LED lighting for Industrial, Commercial and Institutional Premises

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Abstract
Fluorescent tubes have long been the mainstay of lighting for many premises, due to their high efficiency and long life. However they are sensitive to power system voltage disturbances, which result in visible light flicker and they produce harmonics. Furthermore their brightness can only be controlled over a narrow range (with active ballasts) and the light spectrum produced is not ideal. The most efficient white LEDs now achieve light outputs in excess of 100 lumens per watt of electrical input power, surpassing the efficiency of fluorescent tubes. With suitable drive circuitry they can be made immune to electrical disturbances, with dimming and controllable colour rendering readily achievable.
A new multichip LED lamp with spectrum adjustment, mounted in a four foot fluorescent fitting, with ballast replaced by driver electronics is compared with a commercial white LED fluorescent tube replacement and a white fluorescent tube, mounted in the same four foot fitting, with conventional inductive ballast. Practical results for spatial distribution, intensity and spectrum of light output are compared for all three lamps, with the same power input. Sensitivity to mains disturbances and harmonic current draw are also compared.

1. Introduction

Fluorescent tubes have long been the mainstay of interior lighting for industrial, commercial and institutional premises. However there are a number of drawbacks with the technology, including harmonic current draw, sensitivity to supply disturbances causing light flicker, difficulty of achieving dimming over a wide intensity range and non-ideal spectral power distribution, leading to sub-optimal colour rendering.

With recent advances, efficiencies of Light Emitting Diodes (LEDs) have increased to levels exceeding those of fluorescent tubes. Although an LED solution is still more expensive to implement, the costs are reducing and the shortcomings of fluorescent technology can be addressed, including energy savings by dimming, colour temperature control and immunity to flicker.

The global move towards more efficient use of energy to reduce CO_2 emissions has impacted on all sectors of industry. Artificial lighting makes up a considerable portion of the electrical load on power systems and LED lighting will have its place in reducing that load to sustainable levels.

The variation of luminous flux (or the light intensity level) from electrical lighting can have a detrimental effect on the human physiological system. Disturbances or transients on electrical power systems can cause lighting level to fluctuate at magnitudes and frequencies visible to humans. It is therefore important to ensure new lighting technologies are immune to voltage disturbances

The work reported describes a practical comparison between a new dimmable, colour correctible LED lamp, designed for retrofitting into existing fluorescent light fittings, a conventional fluorescent tube with passive inductive ballast and a recently launched, commercial, white LED fluorescent tube replacement, also with passive inductive ballast. After a brief discussion of current LED technology, the design and operation of the three lamps are detailed. Performance results for all three lamps are presented, covering light quality issues such as spectrum, intensity and flicker and electricity network issues such as overall efficiency and harmonic current draw.

2. LED Technology

Over recent years extensive research of semiconductor materials has lead to the development of LEDs which cover a wide range of spectral wavelengths. In particular those visible to humans (400nm-700nm) have followed Haitz's Law where the luminous flux (total light output) doubles every 18-24 months. Since the pioneering work in the late 1990s, the commercialization of high power LEDs has impacted on Haitz's law; a knee-point has emerged defining the moment when LEDs moved away from being indicator lamps to becoming powered sources of light [1].

The fundamental principles of LED operation have restricted the development of 'white' light LEDs, suitable for lighting human environments. Although individual LEDs have been developed to emit narrow wavelength bands across the visible spectrum, white light can not be produced directly from a single substrate.

There are two general approaches to the generation of white light using LEDs [2]. One approach mixes the light from three or more monochromatic substrates, usually red, green and blue (RGB) in appropriate proportions to achieve the correct colour balance. As the spectral bandwidth of LEDs is generally narrow, this approach leads to poor colour rendering as there are large gaps in the light spectrum. Other colour LEDs can fill these gaps but further complexity and cost are added.

The other approach uses phosphor conversion technology, as found in fluorescent lighting. An Ultra Violet LED excites the phosphor - all the UV photons are fully absorbed by the phosphor and more photons are re-emitted at visible wavelengths. Alternatively a blue LED excites the phosphor - a portion of the blue light is able to pass through the phosphor with the remainder re-emitted over a range of other visible wavelengths. The output light spectrum is greatly dependent on the phosphor material and poor colour rendering can again be a problem.

In a previous paper, the authors described LED lamps employing each of the above approaches [3]. It was found that the second method, using blue-light-based white LEDs produced the best results, in combination with some additional colour correction LEDs. At the time we were able to use LEDs with a light output of 50 lumens per watt. For this work an improved version of this lamp was produced, using 80 lumen per watt LEDs. (At the time of writing, LEDs with an output of greater than 100 lumens per watt are available).

3. The lamps

LED lamp: The new 4ft LED lamp has been designed to be mounted in existing 4ft fluorescent fittings. By using existing fittings and wiring in commercial buildings, the cost of retro-fitting the LED lamps can be reduced. Existing fluorescent fittings include ballast circuitry to start and operate the fluorescent tubes; this must be removed and replaced with a new driver circuit.

A 1W range of surface mount LEDs were selected as they offer excellent price per lumen and are produced in a wide range of colours including 'white' (using a 'royal blue' LED). The forward voltage drop is typically 3.15V at 25°C with light output of 23-100 lumens per watt, depending on colour. In this case 80 lumen per watt (minimum at 25°C) white LEDs were used, with a typical colour temperature of 6500K and a colour rendering index (CRI) of 70. The voltage drop and efficiency both fall with increased junction temperature.

