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A novel method for EMI evaluation in random modulated power electronic converters ☆

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ABSTRACT

However, the theoretical analyses as well as experimental results have indicated that ostensible reduction of the EMI level generated by random modulated converters results from the methodology of the EMI spectrum measurement, adopted in currently binding standards, rather than physical nature of interference generation phenomenon. The experimental investigations, presented in the paper, have shown that utilization of commonly used EMI measuring standards might lead to wrong conclusions in a case of assessment of electromagnetic compatibility of random modulated converters. The aim of this paper is to propose the novel, efficient method enabling objective evaluation of the EMI generated by random modulated converters.

1. Introduction

The technique of random modulation (RM) has been used in power electronic converters since the 80's [13,18]. Primarily, the purpose of RM application was the reduction of an acoustic noise linked with switching frequency of the power electronic converters. In the case of RM the power of the high frequency components is spread over a frequency range, contrary to deterministic modulation (DM), where the spectrum power density is concentrated near harmonics of a converter switching frequency. Despite significant differences in frequency domain the number of the switchings, in long enough time, remains the same for both modulations as well as the parameters of voltage slopes and interference current paths. Thus, the power of interference remains practically the same for both DM and RM modulation [17]. The spread of the interference power over frequency range, in a case of a RM, implies reduction of the highest spectrum levels in comparison with deterministic modulation [18,10,11,15,9,16,3,19,12,6]. This is why RM is often treated as EMI reduction technique for power electronic converters [1,11,15,16,19,6,7,20,8]. Unfortunately, from electromagnetic compatibility (EMC) assessment point of view the below presented case might be treated as an exemplification of the inability of currently biding EMI measuring techniques for EMC assessment of random modulated converters.

According to the definition adopted by the IEEE, electromagnetic compatibility means "the ability of a device, equipment, or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment". The producers declare EMC assurance of their product according to this definition. The fulfillment of the requirements of related standards [4] enables only presumption of conformity with EMC legal requirements. Thus, it is essential for equipment producers that standards, concerning EMI measurement techniques, should be designed in the way that allows proper assessment of EMC.

Fig. 1 shows the measured conducted EMI spectra of a computer power supply operated with a deterministic switching frequency and a RM one. The measurement was done according to the standard and using a average detector. The maximum level of the spectrum measured for the RM is 8 dB (more than 2.5 times) lower than in a case of deterministic modulation. Such significant reduction without hardware changes might be interesting for the converter designers. However, Fig. 2 shows box and whisker plots of transmission times of frame of the data, transmitted using Power Line

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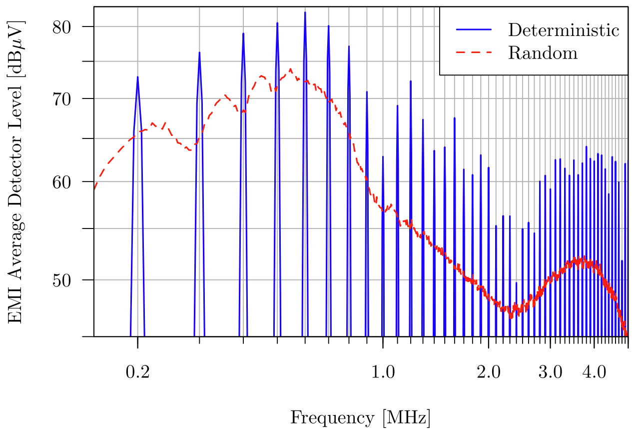

Fig. 1. conducted EMI spectra of a computer power supply operated with a fixed and randomly distributed switching frequency.

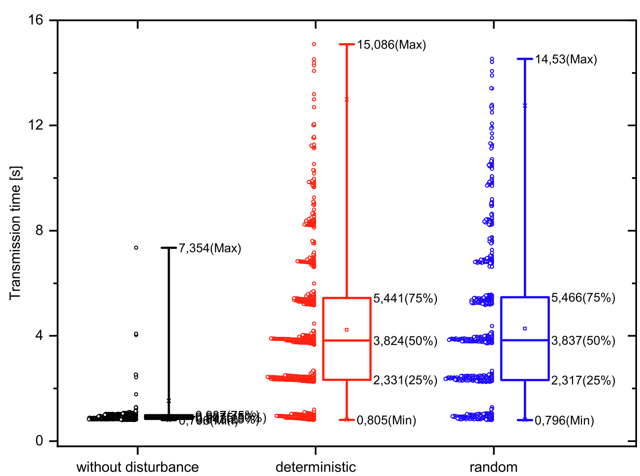

Fig. 2. Box and whisker plots of transmission time of data frame between smart meter and concentrator using PLC.

Communication (PLC) between commercially available smart meter and data concentrator.

The data frames were transmitted in system without interferences (converter switched-off) and with interferences introduced by converter with deterministic and RM – spectra presented in Fig. 1. In the system without interference the average transmission time was near 1 s. The power meter and concentrator operated properly in system without interference with transmission time declared by the producer. In the system with interference the average transmission time increased almost four times. The results are important from practical point of view, because an increase in transmission time results in a decrease of the number of power meters to be processed by the concentrator. It should be noted that, despite significantly lower level of interference (8 dB, 2.5 times) measured for RM, the box and whisker plots of transmission times for deterministic and RM are practically the same. This means that transmission errors caused by interference introduced by the converter with both deterministic and RM appear with almost the same probability.

