Sindh Univ. Res. Jour. (Sci. Ser.) Vol. 48 (2) 407-412 (2016)

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Power Quality Assessment of Compact Fluorescent Lamps

I. A. HALEPOTO[++], F. R. ABRO[++], A. R. CHACHAR[*], ADEENA[**]

Department of Electronics Engineering, Mehran UET, Jamshoro

Received 06th October 2015 and Revised 24rd April 2016

Abstract: Electricity consumers in Pakistan are facing long duration power outages and high energy prices. Due to increasing demand and supply gap, energy conservation policies are required to be initiated. Compact Fluorescent Lamps (CFLs) have emerged as replacement of conventional incandescent bulbs and fluorescent lamps. Compared to conventional illumination sources CFLs have less power consumption and longer life; therefore replacement of conventional illuminators with CFLs is economically justified. Power quality degradation caused by nonlinear loads badly affects power system efficiency. Operating life of consumer appliances and power system components is also affected by poor power quality. CFLs being nonlinear loads will inject harmonics in power system.

In this research work, harmonic distortion and power factor of different CFLs is performed. Fluke 43B Power Quality Analyzer is used to measure Total Harmonic Distortion (THD) for current and voltage of five different brands of CFLs used in Pakistan. Experimental results show that power factor of all analyzed CFLs is poor in the range of 0.57 to 0.62 lagging. THD for current is observed very high in excess of 71% whereas THD values for voltage lie between 5.7 to 8.5%, which is also greater than acceptable value of 5% as set by IEEE standard 519-1992.

Keywords: Compact Fluorescent Lamps; Harmonic Distortion; Total Harmonic Distortion, Power Factor.

1. INTRODUCTION

Energy is considered as backbone for any growing economy. The sustainable growth can notbe achieved without the energy especially. Systematic infrastructure, cleanliness, ease of control and transmission from one point to another makes electrical energy superior to other forms of energy (Sahito, 2014). Currently, Pakistan has the installed generation capacity of around 22000MW, but in practical situation, the Pakistan's generation is never been more than 17000MW. This means that at maximum only 75% of total installed capacity is being generated (Halepoto, 2015). This is the major reason of on-going power crisis. On other side, since last decade, the electricity demand in Pakistan is rising at the rate of 11% per year as an average, whereas the power generation has the negligible addition. The negligible development of hydel and nuclear power generation, unstablizefusel fuel prices,imbalance energy mix-up, and ignorance of renewable energy source are major causes for current crises in electricity sector. Electricity theft and technical losses inaged power system also elevate the severity of the problem (Sahito, 2015).

Energy conservation policies have been introduced to cater the raising power consumption and specially peak load demands. Electricity tariff structure can be planned in way to compensate and penalizes the residential consumers for energy usage using off peak and peak load hours. Time of Ue (ToU) priceoncept can be introduced where, electricalenergy unit price can be increased during high peak hours and vice versa can be reduced in off-peak hours.

Power quality refers to the quality of electric powersupply variables and characteristics (voltage, current, frequency, power factor, waveform, lamp flicker, unbalance, reliability, availability, interruptions and etc.) with reference to permissible limits of variation and quality of power supply to satisfy required and specified needs (Nasif, 2009). Power quality is powering and operating electronic equipment in suitable manner. Power quality is a customary intended performance requirement of equipment in a proficient way without compromising the quality and maintaining the service excellence and life cycle of different electrical parameters. The performance excellence and life cycle are the two basic requirements for any equipment. Any form of disturbance in power supply that affects any of these two is the violation of power quality.

CFLs are considered as nonlinear loads due to electronic ballast circuit and therefore potentially can inject the harmonics in power system. Different researchers have contributed to assess thepower quality issues of CFLs. (Watson et.al, 2009) have focused on not only increasing the number of CFLs due to

[++]Corresponding Author: irfan.halepoto@gmail.com far786_abro@yahoo.com

*Department of Electrical Engineering, Mehran UET, Jamshoro

**Institute of Information & Communication Technologies, Mehran UET, Jamshoro

economic benefits but also suggested a need to analyze their effects on system losses and harmonic distortion. Haroon et.alhas considered the impacts of non-linear loads on distribution system power quality (Haroon, 2011). Using ETAP, they simulated a portion of distribution circuit and observed the effects of non-linear loads on distribution system.The results revealed that Injected Harmonic Distortion (IHD) and THD at the point of connection of different consumers were beyond the acceptable limits.