The LED lamp consists of the following three series LED strings: 48 white, 12 blue plus 12 cyan, 12 red plus 12 red/orange. Using a common anode connection, three strings can be accommodated using the 4 available contact pins on a standard fluorescent fitting. The two colour correction strings were chosen based on the findings of previously reported work [3]. In order to mix the light as well as possible the sequence of LEDs along the lamp is ordered as follows: red-orange, white, cyan, white, red, white, blue, white and so on. A single heat sink runs along the back of the circuit board for cooling.

Fluorescent lamp: A TL-D 36W/840 white tube was used. At 36W and 30°C an output of 3000 lumens, or 83 lumens per watt, is quoted, with a colour temperature of 4000K and a CRI of 85.

Commercial LED fluorescent replacement lamp: An EverLED E25T8-48-S4N was used. This has a rated power of 25W and a quoted output of 2900 lumens, with a CRI of 85. This lamp consists of 36 white LEDs in a series string, in parallel with which is placed a pair of 10uF capacitors. In each end cap is a full bridge rectifier, ensuring that the lamp can be placed either way round in a fluorescent fitting and work correctly.

Figure 1 shows one end of each of the three lamps. The sequence of different LEDs is clearly visible.

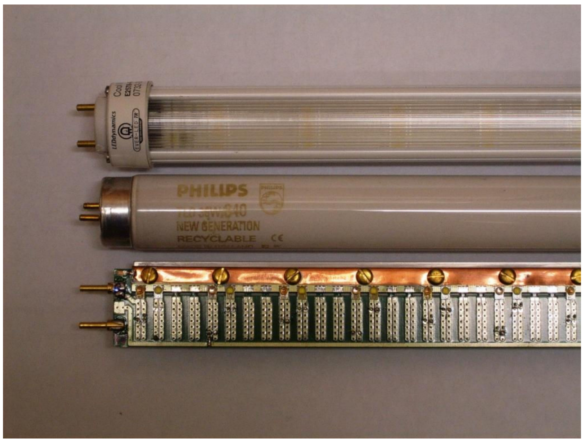

Figure 1. End section of the three lamps

3.1 Drive Circuitry

LED lamp: The LED lamp drive circuitry consists of two parts: a 230VAC 50Hz rectifier stage (Figure 2.) followed by three constant current drive circuits (one for each of the three LED strings) (Figure 3.) on the DC bus. This allows for independent control of each LED colour string. The mains input passes through a fuse and EMC filter and then a full wave bridge rectifier. The rectifier is followed by a Unity Power Factor Correcting (UPFC) boost converter, based around the IR1150 integrated circuit. The boost converter works in continuous inductor current conduction mode with a switching frequency of about 100 kHz. The active switching device is a 560V SPD02 CoolMOS power MOSFET. The IR1150 control circuit measures the inductor current and controls the duty cycle such that the current follows an approximately sinusoidal profile. A 600V CS0106 SiC Schottky device is used as the catch diode.

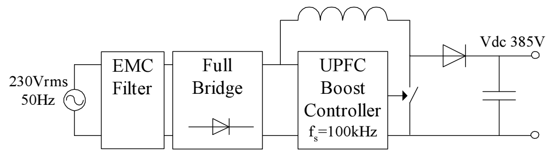

Figure 2. Unity Power Factor Rectifier

The DC reservoir capacitor was chosen as 33uF, with the DC bus controlled at a nominal 385 VDC. With 48 white LEDs in series, the voltage drop of the string is approximately 150V. At an LED power input of 36W the forward current is hence around 240mA. This gives a theoretical hold-up time of a little over 30ms, or 1.5 cycles.

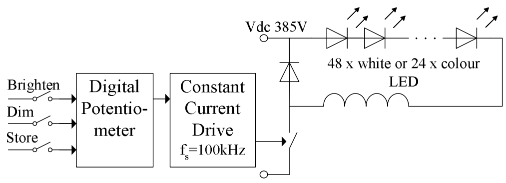

Figure 3. LED Constant Current Driver

The LED driver stage (Figure 3.) takes the form of a buck converter, acting as a switching constant current source with the LED string as load, based around the MLX10803 LED driver integrated circuit. This integrated circuit monitors the inductor current (again operating in continuous conduction mode at around 100 kHz) and compares it with a reference level, derived from a voltage reference through a digital potentiometer, and alters the duty cycle appropriately. Three digital inputs control the wiper position of the potentiometer and hence the brightness of the lamp. As the RMS and average currents are of the same order as in the input boost converter, a similar MOSFET and catch diode are used as in the input circuit.

The efficiency of the drive circuit is plotted against power level in Figure 4. At rated power, losses are less than 3W.

