Effects of Replacing Incandescent Lamps with Energy Saving Compact Fluorescent Lamps

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ABSTRACT

The Australian government has introduced a policy to replace all inefficient incandescent lamps with energy saving compact fluorescent lamps by 2010. However, unlike incandescence lamps, compact fluorescent lamps do not draw sinusoidal currents at almost unity power factor. Therefore, implementation of this policy may introduce serious power quality problems for the power supply authorities. This paper investigates the impact of current harmonics generated by a number of different types of compact fluorescent lamps, commonly available in Australia, on the quality of the conventional supply. Experimental results are presented to show a comparison of the actual energy consumption, power factor, costs, Lumen levels and current harmonics of compact fluorescent lamps and incandescent lamps. These results show that the power quality and the amount of light output from compact fluorescent lamps do not depend on the cost of compact fluorescent lamps. Simulation results are presented using the experimental data to determine the impact of large influx of compact fluorescent lamps on the third harmonic component present neutral current. It is also shown in this paper that direct replacement of incandescent lamps by equivalent wattage compact fluorescent lamps may give rise to safety issues.

Introduction

In Australia, lighting makes up for around 12 percent of Greenhouse gas emissions from households and around 25 percent of emissions from the commercial sector (Australian Government 2008). Compact fluorescent lamps (CFLs) can be used to reduce Greenhouse emissions from lighting loads. CFLs consume about 20% of the power of standard incandescent lamps to produce the same amount of light. CFLs can last up to 15,000 hours and produce less heat, leading to reduced loads on air conditioning systems. While CFLs are more efficient than their incandescent counterparts, they only convert between 15% and 20% of the input electrical energy to light (Coghlan 2007). This paper investigates effect of direct replacement of incandescent lamps by equivalent wattage CFLs on the level of light.

While the power factor of CFLs can range between 0.5 and 0.9 (NAEEEC 2005), the minimum acceptable power factor is 0.55 (AS/NZS 4847.2(Int):2008). In this paper, tests were carried out to establish if the power factor of commonly available CFLs is influenced by its cost. Power factor is also related to harmonics and non-linear loads such as CFLs draw harmonic currents. Harmonics can cause problems such as heating of transformers, motors, power cables, premature aging of capacitors, interference with communication equipment, and premature tripping of circuit breakers. Poor power factor also reduces the efficiency of power distributions networks.

The characteristic current waveform and harmonics introduced by CFLs have been researched and published [Gonos *et al* 1999 and Cunill-Sola Salichs 2007]. The early design of CFLs focused mainly on low power consumption and less attention was paid to the generation of harmonics by these lamps. Hence there are CFLs available in the market with total harmonic distortion of greater than 100% (Cunill-Sola Salichs 2007). Newer types of CFLs use electronic ballasts to significantly reduce the level of harmonics distortion. However, it will be shown in this paper that a major problem for consumers is that the level of harmonics generated by CFLs varies widely between manufactures.

Tests have also been carried out by Bemis (Bemis 1992) to show that replacement of a large number of incandescent lamps by CFLs will cause some increase in current distortion and a small increase in voltage distortion. However, with the total phase out of CFLs in Australia, there is a need to look particularly at the effect of the triplen harmonics on the power transformers. Also, the combined effects of the addition of a large number of CFLs to existing high volumes of non-linear loads used by some customers may lead to power quality problems at that customer point of common coupling. Therefore, this paper provides important information to allow consumers to choose CFLs that will minimize this effect.

Safety Issues

CFLs contain a maximum amount of 5 mg of mercury per lamp (AS/NZS 4847.2(Interim):2008). Mercury is a potential neurotoxin and is dangerous to humans and because of this there is a problem with the disposal of CFLs. In Australia there is currently only a limited recycling option and consumers are generally advised to dispose of them in their regular trash. However mercury in landfill can leach out of landfills and into water supplies and become the far more dangerous methyl mercury (Appell 2007). While this is of concern it is outside the scope of this paper.

CFL Harmonic Measuring Procedure

Tests to determine the electrical performance characteristics of various makes of CFLs were conducted under the same conditions and using the same test equipment. A Fluke power quality analyser (43B model) was used to obtain power quality data for the lamps and a Tektronix digital oscilloscope was used to validate these results. Both instruments were connected to provide voltage, current, power factor and harmonics data simultaneously.

