การตรวจสอบคุณภาพไฟฟ้าและประสิทธิภาพของหลอดไฟฟ้าเชิงพาณิชย์ในประเทศไทย

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บทคัดย่อ

โครงการวิจัยนี้มีวัตถุประสงค์เพื่อตรวจสอบคุณภาพไฟฟ้าและประสิทธิภาพของหลอดประหยัดพลังงาน หลอดประหยัดพลังงานมีคุณลักษณะใช้กำลังไฟฟ้าน้อยแต่ให้ปริมาณแสงออกมามากเมื่อเทียบกับหลอดแบบเดิมที่ใช้งานอยู่ทั่วไป อีกด้านหนึ่งหลอดประหยัดพลังงานเป็นแหล่งกำเนิดฮาร์มอนิกส์ ที่เป็นสาเหตุของปัญหาคุณภาพไฟฟ้าและยังทำงานที่ตัวประกอบกำลังต่ำ ทำให้ต้องการกำลังไฟฟ้ารีแอคทีฟจากการไฟฟ้าเพิ่มมากขึ้น เพื่อตรวจสอบคุณภาพไฟฟ้าจากการใช้ประหยัดพลังงาน ได้ทำการเลือกกลุ่มตัวอย่างเป็นหลอดประหยัดพลังงานที่มีขายในท้องตลาดของประเทศไทยนำมาทดสอบ ทำการทดสอบในห้องปฏิบัติการแสงสว่างโดยใช้ทรงกลมรวมแสง (Luminous flux tester) ตามมาตรฐาน IEC และใช้วิธีการทดสอบตามมาตรฐานผลิตภัณฑ์อุตสาหกรรมเลขที่ 623 (มอก.623) ทำการเปรียบเทียบค่าตัวประกอบกำลังกับค่าตามข้อกำหนดของการไฟฟ้าและปริมาณฮาร์มอนิกส์เปรียบเทียบกับมาตรฐาน IEEE 519-1992 และ IEC 6100-3-2 และข้อกำหนดกฎเกณฑ์ฮาร์มอนิกส์เกี่ยวกับไฟฟ้าประเภทธุรกิจและอุตสาหกรรมของประเทศไทย ผลการเปรียบเทียบพบว่าปริมาณฮาร์มอนิกส์แรงดัน (THD_V) ที่ได้จากการทดสอบกับกลุ่มหลอดตัวอย่างมีค่าเกินค่าพิกัดตามมาตรฐาน IEEE 519-1992 ในขณะที่ปริมาณฮาร์มอนิกส์แรงดัน (THD_V) และฮาร์มอนิกส์กระแส (THD_i) ของหลอดประหยัดพลังงานเกือบทั้งหมดเกินค่าพิกัดของมาตรฐาน IEC 6100-3-2 ค่าตัวประกอบกำลังของหลอดประหยัดพลังงานมีค่าไม่ถึงตามที่การไฟฟ้ากำหนดไว้ จากผลการทดสอบพบว่าหลอด LED และหลอดคอมแพคฟลูออเรสเซนต์ ใช้พลังงานต่ำแต่ให้ปริมาณแสงมากกว่าหลอดมาตรฐานอินแคนเดสเซนต์และหลอดแสงจันทร์ จากข้อมูลที่ได้จากการทดสอบ การเลือกหลอดควรจะพิจารณาระดับปริมาณฮาร์มอนิกส์ ตัวประกอบกำลัง การใช้พลังงาน ประสิทธิภาพ และตัวประกอบต่างๆ ที่เกี่ยวข้อง และนวัตกรรมหลอดประหยัดพลังงานควรจะได้รับการพัฒนาให้มีค่าตัวประกอบกำลังเพิ่มมากขึ้นและปริมาณฮาร์มอนิกส์มีค่าต่ำ

คำสำคัญ : หลอดประหยัดพลังงาน / ฮาร์มอนิกส์ / ตัวประกอบกำลัง / คุณภาพไฟฟ้า / ประสิทธิภาพทางแสง

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Investigation of Power Quality and Luminous Efficacy of Commercial Lamps in Thailand

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Abstract

The objectives of this paper were to investigate the electrical power quality and efficacy of energy saving lamps. These lamps consume less real power and produce higher relative illumination than traditional lamps. However, energy saving lamps produce high harmonics causing power quality problems. Moreover, they operate at low power factor and demand additional reactive power from the electrical utility. To investigate the power quality of these lamps, a sample of commercial energy saving lamps in Thailand was tested. The experiments were performed by using a luminous flux tester according to IEC standard and the experimental procedures followed the Thai Industrial Standard number 623. The resulting power factors were compared with the requirements of utility and the harmonic distortion was verified with IEEE 519-1992, IEC 6100-3-2 and the requirements of harmonics for business and industry in Thailand. We found that THD_V of the sample models exceeded limitations of IEEE 519-1992 while THD_V and THD_i of almost all the energy saving lamps exceeded the limitations of IEC 6100-3-2. Moreover, the power factors of energy saving lamps did not reach to requirements of utility. It was also found that LED lamps and the compact fluorescent lamps had lower energy consumption and higher illumination than the standard incandescent and mercury lamps. As a consequence, we suggest that choice of a lamp should be considered in regard to the degree of harmonic distortion, power factor, energy consumption, efficacy and associated factors. It is also proposed that innovative energy saving lamps that can raise power factor and lower harmonic distortion should be developed.

