

Influence of LED Lamps Luminous Flux Regulation on Current Harmonics Emissions

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Abstract – Modern LED lighting offers significant advantages over incandescent lighting regarding efficiency and over CFL lighting, both regarding the efficiency and including the ability to regulate luminous flux. However, LED lamps are nonlinear loads that inject higher-order current harmonics into the power grid. In this paper, the impact of switching to single-phase dimmers and DC-controlled drivers on power quality will be analysed.

Keywords – LED, dimmer, harmonics, power quality, THDI.

I. INTRODUCTION

In response to global demands for energy savings, two lighting technologies have emerged as alternatives to incandescent lamps: compact fluorescent lamps (CFL) and light-emitting diode lamps (LED) [1]. LED technology has become dominant in residential, commercial, and industrial lighting due to its energy efficiency, longevity, and flexibility in lighting design. LED lighting has several advantages over CFLs, including improved performance, greater efficiency, and a lower environmental impact. LEDs are known for their exceptional energy efficiency, using less energy than CFLs to produce the same amount of light. LED bulbs use up to 75% less energy than incandescent bulbs and approximately 25-30% less than CFLs. Efficiency is reflected in lower electricity costs and reduced environmental impact. One of the outstanding features of LEDs is their impressive lifespan. LEDs can last between 25 000 and 50 000 hours, while CFLs typically last 8 000 to 15 000 hours [2]. The extended lifespan means LED bulbs require fewer replacements, which saves on maintenance costs and reduces long-term waste. LEDs provide instant full brightness as soon as they are turned on, unlike CFLs, which take a while to reach full brightness — especially at lower ambient temperatures. In addition, LEDs are much more durable and robust than CFL bulbs. Because the active material is a solid-state semiconductor, LEDs do not have fragile filaments or thin glass tubes, making them less prone to breakage. Another important consideration is safety: CFL bulbs contain small amounts of mercury, which poses an environmental hazard if the bulb is broken or not disposed of properly at the end of its life. In contrast, LED bulbs do not contain toxic substances,

making them a safer solution for both users and the environment. Over their lifetime, LED bulbs produce less CO₂ due to their lower energy consumption [3]. Furthermore, LED bulbs offer a wide range of colour temperatures and brightness levels, providing flexibility in lighting design. Unlike CFL bulbs, which can degrade in colour over time, LED bulbs maintain their brightness and colour quality throughout their lifetimes [4]. They also heat up less, helping prevent heat buildup in rooms and reducing the need for air conditioning [5, 6]. Although the initial cost of an LED bulb may be higher than that of a CFL bulb, their long lifespan and lower energy consumption make them more cost-effective over time. This results in a better return on investment, thanks to fewer replacements and energy savings. One common feature of CFL and LED lamps is their nonlinear nature, which injects higher-order current harmonics into the power grid [6].

One characteristic of LED technology is the efficient regulation of light flux through dimming the light sources. The versatility of LED technology is also evident in its integration with smart lighting systems.

Several dimming methods are used for LED bulbs. The most common household method is phase-shifting, which effectively adjusts the bulb's brightness. Another widely used technique is pulse-width modulation (PWM), which is often found in various electronic devices. The third most common method is analogue dimming, which works by reducing the current supplied to the LED. LED dimmers - especially those with phase-shifting - increase harmonic distortion on the electrical network by chopping the current into sharp pulses, increasing low-order and high-frequency harmonics, especially at low brightness levels [7].

In this paper, the impact of changing the lighting with single-phase dimmers and a DC-controlled driver on the quality of electricity will be analysed. The manuscript is organised as follows: in the second section, the influence of higher harmonics on the power grid will be briefly elaborated. In the third section, the measurement apparatus used in this research will be described. The measurement results regarding single-phase-shift dimmers and an LED driver controlled by a DC source will be presented in detail in the fourth section. The fifth section concludes this manuscript.

