OFFLINE PD DIAGNOSTICS USING SEVERAL EXCITATION VOLTAGES

Hein PUTTER
Megger – Germany
hein.putter@megger.com

Frank PETZOLD
Megger – Germany
frank.petzold@megger.com

Philipp LEGLER
Megger - Germany
philipp.legler@megger.com

ABSTRACT

Diagnostics on both MV and HV cables is nowadays almost applied at every utility. Not only for condition monitoring to determine local defects and ageing status of the cable. But also as part of a commissioning test; to check the quality of workmanship of newly installed cables and accessories. With regards to offline partial discharge diagnostics, especially in the medium voltage range, there is a wide variety of systems available with each having its own type of excitation voltage. For proper decision making it is of importance that the PD characteristics measured with the offline PD system are directly comparable with the PD characteristics at power frequency. If not, it can happen that either incipient faults will not be recognized, or that a recommendation is given to replace a defective component which was not needed as with power frequency the conditions were still ok.

This paper will go into detail to all available excitation voltages for offline PD diagnostics. For this research, using all types of excitation voltages, a number of on-site practical measurements on MV-cables have been performed. Both newly installed cables as well as service aged cables were part of the test program. As the measurements were performed very close in time on the same day, data of each type of excitation voltage can be directly compared with each other, influences like water infiltration or soil temperature can be excluded. The measurements have shown some significant differences between the different types of excitation voltages which will be discussed at the end of this paper.

INTRODUCTION

The importance of high reliability of distribution cables increases in times of higher competition between utilities and due to regulatory requirements. Customer minutes lost have to be monitored and the asset management departments are requesting clear indication about the condition of medium voltage (MV) cables and the accessories. Failures in MV-cables can be divided into two categories; failures inside the cable insulation and failures in accessories (terminations and joints). In most cases insulation failures are either related to integral degradation of the insulation like water treeing in XLPE cables and degradation of cellulose for PILC cables, or caused by external damage such as roots from trees or excavation works. Faults in accessories are local problems such as bad workmanship of a jointer, accelerated ageing because of overloading the cable or a decreased oil-level in case of oil-filled joints/ terminations.

To reduce the amount of failures by internal defects, on-site cable diagnostics can be applied. Failures caused by ageing of the cable insulation can be reduced by applying dielectric losses measurements. Local types of defects can be identified by using partial discharge diagnostics. In XLPE insulated cables these defects are mainly located in accessories. In paper insulated cables also global drying out of the paper layers can be identified.

Off-line PD diagnostics can be performed with different type of excitation voltages. From the asset-manager point of view it is of major importance that the offline PD measurements reflect normal operating conditions. This too have a solid and reliable source of information to base decisions such as repair or replacement activities on. So ideally the offline PD diagnostics should be performed with a 50 or 60 Hz power source, but this is as of financial and also technical reasons not really possible. Therefore Off-line PD diagnostics are mainly performed using either a 0.1Hz VLF Sinusoidal (VLF SIN 0.1Hz), 0.1Hz VLF Cosine-Rectangular (VLF CR 0.1Hz) or Damped AC (DAC) excitation voltages.

EXCITATION VOLTAGES FOR PD MEASUREMENTS ON MV CABLES

For offline PD measurements on MV cables 3 types of excitation voltages are established, VLF Sinus 0.1Hz, DAC and VLF CR 0.1Hz.

VLF Sinus 0.1Hz:

In the beginning of the nineties VLF sinusoidal 0.1Hz test systems were introduced. Main driver as DC testing created space charges [1] and in addition as of the other disadvantages DC testing has [2]:

- It is “blind” to certain types of defects, such as clean voids and cuts.
- It may not replicate the stress distribution existing with power frequency ac voltage. The stress distribution is sensitive to temperature and temperature distribution.

The advantage of using a pure sinusoidal excitation voltage is that these systems can also be combined with diagnostics like e.g. a PD-diagnosis or a tanDelta measurement. However as the testing frequency differ 500 or 600 times with the operating frequency, the PD characteristics are not the same anymore as concluded by Voigt [3]. A direct correlation of important PD parameter obtained at 50/ 60Hz power frequency has therefore not been given anymore. Moreover a recent research has concluded that the PD seems to “die” out at lower frequencies [4].