Keywords : Energy saving lamps / Harmonics / Luminous efficacy / Power factor / Power quality

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1. Introduction

Due to the increase in cost for energy production combined with the decrease in power sources, these reasons forced the electric utility to promote using the energy saving lamps. The energy saving lamps are very popular because they can reduce the electrical energy consumption and longer lifetime compared with conventional incandescent lamps. Furthermore, wide application of these lamps will reduce the peak of the demand curve and also decrease average demand of using energy [1] - [5].

Even though, these lamps consume less real power and produce higher relative illumination compared with traditional incandescent lamps, however, the energy saving lamps produce high harmonic distortion that causes power quality problems. Moreover, the lamps operate at a low power factor and demand additional reactive power from the electrical utility [6] - [12]. There are many reports which published the mentioned advantages and disadvantages of these lamps, especially the harmonics from compact fluorescent lamps [13] - [23] and light emitting diode lamps (LED) [24] - [25].

To investigate the above characteristics of lighting sources in Thailand, four types of the energy saving lamps including tubular fluorescent, light emitting diode, small and large size compact fluorescent lamps that are available in the market place were selected as the sample models. These lamps were tested to verify the results with the traditional standard incandescent, tabular fluorescent and mercury lamps. The experiments were performed in the illumination laboratory by using the luminous flux tester that was developed according to IEC standard. The luminous flux tester comprises a luminous flux integrating sphere in 1.5 m diameter and the equipment to obtain lighting and electrical characteristics. The harmonics from lighting sources were measured by using Fluke 435 power quality analyzer meter showing in graphical form of harmonic orders and were compared with relevant international and Thailand standards. The voltage and current waveforms were obtained by using an oscilloscope.

2. Experiments

2.1 Description of lamps under consideration

Twenty-two sample models of lamps available in the market were obtained from four different manufacturers. The selected models are summarized in Table 1.

Table 1 The lamps under consideration

Order	Type of lamps	Power rated (W)	Code
1	Compact fluorescent	5	CFL-5
2	Light Emitting Diode (LED)	8	LED-8
3	Compact fluorescent	8	CFL-8
4	Compact fluorescent	11	CFL-11
5	Compact fluorescent	12	CFL-12
6	Compact fluorescent	13	CFL-13
7	Compact fluorescent	14	CFL-14
8	Compact fluorescent	15	CFL-15
9	Compact fluorescent	18	CFL-18
10	Compact fluorescent	20	CFL-20
11	Compact fluorescent	23	CFL-23
12	Compact fluorescent	24	CFL-24
13	Fluorescent tube	28	T5(28)#E
14	Fluorescent tube	36	T8(36)#M
15	Fluorescent tube	36	T8(36)#E
16	Incandescent	40	Inc-40
17	Compact fluorescent	45	JCFL-45
18	Incandescent	60	Inc-60
19	Compact fluorescent	65	JCFL-65
20	Compact fluorescent	85	JCFL-85
21	Incandescent	100	Inc-100
22	Mercury	160	ML-160

These lamps can be classified into 6 categories;

2.1.1) Incandescent lamps with rated powers 40, 60 and 100 W. These lamps are identified as reference lamps and are used to find luminance flux of testing lamps according to definitions and methods of Thai Industrial Standard number 623 [26].

2.1.2) Small size compact fluorescent lamps with rated powers 5-26 W. The ballast is included in the E27 screw base. Theses lamps are energy saving lamps that are popular to be used as a replacement of traditional incandescent and tubular fluorescent at present.

2.1.3) Large size compact fluorescent lamps with rated powers 45, 60 and 65 W with E27 screw base. The ballast is included in the base. These lamps are selected as the sample models because they are a popular replacement of mercury lamps (ML). It was found that they can save energy up to 74% over standard mercury lamps [21].

2.1.4) T5 and T8 Tubular fluorescent with rated powers 28 and 36 W, operated with electronic and magnetic ballasts. T5 tubular fluorescent lamp is an energy saving lamp operating with electronic ballast and has been promoted to be used at present.

The T8 traditional tubular fluorescent lamps are used in general residential and commercial buildings. They can operate with both of electronic and magnetic ballasts. In this paper, T5 (28) #E, T8 (36) #E and T8 (36) #M are selected.

2.1.5) 160 W Mercury lamps are selected as a reference to verify with the large compact fluorescent lamps.

2.1.6) Light emitting diode (LED) with rated power 8 W. This lamp is selected because it is a new technology of energy saving lamps.

