# Your compass for testing and diagnostics of medium voltage cables

Megger

Withstand testing and monitored withstand testing

Loss factor measurement (Tan Delta)

Partial discharge diagnostics

Sheath testing


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EN
ENGLISH

# Do you already know all the advantages of the 4 excitation voltages?

## Our recommendation is based on many years of experience

Everyone is different, and that is a good thing. Diversity and differences are what make our world. Cables too have different properties and material conditions. But unfortunately this makes it difficult to carry out uniform troubleshooting, testing, or maintenance.

The world market does not offer any all-in-one test systems for commissioning testing, condition monitoring, and fault location that meet all performance requirements, but Megger is close to it and offers technically excellent solutions for every problem.

We target our many years of experience and expertise towards ensuring our customers' success. In this way, we enable safe working, save time and costs, and increase the reliability and availability of the power grids.

## Strategy in detail

You shouldn't play Russian roulette with the grid and power supply. Instead, you should play the 4 aces that Megger gives you. On the following pages, we explain our strategy proposal in detail and present successful practical examples.

**Business CASE 1:**
Tan Delta measurement and partial discharge diagnostics **Page 14**

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Partial discharge diagnostics with 3 different test voltages **Page 18**


Megger.

# Ensuring reliable power supply through advanced cable testing and diagnostics

## Effective cable testing and diagnostics – the key to the security of supply in cable networks

Cable testing and diagnostics are essential tools in ensuring the security of supply in your cable networks. While cable testing is limited to detecting immediately hazardous faults directly after cable routing or repair, cable diagnostics provides a way to obtain detailed information about the integrity of cable insulation. This newly acquired information can be used to budget, plan, and integrate future maintenance work on the respective cable section into normal network operation.

**Budget, plan, and integrate maintenance work into normal network operation.**

Both approaches to improving fail-safety are becoming increasingly important as the energy transition progresses and they are therefore gaining recognition worldwide. However, the central issue in both approaches is the informative value of a test or measurement, since a standard 50 Hz AC voltage cannot be used directly for the on-site test and cable system diagnostics due to the strong capacitive properties of the cable. Over the past 30 years, the VLF test method for cable tests has become established as an alternative to the 50 Hz AC voltage test, while the damped AC test voltage is increasingly used for cable diagnostics. These type of excitation voltages enable both the operational safety of a cable system by means of cable testing and a meaningful partial discharge measurement comparable to the 50/60-Hz AC voltage. The advantage of these methods is the reduced power requirement for the voltage source, which allows the test equipment to be more compact. As a result, cable testing or diagnostic measurement devices can be smaller, lighter, and more portable, making on-site measurements much easier.

## Asset management

Cable asset management is a key tool for energy suppliers to ensure the safe operation of their supply network. There are various strategies to prevent unplanned outages while maximizing the lifespan of the installed technology. Since the early 1990s, cable withstand testing using 0.1 Hz VLF Sine waves and 0.1 Hz VLF cosine-rectangular waves has become standard. These tests confirm that there are no immediate faults in the cable insulation and that the cable system is ready for operation. However, because cable testing cannot predict the future condition of the system, cable diagnostics have grown in importance over the past few decades. Diagnostics provide more detailed insights into the condition of the cable insulation, allowing for better-informed decisions about potential maintenance needs.

**... for better-informed decisions about potential maintenance needs.**

## Cable testing – why and what's the origin?

Cable testing using modern 0.1 Hz VLF methods became widely established in the early 1990s. The focus of this testing was to identify operationally hazardous defects caused by "electrical trees," which are triggered by "water-treeing" within plastic-insulated cable systems. The first generation of (XL)PE cables had significant issues due to water molecules trapped in the insulation during the manufacturing process. Under the influence of an electric field, heat and other by-products and processes, the water molecules over time lead to the formation of "water trees" in the insulation. These water trees degrade the insulating properties of the material, eventually turning into "electrical trees." Electrical trees can cause a rapid breakdown of the cable insulation, leading to an unplanned failure of the cable section.
In the early 1990s, as cable failures caused by these phenomena became more frequent, academic research began to explore how to prevent treeing issues in the future. At that time, sensitive diagnostic measurements on-site were not yet available, so cable testing was the only way to ensure a cable system's operational readiness. The testing process would trigger defects to break down during the test itself, rather than during normal operation, thereby preventing unexpected outages. Today, manufacturing processes for XLPE cables have improved, preventing water molecules from being trapped in the insulation. As a result, the formation of water trees is now either nonexistent or negligible. VLF withstand testing on newly installed cables is still used to detect any significant workmanship-related issues and to ensure the safe energization of the cable system.

