1.3 INTEGRAL CABLE CONDITION ASSESSMENT

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ABSTRACT

Motivation for condition based assessment

Practical experiences with different diagnosis measurements

A combination of measurement methods lead to an economic cable assessment

INTRODUCTION AND PURPOSE

Distribution network operators throughout the world face the same problem: maximizing the availability of the grid while keeping the costs of maintenance low, two goals that often work against each other. Yet meeting both is desirable as a matter of policy and technology to ensure the reliability of power supply. For operating resources in particular, which are generally inaccessible (medium-voltage cable in the present case), it is difficult to find the best path in this conflict of objectives. Cable stock in medium and low-voltage networks account for 60 to 80 percent of the actual replacement value in the distribution network [1] and thus is deserving of the best possible strategy not only for network construction and expansion but for maintenance as well.

There are a various approaches to maintenance which have their place between the extreme objectives of maximum availability and minimized maintenance costs. These fall roughly into three categories:

1. Minimizing maintenance expense and effort and accepting frequent grid failures (event-oriented strategy)
2. Maintenance dependent, for example, on the type and age of operating resources (a kind of preventive strategy)
3. Future-oriented maintenance based on technical and economic criteria as well as considering the risks and consequences of failures

In evaluating these strategies, three groups of factors must be kept in mind:

- Technical/organisational aspects
    - Operational safety and reliability
    - Work safety
    - Stress on cables in operation
    - Repairs incurred
    - Importance of the cable line to the reliability of the power supply
    - Frequency and probability of failure
    - Availability of maintenance crews, equipment and spare parts
    - etc.
- Economic aspects
    - Repair costs
    - Personnel capacity costs
    - Maintenance costs
    - Consequential costs of power failures due to loss of earnings or recourse claims by third parties
    - Capital expenses for spare parts and equipment
    - Consequential damages due to network faults
    - etc.
- Social aspects
    - Reliability of supply risk for non-commercial facilities
    - Reputation damage as a result of power failures
    - etc.

These factors, which are cited in Guideline 420 from CIGRE [2], are increasingly accompanied by policy demands by regulatory authorities, for example, who implement a sort of "benchmarking" for mains operation with the aim of optimising costs through market competition and thus contribute to setting budgets.

Given that the medium-voltage network experiences the most failures per year [2,3], maintenance of the distribution network is very important. According to the source cited, in the Netherlands – a country with relatively high mains availability – there are about 0.25 power failures per customer caused at the medium voltage level each year, responsible for about 70 minutes without power. For comparison, high voltage is responsible for about 0.075 failures and 35 minutes. [1] assumes that with a ratio of about 60 percent paper-insulated cables and 40 percent XLPE cables, a statistical average of one cable failure per 100 km medium voltage cable network will occur each year. Nonetheless, high voltage networks are given higher priority in matters of maintenance and condition monitoring than the distribution network. However, today many mains operators are already applying high voltage knowledge and experience to medium voltage systems and operate their distribution network with greater commitment – and often with great success, financially as well.

In view of the general conditions, the strategies for maintaining the medium-voltage network mentioned previously can be evaluated easily. The first – waiting for (possibly repeated) network faults – leads to comparatively high repair costs, may cause consequential damages as well as considerable loss of reputation in some cases. It is simply not viable, technically or economically. Thus event-oriented maintenance is seldom still practised.

The other extreme, preventive replacement, for example based on the type and age of the cables, can also become a money pit as [1] describes. With a utilisation period of 50 years and a total network length of 1000 kilometres, there would be 20 kilometres of cable to replace each year. At 150 Euros per metre, the costs to be covered each year for civil engineering and cables would include 3 million Euros capital investment for replacement. However, this does not ensure that defective cables are in fact replaced, because age and ageing condition (and the associated frequency of failure) do not necessarily correlate with one another. There are also cable facilities which have done service for 80 years or more with little or no trouble as well as PE cables that experience premature failures.

The middle course is indeed the best: the condition-based maintenance described in the third point. In fact, this strategy is not based solely on the condition of the cables, but considers a great variety of information to enable the best maintenance possible and prepare for the necessary decisions.

Evaluating cable condition

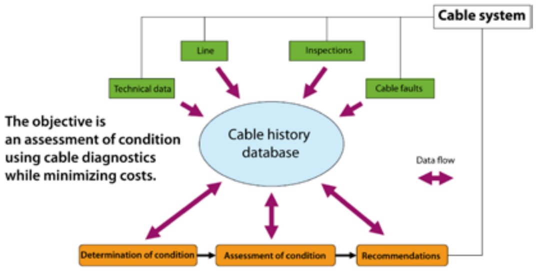


Figure 1: Systematic condition evaluation of medium-voltage cables [4]

The condition of the cable is defined by quantitative and qualitative factors. Qualitative factors include product-specific ones, such as

- manufacturer, design and type,
- age,

and historical data such as

- utilisation (operating condition),
- cable faults,
- the number of sections and joints, and
- repairs incurred.