From EMC assessment point of view, converter with RM has no advantage over the same converter with DM, despite significantly lower level of EMI, measured according to currently biding standards. As it will be shown in the paper the ostensible reduction of the interference, which might be confusing, is related to the adopted measuring technique, rather than physical phenomenon.

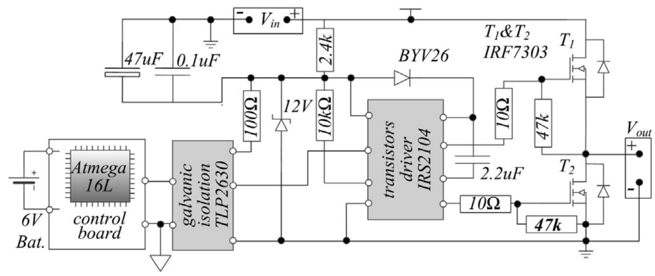

Fig. 3. The schematic diagram of the DC/DC converter.

In this paper a novel, efficient method, enabling objective evaluation of the EMI, generated by random modulated converters, in the context of EMC assessment is presented. Additionally, the theoretical background concerning EMI measuring techniques, supported by experimental results, might be interesting for designers and producers of power electronic converters as well as Smart Grid and Cyber-Physical Grid integrators, involved in EMC assurance.

All analyses and measurements carried out within the scope of the research presented in the paper have considered a half bridge DC/DC converter. To more clearly show all EMI effect related to pulse width modulation, the analyzed converter has a very simple construction, consisting only of the most important elements transistors and its drivers. A signal generator (control board with micro-controller) which may also generate EMI is galvanically isolated from the circuit. Additionally, the control board is powered by a battery, to avoid additional couplings through the power source. Fig. 3 shows the schematic diagram of tested converter. During all the test, the converter has been powered by a regulated, laboratory power supply (Fig. 4). The typical 50 μH, 50 Ω LISN has been connected between the converter and the power supply. As a load the RLC circuit has been connected to the output of the converter. Such a load is the artificial circuit for high frequency EMI current and corresponds to a typical common mode path of interference. In a real system the presented inductance can be associated with the inductance of the connecting wires. Presented capacitance corresponds to parasitic couplings to the ground.

We used a Pulse Width Modulated (PWM) signal to control the converter transistors. The internal timer of the microcontroller generates such a PWM signal. We analyzed two types of modulation, RM and DM one. According to the literature, among many types of RM the most favored, due to lowering of the harmonics, is Randomized Frequency Modulation [10,11,1,15], where the fundamental PWM frequency varies randomly. The randomness factor – RF sets the range of frequency variations. The formula for n-th PWM frequency can be presented as follows (1):

$$f_n = 1/T_n = f_{PWM} \cdot (1 + RF(rand - 1/2)) \tag{1}$$

where:

f_{PWM} – fundamental PWM frequency, *rand* – random number from the range (0–1), f_n – n-th PWM frequency.

2. Currently used spectrum measuring methodology

To assess the EMI emission following EMC standards[5,2], one needs to use an EMI test receiver. The EMI receivers are superheterodyne micro voltmeters which perform selective measurements in the frequency domain. Therefore EMI receiver typically measures a voltage, but after connecting auxiliary transducers like probes or antennas one may measure other quantities like an electromagnetic field or current.

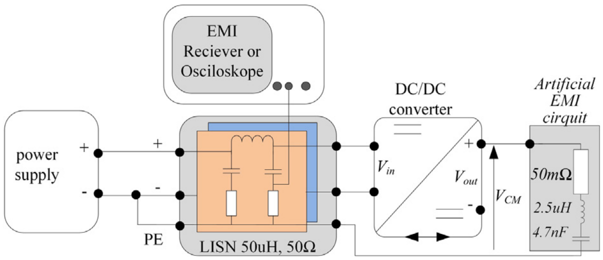

Fig. 4. The scheme of measuring test bed.

The EMI receivers are very complicated devices that have to meet many requirements related to selectivity, pulse response, intermodulation effects, noises and internal unwanted signals and shielding [5]. To explain the principle of its operation, we can assume that the receiver only consists of few main blocks. Those blocks are input, superheterodyne, selective filter, detectors, and indicator The input block adjusts the level of an input voltage. The superheterodyne shifts the input signal frequency into Intermediate Frequency (IF). After that, the selective/bandpas filter extracts the fragment of the signal. The selective filters (Intermediate Frequency filter) have the Gauss-like function shape. The precise descriptions of such filers are given in EMC standard [5]. The main parameter of the filter – IF BW (Intermediate Frequency Band Width) varies depending on the scanned frequency range. Next main element of a receiver is a detector which enable measurement of various standardized EMI parameters (peak, average, rms value etc.). Finally, the indicator presents the obtained results.

Fig. 5 shows a classic procedure of measuring the spectrum by the EMI test receiver. In the first step, the EMI receiver tunes to the required frequency in a similar way to a radio receiver (sets the frequency of superheterodyne). In the second step, the selective, Gauss- shaped filter passes the narrow part of the signal. Then the detector measures the signal parameter, e.g. the average value. After the measurement, superheterodyne changes the frequency (receiver tunes to next frequency point). The operator may set the step of measurement in every EMI receiver. Although, typically the measurement step is related with the IF BW (should be no bigger than half of the IF BW).

