Assesing the Impact of Led Lighting in Power Distribution Systems

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***Abstract*— In recent years the interest of making loads more efficient and reliable has led to the development of new lighting systems, such as light Emitting Diodes (LEDs), which have been suggested for commercial, industrial and residential applications due to their low power consumption. Usually LED systems use a power electronic based-drive to provide a dc constant voltage for the diodes. As a result, the power quality at the ac side gets degraded due to the introduction of low-order current harmonics that affect the voltage waveform at the Point-of-Common Coupling (PCC).The purpose of this paper is to evaluate the impact of harmonics injected by a LED system on a scaled-down system representing a real feeder. Experimental results on the low-voltage low-power test bench indicate the contribution of each harmonic component to the THD when a transformer with a 1% impedance is used as interface with the grid.**

Keywords—Light Emitting Diodes, Total Harmonic Dstortion, Power Quality.

I. INTRODUCTION

Since the invention of the first lamp (with tungsten filament capable of withstanding high temperatures) more than a century ago, light systems using incandescent lamps have been widely used in the commercial, industrial and residential sector. Their low cost, simplicity and durability make them ideal for different applications. However, they are considered very inefficient due to the large amount of energy dissipated into heat [1]. Different types of lighting solutions such as fluorescent lamps or compact fluorescent lamps (CFLs) and more recently the use of light emitting diodes (LEDs) have been considered as oppose to the conventional lighting system for all applications.

The LED lighting technology is an attractive alternative to incandescent lamps because of advantages such as: Long life expectancy, mercury-free, high efficiency, high brightness in various colors, among others [2]. With the development of new semiconductor devices, LED systems have reached up to 130 lm/W and a life-time expectancy of 50,000, which is better than incandescent lamps (15 lm/W with a life-time expectancy of 1.000 hours) and fluorescent lamps (80 lm/W with a life-time of 8.000 hours) [3]. Furthermore, has been reported in [4] that LEDs have achieved efficiencies up to twice as CFLs and ten times more than incandescent lamps.

Only one LED is not able to generate sufficient luminous flux in comparison with the incandescent lamps and other lighting devices [5]. For this reason, LED systems are connected in parallel and/or series in order to meet design requirements. However, as a consequence of the converter used for the ac-dc process, the current at the ac side gets distorted causing problem in upstream loads. There are two international standards that establish maximum limits of harmonic distortion at end user level: IEC-61000-3-2 [1] IEEE-519-1992 [6].

The focus of this paper is to present a complete analysis of the harmonic content present in the current and voltage waveforms at the input of a LED drive unit. To this end two cases are conducted. A set of lamps connected to the power grid without galvanic isolation: Case A and with galvanic isolation: Case B. The paper is divided as follows: First, Section II describes some power quality issues. Then the operation of a LED system is introduced in Section III. Section IV presents the case study, and finally Section V provides conclusions about the research work.

II. POWER QUALITY ISSUES

New trends in power systems have demanded the use of power electronics converters (e.g., ac-dc, ac-ac, dc-ac) that use semiconductor devices such as Si and SiC IGBTs and MOSFETs as switching devices. In general, these power converters are found in variable speed drives, computers' ac-dc power supplies, FACT devices, active filters and other appliances; however, they are considered nonlinear loads that distort current and voltage waveforms, affecting the operation of motors, transformers and generators.

When a power quality issue reach the Point-of-Common Coupling (PCC), its negative effect spreads throughout the power grid affecting healthy feeders. Some problems associated to harmonics at the PCC are [7]:

- Damage on sensible equipment at residential and industrial level
- Loss of production due to blackouts
- Overheat of motors and transformers
- Loss of reliability

- Unbalances and currents flowing through neutral conductors.