(Gil-de-Castro, 2012)has studiedand analysed the harmonic distortion of residential consumers with incandescent lamps and CFLsmeasurements taken for a domestic consumer confirmed that there is significant increase in harmonic currents injected in network. (Matvoz, 2012) has developed a simulation model of electricity network portion and observed the effect of LEDs and CFLs in connection to other loads. Simulation results revealed that there is a considerable portion of harmonic voltages in the system.

Considering these facts, in this work, power quality aspects of CFLs commonly available in Pakistan are experimentally analyzed. Total Harmonic Distortion (THD) is used as a comparative measure of harmonics injected in power system. In addition to harmonic analysis, power factor of different CFLs are also analyzed.

The rest of paper proceeds as follow: In Section 2 basic construction of CFL is discussed. Section 3 explains the harmonics and their impacts on power system. Power factor and its impact on harmonics is discussed in section 4. Section 5 contains the experimental results for power quality assessment of different CFLs. Section 6 concludes the paper and recommendations are given based on observations of the experimental results.

2. COMPACTFLUORESCENTLAMP

CFL has emerged as an energy saving potential alternate for conventional fluorescent and incandescent lamps. CFLs are being promoted worldwide as lighting estimated to consume around 30% of the total electric power (Rava, 2014).CFLs are specially designed to fit in existing light fixtures of incandescent lamps and therefore replacement becomes straightforward mechanism. The initial cost of CFL is touch higher than the conventional incandescent lamp but it potentially consumes less power and has longer operating life (Aman, 2013). Illumination of 25W CFL is equal to that of a 100W of incandescent lamp (Khan,2011). CFL has two main parts; electronic ballast and bulb (gas filled tube). CFLs are available to be used with both AC and DC supplies. Electronic ballast consists of rectifier which converts the AC input power to DC. Capacitor filter circuits and inverter circuits are also part of the electronic ballast of CFL. Current flows through ballast to gas filled tube, where mercury vapors heat up and emit ultraviolet light. Phosphor coating inside tube is excited by the ultraviolet light to produce visible light (Aman, 2013).

Integrated and non-integrated lamps are two major categories of CFLs. Integrated lamps are designed to be used with existing light fixtures of incandescent lamps and thus cost of replacement is lowered. It combines a bayonet fitting or Edison screw, electronic ballast circuit and a tube in a single assembly. Dimmable models with standard boxes are also available for particular usage (Watson, 2009).

Non-integrated CFLs combine the different parts through specified wiring. These CFLs can be either bi-pin or quad pin. An external starter is used with quad pin CFLs. Tubes used for CFLs are available in different shapes like circular, butterfly, quad turn, triple turn, double turn and single turn. Non-integrated CFLs are larger in size as compared to integrated CFLs as ballasts are placed in light fixtures. Once the bulb reaches its life, one has to change only bulb and ballast remains same (Khan, 2011). These are also expensive and sophisticated as compared to integrated CFLs but have longer life and lower replacement future costs.

Lifespan of a CFL is typically between 8 to 16 thousand hours as compared to around one thousand for incandescent lamps. Therefore CFLs have rated life 8 to 15 times more than that of an incandescent. CFLs are also called cold light (Khan, 2011) as incandescent emits more heat. In cold countries this is a drawback of using CFL as more cost will be required for space heating. In hot atmosphere of Pakistan it becomes an additional advantage as cost for temperature control is reduced somewhat.

3. IMPACT OF HARMONICS

Energy consuming equipment's aredesigned to operate at a fixed frequency called fundamental frequency. In Pakistan standard line frequency is 50 Hz. Harmonics are associated with distortion in waveform, introducing the components having other frequencies, which are multiples of fundamental. **(Table-1)** gives harmonic order and associated frequency for 50 Hz fundamental (Soomro, 2014). Chief contributor to the harmonics is the use of electronic devices having non-linear behaviour. Electronic ballasts, CFLs, and electronic drives are also using electronic components for their operation and therefore will affect the power quality.

