collected.

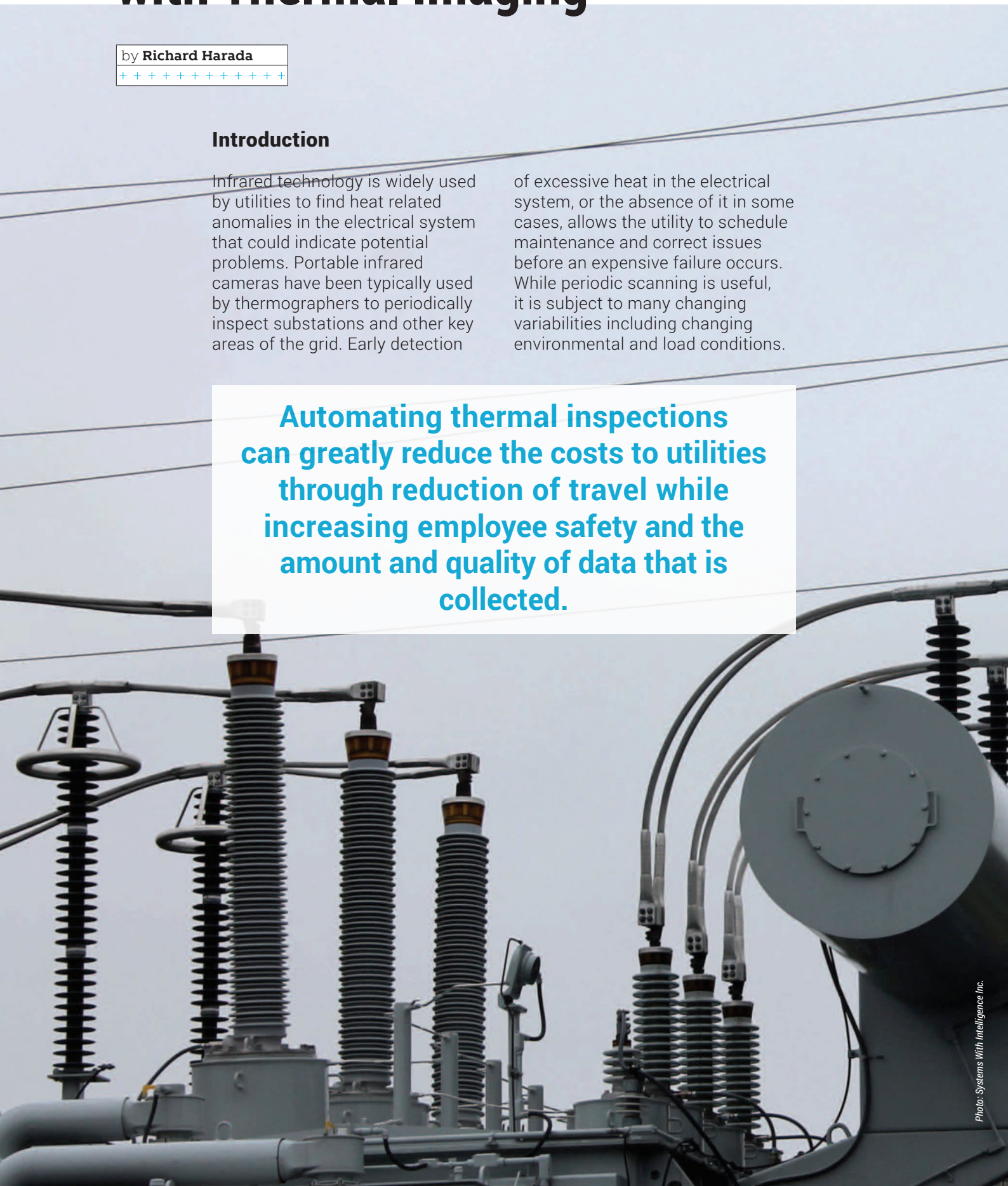


Photo: Systems With Intelligence Inc.

Richard Harada has more than 20 years of experience in industrial networking communications and applications. Prior to joining Systems With Intelligence, Richard worked at RUGGEDCOM and Siemens Canada, where he focused on industrial communications in the electric power market. Richard is an electronic engineering technologist and has a Bachelor of Science degree in computer science from York University in Toronto.

Being able to monitor your substation remotely is one of the keys to going touchless.

Automating thermal inspections can greatly reduce the costs to utilities through reduction of travel while increasing employee safety and the amount and quality of data that is collected. Furthermore, the data can be made available to SCADA and asset management applications as part of a condition-based maintenance program to increase the utility's bottom line through improved asset life, efficiency and reduced outages.

