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International Journal of Ambient Energy

ISSN: 0143-0750 (Print) 2162-8246 (Online) Journal homepage: https://www.tandfonline.com/loi/taen20

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To cite this article: Rashid Alammari, Mohd. Shafiul Islam, Noor Alam Chowdhury, Abdul Kader Sakil, Atif Iqbal & Amith Khandakar (2017) Impact on power quality due to large-scale adoption of compact fluorescent lamps – a review, International Journal of Ambient Energy, 38:4, 435-442, DOI: 10.1080/01430750.2015.1121921

To link to this article: https://doi.org/10.1080/01430750.2015.1121921

Accepted author version posted online: 20 Nov 2015.
Published online: 06 Jan 2016.

INTERNATIONAL JOURNAL OF AMBIENT ENERGY, 2017
VOL. 38, NO. 4, 435–442
http://dx.doi.org/10.1080/01430750.2015.1121921

Impact on power quality due to large-scale adoption of compact fluorescent lamps – a review

Rashid Alammari, Mohd. Shafiul Islam, Noor Alam Chowdhury, Abdul Kader Sakil, Atif Iqbal and Amith Khandakar

Department of Electrical Engineering, College of Engineering, Qatar University, Doha, Qatar

ABSTRACT

The demand of electrical energy has grown tremendously in the last couple of decades across the globe. The energy conservation and management has attracted the attention of stake holders for efficient utilisation of the resources. One of the major steps taken by the authorities towards conservation of electrical energy is replacement of incandescent lamps (ILs) by compact fluorescent lamps (CFLs). CFL uses electronic circuit for its ignition, making them a non-linear load on utility grid. Large-scale replacement of ILs has enormous effects on utility grid in terms of power quality. This paper reviews the work conducted by several researchers investigating the effect of using CFLs on power quality. Basic terminologies related to power quality is defined. The experimental results elaborate the pollution on the grid in the term of total harmonic distortion in current due to adoption of CFLs. The methodologies of harmonic measurement system are reviewed. Different software used for the analysis is presented. The paper will help the researchers to receive a comprehensive overview of power-quality issues.

ARTICLE HISTORY
Received 14 July 2015
Accepted 16 November 2015

KEYWORDS
Power quality; total harmonic distortion; harmonics; compact fluorescent lamps

1. Introduction

Worldwide drive is to replace the energy in-efficient incandescent light bulbs with the fluorescent lights (FLs) and other solid-state lighting (SSL) systems such as compact florescent lamps (CFLs) and light emitting diodes (LEDs). FL bulbs are in service for long period, while compact FLs are now increasingly employed. The FL lighting system initially used to be ignited using traditional choke and starter circuit (Chen and Murray 1980; May and Collins 2010; Maheswaran et al. 2012), while new installation uses electronic circuit for their ignition. The conventional inductor that is used for generation of high voltage that is needed for ignition of filament, due to high d*v*/d*t* causes electro-magnetic interference (EMI) problems (Zenebe and Matti 2011). Nevertheless, the electronic ignition system causes power-quality problem due to harmonic injection in the utility grid (Meyer, Schegner, and Heidenreich 2011; Timens et al. 2011, 2012; Keyer et al. 2013. The same problem is existent in CFL, LED and other type of SSL system. The current drawn by these lighting devices is highly distorted that results in the pollution of utility grid (Energystar 2005; Das 2012). The injected harmonic have several far-reaching ill effects such as (*Generation, Distribution and Utilization of Electrical Energy* 1993; Alvarez-Caicoya, Cosme-Torres, and Ortiz-Rivera 2011; Bodo 2011; Cole and Driscoll 2012): (i) malfunctioning of switchgear and protection devices installed at power stations, (ii) false tripping of circuit breakers and excessive arcing, (iii) vibration, noise, torque pulsation, increased copper losses in the grid-fed motors, (iv) increased losses in transformers, cables and dielectric breakdown, (v) malfunctioning of communication and data lines, (vi) reduced operational life of electrical equipment, increased chances of tripping and production losses and (vii) unbalanced power-system network. Additionally the power factor (PF) of the currents drawn from the grid by such lighting systems is poor that causes reactive power loading on the utility grid (Swagatam 2010. Harmonic injection in the grid is largely ignored since the use of CFLs/LEDs was minimal. However, with new governmental regulations, the future forecast of widespread use will have determinant effect on utility network. Further, the design of harmonic filter for the lighting system is difficult because they are widely distributed over the large power distribution network. It is more convenient to design and use harmonic filter individually in each SSL; however, it will add to the cost, volume and weight. The most common among different types of SSL is CFL. Hence it is extremely important to investigate the effect of using large-scale CFLs on the power quality of the utility grid. The following sections present an overview on the findings by different researchers on the effect of using CFLs as lighting source and the method of computing the harmonic distortion.