Damped AC (DAC):

To generate damped AC voltages with duration of a few tens of cycles of AC voltage at frequencies between 50Hz and 500Hz, a system has been developed that is based on a resonance circuit between the cable capacitance and the inductor of the test system itself. This DAC method to energize, measure and locate on-site partial discharges in power cables is in accordance with IEC 60270 and IEEE 400.4 recommendations and is world-wide in practical use for over ten years. Figure 1 shows a DAC voltage measurement with PD. The main advantage of the DAC excitation voltage is, that the frequency is close to power frequency and therefore PD characteristics are the same. In addition as of the decaying voltage the PDEV can easily be determined.

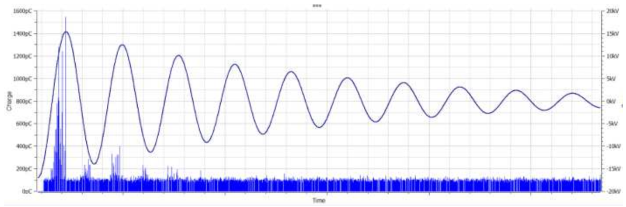

Figure 1: Typical DAC excitation voltage.

VLF CR 0.1Hz:

In several publications the operating principle of VLF cosine rectangular (VLF CR) testing systems are described [5, 6]. Its use for PD measurements is not new; several researches have already been performed. Since 2014 its use on MV cables is widely performed. The PD measurement takes place during the polarity reversal from either positive to negative period, or negative to positive period, see Figure 2. The polarity reversal itself is caused by a resonance circuit between the cable capacitance and the test systems inductance. The frequency of the polarity reversal is between 20 and 400Hz and depends on the cable capacitance and therefore cable length. The longer the cable, the lower the frequency of the polarity reversal will be. Research has shown that the PD magnitude and intensity is often higher compared to that measured with 50Hz power frequency [7]. This can be seen as an advantage as this will simplify the PD localisation process.

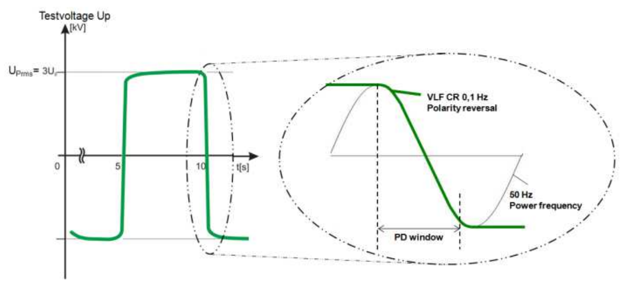

Figure 2: VLF CR 0.1Hz excitation voltage with PD measurement window at polarity reversal.

CASE STUDIES

The following case studies are PD measurements performed with three different excitation voltages (VLF Sinus 0.1Hz/ VLF CR 0.1Hz/ DAC) on service-aged cables. As the measurements are performed on the same day the PD characteristics of the individual excitation voltages can be compared with each other. Influences such as water infiltration, temperature difference or further ageing can therefore be excluded. All PD diagnostic measurements have been performed with a combined test set either integrated in a test van or as a stand-alone system. As of this, influences such as different set-up or different PD coupler used, can also be excluded.

Case Study 1:

The first practical case study is a measurement performed on a 12/20 kV service-aged mixed cable. The cable is mainly composed of XLPE insulation, only a smaller portion is mass-impregnated insulation. The cable has 11 joints and a length of 1335 m (Figure 3).

Figure 3: Schematic display of the 1335m long cable, green XLPE cable, blue is PILC cable

The three measurements have been performed with a fully integrated system inside a test van as can been seen in Figure 4. On the measurement side the cable ended in a SF-6 insulated compact switchgear, a test adapter has been used to get a PD free connection to the test object.

Figure 4: Connection of PD diagnostic system to the test object

The PD diagnostic measurement results performed with the three different excitation voltages (i.e. VLF Sinus 0.1 Hz, VLF CR 0.1 Hz and DAC) are shown in Figure 5. On the left hand side the PD mappings at Uo are shown, on the right hand side the PD mappings at maximum test voltage 1.7Uo are shown.