## Five decades of VLF technology

**1980s**

- The first VLF system is developed and patented by HDW, based on the VLF cosine-rectangular principle.
- Several utilities begin field testing VLF systems on power cables, using them as an alternative to DC testing, particularly for older installations, due to concerns over insulation damage from DC high-potential (HiPot) testing.

**1990s**

- The first VLF sinusoidal systems are introduced to the market, providing a more precise waveform for cable testing.
- Commercial VLF test systems become widely available, gaining wide-spread use among utilities for the testing of medium voltage (MV) and high voltage (HV) cables.
- VLF testing gains traction as utilities recognise it as a more reliable method for diagnosing insulation health, especially compared to traditional DC testing.

**2000s**

- VLF testing begins to be incor-porated into major electrical cable testing standards, such as IEEE 400.2 and IEC 60060-3, solidifying its role as a recognised testing method.
- The first large-scale case studies involving over 10 000 tests are published, demonstrating the effective-ness of VLF testing in both commissioning new cables and assessing the condition of aged cables.

## Cable diagnostics – uncovering hidden defects and preventing unplanned outages

While the primary goal of cable testing is to identify operationally hazardous defects and safely break them down, cable diagnostics focus on detecting issues without risking damage to the cable system. Diagnostics aim to uncover and locate potential problems within the cable system while ensuring the insulation remains intact. Research over the years has shown that assembly errors, which don't cause immediate electrical breakdowns, are often the root cause of cable failures. These faults take time to develop and can't be detected by standard cable testing. This is where partial discharge (PD) diagnostics become essential. Assembly errors in cable accessories can lead to partial discharges, causing the accessories to age prematurely and eventually fail. With advanced PD measurement techniques, these discharges can be efficiently detected and pinpointed, allowing you to identify which accessories are likely to fail in the future – without pushing the cable to the point of breakdown or requiring immediate repairs.

Another powerful diagnostic tool is tan delta measurement, which assesses the overall ageing of cable insulation by measuring its dielectric losses. Elevated losses often indicate insulation deterioration or moisture ingress, potentially leading to cascading failures. Tan delta measurements provide valuable insights into the cable's ageing process, enabling more informed asset management decisions and helping to prevent future operational failures.

**2010s**

- VLF testing is formally integrated into the IEC 60502-2 standard in its 2014 revision, providing a globally recognised framework for testing cables with extruded insulation up to 30 kV.
- Refinement of test procedures, recommending testing times typically ranging from 15 to 30 minutes at 0.1 Hz and test voltages around $3U_0$ (three times the operating voltage).
- Advanced VLF diagnostics – such as VLF Tan Delta and VLF Partial Discharge (PD) testing – become more widely used, greatly improving the ability to detect insulation deterioration and pinpoint cable defects.

**2020s**

- Widescale statistics from over 50 000 tests continue to demonstrate that VLF testing remains a critical tool for assessing the condition of power cables and ensuring network reliability.
- Partial Discharge (PD) measurement becomes a compulsory test for many utilities, as it provides deeper insights into the condition of cable insulation and helps in early detection of potential failures.

## The *first* ace up your sleeve – DC voltage

For decades, DC excitation voltage was the standard for cable withstand testing. Today, it's only used for HVDC cables due to the risk of insulation damage and its inability to detect certain type of defects. So why is DC voltage still relevant? Primarily, it's essential for sheath testing in compliance with IEC 60229, typically conducted at 5 to 10 kV. If a sheath fault is found, pulsed DC voltage enables precise pinpointing of the fault location, making DC testing an indispensable tool for sheath integrity assessments.

**...making DC testing an indispensable tool for sheath integrity assessments.**

### Field of application of DC voltage:

- Sheath testing (IEC 60229)
- Sheath fault pinpointing (pulsed DC)
- Withstand testing for paper-insulated cables (IEEE 400.1)

**Advantages:** Compact and lightweight systems

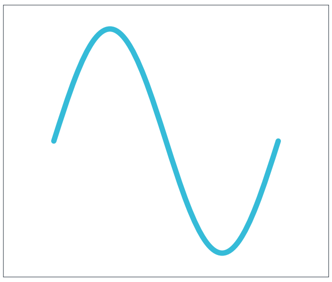
**Drawbacks:** Not suitable for polymeric insulation testing; can damage aged cable insulation

### The *second* ace up your sleeve - 0.1 Hz VLF Sine voltage

With two VLF technologies integrated into the all-in-one TDM systems, which is preferred for cable withstand testing? The answer is clear: VLF cosine-rectangular voltage is the optimal choice for withstand testing. So why use 0.1 Hz VLF Sine voltage? If you're looking to assess insulation aging, dielectric loss (tan delta) measurement using the 0.1 Hz VLF Sine wave is essential. It also ensures standard-compliant testing for short cables. When tan delta is integrated, a monitored withstand test – tracking dielectric losses during testing – is recommended, similar to how leakage current is measured with VLF cosine-rectangular voltage. While 0.1 Hz VLF Sine can also be used for partial discharge (PD) measurements, it's not the recommended solution. Due to its limitations in detecting weak spots, Megger recommends the VLF cosine-rectangular technology for more reliable PD testing, as demonstrated in real-world case studies.

