THE INTRIGUING BEHAVIOUR OVER TIME OF PD'S FROM DEFECTS IN MV CABLES AND ACCESSORIES; LESSONS LEARNED WITH SCG, AN ON-LINE MONITORING SYSTEM

Fred STEENNIS
KEMA – the Netherlands
fred.steennis@kema.com

Denny HARMSEN
Alliander – the Netherlands
denny.harmsen@alliander.com

Theo VAN RIJN
Alliander – the Netherlands
theo.van.rijn@alliander.com

Jan MOSTERD
Alliander – the Netherlands
jan.mosterd@alliander.com

Leon BOKMA
Westland Infra – the Netherlands
leon.bokma@westlandinfra.nl

Piet SOEPBOER
Enexis – the Netherlands
piet.soepboer@enexis.nl

Alfred ARTS
Enexis – the Netherlands
alfred.arts@enexis.nl

Nico VAN DONK
Stedin - the Netherlands
nico.vandonk@stedin.net

Branko CARLI
Stedin - the Netherlands
branko.carli@joulz.nl

Vincent BRONGERS
Stedin - the Netherlands
vincent.brongers@stedin.net

Osrick ANITA
Stedin - the Netherlands
osrick.anita@stedin.net

ABSTRACT

SCG is an on-line partial discharge (PD) based monitoring system for mv power cable systems up to 8 km. Formally SCG was called PD-OL. With SCG, PD sources are being monitored (days, weeks, months, years) and located. The results are being made visible via internet with an hourly update. This paper shows the results of the use of SCG by monitoring about 150 circuit km of mv power cable with more than SCG's since 2007.

It will be shown that the proven effectiveness in preventing failures is 84%. It is also shown that in cases PD's are seen indeed, there is enough time to perform a repair action.

INTRODUCTION

Many grid owners indicated the need for an on-line PD measuring system, i.e. while the cable circuit remains in-service. This need has been expressed already for years, both for hv and mv cables.

At the Cired in 2009, a measuring system that was and is able to monitor PD's and locate these while the cable is in service was presented [1]. The system is called SCG, which stands for Smart Cable Guard (formally called PD-OL) and can be applied for MV cables only for reasons explained in [1]. But since failures in MV cables in many if not most countries contribute to a large part of the outage time as experienced by electricity users, such a measuring system is a valuable tool to increase the performance of the over-all electricity network.

The way SCG is measuring is shortly explained in the Section "SCG MEASURING PRINCIPLES" of this paper.

The main part of this paper discusses the experiences obtained so far with SMG and these will be summarized in the Section "FIELD RESULTS" of this paper.

The last Section of this paper summarizes the knowledge rules that can be derived from these experiences, showing that there is a wide range of possible behaviours of PD's until the actual failure (if this failure is not avoided by a repair of the discharging component of course). This Section is called "KNOWLEDGE RULES".

This paper is the result of a combined task force of KEMA and most of the network owners in the Netherlands. These network owners all together represent about 90 % of the total Dutch MV cable network length of 100.000 km.

SCG SYSTEM PRINCIPLES

<u>Measuring setup</u>

One SCG system consists of two separate measurement units, each of these to be installed at one of the cable circuit ends in either substation or RMU(s) (Ring Main Units). See for an illustration Figure 1.

Each measurement unit consists of a Sensor/Injector Unit (SIU) and a Controller Unit (CU).

The measured PD data and control data is communicated via internet with a server.

The Sensor Injection Unit SIU

The SIU, as the name suggests, contains both a sensor, to measure pulses from the cable, and an injection device, to inject pulses into the cable. The SIU is placed around the cable or earth lead (not both) and is of the inductive type. The SIU is separable and thus can even be mounted without disconnecting the cable termination. Depending on the safety rules, it can in this way even be mounted while the cable is in service.

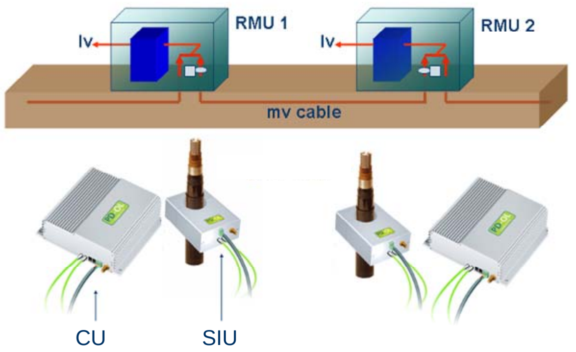

Figure 1 Measuring setup of SCG. At each cable end there is a control unit (CU) for signal processing and a sensor/injector unit (SIU). Each CU communicates with a central server via internet.

