PARTIAL DISCHARGE ON-LINE MONITORING IN MV UNDERGROUND POWER CABLES AS PART OF CONDITION BASED MAINTENANCE STRATEGY

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ABSTRACT

Predictive maintenance actions are beneficial to improve the reliability of the Utility's technical assets. Assessing the condition of the cable system while it is energized will enable the asset manager to better prioritize its decisions regarding cable rehabilitation or replacement programs. Partial Discharge On-line monitoring systems look rather promising, filling the gap that Off-line systems couldn't fulfil, as they give you a time continuous analysis of the cable system, enabling you to act before breakdown occurs.

INTRODUCTION

EDP Distribuição (EDP Group), is the main Distribution System Operator (DSO) in Portugal, with more than 6 million customers. EDP Distribuição operates over 400 HV/MV Substations , 60 thousand MV/LV Substations, 80 thousand km Network (HV/MV) and a LV Network about 140 thousand km.

Lately, EDP Distribuição has been struggling against a high rate of failures in its MV underground network, due essentially to asset aging.

The growing importance of EDP's underground cable network, the pressure of the regulator's and the negative impact on customer's service, enabled EDP Distribuição to take several measures to improve the overall performance of this system.

In October 2010, EDP Distribuição sponsored a Workshop on MV underground networks:

This event gathered several cable and accessories manufacturers as well as EDP's main contractors. It was an opportunity to share experiences, to try to understand better what were the causes and, above all, to figure out the best solutions for the existing problems.

As an outcome of this Workshop, EDP Distribuição decided to sponsor eight projects. One of the projects consists in evaluating state-of-the-art Partial Discharge On-line monitoring systems.

Partial Discharge activity is an indication of incipient faults in the insulation and is widely regarded as one of the best 'early warning' indicators of the deterioration of medium and high voltage insulation. In fact, Off-line measurements have been used for more than 15 years in cable condition analysis with very good results. For example, EDP Distribuição currently conducts this type of tests in new installed cables, before delivering them to service.

Off-line diagnostics require the cable to be taken out of service for the measurement period and allowing only to take snapshots of its condition. This points towards the use of a system capable of measuring PDs while the cable is In-service, i.e. On-line, and over a long period of time. Obvious advantages emerge:

- The power supply is not discontinued during the measurement (although it's not always possible to install the sensors safely without cutting the power supply, even if it's only for a few minutes). Under Off-line testing, redundancy is not always present but even rerouting power means an increased risk in loss of power, since the cable under test is not available as a back-up;
- The cable system is tested under exact operating conditions, including over-voltages and load variations;
- After installation, a continuous monitoring On-line system hardly requires any personnel effort;
- Data is continuously registered, thus time-related information on PD activity can reveal events of over-voltages or cable temperature variation. Also PDs occurring shortly before failure can be captured, in contrast with occasionally applied Off-line tests.

On-line PD measurement has inherent advantages over conventional Off-line measurements, but it also suffers from a very significant Electro-Magnetic Interference (EMI) problem due to the small PD signal levels being monitored. The large magnitude EMI signal often completely swamps the smaller magnitude PD signal, making it difficult to monitor anything but extremely large PD activity. Monitoring cable condition and assessing insulation degradation trends require advanced techniques. From empirical evidence one can conclude, however, that PDs close to a breakdown moment (days before) are often large enough to overcame EMI.

In sum, On-line PD monitoring systems became very attractive to Power Utilities because of all the advantages they present against the more traditional Off-line methods. Although it is possible to acquire commercial On-line systems with a few years of experience, they still have to prove their effectiveness and usefulness, especially if you compare their performance with the performance of the Off-line more experienced products.

So, after a period of benchmarking, with the cooperation of some Company partners, such as EDP's Hidro Cantábrico from Spain, with a participation in project DENISE, and LABELEC, EDP's internationally referenced laboratory, EDP Distribuição decided to trial, for a period of 6 months, two different On-line PD monitoring systems, both commercially available solutions: "Smart Cable Guard" from DNV KEMA and "4 Phase PD Test and Monitoring Solutions" from HVPD Ltd, UK.

SMART CABLE GUARD (DNV KEMA)

It's probably the world's most experienced On-line permanent monitoring system. Commercially available since 2007, SCG ®, formally known also as PD-OL - "Partial Discharge testing On-line with Location", has been tested all around the world and some Utilities, such as CEM, Macau's Electricity Company, have been wide spreading the use of this monitoring solution after a long period of apparently well succeeded trials. EDP Distribuição decided to monitor 8 circuits during a period of 6 months.

In simple terms, one SCG system consists of two measurement units, each installed at one of the cable ends in either a substation or a RMU ("Ring Main Unit") [1]. Why did DNV KEMA engineers decided to use this design? Because in an On-line situation, power cables are in many cases connected to a contiguous cable and PD's do not reflect at all or only to a minor degree at this point.

