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Interharmonics-Flicker Curves of Lamps and Compatibility Level for Interharmonic Voltages

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Abstract: - Flickers and interharmonics have an inherent relationship. The aim of the paper is to describe procedures for systematical determination of immunity of lamps to supply voltage variations caused by interharmonics. The curve of lamp immunity is presented as an interharmonic magnitude versus interharmonic frequency curve and is called interharmonic-flicker curve. The interharmonic-flicker curves of lamps are determined by utilizing a modified concept for measurement of a lamp gain factor in frequency domain and by utilizing the published limits on voltage flicker. Further a complex measured data file of interharmonic-flicker curves in various combinations of fluorescent lamps and ballasts are pointed. Measured and compared combinations include various types of fluorescent lamps, various wattages, modes of operation of the ballast and its specific designs and dimensioning of circuit elements etc. Finally, determined interharmonic-flicker curves of chosen lamps are used for proposal approach how to revise the compatibility level for interharmonic voltages relating to flicker.

Key-Words: - Light flicker, Interharmonics, Voltage variations, Flicker curve, Compatibility level

1 Introduction

The variation of the luminous flux of light sources leads to the flicker effect. From the point of view of the perception of the variation of luminous flux by a human eye, changes within the range (0.1 ÷ 35 (40)) Hz are significant. Optic perception is disturbed in a case when the magnitude of luminous flux variation exceeds a threshold value within this frequency range. Such a case is called flicker perception and the reference threshold sensitivity of the human eye to this type of disturbance has been found with a relatively high precision [3].

Light flicker in the sensitive area is given by transfer function of a light source and it is caused by the fluctuation of supply voltage. Any voltage fluctuation results in a group of subharmonic and/or interharmonic components. So the magnitude of the voltage can fluctuate if it contains one or more subharmonic and/or interharmonic components [7][2].

The transfer function of the lamps is proportional to the capability of the lamp to transfer a voltage variation to a variation of the luminous flux. The sensitivity of a light source and hence its transfer function are given by its type and principle function as well as by the wiring, circuit designing and dimensioning in a given case [2]. The ratio between the change of light output and the change of input voltage for a given modulating frequency determines the gain factor. The gain factor is proportional to the sensitivity of the lamp and determines thus its transfer function. To ensure that gain factor will be a general transfer function, the fairly linear relation between the voltage fluctuation and corresponding relative luminous flux variation must be valid. If not, the gain factor is valid only for the measured value of the interharmonic component. The definition and description of the gain factor which is determined by virtue of luminous flux frequency components and voltage can be found in [2].

The limit for lamp flicker caused by interharmonics is defined for practical use by limits of interharmonic voltages. The curve of interharmonic voltages could be called the interharmonic-flicker curve. So an interharmonic-flicker curve of an individual light source determines for each interharmonic frequency its maximal acceptable interharmonic magnitude for which no light flicker can be perceived by the human eye. That means the P_{st}=1 [4]. Actually that curve exists only for incandescent lamps 60W 230V (120V). The interharmonic-flicker curve for a 60W 230V (120V) incandescent lamp is derived from a flicker curve for rectangular voltage changes [3][4] and is defined in new standard EN 61000-2-2 [3] as compatibility level for interharmonic voltages (Fig. 1).

Fig. 2 shows the compatibility level for interharmonic voltages as function of the interharmonic frequency. The corresponding interharmonic frequency f_{IH} is calculated from beat (flicker) frequency f_M using equation as follows:

$$f_{IH} = k \cdot f_1 \pm f_M \quad for\ all\ k = 1,3,5,7,... \qquad (1)$$

where f_1 is the fundamental system frequency.

