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Temperature Monitoring in Low-Voltage Switchgear

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ABSTRACT
This article evaluates temperature monitoring solutions in low-voltage switchgear employing existing technologies, evaluating the effectiveness of an alternative, contemporary self-diagnosing embedded solution. The design of the proposed system incorporated the monitoring of temperature-rise within low-voltage switchboards and emergency escalations to duty holders and end-users when electrical equipment has surpassed its thermal limits, predicting failure, rather than reacting to it. This ‘intelligence’ in low-voltage switchgear will prove a key component in end-user asset management and integration into ‘Smart Grid’ networks and ‘Internet of Things’ (IoT).

KEYWORDS: Condition Monitoring, Temperature Monitoring, Low-voltage Switchgear, Predictive Maintenance, Self-diagnostics.

INTRODUCTION
Low-voltage (LV) switchboards, are infrastructurally positioned at the centre of a building or site electrical distribution system. Armah Switchgear Ltd (ASL) is a specialist manufacturer of this integral piece of equipment. Switchboards are responsible for the supply and protection of electrical equipment throughout an installation from overload and short-circuit currents. Similarities can be drawn to the familiar consumer unit, fuse or circuit breaker distribution board, found in domestic dwellings, but on a larger and more complex scale.

Example installations of the LV switchboards manufactured include: high-integrity data centres, manufacturing process plants within the motor industry, MoD sites, transport, prisons and hospitals, together with applications demanding robust redundancy to life safety equipment supplies (lifts, smoke ventilation, sprinkler pump systems, medical theatres). Continuity of supply, the lifespan of assets and operative safety are imperative within any electrical installation.

Through rigorous laboratory testing of the product, full compliance with and beyond the requirements of the governing standard BS EN61439 (BSI, 2011) has been achieved with partner businesses. These are discussed in more detail hereinafter.

The research evaluated existing temperature monitoring technologies to consider alternative improved methods for integration into intelligent LV switchgear systems, with several objectives set to identify existing sensor products and systems available within market.

Technologies and methods used within existing products and systems for temperature monitoring electrical power
distribution equipment have been evaluated. A concept has been developed for an improved approach/method of temperature monitoring of LV distribution equipment. This concept will be developed post-research into a standard model and along with the methods of interpreting inputs within a closed-loop system and communication of data to a supervisory monitoring system.

This report set out to explore the requirements of a predictive maintenance, closed-loop control system; utilising hardware and software, to warn, and if required, provide outputs to de-energise circuits to ensure safe operation within design parameters. These requirements cover the legal obligations of duty of the asset holders.

MONITORING TECHNOLOGY
The research motivation for developing an ‘intelligent’ system for energy and temperature monitoring is rooted in the Smart Grid initiative, detailed in Figure 1 below.

Smart Grid demands implementation of methods of continuous system monitoring, (as shown in Figure 2) through modernisation of existing electrical systems from grid to socket. This is achieved by use of ‘information and technology to monitor and actively control generation and demand in near real-time’ (Ofgem, 2014). This research is intended to ensure the ASL LV product is technologically prepared for dynamic condition reporting, so energy consumption and the correct operation within the thermal limits to which the assembly has been tested to can be monitored by an end-user’s supervisory system.

Figure 1. – Features of Proposed Technology

TEMPERATURE MONITORING
A popular method of switchgear temperature monitoring, to check for hotspots at cabling termination points or copper busbar connections such as joint fishplates, is by the use of an infrared (IR) thermal imaging camera, allowing inspection via special crystal or mesh viewing ports mounted on the switchboard’s external coverings, Figure 3. Usually conducted annually, the inspection will most likely not highlight a problem area if load or ambient temperature in room is lower than occasionally sustained.

Figure 2. Remote Condition Monitoring of LV Switchgear

Figure 3. Thermal imaging view ports (left/centre) and hotspot within fuse chamber (right)

Source: Yan, et al. (2017)

DeGrate et al. (2015) describe the main limitations of thermal imaging to be the restrictive viewing angles available to
interrogate internal switchboard connection temperatures, those which are immediately behind coverings, as seen in Figure 4.

