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# Input to EPA consultation on Power Factor requirements for LED lights as given in Version 2.0 (FINAL DRAFT) of its Eligibility Criteria for Lamps (Light bulbs)


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**Background:**

AccurIC Ltd is a UK-based innovator in the area of LED lighting and is particularly focussed on developing ultra-low flicker, ultra-deep dimming power electronics. Its CEO, Dave Bannister, was a member of the IEEE P1789 Working Group on LED flicker that produced the IEEE Recommended Practices document which specifies acceptable levels of flicker in LED lighting. Against that background, we welcome the opportunity to give input into the V2.0 final draft of the eligibility criteria for LED lamps. We particularly wish to comment on the proposed change to the Power Factor specification which we see as a retrograde step. Our comments are made primarily in response to the justification offered in Note Box 15 and draw upon an analysis of leading peer-reviewed research into the likely and easily avoided impact of PF degradation on the grid and in particular upon transformers.

**Comments:**

We begin by drawing the EPA's attention to the fact that the effect of low Power Factor – both in displacement and distortion terms – on the overall quality of power distribution within the grid has been investigated and modelled by several research teams in the context of CFL. These include Jabbar et al (1) Nohra et al (2) and Al-Naseem & Adi (3). The most relevant of these pieces of research in the context of the proposed change to the PF specification for LED lamps is (2). This research specifically investigated the effect of introducing relatively low PF lamps into an ensemble of devices, where the other devices (50 Refrigerators and 50 TVs) presented an aggregate inductive load to the grid and where collectively, these other devices had a combined Power Factor of 0.84, and where this combined PF was made up of a displacement PF (Cos$\phi$) of 0.875 and a THD of 25.13%. The model used to represent each CFL lamp was fitted, with high accuracy, to measured results. Each CFL drew a fundamental input power of 23W and had a PF of 0.648, which was made up of a displacement PF of 0.932 and a THD of 102.1%. These PF, DPF and THD figures for CFL lamps at this power level are fairly typical.

The model of each CFL (fitted to real measured data) was then used by Nohra et al to model the effect of replacing 100W incandescent lamps with 23W CFLs within the ensemble of electrical devices. The effects (shown in figs 8, 9 and 10 of (2)) show some startling and from a grid resilience perspective, highly worrying results. Taking just one representative example, where the number of lamps is 600 (12 lamps per refrigerator) the overall PF for the ensemble drops from 0.945 (using incandescents) to 0.895 (using CFL) and the overall THD for the ensemble increases significantly, from 8% to 44%. Already, from this one result and indeed from all the results presented in (2) we can see the basic problem. A relatively small (though not insignificant) drop in overall PF, resulting from a move from incandescent to CFL is actually masking a far more significant increase in THD.

Several peer-reviewed research publications over the last few years have highlighted the fact that one of the most significant causes of increased transformer failure in electrical distribution grids worldwide has been the increasing accumulation of current harmonics that has accompanied the introduction of CFL technology (3,4,5,6). Having reviewed the effect on network-level THD of CFL proliferation it is necessary to expand this analysis further, in order to investigate the corresponding effect of LED lamps meeting the overall PF specification at 10 Watts (for which the EPA are proposing a reduced PF specification of 0.6). In performing and reviewing such an analysis, it is important to keep in mind that any reduction in PF specification is pretty-much certain to lead to an increase in THD in lamps that target this lower PF specification. The reason high PF LED lamps have a high PF is because they have a low THD value. Put another way, the reason CFL lamps tend to have low PF's is because they have poor THD values.

In order to investigate, with a high degree of confidence, the effect of the proliferation of low PF (high THD) 10 Watt LED lamps, we begin by recreating the results of Nohra et al, through the re-creation of the mathematical model that lead to their results. We then drop the power per lamp from 23 Watts to 10 Watts and set the THD of each lamp to a value that results in a lamp-level PF of 0.6. We then look at what the use of such a lamp technology would have on the overall THD of an ensemble of electrical devices including the lamps, together with an overall inductive load, including refrigerators and TVs. Figure 1 below shows the re-creation of Nohra et al's results for the THD of the ensemble (50 TVs, 50 Refrigerators and an increasing number of 23 Watt lamps, each with a PF of 0.648, made up of a displacement PF of 0.932 and a THD of 102.1%). This figure provides a very good fit to the results of Nohra et al, with modelled overall THD within 0.5 percentage points of the results presented by (2).

