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UHF-PD-MONITORING AND ON-SITE-COMMISSIONING-TEST OF 400 KV XLPE-INSULATED CABLE CIRCUITS AT JEBEL ALI / DUBAI

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1. ABSTRACT

This paper describes experiences with Partial Discharge measurements of after installation tests of six 400 kV XLPE insulated single core underground cable systems in Jebel Ali/Dubai tested with AC series resonant voltages.
Considering the importance of the power station permanent PD monitoring will be performed at 36 GIS cable terminations after commissioning.
A new system applying UHF sensors and acquisition was developed, suitable for any kinds of HV XLPE cable terminations like transformer sealing ends, cable terminations for metal-clad substations and outdoor sealing ends based on past experiences during investigations on site.
The measuring equipment for UHF-PD monitoring on HV power cable systems is especially designed for on-line high sensitive continuous partial discharge monitoring in three-phase high voltage power equipment.
Transient signals generated by possible PD inside the terminations of the HV power cable will be detected and processed to get information about the insulation status.
The results of the PD monitoring are further evaluated with different software tools. For continuous monitoring the PD parameters are transmitted and displayed permanently.
The acquired raw PD data are not only used to generate an alarm signal in case of increased PD activity but more functions are realized for the evaluation of the fault severity such as PRPDA, H(v, phase), v(t), n(t), I(t), H(phase), v_{peak}(phase), v_{mean}(phase) and H(v).

KEYWORDS

High Voltage Cables Circuits – UHF/PD Monitoring – Commissioning Test – On Site Test

2. INTRODUCTION

Most defects observed in today's extra high voltage (EHV) cable systems cause partial discharges (PD) in the accessories under AC stress. Combining AC testing and sensitive PD measurements results in best test efficiency.
In addition, fact is that all the power cables with polymer isolation are tested in the factory according to IEC 60840 and IEC 62067 with the best methods and with calibrated PD-measuring systems in screened test rooms with high sensitivity.
After transport and laying the oversheath test and corrosion protection test are performed on power cables using high DC voltage between metal sheath or screen and ground. If the sheath is undamaged it can also be confirmed that the polymer isolation is intact and no mechanical damages occured during transport and laying. The isolation of cable is still in the good PD-free condition as tested with the routine test at the manufacturer site.
However, for the assembly of the terminations and joints on the cable ends one works again directly on the isolation. Here errors can occur. Therefore a partial discharge test is very important with a focus on the terminations and joints after jointing.
This requirement has lead to a development of new measurement systems for PD-On-Site-Tests on HV- and EHV-XLPE cable systems. In dependence on the special conditions in the network we work with the UHF-PD measurement method.
This paper reports on present Brugg Cables` and LDIC`s successful efforts to measure PD in the accessories after jointing in the EHV-XLPE cable systems and describes the UHF-PD measurement method.

3. PROJECT DESCRIPTION

Brugg Kabel AG, Switzerland, has been awarded and has successfully commissioned a 400 kV cable project in Dubai. The project consists of (Fig. 1):

- Six 400 kV XLPE cable systems for connections between the HV-side of the Unit Step-up Transformers and the 400 kV Substation bays with different cable lengths (120…320 m),
- 36 pcs GIS-sealing ends with pre-fabricated and pre-tested stress-cones manufactured from silicone,
- 18 pcs UHF-PD sensors with ground-connexion and TNC connector,
- 18 pcs UHF-PD sensors without ground-connexion and TNC connector,
- one complete On-line UHF-PD Monitoring System supplied by Lemke Diagnostics GmbH (LDIC) from Germany.

All HV cables and accessories have had successfully passed a Type Test, a Pre-qualification Test and the Routine Tests in the factory according to IEC 62067.

