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GROUP REF. : B1
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QUESTION N° : 3

Probabilistic engineering of cable systems

This contribution concentrates on probabilistic engineering of cable systems focused on the current rating. These systems can be AC and DC. An example is provided for a submarine cable system.

The current rating of a power cable is for an important part determined by the cable environment rather than by the cable itself. In such calculations, key environmental parameters are the soil thermal properties, the depth of burial and the ambient temperature, while a key cable parameter is the electrical conductor resistance. These parameters both have a variation and an uncertainty.

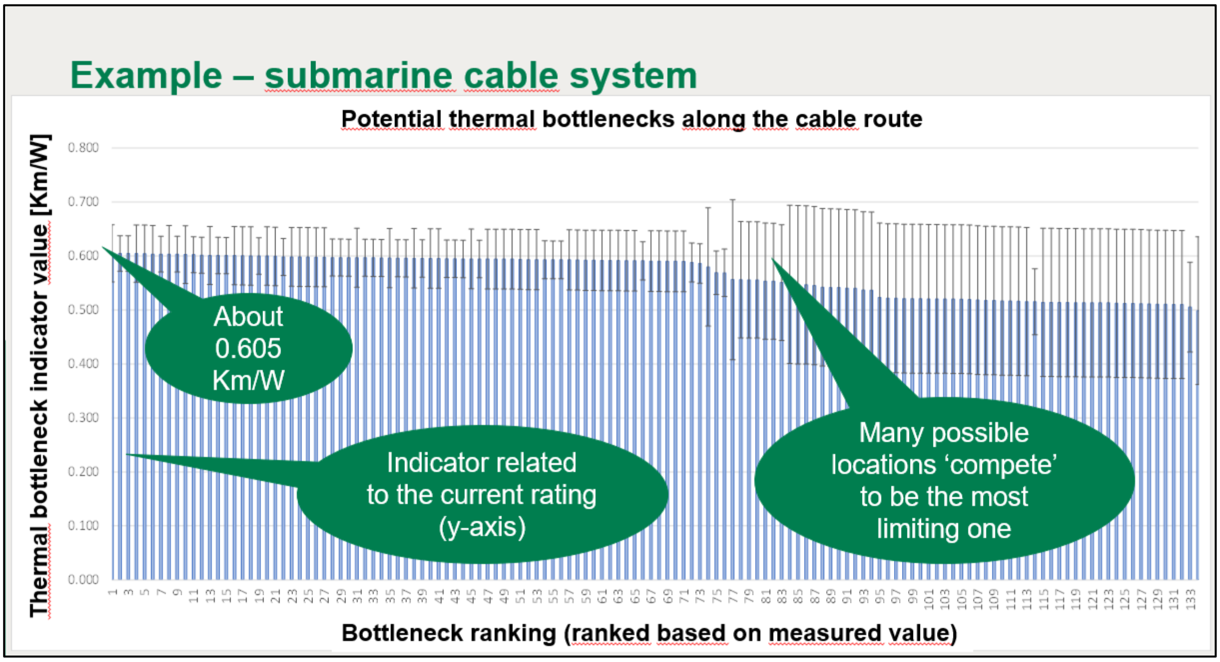
The soil thermal properties can largely vary over the cable length, while the uncertainty of the property is average (at best). The depth of burial can also largely vary over the cable length, while the uncertainty with which the burial depth is known is high. The ambient temperature of the cable environment has a smaller but still fair variation over the cable length while the uncertainty is low and the cable electrical resistance does vary only a bit, while the uncertainty is low.

It is our experience that uncertainties can be quite high in real situations. However, all uncertainties can be challenged, quantified and identified, though it is not always easy or straightforward. Furthermore, it is noted that some environmental parameters may change over time, meaning that current ratings become time dependent, and/or that measurements may have to be redone after some time.

As an example, the burial depth measurement of a submarine cable can be considered (not shown in slides), showing a strongly varying burial depth both for raw data and for the situation where the data is slightly averaged to remove artefacts from playing a role. It is interesting to understand whether this variation is actual variation of the burial depth, or if it is showing the uncertainty of the measurement, which is also present to an important extent.

Such variations and uncertainties of the cable environment must be taken into account when calculating the current rating. This can be done by understanding how measured values are distributed and subsequently taking that distribution into account. For example, many measurements of a same parameter may be normally distributed around a certain value, which means that the likelihood of a certain occurrence of a value is known. With the relevant distribution taken into account, the current rating of the cable system can subsequently be calculated. This can result – our experience – in a cable circuit that has many thermal bottlenecks that are in competition with each other to be the most onerous one.