Additional information, for example regarding geographical conditions, is also advantageous. The qualitative factors can also be drawn from an ERP system such as SAP and a GIS.

Quantitative technical factors are

- the frequency of partial discharges (PD),
- PD inception and extinction voltage,
- the dissipation factor (see below), and
- recovery voltage or relaxation current.

This information must be determined individually for each cable or each cable section. It should be mentioned at this point that conventional cable testing by VDE methods on (V)PE cables with $3xU_0$ for 1 hour does not result in reliable statements regarding the condition of the cable. This testing, carried out after commissioning or restoring a line, merely reveals whether the cable was able to cope with the test voltage at the time of testing. Possible damage to older cables, for example from transient grounds, cannot be detected reliably.

Moreover, the importance of the cable to the grid is relevant for evaluating measures such as repair or replacement. One measure which can be used in this regard is the amount of energy not delivered due to failures (excluding those due to outside influence). This is determined by the number of failures and their duration, the consumers connected and the structural function of the cable and/or redundancy in the relevant network segment.

Practical examples of economic benefits

The question is whether it is worth the effort to measure the dissipation factor (tan δ) and the partial discharge. The answer is 'yes'. Particularly for the sections of line critical for power supply or those which have become prominent by failures, but for others as well. The time required for measuring the dissipation factor and partial discharge is altogether about 70 minutes. The cost for diagnostic measurements is about that of ten metres of cable (including excavation), but valuable information is obtained which indicates whether an exchange or repair makes sense or whether the cable can continue to be used despite its advanced age. Moreover, unexpected damages can be avoided, which require fast (and often expensive) responses, and repairs can be limited to what is truly necessary. Here is a practical example from the RWE Rhein-Nahe-Hunsrück regional centre:

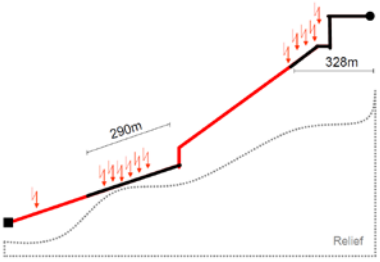


Figure 2: A stretch of cable approximately 1945 metres, type NASXSY / 150 mm², laid in 1978 [4].

The cable line shown in Figure 2 appears to have numerous faults – with topography as a contributing factor in some cases – and various damage due to water trees (see the box). However, replacing a line of nearly 2 kilometres should be avoided if possible. Measurement of the tan δ (Figure 3) showed that conductor 3 had aged considerably. Further measurements (partial discharge measurements and VLF testing) enabled the limits of the damaged areas to be determined. Only 618 metres of cable altogether in two sections needed to be replaced. Total costs for this, including all ancillary costs for fault location, testing, etc. ran to 67,455 Euros. Replacing the entire cable line would have cost 199,415 Euros. Thus diagnostic measurements and subsequent determination of the faulty sections reduced costs by two-thirds.

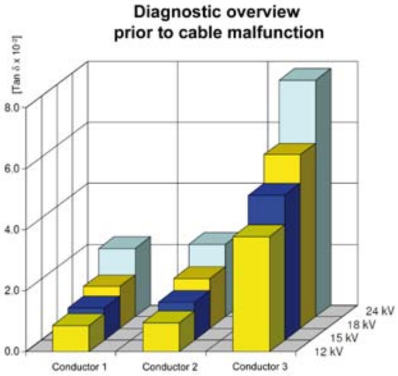


Figure 3: Measurement of tan δ on the cable line from Figure 2. Indications of severe ageing were found on conductor 3 [4].

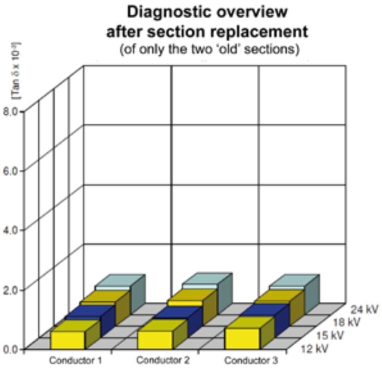


Figure 4: Values of tan δ on the two replaced sections of cable line from Figure 2 [4].

