RESULTS OF LABORATORY TESTS AND ANALYSIS TO QUANTIFY THE ELECTRICAL BEHAVIOUR OF THE MODERN CFL

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With the federal government banning the sale of traditional incandescent general lighting service (GLS) light bulbs from 2009, the only viable short-term alternative for domestic customers is the Compact Fluorescent Lamp (CFL). Important technical challenges may arise as a result of wide spread installation of CFLs. It is well known that the CFL is a highly non-linear load and mass installation has the potential to increase voltage harmonic levels on the electricity network. Given the distributed nature of the domestic lighting load, if harmonic levels become a problem they will be extremely difficult to mitigate.

That the CFL presents an energy saving on traditional incandescent light sources is undeniable. CFLs consume some 75% less active power for the same stated light output as traditional incandescent globes. Reductions in lamp power requirements present a suite of benefits to both consumers and electricity supply utilities including reduced electricity bills for consumers, and reduced active power demand and network losses for electricity supply companies. On average, CFL lamp life is also considerably longer than that of traditional incandescent lamps.

HIGHLY NON-LINEAR LOAD

On the downside, CFLs are a highly non-linear load. This means that they will draw a significant level of non-active or harmonic power. The highly non-linear nature of the CFL load presents 2 main drawbacks. The first is that the harmonic power of the device must be delivered by the electricity network to the lamp. As such the overall (active and non-active) power saving to the electricity supply company is somewhat less than the touted active power savings. The electricity supply utility may also experience non-active power losses that did not exist before CFL installation. The second main issue relates to questions regarding the impact of the harmonic current drawn by the CFL on distribution network harmonic voltage levels. Given the highly distributed nature of the CFL load, mitigation of harmonic currents due to CFLs would be extremely difficult if not impossible.

MUCH REDUCED LIFESPAN

CFLs also have some other electrical characteristics which may not be desirable. Basic CFLs cannot be used with dimmers. CFLs are also not suited to places where they will be switched on and off regularly over short periods as this leads to much reduced lifespan. There are also concerns about the light output intensity and colour as well as the time taken by many lamps to come up to full brightness. In addition, it is well known that CFLs will not operate well under low temperature conditions and the lamps may not light at all if the ambient temperature is too low.

THE CFL CIRCUIT

Most modern CFLs have very similar circuits. This circuit consists of 3 main sections; AC bridge rectifier, EMI filter and half bridge inverter. A photograph of the components of a basic CFL circuit is shown in Figure 1a. There are also some CFLs which include additional components to provide some filtering to minimise current waveform distortion. These CFLs are known as high power factor CFLs due to the fact that they improve the true power factor. A photograph of the components of a high power factor CFL is shown in Figure 1b. It can be seen that there is a much higher component density on the PCB for the high power factor CFL (Figure 1b) than is the case for the basic CFL (Figure 1a).

