Electric Cables in Ships and Cities - Can Higher dc Voltage be Imposed as Compared to ac?

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***Abstract*—Need of compact and efficient energy distribution has garnered interest in dc for electric cables in ships and cities. There is a general consensus that a higher dc voltage can be imposed as compared to ac, but a proper quantification and its consequences in terms of lifetime cable performance is an open research question that this study attempts to address experimentally.**

I. Introduction

In an all electric ship, space limitations make dc a favourable option as it can lead to reduction in cable size for the same power level [1], [2]. In cities, compact power distribution is advantageous too, but in this context a greater driving force for dc is its ability to deliver power more efficiently and at higher capacity for the same thermal constraints [3]. For both these applications, a critical assumption is that as compared to ac, a higher dc voltage can be imposed on the same cable. A convincing proof of this assumption, that quantifies and validates the lifetime performance, is missing from the literature. This work tries to fill this gap in knowledge experimentally.

In general, with increasing ac voltage, the partial discharges (PD) in cables may become more prominent, specially at higher operating temperature. On the other hand, some studies suggest that the discharge behaviour for dc for internal voids maybe inherently lower than ac for the same voltage level and temperature [4]. It is assumed that raising the dc voltage to $\sqrt{2}$ times the rms ac voltage is a possible option, considering that this magnitude is also seen in ac conditions twice every fundamental cycle. This assumption, however, is more of a safe inference, rather than backed with a robust validation with meticulously designed experiments. Therefore, it is necessary to know how much the dc voltage can realistically be raised so that the detrimental effect of PD to the cable lifetime is not higher than that under ac conditions.

II. Research Objectives

The center for Electromechanics at the University of Texas at Austin (UT-CEM) is involved with experimental study that tries to address this question from the standpoint of reduction in shipboard cabling infrastructure. Delft University of Technology, The Netherlands is collaborating to further the study on differences in PD behaviour under ac and dc voltages for medium voltage cables for improving efficiency and capacity of power distribution in cities. The following research objectives are addressed in this study:

- Quantifying the ratio of inception voltage for the same cable under ac and dc conditions.
- Comparing the partial discharge behaviour in terms of repetition rate and discharge magnitude under varying ac and dc voltages.
- Studying the impact of high temperature on the discharge behaviour.
- Identifying the worst case scenario in order to ascertain how much the dc voltage can be enhanced in practice.

The experimental study designed to look into the mentioned objectives suggests that the dc voltage can significantly be increased without observing similar partial discharge behaviour as under ac conditions. A complete presentation of the results pertaining to the above listed objectives is beyond the scope of this abstract. The focus of this abstract is to showcase some preliminary results pointing towards the worst case scenario observed.

III. Preliminary Results

A 5 kV EPR cable (5 kV 133% insulation Cu 2 EPR cable) with artificial defect is used. The defect of 6 mm diameter and 1 mm height is created at the surface of the semicon layer of the cable.

This is considered to be the worse case scenario as the void is not internal to the insulation. Two different types of tests were conducted. In the first test, the cable was tested under ac voltage. In the second test, the same cable with artificial defect was tested under dc voltage. The operating condition was at ambient room temperature and pressure. In order to avoid the effect of space charges, ac test was conducted before the dc test. The voltage was slowly raised until the inception voltage and the pd was measured from high frequency current transformer installed at the ground using a PD smart meter. A C-L-C filter was installed between the supply and the test cable in order to avoid the source noise from affecting the results.

The pattern diagram for partial discharges at 4.5 kV rms ac and 6.6 kV dc are shown in Fig. 1 and Fig. 2 respectively. Note that the voltage reference is out of phase with the actual imposed ac voltage, which explains the shift in expected phase angle at which the discharges are observed in Fig. 1.

In the dc case at 6.6 kV, the repetition rate was sporadic at ≈ 5 per second, which was the observed inception voltage. In the ac case, the repetition rate was much higher at 200 per second at about root 2 times lower rms voltage of 4.5 kV. The

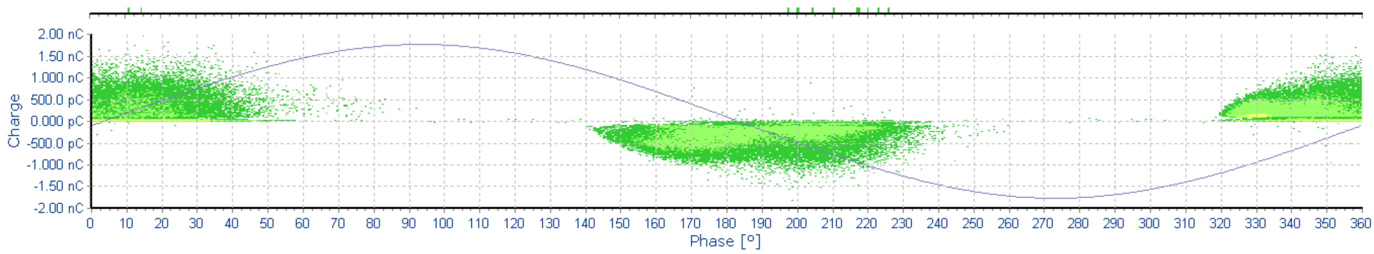

Fig. 1. Pattern diagram for partial discharges under 4.5 kV rms ac conditions.

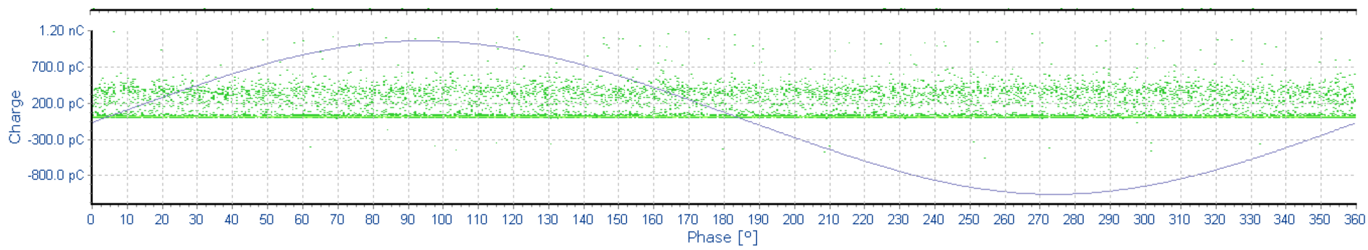

Fig. 2. Pattern diagram for partial discharges under 6.6 kV dc conditions.

inception voltage for ac was 3.5 kV at which the repetition rate was 5-70 per second with an average of 20 per second. The maximum discharge magnitude was the same ($\approx 2\,$nC) for both ac and dc.

IV. Conclusion

The preliminary tests show that it maybe reasonable to conclude that an operating dc voltage of $\sqrt{2}$ times the rms ac voltage can have lower pd in terms of repetition rate. Considering that the cable lifetime performance is directly related to the repetition rate of pd, it is indicative that dc maybe better than ac on this count. Further experiments under better controlled test environment under varied conditions highlighted in the research objectives are important. In case of completely internal voids, an even better performance under dc conditions is observable, but a robust theoretical explanation supporting the observed experimental results is lacking in the literature. Nevertheless, an inception close to root 2 times the rms during the assumed worse case indicates that this may be a possible voltage enhancement factor to be considered.

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