Emission and immunity of equipment in the frequency range 2 to 150 kHz

E. O. A. Larsson, *Student Member, IEEE,* and M. H. J. Bollen, *Fellow, IEEE*

***Abstract*--This paper gives an overview of emission and immunity standards in the frequency range from 2 to 150 kHz. Based on existing standardization a complete set of limits is proposed by the authors. A distinction is thereby made between narrowband emission, broadband emission and recurrent oscillations.**

The measuring technique is vital to the results. In this frequency range, there are two different sets of standards covering measurement equipment. Due to fact of development of time-domain based instrument we propose to only use this type of instruments for the whole frequency range.

***Index Terms*--Power quality, electromagnetic compatibility (EMC), low-voltage equipment, low-voltage networks.**

I. Introduction

THE frequency range from 2 to 150 kHz is not sufficiently covered in international standards. The contrast with the frequency range below 2 kHz is striking. There have traditionally been good reasons to emphasize on the lower frequency range, where the absence of mitigation measures would lead to serious problems.

For frequencies above 150 kHz, potential interference with military and public radio broadcasting has been the driving force for standardization.

In the frequency range 2 – 150 kHz no significant sources of emission used to exist. Also no widespread problems due to high disturbance levels in this range have been reported yet.

There are however two good reasons for turning the attention to this frequency range. The first is the use of (part of) this frequency range for power-line communication. The second is the increasing use of end-user equipment emitting conducted disturbances in this frequency range.

This document will give an overview of the existing standards in this frequency range and propose additional standardization towards a more complete set of standards. The proposals are based on a range of measurements of voltage and current disturbances in this frequency range.

II. Disturbances in the frequency range 2 to 150 kHz

Measurements have been performed of the voltage distortion to which equipment is exposed in the frequency range from 2 to 150 kHz. The results of these measurements are presented among others in [1][2][3]. This work and other publications have resulted in the following subdivision of disturbances occurring in this frequency range:

- Narrowband signals appear in the form of individual frequencies, mainly due to power-line communication.
- Broadband signals are due to individual end-user equipment with active power-factor correction.
- Recurrent oscillations (typically every 10 ms) are due to limitations of the power-electronic converters around the current zero crossing.

Also equipment occasionally emits narrowband signals, e.g. remnants of switching-frequency components emitted by HF ballasts of fluorescent lamps. But these are normally much lower than the voltage emitted by mains signalling equipment.

“Broadband signals” can also be found at some power line communicating techniques. E.g. “Direct Sequence Spread Spectrum” modulation is used by some manufactures of PLC and some manufactures use “Frequency Hopping Spread Spectrum” modulation. However from our experience of measurements in the grid these modulation techniques are not that commonly used. Most “broadband signals” can be traced to power supplies and HF ballasts with APFC circuits.

“Recurrent oscillations” might also occur due to other sources such as remains from commutation at controlled rectifiers from e.g. variable speed drives. If this is the case the commutation will likely occur as recurrent oscillation which might be shifting over time due to different firing angle.

For each of these three types, emission, compatibility and immunity levels should be defined. The setting of these levels will be discussed in Sections III, IV and V. Based on the compatibility levels, voltage characteristics and planning levels can next be chosen. The measuring and analyzing technique also play a important role.

The aim of the above subdivision in three types of disturbances is not to uniquely classify every measured disturbance into one unique type. Instead the aim is to provide a framework for standardization, Classification of measured disturbances into these three types, especially automatic classification, is an interesting signal-processing challenge but far beyond the scope of this paper.

The financial support from Elforsk and from Skellefteå Kraft is gratefully acknowledged.

E.A.O. Larsson and M.H.J. Bollen are with EMC-on-Site, Luleå University of Technology, 931 87, Skellefteå, Sweden. M.H.J. Bollen is also with STRI AB, 771 80, Ludvika, Sweden.