Automated and remote inspections can lead to more efficiencies and cost savings for utilities by allowing them to go "touchless."

Figure 1 shows a thermal monitoring camera that can be programmed to automatically monitor equipment in the substation. A thermal image of a transformer shows temperatures of transformer components and allows thermographers to define areas to take temperature readings. The readings are digitized and converted to temperature points.

Utilities such as PPL Electric Utilities and PSE&G [1], [2] are implementing touchless substation projects that involve remote monitoring to gather the health information on substation equipment and condition-based maintenance (CBM) to plan and prioritize service work. Remote monitoring can involve many types of connected sensors such as those that measure current, voltage, temperature, dissolved gas, etc. Some of the key areas to monitor with sensors are transformer components such as bushings, cooling fans and load tap changers.

Advancements in infrared technology and the communications around it make thermal imaging more widely available through reduced cost, ease of use and accessibility to the data.

Figure 1. Substation rated, infrared monitoring sensors can be permanently installed on pan-tilt mounts to automate the thermal scanning process.

Photo: Systems With Intelligence Inc.

Background on Thermal Imaging

Thermal imaging is the technique of measuring infrared radiation from an object and converting it into a temperature value. An important feature of thermal imaging is that it is non-invasive — it uses a sensor that can measure temperature values without physically touching the object. It is not required to power down equipment to install the sensor or to make the measurements. The measured value can be affected by many environmental factors including ambient temperature, humidity, wind and emissivity of the target object. With these factors in mind, it is often more meaningful to use comparative measurement; comparing the temperature differences between like components instead of trying to measure an absolute temperature value on each, effectively cancelling out the environmental variables. An advantage in the electric power industry is that the power system runs on three phases, so in many cases inside a substation it is possible to measure like components on different phases, i.e. measuring the temperature difference between the A, B and C phase transformer bushings [2]. In this case, instead of trying to calculate what an absolute temperature value should be, it is simpler and more meaningful to compare temperatures between phases. Typically, the temperature of like components should be within 1°C of each other. If not, there could be a load problem or a component problem in the system.

The International Electrical Testing Association (NETA) has established a guideline of comparative measurements and relative comparisons to ambient temperature.

Thermal imaging is useful to find heat related anomalies in many areas of a substation.

As outlined in Table 1, NETA has recommendations for actions to take when comparative readings reach defined levels.

Thermal imaging is useful to find heat related anomalies in many areas of a substation, such as connection points, disconnect switches, breakers, insulators and arrestors.

Around transformers the key points to monitor are:

Bushings and surge arrestors – Hots spots on the connection point could be due to loose or dirty connections. Hot spots on the body could indicate a breakdown of the insulation.

Cooling Systems – Cool spots on radiators could indicate blockages or low coolant levels. Cool or hot areas in fans can indicate electrical or mechanical problems that require maintenance.

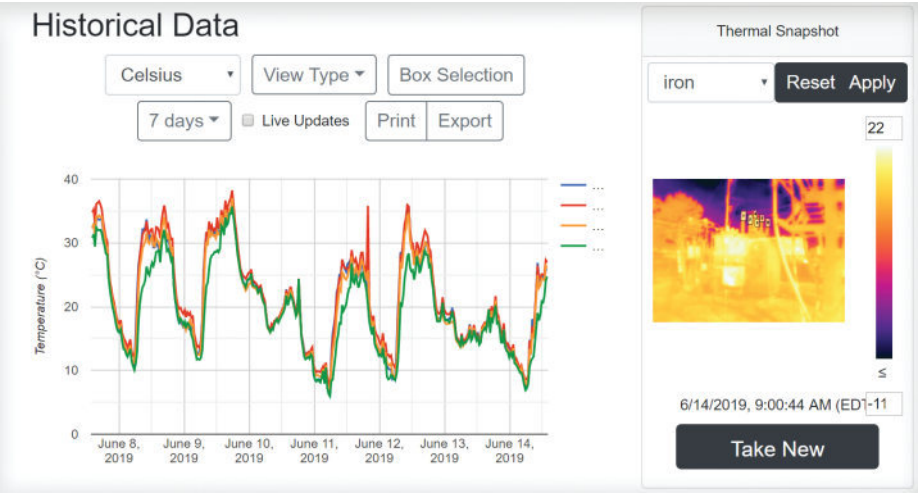
Load Tap Changers (LTCs) – The LTC tank should be the same or lower temperature than the body of the transformer. A bad connection on the tap changer will heat the tank only if it is carrying load. A faulty tap may not show up in a thermal scan if it is not connected at the time of the reading.