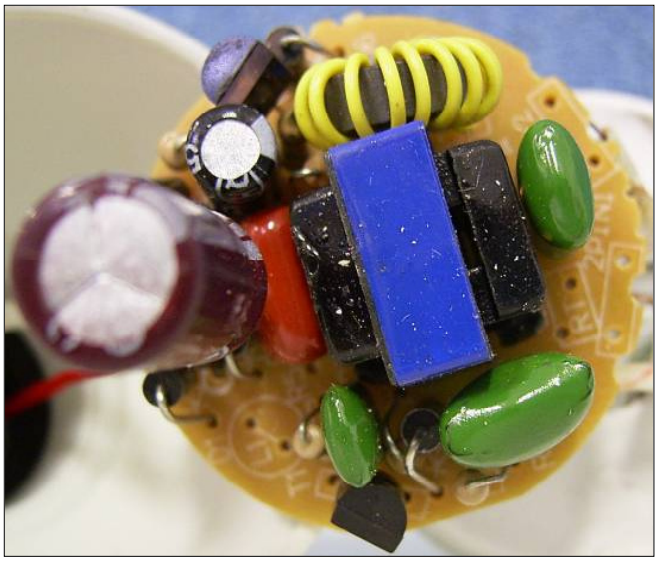

Figure 1a *Basic CFL Components*

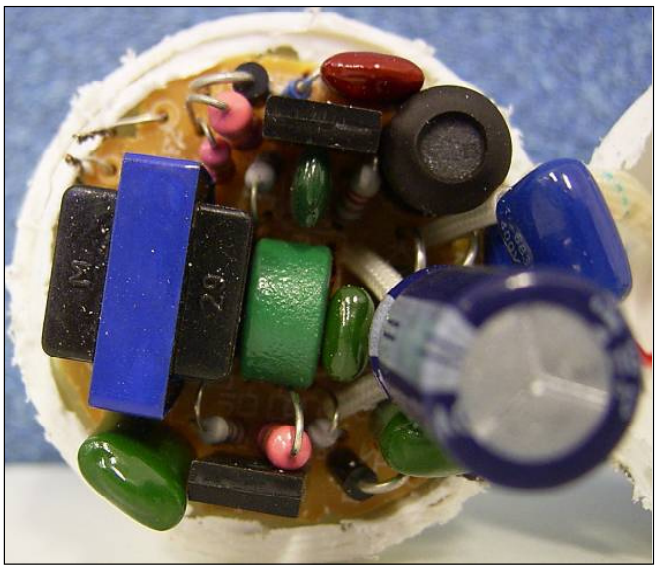

Figure 1b *High Power Factor CFL Components*

CFL ELECTRICAL CHARACTERISTICS

The electrical performance of 25 CFLs has been assessed in the laboratory using a low output distortion programmable source. These lamps represented a range of construction, price and brand types.

CURRENT WAVEFORMS AND CURRENT HARMONICS

Figure 2 shows a sample of 3 current waveforms when the lamps were supplied using a 230 V RMS input voltage (the sinusoidal voltage waveform is shown for comparison). These three waveforms represent the typical waveforms observed across the lamps tested. It can be seen that there is considerable variation in the shape of the current waveforms. Sample 3 is shown to have a waveform somewhat closer to sinusoidal, while Sample 1 has a very peaky and distorted waveform. Current THD levels for all CFLs tested were found to range between 30% and 170% with all but one lamp having current THD values above 100%.

The waveforms shown in Figure 2 indicate that the current waveforms of the CFL are rich in harmonics. This is confirmed by the harmonic spectrums of the three sample lamps shown in Figure 3 which shows that the harmonic current spectrum for the CFL with the most distorted current waveform, Sample 1, has characteristic harmonic currents above 10% of fundamental current for all odd harmonic orders up to the 50th. This is of special note as most domestic electronic appliances are characterised by large low order odd harmonic currents which rapidly decrease as harmonic order increases. As such, CFLs with high current distortion to high harmonic orders present a load with behaviour which is atypical of all other domestic electronic appliances. The relatively high levels of high order harmonics have also generated concerns that CFLs will interfere with ripple injection signals used by electricity supply utilities to control loads such as off peak hot water and street lighting. These signals can use frequencies close to the 15th and 21st harmonics.

POWER AND POWER FACTOR

Figure 4 shows active and apparent power measurements for the CFLs which have been tested. It can be seen that the majority of lamps have apparent power levels approximately twice those of the active power levels. This apparent power must still be delivered by the electricity supply company and as such the energy saving to the supply authority will not be the 75% active power saving claimed on CFL packaging. The fact that most lamps draw as much non-active power as active power results in low true power factor values. The exception to this rule is lamp P which is the high power factor lamp. If lamp P is ignored, true power factors for all other lamps are below 0.65. Displacement power factors have also been measured for each lamp. It has been found that displacement power factors are generally high and were found to be between 0.81 and 0.98 leading. The fact that displacement power factor values are relatively high indicates that the poor true power factor is due to harmonic power as opposed to fundamental reactive power.

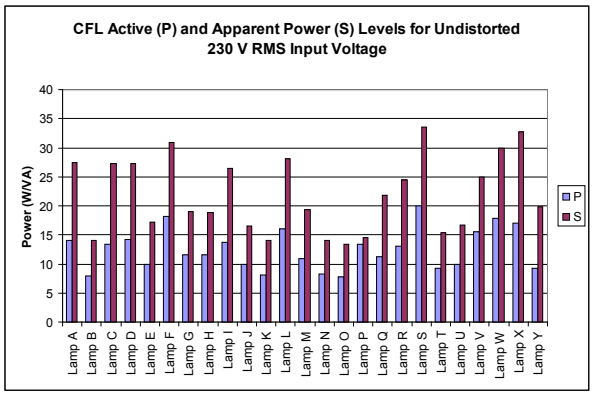

Figure 4 *Active and Apparent Power for each CFL*

HARMONIC PERFORMANCE AND PRICE

Figure 5 shows a correlation plot of CFL price and current total harmonic distortion (THD). It can be seen that there is little correlation between CFL price and current THD performance. The exception to this is the high power factor lamp (Lamp P) which is represented by the point towards the top left corner of the graph.