Voltage and Current Harmonic Limits

The total harmonic distortion (THD) of supply voltage used for the test was also measured to determine if it complied with AS/NZS61000.3.2:2007 (Table 1).

Tab. 1: Maximum allowable voltage harmonics
(Source: AS/NZS 61000.3.2:2007)

Harmonic order (n)	Maximum voltage harmonic (% of fundamental)
3	0.9
5	0.4
7	0.3
9	0.2
$2 \leq n \leq 10$ (even harmonics only)	0.2
$11 \leq n \leq 40$ (odd harmonics only)	0.1

The measured value of THD of the supply voltage was 2.5% and the 3rd harmonic was 0.44%. While these two values were acceptable, the 5th and 7th harmonics of 2.1% and 0.71 % respectively were outside the limits specified in Table 1. Hence, presence of these high levels of the 5th and 7th harmonics in the supply voltage needs to be considered when measuring harmonics generated by CFLs.

The CFLs to replace the 25 W, 40 W, 60 W, 75 W and 100 W incandescent lamps are always less than a rating of 25 W. The harmonic current limits for lighting equipment of less than 25 W given in the Australian standards (AS/NZS 1680.2.1:2008) is presented in Table 2. Test carried out using the different types of CFLs was to determine if the measured values complied with this table.

Tab. 2: Current harmonic limits for lighting equipment rated at 25 W or less
(Source: AS/NZS 1680.2.1:2008)

Harmonic order (n)	Maximum harmonic current per watt (mA/W)
3	3.4
5	1.9
7	1.0
9	0.5
11	0.35
$13 \leq n \leq 39$ (odd harmonics only)	$\frac{3.85}{n}$

Illumination Measuring Procedure

Illumination measurements were carried out in a dark room to comply with the Australian Standard (AS/NZS61000.3.2:2007) requirements for testing lighting equipment. The room was draught free and kept within the required temperature range of 20°C to 27°C. To allow the lamps to warm up they were turned on 15 minutes before any illumination results were recorded.

Direction of Light output from CFLs

CFLs are generally available in tube or spiral type as shown in Figures 1 and 2. The arrow length represents light intensity. As the light from a CFL is radiated at right angles to the direction of the tube enclosure, tube type bulbs tend to radiate light more outwards on a horizontal plain rather than downwards. While on the other hand, because of the way they are designed, spiral type CFLs radiate more light downwards than a tube type. Therefore, depending on the type of CFL light may be more intense in different angles off the bulb.

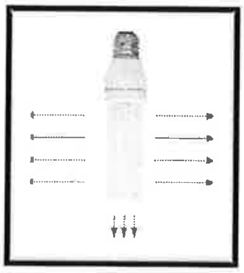

Fig. 1: Tube type CFL with light directions

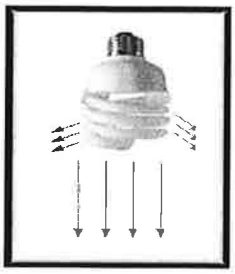

Fig. 2: Spiral type CFL with light directions

Tests were carried out to ascertain the intensity of light from a range of CFLs. This should help consumers to choose CFLs to be suited to many different situations and avoid safety problems.

Recommended Luminance Limits

The Australian standard AS/NZS 1680.2.2:2008 gives recommendations on the light intensity for different tasks relating to an office environment. The standard covers many possible areas and activities including task lighting. Task lighting is provided by small localised lamps such as desk lamps etc. The amount of light output from CFLs for interior and work place task lighting that should comply with the values given in Table 3.

Tab. 3: Recommended luminance for task lighting
(Source: AS/NZS 1680.2.2:2008)

Work detail level	Recommended illuminance (Lx)
rough, simple work	320
fine, detailed	600

Results

Power Quality Results

The waveform and harmonic spectrum of the current drawn by different types of lamps were measured and the results for an incandescent lamp and two of the most expensive CFL are shown in Figures 2 to 4. These results show the maximum (Nelson 'Aladdin' CFL) and the minimum (ECO CFL) levels of harmonic currents that is being injected into the grid supply.

