COMBINED POWER QUALITY AND CONDITION MONITORING OF OFFSHORE NETWORKS

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ABSTRACT

The authors present a paper detailing their experiences (over the past 5 years) in the insulation condition monitoring of land-sea export cables and subsea array and platform interconnection cables in the UK offshore renewables and oil & gas industries. The paper focusses on the use of partial discharge (PD) testing to detect and locate pre-fault PD activity and also the use of time domain reflectometery (TDR) techniques to provide a 'fingerprint' of the cables and to help pinpoint cable faults after they have occurred.

The paper will also discuss a 'holistic' monitoring approach, combining a number of condition monitoring technologies, to achieve necessary information to support improved CBM. For the HV networks, power quality monitoring should be integrated with the monitoring of partial discharge (PD), cable sheath current and weather data (i.e. wind, wave or tidal energy resources, power flows and occurrence of overvoltage/overcurrent conditions), with the further cross-correlation of all of these condition and state parameters, in order to allow for the early detection, faster identification and efficient resolving of faults, failures and other problems during the operation. The purpose of such an integrated monitoring platform is therefore, to provide an advanced 'early warning' against insulation faults to enable planning of preventive or corrective maintenance to be carried out and to avert unplanned outage

INTRODUCTION

The causes of the various cable insulation faults in subsea cable networks are numerous, some being due to poor installation (producing PD in cable joints and cable terminations), inadequate mechanical protection of the cables (leading to external abrasion and subsequent failure) and also the mechanical wear caused by movement of the subsea cables with tidal changes. Prior to failure, these 'incipient' cable faults can produce PD activity which can be detected and located ('mapped') to enable the operator to plan and carry out preventative maintenance and avoid unplanned outages.

The subsea cables in both the offshore renewables and oil and gas industries have the following common characteristics:

- They require a long repair and/or replacement lead time.
- The repairs are expensive to do as a cable lift/repair vessel is often required.
- Unplanned outages are much more expensive than scheduled, preventative maintenance during planned outages.

Operators need to ensure the networks have high reliability, good maintainability and maximum availability. The advantages of carrying out on-line condition testing of in-service subsea cables are:

- The diagnostic can be made without the need for an outage.
- The cable is assessed under normal (and abnormal) operating conditions.
- The data can be used to support Condition Based Maintenance (CBM) to predict and prevent failures by the detection of 'incipient' cable faults.
- The techniques ensure the continuous, reliable operation of the cable networks.

ECONOMIC DRIVERS

It is anticipated that 18 GW of offshore wind could be deployed in the UK by 2020, and that a similar large-scale deployment of marine energy systems (wave and tidal) will follow afterwards [1]. Further development and implementation of these low-carbon generating technologies, however, is strongly influenced by their currently high capital, operational and maintenance costs. In fact, most of the technical and technology barriers to their full-scale deployment are, in one way or another, directly associated with the corresponding costs. Recently the UK, the Department of Energy & Climate Change (DECC) suggested that overall costs of offshore wind generated electricity (from development, construction and operations) should fall to about £100/MWh by 2020 to make this technology truly competitive [1], [2]. It can be concluded, therefore, that there is an urgent need to reduce operating and maintenance costs of both existing and future offshore wind farms.

PARTIAL DISCHARGE TESTING OF OFFSHORE NETWORKS

OLPD Test Strategy

PD testing is performed on the cables in the factory as part of the quality assurance tests, PD testing at the commissioning of cable circuits should also be carried out although is not always the case and often the first PD measurements on the installed cable system are made once it is in service. For testing of in-service cables measurements can be made as a spot-test and as continuous monitoring on a temporary or permanent basis, in order to detect, locate and trend any PD activity over time.

Often a test strategy is developed for large windfarms in which permanent monitors would be installed on the main export feeders (most critical circuits) and then inter-array cables tested routinely either with spot measurements or temporary monitoring.