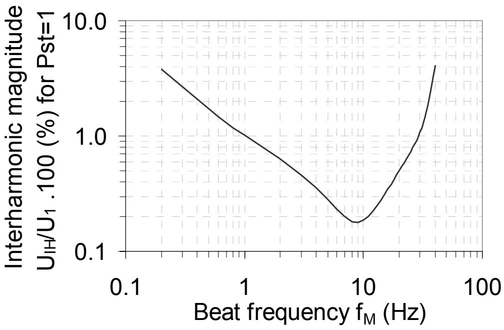

Fig. 1. Compatibility level for interharmonic voltages relating to flicker (for 230V supply network) [3]

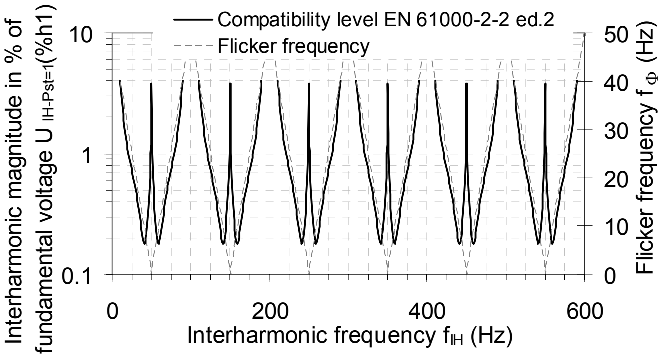

Fig. 2. Compatibility level for interharmonic voltages relating to flicker as function of interharmonic frequency.

All the calculations and the measurements are done for 230 VRMS fundamental voltage and 50 Hz system frequency.

2 Interharmonic-Flicker Curves

One of the methods how to determine the interharmonic-flicker curves for all lamps is to use the known interharmonic-flicker curve of 60W 230V (120V) incandescent lamp. (This interharmonic-flicker curve is known as compatibility lever for interharmonic voltages (Fig. 1) [3]).

2.1 Determination of interharmonic-flicker curve based on gain factor measurement

The gain factor is determined as a ratio between the change of light output and the change of input voltage for a given modulating frequency. The definition and description of the gain factor can be found for example in [5] or [8], where the gain factor is determined from time behaviors of luminous flux and voltage. Nevertheless, high speed fluctuations appear also if the modulation of luminous flux is determined as a difference between average value extremes. So it can be applied only if low-pass filter with cut-off frequency of 40 Hz is used (see Fig. 3).

If frequency components are used, the gain factor can be defined for a corresponding interharmonic frequency of voltage as [2]:

$$G.F. = \frac{\dfrac{\Delta\Phi}{\Phi}}{\dfrac{\Delta U}{U}} = \frac{\dfrac{\Phi_{f\Phi}}{\Phi_{DC}}}{\dfrac{U_{IH}}{U_1}} \tag{2}$$

where $\Phi_{f\Phi}$ is amplitude of luminous flux component at modulating (flicker) frequency:

$$f_\Phi = \left| f_1 \cdot k \mp f_{IH} \right| \quad where\ k = 1,3,5,7,...,K \tag{3}$$

Φ_{DC} is DC component of luminous flux, U_{IH} is amplitude of interharmonic voltage at frequency f_{IH} which is superimposed on the fundamental voltage with amplitude U_1 and with frequency f_1. The gain factor varies in dependence on the injected frequency and with respect to the perception of flicker the gain factor is relevant for $f_\Phi = 1 \div 35$ (40) Hz (see Fig. 3).

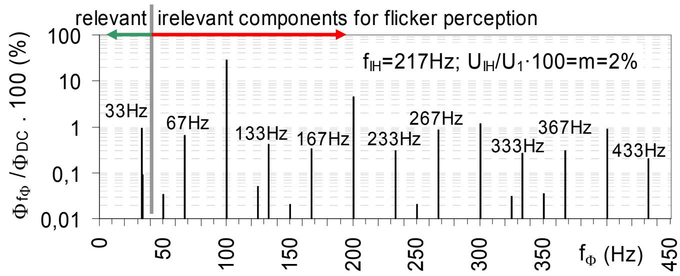

Fig. 3. Example of spectrum of relative luminous flux for injected interharmonic with a magnitude of 2% U_1 at frequency 217Hz.

