Bibliometric review of the analysis of harmonic losses in public lighting systems

Revisión bibliométrica del análisis de pérdidas armónicas en sistemas de alumbrado público

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ABSTRACT

Electricity supply is fundamental for modern society's existence and development, directly impacting health, safety, education, comfort, and other technological applications. One of the important applications of electric energy is lighting, which allows society to make nights even more productive during the day. With the development of LED technology and a significant increase in luminous efficiency, public lighting has undergone a major transformation and replacement of the technology of High-Intensity Discharge (HID) technology. As it is a switched source, this technology is a type of non-linear load, which raises concerns regarding the impacts of harmonic distortions, which can harm equipment connected to the network and cause power losses. In this way, the present study carried out bibliographic research about the losses of electric energy resulting from the incidence of harmonics in the electrical system through the dissemination of the application of LED technology in the public lighting system, using the materials already prepared and published. In this context, this article aims to research studies on harmonic distortions in the public lighting system to identify gaps and research opportunities. For this purpose, a bibliometric literature review was carried out in the SCOPUS database. Among the results obtained, it was found that harmonic distortions in LED are helpful for research and that there has been an increase in studies focused on the theme over the last 10 years. The present work also showed that there are research gaps to be developed.

Keywords: Harmonics, LED technology, power quality, lighting.

RESUMEN

El suministro de electricidad es fundamental para la existencia y el desarrollo de la sociedad moderna, afectando directamente a la salud, la seguridad, la educación, la comodidad y otras aplicaciones tecnológicas. Una de las aplicaciones importantes de la energía eléctrica es la iluminación, que permite a la sociedad hacer las noches aún más productivas en términos de día. Con el desarrollo de la tecnología LED, y un aumento significativo de la eficiencia luminosa, el alumbrado público ha experimentado una importante transformación y sustitución de la tecnología de descarga de alta intensidad (HID).

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Como es una fuente conmutada, esta tecnología es un tipo de carga no lineal, lo que plantea preocupaciones con respecto a los impactos de las distorsiones armónicas, que pueden dañar los equipos conectados a la red y causar pérdidas de energía. De esta forma, el presente estudio llevó a cabo una investigación bibliográfica sobre las pérdidas de energía eléctrica derivadas de la incidencia de armónicos en el sistema eléctrico a través de la difusión de la aplicación de la tecnología LED en el sistema de alumbrado público, utilizando los materiales ya preparados y publicados. En este contexto, el objetivo de este artículo es investigar estudios sobre distorsiones armónicas en el sistema de alumbrado público, con el fin de identificar lagunas y oportunidades de investigación. Para ello, se llevó a cabo una revisión bibliométrica de la literatura en la base de datos SCOPUS. Entre los resultados obtenidos, se encontró que las distorsiones armónicas en el LED son útiles para la investigación, y que ha habido un aumento en los estudios en los últimos 10 años centrados en el tema. El trabajo actual también demostró que hay lagunas de investigación que desarrollar.

Palabras clave: Armónicos, tecnología LED, calidad de potencia, iluminación.

INTRODUCTION

The concern of today's society at reducing CO_2 emissions is a reality worldwide to minimize the effects of climate change and the intensification of the Greenhouse effect. One of the ways to reduce these emissions is by using more energy-efficient technologies, as they can perform the same useful work with lower power demand, reducing energy consumption.

In the last 20 years, the lighting industry has undergone a significant transformation in the use of LED technology, compared to what happened with the emergence of Thomas Edison's incandescent lamp in 1879. Compared to conventional technologies, more efficient, more durable, and non-mercurial products are available in the Brazilian market.

According to the National Energy Plan (PNE), prepared by the Ministry of Mines and Energy (MME), some measures adopted to contain energy inefficiency replacing more efficient technologies and the best organization, conservation, and management of the use of energy. Setting a target of a 10% reduction in energy consumption by 2030 [1].

The Brazilian public lighting park has approximately 13 million registered points, which are fully energized at peak hours, according to data from Eletrobrás, representing 4.5% of peak demand, 2.2GW, and 3.5% of energy consumption [2].

Given the profile of Public Lighting consumption and the growing application of LED technology, there is a potential to reduce cutting-edge demand and energy consumption. On the other hand, when replacing conventional technology, electromagnetic reactors, for LED drivers, there is an increase in harmonic currents in the electrical network, which should be studied for a better analysis of the energy impact of this technology.

For the development of this research, seeking a systematic review and bibliometric analysis, we follow the guidance of Ferenhof and Fernandes' model, which identifies the phases with their respective set of phases and activities of systematization and scientific production of a given theme [3].