Another example: Vattenfall Europe Netservice GmbH tested a new network section in Berlin, which consisted of 12 cables for 10 kV with a total length of about 150 kilometres and altogether some 180 joints and 72 terminations [5]. In addition to testing with 18 kV and sheath testing with 5 kV DC, the company carried out a partial discharge measurement on the cables. Sheath defects were found in 13 cable segments and (only) by partial discharge measurement was it also possible to identify the same number of weak points in the cable joints. Thus it was possible to demand service for the joints while they were still under warranty. Moreover, the partial discharge measurement and repair of the weal spots ensured that the new mains connection will operate without disturbances for a long time. This procedure enabled future recourse claims from possible power failures to be avoided.

Water trees

In spite of their sturdiness some plastic-insulated cables (PE, XLPE) do reach their limits. “Water trees” are often the reason for this. They spread like little trees wherever there is a fault in the insulation, but don’t necessarily affect its function. Water trees can develop even at low field strengths (below 1 kV/mm, for example). They cannot be seen by the eye, and they grow slowly for years. They cannot be detected by partial discharge measurement (see the text), but instead by measurement of the dissipation factor (tan δ).

As of a certain size, they become “electrical trees”, structures where local discharges occur. These electrical trees have hollow structures visible to the eye and lead to (measurable) partial discharges. They grow very quickly, which leads to trouble. A cable where electrical trees are found – even if detected at relatively low inception voltage – can fail within weeks or even hours. This is because the insulation is no longer effective enough. Early detection and assessment of water trees is therefore important for the condition-based maintenance of medium voltage networks and the prevention of damage and power failures.

Water trees are identified by tan δ measurement (see the text). It determines the dissipation factor, i.e. the ratio of effective power and capacitive reactive power. A measured value alone – possibly recorded at low voltage – is not conclusive enough. Therefore tan δ measurement should be carried out at multiple voltages. When measured values are plotted against the voltage, aged cables produce a characteristic curve, the height and slope of which enables conclusions to be drawn regarding condition. In this way, the presence of water trees in the cable can be detected before they become electrical trees. Should the tan δ measurement indicate that the cable has aged too much, the partial discharge measurement provides information on the defective sections or fault locations so that only these need be replaced (see also [8]).

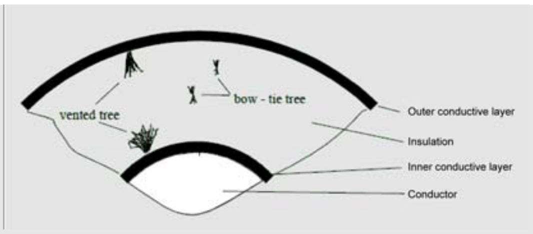


Figure 5: Schematic representation of water trees in cable insulation. Source: [7]

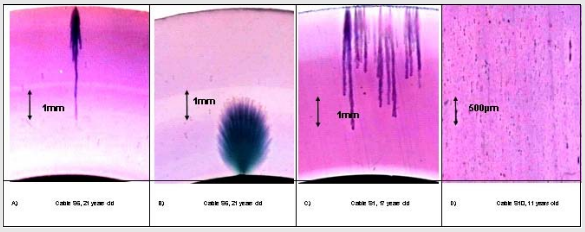


Figure 6: Water trees under the microscope.

Which diagnostic procedures make sense?

Before discussing diagnostics procedures, a short explanation regarding cable testing: In Germany, for example, testing for the commissioning of medium-voltage cables must be carried out in accordance with VDE 0276-HD620, which is intended to ensure safe operation and reliable function. For a plastic-insulated cable, this involves applying a test AC voltage of $3xU_0$ at 0.1 Hz for 60 minutes. The result of the test is “pass” or “fail”. Sheath testing is added to the regimen, for PE-insulated cables with up to 5 kV DC, for PVC cables up to 3 kV DC. This is also a pass or fail test.

However, for cable assets it is of interest to determine how long and how well a cable line can continue to function. For new lines, this is primarily a concern as to whether the lines and associated equipment have been prepared as well as possible for use. Sheath testing, dissipation factor measurement, provide the answer to these questions.

Global and local diagnostic procedures – Differences and significance

Dissipation factor measurement is a *global* diagnostic procedure and enables a status evaluation of aged, water tree damaged medium-voltage cables (such as plastic-insulated ones) in order to determine their operational reliability and anticipated remaining service life. Mixed cable lines are difficult to interpret due to the integrating measurement, but for lines with uniform insulating material there are standard values which enable simple evaluation.

Partial discharge measurement is a *local* diagnostic procedure for evaluating the condition of new and aged medium-voltage cables insulated with paper pulp and plastics. It is used to locate local faults and to perform quality control on cable facilities old and new, including their associated equipment. It is also suited for mixed cable lines. The evaluation of mixed cable lines requires that the location of the individual sections of cable be known.