2.2 Experimental Apparatus

Each lamp was tested by using the luminous flux tester to measure the amount of illumination from the lighting sources. The main construction of luminous flux tester is the integrating sphere with diameter 1.5 m that is invented according to IEC standard. The circuit diagram of the luminous flux tester is shown in Fig. 1. The voltage stabilizer was used to maintain the output voltage to be as close with the normal main voltage as possible and to reduce the impact of existent harmonics from the main supply. It adjusts the voltage level by using an auto transformer. The voltage output and frequency should be in ranges ±0.2 of lamp voltage rated and ±0.5 Hz according to the requirements of Thai Industrial Standard number 623.

The voltage, current, frequency, power factor and active power were measured by a power meter which records in digital form. The harmonic distortion was recorded by Fluke 435 power quality analyzer meter so that the harmonics can be obtained in graphical form via software package. The waveforms of voltage and current were measured by using an oscilloscope for investigating electrical characteristics in transient and steady state.

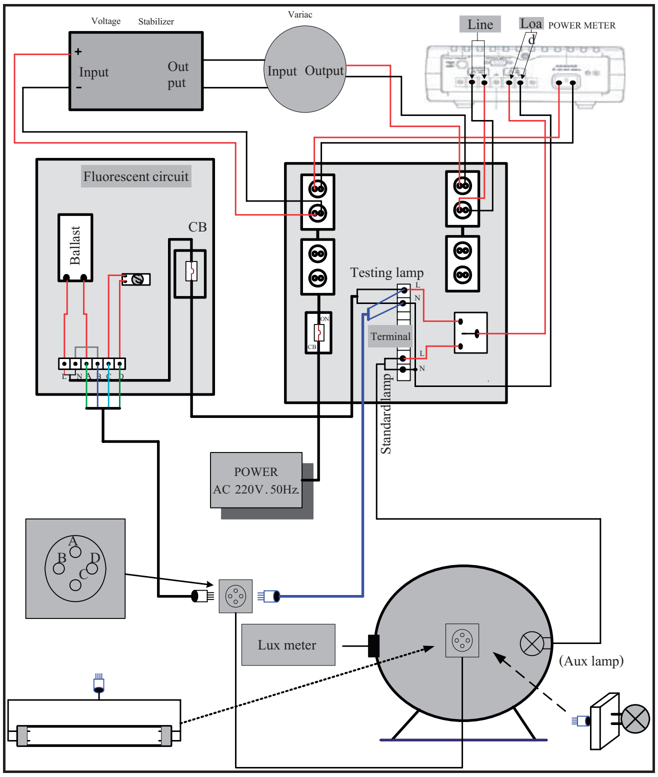

Fig. 1 Circuit diagrame of the luminance flux tester

2.3 Experimental Procedures

The experimental procedures can be separated into five main steps, as shown in Fig. 2, based on Thai Industrial Standard number 623.

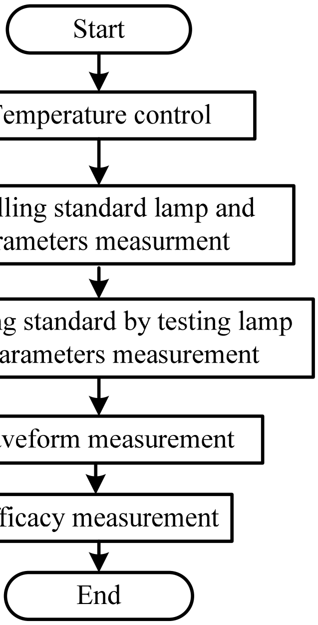

Fig. 2 The experimental procedures

2.3.1) Temperature control: The room temperature was controlled by using an air conditioner at 20-25ºC. The temperature was measured byusing Fluke 54 thermo meter. The inside temperature of the integrating sphere was warmed by a 100 W incandescent lamp for 30 min in order to get rid of the humidity inside the sphere for accurate and stable measurement of the light meter [26].

2.3.2) Insalling standard lamp and parameter measurment: The standard lamp was installed at the center of the integrating sphere and then a constant input voltage was supplied at 220 V. After 1 hour warm-up time for stability of light, electrical and lighting parameters were recorded.

2.3.3) Replacing standard lamp by testing lamp and parameter measurement: The standard lamp was replaced by the testing lamp. A constant input voltage was then supplied at 220 V. After 1 hour warm up time, voltage, current, active power, power factor, frequency were recorded by using the power meter while harmonic distortion was recorded by using Fluke 435 power quality analyzer, as shown in Fig. 3 The illumination was obtained via a lux meter.

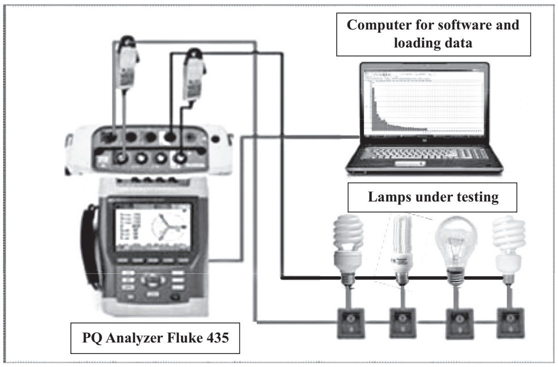

Fig. 3 Schematic diagram of experimental setup for recording harmonics

2.3.4) Waveform measurement: The current and voltage waveforms of the standard and testing lamps were recorded by using the oscilloscope in steady and transient states. Consequently, the relationship between current waveform and harmornic distortion can be observed.