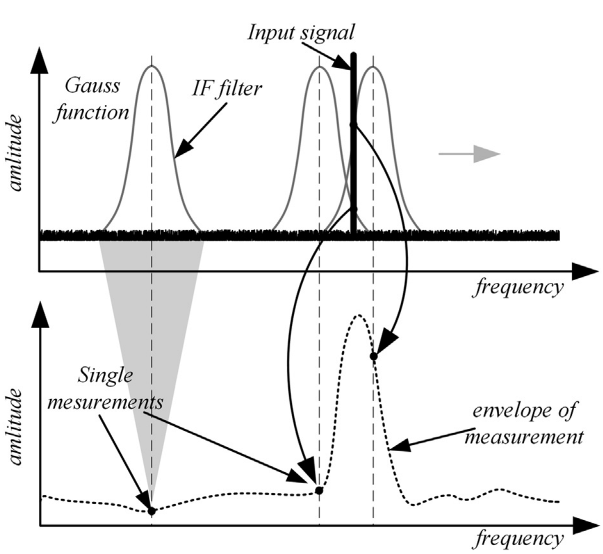

Fig. 5. The scheme depicting the process of spectrum measurements by the EMI test receiver (real input signal, IF BW filter and result of measurement using EMI receiver).

Described measurement procedure (used in receivers) may deform the results. For instance, measuring the sinusoidal signal of a given frequency we obtain the image of the IFBW filter instead of the single spectral line expected from the Fourier theorem (Fig. 5). Consequently, the IF BW significantly affects the measured value. It causes a change in the RMS value of the spectrum and also a nonlinear mapping of the spectral level (especially for multimode signals).

Another disadvantage of superheterodyne EMI receivers is the long time required for the measurement. Spectrum measurement in the full range of frequency requires a lot of single measurements. To increase the resolution, one needs to use a narrower IF BW filter. The narrower IF BW requires the shorter frequency steps and a more significant number of single measurements. However, when the duration of measurement is long a receiver may not catch the signal whose frequency varies in time. For such a signal, the level of the measured spectrum will be too low. Such a case occurs when signal frequency is changing, during measurement more than IF BW. Another and more straightforward method to obtain signal spectrum is to perform a discrete Fourier transform of the sampled signal (e.g. FFT). This signal may be sampled using any measuring devices, which provide the required time and amplitude resolution, such as oscilloscopes or data acquisition cards. The spectrum spreading effect likewise occurs in FFT analysis when signal frequency varies in measurement time. To demonstrate such an effect, let us analyze the simple example. The sinusoidal signal with amplitude one changes the frequency from $f_1 = 10$ kHz to $f_2 = 20$ kHz during observation, as shown in Fig. 6 (a) and described by the Eq. (2).

$$y(t) = rect(t) \cdot sin(2 \cdot \pi \cdot f_1 \cdot t) + rect(t - T/2) \cdot sin(2 \cdot \pi \cdot f_2 \cdot t) \quad (2)$$

where:

$rect(t) = 1 \quad for \quad 0 < t < T/2$

$rect(t) = 0 \quad for \quad T/2 < t < T$

The spectrum of such signal may be described by the Eq. (3).

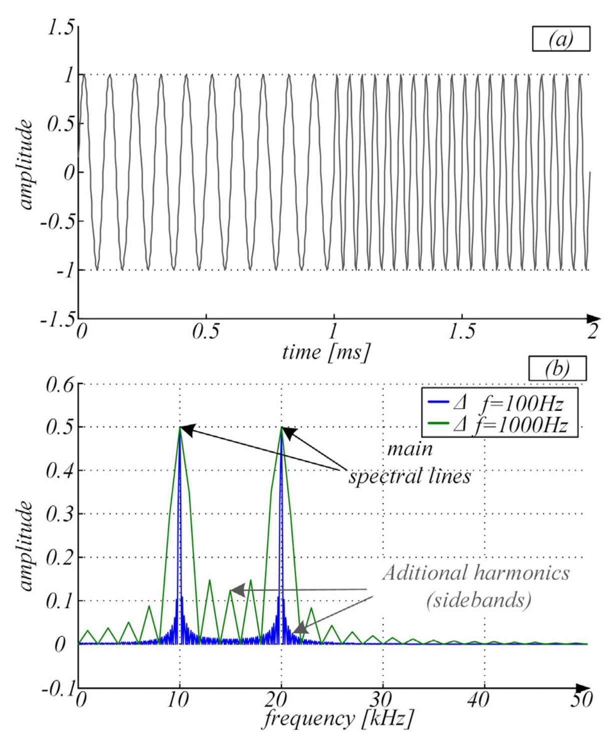

Fig. 6. The signal representation from described example (a): time domain, (b): frequency domain obtained by FFT.

$$Y(f) = \mathcal{F}(y(t)) = 0.5 \cdot sinc(\pi \cdot (f - f_1) \cdot T/2) + 0.5 \cdot sinc(\pi \cdot (f - f_2) \cdot T/2) \quad (3)$$

The spectrum, obtained by means of FFT (Fig. 6(b)) largely corresponds to the Eq. (3). The main difference is that the FFT result is discrete, and conjugate mirrored. The spectrum has a resolution Δf which is related to the measurement time – T_m according to formula (4).

$$\Delta f = 1/T_m = f_s/N \quad (4)$$

where:

T_m – measurement time, N – number of samples, f_s – sampling frequency.

In the spectrum (Fig. 6), one may see the two main spectral lines with amplitude 0.5. Those spectral lines amplitudes are proportional to the signal amplitude (observed in the time domain) and its duration. The amplitude of main spectral lines does not depend on the spectral resolution/ time of measurement. Analogously, more spectral lines with a lower amplitude occur when a signal frequency varies more times during the observation. Thus, a basic, simple comparison of the results might lead to wrong conclusions about EMI parameters. The observed amplitude in the spectrum is lower than the signal amplitude in the time domain.

