Vol.67: e24230786, 2024
https://doi.org/10.1590/1678-4324-2024230786
ISSN 1678-4324 Online Edition

BABT
Brazilian Archives of Biology and Technology

Review - Engineering, Technology and Techniques

Organic Photovoltaic (OPV) with Electronic Protection System: A Systematic Review

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Editor-in-Chief: Alexandre Rasi Aoki
Associate Editor: Alexandre Rasi Aoki

Received: 10-Aug-2023; Accepted: 08-Jan-2024

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HIGHLIGHTS

- Systematic review identifies research gaps in organic photovoltaics.
- Resourceful foundation for future investigations in organic photovoltaics.
- Collaboration to drive advancements in electronic protection systems for renewable energy.
- Importance of addressing partial shading and I-V curve for efficient organic photovoltaics.

Abstract: This paper presents a systematic review focused on organic photovoltaic cells and their electronic protection systems. Utilizing the Proknow-C methodology, the study constructs a bibliographic portfolio to identify the current state of research in this field. Out of 2,231 papers obtained from major scientific databases, only 14 prove relevant to the theme, highlighting a significant research gap. The paper presents the bibliometric analysis of the selected articles, by citations, periodicals and publications per year, in addition to the systemic analysis of the most relevant articles, serving as a valuable resource for researchers, offering an updated overview and foundation for future investigations in organic photovoltaics. By addressing the identified research gap, researchers can drive advancements in electronic protection systems for organic photovoltaic cells, contributing to the progress of renewable energy technologies.

Keywords: Organic photovoltaics; OPV Protection; Proknow-C; Bibliometric Analysis; Systemic Analisys.

INTRODUCTION

The search for alternative energy generation to meet global demand drives the development of new technologies and processes aimed at increasing generation capacity and reducing losses. The use of fossil fuels, besides contributing to pollution, has a limited lifespan, necessitating the adoption of renewable and sustainable technologies [1]. With growing environmental concerns, climate change, and the global fossil energy crisis, research and development of clean renewable energies have received increased attention. Among renewable energy sources, the sun, as a renewable energy source, is the most abundant for humanity [2]. One of the most widely adopted sustainable technologies currently is the generation of energy from photovoltaic cells.

According to [3], Brazil has surpassed 10 GW (gigawatts) of installed power in solar plants and residences, placing it among the top 15 countries in solar energy production. Several technologies are used to generate energy from sunlight, with crystalline silicon being the most common. However, other technologies such as amorphous silicon, CIGS (Copper-Indium-Gallium-Selenide), organic polymers (OPV), perovskite solar cells, and dye-sensitized solar cells (DSSC) can also be applied [4].

The technology of organic photovoltaic film, known as Organic Photovoltaics (OPV), stands out. As described by [5], these cells consist of organic semiconductor photovoltaic films arranged in series or parallel, presenting characteristics that allow diversity in sizes and shapes. Despite having a shorter lifespan, OPV cells exhibit higher efficiency, potentially being up to 20% more efficient than silicon cells.

One of the main challenges faced by OPV cells is related to the partial shading effect, which can create low-resistance paths, damaging the cell and rendering it unusable. One way to predict or mitigate this effect is through Maximum Power Point Tracking (MPPT). To identify potential issues in these elements, it is necessary to trace I-V curves, which provide detailed information about the electrical parameters of a photovoltaic array, enabling performance evaluation and monitoring [6].

Moreover, partial shading is a significant problem encountered in any photovoltaic system, not just in OPV. It causes a drastic drop in energy generated by the systems due to the low efficiency of protection systems, typically employing bypass diodes to interrupt current flow in the shaded cell or cell group. Partial shading directly interferes with cell energy production, absorbing the electrical energy generated by the unshaded cells and reducing efficiency, durability, and even rendering the module inoperable.

According to [7], partial shading directly interferes with cell energy production based on its relative position, making it difficult to identify this problem. Additionally, shaded cells absorb electrical energy generated by unshaded cells, causing hotspots, reducing efficiency, durability, and potentially making the module inoperable.

Considering the growing photovoltaic generation, the pursuit of increased performance and the resolution of classical problems become necessary, involving the reduction of temperature losses and the identification of partial shading [8]. Thus, there arises a need to develop new research and technologies that intelligently address the challenges arising from partial shading, especially in the context of OPV cells, aiming to increase their efficiency.

These considerations, this paper presents a systematic literature analysis using the Proknow-C or Constructivist Knowledge Development Process [9] methodology, a recognized and widely used scientific review process. Proknow-C facilitates the identification of relevant publications, authors, keywords, and the most relevant journals related to the research topic.

METHODOLOGY

The compilation of the Bibliographic Portfolio (BP) is a crucial step in the initial stages of any research, as it allows evaluating the scientific development of the topic in the academic community. In this study, the Proknow-C method was employed to conduct this bibliographic research.

The Proknow-C method comprises a sequence of procedures, ranging from search mechanism selection to portfolio filtering and selection. It includes the following stages [10]: (A) selection of a portfolio of papers relevant to the research topic; (B) bibliometric analysis of the portfolio; (C) systemic analysis of the Bibliographic Portfolio; and (D) definition of the research question and objectives.

These stages provide a systematic approach to identify and analyze the most pertinent papers related to the research topic. The bibliometric analysis of the portfolio allows evaluating characteristics such as citation frequency, influential authors, and trends in the area. On the other hand, the systemic analysis of the BP takes into account theoretical, methodological, and findings aspects of the selected studies.