The SIU also injects pulses into the cable system for both synchronization and calibration, its injection method being patented [2].

Synchronization is needed for accurate time-base alignment of both measurement units in order to eliminate any pulses originating from outside the monitored cable circuit (i.e. to eliminate noise and disturbances), and to locate the weak spots in the complete cable circuit by means of the detected PDs. The synchronisation is done by injecting a pulse on one site of the cable circuit which will travel in exactly the cable propagation time to the other cable end where it is measured and recognized. Both internal clocks of the SIU's will start their measuring sequence of one power cycle (normally 20 ms) immediately after receiving the synchronisation pulse. When both records are later combined (a task of the Control Unit, which sends the data to a central server via internet), the arrival times of PD pulses at both SIU's can easily be corrected for this cable propagation time and thus the PD locations can be calculated.

The SIU offers the possibility of calibration because the injected pulse of the SIU is measured by the sensor part of the SIU and its transfer impedance is depending on the local impedances, i.e. those of the ring main unit including the power cable(s) at hand. Thanks to the calibration it is possible to calculate the actual PD charge from the measured PD pulse shape. Calibration also offers the possibility to calculate and implement digital noise suppression if needed. This digital noise suppression is a task of the CU.

The Control Unit CU

The controller unit (the CU) is connected to the SIU by means of an optical fibre. This eliminates possible EMC interference, which can easily occur in the environments in which the units are applied. The controller unit, which is in fact a small dedicated computer, controls the measurement sequence, the data collection, the signal processing and the data communication towards the Control Centre.

Signal processing is crucial, since practical (and especially on-line) PD measurements are inherently impeded by noise and interference to a large degree. Disturbance by radio stations can be suppressed using adaptive notch filters or cancellers, which hardly affect PD signals. However, broadband noise poses a fundamental limit on PD detection. Matched filtering is the technique for detection of pulses in the presence of noise that is optimal in the sense that the average signal to noise ratio (SNR) at the filter output is (by definition) maximized.

The CU also has communication facilities on board (LAN or mobile cellular phone card) in order to upload the resulting data via the internet to the Control Centre at KEMA for further interpretation.

Centralized Control and Surveillance

The measured PD data will be uploaded via internet to a server for centralized surveillance. After the data is uploaded and combined, various statistical parameters are calculated in order to be able to see the behaviour of groups of PDs from e.g. one specific period of time or from a specific location along the cable. After this, the results are interpreted by means of knowledge rules and experts in this area. The data is also evaluated on trends.

From the server also control data can be send via internet, to adjust for instance the measuring repetition rate or to update the software in the CU's and SIU's.

Most SCG's measure for many weeks to years and capture PD data each minute during one cycle of the power frequency, i.e. 20 ms PD data per minute. In other words, the effective measuring time is 0.03 %. This might seem low, but realize that this is in continuous operation and it can be compared with making a movie of the cable circuit PD performance over month of years, including the effect of load and voltage variations (where and off-line PD test can be seen as a photo). As will be shown below, this measuring efficiency is quite adequate.

FIELD RESULTS

In total so far (2007 to the end of 2010) in total 31 defects were found in the 150 km of cable circuit monitored with SCG. Not all defects showed PD activity before the repair or breakdown (5 cases). In 26 cases there was clear PD activity and network owners were able to replace the defective spot prior to the breakdown. That happened in most cases indeed, but not always, depending on the importance of the circuit. Nevertheless, based on these results one can conclude that the effectiveness of SCG in finding defects on time is 84 %.

Apart from the avoided failures based on direct findings with SCG, there were also various cases mentioned by network owners where they decided to replace more components than just identified with SCG, for instance in other circuits, based on assumed similarity of degradation here. That is an additional advantage which is not taken into account in the effectiveness of 84 % mentioned above.

In this paper, 4 typical PD cases will be treated in more detail. They are chosen because they are informative in nature and show the wide range of typical PD patterns that can be found. Several other examples have been published in earlier papers on SCG, like [3] giving access to other informative references as well. The four typical PD cases treated in this paper are summarized below.