**Field of application of the 0.1 Hz VLF Sine wave voltage:**

- Cable withstand testing according to IEC 60502-2 and IEEE 400.2
- Dielectric loss factor (Tan Delta) measurement as per IEEE 400.2
- Partial discharge measurement in acc. with IEC 60885 and IEEE 400.3



**Advantages:** Suitable for withstand testing and advanced diagnostics, including monitored testing

**Drawbacks:** Limited testing capacity for long cables; PD measurement limitations at 0.1 Hz

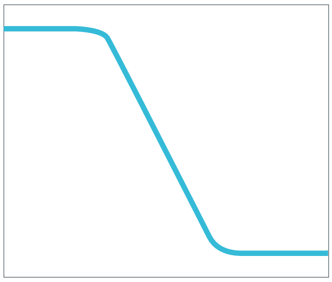
## The *third* ace up your sleeve – 0.1 Hz VLF cosine-rectangular voltage / 50 Hz Slope technology

Megger's VLF cosine-rectangular voltage, also named 50 Hz slope technology, is the ultimate solution for cable withstand testing – whether for short or long cables! Combining near-operational frequency (20-500 Hz) with low power consumption, this innovative test equipment ensures efficient testing at a standard-compliant 0.1 Hz, guaranteeing cable system safety. Its ability to reuse stored power allows testing even the longest cables at a standardized frequency. Additionally, it excels in partial discharge measurements, closely simulating real operating conditions for accurate results. With leakage current monitoring, insulation quality can be evaluated during testing, making it the ideal choice for commissioning and acceptance tests.

**Meggers recommendation for efficient and reliable commissioning testing.**

**Field of application of the 0.1 Hz VLF cosine-rectangular voltage:**

- Cable withstand testing according to IEC 60502-2 and IEEE 400.2
- Partial discharge (PD) measurement as per IEC 60885 and IEEE 400.3



**Advantages:** High testing power for short/long cables, accurate PD measurement at power-frequency comparable levels, leakage current as a quality indicator

**Drawbacks:** No standardised criteria for leakage current interpretation

## The *fourth* ace up your sleeve – Damped AC/DAC

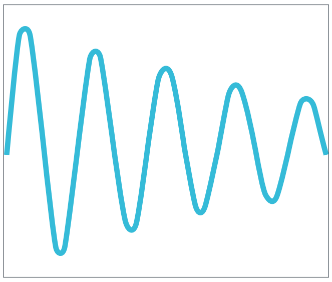
The fourth test or diagnostic voltage is DAC (Damped AC) voltage. DAC measurements are designed to detect partially discharged defects that may not cause an immediate breakdown during a typical cable test but still pose a long-term risk to the cable's lifespan. With damped AC, the cable is exposed to voltage for the shortest possible duration, which is especially critical for aging cable sections. When testing severely aged cables, the goal is to conduct diagnostics without subjecting the cable to unnecessary risk.

DAC minimizes the potential for breakdowns during or after testing by applying a time-limited voltage stress. The DAC voltage form and frequency are highly effective in identifying defects that are prone to partial discharge. The principle of voltage generation is based on a free oscillating circuit, ensuring minimal interference, making DAC an ideal voltage form for partial discharge diagnostics in both new and aging cables.

**...without subjecting the cable to unnecessary risk.**

**Field of application for Damped AC (DAC):**

- Partial discharge (PD) measurement according to IEC 60885, IEEE 400.3, and IEEE 400.4



**Advantages:** High testing power, minimal voltage exposure reduces risk to aged cables, accurate PD at power frequencies

**Drawbacks:** Not suitable for withstand testing

# The choice of the right strategy is in your hands!

Is it possible to hold all the aces?
The answer is a resounding **"YES"!**

**The Megger TDM series delivers all types of on-site test voltages in a single device.**

No matter the challenge, the TDM series equips you with the ideal solution to maximize the performance of any cable network.

Expert support is readily available to assist in selecting, configuring, and implementing the best testing and diagnostic technologies for asset management.