By utilizing the Proknow-C method, it is possible to establish a robust knowledge base on the topic, which contributes to substantiating and guiding the research in a more efficient and precise manner.

Selection of the Bibliographic Portfolio

The initial stage of the Proknow-C process is the Selection of the Bibliographic Portfolio (BP) [10], which involves conducting a survey of relevant keywords related to the research topic. These keywords are used to construct a raw database (RDB) to initiate the filtering process.

In the context of this research, the following keywords were identified: "Organic Photovoltaic," "Efficiency," "IoT," and "I-V Curve." These keywords were used in different combinations, separated by the logical operator "AND," for an initial analysis. The selected combinations were: "Organic Photovoltaic" AND "Efficiency"; "Organic Photovoltaic" AND "IoT"; and "Organic Photovoltaic" AND "I-V Curve."

For the bibliographic research, the scientific databases SCOPUS, Web of Science (WoS), and Google Scholar (GS) were consulted, these platforms were chosen due to the great impact factor in the scientific environment and the variety of publications. The aforementioned keyword combinations were used to perform queries in these databases, utilizing the Publish or Perish®, tool for searching scientific references. This software has the function of searching on different platforms for data about publications according to some key words. Data such as total number of citations, average number of citations per article, and average number of citations per year, which assist in research analysis.

The results of the conducted research are described in Table 1, providing an initial overview of the relevant papers found for the research topic. This approach allowed for obtaining a vast, appropriate, and consistent bibliographic portfolio for the analysis and further exploration of this research.

Table 1. Results of the searches in scientific databases

Search combinations used	Scopus	WoS	GS
“Organic Photovoltaic” AND “Efficiency	200	381	500
“Organic Photovoltaic” AND “IoT”;	63	19	500
“Organic Photovoltaic” AND “I- Curve”	62	6	500
Total number of papers per database	325	406	1500
Papers per database		2231	

The selected journals have a currency period of 10 years, which aids in compatibility with the theme of "Electronic Protection Systems for Organic Photovoltaics" or OPVEPS. The research was conducted in 2023, considering only journals published from 2013 onwards. The identified titles were exported to an Excel® spreadsheet, and then filters were applied to remove duplicate titles between different databases. This resulted in a raw paper database containing 2093 papers.

In the subsequent steps, as illustrated in Figure 1, the application of a title alignment filter according to the theme is highlighted. Due to the large number of raw papers obtained, a Python script was developed to automate the paper selection process.

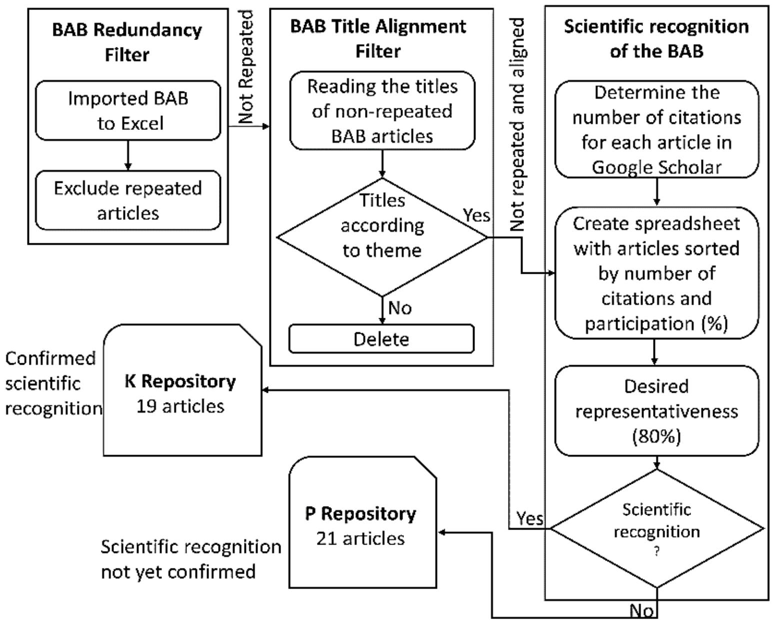

Figure 1. Flowchart overview of the steps for removing repeated papers and titles misaligned with the research theme. Adapted from [9].

One of the main considerations during the initial reading of titles is to identify the context and research field addressed by the publication. Based on this analysis, the titles are evaluated to proceed to the next step and form the Bibliographic Portfolio.

The script employs a wide range of keyword combinations to filter an appropriate number of titles. This approach avoids the premature exclusion of papers that may be relevant to the research topic or have scientific significance. At the end of the automated filtering process, 513 titles were selected for manual evaluation, considering their alignment with the research theme, to compose repositories K and P.

Repository K was constituted by 19 papers responsible for 90% of the total citations from the 513 filtered titles. A minimum quantity of 535 citations was achieved, necessary to form repository K, as described in Table 2.