The most onerous thermal bottleneck in a cable system defines the current rating of the entire cable system, and can be identified in different ways, for example using indicator values which represent the coarse environmental thermal resistance. The highest indicator value shown in the example (refer to slide 3, reproduced below) is 0.605 Km/W, remember this value. That value can be directly related to a certain current rating which then is the current rating of the most onerous thermal bottleneck that was found. What is important is that this example shows that there are 133 separate thermal bottleneck situations where the uncertainty around each measurement are such, that all of them could be the most onerous thermal bottleneck.



Example – submarine cable system

Potential thermal bottlenecks along the cable route

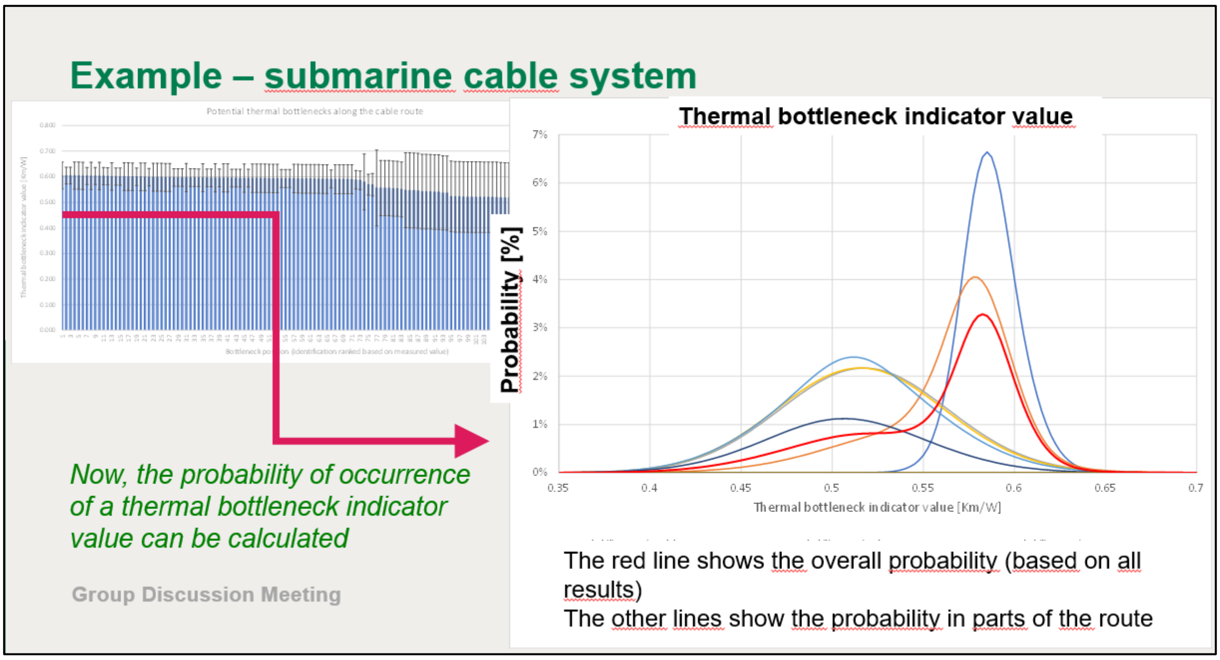
About 0.605 Km/W

Indicator related to the current rating (y-axis)

Many possible locations ‘compete’ to be the most limiting one

Slide 3 - Bottlenecks in a submarine cable route, ranked by thermal impact

When the uncertainties and the distribution are known, also the probability of occurrence can be calculated. In the example on slide 4, the thick red line shows the probability of occurrence of an indicator value.



