Combined Application of Diagnostics Tools for MV Underground Cables

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ABSTRACT

This paper presents the advantages of the application of the combination of offline and online diagnostic tools for underground medium voltage cables. Partial Discharge (PD) online measurement is a useful tool to identify PD activities without the shutdown of a cable circuit. Advantages and challenges of PD online diagnostics combined with the advantages and strengths of offline VLF tan delta and VLF PD measurement are demonstrated by practical case studies. The combination of advanced diagnostic tools allows asset owners to implement condition based maintenance measures most cost and time efficient.

<u>Index Terms:</u> *Online PD, Offline VLF TD, VLF PD, MWT*

1. INTRODUCTION

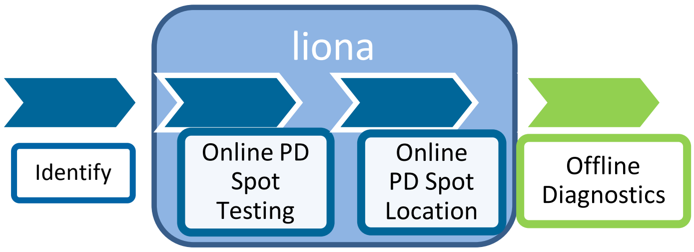
More and more network operators of Medium and High Voltage Underground (MVUG) cable networks are facing the challenge of ensuring highest power supply reliability and at minimizing the costs for maintenance at the same time.

For cost efficient management of assets and maintenance of MVUG cables, condition based preventive maintenance is the key for modern power utilities. Based on condition evaluation of MVUG cables, service aged cables and accessories can be prioritized for maintenance according to their condition. Condition evaluation is also getting more and more important for commissioning tests of new cable installations. The combination of VLF testing and PD monitoring and localization allows to identify installation weaknesses already at the stage of commissioning. Accordingly, long term problems can be prevented in an early stage.

In order to make best use of modern condition assessment, diagnostic tests are used to understand the cable condition. As for all diagnostic investigations, only the right mix of applied technologies can ensure to discover all kind of degradations along new and service aged cables. Especially old installed cables which may consist of hybrid arrangements can present numerous degradation effects in one single cable.

Combined diagnostic methods in MVUG cables have proven to cover all aging characteristics. Different diagnostic tools are expected to deliver highly informative results that allow improving the condition of cables with a minimum of effort in time and costs. In the following chapters, the applied technologies for combined diagnostics are explained in detail.

In general online and offline diagnostic techniques can be combined in order to work in a most efficient way, when power shutdowns are critical and request for fundamental justification.



2. PD ONLINE - DIAGNOSTICS

The portable device “liona” is used for measuring and localizing PD online, i.e. while the power circuit remains in operation. With “liona”, medium- and high-voltage cables as well as switching stations can be tested quickly for PD without major expense and without the effort of disconnection of the cable circuit. Special high-frequency current sensors (HFCT, High Frequency Current Transformers) are used to perform measurements on a connected power cable. The sensors enable to measure the PD signal at the cable screen in the substation as well as link-boxes in transmission circuits (see Figure 1 and Figure 2).

To acquire meaningful information in spite of the active mains operation, it is essential that the device software is able to differentiate between interference signals and the PD activities. One of the strongest tools to differentiate between noise and PD activities is the algorithm called DeCIFer® invented and registered by IPEC Ltd. [1], the core of the software. The algorithm is the result of many years of expertise and experience acquired by IPEC. The algorithm automatically identifies the PD activities out of the interference signals (Figure 4). Noise is the major difficulty to be overcome in online diagnostics.

"liona" presents the result of the fully automatic measurement in a graph that provides information on the level and type of PD. The localization (or mapping) of the PD activities can be done precisely with a transponder unit mounted at the far end of the cable (see Figure 1). For this purpose, the impulse generator (transponder) is connected to the other end of the cable line via an HFCT sensor on the cable line.