Sheath testing

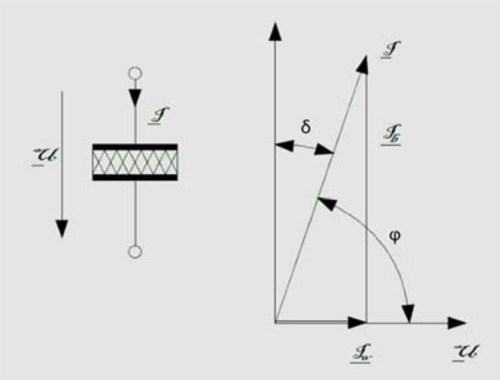
In sheath testing, the outermost electrically insulating sleeve of a cable system is investigated. Common methods are withstand voltage testing – in this case application of DC voltage until breakdown – and insulation measurement. In insulation measurement, DC voltage excitation is used to determine the amount of voltage excitation and the leakage current at the end of a nominal measurement period (of some 5 minutes) with the conductor earthed [6]. Here the capacitive current, polarisation current, leakage current of the dielectric and currents from conductivities based on changes of state combine. The apparent insulation resistance is then derived from the voltage and current at the end of the measurement period (when an essentially steady state is achieved). Among other things, sheath testing is used to check the reliability of the network and detect functional impairment of the insulation, due for example to water penetration. Any damages are located by additional sheath fault testing.

Dissipation factor measurement

The dielectric dissipation factor tan δ

The dielectric dissipation factor tan δ is a key factor for evaluating an insulation medium. The magnitude of the dissipation factor and its dependence on temperature, frequency and voltage are determining factors for the uses of a dielectric material and serve as criteria for quality and purity as well as the ageing condition. The dielectric dissipation factor tan δ is defined as the ratio of the effective power to reactive power for a capacitance applied to a voltage" [7]:

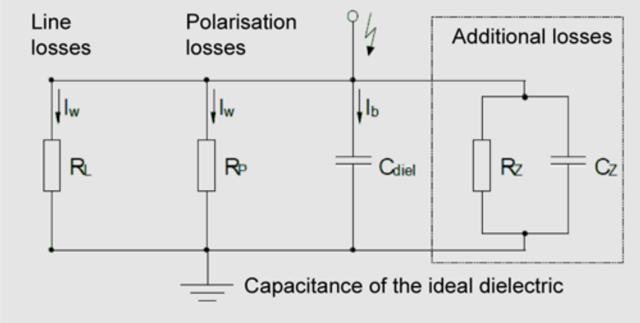
$$\tan\delta = \frac{\text{Effective Power}}{\text{Reactive Power}} = \frac{U \cdot I \cdot \cos\varphi}{U \cdot I \cdot \sin\varphi} = \frac{I_{eff}}{I_b}$$



U	Applied voltage
I	Total current
I_{eff}	Effective current
I_b	Reactive current
φ	Phase difference between current and voltage
δ	Loss angle

Figure 7: Formula and vector diagram for the dissipation factor [7]

Figure 8 can be used as an equivalent circuit diagram for modelling losses:



R_L	Resistance due to line losses
R_P	Resistance due to polarization losses
C_{diel}	Cable capacitance
R_Z	Additional losses due to water tree ageing
C_Z	Additional capacitance from dielectric water absorption
I_w	Effective current
I_b	Reactive current

Figure 8: Equivalent circuit diagram for visualising tan δ as per [7] with key

The dissipation factor consists of tan δ_L from the carrier line and tan δ_P from the repolarisation of molecules in the dielectric. A third component, tan δ_I, accounts for ionisation in the dielectric (but can be ignored with cable insulation materials). Thus the dissipation factor is calculated as

$$\tan\delta = \tan\delta_L + \tan\delta_P + \tan\delta_I$$

The dissipation factor is measured with the following arrangement:

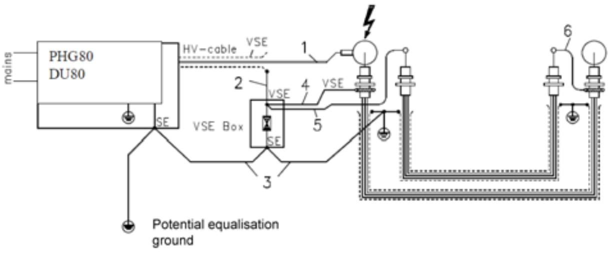


Figure 9: Connection of the BAUR PHG80/DU80 testing device to measure tan δ [9]

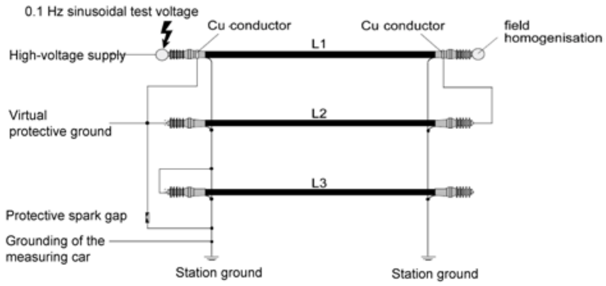


Figure 10: Connection diagram for tan δ measurement. Here, the measurement is on conductor 1, signal return via conductor 2 and conductor 3 is earthed [10].

