Time-Frequency Diversity Measurements in Power Systems

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Abstract

Conducted interference is rapidly increasing due to the widespread use of power electronics. This is causing an increase of interference cases, and is limiting the possibility of using the mains wiring for low-frequency power line communication, such as the mains communication system between smart meters. Increasing the mains communication signal amplitude would result in more interference, while decreasing the emission level of the power electronics via filtering would also decrease the wanted communication signal amplitude. By using low-cost digitisers for measurements of conducted emission in time domain and fast fourier transform to the frequency domain time-frequency spectrograms can be generated. These show that conducted interference is mainly cyclo-stationary and at fized frequencies, showing open areas, or slots, in time- as well as frequency-domain. These slots can be used for the mains communication. This requires smarter EMC standards, and not in frequency domain only.

1. Introduction

Because of the rapid increase of power electronics in all kind of electronic equipment the number of cases of electromagnetic interference (EMI) below 150 kHz is increasing [1,2]. Even smart energy meters are being interfered causing large deviations in measured energy readings [3]. For smart grid applications, the cases become more complicated as the meters are interconnected within the network. The two-way communication technology between home consumers and electrical providers which regulate the supply voltage within the network will read and control the meters automatically. When using mains communication systems (MCS) it becomes even more complicated as the communications have to be counted not only as a victim but also as a source of EMI. In other words, MCS is sensitive to interference but is also a source of interference. To achieve EMC (ElectroMagnetic Compatibility) in the presence of MCS the interference could be mitigated by reducing the interference level, or to reduce it via filters. However, not only the noise signal will be filtered but also the communication signal as the source and victim devices are connected in parallel and operating in the same frequency band. The several working groups are discussing now for years, using only the frequency domain into account. But most of the conducted interference is time-dependent [4], and by using both the time(T)- and frequency(F)-domain simultaneously it is possible to define areas in the TF spectrogram which are free from interference.

2. Cyclic interference

Conducted interference emission levels are defined by the assumption that the interference is time-invariant. To characterize the emission, the disturbance signals are represented in amplitude-frequency diagrams. A switching power electronic device shows in general a voltage as function of time as shown in Figure 1, where the blue line is for a short cable connected to the power electronic device, and the red line is for a long cable. In actual situations, the damped signal will be dependent of the connected cables. The conducted emission shown in Figure 1 can be divided in four time slots. The pulse period is related to the switching frequency of the power electronic device, which is in this case an Insulated Gate Bipolar Transistor (IGBT). Time slot 1 results in only a dc level, and thus no (high) frequencies are generated. In time slot 2 the IGBT is switching with a fast rise-time, creating a large conducted emission spectrum in frequency domain as shown in Figure 2.

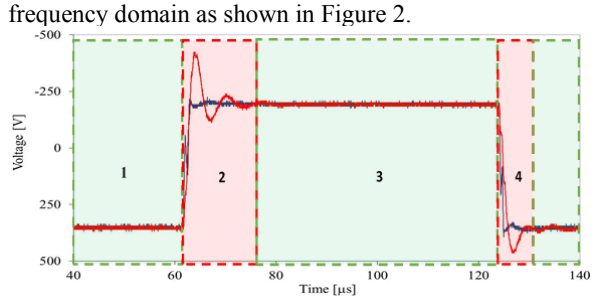

Figure 1. Four time slots of typical voltage swing of the power electronics connected to mains supply

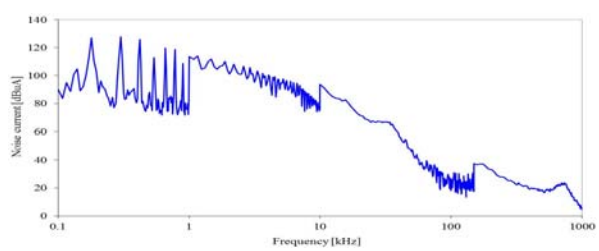

Figure 2. Frequency spectrum in time slots 2 and 4.

3. T-F domain measurements

Measurements have been performed using a low-cost PicoScope 4824. The scope has 8 channels and thus has the capability to monitor waveforms of current and voltage on all conductors of a 3-phase-plus-neutral system [5]. The maximum sampling rate is 80 MS/s for 8 channels. To obtain a clean power supply already at low frequencies (2 kHz) a 140-TMX Pacific Power source is used. This provides a clean 230 V 50 Hz using a 4-quadrant amplifier. Many measurements have been performed [5] and in general, we observed mostly cyclic, or synchronous, short-time interference in power supply networks caused by light dimmers, LED (light emitting diode) lamps and CFL (compact fluorescent lamps), switched mode power supplies. These types of noises are of short duration (a few µs) but periodic and synchronous with the mains fundamental frequency, and/or at a higher periodic rate up to several kHz, also periodic but asynchronous with the mains frequency.

