Compatibility level for interharmonic voltages

FORMER APPROACH

Compatibility levels proposed for interharmonics have been defined in term of interharmonic-frequency ranges. This approach using ranges creates some difficulties, namely:

- Only one point within each range would match the Pst=1 curve. All other points in this range differ to the Pst=1 curve. For example, table 1 gives 0.5% (50 Hz) interharmonic in the range 20-40 Hz beat frequencies. However, the amplitude of the interharmonic for Pst=1 in this frequency range varies from 0.5% to 4.1%, thus up to 800% differences would be measured with the flickermeter.
- Should compatibility levels be defined in terms of interharmonic ranges, the IEC 61000-4-7 would have to specify very large observation windows (>30 cycles) and extreme accuracy requirements in order to be able to measure 0.5% amplitude in the range 58-62 Hz (or 48-52 Hz). The interharmonic assessment in this range is complicated by the fact that the fundamental component has to be removed.
- Compatibility levels must be defined for combination of lamps voltages and frequencies. Countries such as Brazil uses 127 V/50 Hz, Canada and USA uses 120V and 240 V/60 Hz, to name a few, thus levels in table 1 and table 2 are needed both for 50 and 60 Hz.
- When specified as in table 1 and 2, compatibility levels are different for the 50 Hz and 60 Hz

Table 1: Compatibility levels for 230-V lamps (Former approach)

Ranges of Interharmonic Order	Equivalent beat frequency (Hz)		Interharmonic level (% of fundamental)			
			Dr. Mombauer's values		Bergeron's values	
	50 Hz	60 Hz	50-Hz	60-Hz	50-Hz	60-Hz
$0.20 < \mu \leq 0.60$	40-20	48-24	0.51	0.69	0.50	0.68
$0.60 < \mu \leq 0.64$	20-18	24-21.6	0.43	0.58	0.42	0.57
$0.64 < \mu \leq 0.68$	18-16	21.6-19.2	0.35	0.48	0.34	0.47
$0.68 < \mu \leq 0.72$	16-14	19.2-16.8	0.28	0.38	0.28	0.37
$0.72 < \mu \leq 0.76$	14-12	16.8-14.4	0.22	0.30	0.22	0.29
$0.76 < \mu \leq 0.84$	12-8	14.4-9.6	0.18	0.18	0.18	0.18
$0.84 < \mu \leq 0.88$	8-6	9.6-7.2	0.18	0.18	0.18	0.18
$0.88 < \mu \leq 0.92$	6-4	7.2-4.8	0.23	0.20	0.23	0.19
$0.92 < \mu \leq 0.96$	4-2	4.8-2.4	0.35	0.30	0.35	0.29
$0.96 < \mu \leq 1.04$	2	2.4	0.64	0.56	0.63	0.55

Table 2: Compatibility levels for 120-V lamps (Former approach)

Ranges of Interharmonic order	Equivalent beat frequency (Hz)		Interharmonic level (% of fundamental)			
			Dr Mombauer's values		Bergeron's values	
	50 Hz	60 Hz	50 Hz	60 Hz	50 Hz	60 Hz
$0.20 < \mu \leq 0.60$	40-20	48-24	0.68	0.95	0.69	0.96
$0.60 < \mu \leq 0.64$	20-18	24-21.6	0.57	0.79	0.57	0.79
$0.64 < \mu \leq 0.68$	18-16	21.6-19.2	0.46	0.64	0.47	0.64
$0.68 < \mu \leq 0.72$	16-14	19.2-16.8	0.37	0.50	0.37	0.51
$0.72 < \mu \leq 0.76$	14-12	16.8-14.4	0.29	0.39	0.29	0.39
$0.76 < \mu \leq 0.84$	12-8	14.4-9.6	0.23	0.23	0.23	0.234
$0.84 < \mu \leq 0.88$	8-6	9.6-7.2	0.23	0.22	0.23	0.228
$0.88 < \mu \leq 0.92$	6-4	7.2-4.8	0.28	0.22	0.28	0.228
$0.92 < \mu \leq 0.96$	4-2	4.8-2.4	0.40	0.34	0.40	0.34
$0.96 < \mu \leq 1.04$	2	2.4	0.67	0.59	0.67	0.60