It can be clearly seen that the measurement results of both VLF CR 0.1Hz and DAC show comparable results. This was expected as the frequency of the polarity reversal of the VLF CR excitation voltage and the frequency of the DAC wave shape are exactly the same (280Hz).

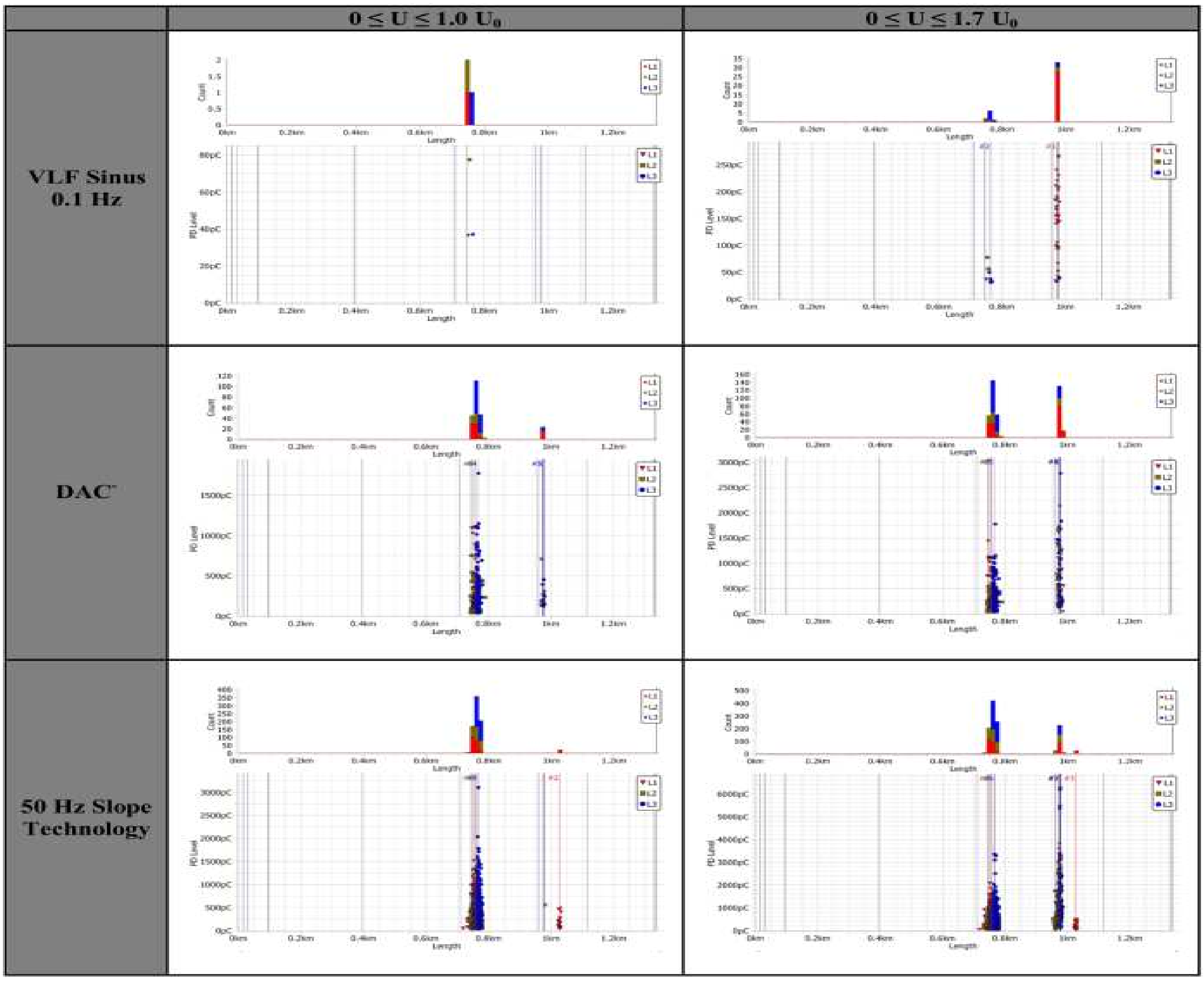

Figure 5: PD mapping comparing 3 different wave shapes at U0 and 1.7Uo. Top VLF Sinus 0.1Hz, middle DAC and bottom VLF CR 0.1Hz/ 50Hz slope technology (x-axes cable length, y-axes PD level).