Further, in Fig. 6b there are additional harmonics near two main spectral lines related to sinc function from Eq. (3). Such harmonics can be called sidebands because the analyzed signal may be treated as an FSK (Frequency-Shift Keying) modulated signal. The level of sidebands harmonics depends on the time of measurement T_m which affects spectral resolution Δf. This dependence can also be explained using the Parseval's identity when the root mean square (RMS) value of the signal is analyzed using Eq. (5).

$$Y_{RMS} = \frac{1}{\sqrt{2}} = \sqrt{\frac{\sum_{n=0}^{N-1} |u_n|^2}{2}} \quad (5)$$

where:

u_n – the amplitude of n-th harmonics (spectrum line).

The value $1/\sqrt{2}$ is a rms value of a sine function with an amplitude of 1. The rms value of two main spectral lines is equal to 0.5. The differences between the expected value ($\sim$0.707) and 0.5 is the rms value of sideband harmonics. But the number of sidebands depends on the spectrum resolution.

Thus, when the measurement duration increases, the spectrum resolution is better, and the level of sidebands is reduced. For RM, a more prolonged measurement also means a greater number of random frequencies and more main spectral lines with lower values.

3. Results of preliminary EMI spectrum measurement

The EMI related issues constitute main application problems of modern power electronic devices. The assurance of interoperability of power converters generating high frequency and high power signals with electronic environment seems to be a key aspect of modern power system development.

All kinds of signals we can analyze in the time or frequency domains. Frequency domain analysis of EMI is required in EMC standards. Therefore in this section, two ways of the EMI spectrum determination will be presented. Fig. 7 shows the EMI spectrum of the converter for two types of modulation RM and DM. The fundamental PWM frequency was set to 10 kHz, with a duty cycle of 50%. The measurements were made using the R&S ESCS30 EMI test receiver. The presented spectrum includes the conducted EMI frequency band from 9 kHz to 30 MHz (CISPR-A and CISPR-B). In the CISPR A frequency band (9 kHz- 150 kHz) IFBW was set to 200 Hz, and for the high frequency band (CISPR B 150 kHz-30 MHz) IFBW was set

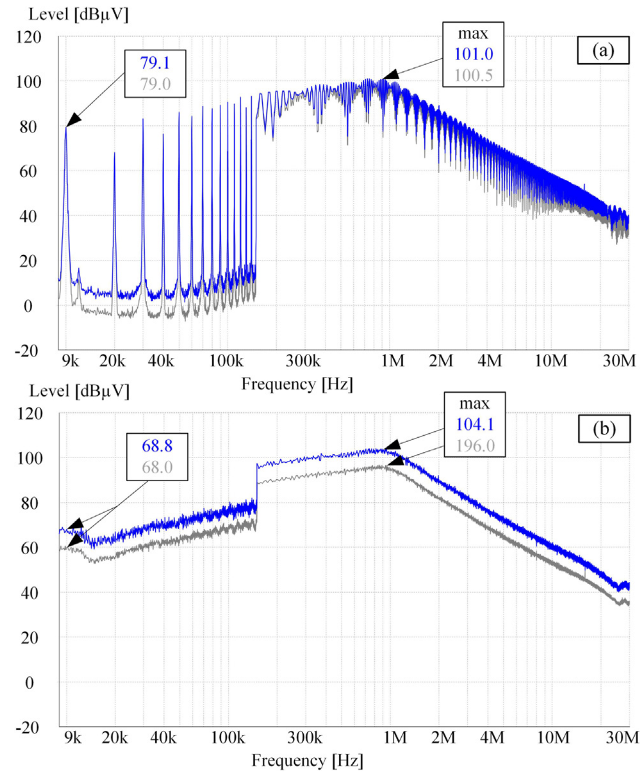

Fig. 7. The EMI spectrum obtained by EMI test receiver with LISN (a) DM (b) RM for RF = 1.

to 9 kHz, both of which are typical values selected according to the standard [5].

For DM, the most dominant harmonics, in the spectrum occur near the fundamental frequency (10 kHz) and their multiples. RM spreads the harmonics on a broader frequency band. The difference between the two modulations is more significant for the low-frequency band than for high-frequency one. The maximum level of the spectrum (observed at about 10 kHz) for DM is about 11 dB for PK detector, and 19 dB for AV detector higher in comparison with RM. The standard IF BW for CISPR A is usually too narrow for proper evaluation of random modulated signal, which frequency varies in a wider range. For a higher frequency range (CISPR-B) the measured difference between RM and DM is insignificant. In this band, RM is better than the deterministic one, for Average detector. Nonetheless the result with Peak detector for RM is slightly worse ($\approx$3 dB) than DM. Likewise, for wider IF BW, the DM seems to be better in all cases.

It is clear that, for a specific PWM frequency and its harmonics, as in presented case of 10 kHz, the measured level is higher for DM when the IF BW is narrow. For other frequencies, RM causes a higher level of interferences. The difference is bigger for the average detector than for the peak or quasi-peak, Fig. 7.

One can see the step at the frequency 150 kHz (better visible for random signals). This step is caused by the change in IF BW. This is due to the measuring principle described in the previous section. Therefore, the result obtained using the superheterodyne EMI test receiver must be analyzed with an understanding of the shown dependencies. In-depth analysis should be performed instead of typical "level-level" comparison.