Problem formulation

A. Research methodology

This research was developed from the selection of a bibliographic collection, followed by a systematic review and bibliometric analysis using the models proposed by Ferenhof and Fernandes [3].

The research was carried out with journals indexed in the Scopus® database as it is an extensivedatabase in the engineering area, allowing an updated, multidisciplinary view and composed of relevant sources for bibliographic research systematically.

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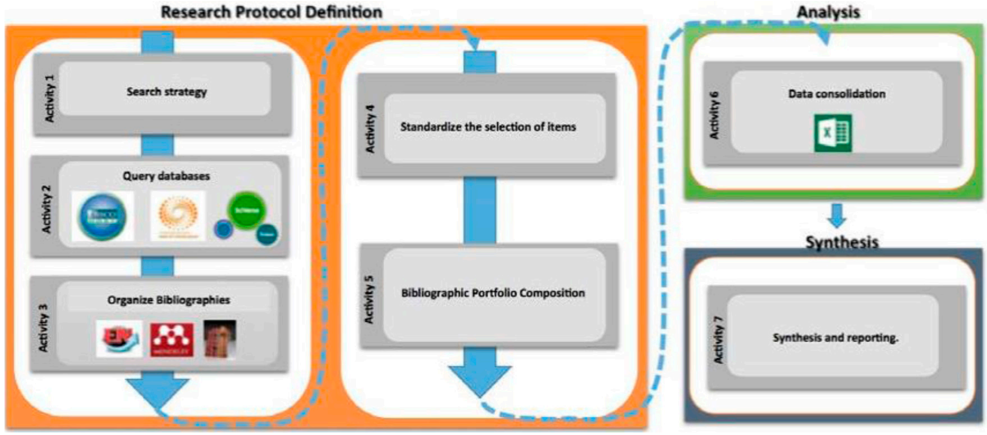
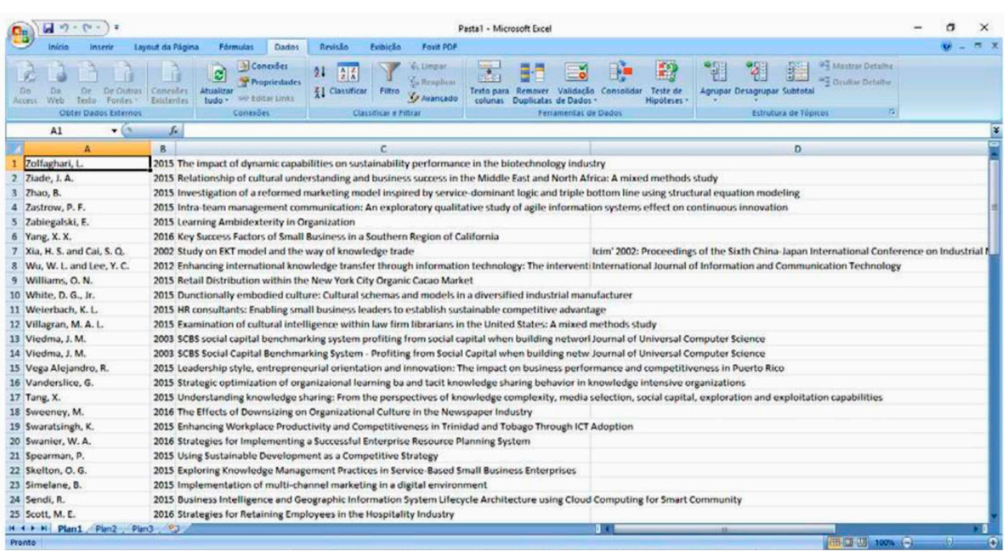


Figure 1. Phases and activities of systematic and bibliometric review [3].

According to these authors, a systematic and bibliometric review begins with the "Definition of the Research Protocol," phase 1, which is the elaboration of a set of rules and sequences, being:

- Activity 1 - definition of the search strategy;
- Activity 2 - consultation in databases;
- Activity 3 - organization of retrieved bibliographic material;
- Activity 4 - standardizing the selection of articles, selecting those that are in line with the search theme;
- Activity 5 - Composition of the portfolio of articles; in this phase, the complete analysis of the articles is carried out, observing the fulfillment of the verification or investigation.