II. THE INFLUENCE OF HIGHER HARMONICS

LED dimmers, as electronic loads, significantly affect the quality of electrical power by generating higher harmonic currents [7]. This causes the voltage waveform to

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remain almost unchanged, while the current waveform deviates considerably from a simple periodic waveform. From the power grid side, the relationship between current and voltage becomes nonlinear, classifying dimmers as nonlinear loads. If many nonlinear loads in the power grid emit higher-harmonic currents, the voltage waveform will also change due to the small but finite grid impedance. Higher harmonics interfere with other devices sharing the same power source [8]. As the number of nonlinear loads increases, this problem becomes more severe, potentially causing damage. Additionally, in a three-phase system in which the phases are equally loaded, the fundamental harmonics of the phase currents cancel out in the neutral conductor. However, odd harmonics that are multiples of three add up, leading to overheating of the neutral conductor, increased losses in the iron and windings of distribution transformers, and increased transformer noise [9].

In linear circuits with linear loads, currents and voltages are sinusoidal, and the power factor depends mainly on the phase difference between them. However, for non-linear loads, additional harmonic-related factors must be included in the power calculations. The power factor can then be expanded to the total or true power factor, in which the apparent power accounts for all harmonic components. The quantitative parameter that characterises the influence of higher current harmonics is THDI, which is calculated as:

$$THDI = \sqrt{\sum_{k=2}^{\infty} \left(\frac{I_k}{I_1} \right)^2} [\%]. \quad (1)$$

TABLE I
The IEEE519-1992 standard current harmonics limits [%]

I_{SC}/I_L	Harmonic order					THDI [%]
	$2 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	
<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

Industry standards set minimum power factor limits. The IEEE519-1992 standard prescribes harmonic current limits, summarised in Table I. The total permissible harmonic current distortion is in the range of 5% to 20%, depending on the ratio of the short-circuit current I_{SC} to the rated current I_L of the load at the connection point [10].

III. MEASUREMENT INSTRUMENTATION

To measure the impact of regulating the luminous flux of indoor LED lamps on current harmonic emissions, a

system for analysing nonlinear consumers in the power grid based on the concept of virtual instrumentation was used [11]. The measurement and calculation of electrical quantities are performed using a measurement setup comprising signal-acquisition modules and software support in the form of a virtual instrument.

The acquisition subsystem handles the acquisition and conditioning of electrical quantities. It connects to the power grid on one side, supplies power to the load, and samples voltage and current signals (Fig. 1). The modules responsible for signal conditioning ensure attenuation, isolation, and anti-aliasing of the voltage and current waveforms.

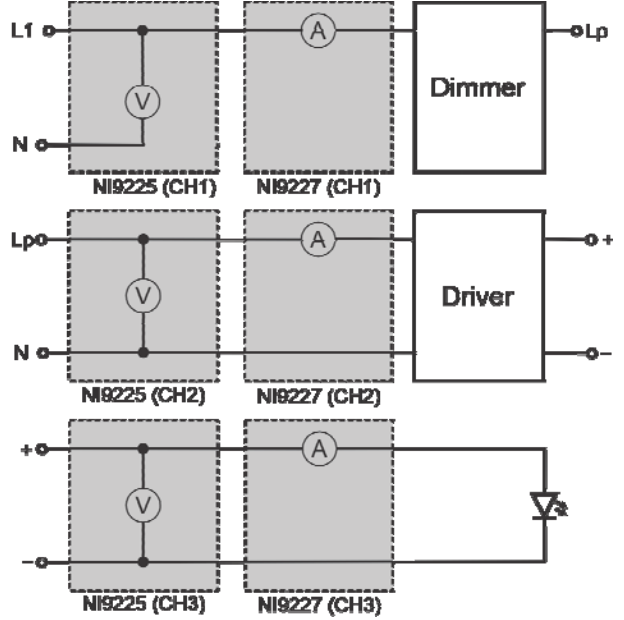


Fig. 1. Connection diagram. The dimmer is connected to the power grid (L1), and the first acquisition channel (CH1) is used to measure harmonics emitted into the power grid.

The acquisition uses a National Instruments cDAQ-9714 expansion chassis, which supports hot-swappable modules. This chassis contains two data acquisition modules: NI9225 and NI9227. It connects to a PC running a virtual instrument via a USB interface. The NI9225 features three channels of simultaneously sampled voltage inputs with 24-bit accuracy, a sampling rate of 50kSa/s per channel, and 600V_{RMS} channel-to-earth isolation, making it suitable for voltage measurements up to the 100th harmonic. Its 300 V_{RMS} range supports line-to-neutral measurements of 240V. The NI9227 is a four-channel input module with 24-bit accuracy, a 50 kSa/s sampling rate per channel, and is designed to measure 5 ARMS nominal and up to 14 A peaks on each channel, with 250V_{RMS} channel-to-channel isolation. In this application, three channels were used for current and voltage acquisition: the first on the AC side between the power grid and the dimmer, the second

between the dimmer and the LED driver, and the third for DC measurement (Fig. 1).