PD's developing to breakdown in days

There are certain typical defects that give PD's over a period of days until a breakdown (if no repair actions are done). There are two examples (defects A and B) given below which are typical.

Defect A – water in a PILC cable. It starts with water entering a PILC cable (after for instance lead sheath corrosion, lead sheath cracking by roots of a tree or water ingress via a joint). The water will stay outside the insulation for a long time because of the oil impregnated paper windings. Thus, no PD activity will be visible for a certain (expected long) time. But slowly the water will degrade the insulation material and there will be a moment that suddenly PD's appear and probably at the same time an electrical will be created that grows in a couple of days to the other side of the insulation. Arrived there, the electrical tree stops growing and (measurable) PD's are not detectable anymore. This degradation is followed by thermal degradation of the electrical tree until a full (thermal) breakdown occurs. The thermal degradation without PD activity is called the period of radio silence and in the cables monitored with SCG the duration of the radio silence was about one week. It was observed so far with SCG in two different 10 kV PILC cables.

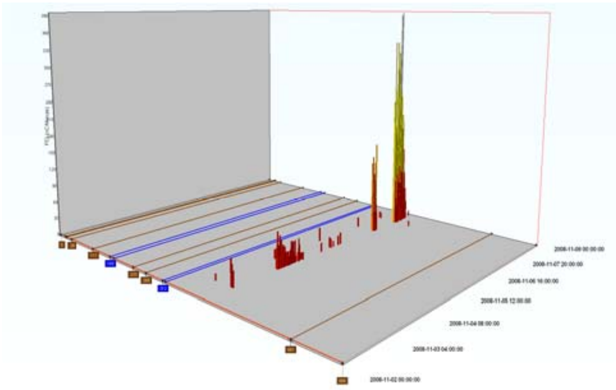

Figure 2 Defect A – PD activity over 1 week in a PILC cable of 666 m, followed by one week radio silence and then followed by a breakdown at 396 m. Only the PD period of one week is shown

Defect B – over heated conductor connector. Here, a cold shrink joint in an XLPE cable had a conductor connector that was not suitable for the cable conductor. Due to that, the conductor extension forces (especially in heavily loaded cables) created a conductor movement inside the connector and due to that there will be a transition resistance rapidly increasing. On its turn the connector will be heated up and the surrounding joint will start to degrade thermally. During this degradation process PD's are clearly visible over a period of several days in the 25 kV systems monitored with SCG, even in cable circuits up to 8 km with several ring main units in this circuit. It was observed so far with SCG in many different MV XLPE cables.

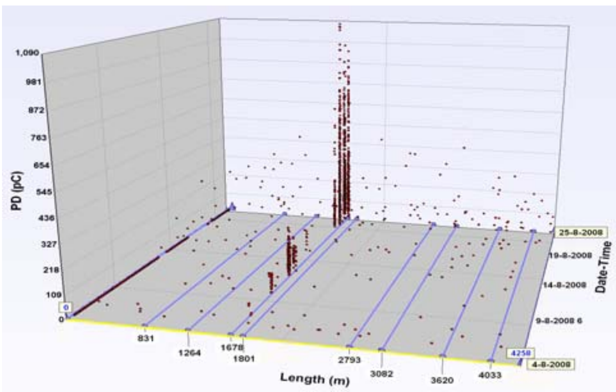

Figure 3 Defect B – PD activity over 3 weeks in a joint at 1678 m in an XLPE cable of 4258 m, followed by a breakdown in that joint.

PD's developing to breakdown in months or years

There are also certain typical defects that give PD's over a period of months or years until a breakdown (if no repair actions are done). There are two examples (defects C and

D) given below which are typical.

Defect C – failing joint in a PILC cable. There were intense PD concentration since over a period of three months. The joint type is not known, but it is a typical joint for a PILC cable, probably a bitumized or oil-filled joint. The self healing properties of such a joint (with oily insulation material) caused the joint to survive the PD's for months until the breakdown happened. Similar examples are available where joints were replaced after many months of intense PD's activity (which disappeared indeed on replacing the joint) but where a joint inspection didn't show much or any electrical degradation, although in all cases clear defects were found like water ingress, showing the validity of the repair action.

