

Hunting the Mighty Milliwatt

The next Technology Step

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Abstract: Milliwatts can turn into “Mighty Milliwatts” (MMW), when resistance increases, typically in loose or bad connections. These MMW, if not detected and allowed to develop can become Megawatts of energy causing catastrophic failure. The exponential growth from milliwatt to megawatt is completed in seconds, but the milliwatt energy signature prior to this situation is typically at too low a level to be detected by conventional metering / Icurrent measurement. The only way to detect these elusive MMW is via the thermal increase at the joint / connection, which can be detected utilising non-contact infrared sensors of sufficient sensitivity & reliability.

Periodic thermal imaging inspections once or twice per year rely heavily on luck and variable site specific conditions. Expensive intervention (shutdown) maintenance every 1 > 3 years is thus still required. For high downtime cost organisations (i.e. Datacentres), new infrared technology now enables continuous 24x7 thermal monitoring of mission critical equipment INSIDE the panels to be cost effectively achieved. The developed system can also be fully integrated into existing BMS/SCADA systems, web enabled, provide on-line real time data.

The best detection method is thermal measurement and non-contact infrared technology has become the universally accepted method for detecting such faults.

Such detection is of particular importance to organisations that have high downtime costs. Examples include financial services, telecommunications, data centres, large scale manufacturing, utilities, media, shipping and urban transportation systems. Throughout all these diverse industries the common denominator is POWER.

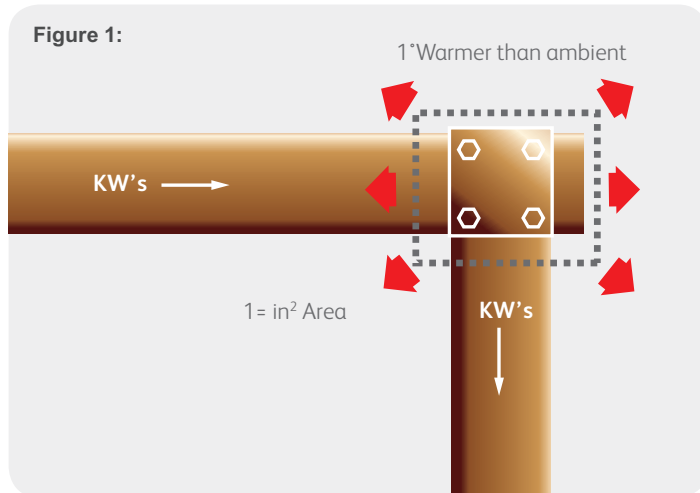
So what is the “Mighty Milliwatt” and how relevant is it to the circumstances described above? Small amounts of resistive energy losses, converted to heat from electrical circuit elements in high power electrical systems, usually at connections, are manifested as a temperature rise above ambient.

0.001Watt in resistive energy lost by circuits using kilowatts to megawatts of power represent less than 0.0001 of the energy transmitted.

Bad joints and connections are the most common cause of failure in electrical equipment yet they can not be detected by conventional metering or load measurement

1. The Calculations

Figure 1 shows the level of milliwatts created from a connection 1 inch square in area and 1 degree F warmer than ambient. As can be seen it is just 2 milliwatts. Milliwatts are created as the resistance from a loose connection increases.



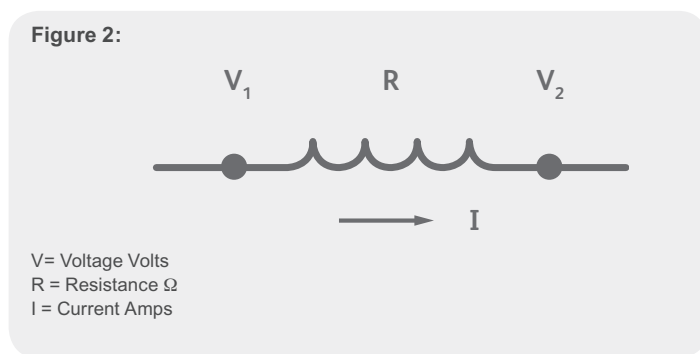
$$q = hr \times A \times (T - T_A)$$

$$= 1 \times \frac{1}{144} \times 1 = .007 \text{ Btu/hr Ft}^2$$

Convert to Watts $.007 \div 3.4 = .002 \text{ Watts}$

= 2 Milliwatts

Figure 2 shows the example for a 100 amp cable.