Table.1. Harmonic order for 50Hz supply

Frequency (Hz)	Harmonic Order
100	2nd
150	3rd
200	4th
250	5th
300	6th
350	7th

Presence of harmonics in a system will distort an ideal sinusoidal wave.Degree of harmonic distortion is measured using THD given in equation. 1 (Rana, 2008). THD is also helpful for comparison of similar equipment of different manufacturers.

$$THD_i = \frac{\sqrt{(I_2^2+I_3^2+I_4^2+I_5^2+I_6^2+I_7^2\ldots\ldots)}}{I_1} \quad (1)$$

High current or voltage harmonics may result in improper fuse blow, nuisance tripping of circuit breakers, transformer heating, consumer appliance heating and excessive wiring heating. Excessive heating caused by flow of harmonic currents will increase power loss in system components. Useful operating life of consumer appliances and utility equipment may reduce. Protection system engineers are concerned about power quality.

The power quality factor characterise the electric grid events that can effect or even damage the sensitive electronic devices; i.e., transformers and capacitor are sensitive to current and voltage harmonics respectively. In power distribution system, odd number harmonics are most important concern which is the multiples of fundamental frequency e.g. 3rd, 5th, 7th, etc. (Soomro, 2014). On other hand, even harmonics are characterise by even number multiples of fundamental frequency e.g. 2nd, 4thand 6th and etc. and are customarily mitigated because harmonics swings correspondingly in both positive and negative directions.

Considering the impacts of harmonics on consumer and utility, it became necessary to establish guidelines and standards for harmonic monitoring. IEEE standard 519-1992 provides harmonic limits for both current and voltage on different operating voltages under steady state operating conditions. This limit is set for the worst operating conditions where system stability is maintained. For distribution system below 69 kV, THD measured at point of common coupling must be less than 5% (Soomro, 2014).

4. POWER FACTOR ANALYSIS

Power factor is a quantification of drawn current utilization by load from the power system in form of real power (P) to apparent power (S)ratio. (**Fig. 1)** shows the standard power triangle where power factor is$cos^{-1}(A)$. In presence of harmonics the total power factor(PF_{total})is the multiple of displacement power factor(PF_{disp})and distortion power factor(PF_{dist})as formulated in equation 2 (Manjuri, 2000). The distortion power factor value will be less than unity if there is a harmonic in the system which introduces the THD value to the system. Thus, when the distortion power factor (PF_{dist}), multiply with the displacement power factor (PF_{disp}), it will result in the lower total power factor (PF_{total}).

$$PF_{total} = \frac{P}{S} = PF_{disp} * PF_{dist} = \frac{P}{V_{rms} I_{rms}} * \frac{1}{\left(\sqrt{1+\left(\frac{THD}{100}\right)^2}\right)} \quad (2)$$

(Table-2) shows power factor measured for different CFLs tested at experimental laboratory. It is clear that power factors of all CFLs are very low as highest observed power factor is 0.62 lagging.

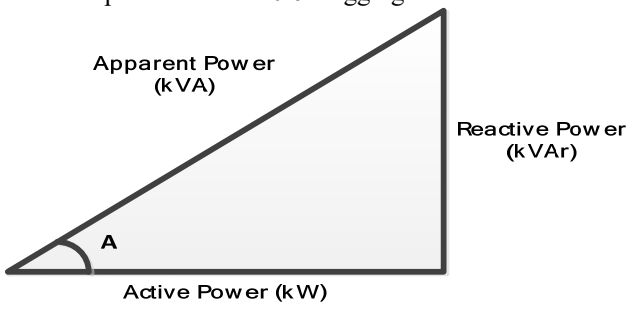


Fig. 1. Power Triangle

Lower power factor will result in higher apparent power and reactive power requirements. Thus higher rating equipment will be required to supply the same load. On the other hand, the heating effect caused by excessive reactive current flow will result in additional losses in the supply system. More voltage drop will result in reduced voltage at the consumer terminals. This reduced voltage will either require higher currents for the loads or the load output will reduce.