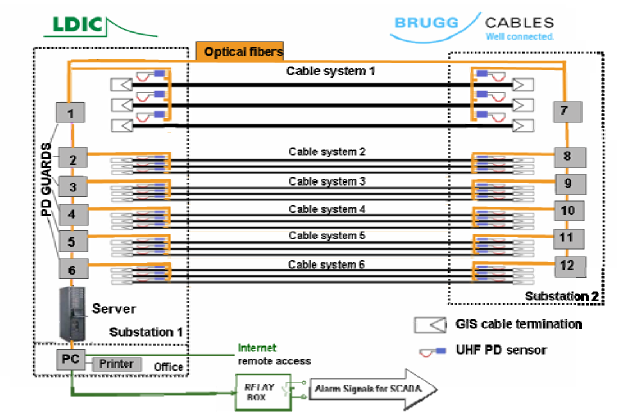

Fig. 1: 400 kV XLPE-cable systems and UHF-PD monitoring set-up

But not all interfaces between accessories and XLPE-cables can be checked before the installation of the final cable system. Hence the electrical quality check on the complete installed cable system has been performed with a mobile power-frequency resonance testing station under the following test procedure (Fig. 2):

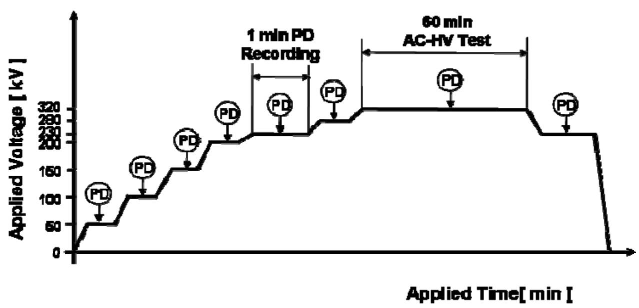

Fig. 2: Test condition for on-site AC test combined with a selective on-site PD test

Increase the voltage in steps of 50 kV and observe the PD pattern at each voltage level. At U = 260 kV take a PD-measurement recording during 1 minute and afterwards increase the voltage in further steps of 50 kV until 320 kV. At each step note the measured PD value. Once reaching 320 kV leave this voltage applied for 1 hour and observe if there is a change in the recorded PD pattern and value, just before the 1 hour test period elapse take another recording of the PD measurement for 1 minute. While ramping the test voltage down, take another PD measurement for 1 minute at U_o = 230 kV.

4. UHF-PD MONITORING SYSTEM

The equipment for UHF-PD monitoring on HV power apparatus is especially designed for on-line high sensitive continuous partial discharge (PD) monitoring in three-phase high voltage power cable system. The transient signals in the insulation system of the HV power apparatus caused by partial discharges are measured in order to get an information about the insulation status of the equipment.

It is possible to do continuous PD monitoring with an extreme high measuring dynamic as well as phase resolved PD measurements. Also a PD signal representation, storage and evaluation of the PD pulses in combination with the corresponding test voltage information can be performed.

The UHF PD sensors are connected to the three phases and an internal multiplexing unit in the PD monitoring device *PD Guard* allows the selection of the different measuring channels. The system is able to evaluate the signal trend of the partial discharges in a very high range. The measuring sensitivity is automatically controlled using the preamplifiers and the amplifiers. The communication system transmits the monitored data and alarm messages to a main control server via Ethernet TCP/IP network communications. The resolution of the A/D-converter is 12 bit unipolar. The measured phase synchronized partial discharge signals are stored on the server.

The control and monitoring program shows a scope mode, trend mode, monitoring mode and setup mode. It allows easy operation by plant personnel on a daily basis (monitoring mode) and sophisticated evaluation by specialists in case of alarm (trend mode, scope mode and setup mode).

In scope mode, partial discharge pulses can be monitored versus phase for each phase (channel) and will be displayed in three different diagrams: PD Pulses, PD Pattern and PD Points. The operator can setup the monitor to control the measuring sensitivity.

Monitoring mode displays characteristic values like NQS (equivalent PD current), avg, peak value and repetition rate vs. PD magnitide simultaneously.

The trending display shows the PD magnitude im mV (peak-weighted acc. IEC60270, average) versus time and the calculated NQS as well as the test voltage versus time.