Phase 2, called "Analysis," is where the compilation of the previous phase takes place, using the criteria of bibliometrics, with the combination of data (articles, journals, and authors most cited and the year with the most substantial number of publications). Therefore, all selected studies are available in a spreadsheet that can be organized differently. Figure 2 presents an example of a type of study organization. Additionally, the user can organize according to each study's keyword and perform quantitative analyzes of studies with personalized



	A	B	C	D
1	Zolfaghari, L.	2015	The impact of dynamic capabilities on sustainability performance in the biotechnology industry	
2	Ziade, J. A.	2015	Relationship of cultural understanding and business success in the Middle East and North Africa: A mixed methods study	
3	Zhao, B.	2015	Investigation of a reformed marketing model inspired by service-dominant logic and triple bottom line using structural equation modeling	
4	Zastrow, P. F.	2015	Intra-team management communication: An exploratory qualitative study of agile information systems effect on continuous innovation	
5	Zabiegalski, E.	2015	Learning Ambidexterity in Organization	
6	Yang, X. X.	2016	Key Success Factors of Small Business in a Southern Region of California	
7	Xia, H. S. and Cai, S. Q.	2002	Study on EKT model and the way of knowledge trade	Icim' 2002: Proceedings of the Sixth China-Japan International Conference on Industrial
8	Wu, W. L. and Lee, Y. C.	2012	Enhancing international knowledge transfer through information technology: The interventi	International Journal of Information and Communication Technology
9	Williams, O. N.	2015	Retail Distribution within the New York City Organic Cacao Market	
10	White, D. G., Jr.	2015	Dunctionally embodied culture: Cultural schemas and models in a diversified industrial manufacturer	
11	Weierbach, K. L.	2015	HR consultants: Enabling small business leaders to establish sustainable competitive advantage	
12	Villagran, M. A. L.	2015	Examination of cultural intelligence within law firm librarians in the United States: A mixed methods study	
13	Viedma, J. M.	2003	SCBS social capital benchmarking system profiting from social capital when building networl	Journal of Universal Computer Science
14	Viedma, J. M.	2003	SCBS Social Capital Benchmarking System - Profiting from Social Capital when building netw	Journal of Universal Computer Science
15	Vega Alejandro, R.	2015	Leadership style, entrepreneurial orientation and innovation: The impact on business performance and competitiveness in Puerto Rico	
16	Vanderslice, G.	2015	Strategic optimization of organizaional learning ba and tacit knowledge sharing behavior in knowledge intensive organizations	
17	Tang, X.	2015	Understanding knowledge sharing: From the perspectives of knowledge complexity, media selection, social capital, exploration and exploitation capabilities	
18	Sweeney, M.	2016	The Effects of Downsizing on Organizational Culture in the Newspaper Industry	
19	Swaratsingh, K.	2015	Enhancing Workplace Productivity and Competitiveness in Trinidad and Tobago Through ICT Adoption	
20	Swanier, W. A.	2016	Strategies for Implementing a Successful Enterprise Resource Planning System	
21	Spearman, P.	2015	Using Sustainable Development as a Competitive Strategy	
22	Skelton, O. G.	2015	Exploring Knowledge Management Practices in Service-Based Small Business Enterprises	
23	Simelane, B.	2015	Implementation of multi-channel marketing in a digital environment	
24	Sendi, R.	2015	Business Intelligence and Geographic Information System Lifecycle Architecture using Cloud Computing for Smart Community	
25	Scott, M. E.	2016	Strategies for Retaining Employees in the Hospitality Industry	

Figure 2. Demonstration of data consolidation.

filters. This tool was used in this study and will be presented later [3].

In phase 3, called "Synthesis," there is the elaboration of reports and bibliometric evaluation of all selected studies. Therefore, at this stage of the methodology, the author can prepare chronological data for a given filter and know the number of studies each author prepares for the particular topic sought [3].

B. Selection and articles analysis

A sequence of steps was used to select the material for the literature review on harmonic losses in LED street lighting technology, as described below:

– 1st Step: Choosing the database - We opted for the SCOPUS database because the main objective of the research is to know the evolution and the state of the art on harmonic losses in lighting in a more way.

– 2nd Step: Choice of keywords and research period - The search in the database from 2005 to 2021. Even though the idea of the research is to find the most recent works, it is also an objective to analyze the evolution of the theme over the years from 2000 to 2020. Initially, the keyword used was "harmonic distortion," limiting itself only to the search for articles, and 11,530 works were found.

  Adding the term "LED" to this research, the volume of articles was reduced to 347 papers, as shown in Figure 3.

  A growing number of publications from 2011 on harmonic distortions in LED, shown in Figure 2, justify a study in this area.

  Still, within this analysis, it was found that India, China, and Taiwan are the countries that published the most about the terms searched, which is not surprising since they are prominent manufacturers of LED lamps and lamps. Figure 4 shows the countries that published the most during the analyzed period.

  The authors who published the most were the Indian Singh, B, with 15 publications, followed by Shrivastava, with 10 works. Figure 5 shows the authors who have published the most on the subject of this research.

– 3rd Step: As the idea of the article is to elaborate an analysis of the harmonic distortions in the LED technology for public lighting, the ''keyword'' filter was used, keeping the articles with the keywords Light Emitting Diodes and Harmonic analysis, reducing to 100 and 60 works respectively, leaving a total of 160 articles.