$P = I^2 \times R = \text{Heat Dissipated as MMW}$

Calculate R for 2MMW (1°F Rise)

For 100 Amp Cable

$$P = .002 = I^2 R = (100)^2 R$$

$$R = \frac{.002}{(100)^2} = \frac{.002}{10,000} = .0000002 \Omega$$

Undetectable via Meter

However the “Mighty Milliwatt” is well named. When Current is increased and Resistance increases i.e. if the connection were to loosen with time/oxidation and the resistance increased to 1 Ω then –

For 100 Amp Circuit

$$\text{Power} = I^2 R = (100)^2 (1) = 10,000 \text{ w}$$

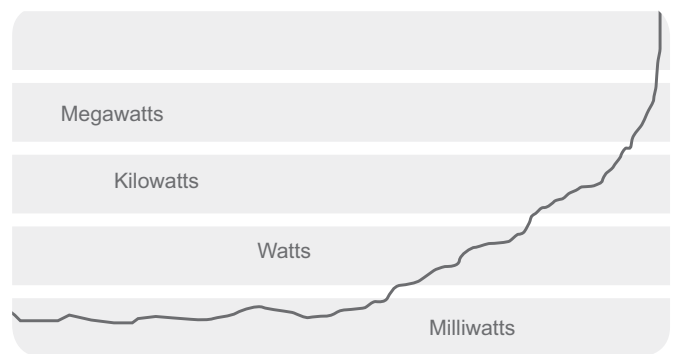
= 10kw

The “Mighty Milliwatt” has turned into ten kilowatts - enough energy to melt 1 ounce of copper in 0.6 second and for the organisation involved - catastrophic failure!

When the resistive loss exceeds a threshold value temperature increase causes rapid and irreversible increase in resistance triggering positive feedback that will escalate to exponential level. **See Figure 3.**

Figure 3

Normal Milliwatts > Mighty milliwatts > Megawatts
= catastrophic Failure



2. Evolution

The resistive energy has lost approximately 50% via radiation and 50% via convection to the local environment. However, the radiation component is detectable via infrared radiation methods of sufficient sensitivity and reliability as a temperature rise above ambient. Temperature rise is very sensitive to load, when load changes by factor of 3, **ΔT changes by factor of 10.**

Thus for high downtime cost organisations continuous thermal monitoring would certainly provide a significant increase in risk mitigation of power failure. Further, with available trend data, intervention maintenance cycles can be extended with confidence, generating significant downtime savings. If we were starting with a blank sheet of paper the requirements for continuous thermal monitoring could be summarised as:

- 1 **Small reliable infrared (non-contact sensors) continuously measuring temperature rises above ambient, capable of placement INSIDE the enclosure.**
- 2 **Variable F.O.V./distance from target**
- 3 **Negligible metallic cross section (non conductive)**
- 4 **Self-Powered**
- 5 **Local signal conditioning outside electrical panels**
- 6 **Wired or wireless data transmission to monitoring computer**
- 7 **Appropriate software/integration capability**

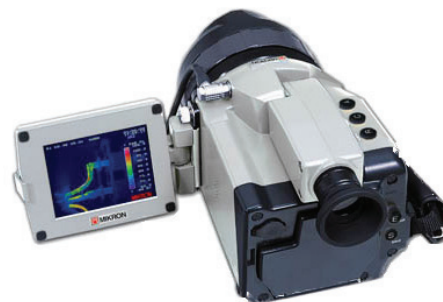
We have thus determined that these Mighty Milliwatts represent the initial stages of a situation, which if left to develop, can cause catastrophic failure, & can only be detected using continuous infrared (non-contact) thermal measurement, (periodic inspection may detect the problem but is reliant on luck, and a number of site specific variables). Let us thus look at how this 'next technology step' has evolved.

Technology Step No. 1

Involved non switch off periodic inspection utilising an engineers hand to gauge the temperature on the panel and determining if it was abnormal. Whilst often effective, this is clearly an unacceptable technology for mission critical equipment in today's high downtime cost environment.



Technology Step No. 2



Was the introduction of periodic infrared thermal imaging technology, enabling no switch off inspections to be carried out on a more objective basis and whilst still dependent on operator skill/experience represented a significant step forward.

However, this still did not resolve certain key issues. It was still periodic; representing 1 or 2 days out of 365, and thereby remained reliant on quite a significant degree of luck, (1 > 2 days out of 365), since it requires the problem to have developed to a point it is detectable, but not to the point of failure.

A further problem was that the inspection was conducted outside the enclosure, measuring the exterior surface of the panel, rather than the actual equipment inside the panel. Consequently, it requires correlation between external & internal component temperatures, that can vary significantly, according to climatic and equipment variances.

2. Evolution *cont...*

Technology Step No. 3

Was the introduction of thermal windows. These can either be mesh/screen or crystal. Whilst this significantly improved infrared transmission, mesh dissipates heat – think of the principle of a fire guard. Thus, whilst improving the IR they typically indicate the area of a problem rather than the location.



Crystal windows vary, but typically cut transmission by approximately 30-70%. The trade off is that the better the crystal transmission the more delicate the material.

However both need direct line of sight to the target, can add significant cost, and still remain periodic rather than continuous.

Thus the conclusion is that whilst periodic thermal imaging was a huge step forward, allowing more objective, recordable, non switch off inspection, and thermal windows provided a further technology step, improving inspection accuracy,

both remain preventative i.e. time based inspection, rather than predictive i.e. continuous monitoring, utilising trend analysis and alarms to predict failure before the event.