Table- 2: Power Factor of Analyzed CFLs

SR. No.	Power (W)	Power Factor
1	25	0.57
2	25	0.59
3	25	0.62
4	25	0.57
5	23	0.62

5. HARMONIC ANALYSIS OF CFLS

Harmonics are experimentally analyzed using Fluke Power Quality Analyzer (PQA) 43B. Five CFLs from different manufacturers are selected for harmonic analysis. Fluke 43B integrates power quality analyzer, a multi-meter, 20MHz oscilloscope, and a data recorder in a single tool. Fluke 43B PQA has computer interface, hence enabling the observed data to be transferred to computer for necessary analysis.

(Fig. 2(a)) shows voltage and current waveforms for first CFL which is rated 25W. It is clear that voltage waveform is slightly distorted whereas current waveform is highly distorted. (**Fig. 2(b))** show Fast Fourier Transform (FFT) analysis for first CFL where THD_i is shown as 77.3%.

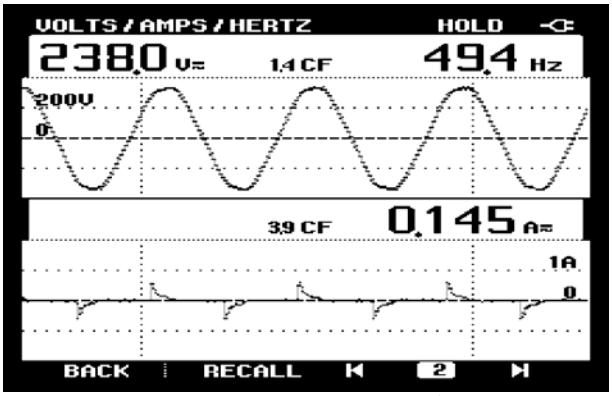


Fig. 2(a): Voltage and Current Waveform for 1st CFL (25W)

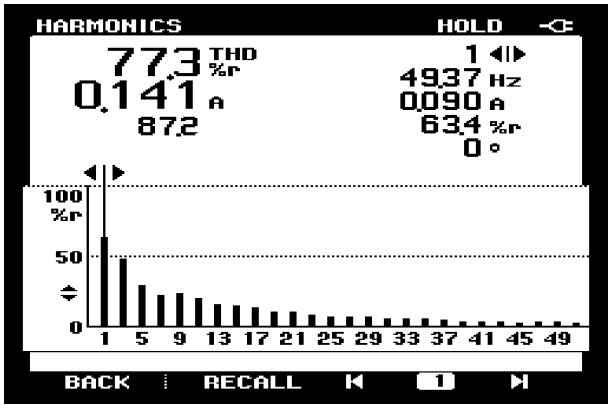


Fig. 2(b): Current Harmonic Spectrum for 1st CFL (25W)

(Fig. 3, 4 and 5) shows the current harmonic spectrum of 2nd, 3rd and 4th analyzed CFLs. Apprantely, these three CFLs have similar power rating of 25W. (**Fig. 6)** shows the current harmotic spectrum for 5th CFL which is rated 23W. At the end all five CFLs are connected together and analyzed for a total power rating of 123W. (**Fig.7)** shows current harmonic spectrum of the combined set of five CFLs.