Table 1. Recommended temperature thresholds and actions for monitoring electrical components.
(Source: NETA World - Infrared Inspections and Applications)

Temperature difference (ΔT) based on comparisons between similar components under similar loading	Temperature difference (ΔT) based upon comparisons between component and ambient air temperatures	Recommended Action
1°C - 3°C	1°C - 10°C	Possible deficiency; warrants investigation.
1°C - 3°C	11°C - 20°C	Indicates probable deficiency; repair as time permits.
------	21°C - 40°C	Monitor until corrective measures can be accomplished.
>15°C	>40°C	Major discrepancy; repair immediately.

and efficiency. The system analytics automatically detect temperature abnormalities in the system and send alarm messages. The data can be stored locally at the site and communicated directly to the control center SCADA or to asset management systems for real time situational awareness.

Figure 2. Continuous temperature values can be trended over time and correlated with weather and load conditions.
(Source: Systems With Intelligence Cloud Dashboard)



Advancements in Thermal Imaging Technology

Processing Power

Thermal imaging runs on computing power. As advancements in thermal imaging technology continues, the performance of thermal imaging is increasing while the price of the technology is decreasing. An automated thermal sensor can capture high, low and average temperatures from hundreds of pre-set points while cycling and scanning through areas of a substation. Using high resolution imaging and the appropriate lens, the temperature on even a small object can be measured from up to 50 meters away. Data processing can be done at the edge of the network to improve reliability

Communications

Major improvements in network communications have been a huge benefit to thermal imaging technology. In the past, with handheld cameras, the data was stored in the camera and transferred to a computer system manually. Now, with modern Internet Protocol (IP) based systems, the temperature measurements are digitized, stored on solid state memory and transferred to storage and control center systems in real time. Many utilities have high speed connectivity to their substation, but even those with little or no connectivity can still take advantage of the edge processing that minimizes the amount of traffic that needs to flow over the network. Utilities with no wired connection to their remote sites can utilize modern 3G and 4G wireless networks that provide high speed connectivity.

Data points can be trended over time to establish a health index and the graphs and current readings can be accessed via an information dashboard (Figure 2). Visual and thermal sensors can send their data wirelessly to the cloud for remote sites that have limited connectivity (Figure 3).

Reliability

Infrared sensor technology has shifted from analog imaging to digital imaging resulting in improved image quality, more efficient methods for transmitting data, and simpler processes for storing and analyzing the data. The previous generation of thermal cameras used analog communications to transport information making it susceptible to degradation and loss. When used in a substation the interference effect was increased due to the presence of high levels of electromagnetic interference (EMI). New, network-connected imagers now digitize the signal at the source and can transmit the data over fiber optic cable which is immune to the effects of EMI. Storage technology has improved so that data can be saved to solid state drives, eliminating the need for mechanical spinning drives. Substation rated equipment is required to meet high levels of reliability and the components and designs can now meet these requirements while maintaining a high level of performance.

The Advantages of Automated vs. Manual Thermal Scanning

Utilities have been doing manual thermal scanning for years, and they are aware of the problems that can be uncovered with the technology. Utilities have thermographers on staff (or they use professional contractors) to perform thermal site inspections. However, there are many advantages to using continuous, automated thermal scanning given the advancements in thermal scanning technology.

Photo: Systems With Intelligence Inc.