2. Basic power-quality terminologies

According to IEC, 'power quality' is defined as 'A set of parameters defining the properties of power quality as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (symmetry, frequency, magnitude and waveform)' (Bollen 2000, 5; IEEE Std 1100–1999 1999). According to IEEE Std. 1100–1999, power quality is defined as the concept of powering and grounding the electrical equipment in an appropriate method to operate that equipment in such a way that, it is compatible with the wiring

CONTACT Atif Iqbal atif2004@gmail.com; atif.iqbal@qu.edu.qa

Table 1. Characteristics of power quality (Ise, Hayashi, and Tsuji 2000).

Voltage stability
Under-voltage and overvoltage, voltage sag and swell
Voltage fluctuation and flicker frequency variation
Continuity of supplying power
Momentary interruption, temporary interruption
Sustained interruption
Voltage waveform
Harmonic voltage and current
Power factor

system and connected apparatus (Ise, Hayashi, and Tsuji 2000). Power quality is a combination of voltage quality and current quality. The abnormality in voltage from the ideal is called the voltage quality. The ideal voltage is a sine wave with constant frequency (50 Hz) and magnitude (220 V rms). Same as the voltage, the abnormality in current from the ideal current is called current quality (Caserza Magro, Mariscotti, and Pinceti 2006).

There are several characteristics of power quality. Table 1 classifies different aspects of power quality (Arrillaga, Bradley, and Bodger 1985; Cornfield 1988; Phipps, Nelson, and Sen 1994; Reid 1996; Simpson 1997; Milanovic and Negnevitsky 1998; Sabin, Brooks, and Sundaram 1999; Cano Plata and Tacca 2000; EN 61000-2-2 2002–2003; Melhorn et al. 2005; Wiczynski 2008; Madhusudan and Ramamohan Rao 2012; ANSI/IEEE Std. 519–1992; IEC 60050 (161)). The definition of each aspect in Table 1 is elaborated further.

2.1. Overvoltage and under-voltage

Overvoltage occurs when the average line to line voltage is greater than the maximum designed voltage for the equipment installed. Depending on the time and size, overvoltage can be classified as continuous, temporary and transient and combined (Baggini 2008). Generally, overvoltage occurs due to fault and disturbances in the network. Overvoltage can also occur due to a sudden large load change in one feeder and switching on capacitive circuits. On the other hand, if the average line-to-line voltage is less than the designed voltage of the equipment, it is called under-voltage. Under-voltage can cause failure of the equipment as well as the system network.

2.2. Voltage sag and swell

Voltage sag is defined as a sudden reduction in rms voltage at the low voltage distribution system, followed by voltage recovery after a very short period of time. This phenomenon is also known as voltage dip. Large motor starting and lighting are the most frequent cause for voltage sag. High current passes through the lines because of large motor starting and lighting (Grady and Heydt 1985), which leads to voltage dip. Voltage swell is opposite of voltage sag. A sudden increase in the rms voltage for a short period of time is called voltage swell. Capacitive loads and open circuits are the main cause for voltage swell.

