Diagnostic measurements and statistical analysis

Reliably predict the remaining life time of medium-voltage cables

With a consistent workflow from cable diagnostics through to evaluation, Baur GmbH provides asset managers with a solution for diagnosing the condition of medium-voltage cables. Statistical estimation of the cable lifetime now completes the package. Valuable knowledge regarding the remaining useful life enables investment in replacement cables to be planned more precisely and their implementation to be postponed for several years in many cases.

Asset managers are finding it increasingly difficult to maintain distribution networks with the allocated budgets. Many medium-voltage cables were installed several decades ago and are now of the age where failures are more likely to occur. In addition, the load now placed on the network is different and often higher due to greater utilisation, whether as a result of increased consumption or distributed power supply.

Condition-based maintenance instead of scheduled maintenance

Under these circumstances, a solution based on evaluating the cable condition is the only cost-effective way to ensure high availability and fewer failures in the medium-voltage network. It enables investment in the repair and replacement of cables to be planned based not on the age of the cable (Figure 1), but on the actual ageing condition (Figure 2). Otherwise, cables that have aged faster than expected would result in power failures or intact cables would be replaced sooner than necessary – both scenarios would result in an unfavourable cost-benefit ratio.

There are two established diagnostics methods for the condition evaluation of medium-voltage cables: partial discharge measurement and dissipation factor measurement (also known as tan δ measurement). Partial discharge measurement is a local procedure. For example, it can be used to detect defects in cable accessories or local partial discharges in damaged plastic insulation and insufficient mass-impregnated paper insulation. In addition to providing values concerning the partial discharge, the measurement also indicates the distance to the fault, making it easier to locate spots that need to be monitored or repaired.

Dissipation factor indicates actual ageing

Dissipation factor measurement, the evaluation of which will be discussed in

more detail below, is a non-destructive procedure for assessing the measured cable route in its entirety. It provides information on water trees (where the insulation on plastic-insulated cables has been damaged by water) as well as faults in the insulation of paper-insulated mass-impregnated cables, moisture in cable accessories, and possible partial discharges. Since the dissipation factor increases as the number of water trees in the insulation increases, this value is an indication of the quality of the insulating effect. For new cables, the dissipation factor is close to zero. As the cables age, this value increases due to the aforementioned impact of moisture on the plastic insulation.

Conclusions concerning the condition of the cable can already be drawn during the dissipation factor measurement. With the Baur Software 4.0, operators can use standardised or self-defined diagnostics sequences and make initial evaluations while the measurement cycles are still running. Due to uniform measurement cycles and the ability to compare results, asset managers receive an objective condition evaluation of the cable network. This provides a good basis for making decisions concerning the planning of maintenance.

Statistical estimation of the remaining life time

The new statex standalone software can be used to evaluate the measurement results in more detail, especially for plastic-insulated cables (Figure 3). statex is available exclusively from Baur and was developed jointly with the Korea Electric Power Corporation (KEPCO). The company operates a power grid in South Korea that includes 41000 km of underground cable (U_o = 13.2 kV). In order to make network maintenance as cost-effective as possible, around ten years ago KEPCO took a close look at cable diagnostics and compared the conventional methods that were available at the time. At the end of the comparison, the network operator selected partial discharge and dissipation factor measurement with VLF sine sources (Very Low Frequency). KEPCO then worked in collaboration with the University of Mokpo (Korea) to develop a method and software that would make it possible to predict the remaining service life. Baur and KEPCO have developed the ideal software for this and it is now available under the name statex. It has been used on the measured values

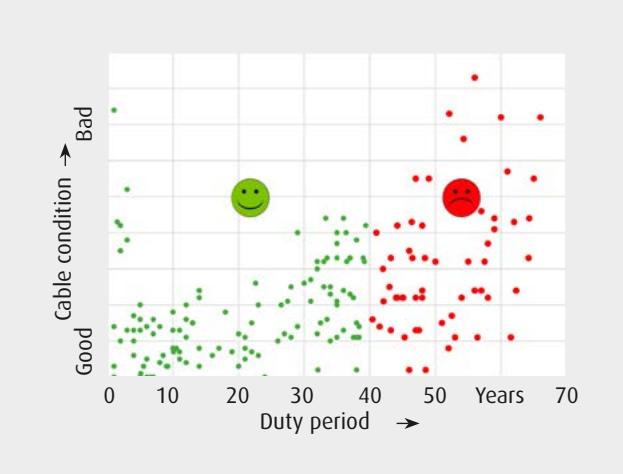

Figure 1: A strategy for replacing cables based on absolute age would mean that many cables that are still intact (as illustrated in the bottom right area of the diagram) would be replaced.

