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Distortion Power Analysis of Energy Efficient Lamps and Proposed Filtering Solution

Geena Sharma[1]

Assistant Professor

Electrical Engineering, Department, Baddi University of Emerging Sciences and Technology, Baddi, H.P., India[1]

Abstract: The aim of this paper is to analyze various power quality indices and luminous efficacy of different types of luminaries (Incandescent Lamp, Fluorescent Lamp, Compact Fluorescent Lamp and Light Emitting Diode). CFLs and LEDs are considered as highly energy efficient luminaries as compared to widely prevalent, low cost incandescent lamps. The replacement of Incandescent Lamps by CFLs and LEDs have resulted in reduction in active power consumption, a reduction in peak current and reduction in distribution system losses. All these aspects have positive impact on energy consumption. However, the other aspect – viz. harmonic distortions in CFLs and LEDs is not being appropriately addressed, which might cause unforeseen problems in the power supply grids, particularly in rural feeders in India. The paper represents comparative analysis of luminous efficacy, distortion power and power factor occurring in different types of luminaries (as defined in IEEE – 1459:2000 Standard).

Keywords: Compact Fluorescent Lamps (CFLs), Incandescent Lamp, Light Emitting Diodes (LEDs), distortion power, Efficacy.

I. INTRODUCTION

In the recent years, Power Quality (PQ) is emerging as an issue of major concern, (globally as well as nationwide) requiring precise monitoring, in-depth analysis and adoption of planned PQ improvement initiatives. A few years back, the main concern of the electricity was reliability of supply, which could be understood as availability of power at rated voltage and frequency. The present scenario, however, has drastically changed in our country, with a large proportion of the industrial, commercial and domestic load now turning out to be non-linear due to growing use of power electronics, automation, computers and information technology [1]. The term Power Quality, in ideal terms, would refer to an uninterrupted power supply, maintained at rated voltage and frequency (within specified tolerances), and having a pure, undistorted sinusoidal wave shape .PQ problems are complex, and often require detailed diagnosis by an expert team to find an optimum techno-economic solution. In early days Incandescent Lamps were widely used in household and commercial lighting, for portable lighting such as table lamps etc. Incandescent Lamp makes light by heating a metal filament wire to a high temperature until it glows. Incandescent Lamps do not require external regulating equipment and have a low manufacturing cost and work equally well on either alternating current or direct current. But approximately 90% of the power consumed by this lamp is emitted as heat, rather than visible light. Thus due to high energy consumption and low luminous efficacy(lm/W), Incandescent lamps have been replaced in many applications by other types of electric lights such as Fluorescent lamps, CFLs, LEDs. These new technologies improve the ratio of visible light to heat generation. European Union are in process of phasing out the use of Incandescent Lamps in favour of more energy efficient lighting. In United States, federal law has scheduled Incandescent Lamp to be phased out by 2014, to be replaced by more energy efficient lighting. In Brazil these have already been phased out. Fluorescent lamp converts electrical power into useful light more efficiently than an Incandescent Lamp. A fluorescent lamp/tube is a gas discharge lamp and uses electricity to excite mercury vapour. The excited mercury atoms produce short wave ultra violet light, which causes a phosphor to fluoresce, providing visible light. Lower energy cost typically offsets the higher initial cost of this lamp .Now a days these larger Fluorescent lamps have been replaced by CFL, popularly known as energy saving lamp. CFL is a type of fluorescent lamp having electronic ballast and can fit into a fixture of general lighting service incandescent lamp. The electronic ballast of CFL has removed the problems of flickering and slow starting which are associated with magnetic ballast fluorescent lamp. It is well established that integrated CFLs presently being used have longer operating life and different light spectrum as compared to that of incandescent lamps. On account of their high energy efficiency, CFLs are recently being promoted as an effective measure to reduce average and peak demand. This has led to aggressive promotion of CFLs, and even free distribution/subsidies in some states. Electricity consumers – both rural and urban are being encouraged to replace their existing incandescent lamps with energy saving CFLs to reduce electricity bills. Another energy efficient luminary is LED. LEDs present many advantages over above discussed luminaries such as low energy consumption, longer life time (20,000 – 50,000 hours, which is about 4 to 8 time than that of CFL) , smaller size, faster switching and greater durability and reliability. However, CFLs and LEDs are known to produce high current distortions due to high frequency switching in the electronic ballast [7]. The power quality aspect of these luminaries is an emerging issue requiring attention as excessive harmonic injections by increasing these non linear loads can adversely affect the

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performance of electrical feeders. In this paper, a true comparison of different types of powers (real, reactive and distortion), power factor (fundamental and distortion) and luminous efficacy are evaluated after detailed experimental work on different types of luminaries.