Points of PD Inception

As most new subsea installations are with XLPE cable, the most likely source of any PDs are at the accessories as shown in Figure 1. For inter-array cables interconnecting wind turbine towers this is generally only the terminations. On export feeder cables this can be the terminations and also any joints on the land cable section, land-subsea transition joints, factory joints in the subsea cable and any subsea joints in the circuit..

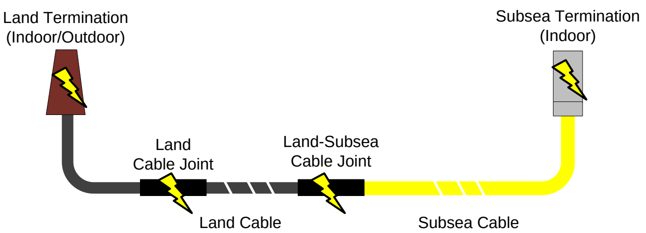

Figure 1 Points of PD inception in subsea cables

PD Sensor Attachment Points

Due to the long lengths of the export cables used, in excess of 10s of km in many cases PD signals from sites far into the cables will become attenuated. In order to obtain best the best sensitivity measurements should be made at both cable ends.

In addition when the land cable sections contain cross-bonding, PD measurements are made at all of the cross-bond/earth bonding points on the cable.

The high frequency current transformer (HFCT) is widely used for PD measurements to detect current pulses that propagate to the cable ends. This sensor is well suited to on-line PD measurements as is non-intrusive and in many cases can be installed without the need for an outage.

The sensor is installed either onto the cable earth connection or around the cable core with earth looped back through. Pictures of both installations on subsea cable circuits are shown in Figure 2 and Figure 3. .

Figure 2 Examples of HFCT sensor attachment

On-line PD Measurement Hardware

The measurement systems for spot-testing and monitoring are based on a wide band oscilloscope with the sampling rate set at 100 MS/s. PC-based signal processing is then made to discrimate PD and noise based on pulse wave shape using PD event recognition methods, further details are in [3]. A photo of a measurement system installed is shown in Figure 3.

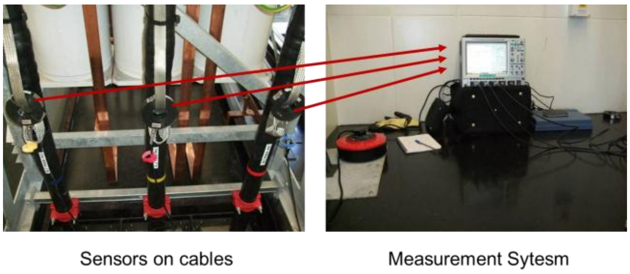

Figure 3 PD measurement system installed at off-shore substation

TDR FINGERPRINTING

In the event of a fault on a subsea cable circuit it is essential to locate the fault to the best accuracy in order on minimise the section of cable which must be replaced. Time-domain reflectometry methods are commonly applied in fault location in which a pulse is injected into the cable at the end and the time to a reflected pulse from the fault observed. This is then compared to the return time for a pulse to propagate the length of the cable.

In order to have the return time readily available TDR finger-printing can be carried out. These tests can also be useful for making an extimate of the attenuation on the cable and detection sensitivity of PD measurements.

Due to the long lengths of export cables, a specialist pulse generators has utilised with amplitude of 100V and variable pulse width up to 10us. The test set-up is shown in Figure 4.

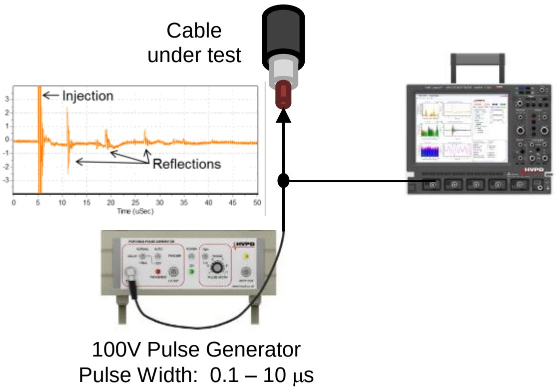

Figure 4 Test set-up for TDR testing

With such techniques TDR testing has been performed cables up to 108 km in length to identify the return time of the cable and positions of land cable joints and land-subsea cable transition joints [4].