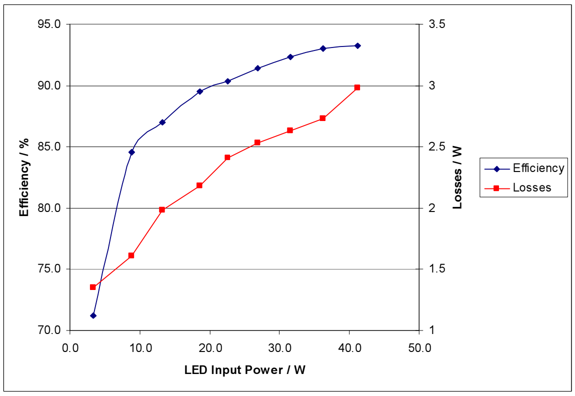

Figure 4. Efficiency and losses vs. LED input power

Fluorescent lamp: The electromagnetic ballast has an inductance of 1.2H and a series resistance of 49Ω, measured at 50Hz - by 150Hz the resistance has risen to 76Ω. With a sinusoidal 50Hz voltage of 230V rms applied to the lamp, the inductor current is 0.41A, yielding losses of about 8W and power of about 35W into the lamp itself.

Commercial LED fluorescent replacement lamp: The LED replacement lamp uses two of the same electromagnetic ballasts in series (2.4H, 98Ω at 50Hz). With a sinusoidal 50Hz voltage of 230V rms applied to the lamp, the inductor current is 0.20A, yielding ballast losses of about 4W and power of about 23W into the lamp itself.

4. Performance Results

4.1 Light Spectrum

Figure 5 shows the comparative spectra for the three lamps at similar power levels, when all the input power to the new lamp is fed to the white LED string. The new lamp shows a big trough in intensity centred on about 475nm, between the 'royal blue'

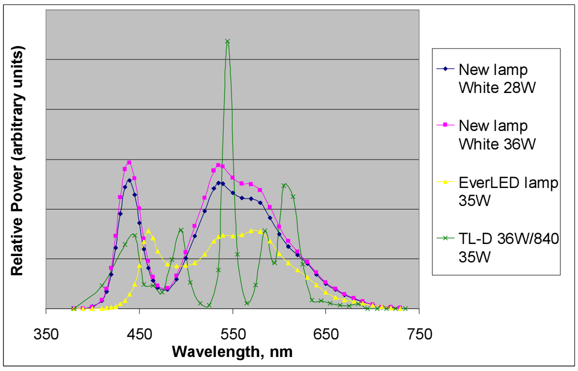

Figure 5. Uncorrected visible light spectra for the three lamps

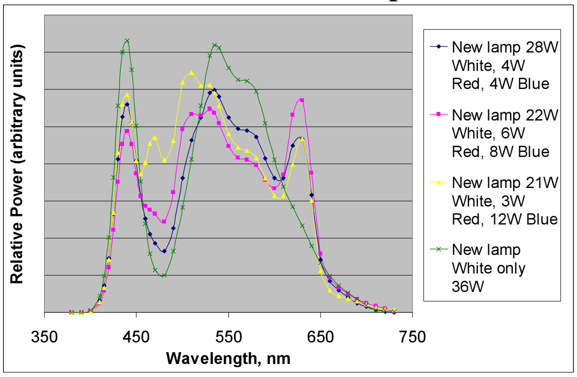

Figure 6. New lamp spectra with colour correction

primary peak at 440nm and the 'green - yellow' phosphor peaks at about 535nm and 570nm. This appears to become more marked at higher input power. The EverLED lamp shows a similar pattern, though compressed into a narrower spectrum at the blue end, and with a less pronounced trough. (The EverLED tube is using white LEDs from a different manufacturer). The fluorescent tube shows five separate peaks resulting from the various phosphors. The main green peak is at about 545nm – this is where the human eye has the greatest sensitivity and thus leads to the greatest perceived brightness. The red peak at about 605nm makes the light appear reasonably 'warm' at a point where the white LED output is falling off. The fluorescent spectrum is almost totally deficient at around 520 and 565nm and low, in a similar way to the new lamp, at about 470nm.

Although the Y axis is in arbitrary units, these results are all to scale – hence it is clear that the EverLED lamp is substantially less efficient than the new lamp.

In order to improve the colour rendering of the new lamp, the 36W of input power is shared between the white, red and blue strings. In Figure 6, three different spectra are recorded in comparison to the white only case. The ‘red’ string actually consists of red and red-orange LEDs in an attempt to broaden the red peak centred on about 630nm. This peak adds ‘warmth’ to the light in a similar fashion to the fluorescent case. The ‘blue’ string actually consists of both blue and cyan LEDs, and adds peaks at about 470nm and 510nm. In the 21W white power case, a spectrum approaching that of the CIE Illuminant C (overcast daylight) is achieved [2]. It is anticipated by inspection that this will have superior colour rendering to the fluorescent and EverLED cases, but this has yet to be experimentally verified.

4.1 Light Intensity and Distribution

The standard four foot fluorescent light fitting was mounted on the ceiling of a darkened, matt black room, 1.7m above a 1.5 x 1.5m working bench. The LEDs used in the new lamp have a typical half intensity angle of 140^{o} and are hence more directional sources than fluorescent tubes (with an even 360^{o} distribution). The light distribution was measured on the working bench surface to give a comparison of the usable working light generated from both technologies. After powering up, the lamps were given time to reach thermal equilibrium. The light intensity was measured at each co-ordinate of a 250mm spaced grid, using a lux meter. The lux meter measures the radiant light power, visible to humans, at the surface. The spectral sensitivity of the detector closely matches that of the CIE spectral sensitivity [4] curve for the average human eye.

The light distribution (in lux) for the three lamps at similar power levels, when all the input power to the new lamp is fed to the white LED string, is shown in Figures 7, 8 & 9. The light fitting is positioned along the gridline A, centred on gridline 4. The grey tones used in all figures are the same for luminance of 50 lux and above, allowing direct comparison of light intensity.

