Best practices for offline diagnosis of MV cables

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INTRODUCTION

The continuously increasing installation complexity for medium voltage power cables, results in many weak spots and therewith cable failures due to bad workmanship. This is mainly caused by the large variety of cable accessories as well as the reduction in insulation thickness and therewith in the margin of error throughout the entire cable installation process. The necessity for both commissioning testing of new cables as well as diagnostic measurements as part of a condition based maintenance is just a logical given fact. Nowadays cable testing as well as condition monitoring are well proven measurement methods for MV power cables which are guided by IEEE 400 [1] and IEC 60502-2 [2] standards.

WITHSTAND TESTING USING VLF VOLTAGE

Scientific researches and practical field experiencs [3, 4, 5] over the past several years have pointed out that it is beneficial to use very low frequencies (VLF) during a commissioning test or cable maintenance on MV cables. This to detect defects at an early stage and before they break down unexpectedly whilst the cable is in service with portable test equipment. Practically two voltage wave shapes are available, VLF 0.1 Hz sinusoidal (Sin) and VLF 0.1 Hz cosine rectangular (CR). Whilst VLF 0.1 Hz CR test systems due to their high output power allows all three phases to be tested simultaneously with the standardized test frequency (as of storage and re-use of the energy during the polarity reversal which is based on the resonance principle), using a VLF 0.1 Hz Sin test equipment the cable system in general has to be tested phase by phase. Furthermore and especially on longer cables using a VLF 0.1 Hz Sin test systems implicates to a reduced measurement frequency (e.g. 0.01 Hz) with an increase of the standardized testing time by factor 10 [6]. VLF 0.1 Hz Sin voltage test systems have the advantage that they can also be used for performing dissipation factor measurements to identify global ageing issues within the tested cable.

In addition there are also systems on the market available which offer both wave shapes within one unit, and can therefore combine the advantages of both voltage wave shapes. Such as dissipation factor measurements with VLF Sinoidal voltage or a monitored withstand test (partial discharge) using the VLF CR test voltage. In the latter case the PD measurement is performed during the polarity reversal. PD monitored withstand testing will lead to further information of existing weak spots or workmanship failures not breaking down during the VLF test, but being relevant for the operation of the cable.

CABLE DIAGNOSIS

Researches and practical experiences have shown that the very low frequencies are very effective and economical to lead failures within power cables and therewith inside the insulation and the accessories to a controlled breakdown. But due to a still remaining percentage value of workmanship failures and weak spots which cannot be found during a standardized VLF test an additional cable diagnosis is required to get an indication of the overall cable condition.

Partial discharge measurements are therefore applied since many years and is nowadays a well proven method for acceptance and maintenance testing, due to being effective in localizing weak spots (e.g. caused by bad workmanship). Additionally it is well known and established that the voltage slope of a VLF 0.1 Hz CR polarity reversal is comparable to 50/60 Hz mains operation frequency [6] as it can be seen in Fig 1. For a realistic interpretation of a partial discharge diagnosis the used voltage wave shape needs to be close to the mains operation frequency and in its application should be non-destructive to the device under test. By using a VLF 0.1 Hz Sin wave shape the differences to the power frequency will be at least 500/600 times (50/60 Hz). Depending on the type of weak spot the interpretation of the PD measurement results can be adventurous. Since the voltage slope of a VLF 0.1 Hz CR is comparble to 50/60 Hz [5] PD characterics are also comparable. In Figure 1 three waves shapes are shown which can be applied for a PD diagnosis (Damped AC (DAC), VLF 0.1 Hz Sin and VLF 0.1 Hz CR).