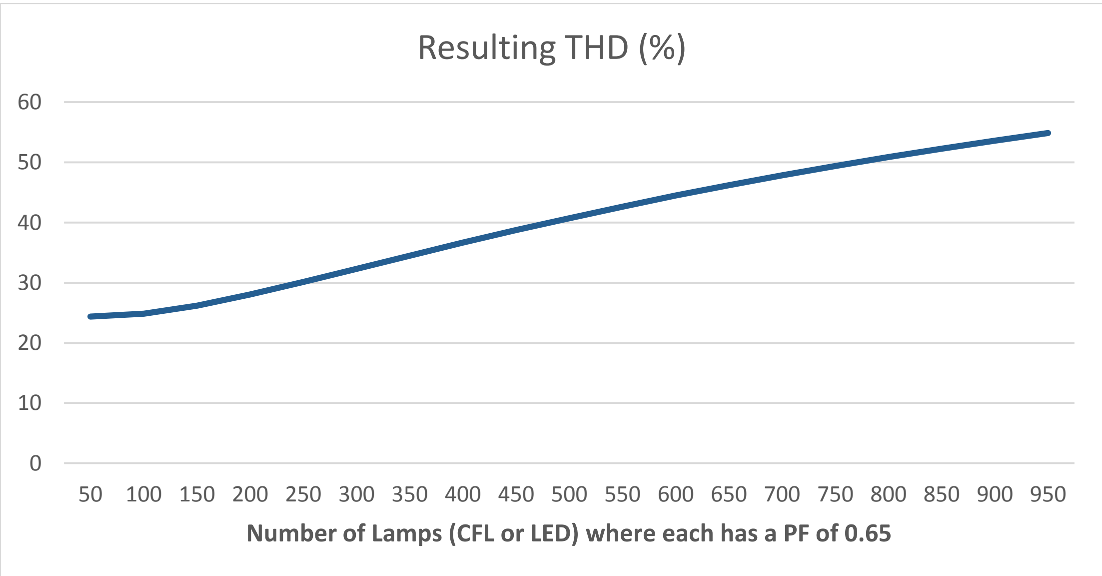


***Figure 1: Overall THD for 50 TVs, 50 Refrigerators and a varying number of lamps, each with a fundamental input power of 23 Watts and a PF of 0.648, made up of a DPF of 0.932 and a THD of 102% (as per Nohra et al)***

This degree of fit between the results presented at (2) and the output of the mathematical model enables us to then to change the input parameters of the model in order to predict, with a high level of confidence, the combined THD of the same ensemble of devices, where the lighting load comprises low-energy lights, each having a fundamental input power of 10 Watts and a PF of 0.6.

Figures 2 shows the results using 10 Watt LED lamps, each with a PF of 0.6, made up of a DPF of 0.93 and a THD of 125%. We see a very similar result to that when using the 23 Watt CFL lamps. Namely, a THD that increases with increasing lighting load and which has a value of 35% for 600 lamps combined with the 50 TVs and 50 Refrigerators.

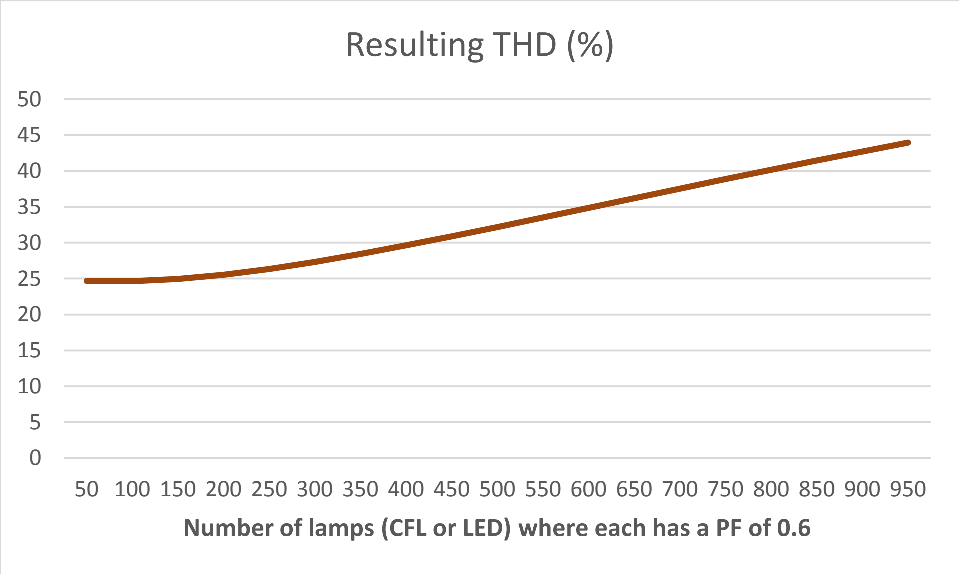


***Figure 2: Overall THD for 50 TVs, 50 Refrigerators and a varying number of lamps, each with a fundamental input power of 10 Watts and a PF of 0.6, made up of a DPF of 0.93 and a THD of 120% (as allowed under the proposed draft of v2.0 eligibility criteria)***