Because of the time domain measurements and the fast-fourier transform (FFT) capabilities of modern computers the conducted emission can be easily represented in a TF spectrogram as shown in Figure 3. Note that the conventional time-domain EMI measuring analysers are converting the radio-frequency (RF) signal to the intermediate frequency (IF), while in this paper very basic digitisers (digital oscilloscopes) are used and thus are using direct conversion.

We can observe in Figure 3 that the interference is not only frequency dependent, as we were traditionally used to observe it, but also time-dependent. It means for each time slot the emission pattern is different.

4. Diversity

In complex wireless systems and platforms the concept of diversity is used. For example on a naval vessel, the coexistence of systems is achieved by using the following domains, either sequential or parallel:

1. Frequency domain (using different frequency bands)
2. Spatial domain (placement of transmitters)
3. Temporal domain (time-blanking)
4. Coding domain (using the coherence of signals)
5. Polarization domain (vertical, horizontal, or circular)

A similar concept, and then using the time-frequency diversity, can be applied for mains communication systems (MCS). By using the time-frequency slots showing low interference levels for the intentional emissions, MCS would be possible without requiring very high emission levels, which could cause interference in connected equipment. The concept is comparable to cognitive radio. In cognitive radio quiet frequency bands are sought. If a white space is found, this band is used for communication. In the next section measurement results show the feasibility of the concept. The most important aspect is the opportunity for standardization committees: we should not only look at frequency-level diagrams, but have to include the temporal domain to complement it. Therefore we have to use spectrograms.

In Figure 3 the area's of low emission are shown in time domain, i.e. at specific periods in time the emission level is low, and MCS should be possible.

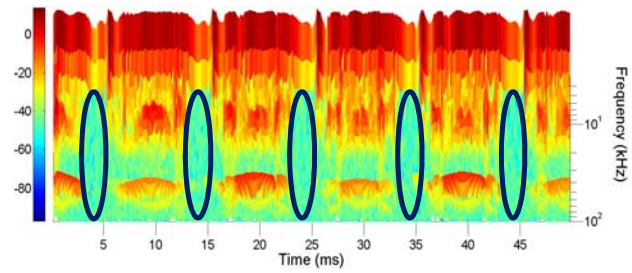

Figure 3. Slots in time for laptop power supply.

In Figure 4 it is shown that areas in the frequency domain show low emission level, i.e. MCS is possible.

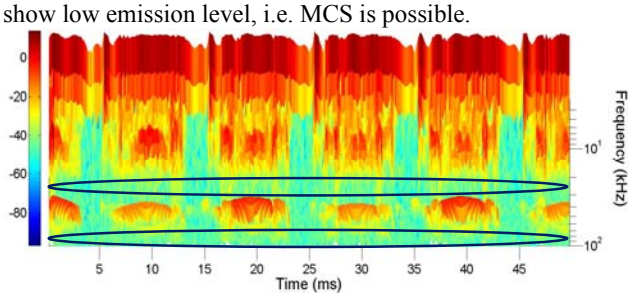

Figure 4. Slots in frequency domain for laptop power supply.

The concept of using TF-diversity for MCS is not new, and has been described in for instance [6, 7]. However, the EMC community is still thinking in the well-known frequency domain (only), resulting in a deadlock in defining smarter limits for interference. For instance the frequency domain limits for MCS in power networks, and proposed emission levels of for instance Active Infeed Converters (AIC) as used in photo-voltaic systems, have been shown in Figure 5 (from [1]).

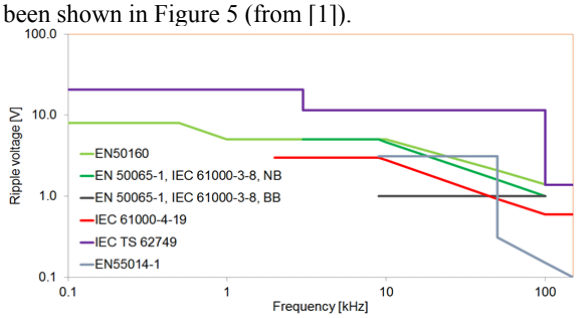

Figure 5. Conventional frequency domain limits.

It might be obvious that the standard approach of horse-trading on levels for conducted emission will not be successful, considering the large differences in Figure 5.

But when allowing high levels of interference in some time, or frequency, slot could allow MCS while not demanding for large filters to decrease the interference levels. While filters would also have a negative impact on the wanted MCS signals.

6. Conclusion

The conventional frequency-domain-only EMI limits created a deadlock in defining interference levels in standards for conducted interference. By using low-cost digitisers with fast fourier transform a spectrogram o conducted interference can be made showing that most interference is cyclo-stationary and fixed-frequency. This allows to find slots in time domain and frequency domain where emission is, naturally, low and which can be used for mains communication systems, and still achieving electromagnetic compatibility.

7. References

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