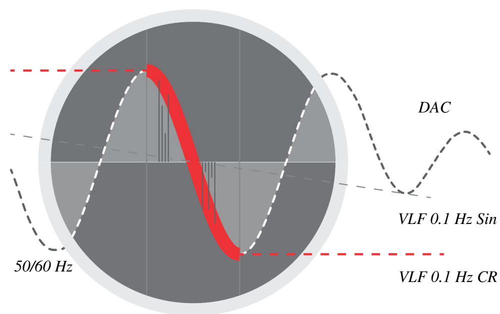

Fig. 1: Polarity reversal of different voltage wave shapes

For detecting global ageing of the insulation the PD diagnosis has limitations, for example moisture ingress cannot be detected. For detecting moisture ingress or water trees dielectric loss measurements are established. Therefore for aged cables always two diagnostics methods are recommended to asses the entire conditon of the cable. To keep the number of test sets limited nowadays commercial equipment is available that merges the advantages of powerful commissioning testing and detailed non-destructive cable diagnosis an example is shown in Figure 2.

Fig. 2: Typical combined test and diagnostic module for cable testing, dielectric loss measurement and partial discharge diagnosis

CASE STUDIES

The following case studies show a comparison of voltage wave shapes and also show how to effectively apply each individual diagnostic method (partial discharge and dielectric loss measurements. Especially dielectric loss measurments can be very helpful on aged cable circuits, not only to detect the global ageing but also to detect local problems.

Case Study 1

The test object for the first practical case study was a 12/20 kV service aged mixed cable composed of XLPE and paper mass insulation, in total the cable has 11 joints and has a length of 1335 m (Fig. 3).

Fig. 3: Cable diagram of the 1335 m long mixed cable (green XLPE, blue PILC)

The schematic test setup with the used test van including the integrated test and diagnosis module can be seen in Fig.4.

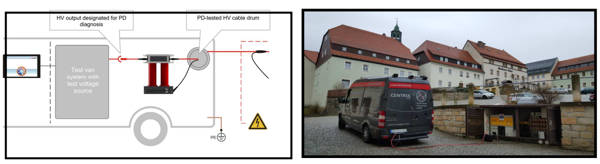

Fig. 4: Schematic diagram (left) and test van with integrated test and diagnostic module (right)

On this cable only partial discharge measurements were performed, no dielectric loss measurement. The measurement results of the PD diagnosis performed with three different voltage wave shapes (i.e. VLF 0.1 Hz Sin, DAC, VLF 0.1 Hz CR/ 50 Hz Slope) provided with a combined test and diagnosis module are shown in the PD mappings in Fig. 5.

The partial discharge measurements for both 50 Hz Slope Technology (based on the VLF 0.1 Hz CR voltage were PD is measured during the polarity reversal) as well as the DAC possess a good correlation in partial discharge inception voltage (PDIV), PD intensity and weak spot location as can be seen in figure 5. The PDIV of both wave shapes was far below the nominal voltage. A slight difference was recognizable in repetition rate and magnitude of the measured signals caused by the diversity of previous impacts. The diagnostic results of the PD measurement performed with the VLF 0.1 Hz Sin wave shape were different compared to the ones of 50 Hz Slope and DAC. First of all the PDIV was higher, second of all only one PD concentration at nominal voltage have been identified and finally the PD intensity is far lower. As of the low PD intensity it is harder to draw conclusions, is this PD weakspot really so dangerous?