Utilities are responsible to provide a premium power quality to customers, meeting with the limits set in international standards and regulations. Power quality problems are classified in four categories [8]:

- *Frequency variations*: Rarely occur in stiff power systems; however, is more likely to occur in off-grid systems operated by a Genset system in which large load variations cause frequency changes.
- *Amplitude changes*: Caused by the operation of fault protections (e.g., breakers, reclosers, etc) and last for a few cycles to hundreds of cycles depending on fault severity.
- *Changes of current and voltage waveforms*: Produced by the introduction of nonlinear loads, whose operation cause harmonic distortion.
- *Voltage Unbalance*: Produced by single-phase loads that cause zero-sequence components that might affect rotating machines, transformers and other sensitive equipment.

The waveform distortion is due to the presence of sinusoidal voltage and current components which frequency is multiple of the fundamental frequency of the power supply. The use of LED lamps system used to replace the incandescent bulbs have introduced harmonics that distort both voltage and current waveforms depredating the power quality. These harmonics cause negative impact on motor drives, transformers, filters, and many others [3].

The maximum allowable percentage of total harmonic distortion index or harmonic distortion (THD) in electrical power systems, depending on the voltage level, is defined in [9]. The THD is an indicator of the amount of components, different from the fundamental, which are in a waveform. However, the increasing use of nonlinear loads such as variable speed drives among others, introduced harmonic current components that affect the waveform of the voltage at the PCC. These harmonic current cause malfunction of variable speed drives, affects measuring equipment, malfunction protection equipment, overheating of equipment such as transformers, motors and generators.

III. LED Lighting Operating Principle

Similar to CFLs, LED lighting requires an ac-dc converter in order to provide constant current at the dc side. This ac-dc converter is used to step-down the voltage while controls the amount of current consumed by the LEDs. The growing of nonlinear loads such as variable speed drives, computers, household appliances, which have regulated voltage sources are mainly affecting the quality energy because of its electronic operation, exceeding the permissible values listed in IEEE Std. 519 [9].

In order to reduce the impact of nonlinear loads, the introduction of filters needed to eliminate those undesirable components is necessary.

$$THD_i = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \quad (1)$$

where I_n is the rms value of each harmonic current component and I_1 is the rms value of the fundamental component.

IV. Case Study

In order to analyze the harmonic content produced by LED systems, different experiments are conducted to obtain the input current and input voltage waveforms. Two case studies are considered: Case A without a transformer, which are the lamps connected directly to the power grid and case B using a transformer to provide galvanic isolation. Table I list the set of lamps used in the experiment. A TEKTRONIX TDS 2023 oscilloscope is used to capture the current and voltage waveforms under different test conditions.

A. Case A:

The experiment test bench consists of the parallel connection of five 45 W panels (type 1) and three bulbs of 9 W (type 2) each. The schematic of the system under analysis is presented in Fig. 1. The experimental results are presented in Fig 2 to 8, whereas the THD for each waveform is listed in Table II and III. As shown, panels do not affect significantly the current waveform. However, when bulbs are connected the current waveform shape gets distorted due to the operation of the ac-dc drive.

Table I. Types of the LED Lamps

Type	Manufacturer	Reference	Power [W]
1	Sylvania	P24564	9
2	Sylvania	P24242	45
3	Natural Led	2835SMD	12
4	Newlighting	KT6595-WH	12
5	Lumik Light	LUM-R200	15
6	Enerlite Leds and Lighting	GU10	5
7	Sylvania	Toledo tube	18

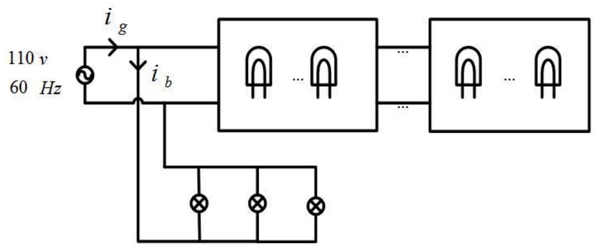

Fig 1. Schematic of the system under analysis, which consist of five panels (up) and three bulbs (down). The total current flowing into the systems is i_g and i_b is the current flowing through the bulbs.