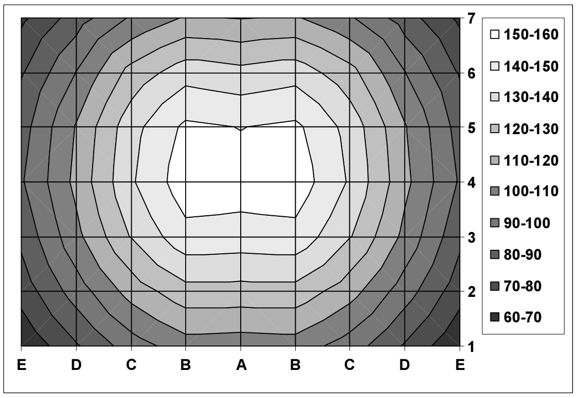

Figure 7. New lamp Luminance Spread, White, 36W

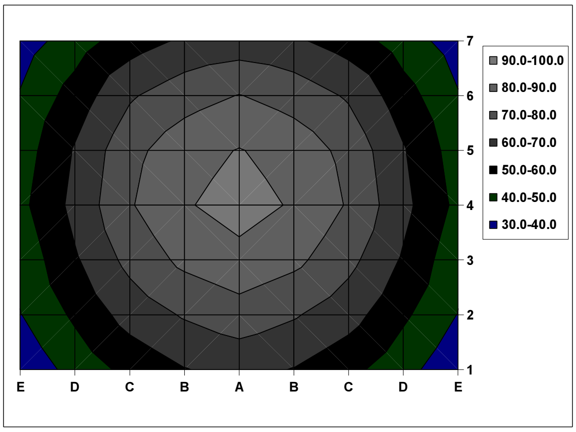

Figure 8. EverLED Luminance Spread, 36W

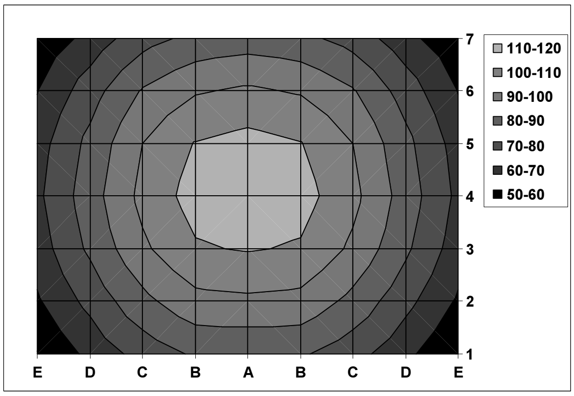

Figure 9. Fluorescent Tube Luminance Spread, 35W

It is clear that the new lamp is about 33% brighter than the fluorescent at the centre, dropping to about 17% brighter at the edges of the surface. On the other hand the EverLED lamp is about 17% dimmer than the fluorescent at the centre and 33% dimmer at the edges.

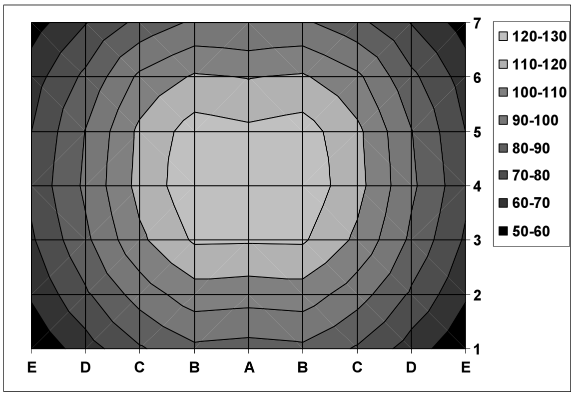

Figure 10. New lamp Luminance Spread, White, 28W

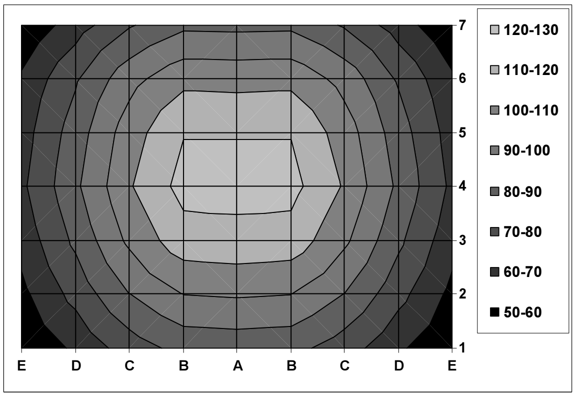

Figure 11. New lamp Luminance Spread, White 21W, Red 3W, Blue 12W (36W total).

Figure 10 shows that dropping the new lamp power to 28W still allows the luminance to equal or exceed that of the fluorescent over the entire surface – this represents a potential energy saving of about 20%. At 28W of input power the EverLED luminance ranged from just under 80 lux at the centre to 28 lux at the edges.

Figure 11 shows that running the new lamp with the improved, approximate Illuminant C, spectrum, at 36W input power, yields surface illumination at least equal to the fluorescent case.