TDM DATASHEET

## 20 kV networks

| Output voltage | |
|---|---|
| DC | 0 to ± 45 kV |
| VLF Sine | 0 to 45 $kV_{peak}$ |
| VLF CR | 0 to 40 $kV_{RMS}$ |
| DAC | 0 to ± 40 $kV_{peak}$ |

## 30 kV networks


| Output voltage | |
|---|---|
| DC | 0 to ± 62 kV |
| VLF Sine | 0 to 62 $kV_{peak}$ |
| VLF CR | 0 to 60 $kV_{RMS}$ |
| DAC | 0 to ± 60 $kV_{peak}$ |

| Summary of our recommendations for cable testing (CT) and cable diagnostics (CD) | | | | | |
|---|---|---|---|---|---|
| Applications of medium-voltage cables/voltage forms | | DC | VLF Sine | VLF CR/ Slope | DAC |
| CT | Commissioning test on short cables | | ✓ | ✓ | |
| CT | Commissioning test on long cables | | | ✓ | |
| CT | Monitored withstand test | | ✓ | ✓ | |
| CT | Sheath testing | ✓ | | | |
| CD | Measurement of dielectric losses (Tan Delta) | | ✓ | | |
| CD | Partial discharge measurement | | | ✓ | ✓ |

| Test standards | Description | Excitation voltages |
|---|---|---|
| **Cenelec HD 620** | Distribution cables with extruded insulation for rated voltage from 3.6/6 (7.2) kV up to and including 20.8/36 (42) kV | **VLF Sine, VLF CR** |
| **Cenelec HD 621** | Medium-voltage impregnated paper insulated distribution cables | **VLF Sine, VLF CR, DC** |
| **Cigre TB924** | Condition assessment and diagnostic methods to support asset management of MV cable networks | **VLF Sine, VLF CR, DAC** |
| **IEC 60055** | Paper-insulated, metal-sheathed cables for rated voltages up to 18/30 kV - Part 1: Tests on cables and their accessories | **DC** |
| **IEC 60060-3** | High-voltage test techniques<br>Part 3: Definitions and requirements for on-site testing | **DC, VLF Sine, VLF CR, DAC** |
| **IEC 60229** | Electric cables - Tests on extruded oversheaths with a special protective function, including post-installation tests | **DC** |
| **IEC 60270** | High-voltage test techniques – Partial discharge measurements | **-** |
| **IEC 60502** | Power cables with extruded insulation and their accessories for rated voltages from 1 kV $U_0$ = 1.2 kV up to 30 kV $U_0$ = 36 kV | **VLF Sine, VLF CR** |
| **IEC 60885** | Electrical test methods for electric cables - Part 3: Test methods for partial discharge measurements on lengths of extruded power cables | **VLF Sine, VLF CR, DAC** |
| **IEEE 400** | Guide for field testing and evaluation of the insulation of shielded power cable systems rated 5 kV and above. | **DC, VLF Sine, VLF CR, DAC** |
| **IEEE 400.1** | Guide for field testing of laminated dielectric, shielded AC power cable systems rated 5 kV to 500 kV using high voltage direct current (HVDC) | **DC** |
| **IEEE 400.2** | Guide for field testing of shielded power cable systems using very low frequency (VLF) (less than 1 Hz) | **VLF Sine, VLF CR** |
| **IEEE 400.3** | Guide for partial discharge field diagnostic testing of shielded power cable systems | **VLF Sine, VLF CR, DAC** |
| **IEEE 400.4** | Guide for field testing of shielded power cable systems rated 5 kV and above with damped alternating current (DAC) voltage | **DAC** |

# Business CASE 1

## Condition assessment of a service aged cable – advantage of having the four aces

As part of the company's maintenance strategy, a condition assessment was conducted on a service-aged power cable. This included Dielectric Loss Measurement (Tan Delta) to evaluate insulation health and detect potential degradation. Partial Discharge (PD) testing was also performed, utilizing the full range of excitation voltages – DAC, VLF CR/Slope and 0.1Hz VLF Sine wave – to identify insulation defects under different stress conditions.

These diagnostic tests provide critical insights into the cable's aging and potential failure risks. The data supports informed maintenance planning, helping to extend asset life, minimize downtime, and ensure system reliability.