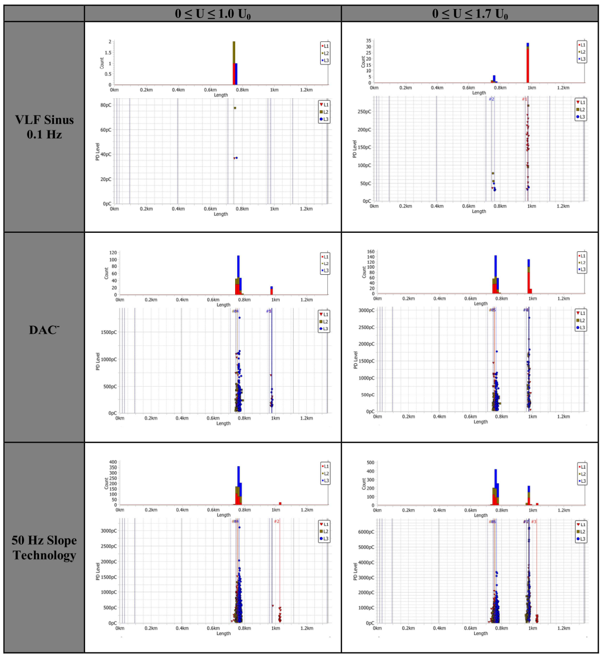

Fig. 5: PD mapping comparing 3 different wave shapes

Case Study 2

Fig. 6 shows the cable diagram of a newly installed 12/20 kV medium voltage XLPE cable (NA2XS(F)2Y) with 7 joints and a total length of 2308 m.

After a successfully passed and standardized VLF 0.1 Hz commissioning test at 3Uo and 60 minutes a dissipation factor and non-destructive partial discharge measurement were performed. The results of the tan δ test can be seen in Fig. 7.

Fig. 6: Cable diagram of a 2308 m long XLPE cable

As it is a newly installed cable it is expected to have low tanDelta values which will not increase with increasing test voltage, however the measurement shows an unexpected increase of the tan δ with the increase of the test voltage. Furthermore the integral interpretation of the results of phase L2 seems to be even more worse than the condition of the other two phases. Evaluating the criteria for the assessment of newly installed cables with XLPE insulation given by the IEEE 400.2 (Table G.1) [7] would result in "Further studies advised" on all three phases caused by the higher average tan δ value at the operation voltage. In general the global condition of the tested newly laid cable should be assessed "Acceptable". The main reason for this, as also concluded by a number of papers, is that the higher average tanDelta and also the increase in tanDelta is most probably caused by additives which still need to diffuse out of the cable as it is a co-polymer XLPE cable. This process could take a number of years and depends on factors like cable load (heat). The main goal for this dielectric loss measurement was to check if local problems can be identified.

	L1	L2	L3
Operation Voltage	12.0 kV	12.0 kV	12.0 kV
Frequency	0.09 Hz	0.09 Hz	0.09 Hz
Capacity	836 nF	844 nF	838 nF
Avg. TD U_0 [E-3]	1.6	1.9	1.5
Delta TD [E-3]	0.6	0.7	0.6
StdDev. TD U_0 [E-3]	0.05	0.00	0.00
Avg. TD (0.5 U_0 .... 2.0 U_0) [E-3]	1.3; 1.6; 1.8; 2.2	1.6; 1.9; 2.2; 2.6	1.2; 1.5; 1.7; 2.1

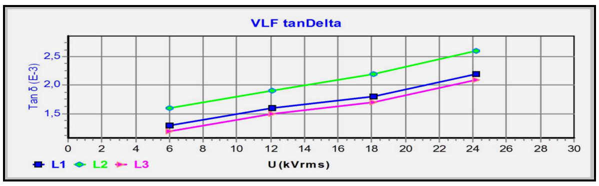

Fig. 7: Measurement results of tan δ test

The subsequently performed partial discharge diagnosis using the damped AC voltage wave shape up to 2.0 U0 like recommended for newly installed power cables did not show any partial discharges at the nominal voltage. However at an inception voltage of 1.5 Uo a continuous increase of PD activity at a location of 1882 m in phase L3 was found(Fig. 8). According to the advanced given cable data (Fig 6) the detected weak spot location did not match directly with the joint position. A further investigation of the cable at the weak spot location, confirmed the matching of the localized PD with the nearest joint.

With a PDIV above the operation voltage the tested cable would be basically in a good condition. Nevertheless newly installed cables should be PD free up to at least 2.0 Uo. Fig. 9 is showing an example of the decoupled PD signal of phase L3 with a clearly visible dispersion and exponential attenuation between first, second and third reflection of the travelling wave.