REVISED APPROACH

Interharmonic compatibility levels with respect to flicker phenomena can be established on the basis of beat frequency in such a way that the levels are the same at 50Hz and 60Hz, thus independent of the power-system frequency. The beat frequency is the difference in frequencies of two beating oscillations which are the interharmonic and the fundamental frequencies in this case. For example, a 0,2-Hz beat frequency with one of the oscillation at 60 Hz is produced by an interharmonic at frequency of 59,8 (or 60,2) Hz. In the case of 50 Hz the 0,2-Hz beating frequency is generated by an interharmonic at 49,8 (or 50,2) Hz. For the same voltage level, both cases 50-Hz and 60-Hz system give identical results for a specific beat frequency such as 0,2 Hz. The beat frequency is in fact the phenomenon that creates the flicker.

In view of the advantages and disadvantages, the flickermeter remains the best approach to measure flicker produced by the beat frequency phenomenon. However, flickermeters supply continuous line in the frequency spectrum as shown in Figure 1. This figure shows that the flicker response for the 120-V and 230-V lamps, are crossing over at 36,3 Hz. Such peculiar characteristic around 36 Hz is simply due to changes proposed in IEC 61000-4-15 for flickermeter specification by the IEC 77A/302/CD, in particular, the cut-off frequency of the filter needed to remove the unwanted components. Actually, the cut-off frequency is 35 Hz for 230-V lamp and 42 Hz for 120-V lamp. There is no rationale to justify different cut-off frequency for different lamp voltage, and such difference should be avoided. This concern was addressed in IEC 77A/302/CD as a note for the manufacturer to allow possible future implementation of this filter of up to a 10^{th} order Butterworth filter (perhaps 52 Hz for both 230-V and 120-V systems).

PROPOSAL TO WG8:

I recommend the use of Figure 1 and/or Equation 1 instead of the former frequency-range approach for defining compatibility levels for interharmonics with respect to flicker. The compatibility level for the 230-V lamps at beat frequencies above 35-Hz should be avoided until the IEC 61000-4-15 is amended to change the low-pass filter cut-off frequency used to remove unwanted components. This cut-off frequency should exceed 50 Hz (see the next section on other type of lamp).