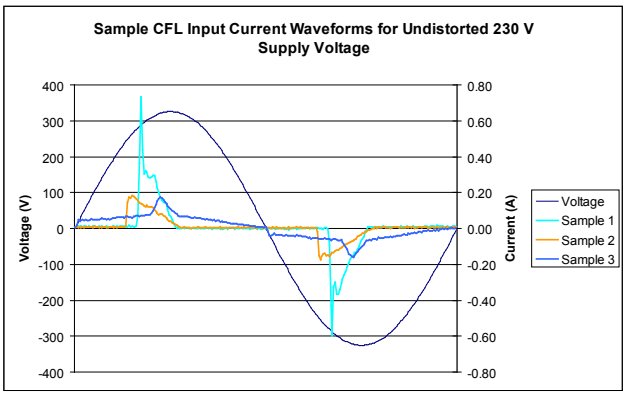

Figure 2 *Sample CFL Input Current Waveforms*

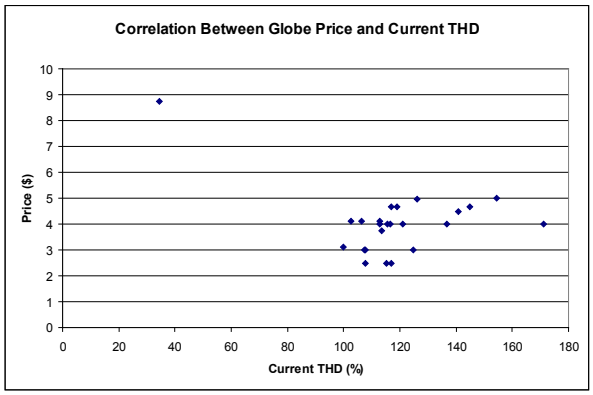

Figure 5 *Correlation between CFL Price and Current THD*

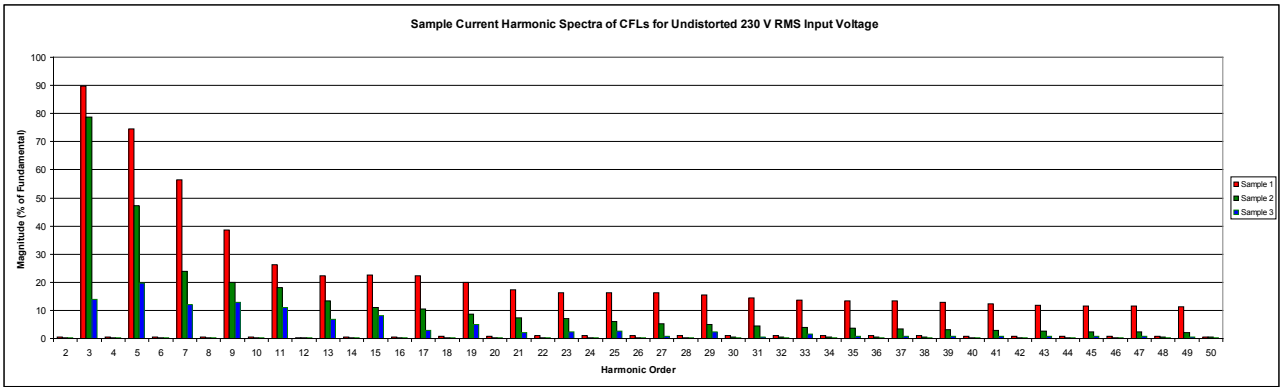

Figure 3 *Sample CFL Current Harmonic Spectrums*

This is the most expensive CFL but also has by far the best current THD performance.

OTHER DOMESTIC LOADS

The modern domestic load will contain a range of electronic appliances, for example, televisions, air conditioners, personal computers and audio visual equipment. These devices are now exclusively powered by switch mode power supplies. As such they present a non-linear load which will draw distorted input currents. The traditional single phase switch mode power supply exhibits a peaky current waveform rich in low order odd harmonics similar to that shown in Figure 6 which shows a PC power supply input current waveform.

Measurements have been made to characterise the performance of a range of modern electronic loads, revealing some interesting results. For televisions, it was found that while modern LCD and plasma varieties consume more active power than their CRT predecessors, they have input current waveforms which are much more sinusoidal as shown in Figure 7. Another interesting result is that modern inverter type air conditioner units also have input current waveforms which are almost sinusoidal and much improved on first generation inverter air conditioner currents. A sample input current waveform for a 3.3kW inverter type air conditioner is shown in Figure 8. The main devices which still exhibit the traditional peaky waveform associated with low power single phase switch mode power supplies are the PC and other smaller power devices such as audio visual equipment and battery chargers.