Table 2. The 19 most cited papers from the bibliographic portfolio

Repository K - Most Cited Papers	Cit.
Beyond efficiency: The challenge of stability in mesoscopic perovskite solar cells	7964
Over 17% Efficiency of Ternary Organic Photovoltaics Employing Two Acceptors with an Acceptor-Donor-Acceptor Configuration	2009
Organometal halide perovskite solar cells: degradation and stability	1602
Eco-compatible solvent-processed organic photovoltaic cells with over 16% efficiency	1286
Perovskite Solar Cell Stability in Humid Air: Partially Reversible Phase Transitions in the PbI2-CH3NH3I-H2O System	1035
Breaking the 10% Efficiency Barrier in Organic Photovoltaics: Morphology and Device Optimization of Well-Known PBDTTT Polymers	955
High efficiency near-infrared and semitransparent non-fullerene acceptor organic photovoltaic cells	937
Recent Progress on the Long-Term Stability of Perovskite Solar Cells	887
Achieving over 15% efficiency in organic photovoltaic cells via copolymer design	836
Determining the optimum morphology in high-performance polymer-fullerene organic photovoltaic cells	830
Interplay between dye coverage and photovoltaic performances of dye-sensitized solar cells based on organic dyes	792
Understanding How Processing Additives Tune the Nanoscale Morphology of High Efficiency Organic Photovoltaic Blends: From Casting Solution to Spun-Cast Thin Film	738
Characterization and photovoltaic performance of organic device based on AlPcCl/p-Si heterojunction	738
Organic photovoltaic cell with 17% efficiency and superior processability	707
Plasmonic Periodic Nanodot Arrays via Laser Interference Lithography for Organic Photovoltaic Cells with > 10% Efficiency	692
D-π-A dye sensitizers made of polymeric metal complexes containing 1,10-phenanthroline and alkylfluorene or alkoxybenzene: Synthesis, characterization and photovoltaic performance for dye-sensitized solar cells	668
Recent progress on indoor organic photovoltaics: from molecular design to production scale	584
Characterization and photovoltaic performance analysis of heterojunction solar cell	580
Evaluation experimental of the impact of Saharan climate conditions on the infinity organic photovoltaic module performance	535

After a thorough analysis, the remaining 494 papers were subjected to a filtering process based on the year of publication, specifically focusing on those published from 2018 onwards. They were then organized in ascending order according to the GSRank provided by Publish or Perish®. Subsequently, a manual analysis of the titles of these publications was conducted to determine their compatibility with the research theme. From this process, the most relevant papers were selected, and their abstracts were reviewed. As a result, Repository P was formed, comprising a set of 21 papers, as detailed in Table 3.

Table 3. The 21 papers with relevance to the topic

Repository P - Papers with Relevant Authors	GSRank	Cit
R Venkateswari, S Sreejith	1	90
Evaluating the Performance of Flexible, Semi-Transparent Large-Area Organic Photovoltaic Arrays Deployed on a Greenhouse	12	1
100 cm (2) Organic Photovoltaic Cells with 23% Efficiency under Indoor Illumination	23	23
Comparing the degradation of organic photovoltaic devices under ISOS testing protocols	48	27
Power performance of solar energy harvesting system under typical indoor light sources	70	16
Performance evaluation of single-junction indoor photovoltaic devices for different absorber bandgaps under spectrally varying white light-emitting diodes	76	5
Optimal design of organic-inorganic hybrid tandem solar cell based on a-Si:H and organic photovoltaics for high efficiency	86	12
Organic Photovoltaics for Indoor Applications	96	0
Indoor photovoltaics awaken the world's first solar cells	103	3
Isoindigo-based small molecules for high-performance solution-processed organic photovoltaic devices: the electron donating effect of the donor group on photo …	115	52
Design and development of an IV curve tracing and electrical performance analyzing system for solar photovoltaic module	155	0
Life Cycle Assessment and eco-efficiency of prospective, flexible, tandem organic photovoltaic module	169	46
Application of Bis-Adducts of Phenyl-C61 Butyric Acid Methyl Ester in Promoting the Open-Circuit Voltage of Indoor Organic Photovoltaics	181	0
Manipulating film formation kinetics enables organic photovoltaic cell with 19.5% efficiency	212	5
Outdoor organic photovoltaic module characteristics: Benchmarking against other PV technologies for performance, calculation of Ross coefficient and outdoor …	253	39
Power Conversion Efficiency Improvement of Planar Organic Photovoltaic Cells Using an Original Hybrid Electron-Transporting Layer	366	6
Toward High-Performance Polymer Photovoltaic Devices for Low-Power Indoor Applications (Solar RRL 12⁄2017)	382	4
A real-time comparative data analysis of different types of solar panels during partial shading with distinct tilt angles	393	4
Rational design of a main chain conjugated copolymer having donor–acceptor heterojunctions and its application in indoor photovoltaic cells	430	22
Utilization of poly (4-styrenesulfonic acid) doped polyaniline as a hole transport layer of organic solar cell for indoor applications	494	36
A. Dolara, G. di Fazio, S. Leva, G. Manzolini, R. Simonetti, A. Terenzi	495	0

The 40 papers from Repositories K and P were subjected to the methodological approach proposed by [9]. This approach suggests steps for constructing the main Bibliographic Portfolio (BP), referred to as 'C', containing the key papers related to the research topic. The steps can be seen in Figure 2. In the end, eleven papers composed Repository C, among which they describe processes for analyzing degradation of organic photovoltaic cells, I-V curve generation processes, and efficiency analysis of solar panels under partial shading conditions. Among them, only one addresses a type of solution regarding the use of protection diodes for cases of partial shading in OPV cells. The list of papers from the main BP can be viewed in section analysis and discussion of this paper, identified in Table 4.