4.2 Light Flicker

The international CIE/IEC light flicker measurement standard [5] details an instrument to determine the light flicker produced by a 60W incandescent lamp from the instantaneous voltage waveform. The standard has been adopted by many regulatory bodies throughout the world, including AS/NZS. A flicker meter, developed by two of the authors has been described in detail in the literature [6]. The flicker meter produces a perceptibility index, P_{st}, where a value of unity defines the threshold at which 50% of people are irritated by the flicker – values greater than 1 are unacceptable.

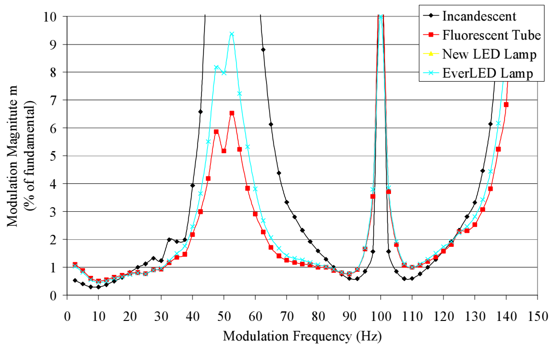

Figure 12. Modulation level for $P_{st} = 1$

Figure 12 shows the amplitude of RMS supply voltage modulation required to produce unacceptable flicker for the various lamps, including an incandescent bulb, versus frequency. The modulation level was restricted to 10%, at which point no perceptible flicker was seen with the new lamp, though the EverLED and the fluorescent cases were similar, requiring less than 1% modulation in the 5 to 30Hz region.

	Voltage dip to 0% 0.02s			Voltage dip to 40% 1s			Voltage swell to 120% 0.5s		
Occurrences	**1**	**3**	**5**	**1**	**3**	**5**	**1**	**3**	**5**
Incandescent	1.32	2.57	3.01	1.32	2.57	3.07	1.53	2.98	3.35
New LED Lamp	0.09	0.14	0.15	0.06	0.07	0.09	0.14	0.21	0.23
EverLED	1.32	2.57	3.01	1.94	3.04	3.41	2.13	2.99	3.46
Fluorescent	1.35	3.17	3.69	1.95	2.72	3.14	2.17	3.18	3.69

Table 1. P_{st} levels for 1, 3 & 5 occurrences of event over a ten minute period

Table 1 shows flicker perceptibility results for three typical supply disturbances – a 20ms dip to 0% (i.e. a missing cycle); a 1s dip to 40% of nominal voltage; a 0.5s swell to 120% of nominal voltage. In each case the value of Pst is given where 1, 3 or 5 of the same event occur within a 10 minute period. The new lamp does not exhibit perceptible flicker under any of the test conditions, whereas all the other lamps make the user aware of the supply problems.

Figures 13 and 14 compare the light output levels for the three lamps during the missing cycle and 1s dip events, respectively. The fluorescent lamp drops out during both of these disturbances and takes 2-3s to restart afterwards. The EverLED output falls to zero and to a very low level respectively, but of course restarts immediately. The new lamp experiences little variation in light output.

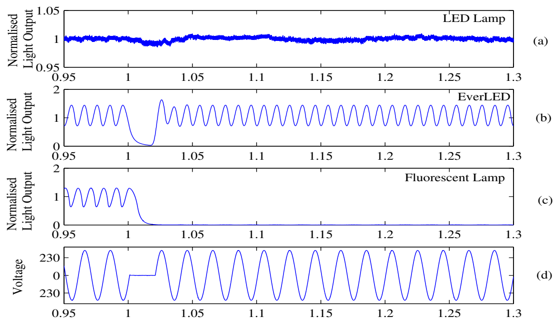

Figure 13. Normalized light output and supply voltage during missing cycle

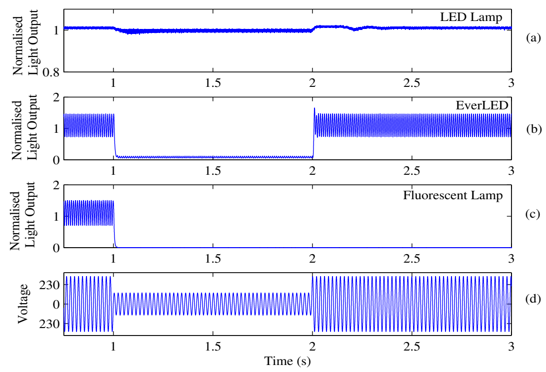

Figure 14. Normalized light output and supply voltage during dip to 40% nominal voltage for 1s

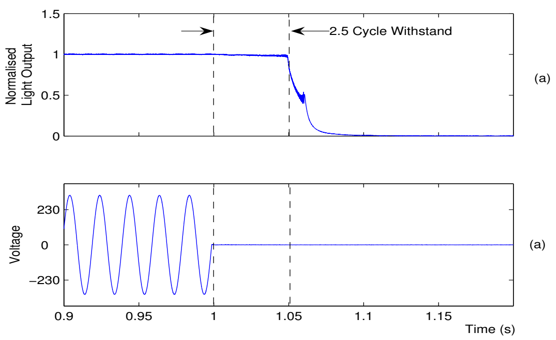

Figure 15. Light Output hold-up of LED lamp to Voltage Drop to 0%

The hold-up capability of the new lamp was tested by applying a supply voltage drop to zero and measuring the time taken for the light output to drop noticeably. As shown in Figure 15, the period is approximately 50ms, or 2.5 cycles.