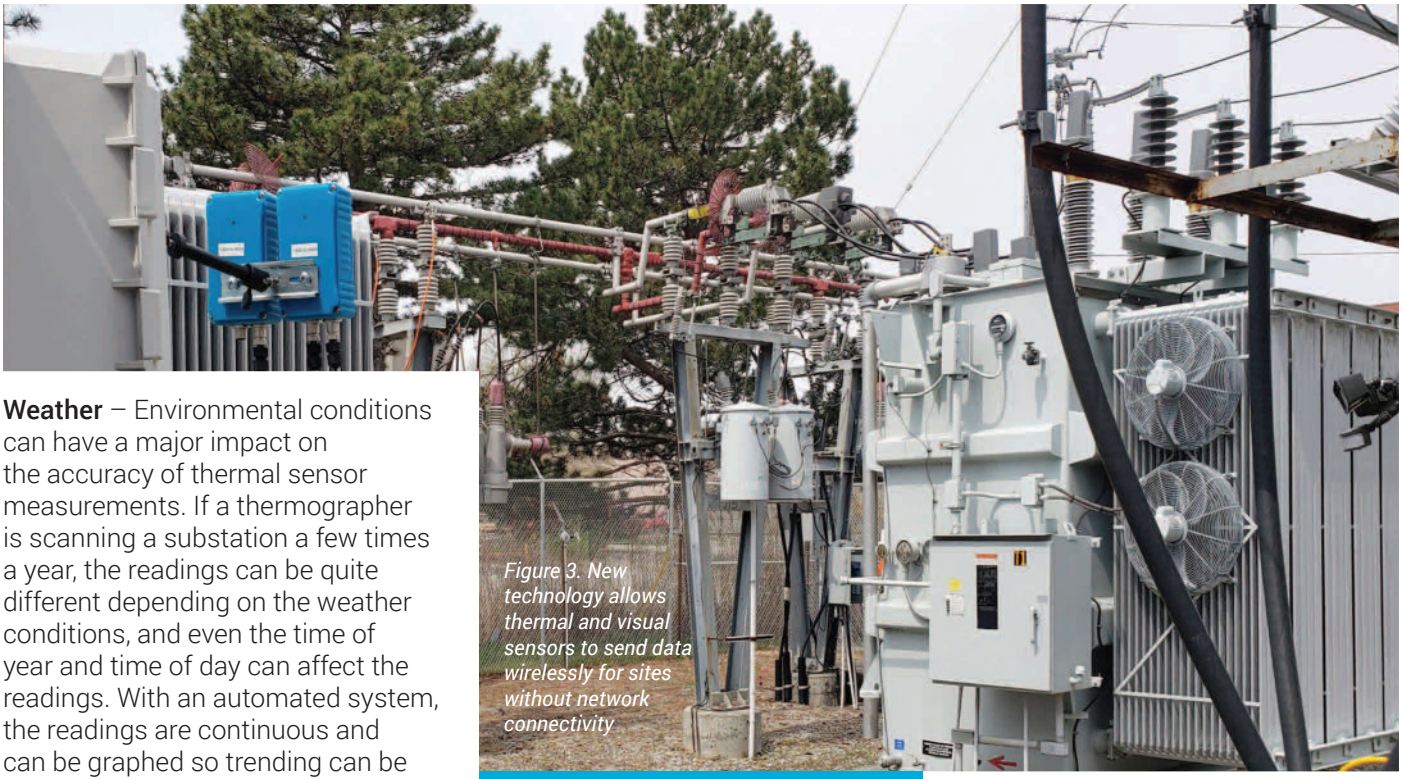


Figure 3. New technology allows thermal and visual sensors to send data wirelessly for sites without network connectivity

Weather – Environmental conditions can have a major impact on the accuracy of thermal sensor measurements. If a thermographer is scanning a substation a few times a year, the readings can be quite different depending on the weather conditions, and even the time of year and time of day can affect the readings. With an automated system, the readings are continuous and can be graphed so trending can be established that will account for weather abnormalities and will even show how temperatures vary daily and seasonally.

Accuracy of data entry – A thermographer using a handheld thermal imager will at some point need to transfer the readings to a computer system. The transfer of data can be prone to error when a manual operation is involved. An automated system records the data to a database and has an interface to send the data in real-time to SCADA, asset management or data aggregation applications, eliminating the possibility of human error.

Consistency and interpretation of results – Thermal scanning results from the substation can vary over time. Aside from the changing environmental conditions, variations in the angle, position and distance to the object may affect the consistency of the readings. Different thermographers may use different imagers and interpret settings and readings differently. An installed thermal imager will be installed in a fixed location and will be programmed by the thermographer to scan the substation at predefined, pre-set positions with high accuracy and consistent parameter settings. This guarantees consistent readings and interpretation of results.

There are many advantages to using continuous, automated thermal scanning given the latest advancements in technology.