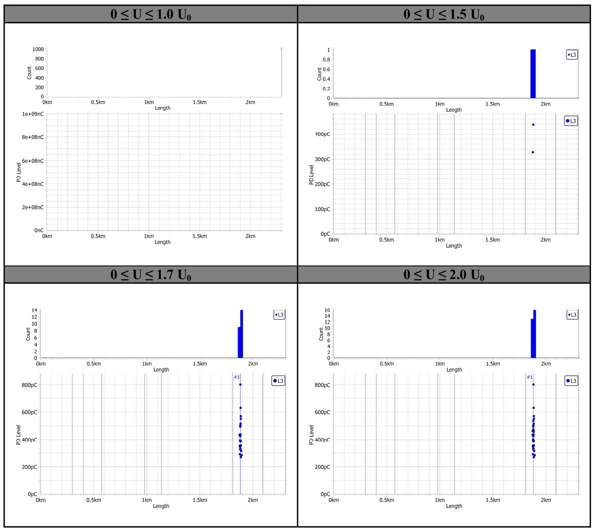

Fig. 8: PD mapping using DAC

According to the measurement results it was recommended to replace the particular joint in phase L3. In addition it can be concluded that a tan δ measurement on a newly laid XLPE cable cannot localize local weak spots within the cable system. The reason for the increased average tan δ causing the further study advised is most probably caused by the additives necessary to cross-link the polyethylene.

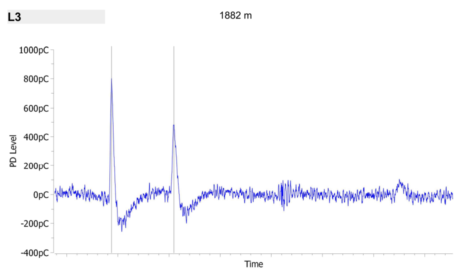

Fig. 9: Travelling wave of decoupled PD signal

Case Study 3

The third case study was done on a 653 m long service aged mixed cable with 7 joints. As shown at Fig. 10 the cable consists mainly out of 3-phase paper-mass impregnated insulation (NEKBA – blue) and only on the first 167 m out of XLPE insulation (NA2XS(F)2Y – green).

Fig. 10: Cable diagram of the 653 m long mixed cable

The dissipation factor measurement showed stabile tan δ values in phase L1 and L2 with a small increase in tanDelta with rising test voltage. As recognizable in both the table and the chart the behavior of phase L3 differs completely with a clear increase of the tan δ with increasing test voltage (Fig. 11), this normally indicates a local problem. Global ageing would normally be the same in all three phases as all phases see the same stresses, especially for 3-phase cables. The last tanDelta stage at 2.0 U0 on Phase L3 was interrupted at the 2nd cycle by a cable breakdown.

	L1	L2	L3
Operation Voltage	12.0 kV	12.0 kV	12.0 kV
Frequency	0.1 Hz	0.1 Hz	0.1 Hz
Capacity	233 nF	231 nF	235 nF
Avg. TD U_0 [E-3]	13.6	10.4	28.6
Delta TD [E-3]	1.5	1.3	7.9
StdDev. TD U_0 [E-3]	0.11	0.09	0.81
Avg. TD (0.5 U_0 .... 2.0 U_0) [E-3]	13.2; 13.6; 14.1; 15.1	10.0; 10.4; 10.8; 11.7	22.6; 28.6; 32.4; 36.5

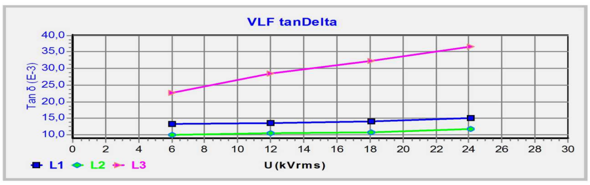

Fig. 11: Measurement results of tan δ test

Fig. 13 presents the PD mappings of the afterwards performed partial discharge measurements on phase L1 and L2 only. Results of the PD measurement with VLF 0.1 Hz Sin wave shape were compared with them of the VLF 0.1 Hz CR/ 50 Hz Slope diagnosis. Both wave shapes could localize PD signals with an inception voltage below the operation voltage. But only the PD measurement with the VLF 0.1 Hz CR test voltage detected and localized PD signals at 480 m. On this position later on, via subsequent cable fault location, the location of the breakdown has been confirmed. The fault was an internal fault and was not caused by any external damage. In Figure 12 a picture of the faulted segment is shown.