The alarm criteria are adjusted by means of creating a template incorporating not only PD-magnitude but also the corresponding repetition rate. In that way the occurrence of false alerts due to possible accidentally strong noise from the environment or switching operations may be minimized.

The results of the PD monitoring are further evaluated with different software tools which can easily be upgraded. For continuous monitoring the PD parameter (PD magnitude as peak value or as average value) is displayed and transmitted in real-time-mode.

For instant evaluation of the acquired PD raw data the following functions are available: v(phase), H(v, phase), v(t), n(t), NQS(t), H(phase), v_{peak}(phase), v_{mean}(phase) and H(v). The windows-based control and analyzing software and the standard windows based TCP/IP network allows an easy operation of the PD monitoring system.

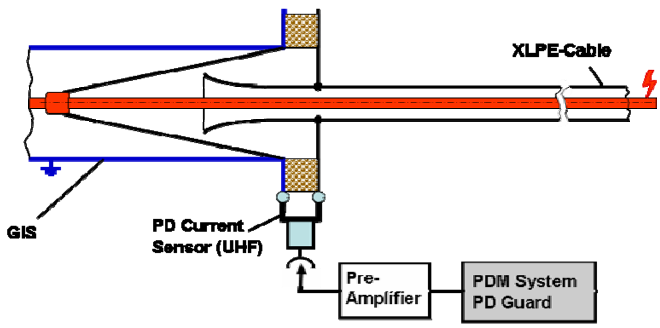

Fig. 3: PD testing circuit for non-conventional measuring method

The general layout is shown in Fig. 3 and 4. Each termination is equipped with a UHF directional PD sensor embedded in a post insulator between base plate and earth. All six sensors of one circuit are connected via fibre-optic (FO) cables to the processing box called PD Guard. The PD Guard is the central acquisition and pre-processing unit of each set of three terminations.

The 12 *PD Guards* of the six circuits in total are linked via optical Ethernet to the Server-PC (Figure 1) located in the substation. This Server-PC unit contains the expert system, i.e. the data evaluation software, as well as a 200 GB harddisk for the data storage and data backup. Communication with the remote PC unit located in an external office is provided via remote control connection (Ethernet or telephone/modem link).

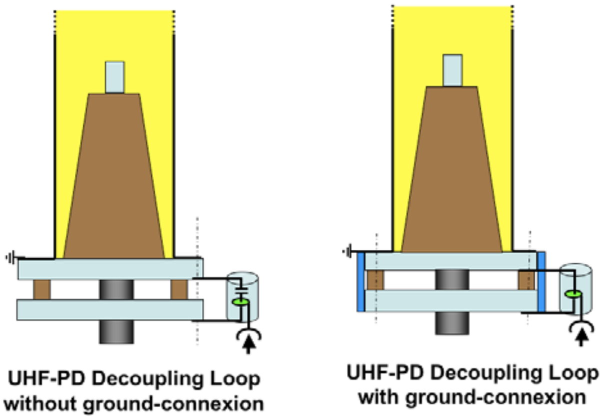

Fig. 4: UHF-PD Decoupling Loop with UHF Sensors

Each UHF PD sensor is embedded in a post insulator located between base plate and earth. The sensors are fully enclosed in a cast resin housing and thus are suitable for outdoor use, as the post insulator can withstand temperatures of up to 55 °C. At the firmly bonded end of the sheath the sensors are in parallel to the earth connection. At the open end the sensor type with internal capacitor is applied for blocking induced currents (see Fig. 4)..

5. LABORATORY PD TEST

In contrast to the well established PD measuring method according to IEC 60270 the described system operates in the UHF frequency domain, hence the derived and evaluated output PD pulse magnitude is more or less a measure of the PD current amplitude and not for the apparent charge as defined in the above mentioned standard.
Any kind of scale factor would be affected by the shape of the captured PD pulses which are depending on the discharge physics of the actual PD source and its position of occurrence in relation to the UHF-sensor.
It is obvious that no general applicable proportional factors may exist for simple transfer calculation between mV-PD quantity and apparent charge im pC.
On the other hand the apparent charge indicated in pC is a well established quantity for the evaluation of the severity of partial discharge activity. So the general demand exists to get the relation of both methods.