So is continuous monitoring really required? If we look at the lengths to which high downtime cost organisations go to in an effort to avoid power failures we can see that other measures include:

- 1 Over specification based on design load (often 50% plus)
- 2 Dual redundancy
- 3 UPS often more than one
- 4 And in addition to all these measures significant sums are spent on fire detection/suppression

Even with all these safe guards in place, it is normal for such organisations to still carry out periodic thermal inspections once or even twice per year. Clearly, risk mitigation could be significantly reduced via the use of continuous thermal monitoring on mission critical electrical equipment.

Technology Step No. 4

Was the introduction of the infrared thermocouple (IRT/c™). Perhaps the most important feature of this unique device is the fact that it is self-powered. All other IR devices require power to the sensor. Because the signal level is so small (microvolts) IR devices require an amplifier to avoid the small signal level being swamped by the power.



The amplifier introduces the possibility of electronic drift and thus calibration will have to be checked on a regular basis. This would be of particular significance to organisations with ISO quality standard systems. The IRT/c™ is self-powered (just like a standard thermocouple) and thus requires no amplifier and thus lifetime repeatable calibration. The IRT/c™ sensors are small, plastic, low cost, ultra reliable, non-contact devices, which measure the rise above ambient, and have recently gained UL certification.

There has also been the recent introduction of specifically designed small plastic cable sensors, also measuring rise above ambient. These can be used where there are cable joints as opposed to copper bus bar, and thus non-contact is not a requirement. The increase in temperature, resulting from the increased resistance from the “bad” connection is conducted down the cable to the sensor which is normally located within a few inches of the connection.

Data Acquisition cards (DAC's), have been developed which both linearise and condition the signal of these unique sensors, making them suitable for noisy electrical environments. These DAC's can accept 8 mixed (IRT/c – cable) inputs and are din rail mounted either in existing spare enclosures within a panel or externally in their own enclosure. This avoids bulky cable looms within the panel, and providing a secondary benefit for clear accurate cable marking. The DAC's per panel are linked via 485 data cable, (typically using a good quality shielded CAT 5 cable).

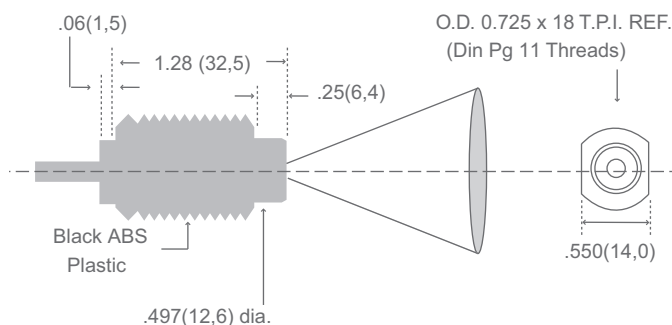
3. The Solution

There are then a number of options regarding/software/integration.

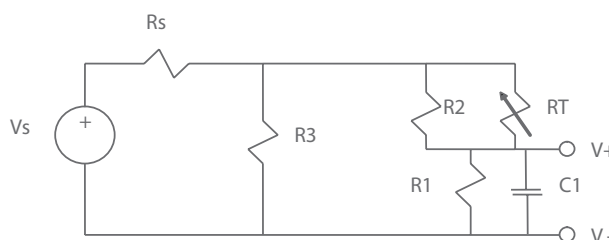


<p>Option 1</p> <p>Interlink all data cards on system and connect back to host computer utilising proprietary software.</p>	<p>Option 2</p> <p>As option 1 with addition of alarm relay to existing BMS</p>	<p>Option 3</p> <p>Introduce protocol conversion hardware prior to host computer thus enabling the system to be integrated with over 400 existing BMS/ SCADA systems</p>	<p>Option 4</p> <p>Utilise data acquisition card capability to provide output protocol in Modbus Probus, BACnet, Devicenet, Ethernet to enable direct connection per panel to existing host system bus cable and subsequent full integration into host system.</p>
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IRt/c.™ Field of View & Dimensions



Self Powered IRt/c.™ Circuit Diagram



This continuous thermal monitoring technology can be designed into new installations or retro fitted to existing installations at next suitable shut down. Where total shut downs are not possible (i.e. data centres/large scale manufacturing) the system can be fitted on a partial and progressive basis.

In choosing what to monitor perhaps the first question to be asked is what is periodically thermally imaged. That would form the basis of what should be continuously monitored. In essence it would be critical joints and connections on the mission critical element of the electrical equipment. The key word is critical.

There are some secondary benefits which derive from continuous monitoring:

- 1 Can potentially provide circa 20% extra life on major capital assets on basis of trend data
- 2 Extend conventional intervention maintenance by circa 2 to 3 years, thus achieving downtime savings which make the thermal monitoring self financing within a short time frame

- 3 Where removal of panels for live imaging is carried out a major risk mitigation in personnel safety is achieved
- 4 The cost of the installed monitoring as a percentage of job cost is typically 1-2%, which can be amortised over the life of the equipment

This new infrared technology has provided the next technology step enabling continuous 24x7 thermal monitoring of mission critical equipment to be carried out inside the enclosures enabling the prediction of failures before they happen.

Why take a snapshot when you can have the whole picture?