The EMI spectrum may be obtained using FFT (Fast Fourier Transform). In such a case, the measurement conditions are also significant for the measurement results. For evaluating EMI emissions (following EMC standards), final measurement for at least

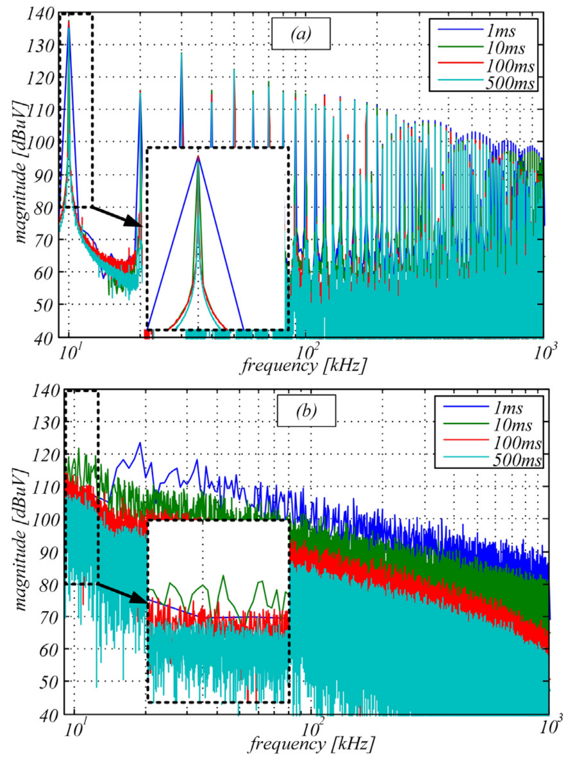

Fig. 8. The spectrum of output voltage obtained by means of FFT calculation: (a) DM (b) RM for RF = 1.

one second is obligatory. Of course, when disorders occur irregularly, the longer time of measurement may be used. However, for RM, the maximum level of the spectrum calculated by FFT depends on the spectrum resolution which corresponds to the measurement time(4). Fig. 8 shows the spectra of a converter's output voltage obtained using FFT for a few measurement durations. We measured the signal using an oscilloscope and calculated FFT from obtained samples. When the measurement duration, taken to calculate the FFTchange, the results also changed. For deterministic modulation the difference occurs mainly in the level of background. Levels of main spectral lines are practically unchanged when measurement duration changes. For RM, the level of the spectrum strongly depends on time of measurement.In general, the longer measurement duration causes the lower measurement results. The mechanism of lowering the level of the spectrum by increasing the measurement duration has been described in . In a more extended time of measurement, there are more randomly selected frequencies, and the spectrum resolution is increased. Therefore, the main harmonics and the sidebands components in the spectrum occur at lower amplitude, but they are located on a more significant number of spectral lines. For this reason, the resolution should be given for the results of the spectral calculation using FFT. Unfortunately, the authors of many scientific articles do not provide such information, which makes it difficult to compare the results reliably.

The presented results prove that RM may lower the measured level of the signal spectrum. In many cases RM may have EMI related advantages. However, in the case of communication standards based on instantaneous values of the transmitted signal such as CAN, MODBUS, MPI, PLC, extended evaluation, must be applied.

4. Spectrum aggregation

As shown in the previous section, the results of spectrum measurements vary with the settings of the measurement device for random signals. This fact might make it difficult for a direct comparison of the obtained results. At least the set of the measuring parameters should be provided to evaluate the influence of RM on EMC aspects properly. To mitigate the problem mentioned above, we can aggregate the spectrum by adjusting its resolution to the requirements. The easiest method of spectrum segregation can be done according to the Eq. (6) [14]. Fig. 9 shows such a process of spectrum aggregation schematically. The aggregation factor F_a is the number of primary spectrum bands (obtained from the FFT calculation) aggregated to one band of the resulting spectrum. Such aggregation can reduce the resolution of the spectrum. Individual harmonics are added geometrically to maintain the RMS value of the signal.

$$u'_k = \sqrt{\sum_{n>(k-1)\cdot F_a}^{n<(k+1)\cdot F_a} u_n^2} \tag{6}$$

where:

u'_k – the k-th harmonics after aggregation, u_n – the n-th harmonics from FFT calculation, F_a – aggregation factor.

4.1. Problem of spectrum aggregation

Simple harmonic summation described by (6) has some drawbacks. When the F_a factor is even number there is a problem to which frequency one must join the spectrum bands lying in the middle of the resulting bands (in Fig. 10 red harmonics for $n = k \cdot F_a$). Of course, one can change Eq. (6) by entering ">=" instead of ">", but the result may be inconsistent with the nature of the signal. The second problem will occur when F_a is not an integer number, as shown in Fig. 11. In this case the number of the summed harmonics is not equal for all spectral bands. Some of harmonics after aggregation are underestimated and some are overestimated.