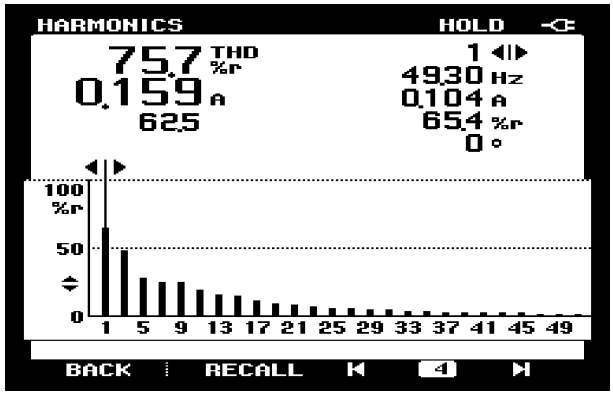


Fig. 3: Current Harmonic Spectrum for 2nd CFL (25W

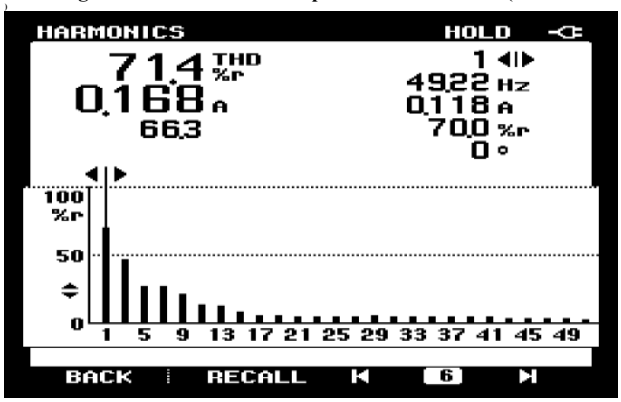


Fig. 4: Current Harmonic Spectrum for 3rd CFL (25W)

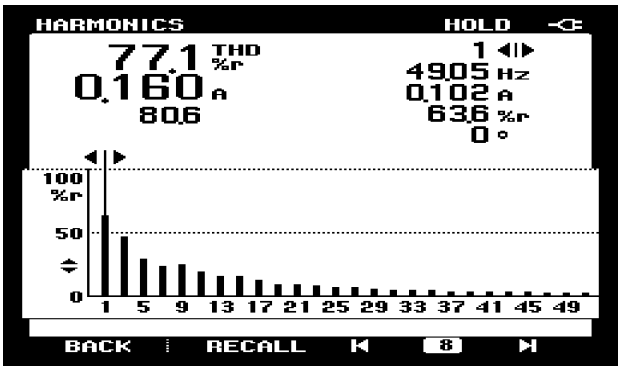


Fig. 5: Current Harmonic Spectrum for 4th CFL (25W)

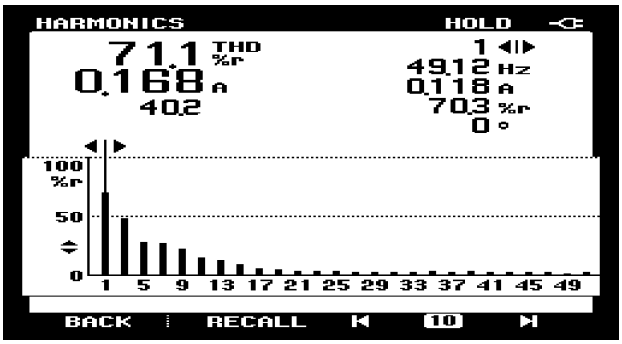


Fig. 6: Current Harmonic Spectrum for 2nd CFL (25W)

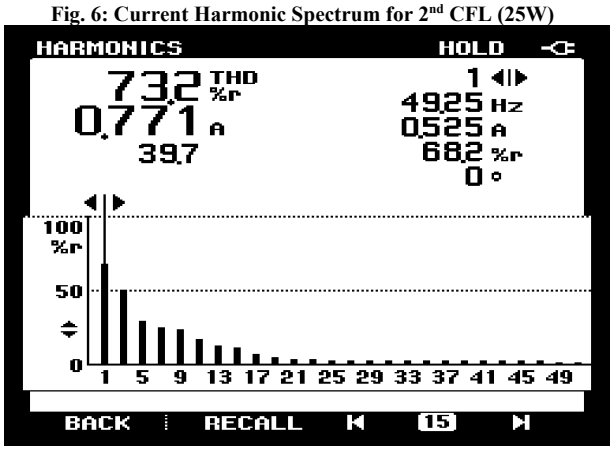


Fig.7:Current Harmonic Spectrum for all CFL Connected Simultaneously (123W).

(Table-3) shows the current and voltage THD for all CFLs separately and when they are connected simultaneously. It is clear that current THDs for all the analyzed cases are greater than 71.4% which is quite high as compared to IEEE standard 519-1992. Voltage harmonic THD for all cases are less as compared tocurrent THD but still these values are greater than acceptable range of 5% as set by IEEE standard 519-1992.