The curves of the functional dependence of the gain factor are different for every individual light source and must be found experimentally. Results of measurement for many lamp types are available also in [2].

The human eye is sensitive to flicker of light not to flicker of voltage. So using the modified equation (2) the luminous flux flicker curve for 60W 230V inc. lamp could be calculated from the interharmonic voltages flicker curve (Fig. 1) and measured gain factor curve (Fig. 4a) as follows:

$$\left(\frac{\Phi_{f\Phi}}{\Phi_{DC}} \right)_{ref,Pst=1} = G.F._{ref} \cdot \left(\frac{U_{IH}}{U_1} \right)_{ref,Pst=1} \tag{4}$$

Combined luminous flux flicker curve is at Fig. 4b). All curves for reference inc. lamp at Fig. 1 and Fig. 4 are designated as reference.

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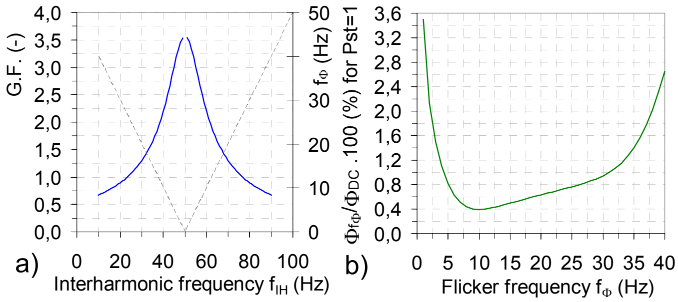

Fig. 4. Gain factor curve (a); and luminous flux flicker curve (b) for 60W 230V incandescent lamp.

For an incandescent lamp, it is well known that there is a linear relationship between the luminous flux fluctuation and the flicker measurement P_{st}. It stands to reason that the light flicker caused by single interharmonic and produced by any type of lamp is the same as the one produced by the reference incandescent lamp. Consequently, the equivalent P_{st} can be defined by equation as follows:

$$P_{st,eq} = \frac{\left(\frac{\Phi_{f\Phi}}{\Phi_{DC}}\right)}{\left(\frac{\Phi_{f\Phi}}{\Phi_{DC}}\right)_{ref}} \qquad (5)$$

So the reference luminous flux flicker curve Fig. 4b) is applicable to light flicker produced by all lamps.

It is clear that it is possible to determine the interharmonic-flicker curve out of the gain factor curve for each monitored light source by means of modified numeric method based on equation (4) and (5) [8]. (The modification is based on frequency component utilizing.) Using substitution of (4) in the equation (5) we get equation:

$$P_{st,eq} = \frac{\left(\Phi_{f\Phi}/\Phi_{DC}\right)}{\left(\Phi_{f\Phi}/\Phi_{DC}\right)_{ref}} = \frac{G.F.\cdot\left(\frac{U_{IH}}{U_1}\right)}{G.F._{ref}\cdot\left(\frac{U_{IH}}{U_1}\right)_{ref}} \qquad (6)$$

where the P_{st} has to be equal to 1. Now, from equation (6), the percentage of interharmonics which cause P_{st}=1 can be determined for a given lamp as follows:

$$U_{IH-Pst=1}(\%) = \frac{G.F._{ref}}{G.F.}\cdot\left(\frac{U_{IH}}{U_1}\right)_{ref}(\%) \qquad (7)$$

An example for FL T8 Osram 36W/21-840 with electronic ballast Beghelli 2x63W follows. Frequency of infected interharmonic is f_{IH}=217Hz and relevant modulation and flicker frequency is f_M and f_Φ=33Hz (3). The reference interharmonic level for that f_M is $(U_{IH}/U_1)_{ref}$= 1.4479% (Fig. 1). Reference gain factor for f_Φ=33Hz is $G.F._{ref}$=0.8156 (Fig. 4a- f_Φ corresponds to f_{IH} via eq. (3)). The measured gain factor of the lamp for f_{IH}=217Hz is $G.F.$=0.9729 [2]. So the calculated interharmonic voltage limit at f_{IH}=217Hz for P_{st}=1 is in case of given lamp 1.214% of U_1 (eq. (7)).