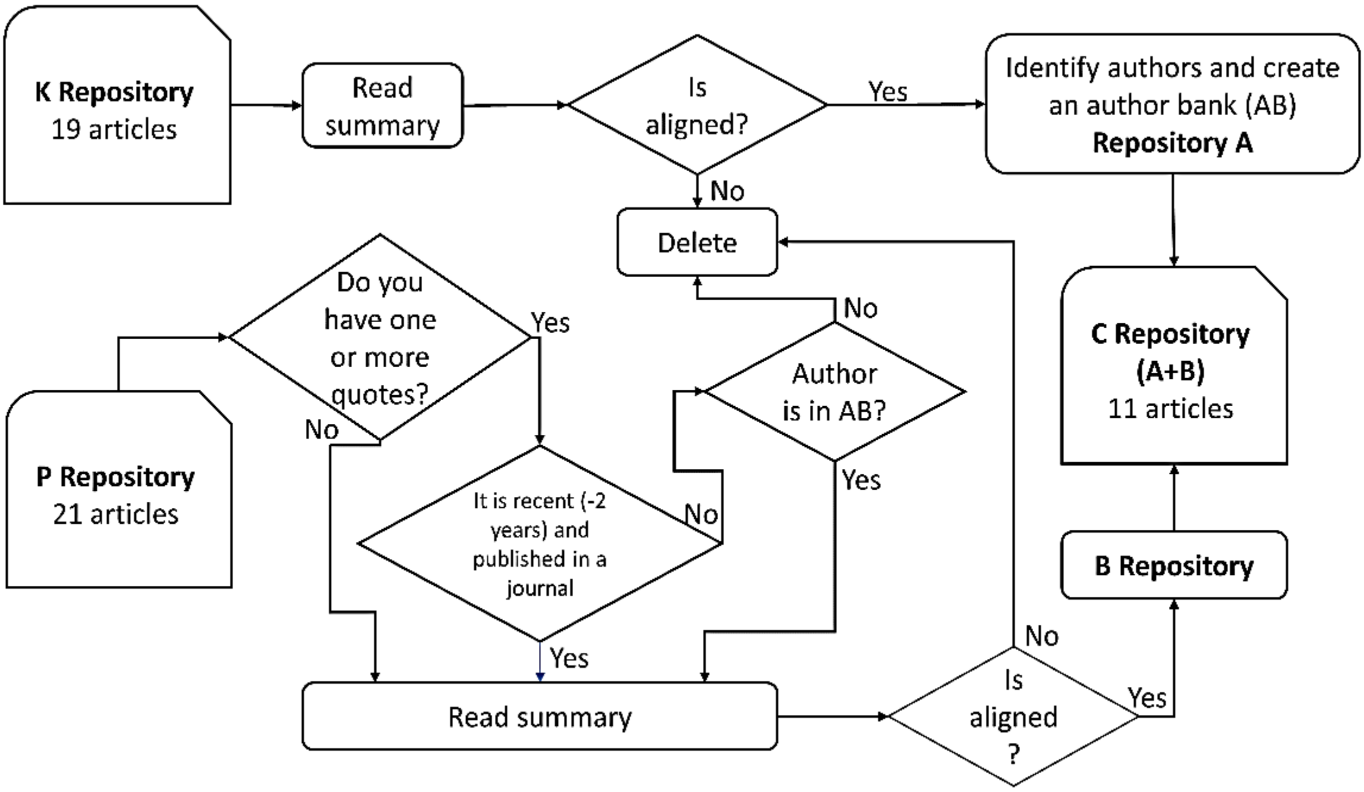

Figure 2. Flowchart overview of the filtering process for Repositories K and P to construct the main Bibliographic Portfolio. Adapted from [9].

Bibliometric Analysis

Bibliometric analysis is a stage that involves examining and quantifying bibliographic characteristics such as citations, authorship, collaboration, and journal impact to study and evaluate the publications within a specific Bibliographic Portfolio (BP). In the case of the specific BP in question, composed of 11 papers, the following analyses were conducted: (1) paper relevance, (2) number of papers per journal, and (3) quantity of papers per year within the bibliographic portfolio.

The quantitative analysis of the BP begins with the examination of accumulated citations for each title. This analysis revealed that 86% of the total citations were concentrated in five publications, as shown in Figure 3. This clustering of citations indicates that these five publications are particularly relevant and have received significant attention in the community. With this information, it becomes possible to direct attention to these more relevant papers, exploring their contents and contributions to deepen understanding and advance the field of study.