2.3.5) Efficacy measurment: Luminous flux (φ) in lumen unit can be calculated by using the followingequation.

$$\phi_t = \phi_s \times \frac{E_t}{E_s} \qquad \textbf{(1)}$$

where ϕ_t and ϕ_s are the luminous fluxes of testing and standard lamps, respectively, E_t and E_s are the intensities of illumination of testing and standard lamps in lux, respectively. So, the luminous efficacy in lm/W was calculated to present the effectiveness of each lamp.

3. Experimental Results and Analysis

The experimental results are shown in Table 2. In order to investigate the characteristics of energy saving lamps, the experimental results are analyzed in the following topics:

Table 2 Electrical performance, luminous quantities and percentage of total harmonics distortion at constant input voltage 220 V, 50 Hz

Order	Type	Input current(A)	Power factor(PF)	Input power(W)	Lux(E)	Lumen(φ)	Efficacy (lm/W)	THD$_i$ (%)	THD$_V$ (%)
1	CFL-5	0.038	0.621	5	76.70	247.98	49.60	56.50	1.80
2	LED-8	0.047	0.831	9	255.00	824.44	91.55	72.00	1.10
3	CFL-8	0.059	0.617	8	155.30	502.10	62.76	60.25	1.90
4	CFL-11	0.066	0.635	9	172.00	556.09	61.79	65.00	1.25
5	CFL-12	0.091	0.627	13	259.00	837.37	64.41	66.80	1.38
6	CFL-13	0.099	0.630	14	251.00	811.50	57.96	72.50	2.13
7	CFL-14	0.098	0.621	13	264.00	853.53	65.66	73.00	1.13
8	CFL-15	0.097	0.611	13	269.00	869.70	66.90	73.95	1.20
9	CFL-18	0.147	0.622	20	372.00	1202.71	60.14	82.25	1.25
10	CFL-20	0.138	0.582	18	383.00	1238.27	68.79	82.50	1.51
11	CFL-23	0.171	0.613	23	429.00	1386.99	60.30	91.00	1.95
12	CFL-24	0.171	0.614	23	488.00	1577.74	68.60	89.50	2.06
13	T5(28)#E	0.134	0.982	29	682.00	2204.96	76.03	55.00	2.31
14	T8(36)#M	0.429	0.484	46	891.00	2880.68	62.62	53.50	1.62
15	T8(36)#E	0.178	0.991	39	883.00	2854.81	73.20	56.50	1.75
16	Inc-40	0.179	0.999	39	133.00	430.00	11.03	28.95	1.35
17	JCFL-45	0.280	0.564	35	889.00	2874.21	82.12	142.00	1.50
18	Inc-60	0.248	0.999	55	184.00	594.89	10.82	23.50	1.15
19	JCFL-65	0.300	0.995	66	1405.00	4542.48	68.83	30.00	1.20
20	JCFL-85	0.218	0.632	30	424.00	1370.83	45.69	82.00	1.18
21	Inc-100	0.428	0.999	94	392.00	1267.37	13.48	29.50	1.15
22	ML-160	0.728	0.910	146	707.00	2285.79	15.66	31.95	1.08

3.1 Power factor

Low power factors directly concern with electric utility because the low power factors can cause high current in transmission lines which consequently increases the voltage drops in the lines. Such high voltages require greater capacity of electric utility requirements in terms of, for example, capacity of generator, transmission line sizes and substation equipment. Electrical utility of Thailand has required maintaining the power factor ≥0.85 for customers and from ≥0.875 in among of Electrical Generating Authority of Thailand (EGAT), Provincial electricity authority (PEA) and Metropolitan electricity authority (MEA) for electrical trading [32].

From the results in Table 2 and Fig. 4, the compact fluorescent lamps have the average power factor of 0.641 that does not meet the requirements of utility; excepting the compact fluorescent with power rated 65W which has the power factor of 0.995. The energy saving lamps whose power factors reach the requirements of utility are T5 (28) #E and T8 (36) #E. The LED-8 has the power factor 0.831 which almost reaches the standard requirements. In comparison, the traditional tabular fluorescent lamp T8 (36) #M which operates with magnetic ballast, has a very low power factor of 0.484. As expected, the power factors of the incandescent lamps are almost unity as well as the power factor 0.91 of the mercury lamp is quite high because it operates without ballast.