In addition for both PD Level and PD intensity only small differences have been observed at Uo and 1.7Uo.
Looking to the Partial Discharge Inception Voltage (PDIV) of all excitation voltages, this was exactly the same for all wave shapes. However some major differences could be observed between the VLF Sinus 0.1Hz excitation voltage and DAC/ VLF CR 0.1Hz excitation voltage. At operating voltage only 1 PD weak spot have been identified with VLF Sinus 0.1Hz whereas 2 weak spots with the other excitation voltages. In addition the PD intensity is far lower at VLF Sinus compared to the other wave shapes. This taken into account that the time of data capturing has been equal. Only at elevated voltages VLF Sinus 0.1 Hz was able to detect the second weak spot inside the cable. PD intensity of the first weak spot hardly increased with increasing test voltage for VLF Sinus 0.1Hz. With the VLF CR 0.1Hz and DAC voltage it did change more. PD level of VLF Sinus 0.1Hz has also been lower compared to DAC and VLF CR 0.1Hz.

Case Study 2:

The second practical case study is a measurement performed on pure 12/20 kV service-aged XLPE cable. As of failing information the number and position of joints was unknown. The cable has a length of 1202m and is composed out of three single cores, see Figure 6.

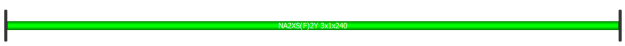

Figure 6: Schematic display of the 1202m long XLPE cable.

Figure 7 shows the individual PD mappings of the PD diagnostic measurements performed with VLF Sinus 0.1Hz, DAC and VLF CR 0.1Hz. On the left hand side the PD mappings at Uo are shown, on the right hand side the PD mappings at maximum test voltage 1.7Uo are shown. The frequency of the DAC excitation voltage and the frequency of the polarity reversal from the VLF CR 0.1Hz excitation voltage was 294Hz.