2.3. Voltage fluctuation and flicker

The cyclic variation in the amplitude of the voltage is called voltage fluctuation. This variation in the magnitude is usually much lower than the sensitivity of threshold of most equipment. Changes on the illumination intensity of lighting system are the main disturbing effect of voltage fluctuation. Voltage fluctuation on low-voltage AC network is produced by fluctuating loads, operation of transformer tap changes and other changes in the connected equipment (Christiansen 1991). Voltage flicker is defined as the impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral disturbance fluctuates with time (Dolara et al. 2011). Voltage fluctuation and voltage flicker is almost same; the only difference is the time of voltage flicker is shorter than that of the voltage fluctuation.

2.4. Frequency variation

Frequency variation is one of the most important parameter to be considered in a power system. Several control units are being installed in order to monitor and control the frequency variation. Under normal conditions, the frequency of power system varies due to the power variation in the system and according to the response speed of its control system. Frequency variation also depends on the effectiveness of actions adopted to clear the fault.

2.5. Momentary, temporary and sustained power interruption

Momentary power interruption is defined as a brief disruption in electric service for a few seconds. Usually, these disturbances are the results of temporary faults in the distribution of electricity. Lighting strike and falling branches on the transmission line are the most common causes for momentary power interruption. Momentary outages can also happen during normal transmission and switching operation. Disruption in power supply for one minute or two is called temporary power interruption. Power system equipments such as circuit breakers, transformers, auto-power factor correction, automatic transfer system etc. as well as human error is sometimes the causes of temporary power interruption. Long-term interruption in power supply of a certain area is known as sustained power interruption. This kind of interruption happens due to fault in the power station, damage to transmission lines, substations and other parts of the distribution system.

The graphical representation of voltage sag, swell, overvoltage, under-voltage and momentary, temporary and sustained interruption is given in Figure 1.

In Figure 1, normal operating voltage is 90–110%. If the voltage level is below 90%, for the first two minute is called voltage sag, whereas after the second minute it is under-voltage. And if the voltage level is above 110%, for first two minute is called voltage swell and afterwards it is overvoltage.

2.6. Harmonics voltage and current

The definition of harmonics is based on the application of the Fourier transform and superposition to the voltage and current waveforms. An ideal power system contains only the fundamental harmonic – 50 Hz (Indian sub-continent, Gulf region, Europe,

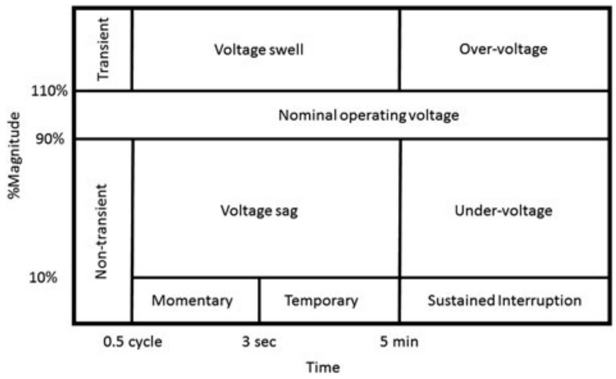

Figure 1. Definition of power-quality aspects by IEEE Std. 1159–1995 (Ise, Hayashi, and Tsuji 2000).

etc.) or 60 Hz (USA and Canada). Harmonics are mainly generated from non-linear loads such as transformers, electric motors, generators, arc furnaces, arc welders, DC converters, inverters, television power supplies, switched mode power supplies, high pressure discharge lamps, compact fluorescent lamps (CFLs), LEDs, laptop and mobile phone chargers and other similar electronics and power electronics equipment (Rönnberg, Bollen, and Wahlberg 2010).

The current $i(t)$ can be expanded into a Fourier series as follows:

$$i(t) = a_n \sin \omega t + b_n \cos \omega t, \tag{1}$$

where,

$$a_n = \frac{1}{\pi} \int_0^{2\pi} i(t) \sin(n\omega t) \mathrm{d}(\omega t), \tag{2}$$

$$b_n = \frac{1}{\pi} \int_0^{2\pi} i(t) \cos(n\omega t) \mathrm{d}(\omega t). \tag{3}$$