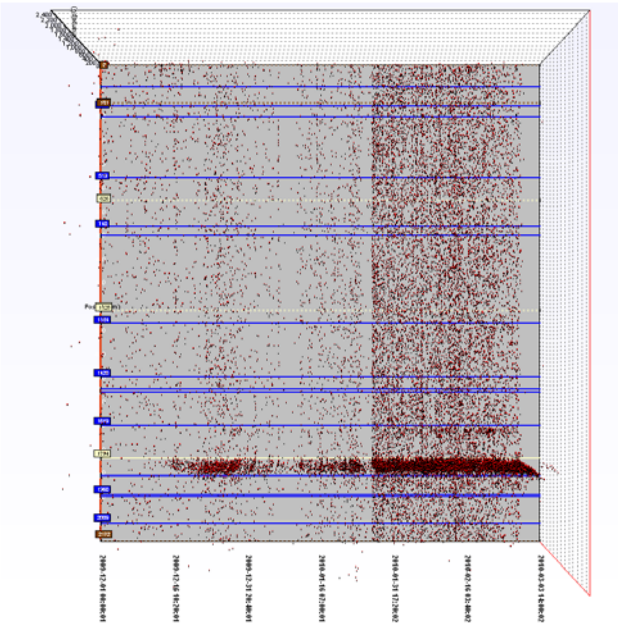

Figure 4 Defect C – PD activity over 3 months in a joint of a PILC cable of 2172 m followed by a breakdown at 1794 m (x-axis is time; y axis is the cable).

Defect D – Earth screen interruption in an XLPE. This caused intense PD concentrations over many weeks probably longer, not measured since the start). In this case, there was not a breakdown because the weak spots (three in total) were replaced before this could happen. However, it is interesting that the PD's were there for many weeks and that there was no failure until repair, which is quite uncommon for PD's from an XLPE cable. The reason is the PD's came from sparking over spots with a melted earth screen. It is assumed that this has happened because of some uncontrolled short circuit currents. The sparking PD's could be considered as surface discharges that hardly attacked the underlying insulation material, but nevertheless were large enough to give inside the insulation a PD type signal.

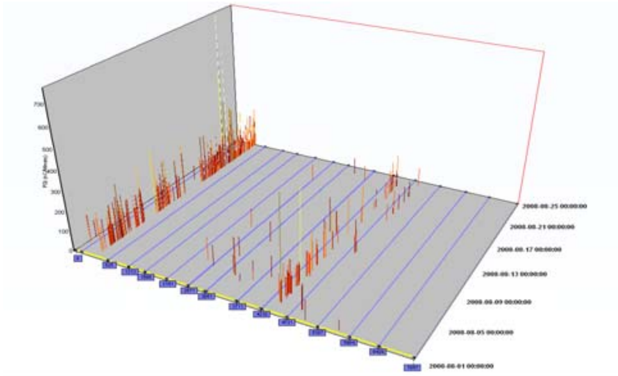

Figure 5 Defect D – PD activity over almost 4 weeks in an XLPE cable of 7057 m, followed by a repair action at three main PD spots.

KNOWLEDGE RULES / CONCLUSIONS

Depending on the type of defect and cable (component), PD's can stay for a longer or shorter period of time. So far, the following general rules could be identified:

- a in some cases (so far 16 %) no PD activity was found before the breakdown.
- b in XLPE cold shrink (probable also heat shrink) joints, a bad conductor connector will normally give PD's over a couple of days before breakdown;
- c in XLPE cable surface PD's along the cable will normally give PD's over a couple of weeks or more before breakdown;
- d in PILC cables water ingress will normally give PD's over a couple of days and a couple of days of radio silence before breakdown;
- e in PILC cable joints of traditional type (bitumized or oil-filled) will normally give PD's over many months or more before breakdown (if any);

In all cases b, c, d and e there was enough time to perform a repair action.

REFERENCES

[1] Peter van der Wielen and Fred Steennis, 2009, "First Field Experience of On-line Partial Discharge Monitoring of MV Cable Systems with location", *The 20th Int. Conf. on Electricity Distribution (CIRED), Session 1, Paper No. 0070*, Prague, Czech Republic.

[2] E. F. Steennis, P. A. A. F. Wouters, P. C. J. M. van der Wielen, and J. Veen, 2002, "Method and system for transmitting an information signal over a power cable", *Int. Patent No. WO 2004/013642.*

[3] P. Wagenaars, P.A.A.F. Wouters, P.C.J.M. van der Wielen, and E.F. Steennis, 2010, "Influence of ring-main-units and substations on online partial discharge detection and location in medium-voltage cable networks", *IEEE Transactions on Power Delivery, 2010.*