CONDITION MONITORING OF HVDC TRANSMISSION SYSTEMS FOR OFFSHORE WIND

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ABSTRACT

The work presented in this paper reviews the methods of detecting PD in a HVDC system. The behavior of PD under DC conditions for common defects types is discussed. The partial discharges studied in this paper are limited to three dielectric samples with discharges from well-defined discharge sites. These include corona, surface discharges and internal voids. The samples were subjected to AC and DC excitation, AC excitation as a sense check to ensure the samples yield the expected PD activity. A further area of investigation was the application of analysis techniques to enable the identification of the type of PD event. The ability to determine the type of PD apparent in the HVDC system feeds directly into the condition monitoring of the HVDC system and identification of the insulation fault.

NOMENCLATURE

AC	=	Alternating current
DC	=	Direct current
HVAC	=	High voltage alternating current
HVDC	=	High voltage direct current
PD	=	Partial discharge
q_i	=	Charge of partial discharge event (C)
t_i	=	Time of partial discharge occurrence (sec)
V_R	=	Peak value of the AC voltage at inception of partial discharge (kV)
$\emptyset$	=	Phase angle of partial discharge occurrence (deg)

INTRODUCTION

The development of offshore wind in the UK to date has been focused on the sites close to shore where conventional high voltage alternating current (HVAC) transmission is the most cost effective solution. Offshore wind farms which are now in planning [1] are reaching a critical distance from shore (60-100 km) where high voltage direct current (HVDC) transmission is more cost effective [2]. Currently there is the reluctance from operators to adopt DC links for power transmission due to lack of operational knowledge of these systems and issues with early HVDC transmission links to offshore wind farms.

The HVDC transmission system forms a critical connection between the offshore wind farm and the onshore grid. Condition monitoring of the HVDC link is critical as any loss of the link would bring significant costs in repairs and lost revenue from power transfer activities. A valuable monitoring technique is the investigation of Partial Discharge (PD) an important area of research is the emission of PD as an indicator of insulation failure in the HVDC system. The emission of PD from HVDC cables is yet to be fully understood to prevent such downtimes.

PD detection under AC conditions is a widely used tool for insulation monitoring, with many different technologies being applied according to the requirements of the scenario under investigation. However, even under AC conditions, PD remains a complex phenomenon with many measurement and diagnostic challenges remaining. The onset

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of insulation degradation under DC conditions is a known area [3], but requires fundamental understanding of the underlying mechanisms coupled with new approaches to interpret the PD data [4].

Under AC conditions the PD magnitude and phase of occurrence are used to diagnose the type of insulation fault apparent in the AC system (Fig. 1a). The alternating voltage applied to the insulation defect leads to the phase relation of PD activity (voltage polarity changes every half cycle). In contrast under DC conditions there is no phase reference, the parameters of interest are the PD magnitude and time of occurrence (Fig. 1b). Under DC conditions the voltage is generally constant and lack of a phase reference means that DC PD data is more suited to statistical analysis methods.

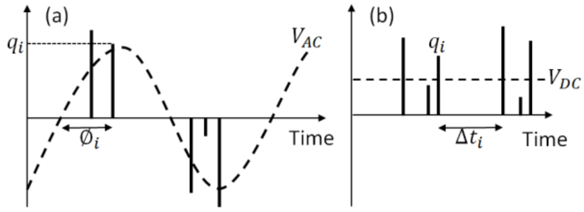

Fig. 1 AC and DC PD behavior (a) AC case, PD magnitude (q_i) related to the phase ($\emptyset$) of the AC sine wave (b) DC case PD magnitude (q_i) related to time of occurrence (t_i)

The repetition rate of PD under AC conditions several orders of magnitude higher than under DC conditions. The difference in PD repetition rate requires that the PD measurement process must be adjusted to reflect this, under AC conditions PD activity can be recorded in tens of seconds compared to tens of minutes under DC conditions.

METHODOLOGY

The methods employed for PD detection under AC conditions can be transferred to PD detection under DC conditions. Common faults in an insulation system are; internal discharges from voids in cable insulation, surface discharge on insulators and corona discharges from exposed sharp edges in the system. When a partial discharge event occurs a high frequency current pulse of nanosecond to microsecond duration is emitted from the defect in the insulation system. Various sensors can be employed to detect this current pulse. Common sensors for the measurement of PD events are; high frequency current transformer (HFCT), measuring impedance and acoustic sensors can also be employed.

In this work a measuring impedance was employed during AC PD testing and under DC conditions a HFCT was used. Both the measuring impedance and the HFCT detect the current pulse emitted from the insulation defect and the sensor converts the current pulse into a voltage pulse for recording purposes. The severity of a partial discharge event is determined by the charge contained within the recorded voltage pulse. The charge contained within a voltage pulse is determined through integration of the voltage pulse. Three dielectric samples exhibiting internal, surface and corona type discharge behavior are detailed in Fig. 2 were selected for AC and DC PD testing.