The higher interharmonic limit is the more immune is the light source to a given voltage fluctuation. The limit of immunity for each lamp is defined as the maximum level of infection (for each frequency) for which no disturbance of optic perception can be perceived by the human eye and corresponds to its interharmonic-flicker curve. Examples of calculated interharmonic-flicker curves for chosen lamps are at Fig. 5 - Fig. 8.

As can be seen the ballast type has decisive influence on immunity of fluorescent-lamp based light sources. A fluorescent lamp with active PFC electronic ballast has relatively high immunity (Fig. 7 and Fig. 8) but topology of ballast must include full voltage control loop and precision dimensioning of its parts has to be performed.

The condition for determination of a lamp interharmonic-flicker curve using this method is to know its gain factor curve. But the gain factor curves can be measured relatively easily and quickly. All of measured gain factor curves were used for calculations from [2].

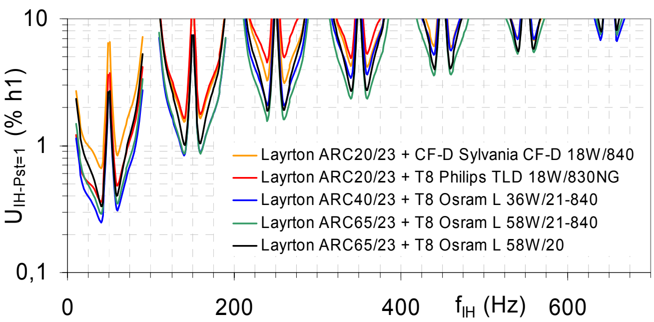

Fig. 5. Interharmonic-flicker curves of fluorescent lamps with induction ballast for various lamp types and various wattages.

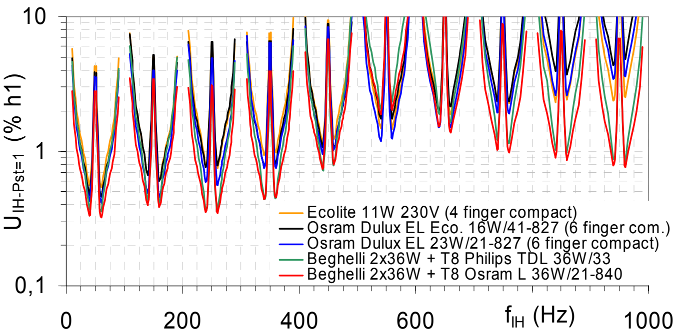

Fig. 6. Interharmonic-flicker curves of fluorescent lamps with simple electronic ballast for various lamp types and various wattages.

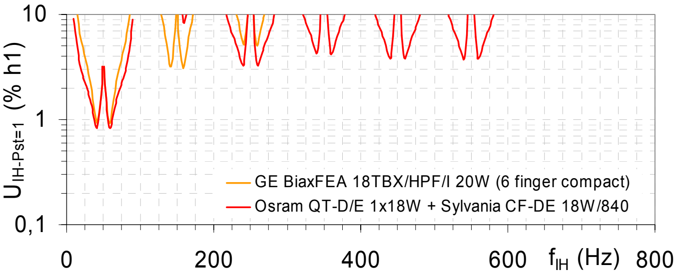

Fig. 7. Interharmonic-flicker curves of fluorescent lamps with active PFC electronic ballast (PFC with constant voltage gain).