II . EXPERIMENT

An exhaustive experiment has been carried out as a part of this work using Power and Harmonics Analyzer (PHA) and Lux meter to measure the type and magnitude of different harmonic components and their efficacy for different types of luminaries. The experimental work broadly comprised two parts. These are:

(i) Measurement of harmonic contents of different luminaries using PHA
(ii) Measurement of efficacy of different luminaries using Lux meter.

An experimental setup has been developed to measure harmonic contents of each luminary. The measurements has be en carried out using Power and Harmonic Analyzer (PHA) to find rms voltage V, rms current I, active power P, reactive power Q, Apparent power S, Total power factor pf, total harmonic distortion in voltage THD_v and total harmonic distortion in current THD_i. Power and Harmonic Analyzer (PHA) is a special purpose, graphic-based, true rms instrument. It can analyze ac voltage and current harmonics up to 99^{th} order along with other important electrical parameters like active, reactive and apparent power, power factor, energy, average demand and maximum demand etc. The instrument consists of 512 KB memory, programmable CT/PT, an RS-232 interface and has the capability to save the captured data.

III. ANALYSIS OF DISTORTION POWER IN CFL

In harmonic environment, the apparent power is given by:

$$S = V_{rms}\ I_{rms} \qquad (1)$$

where

$$V_{rms} = \sqrt{V_1^2 + V_2^2 + V_3^2 + \cdots} \qquad (2)$$

$$= \sqrt{\sum_{h=1}^{\infty} V_h^2} \qquad (3)$$

Similarly,

$$I_{rms} = \sqrt{\sum_{h=1}^{\infty} I_h^2} \qquad (4)$$

According to IEEE-1459 Standard [4] , rms voltage and current can be decomposed into fundamental and harmonic components as below:

$$V_{rms} = V_1^2 + V_h^2 \qquad (5)$$

$$I_{rms} = I_1^2 + I_h^2 \qquad (6)$$

The total apparent power can then be expressed as

$$S^2 = (V_{rms}\ I_{rms})^2 \qquad (7)$$

$$= S_1^2 + S_N^2 \qquad (8)$$

In above equation, S_N is non-fundamental apparent power which comes into picture due to the presence of harmonic frequencies either in voltage or current waveform .An approach suggested by Emanuel decomposes total apparent power S as below [6]:

$$S^2 = (P_1 + P_H)^2 + Q_1^2 + Q_H^2 \qquad (9)$$

$$= S_1^2 + S_N^2 \qquad (10)$$

The term P_H is harmonic active power which rarely exceeds 0.005 P_1 and thus can be safely ignored. This indicates that there is negligible contribution to real power due harmonic frequencies. Q_1 is fundamental reactive power (var) and Q_H is non-fundamental or harmonic reactive power flow due to non-linear load. In harmonic analysis, an important quantity – Total Harmonic Distortion (THD) in voltage and current is expressed as:

$$THD_V = \frac{V_H}{V_1} = \sqrt{\left(\frac{V_{rms}}{V_1}\right)^2 - 1} \qquad (11)$$

$$THD_I = \frac{I_H}{I_1} = \sqrt{\left(\frac{I_{rms}}{I_1}\right)^2 - 1} \qquad (12)$$

The concept of power factor in harmonic domain is also modified to take into account voltages and currents of different frequencies . The total power factor is defined as:

$$pf_{tot} = \frac{Total\ \mathrm{Re}al\ Power\ P}{Total\ Apparent\ Power\ S} \qquad (13)$$

$$= \frac{P_1}{V_{rms} \cdot I_{rms}}$$

$$Also, V_{rms} = V_1 \cdot \sqrt{1 + \left(\frac{THD_V\ in\%}{100}\right)^2}, \&$$

$$I_{rms} = I_1 \cdot \sqrt{1 + \left(\frac{THD_I\ in\%}{100}\right)^2}$$

Assuming THD_V to be less than 10 %, which is generally the case in power system networks as well as in our above experimental work, the total power factor can be expressed as:

$$\frac{P_1}{V_1 I_1 \sqrt{1 + \left(\frac{THD_I\ in\%}{100}\right)^2}} \qquad (14)$$

$$= pf_{disp} \cdot pf_{dist} \qquad (15)$$

In above expression, the first term is known as fundamental or displacement power factor and second term is known as distortion power factor.

The measurements were carried out using Power and Harmonic Analyser to find rms voltage, current, P, Q, S, total pf, and THD in voltage and current for different make of CFLs. Subsequently, the results were obtained by a MATLAB script using Emanuel method of distortion power analysis.