Figure 1 PD online spot testing equipment

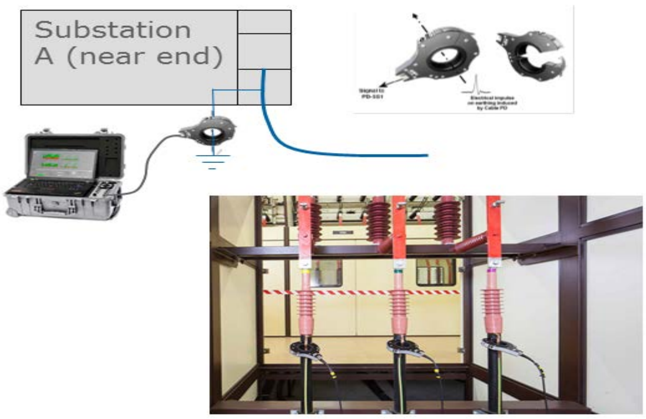


Figure 2 PD online connection arrangement

Thanks to this easy connection, "liona" completes the measurement in minutes and without cumbersome switching actions.

If PD are detected in the cable line during the online measurement, performing a more detailed offline cable diagnostics using tan delta and PD measurement is recommended. PD detection with online measurement can only deliver information on one particular degradation characteristic (PD) at operating condition. Therefore online diagnostics cannot substitute a comprehensive offline diagnostics, where the voltage level can be adjusted. Though, online diagnostics can be used as a powerful tool to justify a power shutdown.

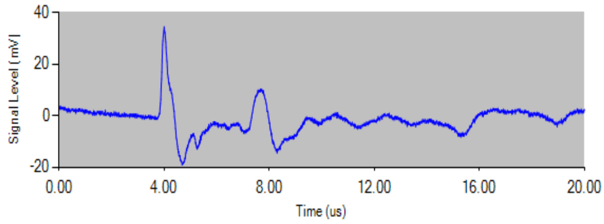


Figure 3 PD online - individual PD pulse

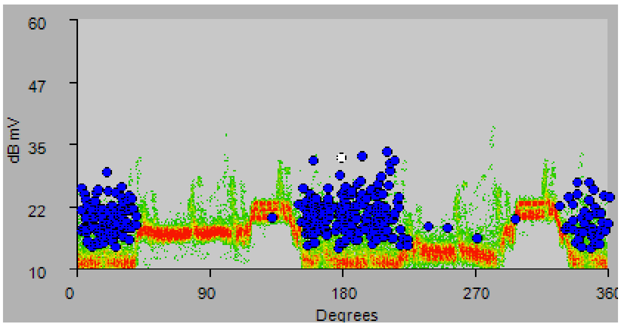


Figure 4 PD online mapping cable #1, indication of PD at 1.0xU_o – online

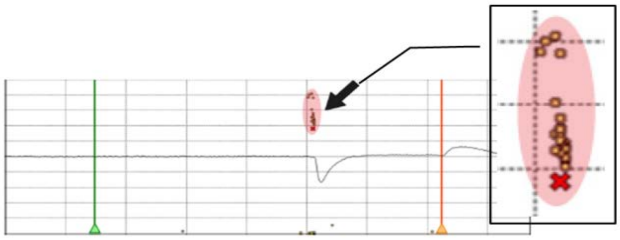


Figure 5 PD online localization cable #1, localization of PD source at 350m in L1 only

The results shown above of cable #1 of online PD spot testing and localization are based on a particular example, where PD activity could be measured in one phase. Clear pattern recognition and identification of the PD among the noise pattern by means of the DeCIFer® algorithm (Figure 4) confirms the presence of PD activities in operating condition (1.0xU_o – service voltage). The online PD localization allows identifying the PD activity at a single position at 350m (see Figure 5).

3. OFFLINE – DIAGNOSTICS

3.1. Tan Delta Dissipation Factor Measurement

VLF tan delta, differential tan delta, tan delta stability, leakage current, and loss current harmonics measurements may be used to monitor aging and deterioration of cable systems. However, tan delta (VLF-TD), differential tan delta (VLF-DTD), and tan delta stability (VLF-TDTS) measurements are the most commonly used methods in the field. [2]

Tan delta is a measure of the degree of real power dissipation in a dielectric material and therefore its losses. The detailed definition can be found in IEEE400.2-2013. [2]

In the case of underground cables, this test measures the bulk losses rather than the losses resulting from a specific defect. Therefore, Tan delta measurement constitutes a cable diagnostic technique that assesses the general integrity of the cable system insulation. Tan delta can be employed to all cable types; however, test results must be considered with respect to the specific cable insulation material and accessory type [3]. The maintenance VLF test according to IEEE 400.2 is an important tool to confirm that no hidden weaknesses are present.

