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Measurement of 2-150 kHz Conducted Emissions in Power Networks

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Abstract — A framework for the comparison of measurement methods of conducted emissions in the frequency range 2-150 kHz is presented. In addition to present non-normative methods published by the IEC, alternative approaches in the literature are considered. Furthermore, test signals and key metrics are described. The comparison results will provide a baseline for specification of a new normative method for power grid measurements.

Index Terms — Electromagnetic compatibility, measurement standards, measurement techniques, power quality, power system measurements.

I. INTRODUCTION

Electric power networks are connecting a growing number of devices with intentional and non-intentional conducted emissions in the frequency range 2-150 kHz, creating a need for electromagnetic compatibility (EMC) regulation to prevent interference problems. Standardization work is in progress and compatibility levels have recently been defined in standard IEC 61000-2-2:2002+A2:2019 [1]. At present, the relevant standards specify only informative (non-normative) field measurement methods for assessment of grid compliance [2], [3]. Comparisons have been made between the informative methods to identify differences in measurement results, but additional alternative methods have not been included. Therefore, this paper presents a framework for comprehensive comparison of existing informative measurement methods and other innovative approaches as a basis for the selection of a suitable new normative method.

II. CANDIDATE METHODS FOR COMPARISON

An essential requirement for a new normative method is comparability of measurement results with compatibility levels, which are defined as quasi-peak values for a bandwidth of 200 Hz with -6 dB attenuation as specified by CISPR 16 [1], [4].

A. IEC 61000-4-7:2002+A1:2009 Ed. 2.1 Annex B

This standard defines an informative method for measuring signals in the frequency range 2-9 kHz [2] based on a windowed Discrete Fourier Transform (DFT). The window length is fixed and must be at least 5 ms to give a minimum frequency resolution of 200 Hz in line with the bandwidth of CISPR 16. For longer window lengths the resulting frequency

components are grouped into bands spanning 200 Hz. In this comparison, window lengths ranging from 5-200 ms are tested to evaluate the trade-off between time and frequency resolution of measured emission.

B. IEC 61000-4-30:2015 Ed. 3.0 Annex C

The informative method defined in IEC 61000-4-30:2015 Ed. 3 Annex C takes a DFT of 32 windows of length 0.5 ms per 200 ms interval [3]. The gaps between measurement windows reduce computational cost, however, some emissions characteristics could be missed. Furthermore, the frequency resolution of 2 kHz does not facilitate comparability with compatibility levels as specified in IEC 61000-2-2.

C. Digital CISPR 16 Compatible Method

The method of CISPR 16 [4] is also under consideration in informative Annex C of IEC 61000-4-30:2015 Ed. 3, specified in terms of the characteristics of a measurement receiver for laboratory EMC testing rather than power quality assessment in uncontrollable field conditions.

A digital implementation that satisfies the specifications of CISPR 16 has been proposed for field measurement in power networks [5]. A 20 ms data window with a Lanczos shape is selected at least every 5 ms giving a bandwidth of 200 Hz with -6 dB attenuation. In order to apply a peak detector, the time series of each frequency component is upsampled to a time step of 0.5 ms or less.

D. Subsampling Technique

By the Shannon-Nyquist theorem, a sampling rate of at least 300 kHz is required to measure emissions up to 150 kHz. A subsampling technique enables the use of existing power quality instruments limited to lower sampling frequencies [6]. An analogue filter bank decomposes the input signal into ten bandwidths of 15 kHz, which can be digitized individually at a sampling rate of 32 kHz. The ten subsampled signals are processed by DFT calculation; the resulting baseband frequencies are corrected to reflect the original components of the respective bands.

E. Compressive Sensing Methods

Compressive sensing has been proposed to increase frequency resolution from 2 kHz to 200 Hz while maintaining a window length of 0.5 ms [6]–[8]. The input signal is

characterized by sparse approximation, i.e. a subset of the 740 frequency components available in the 200 Hz grid from 2-150 kHz is estimated iteratively from the original 2 kHz grid. Orthogonal Matching Pursuit is a greedy algorithm commonly used for sparse estimation [6], [7]; Bayesian Compressive Sensing has also been applied to estimation of supraharmmonic components [8]. The sparsity (number of estimated frequency components) is not known in advance, which presents a challenge with regards to accuracy and computational cost.

F. Wavelet Packet Decomposition

An alternative proposition to a DFT-based method is wavelet packet decomposition (WPD) of the digitized signal [9]. WPD recursively filters and downsamples the signal until a bandwidth of 200 Hz is achieved across the spectrum 2-150 kHz. The result is a downsampled signal for each band, which preserves time variations and it can be processed to calculate the characteristics of the signal.

III. TEST SIGNALS USED TO COMPARE THE METHODS

In order to assess the performance of the above-mentioned methods, emission levels are calculated for a range of test signals with known frequency content, representative of real emissions. Different types of signals have been generated to test the methods in a range of possible scenarios, including narrowband and broadband emission, constant and time-varying amplitudes, with frequencies at the center and edge of 200 Hz bands. The deviation of results from reference values provides an estimation of the accuracy, which is subsequently used to compare calculated emission levels of real signals to compatibility levels.

IV. METRICS USED TO ASSESS THE METHODS

Each method results in spectra of frequency components reported at intervals between 0.5 ms and 200 ms. The amplitudes of each frequency band are aggregated into root-mean-square values, linked to thermal stress of electronic components, and maximum values, linked to the rate of perceptible malfunctions. The method compatible with CISPR 16 specifications additionally provides a quasi-peak value. The measurement accuracy of narrowband emission is assessed by calculating the error in rms, quasi-peak and maximum values of specific frequencies relative to reference levels. Broadband emissions are assessed by aggregating frequency components across a specific range into an integral value.

V. CONCLUSION

This paper presents a framework for the comparison of grid measurement methods in the frequency range 2-150 kHz. The range of algorithms under investigation extends beyond

existing informative standard methods to include alternative approaches designed to satisfy competing requirements such as time and frequency resolution, comparability with compatibility levels and computational cost. Evaluation and analysis of the comparison is in progress and results will be presented at the conference. The main projected outcome of the comparison is knowledge of the accuracy of the measurement methods to facilitate an evidence-based specification for a new normative standard.

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