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Traceable Measurements of Harmonic (2 – 150 kHz) Emissions in Smart Grids

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Summary:
The paper aims to study the supraharmonic emissions in the frequency range of 2 to 150 kHz. The research applied the design of experience approach and a statistically based analysis method to identify the sources of the supraharmonic emission from field measurements on a smart grid. A generic waveform platform was designed and metrological characterized both for the generation and for the acquisition part. The characterization was done in the French Electrical Metrology Laboratory, the obtained expanded uncertainty is ± 1% for the harmonic amplitude.

Keywords: Supraharmonic, Design of experience, Analysis of variance, Smart grids, Uncertainty

Harmonic emissions

The state-of-the art analysis indicates the supraharmonic emissions (emissions from the grid equipment in the frequency range of 2 to 150 kHz) as one of the significant PQ issues in the smart grids appearing with the renewable energy sources [1], [2]. Two relevant challenging aspects emerged from this analysis: design the appropriate measurement system, create the measurement plan. The metrological characterization of the flexible measurement system based on 4 acquisition channels is described in this paper.

Identifying the sources of the supraharmonic emissions in the electrical networks with multiple equipment is challenging due to interactions between the equipment. In this context, our approach relies on the Design of Experiment (DoE) and the Analysis of Variances (ANOVA) statistical method for the network analysis [3].

Measurement system: traceable calibration

The main challenges in the measurement of supraharmonic emissions are: low amplitudes at high frequencies, non-invasive connections (sensors) for the public electrical networks, recording with high resolution and dynamic range to acquire even the smallest emissions.

The measurement system was designed [4] to be flexible and by considering safety aspects in the electrical network. Two channels are dedicated to voltage measurement and two other channels are used for the current measurement. These channels measure fundamental and supraharmonic components separately in order to maximize the dynamic range of the recording device.

The measurement and acquisition system was metrological characterized in the French Electrical Metrology Laboratory in a controlled environment and by means of the calibrated references. This guarantees the traceability of the measurement system and a low level of uncertainties. The linearity with the voltage, respectively the current levels and the frequency response were obtained for all 4 channels. These results lead to the implementation of the adequate corrections. The uncertainty components were estimated both for amplitude and time acquisitions. Repeatability, reproducibility, stability, average daily drift, resolution are evaluated both for fundamental and supraharmonics. In addition, the influences of the factors, such as Fast Fourier transform windows, noise, and cable length on the waveform platform are estimated. The expanded uncertainty ($k = 2$) of the waveform platform is obtained as ± 1% for the amplitude of the studied harmonics.

Measurement principle

The supraharmonic emissions are generated by the electronic converters used in the equipment, such as the PV inverters (PVI), electric vehicle chargers (EVC), heat pumps etc. The network measurement campaign with multiple factors and high sampling rate is challenging and time consuming due to the large amount of the measured data, and the required subsequent data analysis. Therefore, the Design of

Experience (DoE) approach was used. Four factors that influence the generation of supraharmonic emissions are considered: the generation equipment: i) low power, PVI$_R$ and ii) high power, PVI$_I$, iii) the load and iv) the measurement point location, MP. The applied DoE is a full factorial plan at two levels of operation. Once the factors and their position identified, an additive model with interaction effect is chosen. All possible combinations of the two levels of each factor are considered. The measurements are done on the Concept Grid platform according to the results of the chosen model. For each configuration, fundamental and supraharmonic components of both voltage and current waveforms were acquired simultaneously.

Results

The results of the measured data processing are available both in terms of harmonic amplitudes for the frequency components identified both in voltage and current signals and in terms of statistical table (Tab. 1) whose cells show the importance of the individual effects and of the interactions between factors. A color code indicates if a factor or the relationship between 2 factors is highly significant (red) or not (white).

Conclusions

The electrical network tests were carried out in the Concept Grid platform. The measurement and acquisition system is characterized and uncertainty budget is determined.

The voltage emissions are more prevalent at higher frequencies compared to the current emissions. The load and MP are the main factors, which influence the higher voltage emissions in the frequency range of 2 to 150 kHz. The interactions between the Load and MP are highly significant for the voltage emissions in the frequency range of 9 to 11 kHz, and significant for the voltage emissions in the frequency range of 79 to 150 kHz.

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Tab. 1 ANOVA results

Waveform	Frequency (kHz)	Individual Effects				Interactions				
		PVI$_R$	PVI$_I$	Load	MP	PVI$_R$ PVI$_I$	PVI$_R$ MP	Load MP	PVI$_I$ Load	PVI$_I$ MP
Voltage	2-4									
	9-11									
	19-21									
	39-41									
	59-61									
	79-81									
	99-101									
	119-121									
	139-141									
Current	2-4									
	9-11									
	19-21									
	39-41									
	59-61									
	79-81									
	99-101									
	119-121									
	139-141									