HOLISTIC MONITORING SYSTEM

An advanced, flexible and real-time sensing and diagnostic intelligence, capable of correctly identifying state, condition and performance of monitored HV networks, is required for the implementation of improved and more effective condition-based management (CBM) schemes. Essentially, this requires combining a range of power quality and conditioning monitoring, protection and control technologies into a 'holistic' multi-parameter system. Realising these functionalities in an integrated monitoring platform will allow for a confident state/condition/performance identification and subsequent implementation of optimal and cost-effective preventive or corrective control CBM actions and strategies.

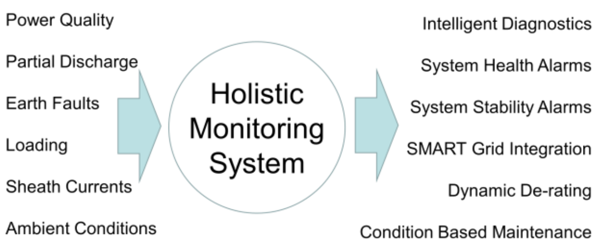

Figure 5 Holistic monitoring system overview

One important advantage of integrating system state identification functionalities and whole-system or individual-component performance and condition monitoring into one multi-parameterised platform is that this will allow assessment of power quality and reliability levels to be combined with the analysis of insulation condition and security-related protection as well as control aspects of system operation.

CASE STUDY – TDR FAULT LOCATION

TDR measurements were made to locate a fault on L3 of the supply cable to a satellite platform at an off-shore gas production site. The cable was 12.2 km, 6.6kV as shown in Figure 6 and was the only supply meaning the fault had caused a loss of power and production.

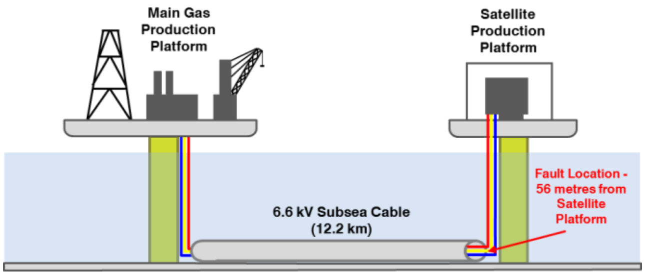

Figure 6 6.6kV Subsea circuit overview

Off-line, pinpointing TDR measurements were used to locate the fault and direct the cable repairs.

The off-line TDR testing was conducted at both ends of the cable. The return time was measured on an un-faulted phase. TDR measurements from the main platform showed the location of the fault at 99.54% of the cable length out from platform. The step response waveform is shown in Figure 7. This was at location of around 56 m out from the satellite platform and coincided with the entry point of the cable to the subsea cable pipe.

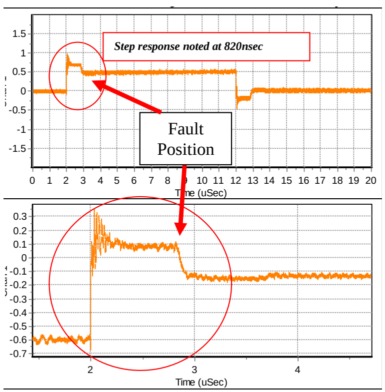

Figure 7 Step response for injection into L3.

It was found that the cause of the fault had been due to the (mechanical) stress-relieving 'bung' at the end of the pipe becoming dislodged. The cable had failed due to abrasion due to mechanical movement of the cable, with respect to the fixed subsea pipe that led to the cable failure through a sheath fault to earth.