The virtual instrument is built using the National Instruments LabVIEW development environment (Fig. 2), which enables efficient development. These instruments include an interface to the acquisition module and an application with a graphical user interface.

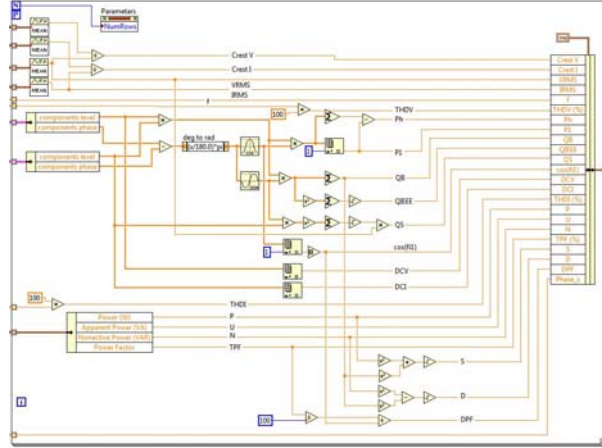


Fig. 2. A part of the LabVIEW graphic code for parameter calculation

The interface to the acquisition module is implemented as a device driver. The cDAQ-9714 expansion chassis and NI9225/NI9227 acquisition modules are supported by NIDAQmx drivers. All measurements are conducted using virtual channels, which are groups of property settings that may include a name, a physical channel, input terminal connections, measurement or generation type, and scaling info. A physical channel is a terminal at which an analogue signal can be measured or generated. Virtual channels can be configured either globally at the system level or via the application interface within the program. Each physical channel on a device has a unique name.

To enhance performance, the main application has been divided into two threads. The first thread handles file operations and saves measured values in an Excel file format. The virtual instrument's user interface features visual indicators and offers advanced measurement functions. All measured values are displayed in a table and saved to an appropriate file after measurement. The interface also includes controls for data manipulation and saving the measured values.

IV. Measurement results

Harmonic current distortion measurements were conducted for two LED drivers. LED lamps are designed to work with 48 Vdc. In the first driver case, three types of phase dimmers: Hager (Table II and Fig. 3), Elgro (Table III and Fig. 4), and Metalka (Table IV and Fig. 5) were

used, along with light intensity regulation via a DC source (1 V to 10 V) for both drivers (Table V, Fig. 6 and Table VI, Fig. 7). The measurements were carried out at a mains voltage of 230V, with a THDV of 3.35%.

Measured data have shown that different phase dimmers, Tables II, III and IV, as well as Figures 3, 4 and 5, could dim an LED lamp to different low levels. For example, the Hager dimmer could dim the LED driver to up to 30.7 V. In contrast, the Elgro could dim it to up to 33.4 V. Metalka dimmed it to up to 33.9 V. The THDI levels are higher when the LED driver is dimmed, decreasing as power increases and voltage reaches the maximum of 48 Vdc. The data also shows that THDI differs for each phase dimmer at the same power, i.e. the same dimmer output DC voltage.

TABLE II

Measured parameters for first LED driver with Hager dimmer: current total harmonic distortion (THDI), AC active power (P), and DC voltage (Vdc)

Dimmer position	THDI [%]	P [W]	Vdc [V]
1	421.6832	1.462134	30.74974
2	409.6983	1.682479	31.47631
3	350.6945	3.847405	32.69118
4	296.0339	9.847667	33.82438
5	265.0927	21.78522	35.19331
6	247.7206	41.97672	36.95475
7	236.2693	71.67507	39.17138
8	231.6427	81.68455	43.30871
9	226.9354	91.391	46.85273
10	135.3517	91.59622	47.91995