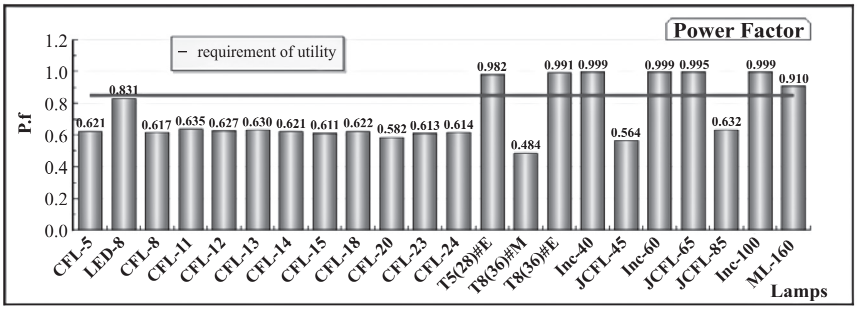

Fig. 4 Power factor of each lamp

3.2 Efficacy

From Fig. 5, the energy saving lamps that are compact fluorescent lamps, LED lamp and T5 tabular fluorescent lamp consume less real power and have higher efficacy in comparison with the traditional lamps, including the T8 tabular fluorescent lamp with magnetic ballast, incandescent lamps and mercury lamp.

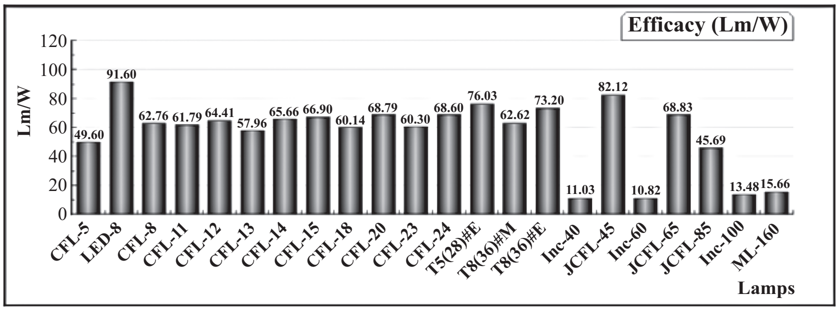

Fig. 5 Efficacy of each lamp

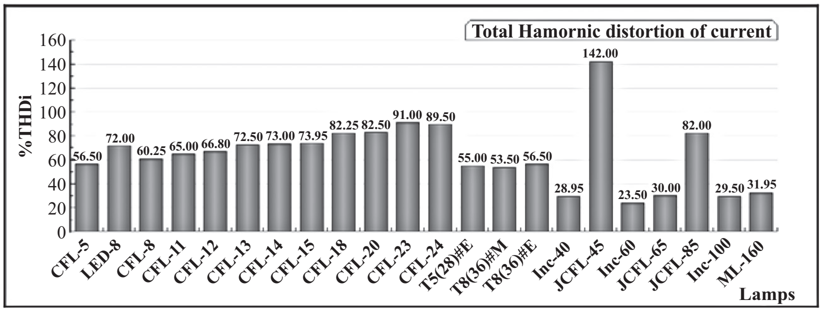

Fig. 6 Total harmonic distortion of current

3.3 Harmonic distortion, voltage and current waveforms

Current and voltage harmonics were produced because of non linear characteristics of the electrical equipment [27] - [31]. Many researches were published concerning harmonics from energy saving lamps especially compact fluorescent lamps that have influence to equipments and electrical networks. The impact of harmonic distortion can be divided into 3 categories as the following topics.

Heating effects: Flowing of harmonics in power system equipment raises the temperature and leads to the reduction of insulation life [27], [31].

Insulation effects: Harmonic voltage distortion can cause over corona inception voltage and insulation degradation and breakdown. Capacitors appear to be the most sensitive load equipment, with steady state peak voltage limited to values less than 20% greater than rated peak voltage values to prevent corona inception. Additionally, harmonics have caused failures of components used with power line such as failure of 33 kV cables [27], [31].

Disruption: Disruption is defined as the abnormal operation or failure of equipment because of voltage or current distortion. Harmonic currents can cause erroneous operation of devices, such as induction disc devices of watt hour meters and over current relays that are designed to monitor only at fundamental current [27] , [31].

3.3.1 Standard of harmonics distortion and comparison results

1) IEEE Std. 519 – 1992

The standard recommends practices for individual consumers for general system to keep $THD_V \leq 5\%$ as shown in the Table 3. The limits for harmonic distortion of current (THD_i) are presented in Table 4. I_{SC} is the maximum short circuit at the point of common coupling and I_L is the maximum demand load current at the point of common coupling [30] , [33] , [34] , [38]. In order to determine limitations for harmonic distortion of current, the I_{SC}/I_L ratio must be known.

Table 3 Std. 519-1992 voltage system classification and distortion limits

	Special Application*	General System	Dedicated System**
Notch Dept	10%	20%	50%
THD(Voltage)	3%	5%	10%
Notch Area (A_N)***	164000	22800	36500

Note: The value A_N for other than 480V system should be multiplied by V/480

* Special applications include hospitals and airports.

** A dedicated system exclusively dedicated to the converter load.

*** In volt-microseconds at rated voltage and current.

Table 4 IEEE Std. 519-1992 current distortion limits for general distribution system (120V through 69,000V)

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	<11	$11 \le h \le 17$	$17 \le h \le 23$	$23 \le h \le 35$	$35 \le h$	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

General notes for Table 4.

1) Even harmonics are limited to 25% of the load harmonic limit above.