– 4th Step: Selection of articles, the title and abstract of each of the 160 works were read after 84 articles were selected that most resembled the theme that was proposed to be studied.

– 5th Step: Specific analysis - The 84 selected articles were studied minutely. The analyzed criteria include: Objective of the research; type of research (empirical or theoretical); level of

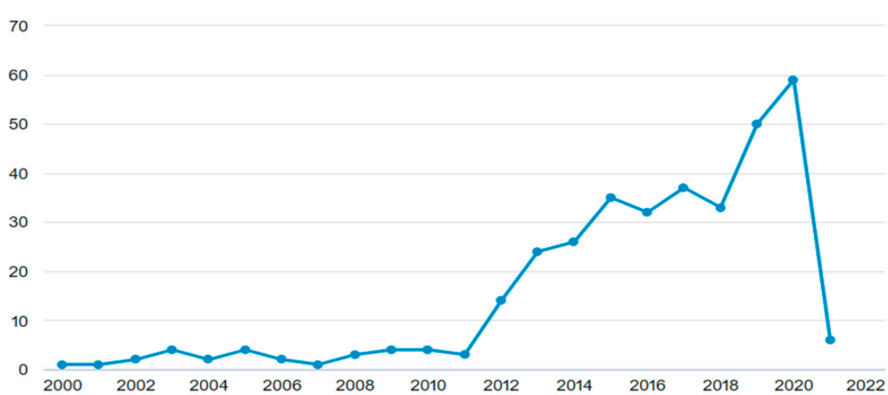


Figure 3. Published articles on harmonic distortions in LED.

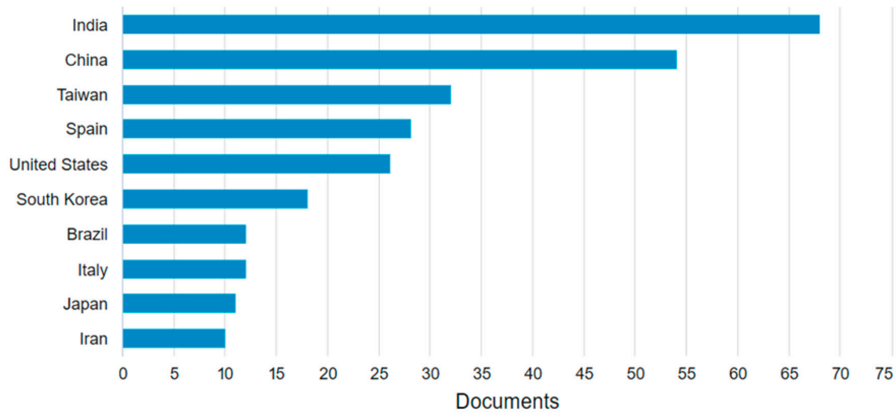


Figure 4. Articles published by countries.

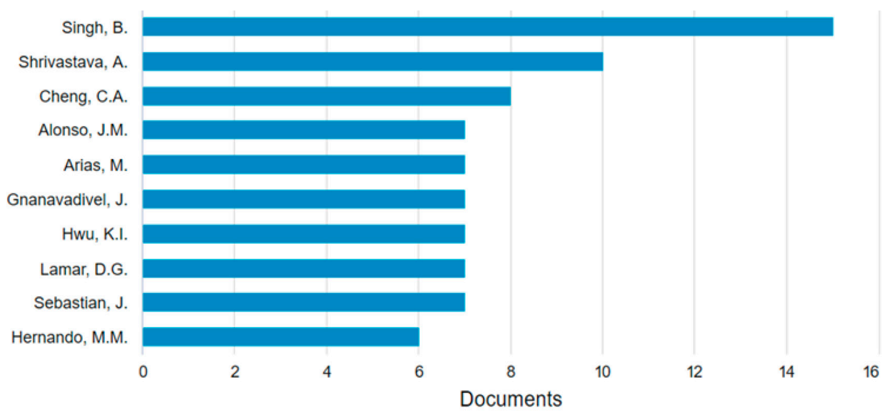


Figure 5. Authors with more publications.

analysis (individual, group, organization, inter-organizational); research method (qualitative, quantitative);

– 6th Step: Understanding the sources of journals, fields of study, and authors who most published in the selected articles - The objective of this phase is to know which journals, fields of study, and authors have published the most within the scope selected for the bibliometric review.

When carrying out a more in-depth analysis of the publications used in the present study, it appears that there are many studies aimed at harmonic distortions in LED technology in some international journals, such as the publication Lighting Research & Technology, which is the magazine that has published the most on the topic compared to the others.