978-1-4244-2235-7/09/$25.00 ©2009 IEEE

III. NARROWBAND SIGNALS

A. Example of measured Narrowband signals

As mentioned before narrowband signals are normally emitted by PLC equipment but also certain types of loads can generate these signals. Fig. 1 below shows the resulting spectrum from an example of a measurement where both power line communication equipment and an induction cocker is connected to the grid at the same time. The spectrum is obtained by using a time-domain sampling instrument of 200 ms and then transforming the measured signal into the frequency domain and grouping the resulting 5 Hz band into 200 Hz band according to IEC 61000-4-7. The induction cocker uses a narrow band signal most dominant at 40 kHz and the power line communication is at 43 kHz.

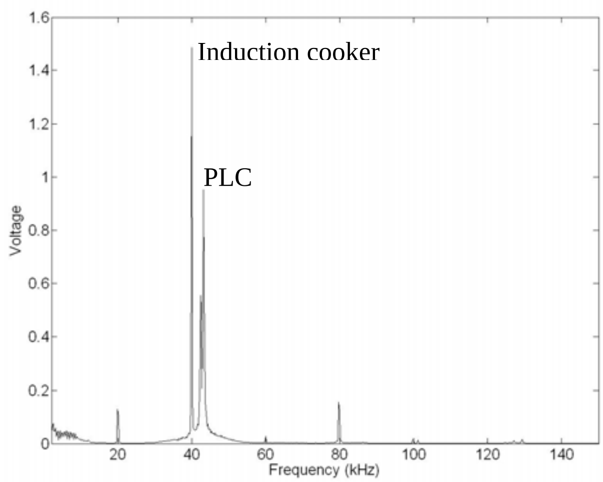

Fig. 1. Resulting spectrum from induction cooker (40 kHz) and PLC (43 kHz)

B. Existing limits

Maximum emission due to power-line communication is given in the form of voltage limits in EN 50065-1 and in IEC 61000-3-8. Voltage characteristics are given in EN 50160, where they are referred to as “voltage levels of signal frequencies”.

The emission limits according to EN 50065 and IEC 61000-3-8 are reproduced in Fig. 2 The two vertical lines indicate the frequency range of interest for this document (2 to 150 kHz). Note that the emission limits are expressed in terms of voltage. There is no reference impedance associated with this limit; the voltage after injection of the communication signal shall not exceed the indicated limit. For frequencies up to 95 kHz the limits are the same for both standards. EN 50065 does not cover frequencies above 150 kHz. IEC 61000-3-8 does give limits but these are an order of magnitude more restrictive than below 150 kHz. This is to prevent interference with commercial broadcasting (the long-wave band starts at 150 kHz).

The limit according to EN 50065 and IEC 61000-3-8 is at 134dBμV (about 2% of 230 Volt) for frequencies between 3 and 9 kHz. The voltage characteristic according to EN 50160 is equal to 5%. The large margin between the emission limit and the voltage characteristic is to allow for the presence of multiple devices and for amplification of voltage distortion due to resonances.

At 100 kHz, the emission limit according to EN 50065 is at 120 dBμV (about 0.5% of 230 Volt) whereas the voltage characteristic is at slightly above 1%. We see the same factor of two as before.

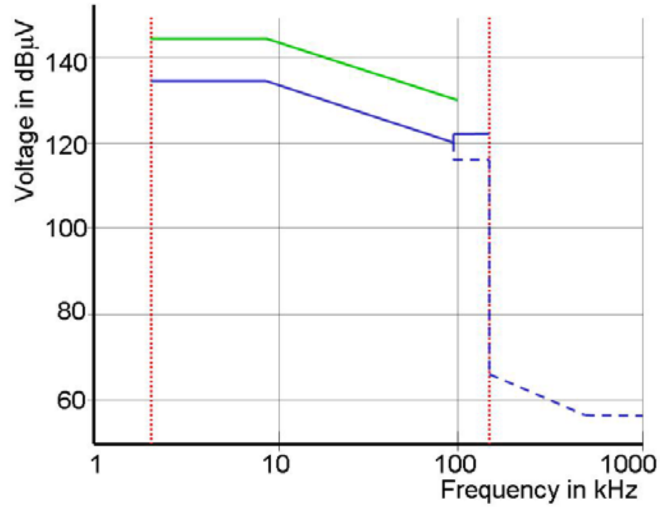

Fig. 2. Emission limits for narrow band signals according to EN 50065 (blue solid line) and IEC 61000-3-8 (blue dashed line). Up to 95 kHz the limits are the same. Voltage characteristics according to EN 50160 (green solid line).