2) Current distortions that result in a dc offset, e.g., half-wave converter, are not allowed.

3) *All power generation equipment is limited to these values of current distortion, regardless of actual I_{SC}/I_L.

2) Engineering Recommendation G.5/3

Limits for harmonics in the United Kingdom Electricity have divided load into 3 stages. Stage 1, for maximum rated of converter or a.c regulator can connect with power network 0.415 kV, 6.6 kV and 11 kV. Stage 2, for 3 phase equipments with rated more than load in stage1. Stage 3, for non linear loads cannot be grouped into stage 1 and stage 2. The limit values must not exceed the values in the Table 5 and Table 6 for 3 phase system [35] , [38] .

Table 5 Permitted harmonic currents for any one consumer at point of common coupling under Stage 2 Limit*

Supply voltage (kV) at PCC	Harmonic Number and Current (A rms)																	
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0.415	48	34	22	56	11	40	9	8	7	19	6	16	5	5	5	6	4	6
6.6 and 11	13	8	6	10	4	8	3	3	3	7	2	6	2	2	2	2	1	1
33	11	7	5	9	4	6	2	2	2	6	2	5	1	1	1	2	1	1
132	5	4	3	4	2	3	1	1	1	3	1	3	1	1	1	1	1	1

*: A tolerance of +10% or 0.5A (whichever is the greater) is permissible, provided it applies to not more than two harmonics.

Table 6 Harmonic voltage distortion limits at any point on the system (including background levels)

Supply System Voltage (kV) at point of Common	THD_V (%)	Individual Harmonic Voltage Distortion (%)	
		Odd	Even
0.415	5	4	2
6.6 and 11	4	3	1.75
33 and 66	3	2	1
132	1.5	1	0.5

3) IEC 61000-3-2 Electromagnetic compatibility (EMC), Part 3: Limits-Section 2: Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)

The equipments are classified into 4 groups that comprise Class A, Class B, Class C and Class D. Lighting equipment and also dimming devices are classified in Class C. The lighting equipments are divided as > 25W and ≤ 25W. The limit values for the lighting equipment > 25 W are shown in the Table 7. The lighting equipment ≤ 25 W uses the limit values of Class D in column 2 of Table 8 [36] , [38].

Table 7 Limits for class C equipment

Harmonic order n	Maximum permissible harmonic current expressed as a percentage of the input current at the fundamental frequency (%)
2	2
3	$30.\lambda^*$
5	10
7	7
9	5
15≤n≤39 (odd harmonic only)	3
*λ is the circuit power factor	

Table 8 Limits for class D equipment

Harmonic order(n)	Maximum permissible harmonic (mA/W)	Maximum permissible harmonic current (A)
3	3.4	2.30
5	1.9	1.14
7	1.0	0.77
9	0.5	0.40
11	0.35	0.33
15≤n≤39 (odd harmonic only)	3.85/n	see another table relevant detail in the standard

4) Thailand standard or requirements of harmonics for business and industry

The standard of harmonics for business and industry in Thailand is referenced to Engineering Recommendation G.5/3, The State Energy Commission of Western Australia (SECWA), IEC1000 and IEC 61000-3-2. The limit values of harmonic currents and voltages for three phase systems are shown in Tables 9 and 10 [37] - [38]. Single phase equipment is referenced to the requirements of IEC 61000-3-2.

Table 9 Permitted harmonic currents for consumer at point of common coupling*

Supply voltage (kV) at PCC	Harmonic Number and Current (A rms)																	
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0.400	48	34	22	56	11	40	9	8	7	19	6	16	5	5	5	6	4	6
11 and 12	13	8	6	10	4	8	3	3	3	7	2	6	2	2	2	2	1	1
22,24 and 33	11	7	5	9	4	6	2	2	2	6	2	5	1	1	1	2	1	1
69	8.8	5.9	4.3	7.3	3.3	4.9	2.3	1.6	1.6	4.9	1.6	4.3	1.6	1	1	1.6	1	1
115 and above	5	4	3	4	2	3	1	1	1	3	1	3	1	1	1	1	1	1

*: A tolerance of +10% or 0.5A (whichever is the greater) is permissible, provided it applies to not more than two harmonics.

Table 10 Harmonic voltage distortion limits one consumer at point of common coupling (including background levels)

Supply System Voltage (kV) at point of Common	THD_V (%)	Individual Harmonic Voltage Distortion (%)	
		Odd	Even
0.400	5	4	2
11, 12, 22 and 24	4	3	1.75
33	3	2	1
69	2.45	1.63	0.82
115 and above	1.5	1	0.5

From details of standards for harmonic distortion, the results from harmonic measurement in Table 2 can be verified with the standard of IEEE 519-1992 and IEC 6100-3-2 because Engineering recommendation G.5/3 standard have only the limit values for three phase system and standard of Thailand for single phase system is referenced to IEC 61000-3-2. From Table 2, the total harmonic distortion of voltage (%THD_V) does not exceed 5% for limitations of IEEE 519-1992 while the total harmonic distortion of current (THD_i) cannot be verified because the I_{SC}/I_L ratios are unknown. Therefore, the harmonic distortion values were compared with IEC 6100-3-2 standard. The results are presented in Tables 11 and 12. From Table 11, the shaded numeric values present the orders of current harmonic distortion for lamps with power rated >25 W that exceed the limit values of Class C equipment in standard of IEC 61000-3-2. From Table 12, the shaded numeric values present the orders of current harmonics for lamps with power rated ≤25 W that exceed the limit values of Class C equipment according to the standard of IEC 61000-3-2.