The device depicted in Figure 9 for measuring the dissipation factor evaluates the measurement signals by Fourier analysis to determine tan δ. The dissipation factor determined is independent of the cable length. The measurement is non-destructive over the entire cable section. Thus dissipation factor measurement is a global diagnostic procedure which does not harm materials (see the box). The test result requires interpretation. For this purpose it is necessary to take measurements at multiple voltages, typically $0.5xU_0$, U_0, $1.5xU_0$ and $2xU_0$ (or possibly $1.7xU_0$).

The following chart shows why measurements are necessary at various voltages: A severely aged cable often exhibits about the same tan δ as a new cable at U_0. As the voltage is increased, the steep rise of the value indicates the presence of water trees (quite apparent at $2xU_0$ and $2.5xU_0$).

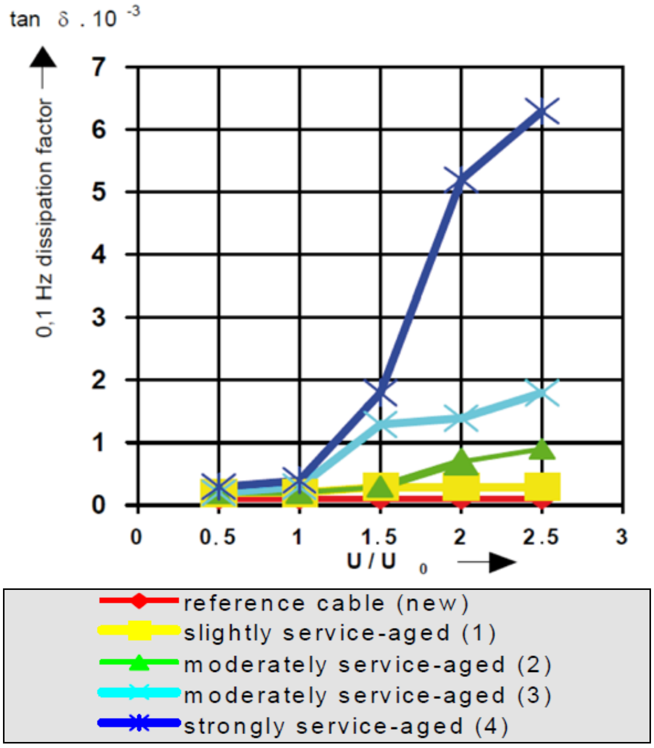


Figure 11: Examples of dissipation factors for various old or aged cables [11]

The highest measuring voltage is also below that used for cable testing ($3xU_0$), which places less stress on the cable. Moreover, measuring the dissipation factor requires only a few minutes at $2xU_0$ (about 5), so the cable is not subject to continuous stress. (Laboratory testing of aged cable sections has shown that with ten cables, none were damaged by a voltage of $2xU_0$ applied for 5 minutes during tan δ measurement, whereas under cable testing conditions nine of ten suffered breakdown [see 10].)

During the measurement, the connection conditions (as per the manufacturer's recommendations) and temperature should be kept as uniform as possible, because as Figure 12 shows, tan δ is temperature-dependent.

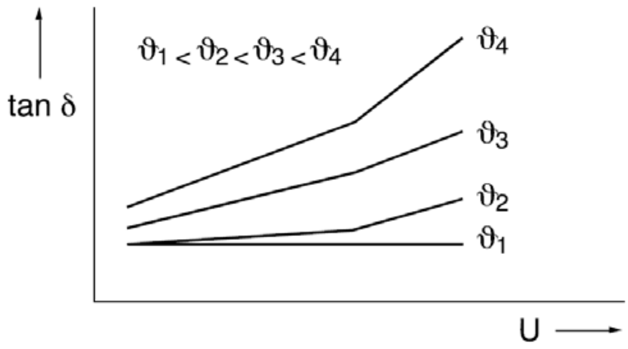


Figure 12: tan δ applied via the voltage at various temperatures [10]

In the meantime, experience from thousands of measurements in Europe has shown that measurement can be classified as follows (when the equipment is used according to the manufacturer's specifications):