Figure 4. Operative carrying out thermal survey of switchgear using IR thermal imaging camera through a crystal viewing port

Source: Yan, et al. (2017)

For intrusive access to continuously monitor temperature at all key locations, IR sensors and thermocouples are utilised, eliminating line-of-sight issues of thermal imaging windows (Durocher and Loucks, 2015). See Figure 5.

Figure 5. IR sensors mounted within switchgear for monitoring all key locations within an assembly

Source: Calex (2018)

SELF-DIAGNOSTICS TECHNOLOGY

Existing condition monitoring systems monitor temperatures and signal alarm or trip signals when temperatures have surpassed safe operational levels. An intelligent approach must be able to continuously monitor working temperatures in-line with the temperature-rise limits of the tested arrangement’s design, verified through standards testing. Early self-diagnosis of premature aging or the initiation of failure of switchgear can be directly related to limits identified during design verification.

The end-user, or the designer, will specify that requirements from the switchboard manufacturer must include compliance to the standard, BS EN 61439 (BSI, 2011), see Table 1. Design verification, the act of ensuring the assembly is compliant, must be carried out by the manufacturer.

The standard allows design verification to be carried out by testing, calculation or by design rules. The data used within this study are derived from testing, conducted within controlled environments in verified laboratories in the UK and Europe within which assemblies have been tested, based on set assembly configurations and arrangements.

Table 1. Extract: BS EN 61439-1, Annex D

<table>
<thead>
<tr>
<th>Characteristic to be verified</th>
<th>Test</th>
<th>Calculation</th>
<th>Design Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature-rise limits</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>

Source: Standard BS EN 61439-1 (BSI, 2011)

SENSOR SELECTION

A range of sensors were considered in the selection process. The K-type thermocouple (Figure 6) is an inexpensive option with a unit price less than £10 and sufficiently accurate, at 0.5% or 2°C, whichever is greater (RS Components, 2018). However, the sensor is ‘intrusive’ as it must be surface mounted to the material which it is monitoring. This introduces the potential for the tracking of leakage currents between conductors and instruments. It would not be possible to busbar mount with sensor in supplementary insulation as it may be detrimental to measurement accuracy.
The IR sensor is unintrusive, has no physical connection, compared to the K-type thermocouple. It is hardwired and expensive in comparison, at over £200 per sensor. Its accuracy is ±1% or 1°C, whichever is greater (Calex, 2018).

The SAW passive sensor is unintrusive and requires no power; components are passive and excited via radio waves, it detects surface temperatures through dynamic response of a piezo crystal directly mounted to the surface of the material. SAW stands for ‘surface acoustic wave’; the wave which is emitted from the piezo crystal upon radio wave excitation. The response of the crystal, picked up by a remote antenna, allows temperature to be measured as frequency responses vary, with an accuracy of ±2°C.

The IR sensor was selected for integration into the proposed system, albeit expensive, it allowed hard-wire connection, providing ease of compatibility, whilst offering unintrusive monitoring; no physical connection to conductors or surfaces is required.

**DATA ANALYSIS AND THEORY**

Data gathered from BS EN 61439 laboratory testing is utilised to gauge overall assembly and switchgear limits. This allows ‘actual’ temperature inputs from IR sensors to be compared with ‘expected’ temperatures or the set limits of the assembly and switchgear. It is important to note, that exceeding the design limit of the assembly may not trigger a traditional temperature monitoring system and would therefore not alert the end-user to exercise ‘predictive’ measures, but only to ‘reactive’ maintenance requirements, or potentially catastrophic failure of switchgear (see Figure 11).

The theory detailing the relationship between electrical energy and thermal losses of switchgear is detailed below in Research and Findings section.

**LIMITATIONS OF RESEARCH**

The research presented by the author is a hypothesis utilising data gathered from laboratory testing. Software along with an embedded algorithmic formula to interpret continuous data inputs from real installations was used. Hardware selection has been considered suitable, site-based case studies and long-term data gathering is still to be gathered to confirm operation due to the incompletion of complementary deployable software.