Table 11 Comparison of individual harmonics of lamps with power Rated > 25 W for class C equipment of IEC 61000-3-2

Harmonic order (n)	2	3		5	7	9	15≤n≤39 (odd harmonic only)						
							15	17	19	21	23	25	27≤ n≤39
Limit values (%)	**2**	**$30.\lambda^{*}$**	**value**	**10**	**7**	**5**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
T5(28)#E	36.00	29.46	22.00	13.00	9.00	8.00	4.50	4.00	4.00	3.80	3.50	3.00	-
T8(36)#M	35.50	29.73	22.00	13.00	9.00	7.00	4.50	4.00	3.50	3.00	2.60	2.50	-
T8(36)#E	36.00	14.52	22.00	13.00	9.00	8.00	4.90	4.90	4.90	4.00	4.00	5.00	-
Inc-40	19.00	29.97	11.90	7.50	5.00	5.00	4.10	4.00	3.90	3.80	3.50	3.50	-
JCFL-45	25.00	16.92	70.10	62.00	50.00	41.00	27.00	27.00	26.00	25.00	31.00	19.00	-
Inc-60	15.30	29.97	9.00	6.00	4.00	3.25	1.90	1.80	1.70	1.50	1.40	1.00	-
JCFL-65	18.00	29.85	10.50	6.50	4.25	3.50	2.00	1.90	1.80	1.70	1.60	1.20	-
JCFL-85	25.00	18.96	58.00	30.00	15.00	12.50	8.00	7.00	7.00	6.00	5.00	5.00	-
Inc-100	19.00	29.97	12.10	7.00	5.00	4.00	2.20	2.10	1.90	1.80	1.70	1.60	-
ML-160	6.50	27.30	26.10	12.00	3.25	5.00	2.00	1.80	1.70	1.20	1.10	1.00	-

*λ is the circuit power factor

Limit value of harmonic order 27≤n≤39 cannot identify.

Table 12 Comparison individual harmonic of lamps with power rated ≤ 25 W for class C equipment of IEC 61000-3-2

Harmonic order (n)	3	5	7	9	11	$15 \le n \le 39$ (odd harmonic only)						
						15	17	19	21	23	25	$27 \le n \le 39$
Limit values (mA/W)	**3.40**	**1.90**	**1.00**	**0.50**	**0.35**	**0.29**	**0.29**	**0.29**	**0.29**	**0.29**	**0.29**	**0.29**
CFL-5	1.97	1.21	0.83	0.53	0.45	0.36	0.34	0.30	0.27	0.27	0.27	-
CFL-8	2.28	1.47	0.95	0.59	0.47	0.35	0.33	0.33	0.33	0.30	0.28	-
CFL-11	2.64	1.54	0.88	0.58	0.55	0.44	0.37	0.29	0.29	0.26	0.22	-
CFL-12	2.66	1.75	0.98	0.70	0.56	0.39	0.39	0.39	0.34	0.28	0.28	-
CFL-13	3.04	1.98	1.23	0.88	0.77	0.39	0.35	0.42	0.35	0.28	0.28	-
CFL-14	3.31	2.11	1.13	0.82	0.71	0.45	0.45	0.41	0.37	0.34	0.30	-
CFL-15	3.28	2.16	1.19	0.89	0.74	0.45	0.41	0.39	0.37	0.34	0.34	-
CFL-18	3.96	2.57	1.32	0.88	0.73	0.51	0.51	0.44	0.40	0.37	0.36	-
CFL-20	3.64	2.76	1.76	1.22	1.07	0.69	0.46	0.46	0.54	0.56	0.46	-
CFL-23	4.16	3.04	1.93	1.33	1.18	0.71	0.41	0.45	0.52	0.52	0.45	-
CFL-24	4.08	2.97	1.85	1.33	1.18	0.59	0.41	0.45	0.48	0.48	0.41	-
LED-8	1.41	0.83	0.73	0.47	0.38	0.26	0.24	0.21	0.18	0.16	0.18	-

Limit value of $15 \le n \le 39$ (odd harmonic only) = $3.85/n = 0.29$ ($n=13$) and harmonic order of $27 \le n \le 39$ cannot estimate.

3.3.2 Voltage, current waveform and relative harmornics

The waveform and relative harmonic distortion of 45 W compact and 8 W light emitting diode (LED) are shown in Fig. 7 in order to investigate the relationship between voltage and current waveforms and harmonic distortion. Most of compact fluorescent lamps have produced waveforms like in Fig. 7. In Fig. 7, the sine waves are the input line voltage waveforms and the spiked waves are the input currents that are completely distorted due to the impact of harmonics. The degrees of harmonics are illustrated in Fig. 8.