C. Proposed emission limits

We propose to use the existing emission limits for communication equipment as shown in Fig. 2 for non-communication equipment. We propose to set the limit for narrow-band emission the same as the limit for broadband emission to be discussed in Section IV. As the emission limits for narrowband signals are much higher than for broadband signals it is important to define in the emission tests what constitutes a narrowband signal. A possible method would be to obtain the spectrum over a 200-ms window resulting in a value for every 5 Hz. Only a limited number of these values are allowed to exceed the limit for broadband emission and all values should be below the limit for narrowband emission.

D. Proposed compatibility level

We propose to set the compatibility level equal to the voltage characteristic according to EN 50160 and shown in Fig. 2 for frequencies up to 100 kHz. For frequencies between 100 and 150 kHz we propose to set the compatibility level at 130 dBμV, independent of the frequency.

E. Proposed immunity limit

According to IEC guidelines, the immunity limit for equipment should at least be equal to the compatibility level. There is no guidance available on the size of this immunity margin. As there are many uncertainties in the emission within this frequency range a relatively large immunity margin seems desirable. We propose to set the immunity level for non-communication equipment against narrow-band signals 6 dB above the compatibility level.

IV. Broadband signals

A. Example of measured broadband signals

As mentioned above loads can produce broadband signals. Fig. 3 shows an example of the spectrum measured from a HF-fluorescent lamp. The spectrum generated by the lamp starts at around 50 kHz and seems to reach to 110 kHz. The resulting spectrum shown in the figure is obtained in the same way as prescribe above to the measurement of the narrow band signal shown in Fig. 1. This resulting spectrum consists of the remains from the active power-factor correction circuit that in this case use variable switching frequency. The variable switching frequency changes from about 50 kHz at the voltage maximum or minimum up to about 110 kHz close to the voltage zero crossing. That results in that the switching frequency changes from about 110 kHz down to 50 kHz and up again about every 10 ms. Since this spectrum is achieved over a 100 ms window it will show up as a broad band spectrum. A more detailed explanation is given in [1].

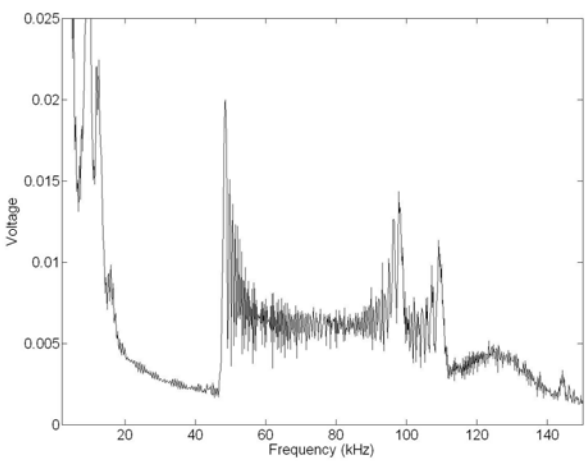

Fig. 3. Resulting spectrum from HF fluorescent lamp with APFC.

B. Existing limits

Emission limits for broadband signals by lighting equipment are given in CISPR 15. Those limits are reproduced as the blue solid line in Fig. 4. The limits are given as a voltage against a reference impedance. Limits for the emission by power-line communication equipment at frequencies not used for communication purposes is given in EN 50065. For frequencies above 150 kHz those emission limits are the same as those in CISPR 15. Fig. 4 also gives the voltage characteristics for narrowband signals, according to EN 50160, as a reference.