Very often the tan delta loss factor is highly influenced by water ingress into joints. In general, the TD stability and the TD stability trend are clear indicators to conclude whether the aging is related to water ingress in joints, water tree aging or tracking behavior in joints. Manufacturer's application guidelines [4] are available to help understand the possible meaning of the TD stability value.

Joints with water ingress can show the following characteristics during measurement:

- Highly fluctuating values throughout each voltage level is an indicator for a high amount of water ingress in joints
- Decreasing values throughout each voltage level stand for small amount of humidity in either a joint or the termination, humidity vaporizing during the application of voltage
- Strongly increasing TD values throughout each voltage level mean tracking inside the joint [5]

In Figure 6 the VLF TD measurement graph of cable #1 is shown. Based on the TD values, this particular cable shows good integrity with no presence of water tree aging or water ingress in joints. In general, VLF TD can only reflect very intensive PD activity. Small PD activities do not influence the losses of the cable a lot.

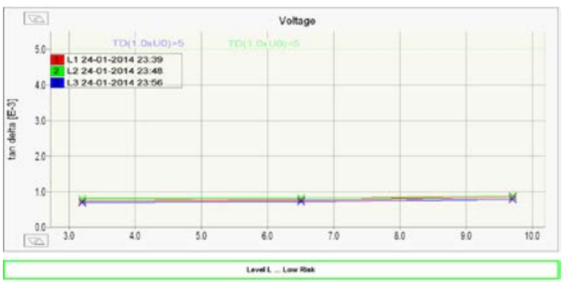


Figure 6 TD result cable #1, XLPE cable, good cable integrity beside joint PD

3.2. PD measurement

Pinpointing of degraded cable sections or joint locations is easily possible if PD activity can be measured. [5]

After the online measurement, the circuit was shut down for comprehensive offline diagnostic. Figure 7 shows the offline PD localization graph which confirms that in the 3 phased cable, only L1 shows PD activity at operating voltage $1.0xU_o$ at a position of 350m.

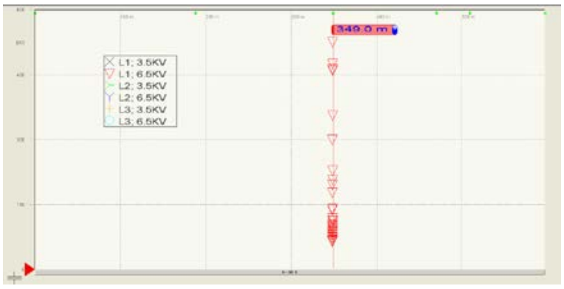


Figure 7 PD-offline mapping and localization cable #1, VLF PD confirmed PD at $1.0xU_o$ at 350m in L1 only

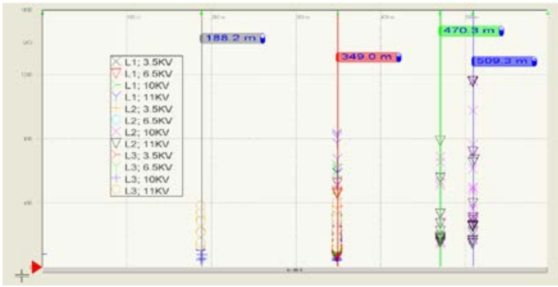


Figure 8 PD-offline result cable #1, up to $1.7xU_o$, XLPE cables, PD in 4 joints

For VLF PD offline diagnostic in general the voltage levels of up to $1.7xU_o$ are scanned. The results show, that in the same cable #1 in total 4 joints could be identified with PD activities that become active at voltage levels above operating voltage. Accordingly it can be understood that VLF PD offline diagnostic can clearly identify weaknesses that cannot be recognized with applying online measurement at $1.0xU_o$.

The joint at 350m has been replaced and dissection allowed identifying the tracking mark of PD activity.

Figure 9 Joint dissection of cable #1, L1 at 350m, PD tracking mark

Cable diagnostic in PILC cables or mixed cables (hybrid of XLPE and PILC cable sections) can be more complex. Aged PILC cables are likely to show PD activities. Figure 10 shows the VLF PD offline diagnostic result with indication of PD activities in the PILC cable sections where all 3 cores show similar PD activities.