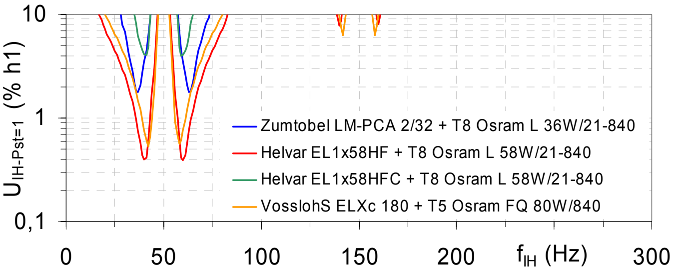

Fig. 8. Interharmonic-flicker curves of fluorescent lamps with active PFC electronic ballast (PFC with full voltage control loop).

As it has been written above, the gain factor as a general transfer function of lamp is valid only if the relation between the voltage fluctuation and corresponding relative luminous flux variation is linear. This phenomena is solved also in [2] and because the gain factor as a general transfer function of lamp is valid only in limited range of injected interharmonic magnitude and frequency for most lamps, the calculated interharmonic-flicker curves of the lamps (Fig. 5 Fig. 8) are also valid in the same limited range. Other way, accuracy of a calculated interharmonic flicker curve for f_{IH}>100Hz is strongly dependent on applied interharmonic voltage level for gain factor measurement. Practically we can use this method for frequency range from 0 Hz up to 200 Hz and for interharmonic magnitude up to 2%.

2.1 Determination of interharmonic-flicker curve based on light-flicker curve measurement

The disadvantage which is described above can be eliminated if the level of injected interharmonic voltage that causes the limit of luminous flux fluctuation (Fig. 4b) will be measured directly. Consequently this second measuring method of the interharmonic-flicker curve is based on following measurement settings. The level of an injected interharmonic at given frequency is increasing until the measured level of the relative luminous flux at corresponding flicker frequency is the limit of luminous flux flicker curve Fig. 4b). Example of measured part of interharmonic-flicker curve and its comparison with calculated interharmonic-flicker curve for a compact fluorescent lamp with built-in electronic ballast is in Fig. 9.

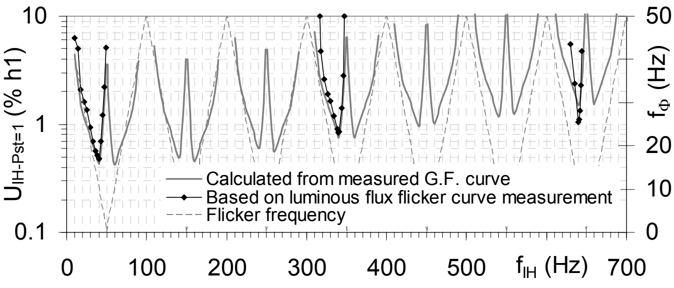

Fig. 9. Interharmonic flicker curves for compact fluorescent lamp Osram Dulux EL 23W/21-827 obtained by two different methods.

It is obvious that the measured interharmonic-flicker curve could be essentially different from the calculated one for the higher interharmonic frequencies. It is caused by ballast type. The input supply circuit of build-in electronic ballasts is almost manufactured as passive rectifier with smoothing capacitor. This circuit behaves as a detector of the supply voltage peak value. The gain factor curve for the calculation of interharmonic flicker curve is measured with constant magnitude of injected interharmonic (in this case 2%). And the relation between peak voltage fluctuation and the magnitude of the interharmonic is nonlinear over the range of interharmonic frequency Fig. 10 (derivation of curves is described in [2]). So the relationship between the measured interharmonic-flicker curve of the compact fluorescent lamp Osram Dulux EL 23W/21-827 (Fig. 9) and peak voltage variation with interharmonic magnitude for each interharmonic frequency is evident. And this is the reason why the real immunity level could be less than calculated level if calculated limit is less then magnitude of injected interharmonic used for the gain factor measurement and conversely.