Example – submarine cable system

Now, the probability of occurrence of a thermal bottleneck indicator value can be calculated

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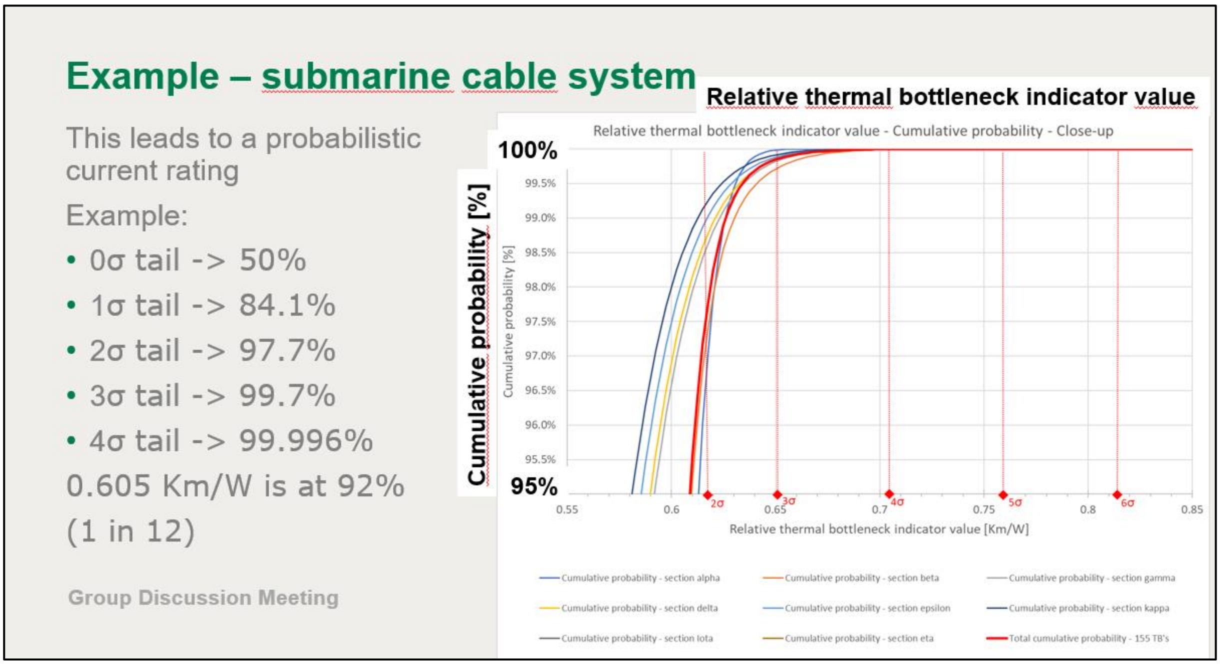
The red line shows the overall probability (based on all results)
The other lines show the probability in parts of the route

Slide 4 – The probability of occurrence of a certain bottleneck indicator value

The cumulative probability on slide 5 now informs us about the likelihood that a certain indicator value is exceeded. The value of 0.605 Km/W is seen to have a likelihood of 92%, meaning there is an 8% likelihood that there is an even more severe thermal bottleneck in the cable circuit than the one that would be the most onerous in the case the uncertainty was not taken into account.



Example – submarine cable system

This leads to a probabilistic current rating

Example:

- 0σ tail -> 50%
- 1σ tail -> 84.1%
- 2σ tail -> 97.7%
- 3σ tail -> 99.7%
- 4σ tail -> 99.996%

0.605 Km/W is at 92% (1 in 12)

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Slide 5 – The cumulative probability of a certain bottleneck indicator value

Given a certain likelihood, e.g. a 3 sigma, or 3 standard deviation likelihood (meaning a 99.7% chance that the value is lower), the indicator value can be identified and immediately from this value, a current rating can be calculated. So, this technique gives the possibility to identify a current rating with a known probability.

In many of todays cable projects, a design requirement is often alike "*a current rating of 1000 A*", without any probability stated. If a design calculation then leads to a calculated value equal or higher than this required value, then the requirement is fulfilled and the design is in accordance to the requirement.

In reality however, there is variation and uncertainty leading to a significant likelihood that the 1000 A requirement is actually not met. In the example provided that likelihood was 8%, which is rather high.

Likelihoods can be calculated and requirements can be stated more precise, so our answer to the question of the special reporter: *"…to what extent do enhanced test methods, perhaps including more variable environmental scenarios offer benefits to enhanced reliability and system integrity?"*, is as follows: We propose to define the design requirements more sharp, more precise by adding a likelihood. That will drive the need to understand the variation and uncertainty in environmental parameters and drive the optimalisation of these. The optimisation may be to use better or more measurements there were the most onerous situations occur, such that the uncertainty there is better than in places where no severe thermal bottlenecks are present. All this subsequently leads to a better known set of environmental parameters and therefore much more certainty that the current rating design requirement is actually met.