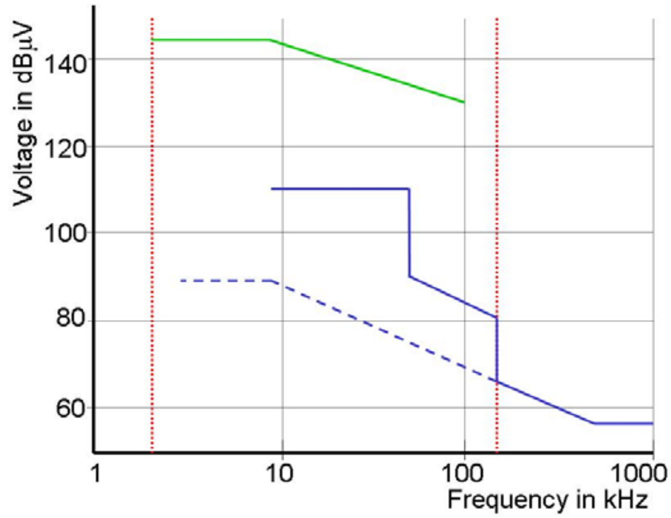

Fig. 4. Emission limits for broadband signals according to CISPR 15 (blue solid line) and EN 50065 (dashed line). The voltage characteristics for narrowband signals (green solid line) are given as a reference.

C. Proposed emission limit

From the previous section it follows that emission limits only exist for lighting equipment and only in the frequency range 9 to 150 kHz.

We propose to extend these emission limits to all devices equipped with an active interface. We also propose to extend the limits to the frequency band 2 to 9 kHz. The emission limits between 2 and 9 kHz should be the same as the limits between 9 and 150 kHz.

Recent measurements [4][5] have shown that the emission of individual equipment strongly depends on the presence of neighbouring equipment. This will have to be considered in the tests, without infringing on the requirement that the tests should be reproducible.

For broadband signals it is important to define a basic measurement window and even a method for frequency aggregation. The method recommended in IEC 61000-4-7, a 200-ms window with aggregation into 200-Hz bands, would be a suitable approach.

D. Compatibility levels

A proposal for planning levels in the frequency range 2 to 9 kHz is presented in [6]. The planning levels for frequencies just below 2 kHz have been used as a starting point in [6]. Next the assumption is made that planning levels above 2 kHz should be the same as the ones just below 2 kHz. This results in a planning level equal to 0.5% (1.15 V).

The compatibility level should be equal to or higher than the planning level.

The emission limit (against a reference impedance) is equal to 0.3 Volt in the frequency range 9 to 50 kHz.

It is recommended to use the same limit in the frequency range 2 to 9 kHz.

Using 1.15 V as a compatibility level gives a factor 3.8 between the emission and compatibility levels.

It is difficult to know, without much more detail about the emission source, how the emission from different sources will add. However, some estimation can be made. If we assume that emission is random between sources, about 14 emitters can be connected to the same locations before the compatibility level is exceeded, assuming the compatibility level is equal to the 0.5% and assuming that the source impedance is equal to the reference impedance.

If we assume that the emission of all sources is identical, about 4 units will result in the voltage disturbance exceeding the compatibility level.

For higher frequencies, above 9 kHz, no guidance exists for the choice of compatibility level. Therefore it is proposed to maintain a constant ratio between emission limit and compatibility level. This results in the following compatibility level

- 1.15 V between 2 and 50 kHz;
- Linearly decreasing from 1.15 to 0.4 V between 50 and 150 kHz.

E. Proposed immunity limits

We propose to set immunity limits 6 dB above the compatibility level.

This results in the following immunity limits:

- 2.3 V between 2 and 50 kHz;
- Linearly decreasing from 2.3 to 0.8 V between 50 and 150 kHz.