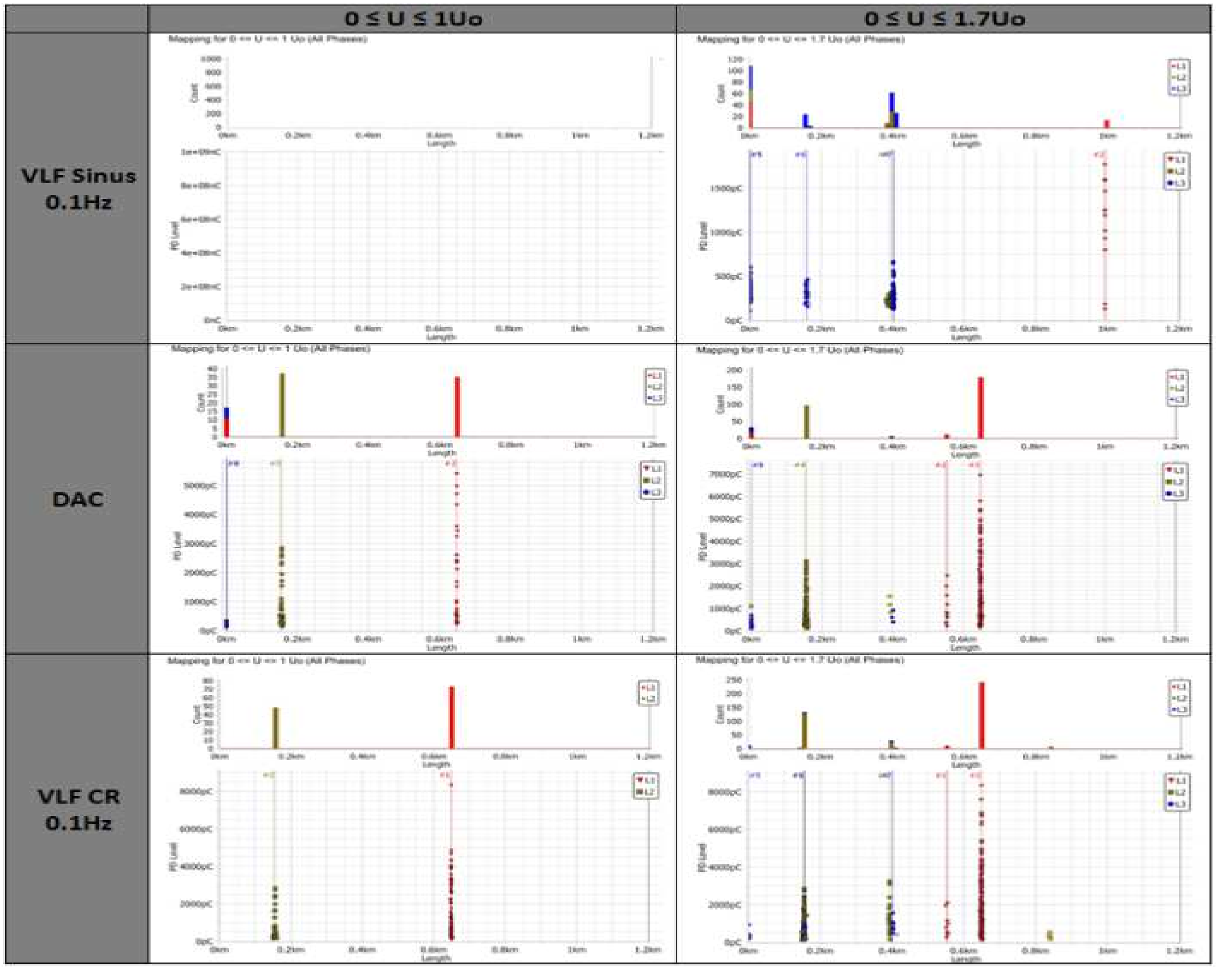

Figure 7: PD mapping comparing 3 different wave shapes at U0 and 1.7Uo. Top VLF Sinus 0.1Hz, middle DAC and bottom VLF CR 0.1Hz/ 50Hz slope technology (x-axes cable length, y-axes PD level).

Comparing the PD mapping at Uo measured with VLF Sinus 0.1Hz with that from DAC or VLF CR 0.1Hz major differences can be recognized. With VLF Sinus 0.1Hz excitation voltage there was no PD measurable whereas with either DAC or VLF CR 0.1Hz two weak spots were identified. One weak spot in Phase L2 at position 155m and one in Phase L1 at 649m. The partial discharge inception voltages measured with DAC and VLF CR 0.1Hz of both weak spots are identical and far below operating voltage. See Table 1 for the comparison of all excitation voltages. With VLF Sinus 0.1Hz excitation voltage even up to maximum test voltage 1.7Uo no PD has been detected in both of these two localized weak spots which had a PDIV below Uo.

Looking to the PD mappings at maximum test voltage 1.7Uo further differences can be recognized. DAC and VLF CR 0.1Hz PD mapping are still both comparable with only some minor differences in PD level and intensity. The higher PD level and intensity are with VLF CR 0.1Hz excitation voltage and is most probably caused by the 5 second DC stage at each period. In total 7 PD weak spots have been detected within the cable insulation/ joints using VLF CR 0.1Hz and just 4 PD weak spots using VLF Sinus 0.1Hz. Three out of the four localized PD weak spots identified with VLF Sinus 0.1Hz are matching with the DAC and VLF CR 0.1Hz voltage. One PD weak spot positioned in Phase L1 at 993m, which incepted at 1.3Uo, has only been recognized using VLF Sinus 0.1Hz. On the other hand four PD weak spots identified with DAC and VLF CR 0.1Hz have not been identified with VLF Sinus 0.1Hz.

TABLE 1: PD INCEPTION VOLTAGE AND FAULT POSITION OF INDIVIDUAL EXCITATION VOLTAGES.