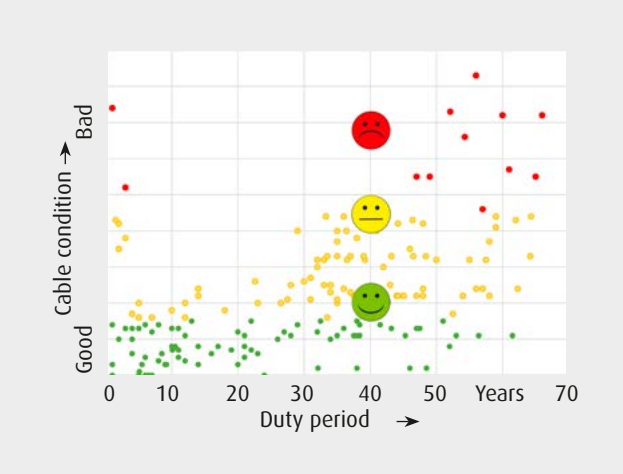

Figure 2: With condition-oriented network maintenance based on diagnostic measurements, old intact cables can continue to be used and newer cables that are in poor condition can be detected promptly and replaced. This minimises costs and increases the availability of the network.

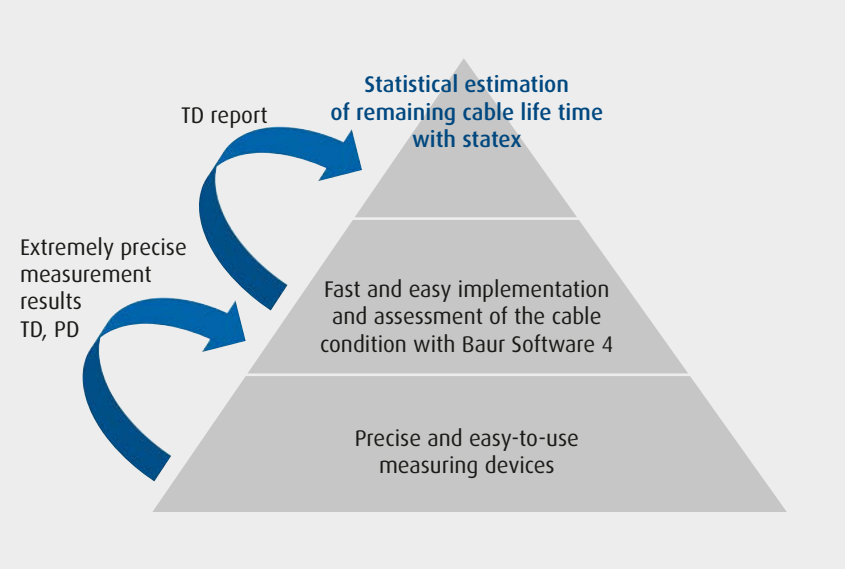

Figure 3: With the new statex software, the values from the dissipation factor measurement can be used to predict the remaining life time of medium-voltage cables.

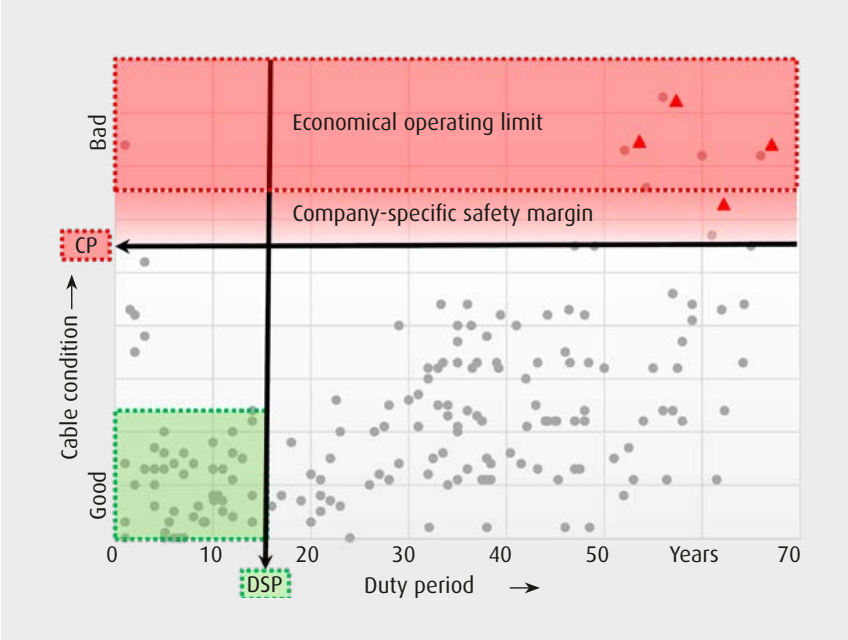

Figure 4: Typically, the ageing process for XLPE cables only begins after more than ten years when the antioxidants in the cable insulation have outgassed and water trees start to form.