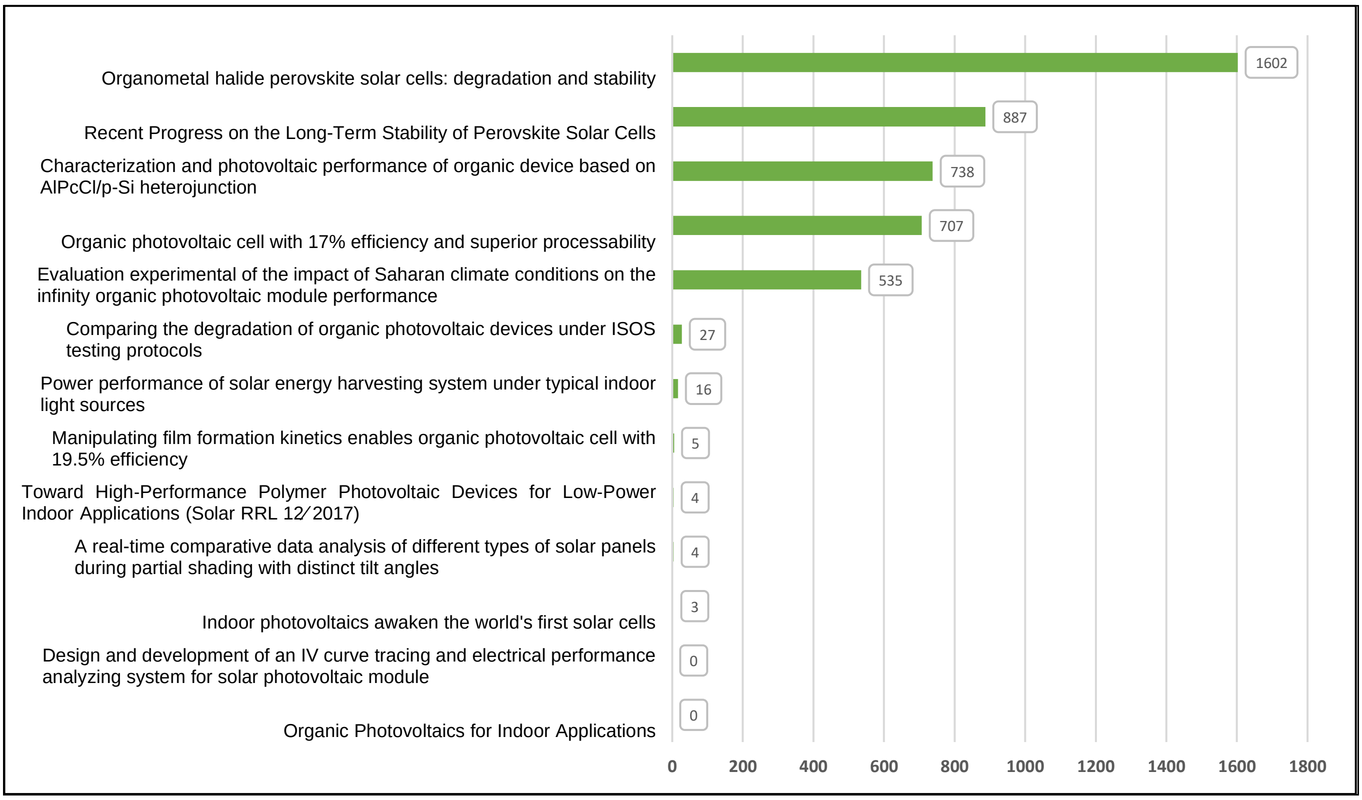

Figure 3. Quantitative analysis of citations in the publications within the BP**.**

Next, the numerical analysis of papers and journals reveals where the papers were published and the concentration of papers per journal. In Figure 4, it can be observed that almost 40% of the papers originate from the Australian Journal of Electrical and Electronics Engineering, indicating the journal's focus on publishing papers relevant to OPV.

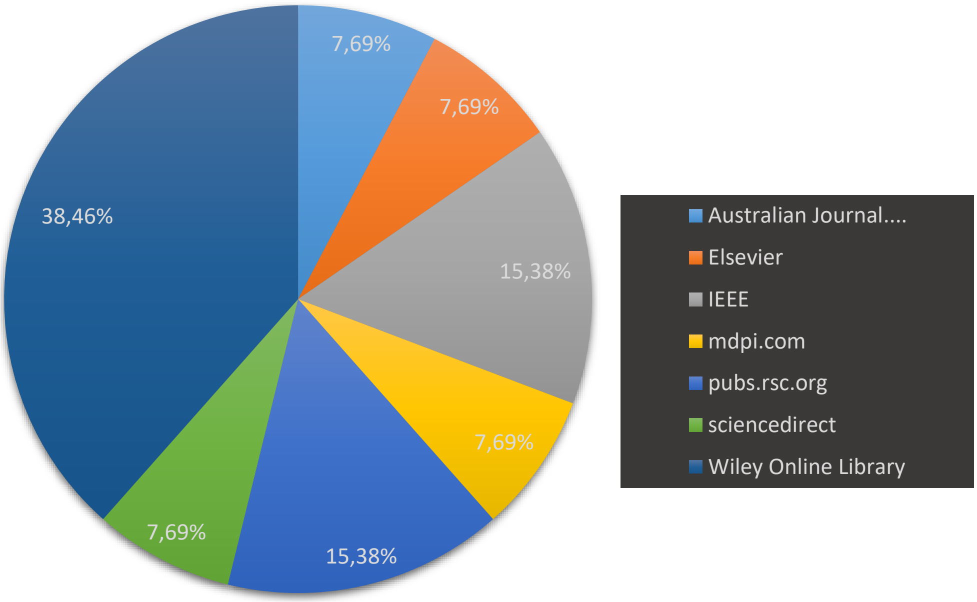

Figure 4. Percentage analysis of the presence of Journals in the BP**.**

The analysis in Figure 5 reveals a significant pattern within the bibliographic portfolio related to the theme of OPVEPS. Specifically, a prominent cluster of seven publications represents a substantial portion of 63.7% of the BP. Moreover, these publications are concentrated in the years 2021, 2022, and 2023.

This temporal concentration highlights the current relevance of the OPVEPS theme, indicating that it is a developing field of study. While these publications may offer valuable insights, they also suggest that there is much more to be explored and understood in this area. The presence of this cluster of publications sparks optimistic interest and curiosity regarding future results and the potential for new contributions.