Root mean square of the current can be expressed by

$$I_{\mathrm{RMS}} = \sqrt{a_n^2 + b_n^2}. \tag{4}$$

The harmonic distortion root mean square of the current can be calculated as

$$I_{H-\mathrm{RMS}} = \sqrt{I_2^2 + I_3^2 + \cdots + I_n^2}. \tag{5}$$

The total harmonic distortion (THD) of current can be calculated as

$$\%\mathrm{THD}_I = \frac{\sqrt{I_{2\ \mathrm{RMS}}^2 + \cdots + I_{n\ \mathrm{RMS}}^2}}{I_{1\mathrm{RMS}}} * 100. \tag{6}$$

Similarly the voltage $v(t)$ can be expanded into a Fourier series.

$$v(t) = a_n \sin \omega t + b_n \cos \omega t, \tag{7}$$

where

$$a_n = \frac{1}{\pi} \int_0^{2\pi} i(t) \sin(n\omega t) \mathrm{d}(\omega t), \tag{8}$$

$$b_n = \frac{1}{\pi} \int_0^{2\pi} i(t) \cos(n\omega t) \mathrm{d}(\omega t). \tag{9}$$

Root mean square of the voltage can be expressed by

$$V_{\mathrm{RMS}} = \sqrt{a_n^2 + b_n^2}. \tag{10}$$

The harmonic distortion root mean square of the voltage can be calculated as

$$V_{H-\mathrm{RMS}} = \sqrt{I_{2\ \mathrm{RMS}}^2 + \cdots + I_{n\ \mathrm{RMS}}^2}. \tag{11}$$

The THD of voltage can be calculated as

$$\%\mathrm{THD}_V = \frac{\sqrt{I_{2\ \mathrm{RMS}}^2 + \cdots + I_{n\ \mathrm{RMS}}^2}}{I_{1\mathrm{RMS}}} * 100. \tag{12}$$

Non-linear loads cause power-quality problems to the electric grid, which are mostly avoided even though the users are benefited from it. These non-linear loads degrade the power quality by injecting the harmonic current to the grid. Additionally, power factor is poor for such loads. Poor power factor means more higher generation capacity (Jabbar et al. 2008). Malfunctioning of the protective equipment is another effect of non-linear loads.

In fluorescent lighting, electronic ballast is being used instead of magnetic ballast. The electronic ballast is more efficient than magnetic ballast. This electronic ballast inject more harmonics in the supply current than magnetic ballast (Qureshi, Akmal,

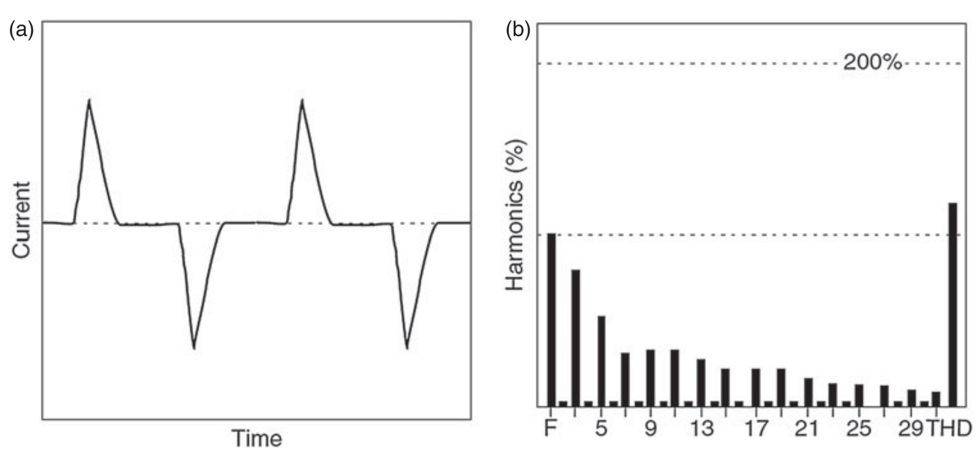

Figure 2. (a) The current waveform of a typical CFL (b) harmonic spectrum of a typical CFL (Baggini 2008).

Table 2. IEEE 519 voltage distortion limit (ANSI/IEEE Std. 519–1992).