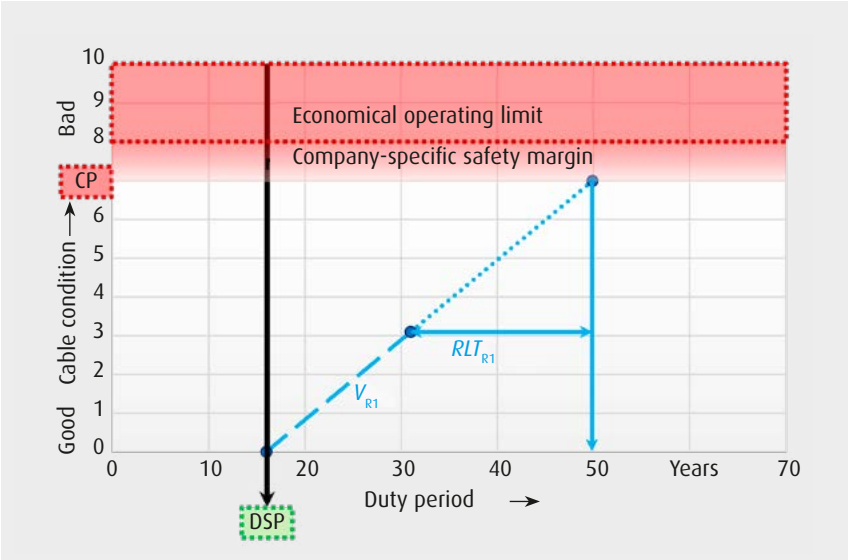

Figure 5: The statex software can use the tan δ measured values to calculate the ageing index and estimate the remaining life time of the cable.

of thousands of plastic-insulated cables. Around 90000 measurement results have been incorporated thus far.

Calculating the ageing index from the measured values

There are three key aspects when calculating the remaining life time of an XLPE cable:

- When does the ageing of the cables begin?
- How rapidly does ageing progress?
- At what point is the cable condition classed as critical?

The KEPCO Research Institute performed analyses to determine when the ageing process begins (Figure 4). For KEPCO's cables, the average Degradation Starting Point (DSP) was around 13 years.

The ageing index of the measured cable is calculated as follows:

$$R = \sqrt{(TD_{norm}^2 + DTD_{norm}^2 + TD_{skirt}^2)}$$

TD_{norm} is the value of tan δ and DTD_{norm} is the deviation (delta) of tan δ. TD_{skirt} predicts the stability of the dissipation factor over several measured values in a measurement cycle, as there are precursors in cables with insulation losses. For example, a constant increase or decrease of the tan δ value or its fluctuation within a voltage step indicates the degree of ageing.

To determine TD_{skirt}, a virtual line is drawn between the largest and smallest tan δ values of eight consecutive measurements. A linear (rising) trend in the measured values indicates a change in the dielectric losses of the cable insulation, while a falling or non-linear trend is usually an indication of moisture or electrical discharge in one or more cable accessories.

Determining the remaining life time with just one tan δ measurement

Ageing index *R* can be calculated by performing just one dissipation factor measurement **(Figure 5)**. When repeat measurements are performed on the same cable, the statistical software incorporates the new results to produce an even more precise estimation **(Figure 6)**. The speed of ageing can be calculated from the ageing index and the actual age minus the DSP, thus providing the time span until a critical point is reached. Operators have the option to define the critical point for each cable type in the software's Life Time Wizard so that an individual safety margin can be included. The DSP can also be specified. In addition to the expected remaining life time, the software also provides recommendations as to when the next cable diagnostics should be performed and for the scheduling of maintenance work or cable replacement.

In addition, statex provides a three-dimensional representation of the measured values for the measured cable(s) **(Figure 7)**. In this 3D representation, operators can also include their own measured values or the results from KEPCO that are stored in statex for comparison, enabling them to compare the condition of different cables.

More reliable prediction of the remaining life time

KEPCO has been using statex for some years now. The software has enabled them to postpone a number of investments, as on average the measured cables were found to be in better condition than would have been expected based on their age. For the older cables that were measured, the number of faults per km was even lower than that of cables that had not yet reached the DSP (13 years in this case). If KEPCO had planned its investment in replacement cables based on the dissipation factor measurement and the evaluation according to IEEE 400.2, 255 km of the 15,000 km of cable measured would have been ready for replacement. Using statex, however, it was possible to calculate that only 54 km of cable were in urgent need of replacement. Compared to the IEEE criteria, the remaining life time was on average around eleven years longer.