4.4 Current Waveforms and Harmonics

To get an accurate idea of the impact of the three lamps on the supply network, current and voltage waveforms were measured using both the local supply (through an isolating transformer and Variac) and a pure sine wave voltage source. In the case of the fluorescent and EverLED tubes, results were repeated with and without the appropriate power factor correction capacitor (PFCC - the value was chosen by trial and error to give unity displacement power factor). Some interactions between the local supply impedance and the PFCC are evident on the appropriate results, but are entirely missing on the pure sine wave source results. The affected results were checked by direct connection to the mains supply (isolating transformer and Variac removed from circuit), yielding slightly different, but generally similar, results. As will be seen, the result of these PFCC interactions is to cause significant additional harmonic distortion, even though the power factor is increased.

The IEC61000-3-2 standard, adopted here as AS/NZS61000-3-2, defines lighting equipment and assigns it to Class C [7]. Where the active input power exceeds 25W, the lamp must meet the Table 2 limits for harmonic currents, expressed as a percentage of fundamental current; note that this table specifies a 2nd harmonic level as well as all odd harmonics up to the 39th, with the 3rd harmonic level dependent on the power factor. Where the active power is less than or equal to 25W, the lamp must meet either the Table 3 limits for odd harmonic currents up to the 39th, expressed as mA/W, or must have a current waveform as defined in section 7.3b of the standard (in which the maximum 3rd and 5th harmonic magnitudes are also defined as a percentage of fundamental). In the >25W case, if the lamp is dimmable, the harmonics must meet the full power Table 2 limits and must not exceed the maximum load allowable values, at any brightness level. In the <=25W case, if the lamp is dimmable, measurement is only made at full load.

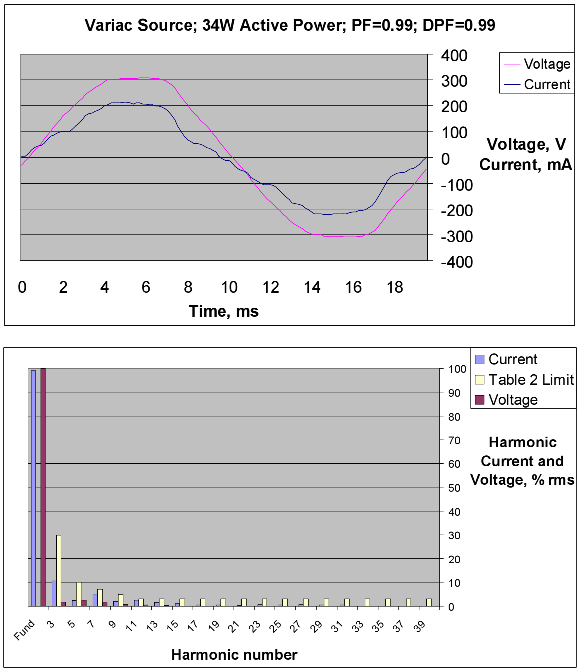

Figure 16. Waveforms and harmonics for new lamp at 34W active input power from local supply

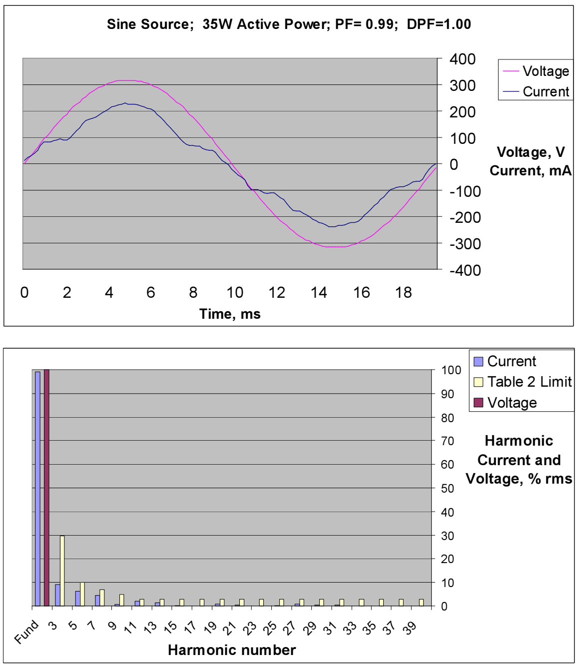

Figure 17. Waveforms and harmonics for new lamp, 35W input power, sine supply

Figures 16 and 17 show the current and voltage waveforms and harmonics for the new lamp at approximately full power running from both the distorted local supply (approximately 4% THD) and the pure sine voltage source. In both cases, although the waveform is not ideal, the Table 2 limits are met. Figure 8 shows the new lamp running from the local supply, with the LEDs dimmed, reducing input power to 21W. It shows the Table 2 limit for the 34W full load case, which it must meet, as well as the Table 3 limit, or the alternative limit (with certain waveform restrictions) it would have to meet if 21W were the full power of the lamp. Clearly the Table 2 limits are met – this is also the case with the pure sine supply.