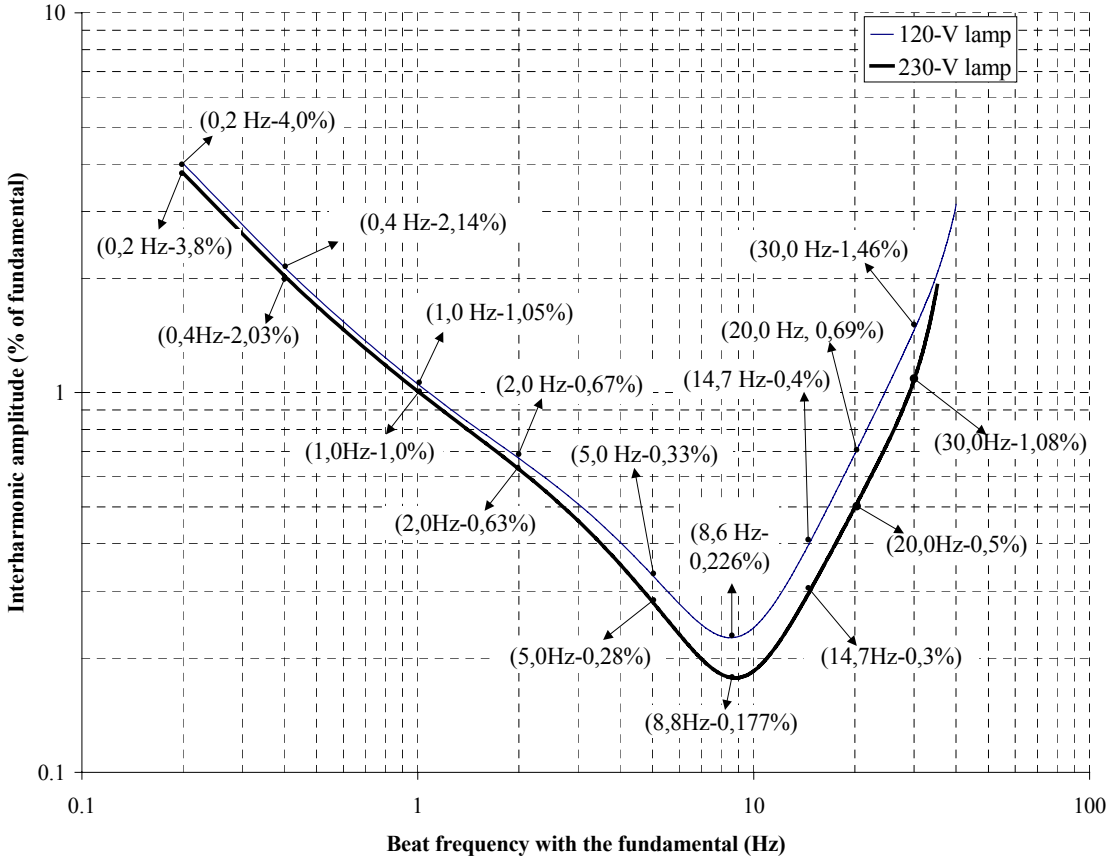

Figure 1: Flickermeter response for Pst=1 related to 60-W incandescent lamps

$$\text{Interharmonic (\%)} = \frac{a + c\times ln\left(B_{freq}\right) + e\left[ln\left(B_{freq}\right)\right]^2 + g\left[ln\left(B_{freq}\right)\right]^3 + i\left[ln\left(B_{freq}\right)\right]^4 + k\left[ln\left(B_{freq}\right)\right]^5}{1 + b\times ln\left(B_{freq}\right) + d\left[ln\left(B_{freq}\right)\right]^2 + f\left[ln\left(B_{freq}\right)\right]^3 + h\left[ln\left(B_{freq}\right)\right]^4 + j\left[ln\left(B_{freq}\right)\right]^5} \quad \text{(Eq. 1)}$$

Where:

Parameters	120 V	230 V
a	1.053667	1.008971
b	-0.72303	-0.4456
c	-1.49776	-1.15209
d	0.160338	-0.02443

Parameters	120 V	230 V
e	1.049672	0.58701
f	0.041496	0.042523
g	-0.45614	-0.20477
h	-0.02191	-0.00044

Parameters	120 V	230 V
i	0.11365	0.051585
j	0.002191	-0.00157
k	-0.01149	-0.00575
B_{freq}	Beat freq. (Hz)	

The values used to plot Figure 1 (see table 3 for reference purpose) are valid for 60-W incandescent lamps. These values were obtained by simulation with software developed in Canada to study the 120-V and 230-V flickermeter behaviour. Most of these values are almost identical to those values supplied by Dr. Mombauer (see table 1 and 2). Dr. Mombauer agreed with the results for 120-V lamp. However, he suggested reviewing the values for 230-V lamp, which seems to have a consistent 2% differences. Dr. Mombauer explained this difference by a scaling factor to be slightly adjusted. Further work needs to be performed to check this 2% but in principle, I do not have any opposition to move the curve for 230-V lamp by 2%.

Note: Table 3 shows detailed values of Figure 1 for reference purpose.

OTHER TYPE OF LAMPS:

In setting such compatibility levels for interharmonics, a problem remains, as other types of lamps are not covered adequately. PEAC conducted a few tests with different type of interharmonics and lamps. The main predictable difference between inductive fluorescent and incandescent is the higher gain response to higher frequencies (above 10 Hz) and the lower gain at low frequency. In addition, the phase jitter or periodic shape changes, typically produced by interharmonic, will cause the arc lamp to produce flicker. Still PEAC reported some flicker for an incandescent lamp due to phase jitter, which could not be explained.
With the electronic ballast fluorescent lamps, all sort of other effects have been reported but they seemed to be related more to the ballast than to the lamp characteristics; in addition, the electronics did not have a consistent or predicable behavior with voltage changes.
Still, aside from those big differences among electronic ballasted lamps (which could be solved by a simple flicker response test during design stage), the only real problem that PEAC saw with the flickermeter model for predicting complaints is the low cut-off frequency of the filter as addressed in IEC 77A/302/CD. Tom Key believes that the cut-off frequency should go up to 50 or 60 Hz to improve prediction.