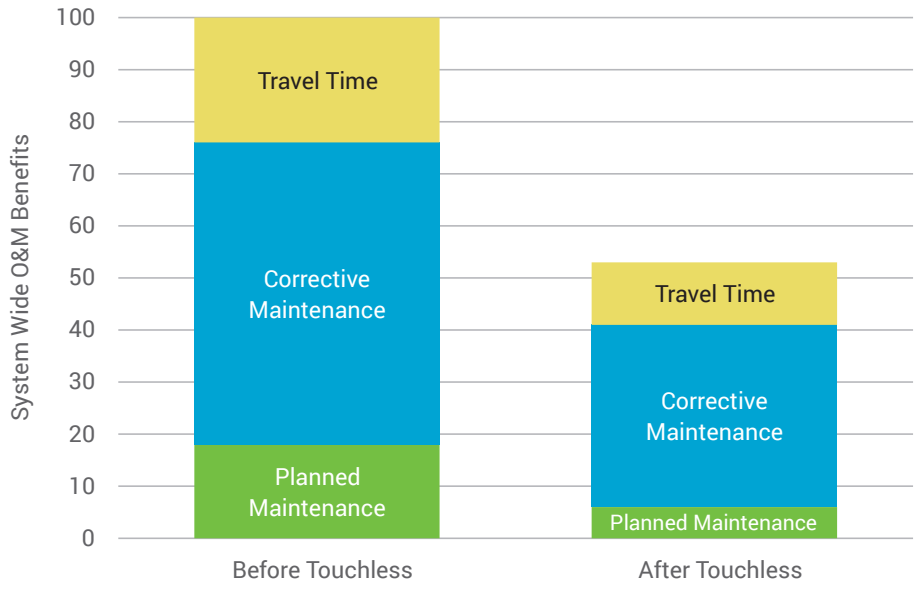
System load – The amount of current being drawn can have a major effect on the thermal scanning results due to the I^2R factor. If current is leaking through an insulator, or if there is a poor or loose high resistance connection, that point will heat up more when there is greater current flow. A faulty tap on an LTC will only show up when that particular tap is connected. Some hotspots may only show up during times of peak load, so if the thermographer is not performing the scan during this time the hot spot will remain undetected. Conversely, the continuous scanning system will find the hotspot during each time the system hits peak load or when a faulty tap on the LTC is connected. This will generate an alarm about the condition.

Continuous thermal data – Manual thermal scanning doesn't provide continuous data. By its nature, data from manual scans is infrequent and can be less accurate unless the same experienced thermographer is doing the scan each time. Continuous thermal data allows for trending of temperature data and relating it to weather, seasonal changes and system load. The thermal data can help asset managers establish asset health indexes for the purposes of condition-based maintenance.

Timing - Periodic inspections are valuable for finding hotspots, but they can miss problems if the timing is off. As and example, a substation that is inspected today may be struck by lightning tomorrow, damaging an arrestor. That damage may not be discovered until the arrestor fails.

Connection to Management Systems – With automated thermal imaging, data transfer happens seamlessly. As the temperature data is collected, it can be uploaded directly to connected SCADA systems, data aggregation systems such as OSISoft, or asset management systems using industry protocols such as DNP, Modbus or IEC 61850. This type of connectivity provides operators with real time data and asset managers with data that can be used to track asset health and condition.

Figure 4. Reduction in O&M costs using condition-based maintenance. (Source: The Future is a Touchless Substation [2])



Condition Based or Preventative Maintenance

As utilities strive to get the most out their assets while making the most efficient use of maintenance resources, they are turning to condition based maintenance to try and achieve these goals. As shown is Figure 4, CBM saves a utility money by reducing trips to the field by alerting crews to equipment problems before failures occur. CBM can extend the life of assets by allowing crews to perform repairs before costly failures occur [3]. With constant monitoring, utilities know the condition of their assets and can schedule maintenance only when required instead of on a time-based schedule. This makes the most efficient use of personnel and materials. Automated thermal monitoring provides a constant source of timestamped temperature data that can be connected directly with asset management databases and correlated with weather, load and other situational conditions in the substation.

Summary

Utilities know the benefits of thermal monitoring, and new technology can now make it automated and more affordable. While there is an initial capital expense to install a continuous thermal monitoring system, there are many benefits that a utility can realize in a relatively short amount of time that can save operations and maintenance costs, help prevent outages and extend the life of high value assets.

Thermographers can set up the system to perform automated thermal scans of the substation. The thermal cameras can be programmed to take temperature measurements on hundreds of points with thresholds set to determine if the readings are within tolerance. The thermographer can also take control of the system remotely for focus on specific areas of interest. Since the system will typically include visual cameras, substation managers can also perform remote visual inspections of equipment and conditions in the substation. Utilities benefit from remote inspections by:

- Reducing the frequency of truck rolls by eliminating the need to be on-site for inspection.
- Increasing safety by reducing the amount of exposure that employees have to hazardous areas.
- Monitoring crews on site, which can influence behaviour and ensure that crew follow safety procedures. If any incidents occur, a video recording can provide valuable evidence and training for the future.
- Increasing the volume of inspections, which ensures that the substation is in top condition, animals are not moving in, and the substation remains a safe environment for the public and for employees.
- Allowing remote troubleshooting and visualization, which informs the crew of equipment condition and failures before going to the site. This may allow them to have the right parts on the truck before rolling out.
- Providing constant and consistent data for condition-based maintenance.

