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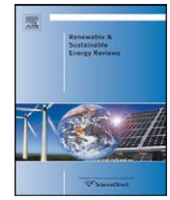

Comparative study of energy saving light sources

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ABSTRACT

Techno-economic performance comparison of compact fluorescent lamps (CFL) with light emitting diodes (LED), electrode less fluorescent lamps (EEFL), fluorescent tubes, incandescent bulbs, photovoltaic (PV) and fiber optic lighting systems was carried out in view of worsening power and energy crisis in Pakistan. Literature survey showed 23 W CFL, 21 W EEFL, 18 W fluorescent tube or 15 W LED lamps emit almost same quantity of luminous flux (lumens) as a standard 100 W incandescent lamp. All inclusive, operational costs of LED lamps were found 1.21, 1.62. 1.69, 6.46, 19.90 and 21.04 times lesser than fluorescent tubes, CFL, EEFL, incandescent bulbs, fiber optic solar lighting and PV systems, respectively. However, tubes, LED, CFL and EEFL lamps worsen electric power quality of low voltage networks due to high current harmonic distortions (THD) and poor power factors (PF). Fluorescent lamps emit UV and pollute environment by mercury and phosphors when broken or at end of their life cycle. Energy consumption, bio-effects, and environmental concerns prefer LED lamps over phosphor based lamps but power quality considerations prefer EEFL. CFL and EEFL manufacturers claim operating temperatures in range of $-20\,^{\circ}\mathrm{C} < T_{CFL} < 60\,^{\circ}\mathrm{C}$ and $-30\,^{\circ}\mathrm{C} < T_{CFL} < 50\,^{\circ}\mathrm{C}$ but CFL frequently damage in wet and damp locations. Costs of low THD and high PF CFL, EEFL and LED lamps may be five to ten times higher that high THD and low PF lamps. Choice of a lamp depends upon its current THD, PF, life span, energy consumption, efficiency, efficacy, color rendering index (CRI) and associated physical effects. This work proposes manufacturing and user level innovations to get rid of low PF problems. Keeping in view downside of phosphor based lamps our research concludes widespread adoption of LED lamps. Government and commercial buildings may consider full spectrum hybrid thermal photovoltaic and solar fiber optic illumination systems.

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Contents

1. Compact fluorescent lamps

Compact fluorescent lamps (CFL) have emerged as a potent alternative of incandescent lamps (bulb) due to lower power consumption and longer life. Lighting loads in homes and offices may vary from 25 to 30% of total domestic power consumption. A 23 W CFL produces same luminous efflux as a 100 W bulb. CFL consumes 2–5 times less power, lasts 8–10 times longer and saves $30 (Rs2500/year) over its life compared to a bulb. 100 W bulb converts only 2.6% of power to white light whilst a CFL converts 6.6–8.8% of input power to white light. However, CFL produces distorted currents with current THD > 100% and low (0.47–0.67) PF leading to excessive utility energy losses [1]. Synergic effect of low power factor (0.457–0.67) CFL or switch mode power supplies

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(SMPS) would force utilities to supply 1.5–2.0 times more apparent power than the real loads. CFL requires high starting inrush currents and its harmonics cause additional I^2R losses due to increased system resistance at higher frequencies. It might cost about $1–2 per CFL to add PF correcting circuit but the company might not be able to compete in market at least in underdeveloped countries. Recent low ($THD_I \leq 20$), medium ($20 < THD_I \leq 50$) and high ($THD_I > 50$) categorization helps guide the customers. CFL cost, depending on PF, THD and efficacy may vary from $0.50 to $55 [2]. Bad quality CFL may have 0.45 PF and 180% THD but a good CFL may have PF > 0.9 and THD < 20%. However, the PF correcting and THD mitigating circuits can reduce overall efficiency. Normally we say 40 W fluorescent tube but its magnetic ballast may consume additional 5–6 W power that is not reflected to customers, anyway. Chinese make CFL costs 3–4 times lower than the western technology based CFL. Utilities must test available CFLs and recommend the high PF and low current THD brands to reduce their reactive power losses. Circuit diagram and picture of modern CFL ballast is shown in Fig. 1 [3].