CASE STUDY

After carrying out the previous steps, this session presents a deeper analysis of the works found on distortions or harmonic losses in LED technology.

The theoretical framework of the selected articles

Davidovic [4] wrote a paper on harmonic voltage distortions in installing LED street lights. Twopower quality problems are considered: voltage distortion and voltage drop along the line of different electrical installations. The research includes three parts: (1) development of a new model and the corresponding software for calculating voltage harmonics in three-phase LED public lighting installations, where the load is non-symmetrical and non-linear. The model is based on applying symmetrical components and the phase impedance model. (2) Experiments in two sections of a pilot public lighting installation, one with 6 poles at neutral white and the other at 5 warm white LED luminaires (the former were conventional drivers, and the latter improved drivers concerning harmonic emissions). Its results were used to define the LED luminaires' harmonic characteristics and validate the model. (3) The software developed was applied to four typical public (road) lighting installations, two with a single side and two with a central pole layout. The main result was the determination of the maximum allowed number of LED luminaires that can be connected to the power cable without exceeding any of the limits related to voltage drop, total voltage harmonic distortion, and individual voltage harmonic in total public lighting regimes or reduced [4].

This article on the design of electronic drivers at the University of Catania [5], in Italy investigated the different problems related to the input current distortion in a QR flyback LED driver. Various effects, such as distortion caused by the pacing current, distortion due to transformer leakage current, and distortion due to the input storage capacitor, have been experimentally reported and have resulted in some practical guidelines for designing a QR Hi-PF flyback driver.

In this research, Djuretic [6] applies dimerization scenarios, where more significant gains in energy savings can be achieved by an LED luminaire when compared to a high-pressure sodium luminaire corresponding to the installation. However, both field experiments showed that the tested LED drivers (standard or dimmed characteristics) have the disadvantage of low power factors (up to 0.67) at lower light levels. Furthermore, a higher presence of current harmonics and high values of total harmonic distortion was observed at low light intensity levels, representing another disadvantage of LED technology concerning power quality. The relevant electrical characteristics of the commonly used LED drivers have been analyzed in detail, and the reasons for the low power quality have been identified. A new generation of LED drivers with a considerably narrower input voltage (AC) range will allow acceptable power factors and limited current harmonic emissions to be achieved in virtually any scope of light intensity [6].

In this article on smart luminaires, [7] the application of LED technology to replace conventional HID technology resulted in 19-44% savings. By incorporating intelligent control via integrated wireless sensors based on pedestrian flow, these savings varied between 40-60%.

In this research, Wisniewski [8] analyzed the effective energy savings in LED technology according to the variation of the luminous flux through the dimerization process. However, before establishing the process of luminous flux variation , the author evidenced the importance of analyzing the energy savings expected for the method and the negative consequences provided by the network. Therefore, the author proposed two different methods. The first method establishes a linear relationship between the power of the sample and the luminous flux. The first proposed method has been tested by considering two lines. The theoretical line, being considered two extreme points, nominal power and nominal luminous flux, minimum power, and minimum luminous flux, understands the first straight line. The second line is comprised of the variation of the luminous flux and the power measurement for the respective luminous flux. The author concluded that the method indicated a high variation in the measured and theoretical power; therefore, it is an unsuitablemethod for analyzing energy savings.

The second method proposed by the author is based on analyzing energy savings using the DIALux software. The luminous flux was measured at some points in a real room, and the average of the values was entered into DIALux to test the method.The author concluded that the simulation in the software is a valid method for analyzing energy savings in processes of variation of the luminous flux.

The author [8] also concluded that the energy-saving process results in an increase in the harmonic distortion of current and a reduction in the power factor, according to the reduction of the luminous flux. Therefore, an analysis of the established economy and the consequences of the process was recommended to reach a viability conclusion [8].

Fonseca in [9] proposed a controller topology for LED lamps that is different from the usual ones today. The author used a single stage based on boost or buck-boost converters to test this study. The single stage is intended for power factor correction of the LED lamp. At the proposed topology, analyzing the results presented by the author, the level of current harmonic distortion and power factor was 15% and 0.98, respectively, considering nominal power. However, by reducing the output power to 30% of the nominal, the current harmonic distortion and power factor level were 60% and 0.85, respectively. However, the author characterized the project as feasible because the topology, operating at nominal power, met the limits imposed in Class C of IEE Standard 61000-3-2 [9].