References

[1] E. Rosenberger, M. Coyle, *PPL Touchless Substation Project*, 2017.

[2] D. O'Rourke, R. C. Alvarez, M. Khan, "The Future is a Touchless Substation," *T&D World Magazine*, 2019.

[3] D. A. Genutis, *NETA World – Infrared Inspections and Applications*, 2006.

[4] J. Lonneker, B. Baker, "SDG&E Takes a Proactive Approach to Maintenance," *T&D World Magazine*, 2013.

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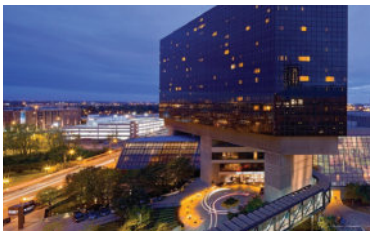

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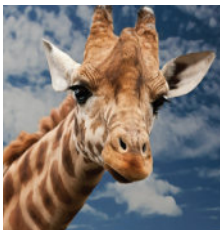

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Saturday night early bird venue TBD — details on all to follow.

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Face-to-face in a digital world – the value of industry events

In an ever increasing virtual world, where do industry events fit? Can we gain the knowledge we need to do our jobs today and in the future from the digital world alone? Or should we also realize the value of stepping away from the screen? **This article explores the benefits of sharing knowledge face-to face through industry events, investing in people for their personal development and, ultimately, realizing how organizations are reaping the rewards.**

In the March 2019 edition of Transformer Technology magazine, Alan Ross, Editor in Chief, asked the question "What if much of that legacy knowledge isn't worth passing on in the first place? What if things have changed and are changing so rapidly in our field of electrical system reliability that much of that legacy knowledge is outdated, or even worse, what if it is flat out wrong? Would we want to make sure the next generation learned it?"

This question on the surface appears easy to answer. But how do you continue to ensure individuals and organizations gain the knowledge and skills required to be successful?

Choosing and attending the right industry events can be an important starting point.

Photo: Shutterstock

Motivation!

Some events are considered expensive, requiring time away from the office, and the return-on-investment isn't always clear. But they provide opportunities that you simply cannot get elsewhere.

Having the opportunity to learn, meet with experts and peers, and have a bit of fun(!) is a great way to motivate people. From time to time, everyone's motivation dips, especially when facing the same routine and set of challenges each day. An industry event provides a great opportunity to free your mind from day-to-day tasks and experience something refreshing and motivating.

An organization with motivated, proactive employees, contributing new ideas is always more likely to succeed.

Learn something new and imagine new ideas!

Reading industry publications, blogs and whitepapers can certainly contribute to a better understanding of new developments and trends in our industry. However, watching, listening and interacting with experts face-to-face is invaluable. Attending an event allows people to ask questions and make important connections with industry experts and peers. Attendees learn new skills and best practices, leading to practical ways to achieve long-term success as an individual and organization.

Industry events also present the opportunity to meet like-minded people who share similar interests and face similar challenges in the workplace. Stepping away from daily work life and networking with peers can generate fresh, new ways of thinking and learning, translating into ideas and concepts that provide a strong ROI to organizations.

Networking, in person!

In a digital world, networking in person is becoming more and more difficult. We often forget how effective in-person interaction can be.

We cannot expect that an individual has the answer for every challenge today's world throws at them. Having a strong network of experts and peers from within a given industry to call upon can provide a leverage to solve new problems, discover best practice and learn from similar challenges. Events provide valuable time to network and socialize as an industry. Investing in building an individual's network reaps benefits for employers and organizations for years to come when new challenges inevitably present themselves.

Attending industry events should be part of all organizations overall improvement and growth strategy. Understanding industry trends and current developments is key to being successful and competitive. Having motivated, engaged individuals in an organization can only lead to additional benefits, now and in the future.

So referring back to Alan Ross's question, lets equip ourselves and future generations with the knowledge and skills required to ensure our industry of transformers, power generation, transmission and distribution can be successful for years to come - and it is evident industry events play a leading role in confidently knowing that up-to-date research and ideas are being discussed and passed on.

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