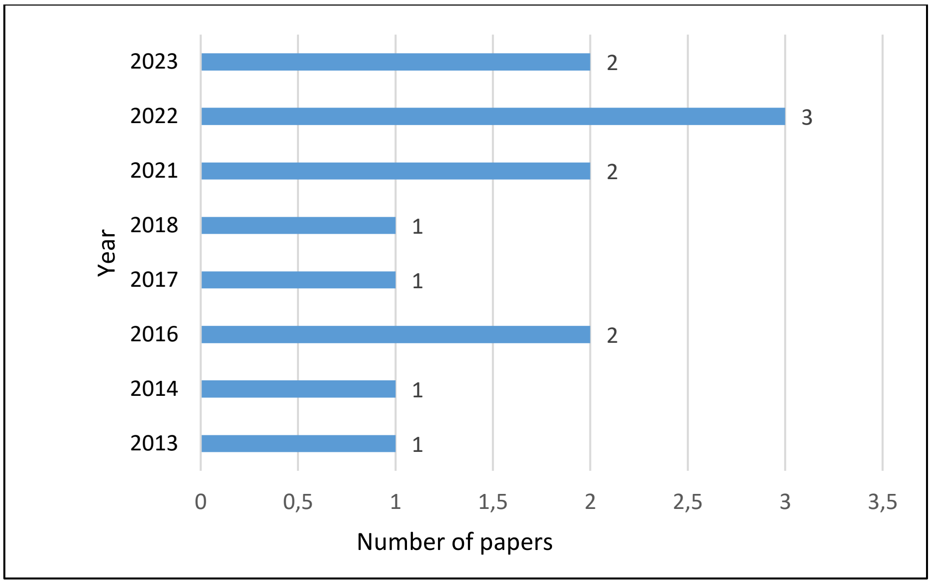

Figure 5. Comparison of publication in journals present in the BP.

Systemic Analysis

After the selection of papers and bibliometric analysis, it is essential to conduct a systemic analysis of the bibliographic portfolio. At this stage, the content of the papers, their development, techniques used, challenges faced, positive aspects, and similarities are evaluated. This analysis provides a deeper understanding of the examined studies, identifying patterns, knowledge gaps, and significant contributions. Through a systemic analysis, data can be obtained to aid in the synthesis and interpretation of results, as well as guide future investigations.

Among the 11 selected papers from Repositories K and P, listed in Tables 2 and 4, a focus on performance analysis methodologies of OPV modules is evident, with techniques for generating characteristic curves to analyze module degradation and performance under partial shading conditions.

For instance, in [11], the development of a data acquisition system using the ISETmpp meter provided by IWES to collect performance information of photovoltaic modules or cells is presented. Additionally, a Java program was developed to analyze the collected data and sketch OPV characteristic curves. Within the system, it is possible to configure a time interval to detect and analyze periods of partial shading. This approach allows for a more detailed analysis of photovoltaic system performance under partial shading conditions, providing relevant information for system optimization and improvement.

In [12], an investigation of the electrical properties of planar heterojunction OPV cells with Au/AlPcCl/p-Si/Al structure is performed. The electrical properties of the OPV were obtained through the analysis of current-voltage (I-V) and capacitance-voltage (C-V) curves. I-V measurements were carried out using a programmable high-impedance electrometer, while C-V characteristic curves were measured using the computerized system CV-410m (model 4108). All measurements of I-V and C-V curves were conducted with the OPV under dark conditions. The I-V characteristics were studied under a tungsten lamp, and the light intensity was inferred through a digital lux meter.

In [13], the efficiency of OPV modules installed in a greenhouse is analyzed and monitored over time. Each panel has dimensions of 800 mm vs 1000 mm and is composed of 4 modules with 10 cells each connected in series. Using Python, a voltage-current reading system was developed to perform electrical monitoring of the OPV arrays. This system utilizes serial communication between a laptop computer and a programmable CC electronic load device. The OPV arrays were connected to the electronic load and the I-V curve tracer system.

In [14], the stability of OPV modules with different compositions is investigated, and the results are analyzed under different ISOS (acronym) test protocols. It was observed that the stability of the devices varies significantly depending on the protocol used, highlighting the importance of carefully selecting the test protocol. These findings emphasize the need to consider different conversion options and choose test protocols that are more representative of the real operating conditions of the OPV devices.

The study conducted by [15] examined the performance of Crystalline Silicon (c-Si) and Copper Indium Gallium Selenide (CIGS) solar modules. A box with a light source and a controller for the light irradiance range to which the cells were subjected was assembled. The efficiencies obtained for the studied cells, in an indoor environment, were below 8.0%, and the spectrum of the light source had a direct impact on the measured efficiency. This fact highlights the potential of OPV for indoor applications, which achieve an efficiency of more than 20% in energy conversion.

The work carried out by [16] tested the application of organic and inorganic diodes to minimize the effects of partial shading. The use of diodes to create a bypass effect under the OPV cell is suggested to eliminate the reverse currents developed by partial shading. In relation to the comparison between organic and inorganic diodes, no significant gain was observed in the use of inorganic diodes (Si and GaAs) as bypass. In this regard, the organic diode showed a higher reduction in loss in OPV (30%) under partial shading conditions and also has the advantage of integration into the cell itself during its processing, facilitating the installation process. In summary, shading in organic photovoltaic modules results in the shutdown of the entire module if one cell is shaded. In such a case, a loss greater than 99% is reported.

ANALYSIS AND DISCUSSION

The systematic analysis of the bibliographic portfolio, using the Proknow-C filtering methodology, revealed a significant research gap in the development of electronic protection systems aimed at application in OPV-type photovoltaic modules. It is important to highlight that no systematic literature review publication focusing on OPVEPS was found, highlighting the innovative approach of this work in this specific field. In contrast, literature related to similar types of protection systems but directed at conventional photovoltaic modules is extensive and widely disseminated in the academic community.

Therefore, with the aim of supporting the development of new research on the subject, a manual search of potentially useful works focused on traditional photovoltaic modules was conducted through Publish or Perish®. These works were carefully selected and incorporated into the final bibliographic portfolio with the purpose of adding value and enriching the development of projects and research in this specific area. This approach allowed for the construction of a comprehensive state-of-the-art on the topic, providing a solid foundation for future studies and advancements in the field of study. The manually selected papers are described in Table 4, identified by the underlined titles at the end of the table.