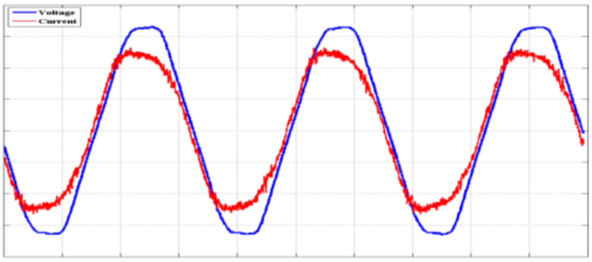

Fig 2. Five lamps: Input current waveform (red) at 1 A/div and input voltage waveform (blue) at 50 V/div, both with a time scale of 5 ms/div

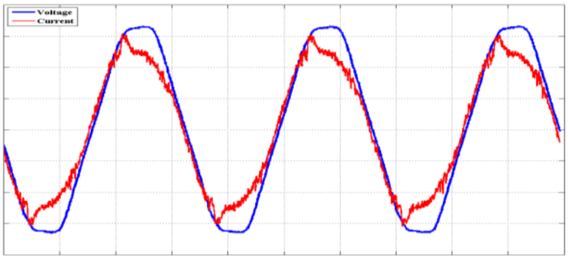

Fig 3. Five lamps and one bulb: Input current waveform (red) at 1 A/div and input voltage waveform (blue) at 50 V/div, both with a time scale of 5 ms/div

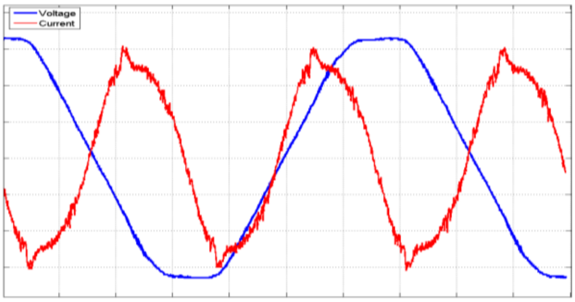

Fig 4. Five lamps and two bulbs: Input current waveform (red) at 1 A/div and input voltage waveform (blue) at 50 V/div, both with a time scale of 5 ms/div.

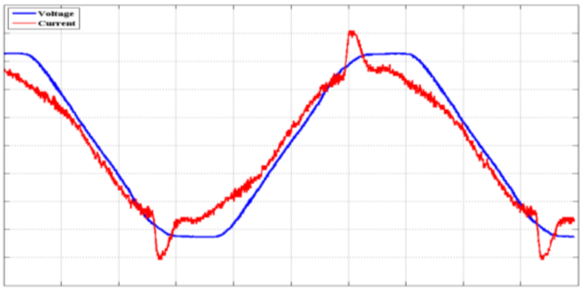

Fig 5. Five lamps and three bulbs: Input current waveform (red) at 1 A/div and input voltage waveform (blue) at 50 V/div for, both with a time scale of 5 ms/div.

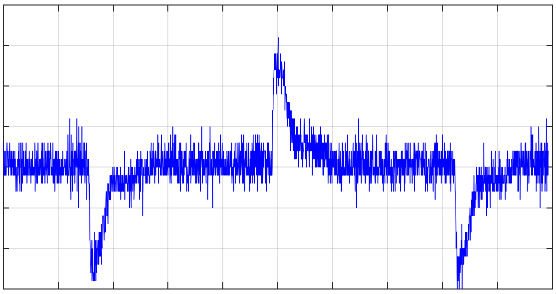

Fig 6. One bulb: Input current waveform at 200 mA/div with a time scale of 5 ms/div.

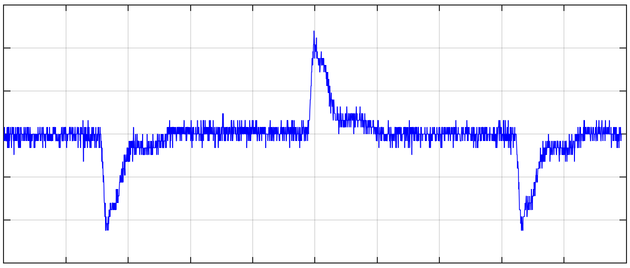

Fig 7. Two bulbs: Input current waveform at 500 mA/div with a time scale of 5 ms/div.