4.2. Description of the proposed spectrum aggregation method

Due to the described drawbacks of simple harmonic summation, we propose to aggregate the spectra, wherein the value of a particular band is the geometric sum of harmonics in a fixed width cosinusoidal shaped window. Fig. 12 shows the graphical representation of the spectrum aggregation process. The formula for the k-th aggregated spectrum line is presented in (7).

$$u'_k = \sqrt{\sum_{n>(k-1)\cdot F_a}^{n<(k+1)\cdot F_a} u_n^2 \cdot cos^2\left(\frac{\pi(n-k\cdot F_a)}{F_a}\right)} \tag{7}$$

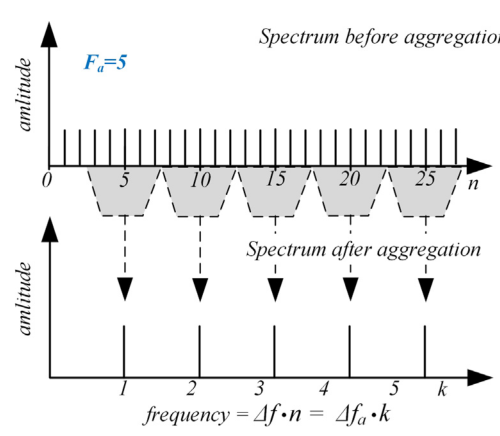

Fig. 9. Spectrum aggregation.

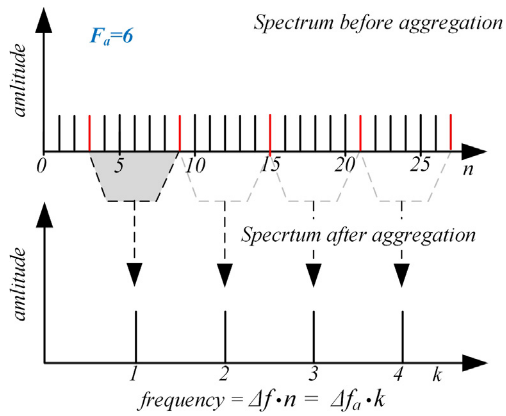

Fig. 10. Spectrum aggregation when F_a is even number.

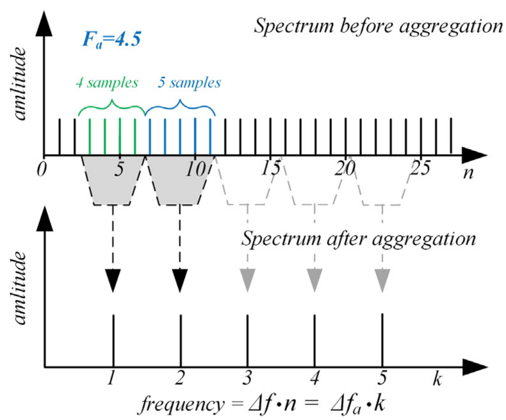

Fig. 11. Spectrum aggregation when F_a is a non-integer number.

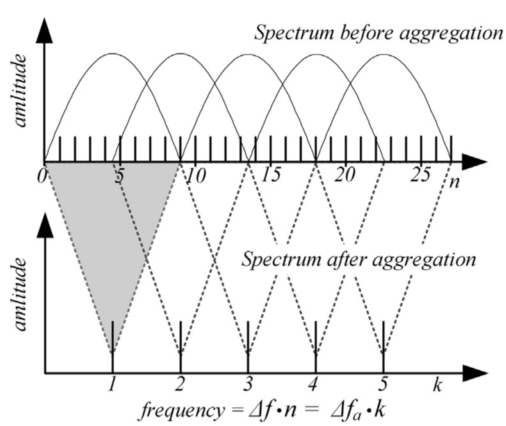

Fig. 12. The graphical representation of spectrum aggregation.

where:

u'_k – the k-th harmonic after aggregation, u_n – the n-th harmonic from FFT calculation, F_a – aggregation factor, Δf_a – spectrum resolution after aggregation.

The cosinusoidal shaped window is used to give results when the aggregation factor is not an integer number. In this case, each aggregated spectrum line is calculated for the same frequency width. The use of the cosinusoidal shaped window makes the spectra measurement more accurate, and more similar to measurement by EMI receivers.

4.3. Comparison with the EMI receiver

The proposed cosinusoidal window simulates the shape of the intermediate frequency filter used in EMI test receivers. In Fig. 13 the comparison of cosinusoidal and Gaussian windows are presented. As one can see, the difference between a Gaussian and a cosinusoidal shape is quite small. However, the trigonometric shape has an advantage in comparison with the Gauss function. According to Parseval's theorem, after aggregation the RMS value of the signal will be the same as it was before aggregation. Furthermore the Gaussian function is infinite, so one frequency band is obtained from all frequencies of the signal. In the proposed method the width of the measured window is finite and the band of frequency k is calculated from frequency range.

$k \pm \Delta f_a$. Spectral aggregation produces similar results to those from EMI receivers. However, it should be kept in mind that the width of the window is differently defined. In EMC standard CISPR 16–1-1 [5] the bandwidth IF BW is defined as an interval between the envelope of a filter at an amplitude level of 0.5, which is -3 dB. In the proposed method the width of the window is defined at the bottom of its shape and is equal to $2\Delta f_a$, as shown in Fig. 13. To obtain a measurement similar to those received by an EMI receiver, the spectrum resolution Δf_a should be equal to 0.75 of the IF BW.

Another critical issue during measurement by EMI test receivers is choosing the appropriate frequency step. In practice, it is assumed that the step should be less than half of the IF BW. Adopting such a step due to maintaining the right resolution, but it leads to an increase in the rmf value of the signal. In the proposed method a frequency step equal to Δf_a keeps rmf value of the signal and maps the harmonics amplitude linearly. Fig. 14 shows the characteristics of amplitude mapping for the proposed method and for spectrum aggregation with Gaussian window. Amplitude mapping has been calculated as a geometric sum of the analyzed window samples. The presented characteristics may also be interpreted as a spectrum of Kronecker delta scaled by the number of samples. For the aggregation, with a Gaussian window, the IF BW and frequency step was set to 200 Hz, and 100 Hz respectively, which correspond to parameters required in [5]. For the proposed method, the spectrum resolution Δf_a was set to 150 Hz. In Fig. 14, for the Gaussian window, ripples occur, while for the cosinusoidal shaped window the characteristic is linear and equal to 1, as expected. The higher amplitude for the Gaussian window is caused by a smaller frequency step.