Note that the immunity of equipment should be tested against a broadband signal with a spectrum as defined by the two bullet points above. It is not sufficient to generate individual frequencies as test signals, but the equipment under test should be exposed to all frequencies at the same time.

F. A final observation

The compatibility levels proposed in this section are to a large extent based on existing disturbance levels. The proposed limits are “safe limits” for which we are reasonably certain that no widespread interference will occur. However, there are voices that point to unexplained equipment maloperation and damage that might have been due to disturbance levels within what is perceived as safe limits. On the other side are voices that express doubt on the need to set strict limits on emission in the frequency range above 2 kHz. Their argument is that these limits would pose unnecessary costs on equipment manufacturers and possibly also on network operators without that there is a well-documented case of the adverse consequences if no such limits would be set. Recently there have even arisen calls for increasing the permissible levels of harmonic voltage distortion of higher orders (15 to 40).

The expected introduction of equipment like microturbines, solar panels and battery chargers for electric cars, makes the choice of immunity and emission limits an important issue. An incorrect choice could form an unnecessary barrier against the introduction of such equipment.

V. Recurrent oscillations

From measurements it is known that these oscillations exist [1][2][3] and Fig. 5 shows an example of this. The figure is the result from a filtered phase to neutral voltage measurement of a HF-fluorescent lamp. There is however a lack of knowledge on the levels and frequencies that occur in low-voltage installations but there are some measurements showing amplitude of several volts. Therefore it is not possible to propose any limits at this stage but it is important to keep this phenomenon under observation.

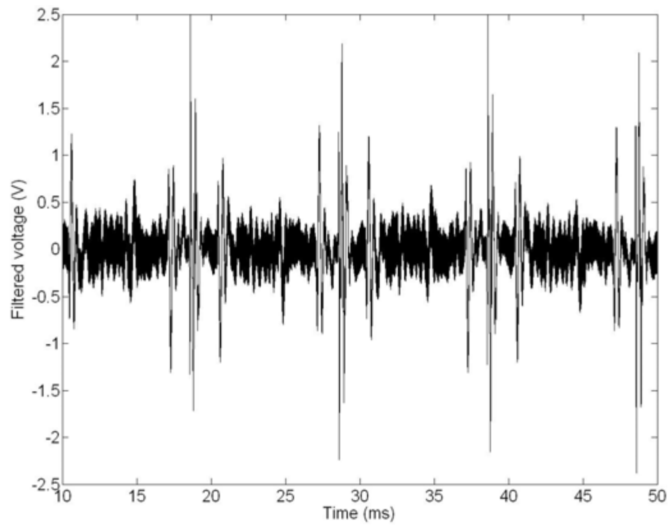

Fig. 5. Recurrent oscillation generated by HF fluorescent lamp.

The further work needed includes:

- A systematic measurement campaign to determine the existing disturbance level. This could next be used as a base for setting a compatibility level and immunity limits.
- A method for characterizing this disturbance as well as suitable indices and measurement methods.
- A study of the impact of this disturbance on different types of equipment. This should give us information on the failure mechanisms (if any) due to these recurrent oscillations. This information will be of additional help in the setting of suitable immunity levels.
- A study on the spread of recurrent oscillations through the network and the resulting oscillations in voltage due to oscillations in current from multiple sources. This information will be of help in relating a compatibility level with suitable emission limits.

VI. Measurement and analyzing technique

The frequency range 2 to 150 kHz is covered by two standard defining the equipment and analyzing methods. IEC 61000-4-7 define in an informative annex a method to measure between 2 to 9 kHz. This method is basically to sample a 200 ms time window and convert this to the frequency domain with the Discrete Fourier Transform. The 200 ms time window will result in 5 Hz frequency separation which is later grouped into 200 Hz channels. This grouping is done to harmonize this frequency range with the higher frequency range, from 9 kHz and up, covered by CISPR 16 standard. One big difference is that the CISPR 16 prescribes to use scanning receiver. The use of scanning receiver e.g.

super-heterodyne analyzer, spectrum analyzer etc is historical. Back in time this was the only way to determine all the frequency components within a signal and for the highest frequencies this is still the case today. The development of digital sampling technique, increased computational capability and storage capacity has made it possible today to go quite high in frequency with time domain based measurements.