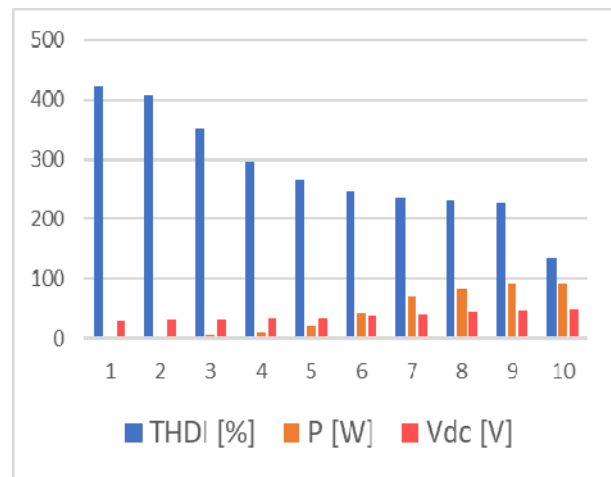


Fig. 3. Measured parameters for first LED driver with Hager dimmer: current total harmonic distortion (THDI), AC active power (P), and DC voltage (Vdc)

TABLE III

Measured parameters for first LED driver with Elgro dimmer: current total harmonic distortion (THDI), AC active power (P), and DC voltage (Vdc)

Dimmer position	THDI [%]	P [W]	Vdc [V]
1	360.23601	9.036604	33.428038
2	273.63445	11.875949	33.841125
3	252.86245	24.219281	35.200585
4	244.42732	46.092964	37.05506
5	236.19941	74.420534	39.362125
6	233.1026	84.172143	43.560784
7	229.62304	91.133947	46.108529
8	103.68131	92.038128	47.921339

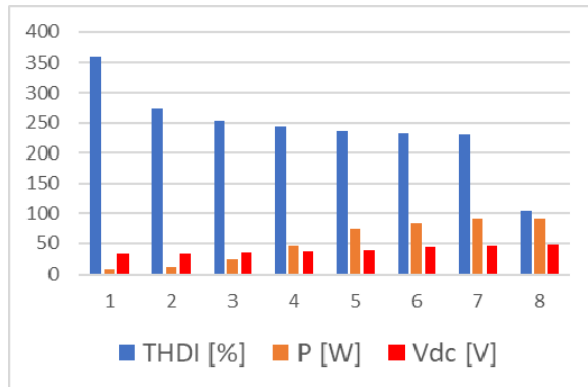


Fig. 4. Measured parameters for first LED driver with Elgro dimmer: current total harmonic distortion (THDI), AC active power (P), and DC voltage (Vdc)

TABLE IV

Measured parameters for first LED driver with Metalka dimmer: current total harmonic distortion (THDI), AC active power (P), and DC voltage (Vdc)

Dimmer position	THDI [%]	P [W]	Vdc [V]
1	301.42692	12.661151	33.975571
2	273.37319	24.368249	35.254693
3	256.31598	44.573819	36.975548
4	244.09647	70.83566	38.890333
5	239.32759	81.687742	43.060701
6	234.74606	89.615591	46.084688
7	176.85041	93.498857	47.920969

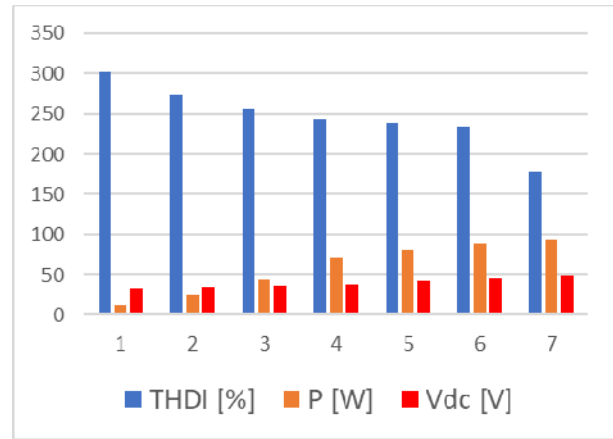


Fig. 5. Measured parameters for first LED driver with Metalka dimmer: current total harmonic distortion (THDI), AC active power (P), and DC voltage (Vdc)

Table V and Figure 6 show the results for dimming the same LED driver with dimming voltages of 1 to 10 V, which is also dimmed with phase dimmers. The lowest dimmed level is the same as that reached with the Hager dimmer and is 30.7 V. The THDI at low-voltage levels is much better than the results obtained with phase dimmers. At maximum power (i.e., DC voltage), THDI is almost the same as with some phase dimmers. The second LED driver that can be dimmed only with 1 to 10 V shows much better THDI characteristics. It could not have produced a DC voltage as low as the first one (30 Vdc), since its minimum is 33.8 Vdc, but the THDI is up to 10 times lower than the first one.