	L1	L2	L3
VLF Sinus 0.1Hz	**1.3Uo** (993m)	**1.3Uo** (394m)	**1.2Uo** (394m)
DAC	**0.7Uo** (649m)	**0.6Uo** (155m)	**1.1Uo** (0m)
VLF CR 0.1Hz	**0.7Uo** (649m)	**0.6Uo** (155m)	**1.1Uo** (0m)

SUMMARY

Summarizing both case studies it can be recognized, like other studies, that both DAC and VLF CR 0.1Hz show comparable results, either related to PDIV or fault positions of the identified weak spots. VLF CR 0.1Hz PD measurements results differ from the DAC results only in PD intensity and level, which is most probably caused by the 5 second DC stage in each half-period. A higher PD level with VLF CR 0.1Hz compared with 50Hz power frequency has also been recognized in a study from Elben [7].

Considering the results gathered with VLF Sinus 0.1Hz compared to excitation with DAC and VLF CR 0.1Hz than it can be concluded that there can be major differences. In most cases the PDIV at VLF Sinus 0.1Hz was higher, which is similar reported by other studies [8]. In case study two although the PDIV of one localised defect was far lower than DAC and VLF CR 0.1Hz, also this has been seen in other research studies. This was mainly observed on cold shrink accessories and may be related to the physical function of refractive stress grading [9]. In the last case study far more defects have been recognized by DAC and VLF CR 0.1Hz compared to VLF Sinus 0.1Hz excitation voltage. Overall it can be concluded that PD measurements performed with VLF Sinus 0.1Hz excitation voltage show lower PD levels.

CONCLUSIONS

PD measurements as part of a commissioning test or as part of condition monitoring are proven to be useful in identifying bad quality of workmanship or ageing type of related defects. For offline PD measurements on MV cables 3 types of excitation voltages are established, VLF Sinus 0.1Hz, DAC and VLF CR 0.1Hz. Several research studies have shown that PD measurements performed with DAC and VLF CR 0.1Hz voltages show comparable results, like seen in these both case studies as well. The PD results obtained with VLF Sinus 0.1Hz however differ with that from DAC and VLF CR 0.1Hz excitation voltage. It can be concluded that in most cases the PDIV is higher at VLF Sinus 0.1Hz compared with the PDIV from DAC or VLF CR. Moreover the PD intensity and level are lower at VLF Sinus 0.1Hz, using exactly the same data capturing time for VLF Sinus 0.1Hz and VLF CR 0.1Hz. Although there has already been a lot of research performed in this field, further research specifically regarding different type of PD defects is recommended. This to confirm which defects incept with VLF Sinus 0.1Hz excitation voltage at lower voltages and which at higher voltages compared to operating frequency. It is known that interfacial discharges incept at a higher voltage at VLF Sinus 0.1Hz compared to 50Hz or DAC/ VLF CR 0.1Hz, this as interfacial discharges are mainly depending on the voltage slope dU/dt.

REFERENCES

[1] F.H. Kreuger, "*Industrial High DC Voltage*", Delft University Press, 1995

[2] IEEE 400-2001 "*IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems*" IEEE guide

[3] G. Voigt, "*VLF-TE Messungen an betriebsgealterten Mittelspannungskabel*", Abschlussbericht FH Konstanz, Germany 2002.

[4] N. Jäverberg, H. Edin, "*Applied Voltage Frequency Dependence of Partial Discharges in Electrical Trees*" Proc. IR-EE-ETK, Stockholm, Sweden, 2009.

[5] D. Götz, F. Petzold, H.T. Putter, "*Zustandsbestimmung und Qualitätskontrolle von Montage an Mittelspannungskabeln unter dem Aspekt zunehmend großer Kabellängen*", VDE ETG Fachtagung, Fulda, Germany, 2012

[6] F. Petzold, H.T. Putter and D. Götz, "*Combination of VLF and Resonance Principle for Withstand Testing of long Cable Length*", unpublished, presented at IEEE / PES ICC Meeting Sub F, Pittsburgh, USA, May 2013.2.

[7] A. Elben, W. Kalkner, R. Plath, „*Alternative Prüftechniken für lange AC-Hochspannungskabel Abschlussbericht*", TU Berlin, Germany, 2015

[8] H.L. Halvorson, "*Condition Assessment of windfarm MV cable joints* " NTNU Trondheim, Norway, 2012

[9] F. Mauseth, "*PD and Diel. Response measurements service aged cable joints*" CIGRE D1.48 Meeting, Paris, France, 2014