Various steps for assessment of distortion power and distortion power factor will include:

(i) Input of the data from Power & Harmonics Analyzer (i.e. V, I, THD, S, P, Q, pf)
(ii) Calculation of Fundamental and Harmonic Voltage and Current from the measured data.

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(iii) Analysis of total apparent power in different luminaries as per IEEE - 1459 Standard.
- Fundamental Apparent power
- Non-fundamental Apparent power
- Voltage distortion power
- Current distortion power
- Harmonic Apparent power

(iv) Calculation of Fundamental and Harmonic Active (Real) powers.
(v) Computation of fundamental and harmonic reactive powers as per Emanuel's method.
(vi) Computation of Fundamental and Distortion Power factors.

IV. RESULTS

The comparative analysis of distortion power, power factor and luminous efficacy of different types of Luminaries at rated voltage (230 V) is tabulated below:

Table 1 Distortion Power Analysis of Different Types of Luminaries

S. No.	Luminaries Parameter	Type Of Luminaries			
		GLS	Fluorescent Lamp	CFL	LED
1	Nominal rms Voltage applied across Luminary V (V)	230.4	229.9	229.5	231.6
2	Total rms Current flowing Through Luminary I (A)	0.680	1.245	0.744	0.174
3	Voltage THD at Luminary terminals (%)	7.7	10.4	7.3	7.7
4	Current THD in Luminary load (%)	9.2	13.9	21.1	65.8
5	Fundamental rms Voltage V_1 (V)	229.72	228.6	228.89	230.68
6	Harmonic rms Voltage V_H (V)	17.6884	24.4	16.71	18.2238
7	Fundamental rms Current I_1 (A)	0.6771	1.234	0.7280	0.1454
8	Harmonic rms Current I_H (A)	0.0623	0.165	0.1536	0.0956
9	Total apparent power S (VA)	155	286.3	169	39
10	Fundamental apparent power S_1 (VA)	155.5527	282.1	166.6261	33.5308
11	Non-fundamental apparent power S_N (VA)	13.101	48.86	28.2269	9.9170
12	Total active power P (W)	156	160	164	10
13	Fundamental active power P_1 (W)	156	160	164	10
14	Harmonic active power P_H (W)	0	0	0	0
15	Total reactive Power Q (var)	0	-0.237	44	38
16	Fundamental reactive power Q_1 (var)	11.805	232.3	29.466	32.3
17	Non-fundamental reactive power Q_H (var)	13.101	232.2	28.2269	19.9170
18	Total power factor	1	0.57	0.97	0.23
19	Fundamental power factor	1	0.56	0.9842	0.2684
20	Distortion power factor	0.9971	0.316	0.9855	0.8569
21	Prominent Harmonic order	5^{th}	3^{rd}	7^{th}	3^{rd}
22	Luminous Efficacy(lumens/ W)	1.83 (min.)	9.725	10	34.78 (max.)
23	Peak Factor	1.32	1.26	1.318	1.32

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V. FILTERING SOLUTION

After measuring voltage and current harmonic contents and THDs of different luminaries, a filtering solution will be implemented to mitigate excess harmonic contents. There are a number of devices available to control harmonic distortion in the power supply networks which are commonly categorized as passive filters and active filters. Passive filters comprise inductance, capacitance and resistance elements configured and tuned to control harmonics.

They are designed either to shunt the harmonic currents off the line or block their flow by tuning the elements to create resonance at a selected frequency. Active filters, on the other hand, are designed to inject harmonic currents to counterbalance existing harmonic components as they show up in the distribution system. Active filters are very expensive and are used in very specialized applications. Passive filters are relatively inexpensive and are being widely used for control of harmonics in industry worldwide.

The proposed filtering design would be based on tuned passive LC filter. The most common type of passive filter is the single-tuned shunt filter. It is also called notch filter and is the most economical type for industrial applications .The notch filter is series-tuned to present low impedance to a particular harmonic current and is connected in shunt with the power system. Thus, harmonic currents are diverted from their normal path through the filter.

Series passive filter, unlike a notch filter, is connected in series with the load. The inductance and capacitance are connected in parallel and are tuned to provide high impedance at a selected harmonic frequency. The high impedance then blocks the flow of harmonic currents at the tuned frequency only. At fundamental frequency, the filter is designed to provide a low impedance, thereby allowing the fundamental current to flow with only little impedance.

VI . HARMONIC MODELLING AND SIMULATION

A simple and effective technique for harmonic analysis is current injection model which is most commonly applied for harmonic simulation studies. This approach treats harmonic producing load as an injection current source to the system assuming steady-state condition. Consequently, all non-linearities in the system are represented as current injections of corresponding harmonic frequencies and therefore, the superposition principle can be applied. Hence, the analysis by current injection method provides a vector of harmonic voltages present in the system.