For PE/XLPE cables

$\tan \delta (2 U_0) < 1.2 \times 10^{-3}$ and $[\tan \delta (2 U_0) - \tan \delta (U_0)] < 0.6 \times 10^{-3}$	Cable line OK
$\tan \delta (2 U_0) > 1.2 \times 10^{-3}$ or $[\tan \delta (2 U_0) - \tan \delta (U_0)] > 0.6 \times 10^{-3}$	Should be re-tested in a few years
$\tan \delta (2 U_0) > 2.2 \times 10^{-3}$ or $[\tan \delta (2 U_0) - \tan \delta (U_0)] > 1.0 \times 10^{-3}$	The cable line (or defective sections) should be replaced

For paper-insulated cables

$\tan \delta (2 U_0) < 50 \times 10^{-3}$ and $[\tan \delta (2 U_0) - \tan \delta (U_0)] < 10 \times 10^{-3}$	Cable line OK*)
$\tan \delta (2 U_0) < 50 \times 10^{-3}$ and $< 70 \times 10^{-3}$ or $[\tan \delta (2 U_0) - \tan \delta (U_0)] > 10 \times 10^{-3}$ and $< 20 \times 10^{-3}$	Cable line OK*)
$\tan \delta (2 U_0) > 70 \times 10^{-3}$ or $[\tan \delta (2 U_0) - \tan \delta (U_0)] > 20 \times 10^{-3}$	The cable line (or defective sections) should be replaced*)

*) Paper-insulated cables should exhibit similar values for all three conductors; many mains operators use a limit value of 50×10^{-3}

It is basically worthwhile to check the ageing of important cable lines every few years. If a value (for XLPE cables) is found in the yellow range, a repeated measurement in two years is a good idea.

A sinusoidal alternating current at 0.1 Hz has proven good as a test voltage for dissipation factor measurement. There are two reasons for this. The first is that the same voltage source can be used for tan δ measurement as for standard cable testing, so the effort and expense with equipment remains low and no additional manual work is necessary for device connections. For measurement and testing after (partial) renovation of a line, this has time and cost benefits.

The second reason is the significance of the tan δ at 0.1 Hz. The tan δ values for 0.1 Hz and 50 Hz sinusoidal AC voltage are in the same range [11], so measurements at 0.1 Hz (aka very low frequency or VLF measurement) enable conclusions to be drawn regarding operational scenarios. VLF technology also provides the opportunity to use smaller devices (see the box), because voltage sources for 50 Hz are big, cumbersome and heavy.

Compact cable testing and diagnostics

The portable cable testing device “frida” from BAUR was upgraded to include a diagnostics function. The new device (“frida TD”, where TD stands for tan δ) has the same compact dimensions and together with testing now enables simple determination of the ageing condition of medium voltage cables up to 20 kV using tan δ measurement. As with the cable testing, dissipation factor measurement is carried out with low-frequency voltage (VLF testing). The true sine generator from BAUR ensures an ideal sinusoidal curve with 0.1 Hz. As the diagnostics with frida TD is possible with the same device as the cable test, no other connections or additional devices are necessary. The frida provides the following voltages: VLF truesinus® up to 24 kV_{rms}, VLF square wave and DC to 34 kV.

Moreover, compared to sheath testing, tan δ measurement not only provides information about the quality of the sheath but also about the insulation further inside the cable, which for safe, long-term operation is more valuable.

Measurements of tan δ have their limits if the cable diagnosis reveals clear signs of ageing damage or defects: Since dissipation factor measurement considers the entire cable, it is not possible to locate faults precisely or to say whether one or more faults has led to the unacceptable measurement values. Therefore further study of the damaged cable line by partial discharge measurement is called for.

Another hint for those who want to subject new cable to dissipation factor measurement as well: As Figure 13 shows, for many types of new cable, the tan δ is still relatively high as long as the cross linking reactions in the cable still take place and the inevitable outgassing is not complete. Only after a few years (see the axial minimum) is this chemical process at an end and the subsequent rise to be seen as a clear indication of the formation of water trees.

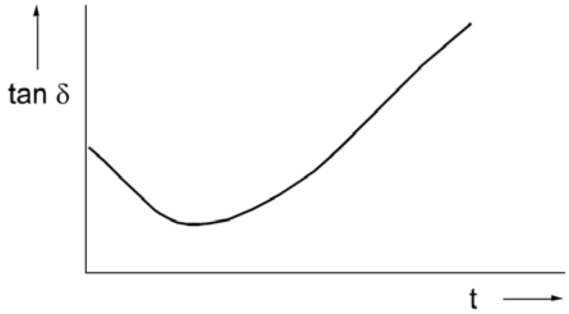


Figure 13: Qualitative representation of tan δ as a function of cable age [10].

truesinus®: the form makes a difference

In the adjacent text, dissipation factor and partial discharge measurement benefit from a sinusoidal voltage at 0.1 Hz. These low frequency signals are also referred to as VLF (very low frequency). Reasons for VLF measurement include:

- Compact devices: To generate the same voltage at 50 Hz would require larger, much heavier equipment with up to 500 times the power of a VLF voltage source. Cable testing equipment for the operating frequency would thus no longer be portable in the truest sense of the word. This would limit the range of applications, and measurement would require more time.
- At 0.1 Hz conventional able testing (as per VDE DIN 0276-620, IEEE P400.2, VDE DIN 0276-621, CENELEC HD 620 and CENELEC HD 621) as well as tan δ and partial discharge measurements can be performed. A cable test van equipped with a 0.1 Hz voltage source is thus able to handle all relevant measurements for new and old cables. The measurements can be performed sequentially; the partial discharge measurement can even be carried out at the same time as the cable test.
- The measurement of sinusoidal VLF voltage is independent of load. Small changes in the grid structure, cable length, etc. thus have no influence on the tan δ measurement.
- With truesinus®, the positive and negative half-waves are identical in form. Thus charging of

the cable cannot occur as with a distorted signal shape with different areas above and below the zero axis. This charging, which occurs quickly with short cables and more slowly with longer ones, is not spontaneously dissipated when the measuring equipment is taken down, so the voltage may still be present when the cable line returns to service. This can lead to damage as a result of the cumulated voltages.

- The truesinus® signal is very reproducible, and measurements can be compared well because of the load independence. By comparing current and past data this way, trends can be identified reliably.
- Partial discharge measurements with a multiple of U_0 – performed out of operation – provide more reliable results than online monitoring of partial discharges. This is because if partial discharges are already present at the operating voltage, little time remains before breakdown of the insulation and possible supply failure occur.
- Measurements at 0.1 Hz AC result in faster, directed growth of water trees, which often break down even after a few minutes and can be detected more easily (see Figure 14). This way, damage can be found even with measurements of short duration and the likelihood of detecting defects increases.

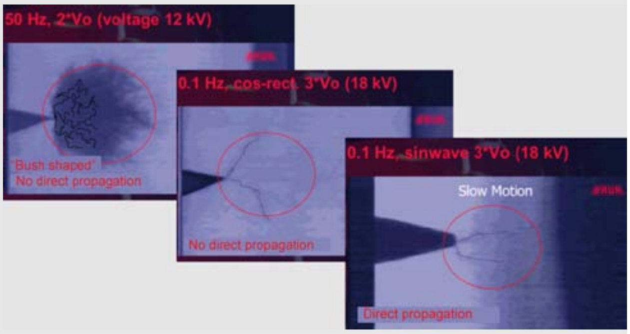


Figure 14: Growth of water trees dependent on the applied test voltage: left $2xU_0$ at 50 Hz (growth rate 1.7 mm/h), centre $3xU_0$ at 0.1 Hz with cosine square wave (7.8 mm/h) and right $3xU_0$ at 0.1 Hz with sinusoidal voltage (12.3 mm/h).

Partial discharge measurement

Partial discharges are neither short circuits nor breakdowns but can lead to breakdown in short order.

They occur, for example, at fault locations and in hollow spaces in the cable due to ageing or the formation of water trees, or at joints or terminations, lasting less than a microsecond. Cables can also exhibit partial discharges when new due to mechanical damage or improper jointing. Thus partial discharge measurement is justified for new cables as a quality control measure as well as older systems for purposes of diagnosis and fault location. Partial discharge measurement with location of the source of the partial discharge closes the gap in insulation diagnostics for paper-insulated cables and increases the reliability of assessments for plastic cables.

A key criterion for assessing the condition is the frequency of partial discharges at a location. In other words, if clusters of partial discharges occur at very specific spots. Moreover, such a place with critical partial discharges must be able to be pinpointed in order to carry out repairs where needed and with low cost and effort. Therefore partial discharge measuring equipment for cables is typically differs from that for other operating resources, including integrated runtime measurement which enables faults to be located with nearly meter accuracy.

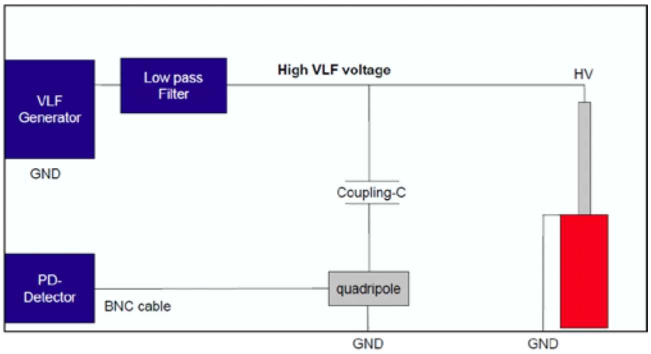


Figure 15 shows the basic arrangement for partial discharge measurement.