Table 4. Bibliographic Portfolio

Repository C + Relevant Papers	Cit.
Recent Progress on the Long-Term Stability of Perovskite Solar Cells	887
Characterization and photovoltaic performance of organic device based on AlPcCl/p-Si heterojunction	738
Comparing the degradation of organic photovoltaic devices under ISOS testing protocols	27
Power performance of solar energy harvesting system under typical indoor light sources	16
A real-time comparative data analysis of different types of solar panels during partial shading with distinct tilt angle	4
Evaluating the Performance of Flexible, Semi-Transparent Large-Area Organic Photovoltaic Arrays Deployed on a Greenhouse	1
Design and development of an IV curve tracing and electrical performance analyzing system for solar photovoltaic module	0
A Novel Computational Model for Organic PV Cells and Modules	8
Development of an organic photovoltaic energy harvesting system for wireless sensor networks	4
Evaluation of Latest Photovoltaics Technologies Applied to Telecommunication Systems Operating in Shaded Environments	0
Evaluation of Latest Photovoltaics Technologies Applied to Telecommunication Systems Operating in Shaded Environments	0
A comprehensive review on bypass diode application on photovoltaic modules	97
Photovoltaics in the shade: one bypass diode per solar cell revisited	89
An electromagnetic strategy to improve the performance of PV panel under partial shading	37
Flexible polymer photovoltaic modules with incorporated organic bypass diodes to address module shading effects	29

Additionally, articles were identified addressing the effects of partial shading and techniques for generating I-V curves of OPV modules, which were originally excluded during screening of the P repository. This exclusion occurred due to human error, as the compatibility analysis of 494 articles with based on their titles proved to be a laborious task. However, through the use of Publish or Perish, it was possible to identify and retrieve these articles and add them to the repository. Furthermore, a second analysis of the titles found was carried out to ensure their relevance to repository C. These publications are highlighted with a border in Table 4.

As an additional contribution with regard to the analysis of techniques for generating characteristic curves, resulting from this parallel research, is the work mentioned in the article [17].

In this study, a comparative analysis was carried out between the computer simulation of OPV cells and their operation in a system through mathematical modeling of OPV cells. The analysis was carried out using a resistive load, and the electrical parameters of voltage, current and power of the device were observed. To validate the proposed mathematical model, tests were carried out in the Matlab application, where experimental curves were also compared.

Through testing carried out, both in a simulation environment and in the field, with representative results of some operational conditions, additional comparisons were carried out, further confirming the validity of the proposed model. This model can be used in computer simulations to evaluate the performance of OPV cells under various operating conditions, in terms of irradiance, wind speed and temperature.

In the same context, the work in [18] presents the development of a data acquisition system to evaluate the efficiency of OPV cells. The acquired data indicates only a small degradation of the OPV when tested under indoor conditions over a period of 21 months; at a luminance level of 1000 Lux, only a 10% relative drop in performance was measured. Finally, field data is used to optimize OPV and battery size for future indoor applications that have different power loads. Based on the energy efficiency model, the loss of power supply probability (LPSP) of the indoor application system is calculated for different combinations of PV sizes, battery sizes, and load energies. This model provides a method for calculating the OPV output power required to ensure remote operation of other IoT electronics.

Regarding partial shading, there is a study of shading in an OPV model and commercial silicon cells in [19]. However, no type of protection is presented and the authors concluded that partial shading directly affects the efficiency of the modules. Through studies carried out using the acquisition systems developed for the project, the authors considered that both technologies present losses, with crystalline silicon losing 100 to 1,300% more power than OPV. On the other hand, the lack of protection in OPV systems leads to greater degradation, suggesting the need for protection circuits in OPV cells that were not further explored in the article.

Finally, it is evident that in electronic protection systems applied to photovoltaic modules, the use of bypass diodes is a common approach. These diodes are connected in parallel, usually in groups of photovoltaic cells within a module, reverse biased.

As illustrated in Figure 6, although there is uniform availability of incident light throughout the module, the short-circuit currents of groups of cells or isolated cells remain compatible and the diode functions as an open circuit. In a partial shading situation, the diode is reverse biased, thus conducting current from the unaffected cells and allowing their respective currents to flow through the circuit.

However, there are challenges to be overcome, such as hot spots, implementation costs and shadowing effects, as discussed in [20]. In the study, researchers carried out extensive research on the use of bypass diodes (BP), reaching the conclusion that BP diodes are essential for the reliability of photovoltaic modules, although they are devices susceptible to failure, which can lead to consequences of power losses and the hotspot phenomenon. Furthermore, they found research that uses hybrid techniques, based on transistors and the use of artificial intelligence to improve processes, being new alternatives that generate better efficiency gains in solar cells.

The protection systems approach using relay switches instead of bypass diodes proved to be more efficient in conventional photovoltaic cells, the proposed method worksThe protection systems approach using relay switches instead of bypass diodes proved to be more efficient in conventional photovoltaic cells, the proposed method works a successfully and consumes only 150 mW of power losses under partial shading condition, which is very low compared to the bypass diode, which consumes 550 mW at 0.62 A under the same shading condition. The proposed method is considered a better alternative, replacing conventional methods in terms of absence of thermal runaway condition, lower requirement for control circuits, elimination of open circuit faults and reduction of direct losses [21], a technique that could also be applied to OPVs.