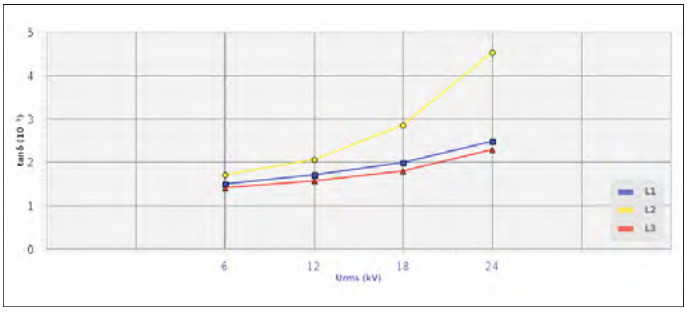
### Tan Delta and partial discharge diagnostics with 3 excitation voltages:

- Cable data: 12/20 kV XLPE cable from 2007, 995 m, number and position of joints unknown
- Test voltage source used: van-mounted version of the TDM4540 with internal PD coupler

## Dielectric loss measurement

The dielectric loss measurement revealed elevated losses across all phases, with results deemed critical per IEEE 400.2-2014 Annex I, indicating the need for further investigation. Notably, phase L2 exhibited significantly higher losses compared to the other two phases, suggesting a localized issue, such as a fault in a joint or termination.

Since dielectric loss measurement provides only a global assessment of the cable's condition, it cannot precisely locate the issue. To pinpoint the fault, either a Partial Discharge (PD) measurement or a withstand test is recommended. It should be noted that a withstand test will only identify the problem if the defect is severe enough to cause immediate failure during testing.



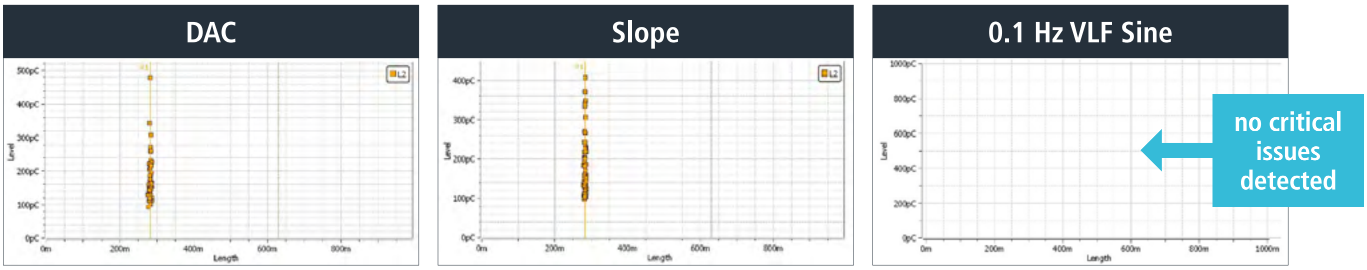

| Operationally aged XLPE cable | L1 [$10^{-3}$] | L2 [$10^{-3}$] | L3 [$10^{-3}$] |
|---|---|---|---|
| **Standard deviation @ 1.0 $U_0$** | **0.00** | **0.06** | **0.06** |
| **Differential Tan Delta (2.0 $U_0$ - 1.0 $U_0$)** | **0.80** | **2.40** | **0.70** |
| **Tan Delta @ 2.0 $U_0$** | **2.50** | **4.50** | **2.30** |

*Key Tan Delta factors for condition assessment according to IEEE 400.2 Annex I.*
*Color coding indicates the condition status.*

## Partial discharge measurement

The utility decided to conduct a PD measurement on the cable, utilizing three excitation voltages to fully leverage the capabilities of their TDM unit. In graph series 1, the PD mappings at nominal voltage Uo are shown for DAC, VLF CR/Slope, and 0.1 Hz VLF Sine wave excitation voltage. Both DAC and VLF CR/Slope identified a defect in phase L2 at approximately 280 m, aligning with the previously observed anomaly from the dielectric loss measurement, likely indicating an issue in a joint.

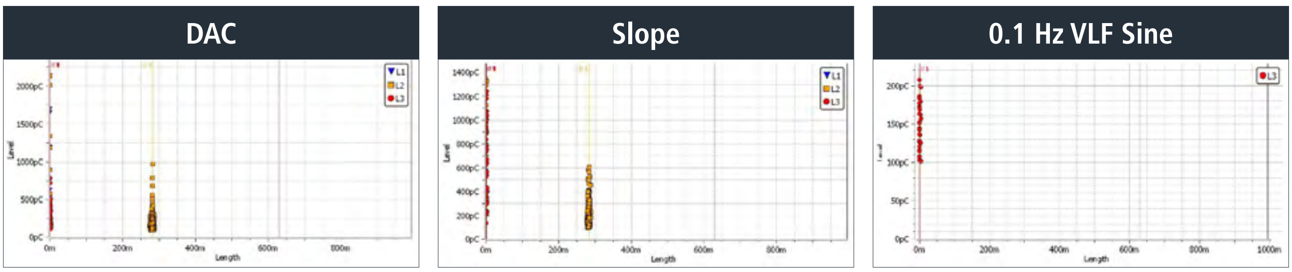
Interestingly, this weak spot was not detected using the 0.1 Hz VLF Sine wave excitation voltage, highlighting the sensitivity differences between the individual testing methods.