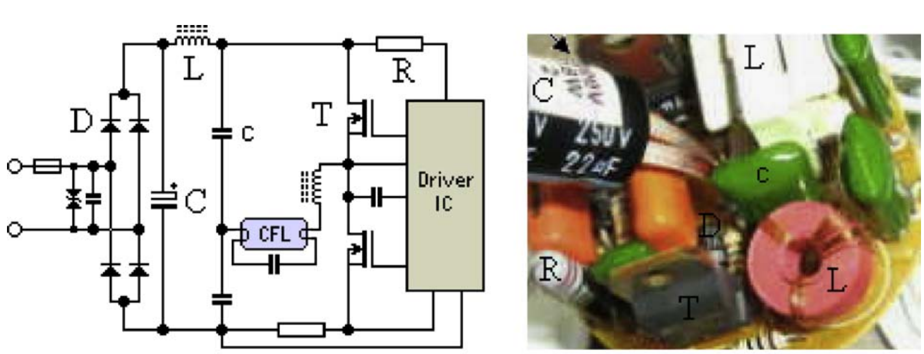
Detrimental affects of a few customers may be overlooked but huge power losses arising out of widespread adoption of CFL cannot be ignored. CFL current with no or poor, average and excellent filtering may be in range of 180–200, 100–130 and 5–10% [4]. It is difficult to allay CFL induced harmonics due to their dispersed nature. It is easier to design high power factor and low THD compact fluorescent lamps by employing in-built filters compared to utility level mitigation. Passive or active power factor correction circuits may cost $0.50–0.85 or $2.0–2.50 per CFL [5]. If CFL load is as high as 26% of building's load then voltage THD would remain below 5%. Simulation results show a typical building may have 115% current THD at power factor of 0.60. Some researchers found few CFL having capacitive PF of 0.55–0.93. However, electric power loss in a typical office building wiring due to current harmonics may be more than twice of the linear loads due to higher resistances. Capacity of a transformer may decrease down to 50% in the presence of harmonics due to eddy current losses. Rated 220 V AC is not enough to start the fluorescent lamp that requires an electronic ballast to provide the starting 600–1000 high voltage ignition spike. CFL produces odd harmonics.

Four CFL simulation study showed 28.5% current THD, 0.92 PF, wiring and iron core hysteresis losses due to eddy currents [6]. Low PF and high current THD CFL squanders power rather than conserving energy. There are many technologies to correct power factor and mitigate harmonics. Methods of PF and THD mitigation using active PF correction and a harmonic filter circuits already reported by many researchers [7–8]. CFL not only produces harmonics rather its own performance is seriously affected in the presence of high voltage THD. It is a positive feedback effect that in case of wide adoption of CFL technology may lead to run way. Arseneau and Quellette [2] studied adverse effects of voltage harmonic distortions on performance of CFL. They reported variations in power factors and current harmonic distortion under voltage harmonics rich power supplies. Similar magnetic ballast CFLs power factors at THD_V 0.1% mains power supply may vary from 0.50 to 0.53 and THD_I from 9.2 to 12.8%. Electronic ballasts PF varies from 0.55 to 0.58 but their THD_I increases to 78.70 to 82.90%. Even the most expensive 0.97–0.99 high PF CFL was found to have 12.5–20.9% THD_I. It is worth noting PF of multiple make magnetic ballast CFLs at 4.6, 15.5 and 36.4% mains power supply THD_V may vary from 0.46–0.53, 0.43–0.53 to 0.46–0.55 whilst theirs THD_I varies from 9.0–12.8, 8.6–12.9 to 13.2–16.8%, respectively. However, electronic ballast CFL PF may vary from 0.54–0.59, 0.33–0.35 to 0.42–0.37 and THD_I from 84.3–87.8%, 94.4–99.5% to 92.8–99.8%, respectively. Even for supply with $THD_V < 2.5\%$ the THD_I varies from 92.3 to 143.9%. Attenuation factors for 3rd to 7th harmonics decrease with increasing wire length but start increasing with wire length for 9th harmonic [1].

CFL cannot operate in microwave ovens, refrigerators, humid indoor or out door locations. CFL operation exhibits optimum performance at 20 °C and its efficiency decreases at higher and lower temperatures. At extremely low temperatures the CFL may fail to start without cold start circuits which again increase cost reducing power saving. According to a Chinese researcher [9] their CFL technology is 40% less efficient than competitive Western technology. Chinese produced 3.0 billion CFL in 2007 that is about 80% of world CFL market. Quality check passing rate is 100% for large manufacturers, 62.5% for medium and 50% for small companies. Chinese consume 1 billion CFL in homeland exporting the rest abroad. It is not sure what will be the fate of surplus 200 millions defective CFL pieces? Strict health compliance laws do not allow manufacturing CFL in Europe and USA. Many companies have chosen China and India due to their relaxed public health laws. Five to six foreign companies in addition to many local companies make CFL in China a few in India. Chinese exponentially rising CFL production is shown in Fig. 2.

China seems to phase out conventional bulb production by 2010 when CFL production would exceed 5 billions per year. In 2002 about 80% of world CFL production came from China [10]. CFL production is likely to decline by 2015 due to CFL's long life. Chinese Government distributed 29 million CFL, 21 million linear and some LED lamps in 2008 [11]. May be WAPDA buys 30 million CFL worth Rs6.7 billion in 2010.

New CFL glass prevents UV escape but aged pieces may not stop leakage completely. CFL phosphors are gradually sputtered off due to bombardment of electrons. Some types of CFL have been found to emit UV-B and traces of UV-C radiations [12]. NEMA rules force manufactures to use maximally 5 mg of mercury for CFL < 25 W and 6 mg for 25–40 W CFL. Glass walls and tube electrodes gradually absorb mercury. When mercury runs out the CFL starts glowing dim pink. CFL manufacturers claim (@0.012 mg Hg/kWh)



(a) CFL drive circuit (b) Drive circuit picture

Fig. 1. Compact fluorescence lamp ballast [3].

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