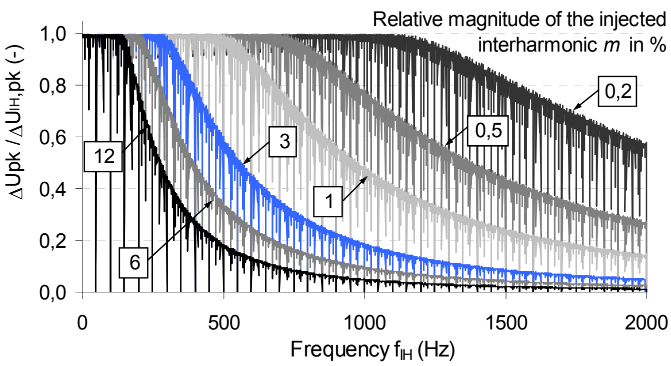

Fig. 10. The relative peak fluctuation with interharmonic magnitude distortion variation [2].

The measured interharmonic-flicker curve based on luminous flux flicker curve measurement which is shown at Fig. 9 was verified by direct measurement of human eye perception and the correspondency is better than +-10% for frequency range over 200 Hz and up to 2 kHz. But more complicated measurement is the disadvantage.

3 Proposal Approach for Revision of Compatibility Level for Interharmonic Voltages

Current compatibility level for interharmonic voltages for all frequency range from 0.1 Hz up to 2.5 kHz is based on interharmonic-flicker curve of incandescent lamp 60W 230V (120V respectively). But it is unreasoning, because the incandescent lamp can not produce the light flicker in the range of sensitive frequencies f_{Φ}= (0.1 – 40) Hz for injected interharmonic components at frequencies f_{IH}>100Hz [2]. So for use of interharmonic-flicker curve of 60W 230V (120V) incandescent lamp for definition of compatibility level for interharmonic voltages only the range of interharmonic frequencies f_{IH}= (0.1 – 100) Hz is well-founded (Fig. 2).

It stands to reason that the intersection of interharmonic-flicker curves of all lamps (used, CE marked and technically correct) has to be applied for determination of the compatibility level for interharmonic voltages in range over 100 Hz. An example of comparison is in Fig. 11. As there is shown some standard lamp types are partially more sensitive (in range of f_{IH} up to 100 Hz) than the reference incandescent lamp. A possible compatibility level for interharmonic voltages can be determined as the minimum interharmonic magnitude over all lamps for each interharmonic frequency. The result for chosen lamps is in Fig. 11.

Now it is possible to compare current compatibility level for interharmonic voltages with the minimal interharmonic-flicker curve of lamps used as the example (see Fig. 12). Confrontation of compatibility levels with the Meister curve for maximal level of ripple control signals [3] is “interesting” as well.

On the present the compatibility level for interharmonic voltages relating to flicker *Pst*=1 respects only the lamps sensitivity to interharmonic voltages, but there are appliances that are also sensitive to interharmonic voltages. Influence of interharmonics voltages for example on transformers, AC motors, turbogenerators, etc. is described in [6].

4 Conclusion

The interharmonic-flicker curves of lamps which have been found and described in this paper are very useful for compatibility assurance.

Calculated and measured interharmonic-flicker curves define immunity of each lamp to voltage variations caused by interharmonic and for immunity classification of lamps to such disturbance there has to be established a system describing their level of immunity. The space of curves can be divided into marked sections. Acceptable number of the marked sections could be up to seven, than the best lamp can be marked as flicker free. After that, it will be possible to assign the immunity class to each lamp. And lastly the new parameter, which is the lamp immunity class relating to flicker can be included into system for lighting system design and optimal choice of light source to given application.

And as it is shown the interharmonic-flicker curves of all lamps have to be applied also for a better determination of compatibility level for interharmonic voltages relating to flicker. The current limit for frequencies 100 Hz is too strict and at the same time unreasoning.