Bus voltage at PCC	Harmonic distortion	THD
69 kV and Below	3.0	5.0
Between 69 and 161 kV	1.5	2.5
161 kV and Above	1.0	1.5

and Arif 2009), which distorts the bus current. Power-factor-corrected electronic ballast is also available in the market, but it is more costly than the normal ones. CFLs are also a replacement for incandescent lamps (ILs). It emits the same amount of light with less power. A CFL of 11 W emits the same amount of lumens as 60 W ILs (Dolara et al. 2011). It also has a longer lifetime than an IL. Small electronic ballast is used in the CFL, which is also the source of harmonics. The harmonic spectrum and current waveform of a typical CFL is given in Figure 2. These harmonics are also injected to the network grid and pollute the ideal sinusoidal waveform of voltage and current.

Table 2 shows the IEEE Std. voltage distortion limits. Table 3 illustrates the IEEE 519 maximum odd harmonic current distortion for general distribution system.

In Tables 2 and 3, PCC refers to the point of common coupling. It is usually the point where the distribution transformer is located. Limits of even harmonics are 25% of the odd harmonic limits. The term TDD refers to the total demand distortion. I_{SC} is the maximum short circuit current at the PCC, I_L is the maximum demand load current at the PCC and N refers to the number of harmonic order.

2.7. Power factor

Modern lighting system also affects the power factor. The power factor of CFL and LED is very less, which influences the overall power factor of the bus. Due to low power factor, CFLs have high THD*i* (%), which causes severe issues related to the power quality of the network (Mariani et al. 2010). The ratio of real power to the apparent power is the power factor. On the other hand, the power that is consumed and converted by the system is real power. According to a field test by Lulea University in Sweden in 2010 showed PF decrease to 0.82 from 0.87 after using of energy saving lamps LED and CFL in a hotel (Rönnberg, Wahlberg, and Bollen 2010).

3. Review of harmonic measurement

The harmonics due to the lighting system can be measured using power analyzer. The power analyzer is capable of monitoring as well as recording the harmonic spectrum for a limited time period. This device also shows the voltage and current waveforms, real power, apparent power and power factor. The experimental set-up to measure the power quality is given in Figure 3.

Table 3. IEEE 519 maximum odd harmonic current distortion (%) limit for general distribution system (ANSI/IEEE Std. 519–1992).

I_{sc}/I_L	$N < 11$	$11 < N < 17$	$17 < N < 23$	$23 < N < 35$	$N > 35$	TDD
< 20	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