Each measurement unit consists of a Sensor/Injector Unit (SCG – SIU) and a Controller Unit (SCG – CU). The SIU, contains, both, a sensor to measure pulses from the cable and an injection device to inject pulses into the cable. The pulses are injected into the cable system for time synchronization and calibration of the units.

The CU unit controls the measurement sequence, the data collection, the signal processing and uploads the resulting data via the internet to the Control Centre at DNV KEMA for further interpretation. In the same way, they can be reached remotely for diagnostic purposes and updates.

Fig. DNV KEMA Engineer setting up SCG – CU

No physical access to the units is necessary after they're installed. The SCG units can also be easily removed and installed on another cable circuit.

Maybe one of these system's greatest achievements comes from its design. When the results from both cable ends are combined, this leads to the elimination of pulses from other sources and the determination of the location of the PD spot. So, this system is able to filter the main noise components or events that are external to the circuit being monitored, simplifying further analysis. Another important feature is the possibility to determine PD concentrations per length unit. This is far more important than knowing only the total amount of PDs per time unit.

As mentioned before, the interpretation of SCG's measurements is done at the Control Centre at DNV KEMA. The Utilities receive the results translated into risk values. They can follow the PD activities and present risk status of any location in the cable via a secured web site. In the case of sudden high risks, Utilities can be (automatically) warned by means of email or SMS.

FOUR PHASE PD TEST AND MONITORING SOLUTIONS (HVPD)

HVPD Ltd ("High Voltage Partial Discharge") is a company based in Manchester, UK, with over 15 years of experience using on-line PD technology. After consultation, HVPD recommended EDP Distribuição the use of the first 3 phases of a 4-phase asset management solution to detect, locate, diagnose and monitor PD activity in its MV and HV electricity networks.

Phase 1 – "PD Surveying Stage": This first phase in the condition assessment involves the use of a simple screening device, the "HVPD-PDS Air™". This is a portable device incorporating three PD sensors - the transient earth voltage (TEV) sensor for the detection of local e/m activity inside metal clad plant switchgear, an airborne acoustic (AA) sensor for the detection of discharges into air and a third (external) sensor, an HFCT ("High Frequency Current Transformer"), used to detect

PD activity in cables through attachment to the earth connections of in-service MV/HV cables [2].

Phase 2 – "PD Diagnostic Test and Location Stage" – This stage requires the use of the diagnostic HVPD-Longshot™ Unit, an advanced, portable test device, suitable for short duration on-line PD testing. This uses the same sensors as Phase 1 whilst recording data simultaneously from four independent channels in ultra-high A to D resolution. It comes with software designed to provide automatic diagnosis of PD activity. For location of PD activity, HVPD tools use cable PD mapping techniques. For cables longer than 2 km, the use of a portable 'Transponder' unit is recommended.

Fig. HVPD-Longshot™ unit in use by EDP engineers

Phase 3 – "Short Term Monitoring of PD Trends" – The HVPD temporary Multi™ and Mini™ PD monitors continuously detect and analyze PD activity, classifying the results in a coloured scale, and downloading the data to a central server. The Multi-Monitor™ can record data sequentially from up to 16 channels and it is used mainly for monitoring larger primary substations. The 4-channel Mini-Monitor™ is used for monitoring smaller secondary substations and RMU's and provides measurement timing across the RMU and adjacent switchgear panels, to determine statistically the direction of the PD source(s). It's important to underline that HVPD temporary monitors register, not only PD activity present in cables but in the surrounding local power equipments, such as MV switchgear. This is very important to help tracking PD sources in the cable terminations and switchgear.

CONCLUSIONS

The first conclusion EDP Distribuição reached is that 6 months is too short to trial these systems, in particular, for the permanent monitoring solution from DNV KEMA. In fact, although we still have 2 months of trial ahead, we haven't measured any significant PD activity nor was there a failure. Whilst almost all the circuits under monitoring have a fault record history, this, by itself, won't guarantee you finding PD activity now. On the other hand, through the use of the HVPD temporary monitoring solutions mixed with PD diagnostic test tools, EDP's engineers managed to spot and confirm PD activity in more than one site. We (EDP's engineers) have decided to use HVPD Mini and Multi-Monitor to track possible PD activity that we would later confirm, using the HVPD Longshot™ diagnostic unit.

The portability of HVPD test equipment revealed itself to be quite handy. Easy to transport and to install, we've managed to test a significant number of circuits. The circuits were monitored for at least a two weeks period time and the results were later scrutinized with the use of the more reliable diagnostic test tools. The data recorded was then sent to HVPD engineers for further analysis.

The reports made by HVPD engineers confirmed that monitoring systems are, in this case, mainly suitable for application in underground networks with lower noise levels. For example, if you try to monitor underground MV cables in an 'outdoor' substation with overhead lines, it's most likely that your results are going to be critically affected by the presence of e/m noise. So in this type of substations 4-channel synchronous wideband diagnostic HVPD-Longshot™ Unit is preferred to resolve PD signals. The use of Lonsghot™ multiple sensor synchronous capture allows discrimination of interferences to made using signal time of arrival comparison between sensors (for example screening aerials). The presence of RF noise, surface discharge or Corona effects in outdoor HV/MV equipment can be also evaluated through the use of the PDS Air handheld unit with laser guided parabolic receiver.