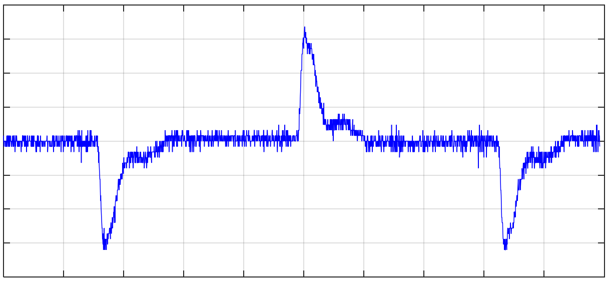

Fig 8. Three bulbs Input current waveform at 500 mA/div with a time scale of 5 ms/div.

TABLE II. THD (%) VALUES FOR LED LAMPS

Parameter	5 lamps	5 lamps, 1 bulb	5 lamps, 2 bulbs	5 lamps, 3 bulbs
i_g	9,4	10,21	59,6	59,71
v_g	3,78	3,75	61,07	61,11
i_b	--	168,4	141,7	140,9

TABLE III. FOURIER'S COEFFICIENTS

Parameter	c_1	c_3	c_5
I_g	1,7379	0,6708	0,6074
$I_{g(1)}$	1,7011	0,7013	0,4245
$I_{b(1)}$	2,2358	2,2093	2,1585
$I_{g(3)}$	1,5528	0,6701	0,1605
$I_{b(3)}$	2,2129	2,0340	1,8095

B. Case B:

A transformer with a 1:1 turn ratio and an impedance of 1%, is used to connect the system with the power grid. In this case lamps type 3 to 7 are used in the experiment. Tables IV to VIII list the voltage and current THD at the primary and the secondary side when lamps type 3 to 7 are connected. The magnitude of the fundamental and the contribution of other components are also listed. The voltage and current waveforms at the primary and secondary side are illustrated in fig. 9 to 18.

Lamps type 3 generate high harmonic distortion for the current and voltage waveforms as shown in fig 9 and 10. The highest harmonic component is the 3rd, which is about 79.5% of the fundamental. The 5th harmonic reaches 58.8% percent of the fundamental, whereas the 7th harmonic is 22.8 % of the fundamental. Notice the high contribution of the 3rd on the secondary of the transformer.

TABLE IV. THD (%) FOR LED LAMPS TYPE THREE

Variables	Primary Side		Secondary Side	
	Voltage	Current	Voltage	Current
Fundamental	123,1 V	0,1 A	132,2 V	0,2 A
THD	3,3	79,5	3,1	114,9
h=3	0,7	58,8	0,8	73
h=5	3,1	24,2	0,9	44,8
h=7	0,7	22,8	0,6	40

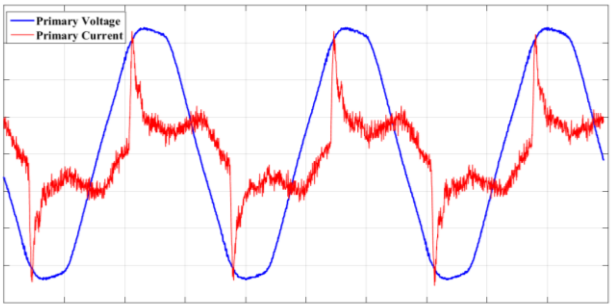

Fig 9. Type three: Current waveform (red) at 1 A / div and voltage waveform (blue) at 50 V / div for the primary side of the transformer, both with a time scale of 5 ms / div.