**RESEARCH AND FINDINGS**

During laboratory verification, an assembly comprising a metalclad enclosure, a
supported copper busbar system and compartmentalised switchgear are all under test. The switchboard assembly connected to a supply at the ‘Main Incomer’ (main switch to accept power from a stable source) and via the busbar system, the outgoing devices supply electrical power to a resistive load bank. This enables a simulation of the switchboard to be tested under load.

During the tests, thermocouples (as per Figure 6) are strategically placed internal and external to the assembly. The temperature is monitored as the board is tested to its design load in amps, ‘In’. At ‘In’, the test load is sustained until a stable temperature measurement can be established by the test equipment. The manufacturer must specify to the laboratory what the maximum working temperature of the switchgear is, and the maximum expected ambient temperatures within which the assembly will be installed.

The term ‘Temperature Rise’ test describes to what magnitude of temperature the assembly’s components can rise, whilst efficiently and compliantly delivering the required amount of energy, or more specifically current, to the load. The data gathered from these tests is the basis of the ‘expected’ or maximum limit to which measured ‘actual’ temperatures will be compared in real installations.

**THEORY AND CONTRIBUTING FACTORS**

Laboratory test data can inform the maximum operating temperature, of a given piece of switchgear operating at its maximum rated diversity factor (RDF). The RDF may be less than the full rating of the device depending on the temperature rise performance of the overall assembly. Neglecting the external factors which will affect temperature rise, the fundamental relationship between power loss, and current (load) is given by:

\[
P_W = P_N \left(\frac{I}{I_n}\right)^2
\]

- **P_W** – Calculated Power Loss
- **P_N** – Power Loss at Rated Current
- **I** – Magnitude of Current (Load)
- **I_n** – Rated Current (RTD) of Circuit Breaker

Source: Kilindjian (1997)

Thus, power loss is proportional to the square of the current flowing through a circuit breaker. Figure 9 shows other ‘actual’ contributing factors will need to be inputted into the final algorithm for comparison with test data.

**SYSTEM OPERATION**

The IR sensor selected seen in Figure 7 can communicate samples to a monitoring relay every 2 seconds. This rate will be adjustable upwards to suit the final design, and when the amount of data which can be handled and stored by the supervisory is established. The system sequence of operation is depicted in Figure 10.

Thus, power loss is proportional to the square of the current flowing through a circuit breaker. Figure 9 shows other ‘actual’ contributing factors will need to be inputted into the final algorithm for comparison with test data.
The proposed algorithm shown in Figure 9. The inputs grouped to the right-hand side of the diagram are assumed as the key variables for this research, with other contributing measurables included which can also inform potential premature ageing of switchgear.

CONCLUSIONS AND NEXT STEPS
Although temperature monitoring in LV switchgear is a common offering throughout the industry, this research intends to demonstrate that the utilisation of the known limits of an assembly allows continuous monitoring of ‘actual’ measurements to be compared with the limits of a derived design verified configuration.

End-users will be able to better manage, monitor and potentially prolong, or better guarantee the life span of their power distribution assets by use of condition monitoring which alerts the user to variables exceeding those of the limits set by the tested arrangement, which can be seen in Figure 11 below:

Figure 11. – Condition Curve / Time. Predictive, Preventive and Reactive Maintenance Opportunities

The chart shows a comparison curve of condition against time, and how early stage warnings better manage cost and risk in maintenance planning; catching failure at its initiation. It will allow for ‘predicative’ maintenance, rather than ‘preventive’ or ‘reactive’ maintenance, rectification or complete replacement of an assembly.

FURTHER RESEARCH
Following post-study research, data will be presented against example tested arrangements. The theory will be developed to allow algorithm design to commence, with software and hardware selection fully identified, and key sensor locations identified for a generic installation. Further analysis will be presented of the requirements for compliance with BS EN 61439, to convey the significance of implementation of a system described within this article.

The final system must be compatible with communications protocol ‘Modbus’ over RS 485 to allow for compatibility with existing building management systems (BMS).

DIRECTOR APPROVAL
The author obtained director approval for the proposed system to be further developed and finalised as a new product offering, following initial research findings.

ACKNOWLEDGEMENTS
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REFERENCES