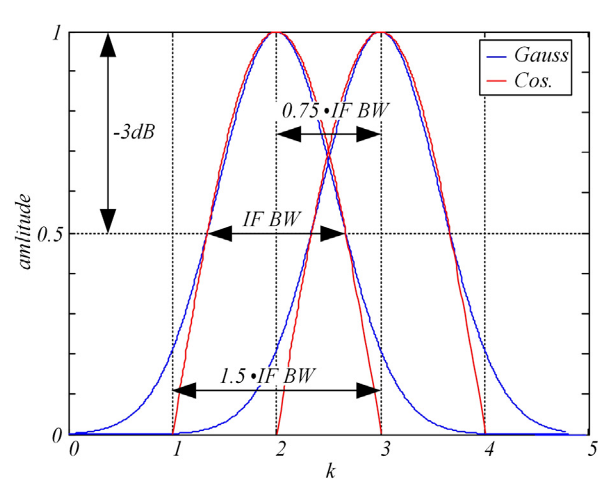

Fig. 13. A comparison of Gaussian and cosinusoidal shaped windows.

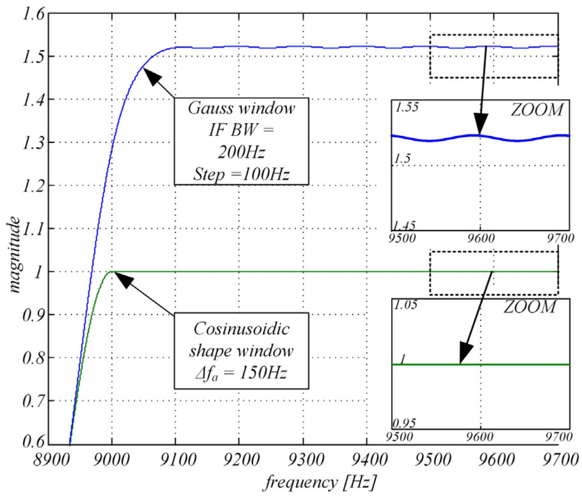

Fig. 14. Characteristics of amplitude mapping.

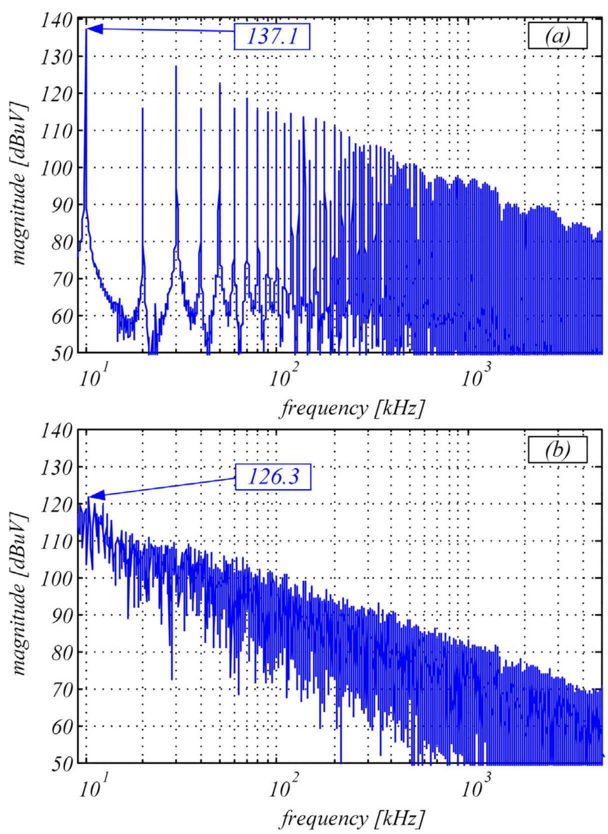

Fig. 15. The spectrum of the output voltage (without aggregation): (a) DM (b) RM for RF = 1.

4.4. Exemplary analysis of the results

The following section will show an exemplary analysis of the spectra, using the proposed method for spectrum aggregation. The output voltage signal of the DC/DC converter was measured by oscilloscope. Random and deterministic modulation was used to control converter transistors. We obtained 5 million samples, with a sampling time of 0.1 us. The measured time was 500 ms which gives a spectrum resolution of 2 Hz. The spectrum for random and deterministic modulation calculated by means of FFT is presented in Fig. 15. As it was expected, RM reduces the maximal level of the spectrum. In the presented case it is about 10 dB. It might be interesting, how the level of the spectrum will change when we change the resolution. Let's assume that the spectrum resolution will be equal to the PWM frequency of 10 kHz. Aggregation factor F_a, in this case, is 5000. Fig. 16 shows the spectrum of the output voltage after aggregation for DM and RM.