The existence of different measuring standards below and above 9 kHz makes it necessary to use different measuring equipment to cover the frequency range from 2 to 150 kHz.

The characteristics of different signals do also affect the result of measurements. For example the magnitude of the broad-band signal shown in Fig. 3 is actually higher but the signal is not present during the whole measurement window (200 ms). This will result in a lower average value of the signal. Compared with spectrum analyzer using either peak or quasi-peak detector this would result in difference in magnitude. There are some articles [7][8] dealing with analyzing methods of time domain measurement that make them as similar to spectrum analyzing equipment with different detectors are possible.

The benefits of using time-domain measurement make it however worth to develop this further. To be able to use multiple measurements with the same measurement equipment is good. Just to stick to the same measuring technique because it has been used up to now is not a good argument. Note for instance that the load has shifted techniques today. To use the quasi-peak detector which was developed according to the human ear and the use of analogue technique doesn't justify that we should still use that detector. So we propose to use time domain measurements throughout the whole frequency band 2 to 150 kHz.

VII. Conclusions

Based on the measurement of voltage and current distortion, disturbances in the frequency range 2 to 150 kHz are divided into: narrowband signals, broadband signals and recurrent oscillations. For each of these disturbance types, compatibility levels, emission limits and immunity limits are needed to come to a working EMC framework.

Proposals are made for narrowband and broadband signals. No proposal has been made for recurrent oscillations due to the lack of information available at the moment.

Development of time-domain measurement equipment and analyzing techniques has made it possible to use only one instrument. We propose to use the time domain for measurements throughout the frequency band 2 to 150 kHz.

VIII. References

[1] Anders Larsson, High frequency distortion in power grids due to electronic equipment, Licentiate, Luleå, 2006

[2] E.O.A. Larsson, C.M. Lundmark, M.H.J. Bollen, Distortion of Fluorescent Lamps in the Frequency Range 2-150 kHz, Int Conf on Harmonics and Quality of Power (ICHQP); Cascais, Portugal, October 2006.

[3] A. Larsson, M.H.J. Bollen, M. Lundmark, Measurement and analysis of high-frequency conducted disturbances, Int Conf on Electricity Distribution (CIRED), Vienna, May 2007.

[4] S. K. Rönnberg, M. Wahlberg, M. H. J. Bollen, C.M. Lundmark, Equipment currents in the frequency range 9-95 kHz, measured in a realistic environment, Int Conf on Harmonics and Quality of Power (ICHQP), Wollongong, Australia, September 2008.

[5] Sarah Rönberg, Martin Lundmark, Mats Wahlberg, Markus Andersson,Anders Larsson, Math Bollen, Attenuation and noise level – potential problems with communication via the power grid, Int Conf on Electricity Distribution (CIRED), Vienna, May 2007.

[6] M.H.J. Bollen, P.F. Ribeiro, E.O.A. Larsson, C.M. Lundmark, Limits for voltage distortion in the frequency range 2-9 kHz, IEEE Transactions on Power Delivery, Vol.23, No.3 (July 2008), pp.1481-1487.

[7] Krug, F. Mueller, D. Russer, P. (2004). Signal Processing Strategies With the TDEMI Measurement System, *IEEE Transactions on Instrumentation and Measurement*, Vol. 53, No. 5, October 2004. pp.1402-1408. ISSN: 0018-9456

[8] Krug, F. Russer, P. (2005). Quasi-Peak Detector Model for a Time-Domain Measurement System, *IEEE Transactions on Electromagnetic Compatibility,* Vol. 47, No. 2, May 2005. pp. 320 – 326. ISSN: 0018-9375