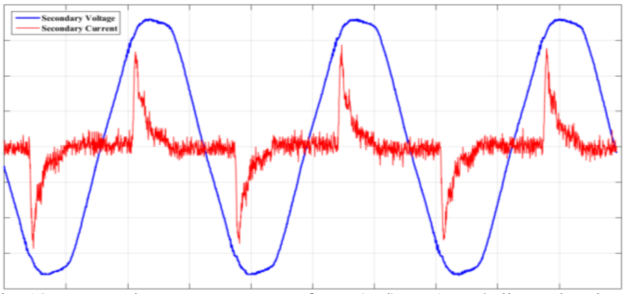

Fig 10. Type three: Current waveform (red) at 1 A / div and voltage waveform (blue) at 50 V / div for the secondary side of the transformer, both with a time scale of 5 ms / div.

In the case of lamps type 4, the harmonic distortion for the current and voltage waveforms is shown in fig 11 and 12. The highest harmonic component is the 3rd, which is about 73% of the fundamental. The 5th harmonic reaches 47.4% percent of the fundamental, whereas the 7th harmonic is 19.5 % of the fundamental. Notice the high contribution of the 3rd on the secondary of the transformer.

TABLE V. THD (%) FOR LED LAMPS TYPE FOUR

Variables	Primary Side		Secondary Side	
	Voltage	Current	Voltage	Current
Fundamental	123,6 V	0,2 A	131,9 V	0,1 A
THD	3,3	74,9	3,2	153,9
h=3	0,8	73	0,6	76,5
h=5	0,6	47,4	3	56,8
h=7	3,1	19,5	0,7	55,8

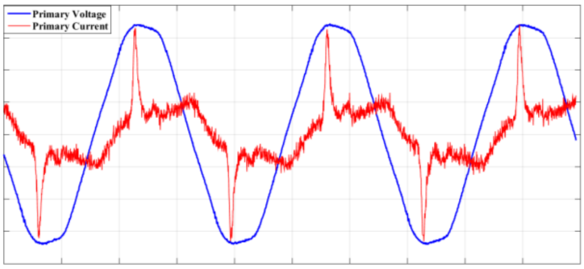

Fig 11. Type four: Current waveform (red) at 1 A / div and voltage waveform (blue) at 50 V / div for the primary side of the transformer, both with a time scale of 5 ms / div.

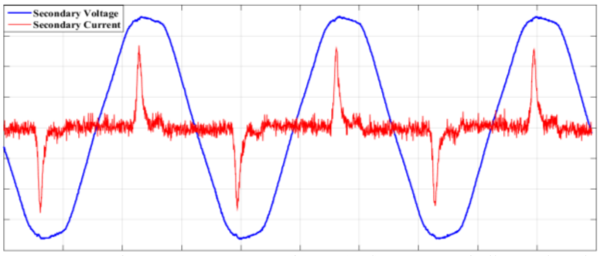

Fig 12. Type four: Current waveform (red) at 1 A / div and voltage waveform (blue) at 50 V / div for the secondary side of the transformer, both with a time scale of 5 ms / div.

In the case of lamps type 5, the harmonic distortion for the current and voltage waveforms is shown in fig 13 and 14. The highest harmonic component is the 3rd, which is about 63.3% of the fundamental. The 5th harmonic reaches 30% percent of the fundamental, whereas the 7th harmonic is 29.2 % of the fundamental. Notice also the high contribution of the 3rd on the secondary of the transformer.

TABLE VI. THD (%) FOR LED LAMPS TYPE FIVE

Variables	Primary Side		Secondary Side	
	Voltage	Current	Voltage	Current
Fundamental	124,2 V	0,3 A	132,2 V	0,2 A
THD	3,1	90,2	3,1	123
h=3	0,4	63,3	0,8	77
h=5	3	30	2,9	51
h=7	0,8	29,2	0,6	45

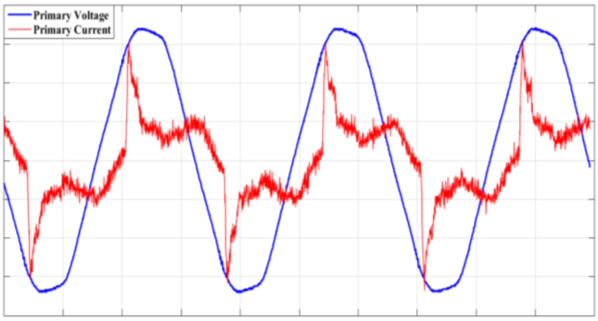

Fig 13. Type five: Current waveform (red) at 1 A / div and voltage waveform (blue) at 50 V / div for the primary side of the transformer, both with a time scale of 5 ms / div.