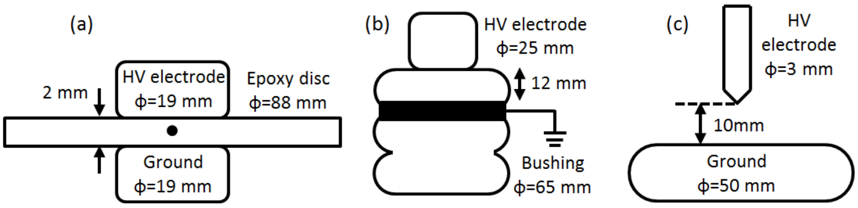

Fig. 2 (a) internal discharge from 5 voids in an epoxy sample (b) Corona from a point plane test cell (c) surface discharge on a ceramic insulator

Initially AC testing was conducted on the three dielectric samples to confirm that the dominant PD source in each sample was as expected at the inception voltage of repetitive and sustained PD. The circuit employed for AC testing is detailed in Fig. 3a. Following AC testing DC testing was conducted on the three dielectric samples using the test circuit detailed in Fig. 3b. A ramp test method was employed in DC testing to apply three different hold voltages ($V_R/2$, V_R and $3V_R/2$) with the voltage held at each voltage step for 10 minutes before increasing to the next hold voltage. The hold voltages were determined from the AC PD test with the peak value of the AC PD inception voltage (V_R) determining the three hold voltages. The analysis methods adopted under DC conditions are based on statistical methods using histograms and analytical methods (skewness and kurtosis) to assess the spread of data.

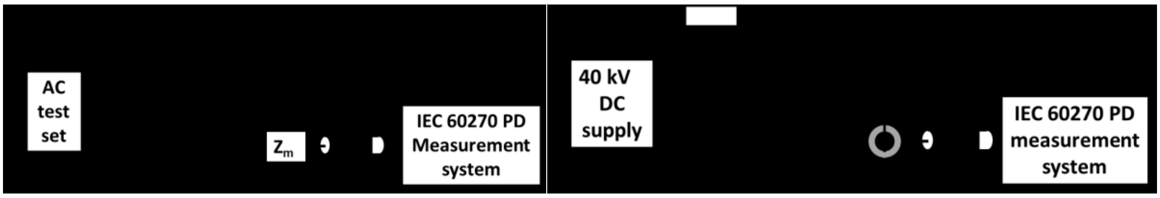

Fig. 3 (a) AC PD test circuit (b) DC PD test circuit

RESULTS

The PD detected under AC conditions was consistent with expected behavior of samples with the manufactured defects through inspection of the relative PRPD plot. The inception voltage for the single void, surface and corona samples were found to be 7 kV rms, 4.7 kV rms and 5.8 kV rms respectively. The peak value of the inception voltage was used to derive the three hold voltages used in the ramp test for DC PD testing for each dielectric sample.

The PD detected under DC conditions for the ramp tests conducted on the three dielectric samples is detailed in Fig. 4. 21 PD events were detected from the single void, 84 from the surface sample over the full ramp test (30 minute test). The corona sample was significantly more active and 4000 PD events were detected in a 2 second period.

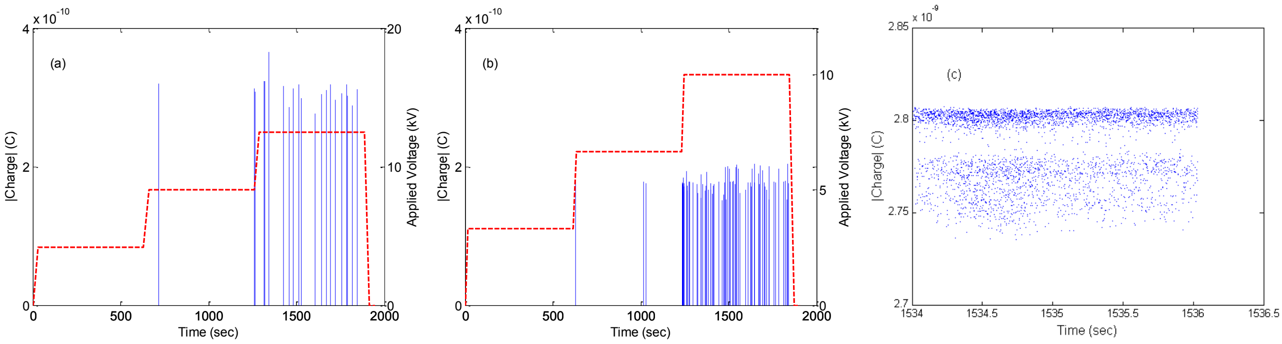

Fig. 4 Current pulse magnitude shown by the blue sold line and voltage ramp shown by the red dashed line in all plots (a) Ramp test data for single void sample (b) Ramp test data for surface discharge sample (c) Ramp test data for corona sample

The relative spread of PD activity was visually represented by producing a histogram based on the recorded charge data during the three tests. The resultant histograms are detailed in Fig. 5 and the interval of each histogram bar is detailed.