This article [10] presents another topology for the converter in which it is commonly used. Defined as a fully integrated buck and boost converter, the controller has an inductor coupled to a core, resulting in a magnetic integration between the two converters. The work presents performance results considering the converters coupled with inductors in two separate cores and the integration with the inductor in 1 core only. Analyzing the results presented by the author, the converter with an integrated core presented a power factor of 0.994 and a current distortion of 10%, considering an output power of 100% of the nominal. The power factor is reduced to 0.82 when operating at 10% of the rated output power; however, the distortion level for this operating condition was not reported. Therefore, the author concluded that the converter with an integrated core presented better power factor performance, efficiency, and harmonic distortion concerning the converter with two separate cores.

In this work, [11] the author describes the operation of a smooth switching converter for LED luminaires. The author implemented a totem-pole bridgeless boost (TPBB) converter with power-factor correction (PFC) and a half-bridge series resonant converter with a bridge rectifier in a single-stage energy conversion circuit. Applying the circuit proposed by the author in a luminaire at a power of 165 W, the results obtained were 0.985 and 7.68% for power factor and harmonic current distortion, respectively. Thus, the author concluded that the project presents satisfactory performance results, in compliance with Standard 61000-3-2, a high power factor, and emphasizes that it is cost-effective, as it has fewer number of components and a more compact circuit.

Yoomak [12] proposed the concept of improving conventional road lighting systems using LED technologies and solar energy applications, known as a ‘‘nanogrid road lighting system’’. Economic comparisons were made for three types of road lighting systems, namely: high-pressure sodium systems powered by the grid, autonomous solar LED, and nanowires are compared in terms of their individual discounted payback period (DPP), net present value (NPV) and internal rate of return (IRR). The results show that, the system can effectively charge its batteries in autonomous mode by controlling the maximum power point (MPPT) and discharge energy to provide the road lighting system. In the grid-connected mode, the electrical energy produced from the solar energy system can be supplied to the electrical network in all ranges of solar irradiance levels by the MPPT control. However, a high total current harmonic distortion (THDi) flows into the mains when the solar irradiance levels are low. Solar lighting systems on roads installed in a central system have a low initial investment cost, resulting in better performance (regarding DPP, IRR, and NPV); consequently, using road lighting systems with nanogrid shows satisfactory feasibility in terms of energy quality and economic performance.

The research proposed by Sohel [13] consists of developing a simulation model in LED lamps to analyze the impact on the distribution network arising from the consumption of the product on a large scale. The author established 4 scenarios that partially change the lighting technology to analyze the level of harmonic voltage distortion in the distribution system. By comparison, it was found that the time-dependent current signal model could be used for large-scale consumption. The author established 4 scenarios that partially change the lighting technology to analyze the level of harmonic voltage distortion in the distribution system. In the first scenario, using only incandescent lamps for lighting, the maximum distortion level was 3.8%, comparing the 3 phases in the transformer. In the second scenario, half of the lighting load was replaced by an LED lamp, resulting in a 6.8% distortion also in phase A. Replacing 80% with an LED lamp (scenario 3), the level of distortion increased in all phases, where the maximum distortion recorded was 8.5% and exceeded the limit established by the IEC. In scenario 4, the entire lighting load was replaced by LED; thus, the level of distortion increased to 11.74%. Finally, the LED lighting was mixed with 4 different lamp models, where the difference consists of the type of filter used. In this scenario, using different topologies, the level of distortion decreased to 9.75%, but still higher than 8%. As a result, the author concluded that the increase in LED technology results in a higher level of harmonic distortion of voltage exceeding the limit imposed by Norma and, consequently, an increased level of harmonic loss in transformers.

Singh [14], in his study, analyzed the impact of harmonic voltage distortion on different topologies of LED lamp controllers. The author selected 3 types of topologies to support the analysis of the effect of the high switching frequency of the controllers. Using different operating conditions, analyzed the average light power and the modulation of the light power. Thus, three input waveforms were tested, and the aim was to analyze the controller's behavior in each situation. The first waveform is the supply of the local network's own, the second waveform is a spectrum obtained in an establishment containing cumbersome machinery, that is, containing harmonic components, and the third waveform consists of a spectrum obtained in a commercial establishment. In this way, the author submitted the 3 (three) waveforms mentioned above in the selected samples and, considering the photometric scintillation, concluded that no indicated topology presented immunity to distortion. Therefore, the results showed oscillations in the average light output and the light output modulation, characterizing a reduction in the controller's efficiency.

The work developed by Ronnberg [15] consists of a massive survey of the understanding and challenges of research regarding supra-harmonics. The author has prepared a work with an extensive bibliography on the subject in which they can help in the unfolding of the subject. In view of this, the article brings problems already reported on network modeling to seek an understanding of how to propagate interference at high frequency. The author presented some sources of interference emission and the corresponding emission frequency range. However, it was clear that the main sources of emission are electronic power converters with active or passive switching, and power line communication transmitters, used for measurement. The article also describes the guidelines for developing high-frequency component measuring equipment, equipment with better measurement accuracy for a wide frequency range, and filter application instructions to avoid measurement errors due to the effect of aliasing. Thus, the author concluded that there is currently a voluminous amount of published material, serving to understand and assist in the unfolding and understanding of emission and modeling of high-frequency sources.