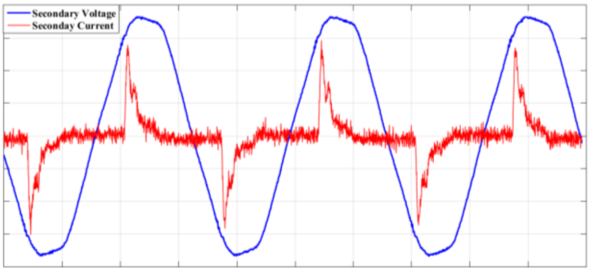

Fig 14. Type five: Current waveform (red) at 1 A / div and voltage waveform (blue) at 50 V / div for the secondary side of the transformer, both with a time scale of 5 ms / div.

In the case of lamps type 6, the harmonic distortion for the current and voltage waveforms is shown in fig 15 and 16. The highest harmonic component is the 3rd, which is about 45.5% of the fundamental. The 5th harmonic reaches 9.8% percent of the fundamental, whereas the 7th harmonic is 10.4 % of the fundamental. Notice also the high contribution of the 3rd on the secondary of the transformer.

TABLE VII. THD (%) FOR LED LAMPS TYPE SIX

Variables	**Primary Side**		**Secondary Side**	
	Voltage	**Current**	**Voltage**	**Current**
Fundamental	126,3 V	0,2 A	134,9 V	0,1 A
THD	3,4	52,3	3,4	128,6
h=3	0,,3	45,5	0,3	74,7
h=5	3,2	9,8	3,2	45
h=7	1,1	10,4	1,1	43,4

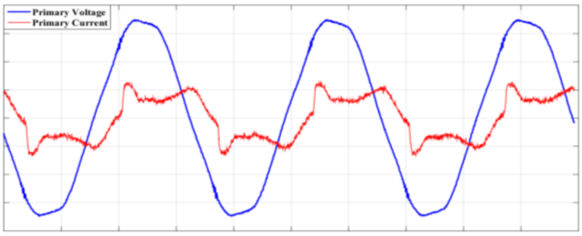

Fig 15. Type six: Current waveform (red) at 1 A / div and voltage waveform (blue) at 50 V / div for the primary side of the transformer, both with a time scale of 5 ms / div.

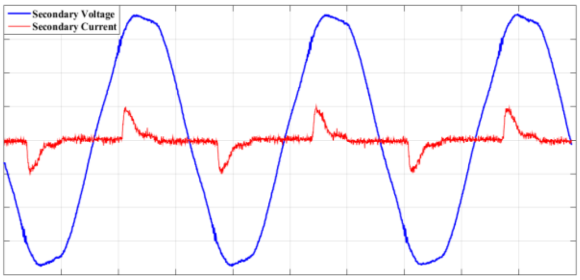

Fig 16. Type six: Current waveform (red) at 1 A / div and voltage waveform (blue) at 50 V / div for the secondary side of the transformer, both with a time scale of 5 ms / div.

In the case of lamps type 7, the harmonic distortion for the current and voltage waveforms is shown in fig 17 and 18. The highest harmonic component is the 3rd, which is about 68.7% of the fundamental. The 5th harmonic reaches 33.5% percent of the fundamental, whereas the 7th harmonic is 32.9 % of the fundamental. Notice also the high contribution of the 3rd on the secondary of the transformer.

The magnitude of the 3rd, 5th and 7th harmonic components for lamps type 3 to 7 when the isolated transformer is used, it is illustrated in Fig. 19 and 20. As shown the harmonic with higher percentage is the 3rd. The 5th and 7th are pretty much similar for all the cases.