Fig. 12: Faulted cable segment, internal fault

The PD detected and localized with VLF Sinusoidial test voltage was located on another position which with the PD measurement at VLF 0.1Hz CR only has been localized at a slightly higher test voltage.

Comparing the PD mappings at higher test voltage levels it can be seen that even at 2Uo it was not possible to detect and locate PD on the position of the breakdown using VLF 0.1 Hz Sin test voltage. In addition PD level and intensity are lower.

On the other hand the PD diagnosis using VLF 0.1 Hz Sin test voltage also located one weak spots were the PD intensity was higher compared to the 50 Hz Slope Technology. But a relevance so far cannot be drawn of those localized weak spots to the cable behavior at operation voltage.

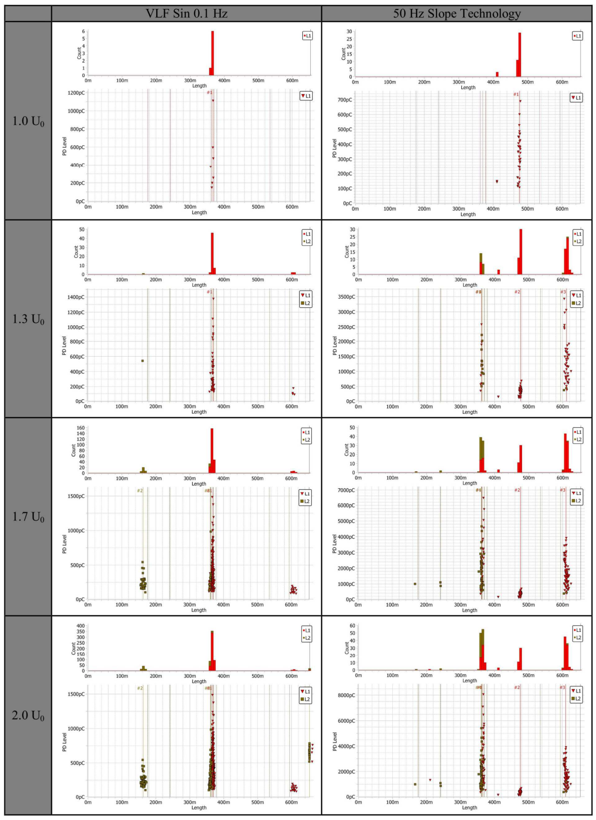

Fig. 13: PD mapping comparing VLF Sin and VLF CR

CONCLUSIONS

The investigation has pointed out, that it is quite important to not only perform VLF 0.1 Hz withstand testing as this cannot identify all in-service relevant weak spots within the cable insulation and the accessories. For commissioning testing it is recommended to either perform a PD diagnosis in addition, or during the normal withstand test. Via this almost all workmanship failures can be identified. Performing a tanDelta measurement as part of the commissioning procedure is not recommended as it will not identify local weak spots. In addition the data obtained can also be influenced by the additives needed for the cross-linking process in the cable insulation.This could lead to increased losses and therefore false decision making. For the PD diagnosis it is important to focus on the correct voltage wave shape. The case studies shown, show differences between PD measurements performed using DAC/ VLF 0.1Hz CR and VLF 0.1Hz sinusoidal.

Especially on service aged cables apart from a PD diagnosis a dissipation factor measurement is recommended. Dissipation factor measurement can give additional information about global ageing and as practical field examples have shown can also identify local weak spots like presented in the 3rd case study.

Regarding the PD behavior using DAC, VLF 0.1 Hz Sin and VLF 0.1 Hz CR voltage wave shapes more medium voltage cable relevant investigations are required. It seems that DAC and VLF 0.1 Hz CR wave shapes are more effective for PD measurements compared to VLF 0.1 Hz Sin measurements. Which is supported by a number of scientific publications.

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