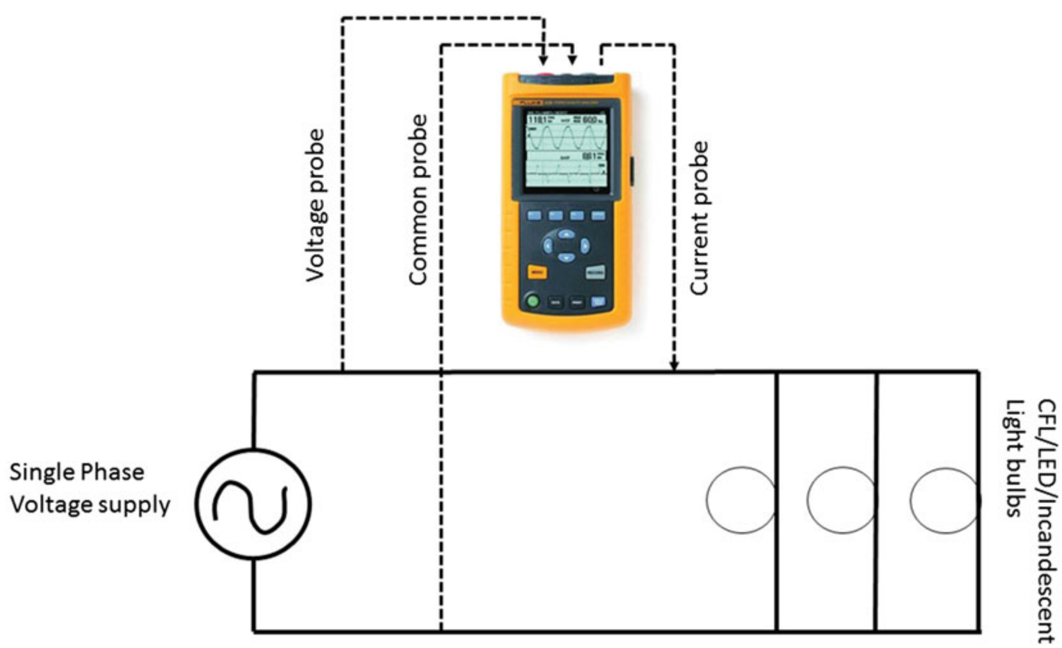

Figure 3. Experimental set-up to measure the power quality.

In Figure 3, Fluke 43B single-phase power analyzer is used to measure the power quality. Light bulbs are connected in parallel with the single-phase distribution power socket. Two probes are connected in parallel with the load to measure the voltage. A current clamp is connected with the single-phase line. If a power extension is used, the insulated wire should be striped and the current clamp should be connected with the line (Life). With the help of a digital recorder and a digital wattmeter harmonics are measured and monitored. Only voltage measurements are done using the digital recorder and the current measurements are obtained by using a 0.1 $\Omega \pm 1\%$ anti-inductive shunt. Five types of indoor and street lighting systems were tested. First type of lighting system contains 2×36 modular ceiling lights with 1×36W FL and electro-mechanical power reactor. Second type of lighting system contains same amount of ceiling lights but with electronic power reactor. The third one also contains same amount of ceiling lights but with an integrated power reactor. Next type contains 1×35 modular ceiling lights equipped with 1×35W FL and electronic power reactor. The last type of lighting system contains 49.5 W LED lighting with a 60 W electronic power supply system and dimmer. The test will provide the fundamental frequency, power factor, voltage and current RMS value (VRMS and IRMS), active and apparent power (P, S), harmonic active power and harmonic apparent power (VH, IH, PH and SH). It will also provide voltage and current THD (THDV and THDI). From the result, it is seen that the harmonic performance can be enhanced by using electronic reactor instead of electro-mechanical reactor. In case of electronic ballast, the power supply control procedure has an impact on the harmonic performance of the lamp.

A typical house was built in the laboratory of Lulea University of Technology for experiment. In this experiment, four different kinds of scenarios were tested. The test was conducted with equal light output in lumen. In the first scenario, all the lights are incandescent. In the second one, half of the lights were replaced with CFLs. In the third scenario, rests of the ILs were replaced by 7-W LED lights. All the lights were replaced by 7-W LED's in the last scenario. The power factor of all LEDs and CFLs were 0.6. Other loads were also connected in compliance with the lamps. In order to analyse, two different instruments are used. To obtain the power-quality parameters, a Dranetz PX5 power-quality analyzer was used, which will record one minute values for all the power-quality parameters. Two hundred and fifty millisecond high frequency snapshot was taken every minute using a Hioki Memory Hicorder with a sampling frequency of 10 MS/s. The test result shows that, the replacement of ILs with LED and CFL reduces the power consumption. Due to the replacement, the amount of reactive power produced by the load as well as the harmonic emission was increased. So, the reduction of ILs reduces the power consumption but pollutes the grid network by injecting harmonics into the grid.

A power analyzer and an oscilloscope were used to measure the voltage and current waveform. A 0.2 Ω power resistor is used to get the voltage waveform. A group of 23 W CFL is used for testing. Each CFL draws about 0.135 A.

The same experiment was carried out again for measuring harmonics but this time with two different kinds of loads. The first one is done with 23 W CFLs and the second one is done with 40 W fluorescent lamps (FL). While testing with CFL's, the current drawn by the CFL is 135 mA and the value of THD*i* was found to be 120%. After that all the CFLs are replaced with 40 W FL bulbs. At that time the average current drawn by the FL lights are 380 mA and the value of current THD was 23.5%.

Table 4. Harmonic magnitude (CFL load).

Harmonic order	Percentage magnitude
3rd	76.28
5th	56.29
7^{th}	43.39
9th	34.95
11th	29.14
13th	24.93
15th	21.76
17th	19.29

Table 5. Harmonic Magnitude (FL Load).