In order to approach the subject comparative measurements of the measuring method according to IEC 60270 and the UHF method were performed in the HV lab.
The calibration of the standardized measuring circuit was done by the injection of charge pulses into the terminals of the test object. The calibration of the UHF measuring technique was performed by application of very fast pulses generated by the UHF pulse injector generating pulse rise times below 200 ps.

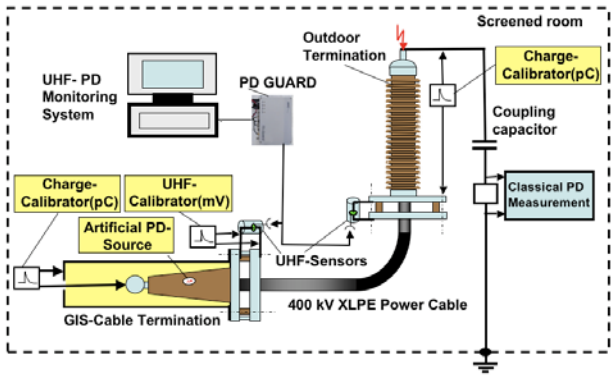

Fig. 5: The calibration of the UHF PD sensors were carried out in the manufacturers place Brugg Cables

The best validity of the results of such comparative measurements are achieved when the on-site arrangements are simulated in the laboratory as realistic as possible.
For that purpose comparative measurements were carried out in the HV lab of the cable manufacturer Brugg Kabel in the test arrangement evident from Fig. 5. All components have been selected to simulate the on-site arrangements such as cable-termination-type, UHF-coupler and measuring devices.
In order to create a realistic PD source a sharp electrode on ground potential was mounted inside the metal clad gas chamber.
Fig. 6 shows one typical phase resolved PD pattern. For comparison purposes the PD-peak value weighted as recommended in IEC 60270 was applied for both, the pC reading as well as for the mV reading.

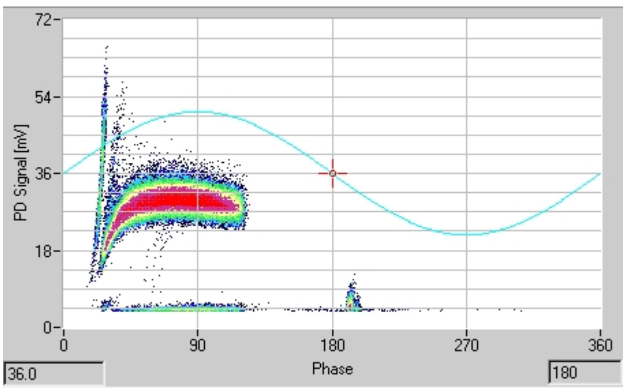

Fig. 6: typical phase resolved PD pattern of the artificial PD-source

Fig. 7 shows another helpful display mode (3-dimensional) that indicates typical characteristics of the PD source as fingerprint.

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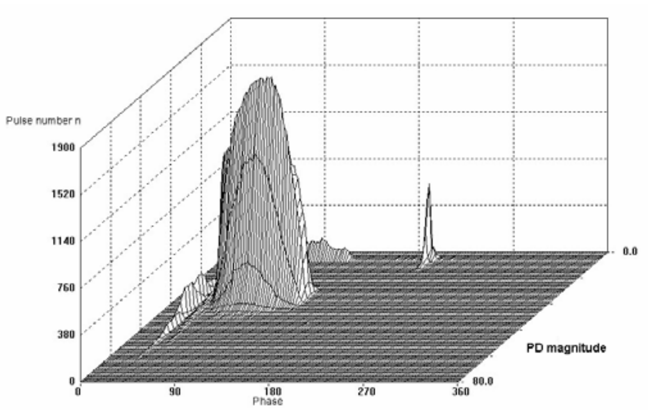

Fig. 7 3-D display mode of the artificial PD source in the lab

6. ON-SITE TESTING

Basing upon the experriences obtained during the sensitivity check in the lab actual PD measurements have been caried out at cable terminations during the high voltage test on-site. For that the UHF measuring technique was applied at the pre installed UHF couplers as described above.
In the following the measuring results shall be illustrated by means of selected typical figures.
Fig. 8 shows the measuring result in mV of a cable termination. It is evident that no significant partial discharges can be observed above the comparatively low noise floor (white noise). In that particular case even no increased noise pulses could be observed.