In practice, however, one bypass diode per solar cell is usually very expensive, and bypass diodes are usually placed in groups of solar cells instead. The voltage on the shaded or low-current solar cell is equal to the forward bias voltage of the other cells in series that share the same bypass diode plus the bypass diode voltage [22], as shown in Figure 6, which makes it another small disadvantage in this type of application.

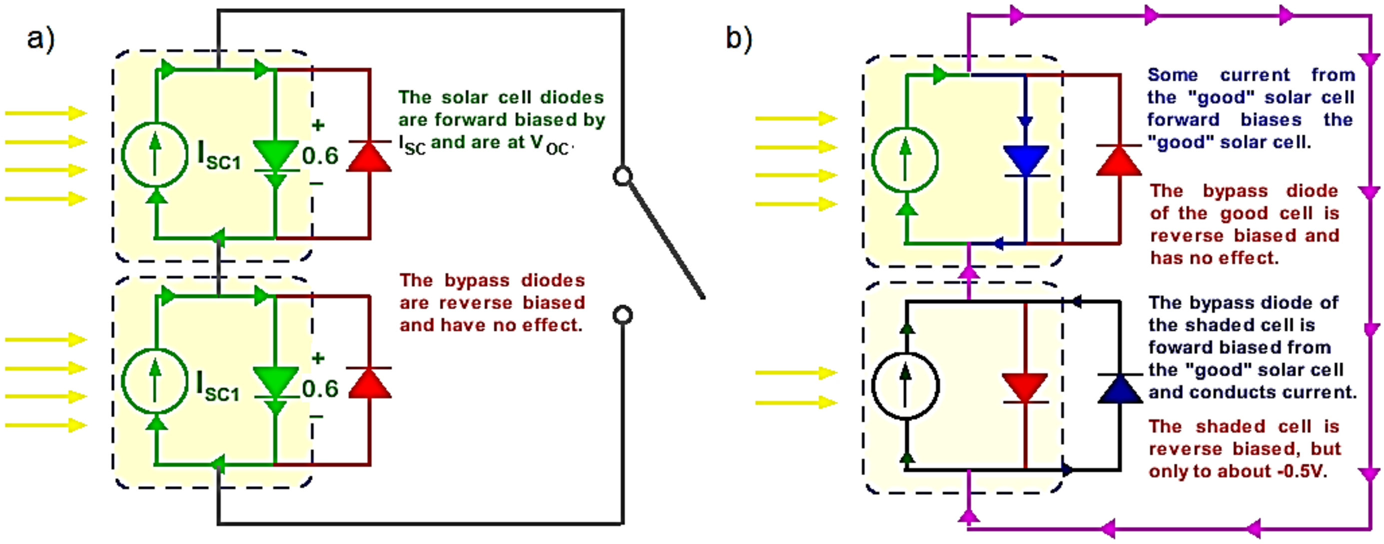

Figure 6. Illustrates the application model of the bypass diode in (a) normal operation of the module and (b) module under partial shading conditions. Adapted from [22].

Therefore, shading management in OPV panels will be one of the main points to be addressed in the coming years. Compared to first and second generation panels, especially silicon, this technology will continue to stand out due to its low manufacturing cost, at low temperatures (< 200˚C) and atmospheric pressure, on large surfaces and on flexible substrates (e.g., blade coating and roll to roll), and its constant improvement can guarantee another source of renewable energy and devices that increase its efficiency [23,24].

Additionally, in the current scenario in Brazil, and potentially extendable to the rest of the world, photovoltaic generation already occupies second place in the electrical matrix and has high potential for the development of hardware and software aimed at its efficient use, its wide use and the position Brazilian geographic region, makes the incessant search for new energy alternatives inevitable, which increases the supply of quality, renewable energy with high efficiency and power quality [25-27].

CONCLUSION

This research was conducted to gather relevant bibliographic data on the topic of Organic Photovoltaic (OPV) cells, specifically focusing on partial shading, techniques to reduce losses, and data acquisition strategies related to the efficiency of this type of cell. A systematic literature review on OPV from the last decade (2013-2023) was performed. For the first time, the Proknow-C methodology was applied in this context, resulting in a final bibliographic portfolio with 14 directly relevant publications.

The limited number of relevant titles in this portfolio highlights the innovative nature of the proposed theme. In summary, the bibliometric analysis presented in this paper fills an existing gap, given the scarcity of research on the topic. This systematic literature review aims to aid in understanding and advancing the state of the art on OPVEPS, contributing to the development of new research that can significantly enhance photovoltaic generation technologies' efficiency and increase microgeneration capacity.

The low number articles for this theme, reflect in new research possibilities, embedded protection circuits or circuits for protection per line, MPPT systems to elevate the efficiency of the generations with OPVEPS, for example. Thus, new researches are necessary to implement this technology applied a micro generation with OPVESPS.

Funding: This research was also partially supported by FACEPE agency (Fundação de Amparo a Pesquisa de Pernambuco) throufht the project with references APQ-0616-9.25/21 and APQ-0642-9.25/22. O.H.A.J. was funded by the Brazilian National Council for Scientific and Technological Development (CNPq), grant numbers 407531/2018-1, 303293/2020-9, 405385/2022-6, 405350/2022-8 and 40666/2022-3.
Acknowledgments: The authors would like to thank the support of the Coordination for the Improvement of Higher Education Personnel – CAPES, Foundation for the Support of Science and Technology of Pernambuco - FACEPE, the Brazilian National Council for Scientific and Technological Development – CNPq.
Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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