Although EDP's engineers managed to perform TDR ("Time-Domain Reflectometry")measurement techniques On-line - an important step to determine with very good accuracy the localization of PD sources -, identifying real PD on site and afterwards locating its source, it's a much more difficult task. For this type of analysis you need to use HVPD Longshot™ along with a Transponder Unit, installed in a similar way as SCG's SIU Units. This is really where it becomes tricky and, even with the help of advanced software analysis tools, developed by HVPD, we've understood that we still have a lot to learn before we start to trust our own analysis. So, the cooperation with HVPD engineers and their expertise was fundamental to achieve the good results during this trial.

SCG is, in fact, a service provided by DNV KEMA. This permanent monitoring solution is a very accurate system due, above all, to its conception design. Its accuracy overcomes some constraints/requirements to follow during installation, such as:

- You need to ensure that the earth path in the circuit being monitored is not interrupted. This has been a problem in EDP Distribuição underground circuits because we've adopted in the past a recommendation from DNV KEMA experts, in which one of the circuit ends of the cable should be disconnected from earth to reduce the possibility of existing electromagnetic field induced currents. Nowadays, engineering solutions can overcome this problem but they might need some additional efforts and come with some extra costs;

- If at least one of the SCG measurement units is installed in a cable circuit end, with no connection to a downstream cable, one have to make sure that there is not a big difference in impedance at that point, or else, both units won't be able to synchronize. For instance, in a terminal MV/LV Substation, the impedance of the Power Transformer should be enough to ensure this condition;
- In similarity to the installation of the HVPD HFCT sensors, you have to ensure that the earth path embraced by the sensor is the only way to the earth bus bar. Some cable terminations, particularly in old PILC EDP D cables, don't meet this requirement.

Another situation EDP's engineers experienced was the presence of HF noise, due to rotating machinery operating nearby: one of the SCG Units was installed in a factory's RMU. The HF noise produced by the factory's machinery, during production cycle, made it impossible for the equipments to synchronize during that same period. DNV KEMA recently announced that an updated version with a more sophisticated time sync system might overcome this problem.

This need for synchronization between SCG measuring equipments along with the unique characteristics of each circuit (cable types, length, number of joints) helps to define the maximum length of operation. During this trial, we've been able to monitor a circuit of XLPE cable, 2,5 km long, with 6 RMUs in between and 18 joints. None of the EDP Distribuição installations mentioned above has more than 2 MV circuits: one way in, one way out. If the RMUs in the measured circuit have more circuits, the amplitude of the PD signals will be gradually lost, according to the number of derivations, up to a point where there isn't sufficient amplitude to be measured. For these type of situations, DNV KEMA recommends the use of supplementary SCG systems.

Despite all these constraints, SCG has proved to perform very well. A recent publication from KEMA in collaboration with many utilities has shown an 85% success rate preventing failures and accuracy rates of 99% in location measurements [3]. Until this point we weren't able to confirm those numbers, because of the lack of events in these 4 months of trials, but we strongly believe in its good performance.

Anyway, Utilities need to evaluate very carefully their needs before appealing to these types of services. This is where risk assessment policies 'kick in'. It's simply not sustainable, or cost-effective, to apply this type of solution to cover all of a Utilities assets. So, SCG is the type of solution you should install to monitor your most critical cable assets. On the other hand, the use of HVPD equipment by Utilities engineers, supported with HVPD background analysis and recommendations, has proven its usefulness in tracking hidden problems in the underground network. This opens new doors for the implementation of permanent monitoring systems, particularly SCG, as a complementary tool to the use of PD screening and diagnostic test equipment tools.

So, after PD activity is spotted and confirmed, implementation of SCG becomes more justifiable, since it will guarantee you a permanent and accurate follow up of the evolution of your asset condition, preventing eventual failures and postponing possible investments.

SUMMARY

The power Utilities growing need for predictive maintenance tools is having a positive effect in the growing commercial offer of this type of products and services. Particularly, PD on-line diagnostic and monitoring solutions, are a short step away from becoming everyday tools. Of course, there is still a margin of improvement and, essentially, experience to gain regarding data interpretation and analysis.

The benefit in the appliance of these products/services is very much dependent on a good, condition-based risk assessment policy. So Utilities have to do their part, notably, identifying their most critical assets. EDP Distribuição is currently in process of implementing a new asset management policy with associated tools. One of the key issues regards the definition of Health Index algorithms that match the results of asset condition surveillance with other risk factors.

In the case of the use of this type of preventive tools, our next challenge is to find out the best way to manage the resulting data and feed these algorithms. It's something we would like to share with you in a future paper.

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