*Partial discharge mapping for all excitation voltages (DAC, VLF CR/Slope, and 0.1 Hz VLF Sine wave) at nominal voltage $U_0$. X-axis is the cable length, Y-axis is the discharge height.*

In graph series 2, the PD mappings are displayed at a test voltage of 1.7 times the nominal voltage Uo, the standard maximum test voltage for PD measurements on medium-voltage cables. As expected, the PD concentration and intensity at the localized weak spot (~280 m) increased with both DAC and VLF CR/Slope compared to the measurements at nominal voltage.

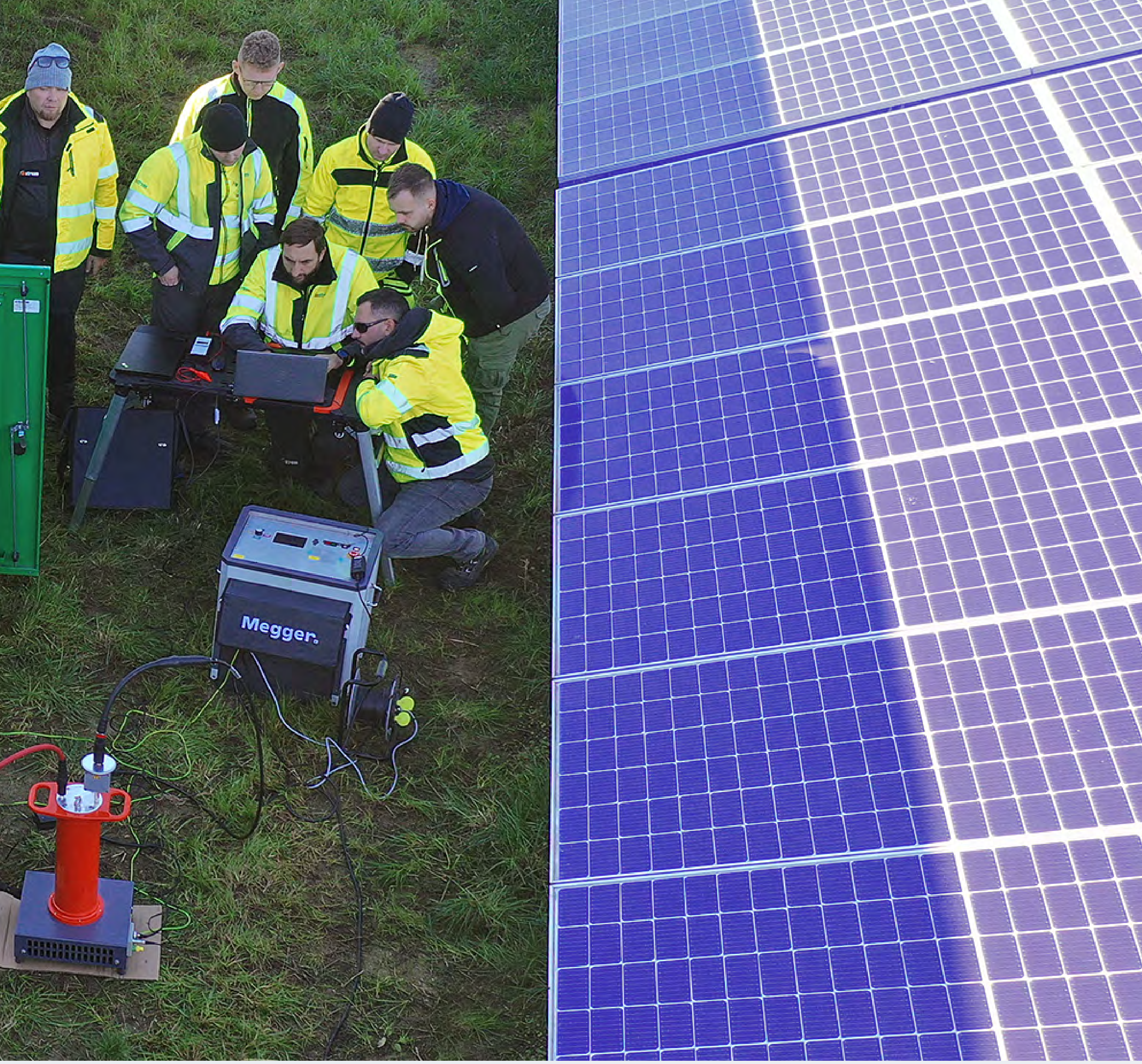
However, even at $1.7U_0$, the weak spot identified by DAC and VLF CR/Slope remains undetected using the 0.1 Hz VLF Sine wave, highlighting a significant difference in detection capabilities between the testing methods.