TABLE V

Measured parameters for the first LED driver regulated using a DC voltage source, voltage range 1V – 10V: current total harmonic distortion (THDI), AC active power (P), and DC voltage (Vdc)

LED driver dimming input voltage	THDI [%]	P [W]	Vdc [V]
1	236.49753	2.020544	30.743047
2	218.85188	2.257764	31.470705
3	161.78047	4.108063	32.624303
4	124.46427	9.678429	33.773837
5	102.58714	20.991113	35.174579
6	104.1749	40.21687	36.9727
7	110.4835	69.362088	39.366858
8	114.53186	78.436431	43.321817
9	113.95999	88.739288	47.153908
10	116.94885	90.813224	47.903157

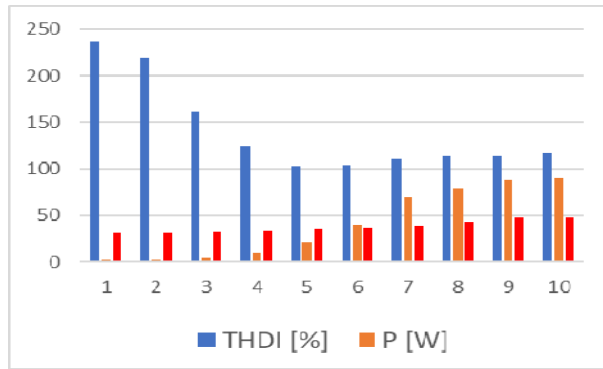


Fig. 6. Measured parameters for the first LED driver regulated using a DC voltage source, voltage range 1V – 10V: current total harmonic distortion (THDI), AC active power (P), and DC voltage (Vdc)

TABLE VI
Measured parameters for the second LED driver regulated using a DC voltage source, voltage range 1V – 10V: current total harmonic distortion (THDI), AC active power (P), and DC voltage (Vdc)

LED driver dimming input voltage	THDI [%]	P [W]	Vdc [V]
1	101.44979	9.261396	33.882552
2	33.413078	19.397303	34.904292
3	27.205302	27.855875	35.7635
4	22.576161	35.956902	36.556301
5	19.428005	44.837515	37.322966
6	16.650518	54.111311	38.040522
7	14.082471	63.582656	38.7435
8	10.891673	87.934312	47.387669
9	10.717613	89.745142	47.994337
10	10.697515	89.707852	47.993866

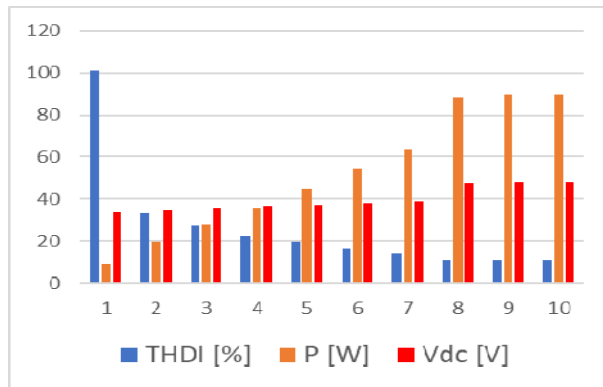


Fig. 7. Measured parameters for the second LED driver regulated using a DC voltage source, voltage range 1V – 10V: current total harmonic distortion (THDI), AC active power (P), and DC voltage (Vdc)

IV. CONCLUSION

This paper presents measurements of current harmonic distortion in LED drivers across different dimming levels. Two dimming techniques were used: phase dimmers and direct DC voltage regulation. Measurements show that current distortion (THDI) is significantly higher with phase dimmers than with DC voltage regulation at the same light intensity. As light intensity increases, THDI decreases monotonically. The reduction in harmonic distortion with increasing light intensity is more pronounced with DC voltage regulation.

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