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Table 3: Interharmonic voltage amplitude (% of fundamental) for Pst=1 related to 60-W incandescent lamp

Beat	Lamp voltage		Beat	Lamp voltage		Beat	Lamp voltage	
Frequency (Hz)	120 V	230 V	Frequency (Hz)	120 V	230 V	Frequency (Hz)	120 V	230 V
0,2	4,0135	3,7874	7,8	0,2304	0,1837	15,4	0,4366	0,3236
0,4	2,1427	2,0320	8,0	0,2284	0,1814	15,6	0,4463	0,3304
0,6	1,5391	1,4661	8,2	0,2271	0,1796	15,8	0,4562	0,3373
0,8	1,2365	1,1817	8,4	0,2264	0,1783	16,0	0,4661	0,3443
1,0	1,0537	1,0085	8,6	0,2263	0,1776	16,2	0,4762	0,3513
1,2	0,9304	0,8897	8,8	0,2268	0,1773	16,4	0,4864	0,3584
1,4	0,8412	0,8019	9,0	0,2278	0,1775	16,6	0,4967	0,3656
1,6	0,7727	0,7331	9,2	0,2294	0,1782	16,8	0,5071	0,3729
1,8	0,7176	0,6768	9,4	0,2314	0,1793	17,0	0,5177	0,3802
2,0	0,6713	0,6288	9,6	0,234	0,1808	17,2	0,5284	0,3876
2,2	0,6312	0,5869	9,8	0,237	0,1827	17,4	0,5392	0,3951
2,4	0,5959	0,5500	10,0	0,2405	0,1849	17,6	0,5501	0,4026
2,6	0,5643	0,5169	10,2	0,2444	0,1875	17,8	0,5611	0,4102
2,8	0,5356	0,4870	10,4	0,2486	0,1904	18,0	0,5722	0,4179
3,0	0,5094	0,4599	10,6	0,2533	0,1936	18,2	0,5835	0,4257
3,2	0,4851	0,4350	10,8	0,2583	0,1970	18,4	0,5948	0,4335
3,4	0,4627	0,4121	11,0	0,2636	0,2008	18,6	0,6063	0,4414
3,6	0,4418	0,3911	11,2	0,2692	0,2047	18,8	0,6179	0,4493
3,8	0,4224	0,3716	11,4	0,2751	0,2089	19,0	0,6296	0,4574
4,0	0,4043	0,3536	11,6	0,2813	0,2133	19,2	0,6414	0,4655
4,2	0,3874	0,3369	11,8	0,2878	0,2179	19,4	0,6533	0,4736
4,4	0,3716	0,3214	12,0	0,2945	0,2227	19,6	0,6654	0,4819
4,6	0,3568	0,3070	12,2	0,3014	0,2276	19,8	0,6775	0,4902
4,8	0,343	0,2936	12,4	0,3085	0,2327	20,0	0,6898	0,4986
5,0	0,3301	0,2811	12,6	0,3159	0,2380	20,2	0,7022	0,5070
5,2	0,3181	0,2696	12,8	0,3234	0,2434	20,4	0,7146	0,5155
5,4	0,3069	0,2588	13,0	0,3312	0,2489	20,6	0,7272	0,5241
5,6	0,2965	0,2488	13,2	0,3391	0,2546	20,8	0,74	0,5328
5,8	0,2869	0,2396	13,4	0,3472	0,2603	21,0	0,7528	0,5415
6,0	0,278	0,2312	13,6	0,3555	0,2662	21,2	0,7657	0,5504
6,2	0,2699	0,2234	13,8	0,3639	0,2722	21,4	0,7788	0,5593
6,4	0,2626	0,2162	14,0	0,3725	0,2783	21,6	0,7919	0,5682
6,6	0,2559	0,2097	14,2	0,3812	0,2845	21,8	0,8052	0,5773
6,8	0,2499	0,2039	14,4	0,3901	0,2908	22,0	0,8186	0,5864
7,0	0,2447	0,1987	14,6	0,3991	0,2972	22,2	0,8321	0,5956
7,2	0,2401	0,1940	14,8	0,4083	0,3037	22,4	0,8457	0,6049
7,4	0,2362	0,1900	15,0	0,4176	0,3102	22,6	0,8594	0,6143
7,6	0,2329	0,1866	15,2	0,4271	0,3169	22,8	0,8733	0,6238