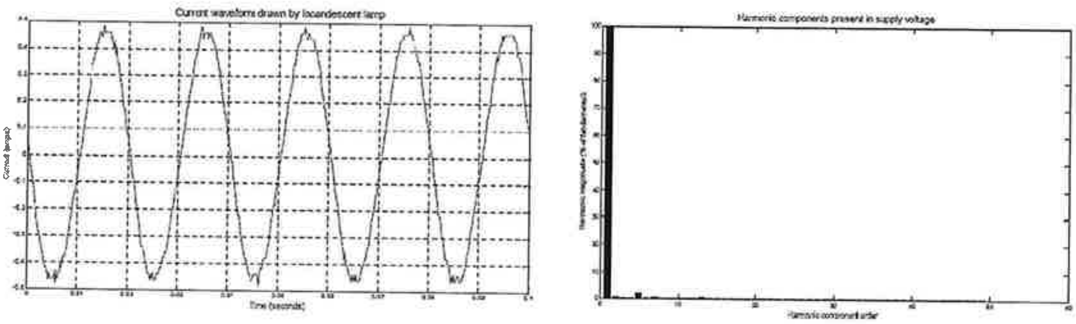

Fig. 2: Incandescent lamp

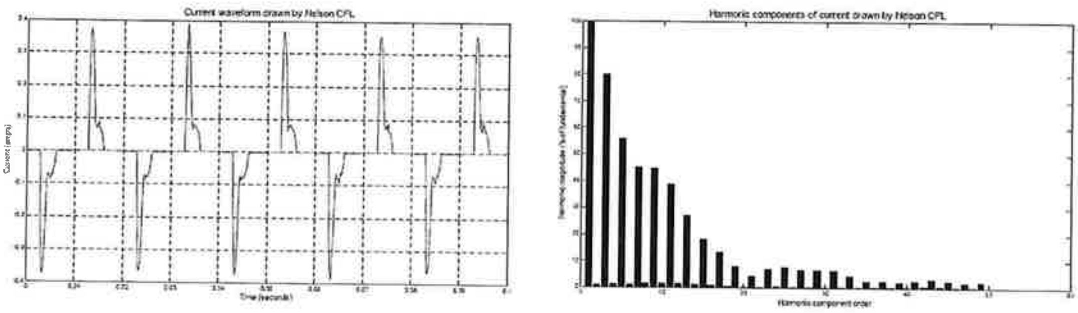

Fig. 3: Nelson 'Aladdin' CFL

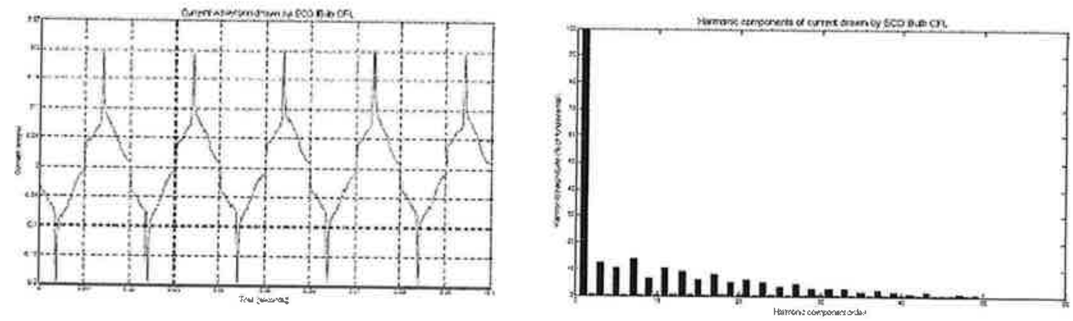

Fig. 4: ECO CFL

A summary of the results for a wide range of CFLs compared to a 75 W incandescent lamp is shown in Table 4. According to their manufacturers, all the CFLs tested in this experiment were equivalent to a 75 W incandescent lamp. These results show that:-

- Consumers are paying almost twice for some CFLs with a higher THD (129.45%) than CFLs with lower THD (104.47%) and better operating power quality.
- Some expensive brands of CFLs also inject the highest level of third harmonics, in this case as high as 80% of the fundamental current.
- Power factor of most of the commonly available CFLs range from 0.54 to 0.58. Only the ECO CFL was 0.95.
- A higher cost of CFLs does not necessarily translate to better power quality or improved level of light output

Tab. 4: Comparison of power quality and illumination of CFLs and incandescent lamps