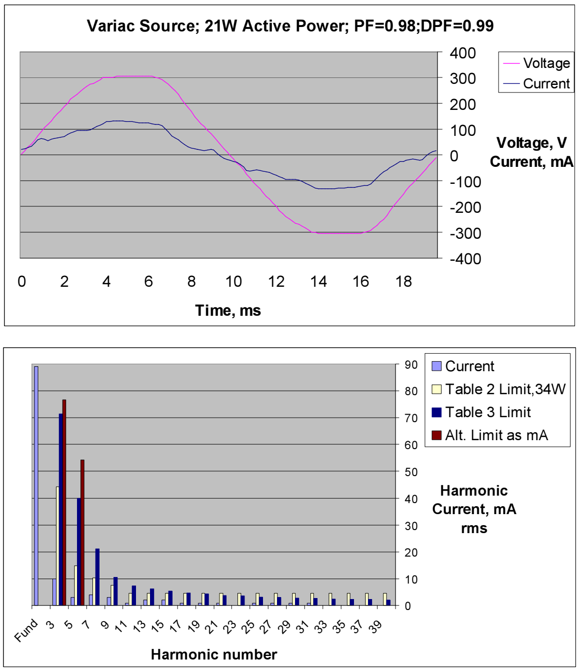

Figure 18. Waveforms and harmonics for new lamp at 21W active input power from local supply

The EverLED lamp waveforms and harmonics, using the sine source, with PFCC fitted, are shown in Figure 19. (The current without the 2uF PFCC is also given.) The EverLED lamp meets the Table 2 limits both with and without the PFCC (latter results not shown), when running from the sine source. When running from the local source, Table 2 results are met without PFCC, but not when PFCC is fitted. This effect is illustrated for the fluorescent case

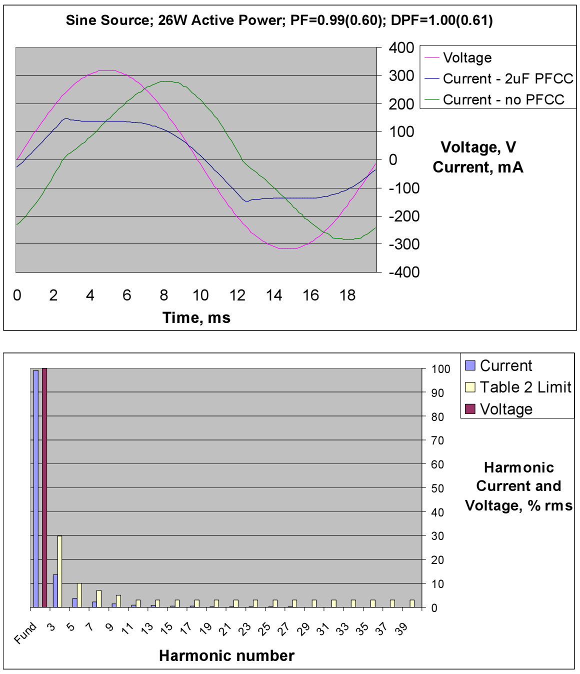

Figure 19. Waveforms and harmonics, EverLED lamp at 26W active input power from sine supply

shown below. When operated from the sine source, as shown in Figure 20, the fluorescent lamp meets the Table 2 limits, both with and without PFCC (3rd harmonic limit is lower than shown, for no PFCC case, being 30% fundamental multiplied by PF).

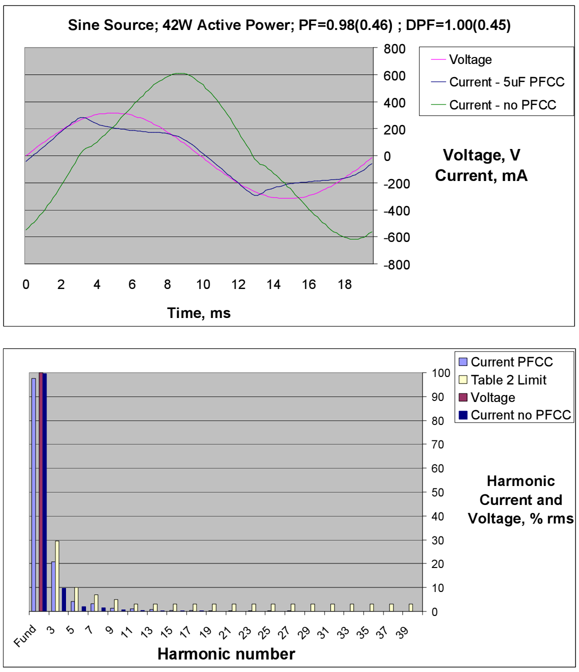

Figure 20. Waveforms and harmonics, fluorescent lamp, 42 W active input power from sine supply

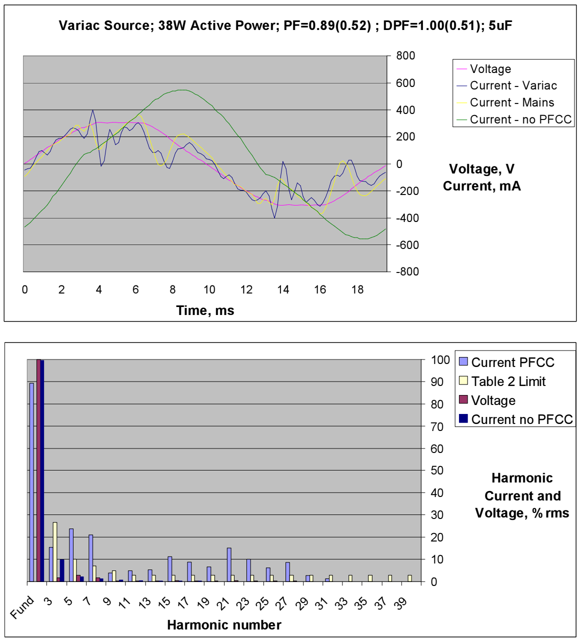

Figure 21. Waveforms and harmonics, fluorescent lamp at 38W active input power from local supply

However, when operated from the local supply, as shown in Figure 21, it meets the limits without PFCC but fails miserably with PFCC, apparently due to some interaction between the PFCC and the supply source impedance. To ascertain if this was due to the isolating transformer and Variac, the current waveform was also studied with a direct mains connection. Although this damps down some of the ringing, the basic wave shape is similar, showing that, in this case, improving the power factor is wreaking havoc with the harmonic current draw.