*Partial discharge mapping for all excitation voltages (DAC, VLF CR/Slope, and 0.1 Hz VLF Sine wave) at nominal voltage $1.7xU_0$. X-axis is the cable length, Y-axis is the discharge height.*


Following the results of the dielectric loss and PD measurements, the utility made the decision to address the weak spot located at approximately 280 m, which was identified as a faulty joint. Upon dissection, workmanship-related issues were discovered, specifically insufficient use of assembly paste and mastic tape to fill cavities, as shown in the images.

After replacing the joint, a follow-up PD measurement was conducted, confirming that the weak spot had been successfully eliminated and the cable is now in optimal condition.




## Conclusion:

This business case demonstrates the effectiveness of combining dielectric loss and PD measurements to identify and localize critical cable issues, such as the defective joint discovered in this instance. By utilizing DAC and VLF CR/Slope, the PD measurement successfully pinpointed the weak spot showing PD activity at nominal voltage Uo already, leading to the proactive decision to replace the joint before a failure occurred.

Crucially, the 0.1 Hz VLF Sine wave excitation voltage failed to detect this critical defect, highlighting the limitations of relying on this method for PD measurements. This case underscores the importance of selecting the right diagnostic tools to ensure accurate fault detection and maintain the integrity of cable systems.

# Business CASE 2

## Partial discharge diagnostics with 3 different excitation voltages

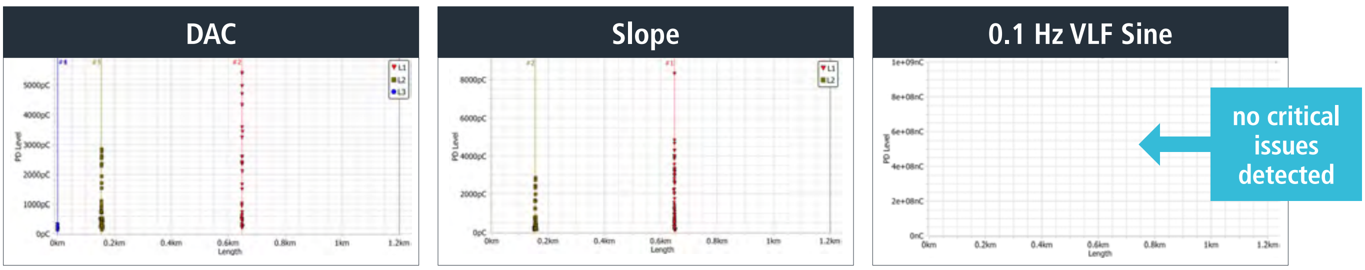
At one of our customer's critical locations, multiple service providers conducted partial discharge measurements on an essential cable, resulting in inconsistent findings. To resolve this, Megger was brought in to deliver a repeat measurement using our state-of-the-art, all-in-one solution. With Megger's trusted technology, we ensured a reliable, accurate, and consistent assessment, giving our customer the confidence they needed.

### Partial discharge diagnostics with 3 excitation voltages:

- Cable data: 12/20 kV XLPE cable from 2004, 1200 m, number of points and position unknown
- Test voltage source used: Van-mount version of the TDM4540 with internal partial discharge coupler

Three comprehensive measurements were conducted on this cable system, utilising all available excitation voltages. For aging cables, damped AC voltage (DAC) is recommended for its superior performance, while VLF CR/Slope voltage is the optimal choice for new cables, such as during commissioning tests. Although the 0.1 Hz VLF Sine wave is a basic option for beginners, it lacks the in-depth insights provided by DAC and VLF slope voltage, as demonstrated in this case

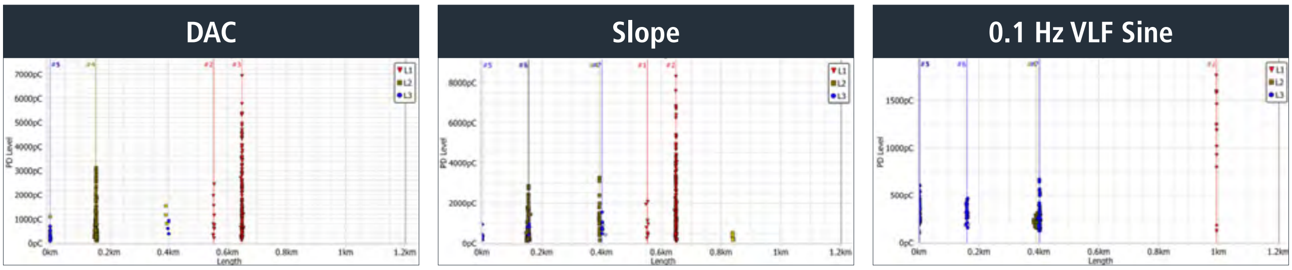
Graph series 1 illustrates the partial discharge mapping at operating voltage, highlighting the cable's condition during normal operation. Notably, two vulnerabilities – located at approximately 175 m and 650 m – were clearly identified using both the DAC and VLF CR/Slope excitation voltage.. These weak points are active during normal operation, degrade the insulation, and will eventually cause cable failure. However, with the 0.1 Hz VLF Sine wave, these critical issues were not detected.




