Challenges Associated with Implementation of HFCTs for Partial Discharge Measurements

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Abstract — The stochastic nature of partial discharge (PD) and the inability to directly detect charge displacement makes representative measurement of such events very challenging. High frequency current transformers (HFCTs) have been favored among sensors due to their non-invasiveness and wide bandwidth. Although simple in design, HFCTs for PD measurements need careful consideration to ensure suitability for their intended environment and task. Traditional phase resolved partial discharge analysis (PRPDA) does not impose strenuous requirements for measurements systems as pertinent analysis can be extracted from peak magnitude and power frequency phase information. However, detailed assessment examining waveform parameters from individual discharge pulses (such as DC PD) requires higher bandwidth, sensitivity, and noise suppression, as well as a clear understanding of the measurements system’s influence on observed phenomena.

Index Terms — Partial discharges, current transformers, measurement, measurement techniques, magnetic sensors

I. INTRODUCTION

Partial discharge (PD) measurements are of great interest to many (predictive condition monitoring based on historical trends or forecasts; quality assurance based on factory acceptance testing using established threshold, research investigating degradation of materials). Regardless of the application, in general, one strives to collect representative data that can be used for reliable interpretations. However, deriving a result from a PD event is not a straightforward task. Measuring PD is a multifaceted complex task with vast interdependencies – some related to the physical phenomena and others related to the measurement system.

A coupling device (CD) is utilized to observe the PD phenomenon. PD manifests itself in multiple manners (light, acoustics, heat, electromagnetic radiation, etc.) and as such different CDs can have very different responses to the same event. Even similar types of CDs, e.g., quadrupoles (measurement impedances) responding to charge displacement during a PD event, can output highly varying responses depending on their characteristics and interactions with other circuit components. This response, including the acquisition unit or recording instrument, have a significant influence on how the end-user observes the event and what information can be correlated with the phenomenon. IEC 60270 describes well-established methods and devices for phase resolved partial discharge analysis (PRPDA). For AC, fundamental quantities can be measured from which further statistical distributions and derived variables can be calculated for finger printing and fault discrimination, such as magnitude, phase angle, and time of occurrence. However, due to the absence of phase information, the same quantities cannot be applied to DC stress. For DC, alternative metrics are needed, e.g., parameters describing qualities related to individual discharge waveforms rather than events distributed over a full phase cycle. As such, novel parameter definitions require higher resolution details related to the pulse shape and interdependencies, i.e., correlations between inputs and observed data.

Inductive couplers such as current transformers are widely used non-intrusive measurement devices converting time-varying current into a voltage (or current) signal scaled by the turn ratio of the transformer [1]. Power frequency applications generally implement cores made from grain-oriented silicon iron while high frequency current transformers (HFCTs) utilize metallic oxide materials (ferrites) [1]. HFCTs are often installed on the ground connection of a device where a current flowing along the conductor through the HFCT (single turn primary) induces a voltage measured across a resistive load (i.e., measurement instrument input resistance).

This paper investigates the performance and design principles for HFCTs intended for PD measurements. The influence of core materials, shielding practices (aperture) and primary winding design are reported and quantified by comparing transfer functions and pulse train characteristics (repetition rate, pulse resolution). Demands for sensitivity in measuring 1 pC range discharge, together with the impact of amplifiers on the HFCT response, as well as other influential components in the measurement systems are introduced.

II. HFCT DESIGN AND PERFORMANCE

Soft ferrite cores such as combinations of manganese and zinc (MnZn), and nickel and zinc (NiZn) are effective couplers between electric current and magnetic flux [2]. Sensitivity of the sensor is significantly improved using such materials; however, ferromagnetic cores introduce nonlinearity to the transfer function, dependent on frequency, temperature and flux density [3]. Initial investigations focused on N30 (MnZn) type cores (hereafter referred to as HFCT A). The transfer function of HFCT A was investigated by varying the number of turns and primary winding design. Since, the current output is inversely proportional to the number of secondary turns \( N_s \) (recall, primary turns \( N_p = 1 \), a lower number of secondary turns results in higher gain (sensitivity), however at the expense of bandwidth (notice reduced lower cut-off frequency in Fig.
The difference between 6 mm wide strip and 0.22 mm wire is evident as a slight variation in sensitivity but not in the frequency domain.

Fig. 1. Transfer function (measured output voltage divided by measured current) for HFCT A sensors of varying designs.

It is often necessary to shield against undesirable interference signals in high voltage environments. One practice has been to bring the measurements instrument (MI) close to the device under test so that measurement cable lengths are minimized. Nevertheless, a short distance between the CD and the MI still remains. RG58 cables of 0.5, 1, 2, 3, and 20 m lengths were compared and it was observed that shorter lengths had minor variations in sensitivity and remained consistent as a function of frequency while the 20 m cable resulted in a slightly reduced bandwidth compared to the other cable lengths. Further electric shielding can be provided by surrounding the HFCT with a grounded enclosure with apertures of varying dimensions [4]. It is worth noting that this aperture does not need to be located within the HFCT core where the primary conductor passes through the toroid. A solid conducting shield can be utilized if it is grounded from one end only.

While maintaining relatively consistent physical dimensions, two further HFCTs were constructed with a N87 core (HFCT D: \(L = 4.2\, \mu H\), \(N_S = 5\), \(\mu_L = 2200\), half that of HFCT A) and 3E5 core (HFCT E: \(L = 4.2\, \mu H\), \(N_S = 5\), \(\mu_L = 8500\), double that of HFCT A). The variability in relative permeability and effective inductance is seen in the lower cut-off frequencies of the sensors whereas gain remains constant (Fig. 2).

Since the sensors are intended for PD applications, two characteristics are of particular interest – sensitivity to small PD events and pulse repetition rate (an oscillatory response is prone to superposition error at a certain repetition rate, which also defines necessary characteristics for the acquisition system). All HFCTs exhibited some distortion in the time domain. The average calibrator pulse input had a risetime of c. 3.5 ns (Fig. 3). HFCT E exhibited the fastest risetime, averaging 5.6 ns, followed by HFCT D with 6.5 ns, and HFCT A with 7.8 ns. 1 pC signals were distinguishable by all HFCTs (Signal-to-noise (SNR) ratio of 2-3), but amplification could improve detection (and derivation of variables). However, amplification can further distort the signal thereby loosing valuable information. Pulse trains (of entire measurement system) were assessed by inputting a 10 ns wide rectangular pulses with varying repetition rates. The rapid settling time of the HFCT response allows for repetition rates between pulses below 1 µs.

Fig. 2. Measured transfer function of N30, N87, and 3E5 cores.

Fig. 3. Measured response of HFCTs to 100 pC calibrator pulse.

VI. CONCLUSION

Although simple in design, multiple variables influence the final performance and limitations of HFCTs for low PD detection and quantification. Further investigation is needed focusing on the upper cut-off frequency range to limit influence of amplification on the signal integrity and suppression of noise. Furthermore, with improved detection of waveshape parameters, correlations between variables can be further defined.

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