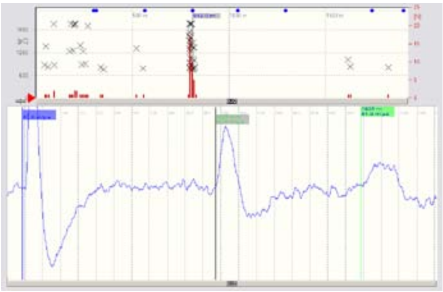


Figure 16: Result of a partial discharge measurement of a mixed cable[4].

The partial discharge measurement values provide information on the cable condition for plastic-insulated and paper-insulated cables. However, the interpretation of the values must ensue with intuition, or better yet experience, as there are considerable differences in measurements depending on the material. Thus, for example, plastic cable insulation should essentially be free of partial discharges (measured values below 20 pC), but paper-insulated cables can show values of several hundred or thousand pC. Strong variations are typically also found at joints and terminations.

In order to make the right decisions based on the values in condition-based maintenance, the data for all conductors of a cable should be noted and compared. Large differences are indicative of a fault. Moreover, a proprietary "knowledgebase" is useful for compiling comparative values for other cables of the same type, for example. Users can also expect help from the IEEE:

Showing partial discharges

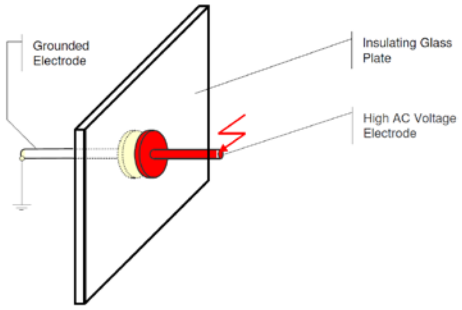


Figure 17: Diagram of an experimental apparatus in the laboratory for demonstrating partial discharges

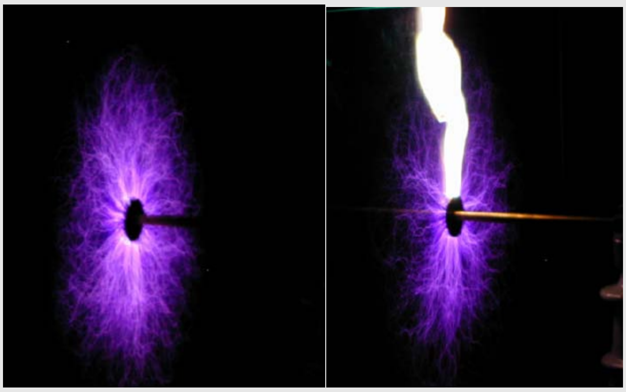


Figure 18a and 18b: Left - partial discharges; right - sparkover (white), which results in an arc to the electrode on the other side of the insulating board.

The organisation intends to publish reference values for assessing condition, which will simplify classification as "potentially critical" or "not a concern".

Summary

Evaluating the condition of medium-voltage cables requires more to be considered than just a single factor such as the age of the cable. To perform condition-based maintenance of the distribution network and use capital equipment in the best manner, a multitude of information is required. As far as technical information is concerned, sheath testing and diagnostic procedures for dissipation factor measurement and partial discharge measurement are among the most valuable sources. In combination, these enable reliable assessments of the ageing condition for plastic-insulated cables and also provide information on weak points such as joints. The values of both diagnostic procedures are also helpful in evaluating the condition of paper-insulated cables. However, here the wealth of experience is less and the possible factors of influence (such as drying, water content, etc.) are more numerous and of greater magnitude. Therefore paper-insulated cables must be evaluated with care. Here as well the diagnostic procedures provide evidence that allows cables to be classified. Strategic planning of investments is facilitated and these need not be driven by events.

Modern devices with a 0.1 Hz sinusoidal generator enable cable testing and diagnostic procedures to be performed with one voltage source and thus little effort and expense. Moreover, some devices also have the DC voltage source needed for sheath testing.

To optimise condition-based maintenance with regard to economic and social criteria as well, it is important not to rely on technical measurements alone. The importance of the cable line must be taken into account as well as experience (i.e. failure statistics) for cables of the same type. The technical evaluation of quality cannot and should not be the only basis for strategic decisions.

Which factors mains operators consider in making decisions and how these are weighted are a matter of individual judgement, because there are various initial conditions to be considered depending on age, growth, maintenance and topology. Fortunately, there are more possibilities than ever before to weight and summarize the information collected in ways to solve the dilemma of conflict between the objectives of maximum availability and lowest cost, thanks to comprehensive software tools and available knowledge from many areas regarding the existing cable stock and maintenance status as well as detailed documentation of grids (topology, network diagrams and statistics) and simple options for diagnostics.

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