TABLE VIII. THD (%) FOR LED LAMPS TYPE SEVEN

Variables	**Primary Side**		**Secondary Side**	
	Voltage	**Current**	**Voltage**	**Current**
Fundamental	125,4 V	0,3 A	131,9 V	0,2 A
THD	3,3	96,8	3,2	125,8
h=3	0,4	68,7	0,7	76,5
h=5	2,9	33,5	2,7	53
h=7	1,4	32,9	1,3	49,6

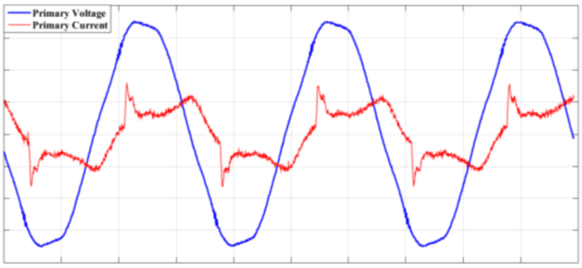

Fig 17. Type seven: Current waveform (red) at 1 A / div and voltage waveform (blue) at 50 V / div for the primary side of the transformer, both with a time scale of 5 ms / div.

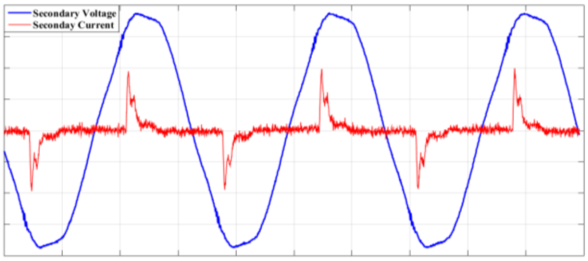

Fig 18. Type seven: Current waveform (red) at 1 A / div and voltage waveform (blue) at 50 V / div for the secondary side of the transformer, both with a time scale of 5 ms / div.

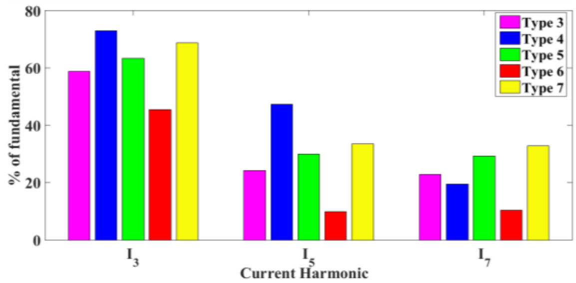

Fig 19. The contribution of the 3rd, 5th and 7th to the THD on the primary side of the transformer.

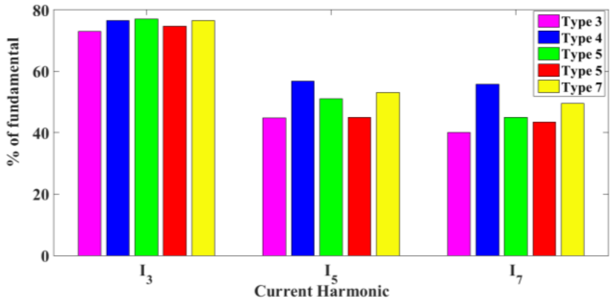

Fig 20. The contribution of the 3rd, 5th and 7th to the THD on the secondary side of the transformer.

V. CONCLUTIONS AND REMARKS

This paper evaluated and analyzed seven types of LED lamps. Two test systems were installed to perform test required in the system. According to results in first test (panels and bulbs LEDS connected to directly grid) it is shows that the highest THD occurs when the three bulbs are connected in parallel. In second test (lamps connected to the grid with a transformer) it is observed that de highest THD occurs whit Type 5 lamp in the 3rd harmonic (fig 20). In this case, the harmonics have a great effect on the transformer due to the distortion that can be seen in current waveform, this distortion whit high peaks reduce useful life of transformer.

Experimental result show that the harmonic distortion produced by LED is closely related to the driver's robustness. For example, if it is observed Fig 2, 6, the waveform with the harmonics maximum is Fig 6 (One bulb). In conclusion, the injection harmonic percentage is no related with nominal power of LED.

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