Harmonic order	Percentage magnitude
3rd	20.5
5th	10.3
7th	5.0

The measurements of CFL load and FL load, which is obtained from the power-quality analyzer, are shown in Tables 4 and 5, respectively.

The voltage and current THD is obtained by the power analyzer. In order to observe the large-scale effect of harmonics, these data are then entered into a power analysing software.

4. Cost–benefit analysis

In Table 6 it is clear that the cost of LED is higher than CFL and ILs. However, in the long-run, LED bulbs should be used instead of incandescent and CFL in order to save energy. Nevertheless, consumer looks at the capital cost undermining about the long-run cost that is due to energy usage. This happens because of consumer's lack of knowledge about the energy-efficient technologies and its long-term benefits (Soni and Devendra 2008; Khorasanizadeh et al. 2015). The government of developing countries should make an energy-efficient policy to encourage the consumer to use green energy. Also, manufacturer can develop new LED bulbs which will be as cheap as CFLs to satisfy consumer needs and it seems to happen in the near future. Holland

Table 6. Cost comparison between incandescent, CFL and LED.

	Incandescent	CFL	LED
Average lifespan for each bulb	1000 h[a]	10,000 h[a]	25,000 h[a]
Watts of bulb (to achieve equivalent brightness)	60[a]	14[a]	10[a]
Average cost per bulb	\$0.5[a]	\$3[a]	\$7[a]
KWh of electricity used over 25,000 h	1500	350	250
Cost of electricity (at 0.10 per KWh)	\$150	\$35	\$25
Bulb needed for 25 k hours of use	25	2.5	1
Equivalent 25 k hours bulb expense	\$12.5	\$7.5	\$7
Total cost for 25 k hours	\$137.5	\$42.5	\$32

Note: [a]The information given in the table are collected from Khorasanizadeh et al. (2015), Soni and Devendra (2008), Holland (2014), Cardwell (2015), Singh and Katal (2013), Islam et al. (2015), Matvoz and Maksic (2012), Shabbir et al. (2014), Das, Pal, and Sadhu (2014) and Di Mauro and Raciti (2014).

(2014) statistically shows that, LED bulbs' prices have been dropping significantly since 2010 compared to CFLs and LEDs. This may cause domination of LEDs over CFLs if the price continues to drop. A recent article (Cardwell 2015) shows that, Philips made a new LED bulb (equivalent brightness to a 60-W incandescent), which costs around $5, and this low-cost LEDs will give a competition to CFL market. Moreover, reduction of CFL uses will decrease the amount of mercury disposal, which will be a key factor for healthy environment (Singh and Katal 2013). Furthermore, THD in LEDs is less compared to CFLs, because it consumes small amount of active power (Islam et al. 2015). On the other hand, the power factor of CFLs is better than LEDs. As a result, the utility should either develop THD mitigation technique or make rules and regulation to use the combination of LEDs and CFLs, in order to balance both power factor and THD (Matvoz and Maksic 2012; Das, Pal, and Sadhu 2014; Di Mauro and Raciti 2014; Shabbir et al. 2014).

5. Harmonic measurement software

It is difficult to measure harmonic characteristics of a large-scale light source in laboratory due to lack of space and sometimes it also costly. In order to simulate large-scale light source, different software packages such as MATLAB, ETAP, CYME, PSCAD are used. Some of the research related to the simulation of harmonic character by using software are described below.

5.1. Electrical transient analyzer program

Electrical transient analyzer program (ETAP) is power-system-analysing software, which is used for modelling and analysing electrical power networks. It is mainly used by the power utility distribution companies. Many industrial companies also use ETAP for modelling and analysing the networks used by the industry (Brown et al. 1990; Khan, Junaid, and Asgher 2009; ChunHua 2011).

For modelling the electric network, branch equipment, power grid, synchronous generator and lumped load are used in ETAP. Branch equipment consists of transformers, cables, transmission line, capacitor, reactor, etc. Power grid is basically a constant voltage source with internal impedance.