Table 3: Interharmonic voltage amplitude (% of fundamental) for Pst=1 (continuation)

Beat	Lamp voltage		Beat	Lamp voltage		Beat	Lamp voltage	
Frequency (Hz)	120 V	230 V	Frequency (Hz)	120 V	230 V	Frequency (Hz)	120 V	230 V
23,0	0,8872	0,6334	28,8	1,3469	0,9757	34,6	1,9776	1,7647
23,2	0,9013	0,6430	29,0	1,3649	0,9914	34,8	2,0057	1,8126
23,4	0,9155	0,6528	29,2	1,3832	1,0075	35,0	2,0344	1,8626
23,6	0,9298	0,6627	29,4	1,4016	1,0241	35,2	2,0637	1,9148
23,8	0,9443	0,6726	29,6	1,4202	1,0412	35,4	2,0937	1,9693
24,0	0,9588	0,6827	29,8	1,439	1,0589	35,6	2,1245	2,0262
24,2	0,9735	0,6929	30,0	1,458	1,0771	35,8	2,1561	2,0855
24,4	0,9883	0,7032	30,2	1,4772	1,0959	36,0	2,1886	2,1475
24,6	1,0032	0,7136	30,4	1,4966	1,1154	36,2	2,2219	2,2121
24,8	1,0182	0,7242	30,6	1,5163	1,1356	36,4	2,2562	2,2795
25,0	1,0334	0,7349	30,8	1,5362	1,1565	36,6	2,2914	2,3498
25,2	1,0486	0,7457	31,0	1,5564	1,1781	36,8	2,3277	2,4231
25,4	1,064	0,7566	31,2	1,5768	1,2007	37,0	2,365	2,4994
25,6	1,0796	0,7677	31,4	1,5975	1,2240	37,2	2,4034	2,5790
25,8	1,0952	0,7790	31,6	1,6184	1,2483	37,4	2,4431	2,6618
26,0	1,111	0,7905	31,8	1,6397	1,2736	37,6	2,4839	2,7480
26,2	1,1269	0,8021	32,0	1,6612	1,2998	37,8	2,5261	2,8378
26,4	1,143	0,8139	32,2	1,683	1,3272	38,0	2,5696	2,9311
26,6	1,1592	0,8260	32,4	1,7052	1,3557	38,2	2,6145	3,0283
26,8	1,1755	0,8382	32,6	1,7276	1,3853	38,4	2,6609	3,1292
27,0	1,192	0,8507	32,8	1,7502	1,4161	38,6	2,7087	3,2341
27,2	1,2086	0,8634	33,0	1,7728	1,4479	38,8	2,7582	3,3432
27,4	1,2253	0,8763	33,2	1,7947	1,4801	39,0	2,8091	3,4563
27,6	1,2422	0,8896	33,4	1,8177	1,5144	39,2	2,8617	3,5738
27,8	1,2593	0,9031	33,6	1,8444	1,5528	39,4	2,9156	3,6958
28,0	1,2765	0,9169	33,8	1,8706	1,5921	39,6	2,9705	3,8222
28,2	1,2938	0,9311	34,0	1,8968	1,6327	39,8	3,0245	3,9142
28,4	1,3114	0,9456	34,2	1,9232	1,6749	40,0	3,13	4,0500
28,6	1,3291	0,9604	34,4	1,9501	1,7188			