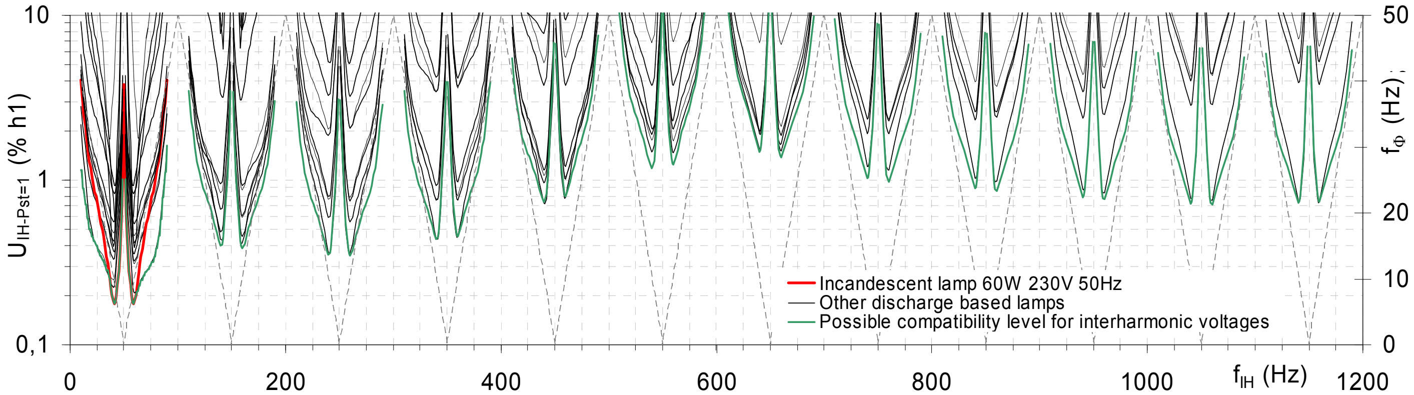

Fig. 11. Comparison of calculated interharmonic-flicker curves of chosen lamps.

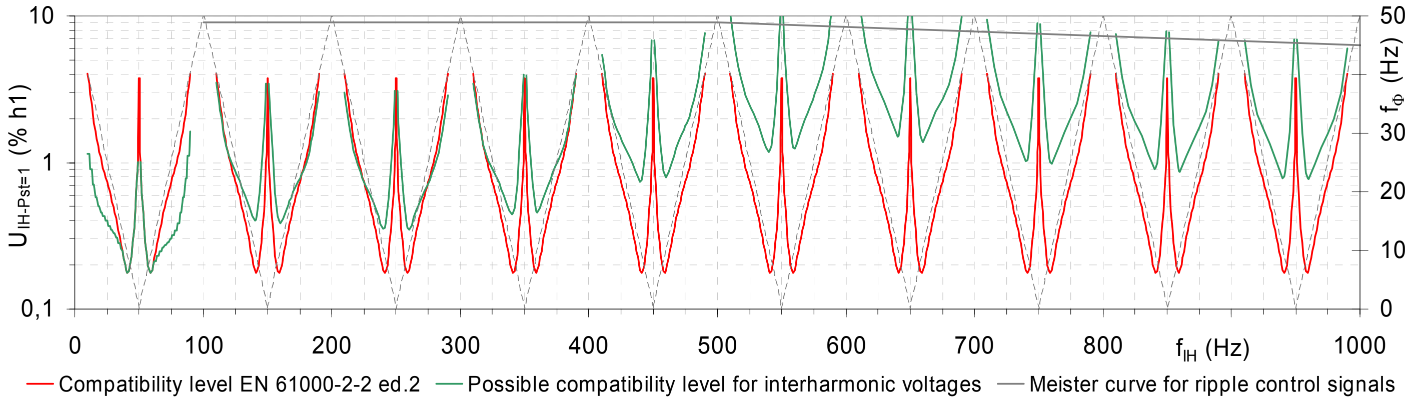

Fig. 12. Current compatibility level for interharmonic voltages in comparison with the minimal interharmonic-flicker curve (Fig. 11) and with the Meister curve for maximal level of ripple control signals.

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