Given the apparent improvements in the input current waveforms of many of the highest power domestic electronic equipment, the fact that most CFLs have highly distorted input current waveforms means that in spite of their small power consumption, the contribution of the CFL to harmonic loading cannot be ignored. Most houses will have several if not many CFLs operating simultaneously and this brings the lighting load power levels up to those of other devices. Figure 9 shows a comparison of the harmonic current magnitudes drawn by a range of domestic appliances. In this figures a load of 10 CFLs is applied to represent the lighting load of a single house. It can be seen that depending on the type of CFL used in the house, the lighting load has the potential to be the largest harmonic load in the house by a considerable margin.

CONCLUSIONS

It has been shown that the basic modern electronic CFL is characterised by highly distorted input current waveforms with high current THD. High power factor CFLs which have additional components to improve the true power factor are shown to perform significantly better in terms of current harmonics than the basic CFL. It is observed that the basic CFL draws as much non-active as active power and this non-active power must be delivered by the electricity supplier. As such, the saving to the electricity supplier will be somewhat less than the 75% saving on active power achieved by the CFL.

Analysis of the performance of a range of other domestic electronic loads has shown that the current harmonic performance of some equipment has improved on first generation models. This means that the CFL with its highly distorted current waveform cannot be ignored as a significant harmonic load in spite of its low power rating. Analysis has shown that 10 CFLs operating simultaneously have the potential to be the single largest residential harmonic load.

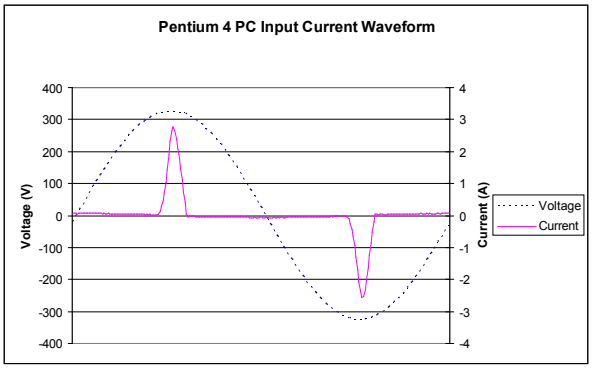

Figure 6 *PC Power Supply Input Current Waveform – Traditional Switch Mode Power Supply Input Current Waveform*

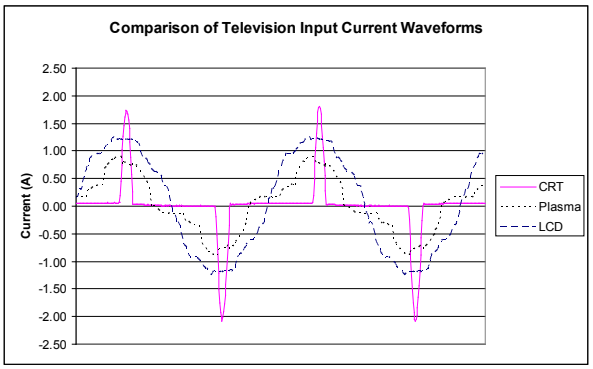

Figure 7 *Comparison of Television Input Current Waveforms*

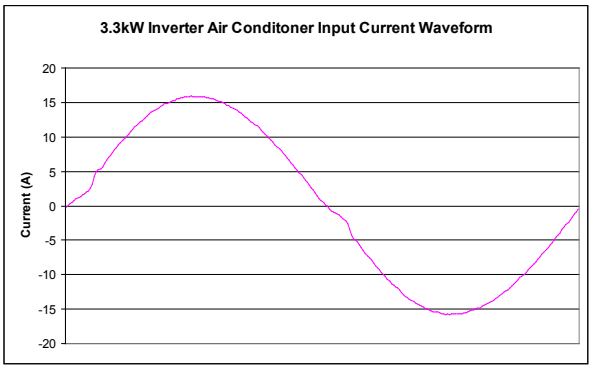

Figure 8 *3.3 kW Inverter Type Air Conditioner Input Current Waveform*

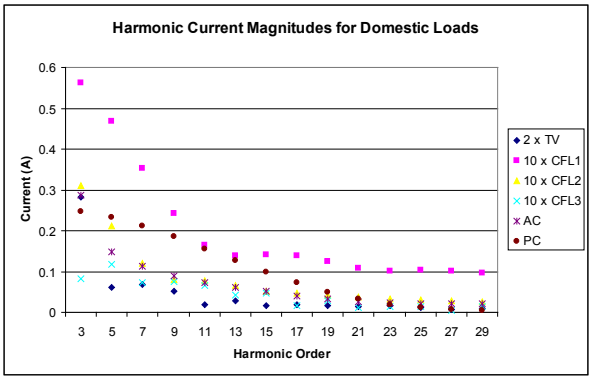

Figure 9 *Comparison of the Harmonic Current Magnitudes Drawn by a Range of Domestic Appliances*