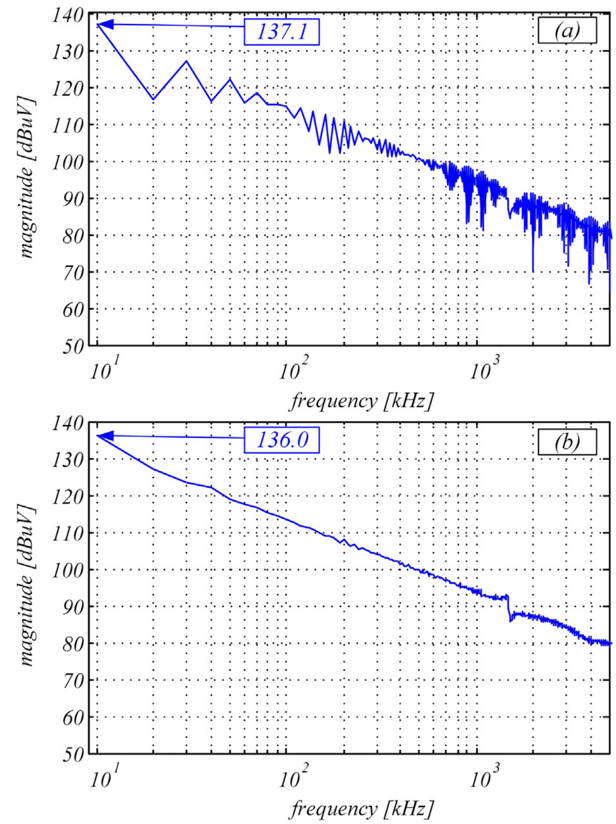

Fig. 16. Aggregated spectra of the output voltage (spectrum resolution 10 kHz): (a) DM (b) RM for RF = 1.

In the aggregated spectrum, the values of harmonics, for DM and RM are very similar. The ostensible reduction of the level of EMI by means of RM disappears. It may be assumed that for all converters, random modulation will give comparable results to deterministic one when the spectrum resolution is equal to or higher than the PWM frequency. To demonstrate this, in Fig. 17 the aggregated spectra of the output voltage with a resolution of 20 kHz are presented. In this case the spectrum level is equal for both modulation methods (the diference is below 1 dB). The components of modulation and the effects associated with the randomness of the signal are removed during aggregation. This simplifies the data analysis, and enabling direct comparison of obtained levels.

5. Conclusion

In the paper the issues associated with measurements of EMI spectra, generated by power electronic converters with PWM random modulation, have been presented.

Based on the experimental results as well as theoretical analyses it has been shown that ostensible reduction of the EMI level generated by random modulated converters results from the methodology of the EMI spectrum measurement, adopted in currently binding standards, rather than physical nature of

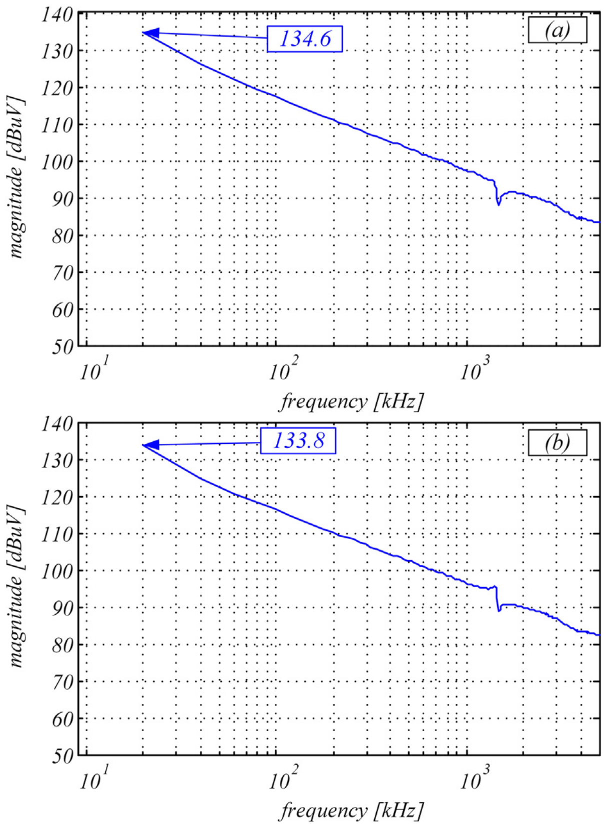

Fig. 17. Aggregated spectra of the output voltage (spectrum resolution 20 kHz): (a) DM (b) RM for RF = 1.

interference generation phenomenon. In measurements by the superheterodyne EMI test receiver, the adjustment of different IF BW filter may strongly affect the level of EMI. For the FFT method, the time of signal observation determines the results. The measurement principles as well as the particular requirements are provided in the EMC standards, however the presented investigations supported by experimental results might be important for both cognitive reason and interpretation of EMI in the context of EMC assessment. Thus in the paper a spectrum aggregation method is proposed. The presented method has several advantages over the currently binding standards:

- it gives an opportunity to change spectrum parameters at the data analysis stage,
- it allows comparison of results for several spectrum parameters, and gives latitude in choosing the resolution.
- there is no need to take care of the correct resolution during measurement,
- the rms value of the spectrum does not change during a change of parameters of the spectrum,
- all harmonics are mapped linearly.

The main problem with spectrum aggregation is choosing the appropriate width of window – the resolution of the aggregated spectrum.We may assume that the use of a broader or equally measured window than the fundamental converter frequency will give stable results for many types of modulation. Based on the analysis shown in the paper, We may conclude that lowering of the spectrum level using RM is measuring effect. Aggregation of the spectral lines in with the appropriate measurement window causes that differences RM and DM disappear, according to physical phenomenon.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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