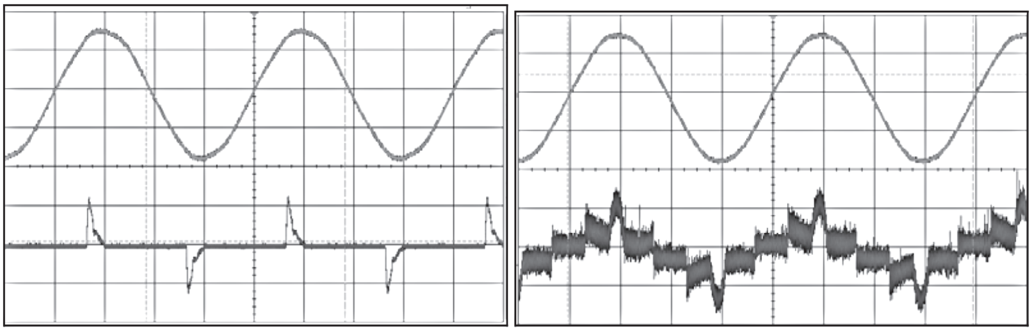

Fig. 7 Voltage and current waveforms of 45 W CFL and 8 W LED

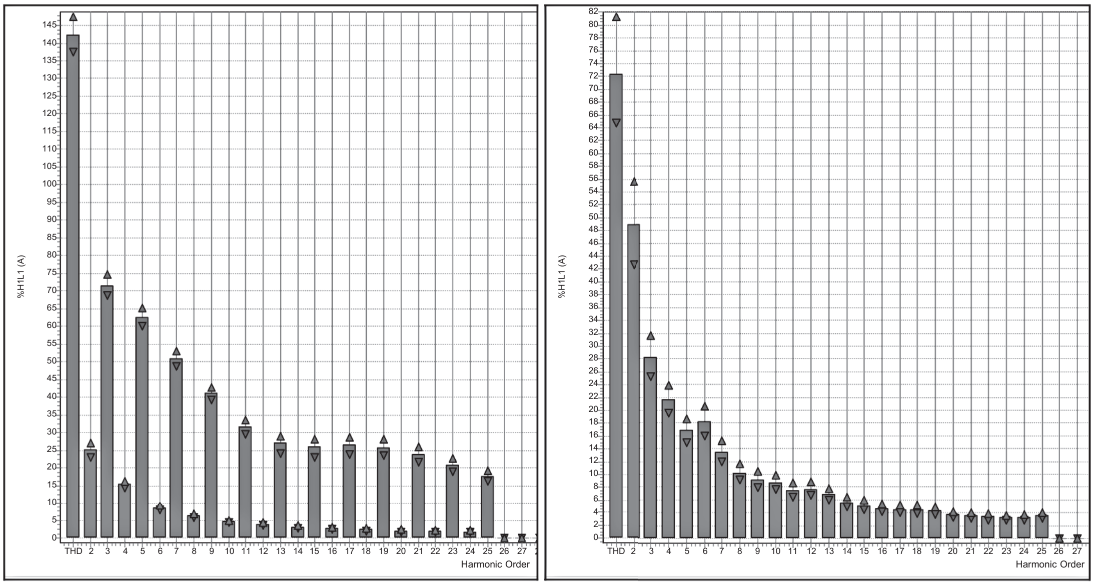

Fig. 8 Harmonics distortion of current of 45 W CFL and 8 W LED

4. Conclusion

The electrical and lighting characteristics of the commercial energy saving lamps in Thailand were investigated. Twenty-two lamp models currently available in the market were chosen from different manufacturers. These lamps can be classified into six groups including incandescent, mercury, tubular florescent, light emitting diode (LED), small size and large size compact fluorescent lamps. The lamps were tested by using the luminous flux tester which is developed according to the IEC standard. The experimental procedures were performed based on the Thai Industrial Standard number 623. The harmonics values were verified with IEEE 519-1992 and IEC 6100-3-2 standards as referenced by the standard of Thailand. The experimental results revealed that the THD_V of the sample models did not exceed the limitations of IEEE 519-1992 while almost all of the energy saving lamps exceeded the limitation of IEC 6100-3-2. In terms of the power factors, the energy saving lamps could not reach the requirements of utility. It was also found that the energy saving lamps consumed less active power and produced more luminous quantity than the traditional lamps. Therefore, using these categories of lamps could result in reducing the active power of the system. On the other hand, the low power factors of these lamps require additional reactive power from the electric utility and therefore result in expensive investments in generation, transmission, and distribution equipment. In addition, wide spread use of energy saving lamps could produce higher harmonic distortion and consequently produce the power quality problems to electrical equipment and networks due to heating, insulation and disruption effects. Overcoming problems with low power factor and high harmonics, energy saving lamps should be improved to have high power factor, low harmonics and lower cost.

5. Acknowledgments

The authors would like to thank the Hands-on Research and Development Project of Rajamangala University of Technology Lanna (HR2S-004), Thailand for strong support this work.

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