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Review

On waveform distortion in the frequency range of 2 kHz–150 kHz—Review and research challenges

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ABSTRACT

The frequency range between 2 and 150 kHz has recently gained significant attention, triggered by standardization needs and increased emission in this wide frequency range. This paper gives an overview of the state-of-the-art concerning these so-called supraharmonics, and noticeably indicates the research challenges associated with waveform distortion in this frequency range, with emphasis on the following aspects: emission; propagation; interference; measurements; standardization; modelling and simulation.

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1. Introduction

Distortion of voltage and current in the frequency range between 2 and 150 kHz is not a new topic; engineers and manufacturers of end-user equipment have known about these emissions and solved problems associated to it, case-by-case for decades [1], but the amount of systematic knowledge and the dissemination of this have been limited. Recently, this frequency range has received more attention by researchers [2,3], and especially by standard-setting organizations [4,5]. There are considerable ongoing activities within IEC (both SC 77A and SC 205A), CENELEC and IEEE to develop standards, e.g. compatibility levels, limits and adequate test methods, covering this frequency range. Some standards do exist already [4] but there is no accepted framework, as there is for lower frequencies. The recent standard development was mainly triggered by the use of this frequency range for power-line communication (PLC) as part of smart metering infrastructure. An additional driving force for research is the increasing amount of equipment with active switching resulting in non-negligible emission in this range. Among others as input to the standardization work, a better understanding is needed of conducted phenomena in this frequency range.

The aim of this paper is to summarize the state-of-the-art and to give guidance to those new to the subject of waveform distortion between 2 and 150 kHz and to indicate research challenges and opportunities for future research.

Section 2 of this paper gives a brief overview of the terminology on waveform distortion. Sections 3 and 4 give the state-of-the-art on emission and propagation in the frequency range 2–150 kHz. Section 5 presents known cases of interference. Sections 6–8 summarize the measurement, standardization and modelling issues. The important research challenges, extracted from the other sections, are summarized in Section 9, followed by the conclusions in Section 10.

2. Terminology on waveform distortion

The frequency range up to 150 kHz contains different classes of distortion. Based on the frequencies involved, the following classes are distinguished:

- Components at integer multiples of the power-system frequency. Waveform is distorted but periodic with the same period as the power-system frequency. These components are referred to as “integer harmonics” or “harmonics”.
- Components at non-harmonic frequencies, (interharmonics).
- Components at frequencies less than the power-system frequency (subharmonics). These are also a subclass of interharmonics.
- The component at zero frequency (dc).
- Components at any frequency between 2 and 150 kHz, referred to as “high-frequency harmonics” [6,7], “high-frequency distortion” [8] or more recently “supraharmonics” [4].

The term “low-frequency emission” is used within IEEE EMC society to refer to frequencies below 150 kHz. Within IEC the term “low frequency” refers to frequencies below 9 kHz. The terminology used for any waveform distortion does not consider the origin or impact of the distortion. There is for example no sudden change in physical character of the distortion at 2 kHz that would justify that as the upper border for harmonics. Also, for example, different causes of interharmonics exist, but regardless of the origin, any component at a non-harmonic frequency will be referred to as an interharmonic. The above terminology also does not consider the time-varying nature of the distortion [9,10,11].

Although the term “supraharmonics” is being used more frequently, the term is still new to the electric power community. But the authors still consider this as the most suitable word available at the moment. The authors therefore recommend using the term “supraharmonics” to refer to all quasi-stationary waveform distortion in the frequency range 2–150 kHz.

The term “supraharmonics” as proposed here, only covers quasi-stationary phenomena in the same way as the terms “harmonics” and “interharmonics”. The frequency range between 2 and 150 kHz also contains transient phenomena, but a further discussion of these is beyond the scope of this paper.

3. Emission

3.1. Types of emission

When considering the frequency domain, principally two types of emission can be considered: narrowband and broadband. In general, a spectrum that contains a distinct single frequency component is considered narrowband while a spectrum with several adjacent components is considered broadband. The bandwidth of the components is depending on the time resolution of the signal, window length, window type, and grouping method (i.e. a 2 kHz grouping might show a narrowband signal, where a 200 Hz grouping shows a broadband). To obtain a spectrum, a certain time window is needed; time variations within this window can blur the distinction between narrow and broadband. A time-varying signal can be narrowband over a short time window but broadband when considering a longer period. It was shown in Ref. [12] that what appeared as broadband emission between 40 and 80 kHz when performing a DFT over a 200 ms window was in fact narrowband emission at changing frequencies with a duration of just a few milliseconds. This phenomenon is due to the variation in