*Explanation of graph series 1:*
*Partial discharge mapping for all excitation voltages (DAC, VLF CR/Slope, and 0.1 Hz VLF Sine wave) at nominal voltage $U_0$. X-axis is the cable length, Y-axis is the discharge height.*

With an increased test voltage of 1.7 $U_0$, the differences become even clearer, as can be seen in the following series of graphs. A total of seven critical defects were identified with DAC and VLF CR/Slope, while only four were identified with the 0.1 Hz VLF Sine wave.

What is particularly important, however, is that the inception voltage (the voltage at which partial discharges begin) with 0.1 Hz VLF Sine wave is not comparable to the results obtained from DAC or slope voltage in any of the identified cases.




*Explanation of graph series 2:*
*Partial discharge mapping for all excitation voltages (DAC, VLF CR/Slope, and 0.1 Hz VLF Sine wave) at 1.7 times the mains voltage $U_0$.*

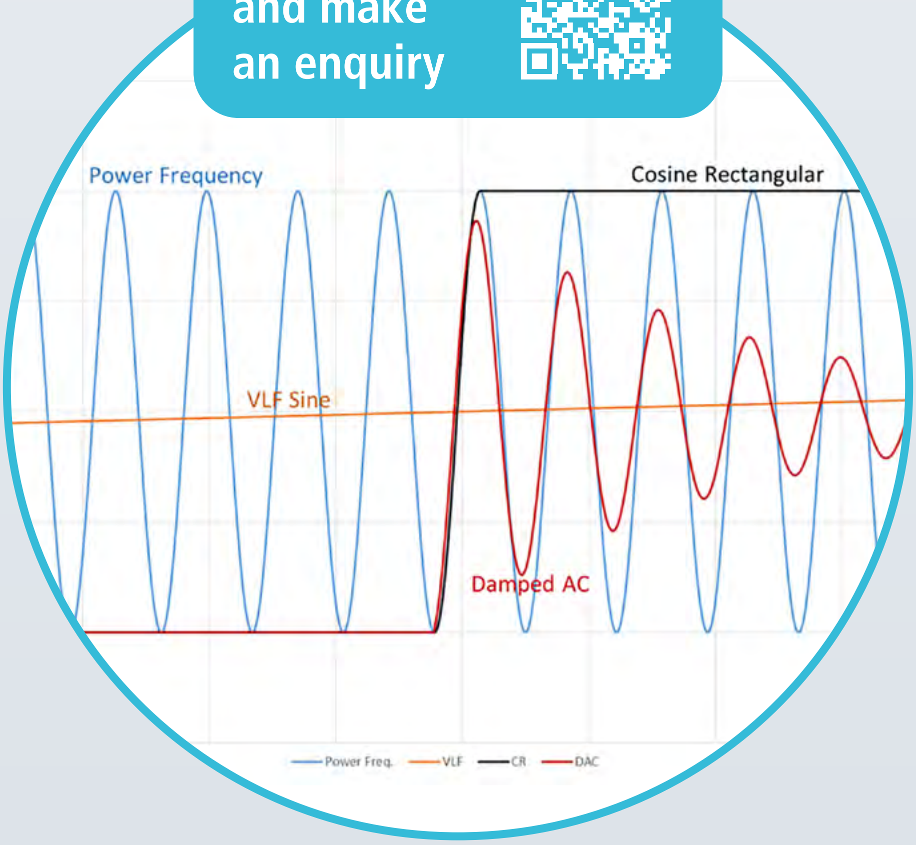
Based on Megger's recommendation, the customer removed and inspected the joint at 650 m. Several critical assembly issues were uncovered, including contamination (sand) within the insulating shrinkable body and incorrect assembly dimensions of the connector. Additionally, the brown discoloration was a clear sign of partial discharge activity during normal operation.

## Conclusion:

This real-world example highlights the significant differences in partial discharge measurements when using different excitation voltages. The visible partial discharge activity in the joint serves as definitive proof of the accuracy and reliability of Megger's recommendations.

## Do you have more questions about the 4 excitation voltages?

Contact us and make an enquiry

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