In [16], the authors proposed a single-stage driver with coupled inductors for LEDs used in public lighting. The work presents a dual buck-boost controller with power factor correction, coupled inductors, and a half-bridge resonant DC-DC converter [16]. The work concluded that the controller reduces the switching effect and presents satisfactory electrical and photoelectric results. The sample achieved a minimum efficiency of 89.5%, a low harmonic distortion index (around 5.55%), and a power factor close to 99% by varying the input voltage between 100 and 120 V [16].

Chen [17] proposed some types of topology for LED drivers using passive components in his research. Adittionally, the presented topologies do not use controlled switches, which are one of the leading causes of harmonic distortion. Therefore, this works aims to evaluate the electrical and photoelectric parameters of each driver considering the same LED configuration and stabilized power supply [17].

The first proposed topology consists of a passive driver with power factor correction (standard valley-fill circuit), and the presented results were satisfactory according to the normative limits. However, this type of topology presented a ripple voltage level of around 100V [17].

The author proposed the second topology, based on a modified valley-fill circuit, to reduce the ripple voltage. This circuit reduced the level to approximately 65V of ripple voltage. This type of topology presented a third-order harmonic level approximately three times that of the previous topology. However, the luminous efficiency exceeded 93% [17].

The third topology uses a small parallel capacitor as a filter to reduce the distortion level at the output of the rectification stage. Logically, the ripple level was reduced to approximately 30 V; however, the harmonic content exceeded 12%, considering the third order. Luminous efficiency was also affected, measuring approximately 92.3% [17].

Finally, the last topology uses the first proposed topology and adds a transformer at the output. Therefore, with the filter connected to the secondary transformer, a reduction in ripple current is expected.

This type of circuit presented the worst performance, exceeding 12% of third-order harmonics and luminous efficiency below 92% [17].

The author concluded that considering that the proposed drivers use passive components and do not contain controlled switches, the results presented were satisfactory. Its long service life, low production cost, and good performance in adverse weather conditions were also highlighted [17].

Therefore, the author concluded that considering that the proposed drivers use passive components and do not contain switches, the presented results were satisfactory. The author also cited the long shelf life, low production cost, and good performance against adverse weather conditions [17].

Camponogara in [18] proposed another alternative for LED lighting drivers, and this also consists of the application of the book-bust converter operating in discontinuous mode, as used in [16]. However, Camponogara used a cascade structure, whereas [16] consists of a single stage. The type of topology presented in [18] has as an intrinsic characteristic the reduction of the ripple voltage level; therefore, the control of the variation of the output current is facilitated. In addition, the use of ceramic capacitors stands out. Therefore, the controller is less susceptible to the life problems of electrolytic capacitors and others.

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The work concluded that the prototype presented satisfactory results, with a high power factor, high efficiency, and longevity. The author also mentioned that, due to cost reasons, this application could be expensive for LED lamps; however,it could be a solution for high-power lamps, considering that their controllers represent a small portion compared to the final cost [18].

CONCLUSIONS

The present study sought to present current articles on harmonic distortions applied in LED technology to discover which gaps are open for the elaboration of new research or the deepening of some public research in this area.

Due to the results of the studies found, there is a need for a better investigation of the impacts of harmonic losses in this technology, especially if it is to analyze the complete replacement of an IP system, because in addition to the positive impacts of energy efficiency. There is also an impact on harmonic losses of this type that has yet to be widely explored in the literature; nevertheless, it can lead to significant results, improving the economic analysis of this decision-making. Further studies and more detailed research on the energy impact of harmonic losses in IP systems are needed to provide a more accurate assessment of the economic impact of LED technology.

Therefore, the work concluded that more detailed research is needed on the energy impacts of harmonic losses in IP systems, mainly in the study focused on the economic impact caused by the power quality problems the driver can generate to the distribution system. Therefore, new studies may deepen the analysis of the impact reflected on the distribution system caused by a possible replacement of lighting points on a large scale, i.e., assessing the need to replace transformers or other equipment, for example.

REFERENCES

[1] Ministério de Minas e Energia, “Plano Nacional de eficiência Energética”, Brasília, Brazil 2011.
[2] Eletrobrás - Procel, “Resultados Procel 2018-Ano Base 2017 - Programa Nacional de Conservação de Energia”, 2018.
[3] H.A. Ferenhof and R.F. Fernandes, “Passos para construção da Revisão Sistemática e Bibliometria - utilizando a Ferramenta EndNote®”, *IGC*I, Versão: 03.06, 2017.