Lamp Type	Power Rating (W)	Cost	Illumination (Lux)**	Illumination (Lux)***	Power Factor	Current %THD	Current (mA)
Incandescent	75	$0.75	75	780	1.00	2.51% *	339
Woolworths 'essentials' 'spiral' CFL	14	$4.00	75	760	0.58 (leading)	104.42%	102
Phillips 'Genie' 'Tube' CFL	14	$5.50	60	660	0.57 (leading)	119.22%	105
Light star 'spiral' CFL	13	$6.00	55	530	0.58 (leading)	114.04%	87
OSRAM 'spiral' CFL	13	$7.95	80	830	0.59 (leading)	104.95%	90
Nelson Aladdin 'tube' CFL	15	$7.95	60	700	0.54 (leading)	129.45%	104
ECO bulb 'spiral' CFL	15	$8.50	75	590	0.95 (leading)	31.15%	51

NB: * The measured value of the supply voltage THD was 2.5%
** Measurement 1.5m below the lamp in a dark room
*** Measured 20 cm horizontally from lamp in a dark room

Comparison of Light Intensity from CFLs

In Table 4, light levels were measured 1.5 meters directly below the lamps. The cheapest CFL, the most expensive CFL and the incandescent lamp all recorded 75 Lux. Some of the other expensive brands registered 20% to 27% lower intensity than the incandescent lamp.

However, when the light levels were measured 20 centimeters horizontally from the lamps (Table 4), the most expensive ECO spiral CFL was about 24% lower than the incandescent lamp and below the recommended luminance for fine detailed work as shown in Table 3.

Light intensity measured at 0.5 meter intervals in a straight line at angle of 53° from the Lamp is shown in Figure 5. This graph shows that light from the spiral type CFL was more than 40% lower then the incandescent lamp 1.5 meters at 53°. The light level fell sharply to 65% below the incandescent at 2 meters from the CFL lamp.

Based on these results, direct replacement of incandescent lamps by CFLs may lead to a breach of workplace health and safety requirements. Working continuously in offices with inadequate lighting may cause eye strain, while poor lighting in stairways can result in accidents.

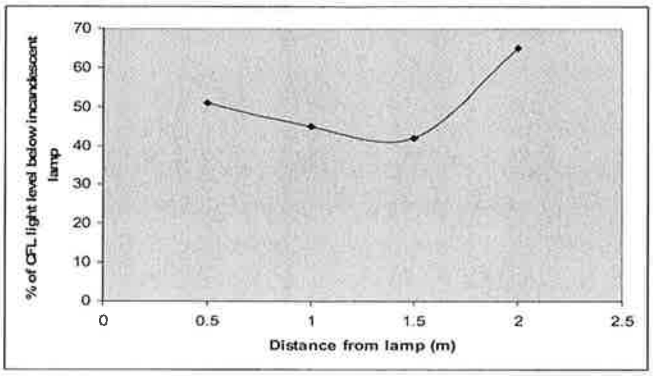

Fig. 5: Spiral CFL luminance measured along an angle of 53 degrees compared to an incandescent lamp.

Transformer Current Distortion due to CFLs

Primary and secondary current harmonics produced by CFLs connected to a three phase, delta–star transformer, is shown in Figures 6 and 7. As expected the measured results of the primary current confirm that the local three phase delta-star distribution transformer filters the triplen harmonics and significantly reduce the magnitude of the odd harmonic currents.