Table 3.THD of analyzed CFLs

SR. No.	Power (W)	THD (%)	
		Current	Voltage
1	25	77.3	8.1
2	25	71.1	6.2
3	25	75.7	7.3
4	25	71.4	5.7
5	23	77.1	8.5
All 5 together	123	73.2	6.8

6. CONCLUSION

The power quality analysis of CFLis an important concern for the electrotechnical community. This work invistagitesthe impact of CFLs on electric grid power quality, considering harmoincs analysis. An analysis of the volatage and current harmoin distortion waveformsaccording to IEEE standard 519-1992 are also presented. The five commonly used CFL types are selected for power quality analysis. Power factor of all five CFLs is observed very poor from 0.57 to 0.62 lagging. Harmonic analysis for all CFLs shows high current THDs above 70%. Voltage THDs are low but still above acceptable level of 5% set by IEEE standard 519-1992. Therefore it is suggested that energy conservation policies through CFLs must consider adverse effects of harmonics and poor power factor.

7. ACKNOWLEDGEMENT

Authors acknowledge the support of Mehran University of Engineering and Technology Jamshoro for providing necessary laboratory resources to conduct the research work.

REFERENCES:

Aman, M. M., G. B. Jasmon, H. Mokhlis, and A. H. A. Bakar (2013).Analysis of the performance of domestic lighting lamps. Energy Policy, 52 (1),482-500.

Gil-de-Castro, A., S. Ronnberg, M.H.J. Bollen, and V. Pallares-Lopez (2012).Harmonics from a domestic customer with different lamp technologies.In IEEE 15thInternational Conference on Harmonics and Quality of Power (ICHQP), 585-590, Hong Kong.

Halepoto, I. A., A. A. Sahito, G. M. Shoro (2015). Design of Integrated Analytical Process Framework for Smart City Transformation based on Strengths-Weaknesses-Opportunities-Threats Analysis. Sindh University Research Journal (Science Series), 47 (2), 221-230.

Haroon, F., C. Zhou, M. Allan, M.E. Farrag, R. A. Khan, and M. Junaid (2011).Investigating the Power Quality of an Electrical Distribution System Stressed by Non-Linear Domestic Appliances. International Conference on Renewable Energies Power Quality, 1-6, Shanghai, China.

Khan, N., and N. Abas (2011).Comparative study of energy saving light sources.Renewable and Sustainable Energy Reviews, 15(1), 296-309.

Manjure, D.P., and E.B. Makram (2000).Effect of nonlinearity and unbalance on power factor.In IEEE Power Engineering Society Summer Meeting, 2(1), 956-962.

Matvoz, D., and M. Maksic (2012).Comparison of LED and CFL lamps and their impact on electric power network.IEEE 15th International Conference on Harmonics and Quality of Power (ICHQP), 320 – 327, Hong Kong.

Nassif, A. B., and W. Xu. (2009). Characterizing the harmonic attenuation effect of compact fluorescent lamps. IEEE Transactions on Power Delivery, 24(3), 1748-1749.

Rana, J. M., M. Al-Dabbagh, A. Muhammad, R.H. Khawaja, M. Akmal, and R.M. Arif (2008).Impact of compact fluorescent lamp on power quality.In IEEE Australasian Universities Power Engineering Conference, 1-5, Sydney, Australia.

Rawa, M.J.H., W.P.T. David, and S. Mark (2014).Experimental Measurements and Computer Simulations of FL and CFL for Harmonic Studies.In IEEE 16thInternational Conference on

Computer Modelling and Simulation (UKSim), 336-339, Cambridge, Unitied Kingdom.

Sahito, A. A., I.A. Halepoto, and S.M. Tunio (2014). Application of Infrared Thermograph in Power Distribution System.Mehran University Research Journal of Engineering & Technology, 33 (3),352-358.

Sahito, A. A, I.A. Halepoto, M.A. Uqaili, Z.A. Memon, A.S. Larik, and M.A. Mahar (2015).Analyzing the Impacts of Distributed Generation Integration on Distribution Network: A Corridor towards Smart Grid Implementation in Pakistan.Wireless Personal Communication, Springer; 85 (2), 545-563.

Soomro, M. A., I.A. Halepoto, A.A. Sahito (2014). Design of Six Pulse Bridge Multiplication Converter Model for Current Harmonic Elimination of Three Phase AC-DC Converter.Mehran University Research Journal of Engineering and Technology, 33(4), 476-484.

Watson, N. R., T. L. Scott, and S. J. J. Hirsch (2009).Implications for distribution networks of high penetration of compact fluorescent lamps.IEEE Transactions on Power Delivery, 24(3), 1521-1528.