Accuracy of Electric Field Estimation in a Full-sized Cable Based on Space Charge Measurement

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ABSTRACT

Electric fields in cable insulation walls can be assessed via space charge measurements, but the estimated distributions are sometimes unstable. In this work, the pulsed electro-acoustic method was applied to a 275-kV-class extruded cable. 216 waveforms obtained under an applied DC voltage of 320 kV were analysed and their field estimation accuracy was ±5.8% with the 95.4% confidence interval. Additional waveforms obtained at 140 kV to measure 'reference' data provided accuracy of ±15.6%. Use of the 'reference' data for accuracy estimation is effective when the test voltage is high enough to cause the field to be distorted.

KEYWORDS

Space charge measurement, pulsed electro-acoustic method, electric field distribution, estimation error.

INTRODUCTION

Estimation of the electric fields in the insulating walls of cables is essential to assess the suitability of these cables for use in high voltage dc systems [1]. Space charge measurements play a major role in these estimation processes [2], and their accuracy is essential for determination of the assessment baseline. The space charge waveforms acquired via the pulsed electro-acoustic (PEA) method [3, 4] require subsequent signal analysis. A 'calibration' method was proposed in [5], but little attention was paid to the accuracy of the analysis.

In the PEA method, charges generate ultrasonic waves with widths of several nanoseconds. These ultrasonic waves are convoluted with the system's impulse response (IR) to enable their detection in distorted shapes. Deconvolution is thus the most relevant signal processing approach, but this is an ill-posed problem because the process is sensitive to noise. In fact, the processing frequently produces undulations in waveforms. The error range that emerges from such a signal analysis must then be assessed for field estimation.

In this study, statistical analysis was applied to such field estimation results to evaluate their accuracy. A 275-kV-class extruded cable was used, and the numerous space charge waveforms obtained were analyzed to assess the reproducibility of the electric field distribution. The stability of the analysis was assessed from the viewpoint of the noise level. Numerical calculations were also used to investigate the noise effect. Deconvolution was performed in the time domain to obtain a stable analysis. However, the accuracy estimated herein could be improved further by enhancing the deconvolution technique.

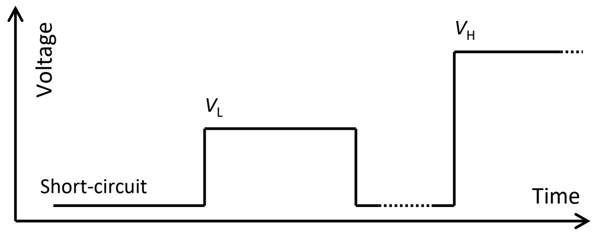

Fig. 1: Schematic of the measurement schedule.

METHODOLOGY FOR ACCURACY EVALUATION

Only space charge waveforms acquired using a regular measurement scheme are required for use in the accuracy estimation (Fig. 1). Waveforms are acquired under application of two different voltages, designated V_L and V_H. The waveform obtained under V_L is often called the 'reference' and is used to extract the system's IR. Usually, data acquisition is performed several times under each condition. Such numbers of data acquired are then usable for statistical analysis. The basic concept of the accuracy evaluation procedure is as follows:

- The waveforms obtained under V_H are mainly analysed to assess the accuracy. The voltage V_H is sufficeently low or is applied for a short duration to ensure that no charge is accumulated. The estimated field distribution is compared with the corresponding field calculated using the Laplace equation, and the error rate is used to assess the accuracy.
- A similar error rate analysis can be performed using the waveforms obtained under voltage V_L. This analysis can provide the maximum error range due to the effects of noise.

Fig. 2 shows the flowchart for the accuracy evaluation. This evaluation procedure includes two stages: optimization of the deconvolution parameters, followed by evaluation of the accuracy via analysis of the waveforms. The first stage of the evaluation begins with selection of a waveform $\boldsymbol{v}$ obtained under the V_L condition. A Tukey window is then introduced such that the ultrasonic wave observed for the cable's outer screen layer is regarded as the system's IR.

Subsequently, the following time-domain deconvolution is performed based on Tikhonov's regularization [6]:

$$\boldsymbol{v'} = ({}^t\boldsymbol{HH} + \lambda\boldsymbol{I})^{-1}\boldsymbol{Hv} \quad (1)$$

where $\boldsymbol{H}$ is the matrix obtained by shifting the IR using an interval in time, λ is the regularization parameter, $\boldsymbol{I}$ is the identity matrix, and the superscripted ^{t} denotes the transpose operator. This time-domain deconvolution