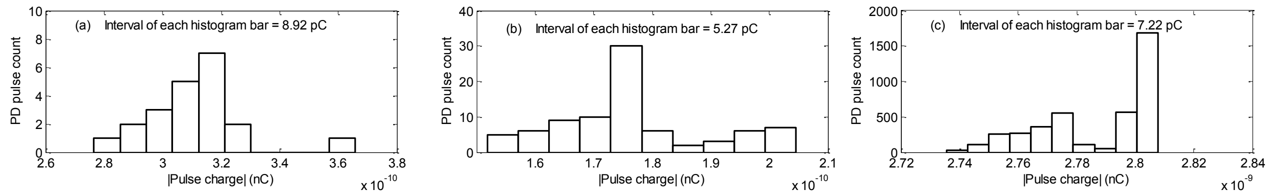

Fig. 5 charge histograms for the three dielectric samples (a) single void sample (b) surface discharge sample (c) corona sample

An analytical method to support the visual representation of the histograms is to determine the skewness and kurtosis of the three data sets [5]. Skewness is a measure of the position of the peak in the data relative to the data set, positive is skewed to the left and negative is skewed to the right. Kurtosis assesses the relative spread of data with less than 3 being platykurtic (wide spread) and greater than 3 being leptokurtic (more deterministic). Fig. 6 details a plot of skewness vs kurtosis for the three samples under test.

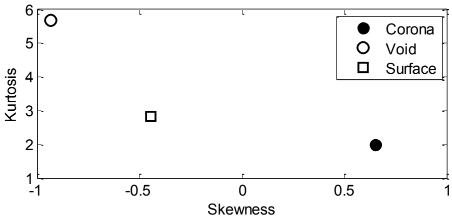

Fig. 6 skewness versus kurtosis for the three dielectric samples

CONCLUSIONS

The requirements for measuring PD under AC and DC conditions and the measurement process for each was discussed. AC PD testing was conducted on the three dielectric samples as a sense check to confirm the dominant source of PD and the inception voltage of repetitive and sustained PD.

The peak value of the AC inception voltage was used to set the three steps in the voltage ramp during DC PD testing. During DC testing PD was generally only consistent at $3V_R/2$, 1.5 times the peak value of the AC inception voltage, as expected from literature [3] a higher voltage under DC conditions was required to initiate PD activity. The amount of PD activity was substantially higher from the corona sample where 4000 events were recorded in a 2 second window compared to 21 in 30 minutes for the single void and 84 in 30 minutes for the surface sample.

Histograms were employed to visually show the relative spread of data for the PD activity from the three test samples. Analytical methods for assessing the spread of data were also employed namely the assessment of skewness and kurtosis. A plot of skewness vs kurtosis was used to illustrate the differences in skewness and kurtosis in the three data sets and how one might distinguish PD activity from different sources in a DC system. A key outcome from this work is the preliminary proposal of how one might distinguish a PD source in a HVDC system.

In terms of future work, the expansion of the hold period in the DC ramp test would enable further PD activity to be recorded over the DC ramp test, in particular for the less active dielectric samples (void and surface discharge samples). Further more detailed work will be conducted into the behavior of void type defects as these are the most common in the cable insulation during reverse polarity and load cycling conditions. The measurement of PD in the field environment has significant challenges in terms of noise from the converter station, measurement distances of sensors and the effect of voltage ripple apparent in the HVDC system on PD inception.

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REFERENCES

[1] European Wind Energy Association, “The European offshore wind industry key trends and statistics 2014”,p. 31, 2015.

[2] P Bresesti, W L Kling, R L Hendriks and R Vailati, “HVDC connection of offshore wind farms to the transmission system”. IEEE Trans. Energy Conversion, Vol. 22, No. 1, pp. 37–43, March 2007.

[3] P. H. F. Morshuis and J. J. Smit, “Partial discharges at dc voltage: their mechanism, detection and analysis”, IEEE Transactions on Dielectrics and Electrical Insulation, vol. 12, Issue 2, pp. 328-340, April 2005.

[4] A. Cavallini, G. C. Montanari, M. Tozzi and X. Chen, “Diagnostic of HVDC Systems Using Partial Discharges”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 18, Issue 1, pp. 275-284, January 2011.

[5] P.R. Hinton, “Statistics Explained”, Third ed. Taylor and Francis, Oxford, UK, 2014, pp. 94-100.