5. Potential Energy Savings and Costs

The EverLED lamp does not compete favourably with the fluorescent tube, having lower light output, equally poor spectrum, similar flicker behaviour and similar harmonic characteristics. However it does have a predicted lifetime of 10 years on the 12 hour cycle (12 hours on, 12 hours off). Under the same conditions the fluorescent tube, operated with an electromagnetic ballast, has a service life of 13,000 operating hours, or 3 years actual time, to about 5% failure or 70% of initial light output. The EverLED tube costs about US$150 in low volumes, as compared to about US$4 for the fluorescent tube (US$2 for larger quantities). [A single four foot fitting costs about US$75 in low volumes (US$40 in larger volumes)].

The new lamp, operated as white only, can save 25% of the energy needed for the same illumination from the fluorescent (without additional savings to be had from dimming, when full power is not needed). On the 12 hour cycle, a 36W nominal fluorescent, which is actually drawing 42W of real power (including ballast losses), dissipates 184kWh per annum. The new lamp, running white only at 28W actually draws 31W of real power (including drive circuit losses) and dissipates 136kWh per annum. The saving of 48kWh is worth about NZ$10 per annum at retail prices. The lifetime of the new lamp is 50,000 hours to 70% of initial light output, or about 11 years on the 12 hour cycle. Over these 11 years the lamp will save NZ$110 of electricity plus 3 replacement fluorescent tubes (NZ$15). The cost of the 48 white LEDs in the new lamp is about US$100, with a further US$50 to be added for the circuit boards and drive circuitry. A realistic selling price would be around US$250 (40% gross margin). (With the colour corrected LED lamp the energy savings are negligible and the cost is higher by about a further US$100). Hence, assuming NZ$1 = US$0.80, the new lamp will not become commercially viable, on the basis of energy savings alone, until the cost reduces to below US$60 (selling price of US$100), or until the LED efficiency increases by a factor of nearly three (lamp saves 135kWh per annum), or a combination of the two. Note that the above still require the whole of the lamp's lifetime for payback, unless the lamp is on for more than 12 hours a day, or the labour and overhead costs of renewing the fluorescent tube are factored in.

6. Overall Discussion and Conclusions

The practical results show that existing fluorescent lighting suffers from a number of drawbacks, including quality of light spectrum, frequency of tube replacement, flicker sensitivity, either poor power factor or, with PFCC fitted, as is usual, the potential for non-compliance with AS/NZS61000-3-2. Nonetheless the efficiency of converting electrical energy to light is still good.

A commercially available LED tube replacement tackles the frequency of tube replacement issue, but fails to offer significant improvements on all other counts.

A new LED lamp, with colour correction and UPFC drive circuitry, designed to be retrofitted into existing fluorescent fittings, improves on all aspects of the fluorescent performance. Nevertheless the cost of the new lamp is still too high, and its efficiency increase is still too modest to allow its adoption on economic grounds. It is possible that its improved performance, and potential for further power savings when used as a dimmable lamp, remote controlled by a building management system, coupled with other added value features, such as local energy storage for integrated emergency lighting and mood lighting, may earn it a niche market. As LED efficiencies continue to increase, whilst their price is falling and whilst the price of electricity continues to rise and carbon markets come on stream, the viability of such lamps for widespread adoption comes closer.

8. References

[1] D. A. Steigerwald et al., "Illumination With Solid State Lighting Technology", IEEE J. Sel. Topics Quantum Electron., vol.8, no.2, pp.310 – 320, Mar./Apr. 2002.

[2] M. S. Shur and A. Zukauskas, "Solid State Lighting: Toward Superior Illumination", Proc. IEEE, vol.93, no.10, pp.1691 – 1703, Oct. 2005.

[3] Bill Heffernan, Lance Frater and Neville Watson, "LED Replacement for Fluorescent Tube Lighting", Australasian Universities Power Engineering Conference, 2007 record, pp. 413 - 418.

[4] 1988 2 Spectral Luminous Efficiency Function for Photopic Vision. Technical Report No. 86, CIE, 1990.

[5] IEC 61000-4-15. Electromagnetic Compatibility (EMC), part 4.15: Testing and measurement techniques 'Flickermeter function and design specifications'. Ed. 1.1, (2003).

[6] Lance Frater and Neville Watson, "Light Flicker Sensitivity of High Efficiency Compact Fluorescent Lamps", Australasian Universities Power Engineering Conference, 2007 record, pp. 429 – 434.

[7] IEC 61000-3-2. Electromagnetic Compatibility (EMC), part 3.2: Limits – Limits for harmonic current emissions (equipment input current <= 16A per phase). Ed. 3.0 (2005) MOD.