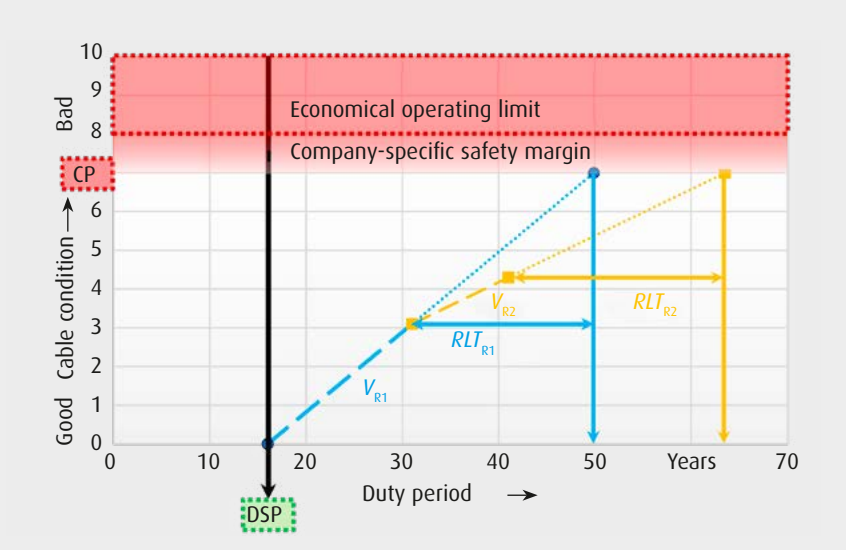

Figure 6: statex recalculates the remaining life time when repeat measurements are performed.

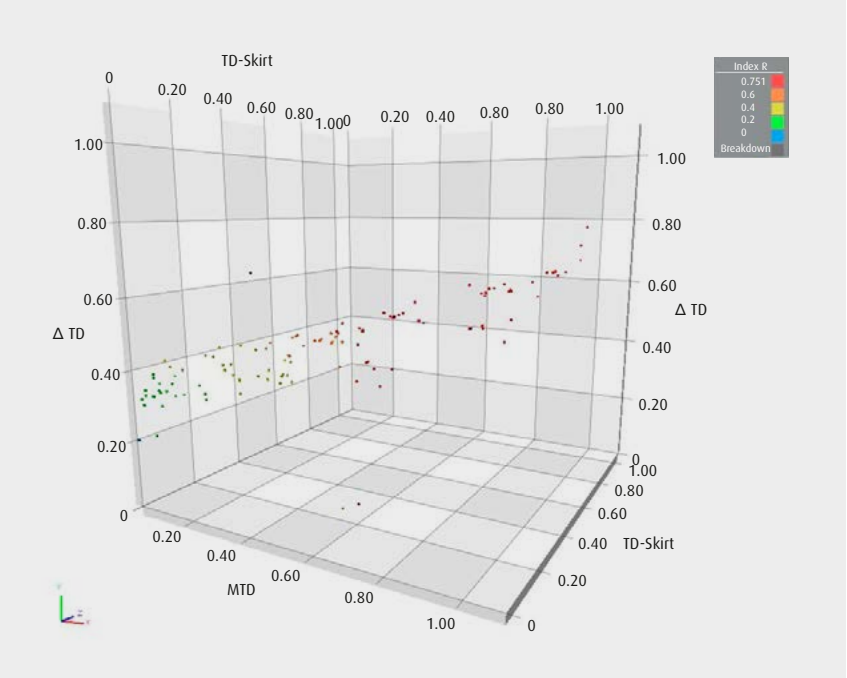

Figure 7: Representation of ageing index R (see legend) for all measured phases as a three-dimensional diagram. Each point represents the condition of a measured phase.

Various software versions

With statex, the ability to predict the remaining life time is available exclusively to Baur customers. statex is available with various licence models:

- statex Core allows cable data to be maintained and monitored in the database, and enables the management of cable data. In addition, the Core version allows you to calculate ageing index R , perform a condition analysis, create a 3D diagram, and prepare reports.
- statex Pro additionally provides the function to determine the remaining life time. The Pro version includes a Life Time Wizard where the operator can enter an individual DSP (degradation starting point) and a critical point based on their own experience. Two days of introductory training on site and another two-day training course to gain greater in-depth knowledge are available to the customer when purchasing the software licence. Additional licences allow additional employees to access the statex Pro database. However, the Life Time Wizard can only be configured by one user, thus ensuring data consistency.

statex provides asset managers with information and recommendations

With the combination of VLF measurement technology, Baur software for performing measurements and the immediate interpretation of values, as well as the statex software for predicting the remaining life time of cables based on statistics, asset managers have all the tools at their disposal to maintain the distribution network in a much more cost-effective way. On average, the results from the statex software allow medium-voltage cables to be used for several more years than would be the case based on their absolute age, a cable condition evaluation according to IEEE criteria, or classification based on tan δ values.

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