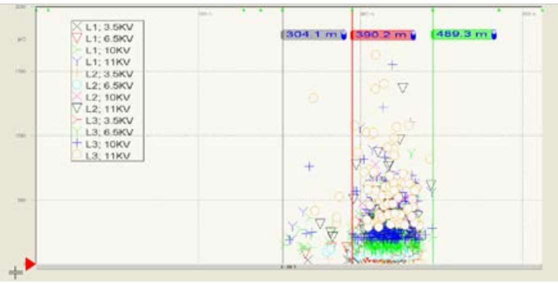


Figure 10 PD result cable #2, PILC/XLPE cable, PD activity in PILC cable section

The VLF tan delta result of cable #2 shows, that beside the aged PILC cable section that shows intensive PD activity, also other degradation elements are present. Detailed analysis of STD and STD trend behavior further allows identifying water tree aging in XLPE cable sections (see Figure 11). As known, water trees cannot be identified with PD measurement.

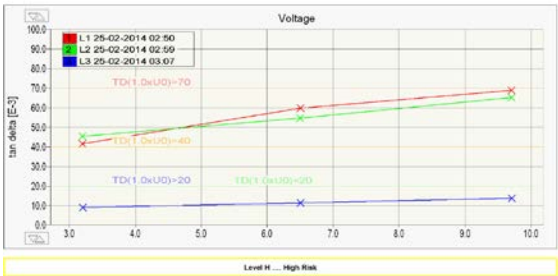


Figure 11 TD result cable #2, PILC/XLPE cable, cable in high operating risk condition, degraded PILC section, water tree aging in XLPE cable section

For cable #2 it was essential, to apply combined diagnostics in order to understand the whole cable aging condition.

3.3. Monitored Withstand Test

A new diagnostic tool is the Monitored Withstand Test (MWT), which combines the existing methods of VLF voltage testing and VLF tan delta measurement. MWT is already included in the new IEEE 400-2012 [6] standard as well as the new IEEE 400.2-2013 [2] standard. The IEEE field guide especially recommends the VLF sinusoidal monitored withstand with tan delta as exclusively “useful” method for aged distribution cable systems.

VLF MWT combines the “ramp up” phase that is equivalent to the VLF TD diagnostic part with the “hold” phase that monitors the TD over time (VLF-TDTS) during the VLF testing period.

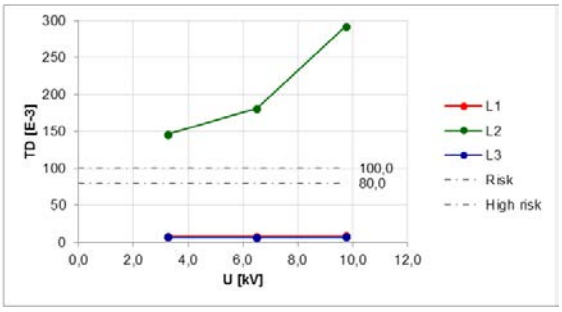


Figure 12 TD measurement, three core cable #3: L2 indicates high TD values and high standard deviation.

Figure 12 and Table 1 show the ramp-up phase of the MWT taken in cable #3. L2 shows a high increase of TD with very high STDTD values. STDTD is a very useful tool to identify water ingress in joints.

STDTD	0.5Uo (kV)	Uo (kV)	1.5Uo (kV)
	3,5	6,5	10
L1	0,068	0,036	0,060
L2	4,453	2,313	9,343
L3	0,063	0,004	0,050

Table 1 standard deviation of 3 cores at different voltage levels

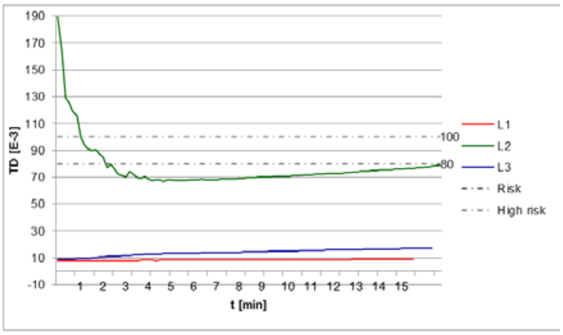


Figure 13 MWT graph which indicates a drying behavior of L2 over time, indication for water ingress in a joint

The behavior of the TD loss factor during the monitored withstand test (see Figure 13) over 15 minutes indicated that one of the suspected joints shows a drying behavior and a significant decrease of TD. This behavior confirms the assumption of presence of water ingress in one of the joints. Appropriate action can be taken. [7] For further information about the identification of joints affected by water ingress, please refer to [5].