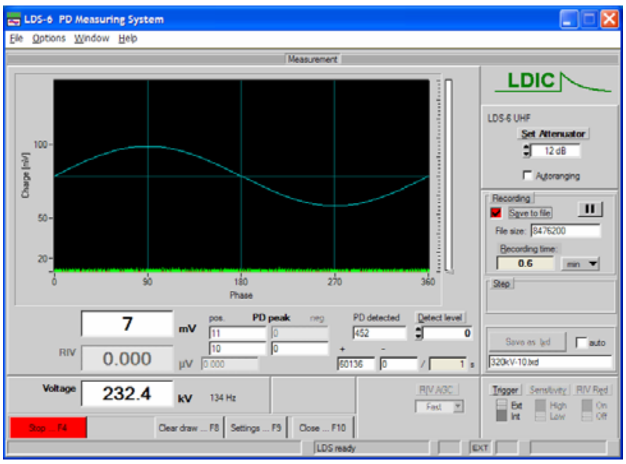

Fig. 8: PD measuring result of one termination at rated voltage

In this context it shall be mentioned that incidentally heavy noise pulse intrusions could be observed. But provided by the sophisticated display and analysis capabilities of the measuring system the noises could be clearly identified and discriminated. Such events showed no phase correlation as evident from Fig. 9.
Provided by the the sophisticated display and analysis tools as well as an additional additional expert system sensitive UHF PD measurements can be performed under on-site conditions successfully.

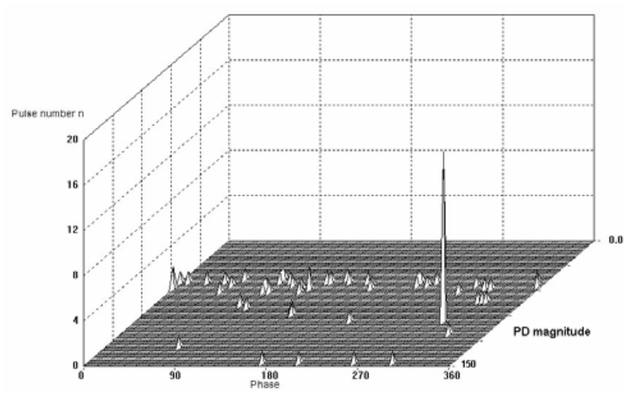

Fig. 9: 3-D display mode of incidentally occurring

7. CONCLUSIONS

Based upon practical experiences in the laboratory and on-site the following conclusions can be drawn:

- The UHF PD method is not suited directly to determine the apparent charge of a PD signal. For that reason the calibration in mV is recommended. Nevertheless it is helpful to perform the sensitivity check im terms of pC by parallel comparative measurements. The relation mV and pC scatters in a more or less wide range due to the variation of original PD pulse shape and position inside the test object. Nevtherless the measuring sensitivity could be proven for the described UHF technique for isolated and firmly grounded cable terminations.
- The PD pulse peak detection weighted according to IEC 60270 is as well suited for UHF measuring results. Well comparable reading with uniform pulse sequence dependancy can be derived.
- Deeper investigation of the relation between pC (IEC) and mV (UHF) are recommended to determine the possible variation range and the main inluences on it. The final target is the evaluation of the severity of PD in mV in future.
- The measuring method is even under on-site-conditions suited to perform sensitive PD measurements provided by its very high measuring frequency and the corresponding noise immunity.
- The sophisticated computer aided data analysis provides the efficient noise discrimination capability.