The cable fault was repaired with new cable joints and OLPD tests were carried out at both ends of the cable circuit after the repair to ensure that the new cable joints had been installed correctly. These tests showed the re-instated cable was discharge-free and thus suitable for service

CASE STUDY – ON-LINE PD DETECTION

Following faults at joints on the land cable section of an offshore wind farm 33kV export cable feeder, it was decided to perform partial discharge monitoring. An overview of the circuit is in Figure 8

The tests involved installing equipment at the on-shore substation to log the PD over time.

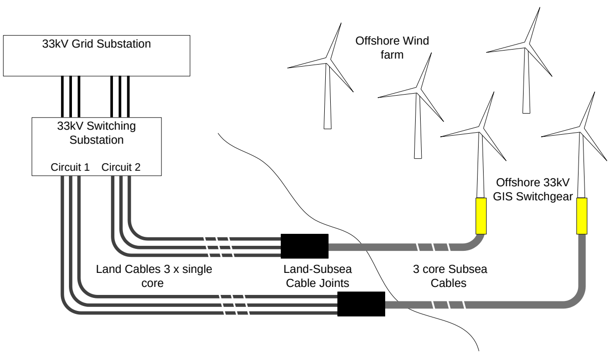

Figure 8 33kV Export cables overview

PD signals were observed during the monitoring session on L3. A PD location was subsequently carried out and one joint in the circuit with PD was identified. The client subsequently replaced the joint. PD monitoring after replacement, showed the high PD activity had been ceased, as shown in Figure 9.

This prompt maintenance gave confirmation the cable insulation was now in a healthy state for continuous operation and reduced the risk of an unplanned outage.

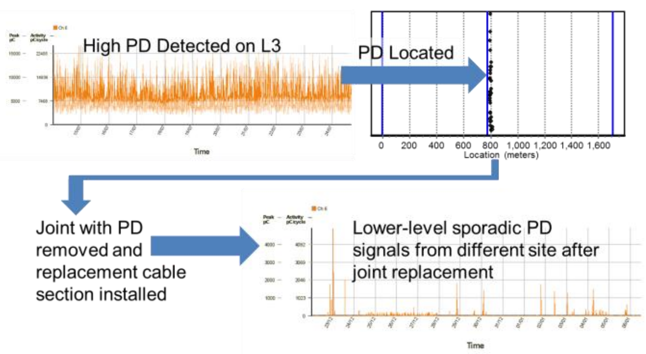

Figure 9 PD detection and location on 33kV cable.

CONCLUSIONS

This paper has presented some of the technical and financial drivers for the application of condition monitoring technology in the offshore wind and oil and gas industries. Such systems are of particular interest to the offshore windfarm operators who are more likely to suffer from higher levels of faults due to early-life, 'infant mortality' failures with their new subsea cable installations.

The offshore windfarm operators have expressed a need for a multifunctional, integrated state/condition/performance monitoring platform to allow for the implementation of optimal and cost-effective preventive maintenance action. Such an integrated system is required for the implementation of improved and more effective CBM schemes. Essentially, this requires combining a range of power quality and conditioning monitoring, protection and control technologies into a 'holistic' multi-parameter system.

A 'holistic' monitoring approach would require a number of complementary cable condition monitoring technologies, including monitoring of partial discharge (PD), distributed temperature sensing (DTS), cable sheath current, power quality monitoring (PQM), weather/tidal data, power flow, and overvoltage/overcurrent events. With cross correlation of all of these condition and state parameters, it will then be possible to provide the necessary level of detailed diagnostic data required for implementing and CBM.

As cost reduction in operation and maintenance costs can only be achieved if there is a radical rethink on present asset management practice, with a move towards CBM viewed as essential. Furthermore, for effective CBM to be implemented, detailed, real-time (continuous) diagnostic intelligence and data on both the state and condition of the MV and HV subsea cable networks is necessary.

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