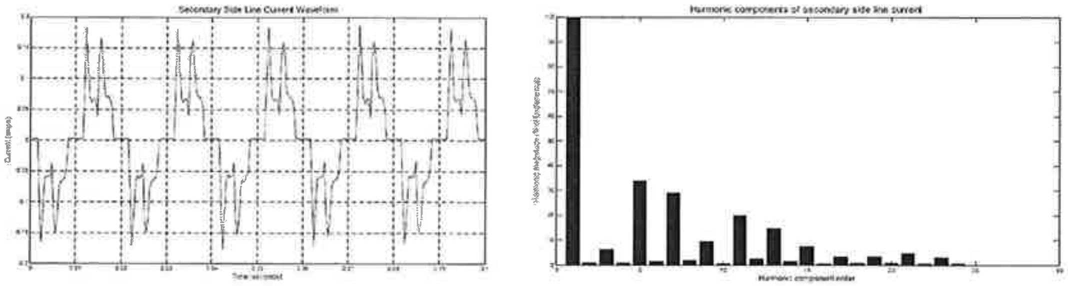

Fig. 6: Secondary side line current harmonics due to balanced CFLs load

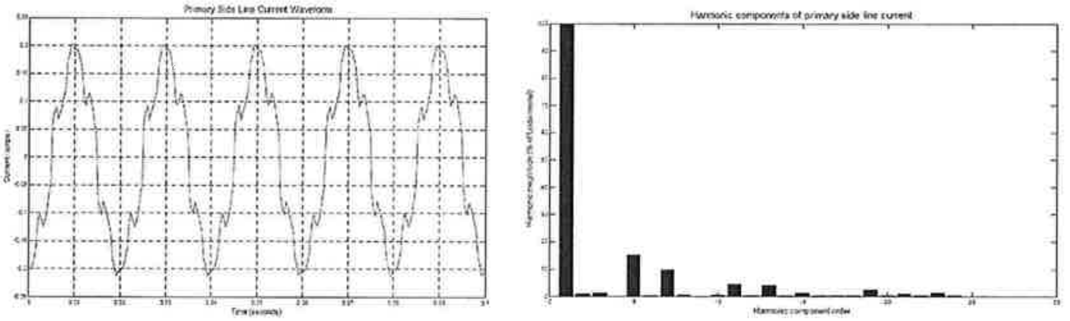

Fig. 7: Primary side line current harmonics due to balanced CFLs load

Neutral Currents due to CFLs

Simulations, using MatLab to determine the neutral current produced by three domestic installations, each using ten Light Star CFLs, is shown in Figure 8. The first 15 current harmonic values measured for the Light star CFL was used to generate the neutral. These simulation results show significant levels of third (65%) and fifth (22%) harmonics present in the neutral current.

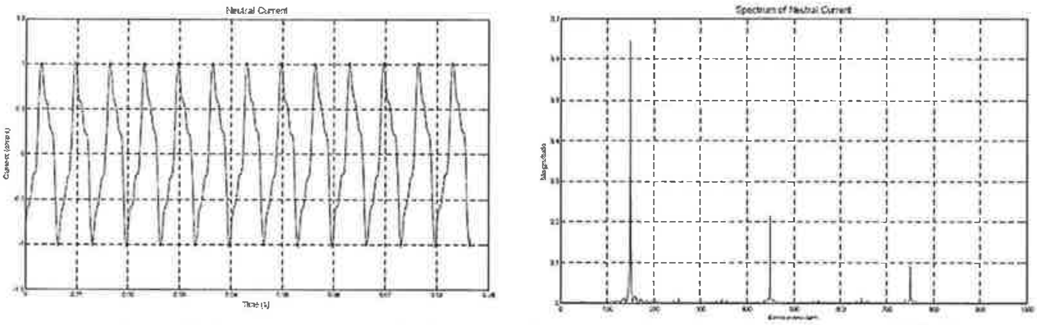

Fig. 8: Simulated neutral current harmonics due to the use of CFLs

The presence of such high levels of triplen harmonic current circulating in the delta windings of the transformer will cause unwanted heating of the transformer. It can also cause high levels of transformer secondary voltage distortion and hence affect operation of other sensitive equipment connected to the customer point of common coupling.

Conclusions

The findings presented in this paper confirm the following:-

- The combined effect of harmonic currents generated by the continuous growth of non-linear loads and the additional harmonics produced by the complete replacement of incandescent lamps by CFLs will lead to power quality problems. These problems will exist at the customer point of common coupling. For example, at University of Southern Queensland, the magnitudes of 5^{th} and 7^{th} harmonics present in line voltages are already unacceptable. Addition of CFLs with high THD will worsen this situation.
- Consumers in Australia are unintentionally contributing to power quality problems by using CFLs with THD as high as 129% and power factor of 0.54, when there are CFLs with THD of 31% and power factor of 0.95 available in the market. Therefore, existing Australian standards need to be revised to reduce the level of current harmonics injected into the grid supply by CFLs.
- Some of the more expensive brands of CFls, available in Australia, inject much higher levels of current harmonics into the grid supply than the cheaper brands.
- Unlike incandescence lamps, the level of light output from CFLs depends on its construction. Consumers need to be informed that replacing incandescent lamps by equivalent wattage 'tube' or 'spiral' type CFLs incorrectly may lead to not meeting the required level of light specified by the relevant Australian Standard. In some application inadequate lighting may give rise to safety problems.

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