The result shows up a number significant problems, from a grid management perspective, of specifying a PF of 0.6 for lamps drawing an input power of 10 Watts each. Firstly, the degradation in lamp-level PF (from the already very low 0.7, to 0.6) will almost certainly result in manufacturers placing on the market, lamps with high THD levels. The reason for this is simple. Those lobbying for such a reduction are looking for an opportunity to trade-off THD against flicker. By 'shaping' the incoming current draw (making it less sinusoidal) one can very easily reduce the corresponding current ripple and therefore flicker at the output. However, figure 2 shows precisely what happens to network-level THD as a result. When one considers that the heating (and therefore, transformer lifetime-degrading) effects of harmonic generation are related to $THD^2$ one can easily appreciate that this is NOT a desirable direction of travel. Secondly and even more importantly, the network/grid-level THD resulting from a combination of inductive and capacitive loads, where each capacitive load has this level of performance is dependent upon the ratio between the number of capacitive loads (CFLs or LED lamps) and the number of inductive loads (such as refrigerators) – thereby making the business of network planning and sizing a significantly more difficult problem than it ever was in the days of incandescent lighting. This is, in our opinion, simply asking for trouble. Grid resilience has been shown (3,4,5,6) to be compromised by the increasing proliferation of low PF, high THD CFLs. This should not be added to, through the proliferation of low PF, high THD LED lamps.

Finally, it is important to demonstrate the fact that it doesn't need to be like this. There are a number of LED lamps on the market with high PF, low THD performance and in which the requirement for flicker-suppression at 100-120Hz is being addressed. If PF was specified at 0.9 for LED lamps at all power levels relevant to mass incandescent replacement (around 8 Watts and above) – which in turn necessitates low THD (below 20%) the behaviour of network/grid-level THD would look like fig 3 below.

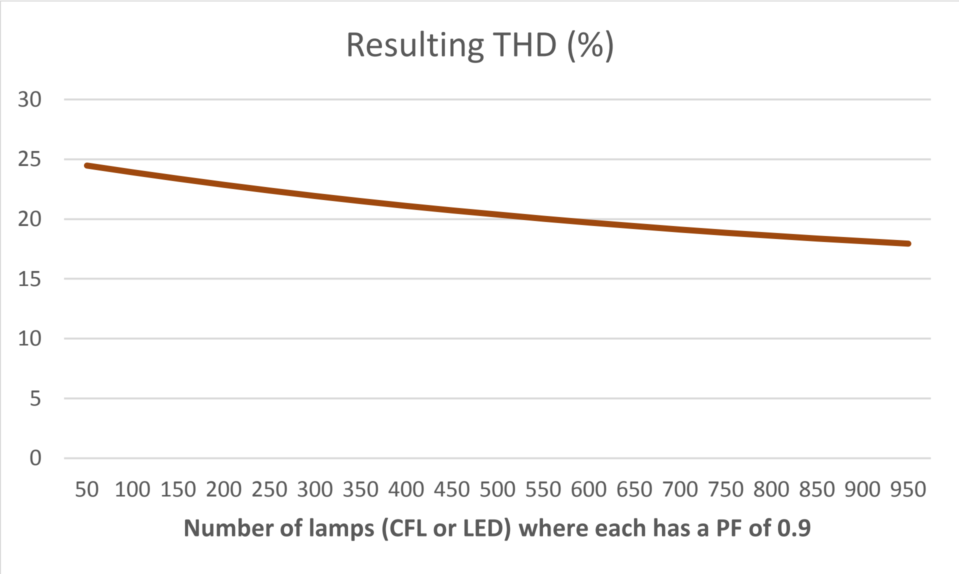


***Figure 3: Overall THD for 50 TVs, 50 Refrigerators and a varying number of lamps, each with a fundamental input power of 10 Watts and a PF of 0.9, made up of a DPF of 0.93 and a THD of 20% (as provided by LED lamps, using active PFC)***

One can see from fig 3, that the proliferation of LED lamps with a PF of 0.9 and a THD of 20% (of which there are several affordable examples already on the market) would not only give rise to low levels of grid-level THD, but would also make the task of maintaining grid resilience much easier, as the grid-level THD would be far less dependent upon the degree of proliferation. LED lighting could then proliferate without compromising the resilience of the grid.

**Conclusion:**

The EPA should be looking to increase the PF specification for LED lamps, from 0.7 to 0.9 – not to reduce it to 0.6. Doing the latter, as proposed in the V2.0 final draft, for input powers up to 10 Watts (a power level equivalent to a 60 Watt GLS lamp) would simply be allowing lamp manufacturers to address the flicker issue, by creating another problem elsewhere in the grid (that of transformer lifetime degradation/burn-out and an increase in the frequency of associated power-outages). Such a move would be particularly lamentable given the improving flicker performance of high PF LED lamps.

Furthermore, given the importance of Total Harmonic Distortion in determining the thermal stress placed on transformers within the grid, we strongly recommend that THD should be specified within the Energy Star criteria for light sources that display non-linear electrical behaviour, such as CFL and LED. It is overwhelmingly the case that THD varies significantly between lamps, whereas Displacement Power Factor (DPF) does not. The relatively small variability of the latter effectively masks the variation of the former.

**References:**

*(1) 'Impact of compact fluorescent lamp on power quality'. IEEE Australian Power engineering conference, 2008, Ranna A. Jabbar et al.*

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