[4] M. Davidovic, N. Djordjevic, J. Mikulovic, M. Kostic, and Z. Radakovic, "Voltage distortion in LED street lighting installations," *Electrical Engineering*, 2021, doi: 10.1007/s00202-020-01181-6.

[5] C. Adragna, G. Gritti, A. Raciti, S.A. Rizzo, and G. Susinni, "Analysis of the Input Current Distortion and Guidelines for Designing High Power Factor Quasi-Resonant Flyback LED Drivers," *Energies*, vol. 13, no. 11, 2020, doi: 10.3390/en13112989.

[6] A. Djuretic, V. Skerovic, N. Arsic, and M. Kostic, "Luminous flux to input power ratio, power factor and harmonics when dimming high-pressure sodium and LED luminaires used in road lighting," *Lighting Research & Technology*, vol. 51, no. 2, 2018, doi: 10.1177/1477153518777272.

[7] E. Juntunen *et al.*, "A smart LED luminaire for energy savings in pedestrian road lighting," *Lighting Research & Technology*, vol. 47, pp. 103-115, 2015, doi: 10.1177/1477153513510015.

[8] A. Wisniewski, "Calculations of energy savings using lighting control systems," *Technical Sciences*, vol. 68, no. 4, pp. 809-817, 2020, doi: 10.24425/bpasts.2020.134186.

[9] Z.P. Fonseca, C.B. Nascimento, and A.A. Bandin, "Single-stage PFC bridgeless converter," *Electronics Letters*, vol. 56, pp. 1267-1270, 2020, doi: 10.1049/el.2020.2009.

[10] G.Z. Abdelmessih, J.M. Alonso, M.A.D. Costa, Y.J. Chen, and W.T. Tsai, "Fully Integrated Buck and Boost Converter as a High Efficiency, High-Power-Density Off-Line LED Driver," *IEEE Transactions on power electronics*, vol. 35, no. 11, pp. 12238-12251, 2020, doi: 10.1109/TPEL.2020.2993796.

[11] C.A. Cheng and H.C. Wu, "A cost-effective electronic lighting driver with high-power-factor and soft-switching for supplying an LED street-light lamp," *International Transactions on Electrical Energy Systems*, vol. 31, no. 3, e12801, 2021, doi: 10.1002/2050-7038.12801.

[12] S. Yoomak and A. Ngaopitakkul, "Investigation and Feasibility Evaluation of Using Nanogrid Technology Integrated into Road Lighting System," *IEEE Access*, vol. 8, pp. 56739-56754, 2020, doi: 10.1109/ACCESS.2020.2978897.

[13] S. Uddin, H. Sharef, O. Krause, A. Mohamed, M.A. Hannan, and N.N. Islam, "Impact of large-scale installation of LED lamps in a distribution system," *Turkish Journal of Electrical Engineering and Computer Science*, vol. 23, no. 6, pp. 1769-1780, 2015, doi: 10.3906/elk-1404-243.

[14] G. Singh, E.R. Collins, S.K. Ronnberg, E.O.A. Larsson, and M.H.J. Bollen, "Impact of high frequency conducted voltage disturbances on LED driver circuits," in *2017 IEEE Power & Energy Society General Meeting*, 2017, doi: 10.1109/PESGM.2017.8274378.

[15] S.K. Rönnberg *et al.*, "On waveform distortion in the frequency range 2kHz-150kHz - Review and research challenges," *Electric Power Systems Research*, vol. 150, pp. 1-10, 2017, doi: 10.1016/j.epsr.2017.04.032.

[16] C. Cheng, H. Cheng, and T. Chung, "A novel single-stage high-power-factor LED street-lighting driver with coupled inductors, " *IEEE Transactions on Industry Applications*, vol. 50, no. 5, pp. 3037-3045, 2014, doi: 10.1109/TIA.2014.2304585.

[17] W. Chen, S.N. Li, and S.Y.R. Hui, "A comparative study on the circuit topologies for offline passive light-emitting diode (LED) drivers with long lifetime & high efficiency," in *2010 IEEE Energy Conversion Congress and Exposition*, Atlanta, GA, USA, 2010, pp. 724-730, doi: 10.1109/ECCE.2010.5617934.

[18] D. Camponogara, G.F. Ferreira, A. Campos, M.A.D. Costa, and J. Garcia, "Off-line LED driver for street lighting with an optimized cascade structure," in *2012 IEEE Industry Applications Society Annual Meeting*, Las Vegas, NV, USA, 2012, pp. 1-6, doi: 10.1109/IAS.2012.6374059.