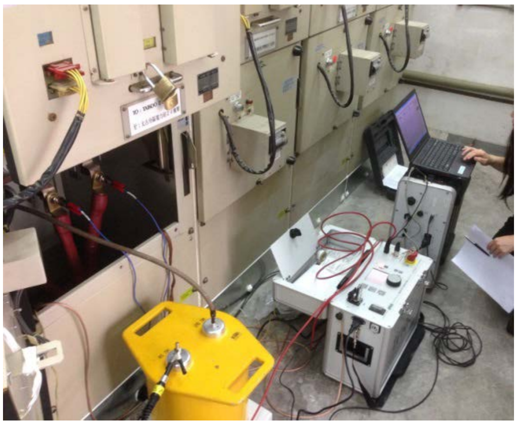
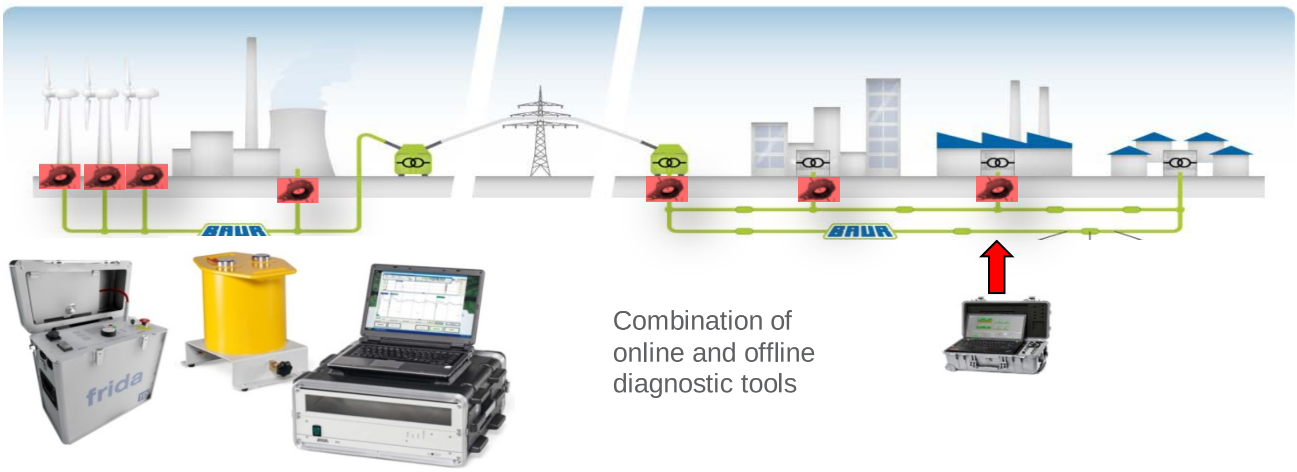


Figure 14 VLF TD PD MWT, frida - VLF offline diagnostic setup

4. CONCLUSION

The combinations of the right diagnostic tools allow assessing the cable condition of MV underground cable networks in a very comprehensive way. Online-PD Spot Testing and Online-PD localization allow recognizing severe PD activities without the request for a shutdown. Due to the operating voltage, only PD sources with inception voltage below or at operating voltage are recognizable.

In order to get the full picture of the condition of a MVUG cable, offline diagnostics shall be done. The combination of VLF tan delta and VLF PD diagnostic allow understanding the cable condition in detail. Offline VLF PD allows identifying weak spots along the cable even the PD inception voltage is above operating voltage. Accordingly, weak spots can be identified early. The combination with VLF tan delta allows to further identifying water tree aging in XLPE cables as well as the effect of water ingress in joints. A monitored withstand test allows confirming assumptions of the source of degradation in order to define the most appropriate action.



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6. THE AUTHORS

Tobias Neier was born in Austria in 1981 and graduated in Electrical Engineering in Austria. With his working experience since 2002 at BAUR Prüf- und Messtechnik GmbH has acted as tutor for training seminars in technical institutes and power utilities as well as conferences worldwide in the specific fields of cable testing and diagnosis technology as well as cable fault location. He has collected international field experience in more than 30 countries in Europe, North Africa, Middle East and Asia Pacific in operator trainings, field tests and strategy development.

Martin Jenny was born in Austria in 1972 and is Product Manager for cable testing & diagnostics. He is leading the product management for BAUR’s cable testing and diagnostics product portfolio since more than four years. BAUR’s portable VLF testers were one of the innovations that Martin drove forward in the last years. He has more than ten years of experience in testing and measurement in different industries.