The advantage of current injection method is that it is computationally effective and can handle several harmonic sources simultaneously. At the end, validity and effectiveness of designed tuned filter will be checked using SIMULINK of Mat Lab.

A complete flow chart for the methodology proposed for carrying out the present work is given in Fig. 1.1.

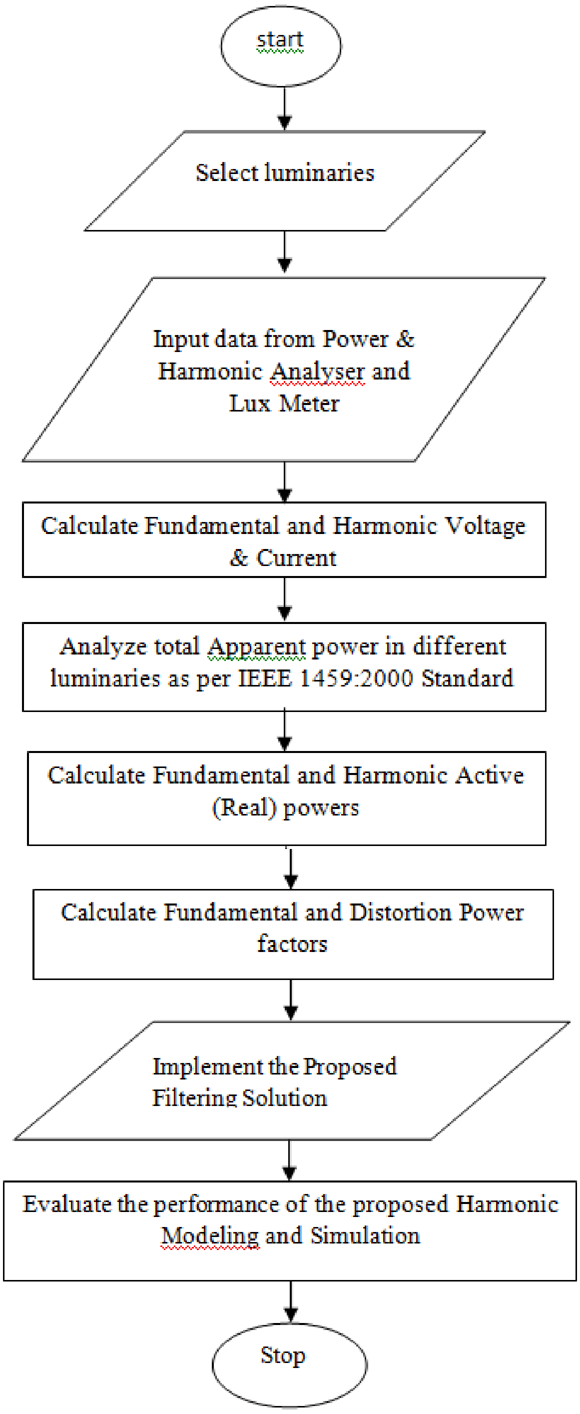

Fig. 1.1 Flow chart for the methodology proposed for carrying out the present work

VII. CONCLUSION

- It is concluded from that Power Quality is emerging as an issue of major concern, globally as well as nationwide, requiring precise monitoring, in depth analysis and adoption of planned power quality improvement initiatives.
- Power quality problems depend on the quality of the voltage supplied by the utility, the types of loads in installation and the sensitivity of the equipment to various kinds of disturbances. There is no single generic solution for this problem. An optimum

techno-economic solution needs to be designed for each site, taking into account the above three interacting factors.

- The power supply system can only control the quality of the voltage, it has no control over the currents that particular loads draw. Therefore, standards in the power quality area are devoted to maintain the supply voltage within limits. There is always a close relationship between voltage and current in any practical systems. Although the generators may provide a near-perfect sine wave voltage, the current passing through the impedance of the system can cause several disturbances to the voltage.
- Various power quality problems are transients, voltage variations (interruption , sags, swells, over voltage , under voltage, fluctuations), voltage imbalance, wave-from distortion , power frequency variation etc.
- Harmonics are one of the primary types of wave-form distortion. Harmonic distortion originates due to the non-linear characteristics of the devices and the loads on the power system. Energy shortage continues to disturb the power sector due to demand-supply mismatch,
- The state electricity boards of India have recognized that the use of CFLs can effectively meet DSM objectives. This has led to aggressive promotion of CFLs. However, CFLs are known to produce high current distortion due to high frequency switching in the electronic ballasts.
- Luminous efficacy of LED is highest among all the luminaries tested in this experiment, but p.f. of LED is very poor which give negative impact on th power quality.

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