The basic version of ETAP has the following analysing tools:

- single line diagram, load flow analysis;
- short circuit analysis, protective device coordination;
- motor starting and transient stability analysis and
- harmonic analysis.

A real model of CFL is developed in ETAP harmonic library to carry out simulation for the evaluation of required power-quality parameters (Grady and Heydt 1985). ETAP can be used for analysing the distribution system at large scale. The whole power distribution network of University of Engineering and Technology (UET) Lahore, Pakistan was simulated for testing in ETAP. In UET, among the load, 10% is lighting load and during simulation this 10% lighting load is replaced by CFLs. From the research, it is concluded with the statement that CFLs produce harmonics, which increase the value of THD*v* and THD_I to an unacceptable level. It is also recommended that the manufacturer must be bound to produce and supply CFLs having improved power-quality-related performance and it is better to use K-rated transformer when CFLs are being used as a large scale. Similar results (i.e. increase in THD*v* and THD*i* value) were found when experimented and simulated again and again with FLs.

5.2. PSCAD

PSCAD™ is compilation-based simulation software, which is capable of simulating circuits and small grid network (Kalbat 2013). A detailed model of the load is needed to simulate the system in PSCAD. THD can be measured by using PSCAD.

An electrical network dominated by lighting load is investigated by simulating the network using the impedance network model in PSCAD v3.0.6 software in George et al. (2011). In this investigation, simulation is carried out using two different types of light sources: CFLs and LEDs. CFLs and LEDs are modelled by the serial impedances and some of the parameters needed for the simulation are obtained from the fundamental harmonic. After the experiment, it is concluded that LEDs are better than CFLs because CFLs causes line losses due to its low power factor.

5.3. Expert data flow and static analysis technical (Paladin)

Expert data flow and static analysis (EDSA) tool is a power-analysing software, which is used by many industrial companies to model and analyse the distribution network (Vanek and Culp 1989). It can also be used for designing electrical system of residential, commercial and industries. EDSA Technical 2005 has the following analysing tools:

- 3 phase system design, load flow analysis;
- short circuit analysis (AC and DC);
- motor starting analysis, harmonic analysis;
- cable sizing, harmonic filter sizing and
- protective device sizing and coordination.

5.4. CYME

CYME Power Engineering Software is power-analysing software with a network editor, analysis modules and user customisable libraries. It has two parts – one is for distribution power system analysis and the other is for transmission and industrial. The basic version of CYME Power Engineering Software has the following features:

- load flow, load balancing and optimal capacitor placement;
- network forecaster, transient stability;
- harmonics analysis, volt/VAR optimisation;
- low -voltage distribution network modelling;
- protective device coordination;
- enhanced substation modelling and
- secondary grid network analysis.

5.5. MATLAB

A MATLAB code and a Simulink simulation is developed for non-linear resistance modelling of mercury types luminaires for a main street lighting system in Istanbul (Acarkan, Zorlu, and Kilic 2005). A cubic polynomial non-linear equation of mercury lamp luminaire for solving the non-linear circuit in MATLAB is used. Newton–Raphson iterative method is used to solve the street lighting system single-phase equivalent circuit with 10 non-linear resistances. Similar circuit was modelled in Simulink for calculating harmonic activities on phase and neutral conductors. After simulation it was found that harmonic activities are affected by physical structure of the lighting system, terminal voltage variation of supply transformer's mast span and incrementing of minimum supply voltage.

6. Conclusion

This paper summarises the harmonic performance of utility grid when employing CFLs on large scale. Due to non-linear nature of CFL, harmonics are injected in the utility grid and the power quality is affected significantly. For a typical CFL, the THD is as high as about 75%. Different software that can be used for the investigating the effect of CFLs on utility grid is discussed. The major problem is the distributed nature of CFLs load on the utility grid. It is important to develop harmonic mitigation technique or to use mixed lamps in order to protect other electrical equipment connected in the same feeder system.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was made possible by UREP [grant number 15-075-2-027] from the Qatar National Research Fund (a member of Qatar Foundation). The statements made herein are solely the responsibility of the authors.

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