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Review Article

Unveiling Insights on Scientometric Exploration of Trends in Power Cable Research – A Review

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ABSTRACT

Power cables play a crucial role in modern power transmission and distribution networks, serving as vital infrastructure for national grids and power utility companies. However, their high installation, operation, and maintenance costs pose significant challenges, especially as global electricity demand continues to rise. Optimizing power cable technology is essential to ensuring reliable, cost-effective, and sustainable energy systems. These challenges align with the United Nations' Sustainable Development Goals (SDGs), particularly in providing access to affordable and clean energy. While extensive research has been conducted on the theoretical and practical aspects of power cables, a noticeable gap remains in bibliometric and scientometric analyses in this field. Understanding research trends, collaboration networks, and emerging technologies is essential for guiding future developments. This study presents the first comprehensive scientometric analysis of power cable research, addressing the gap by systematically evaluating the field's evolution. Using data from the Web of Science

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(WoS) database and CiteSpace for visualization, the study examines publication trends, key thematic areas, and the global impact of scholarly contributions. The findings reveal the leading researchers, the most influential publications, the volume of research output by country, and the extent of international collaboration. Additionally, the analysis highlights emerging trends in power cable technology, including advancements in materials, diagnostics, and the integration of smart grids. By mapping the research landscape, this study provides valuable insights for academics, industry professionals, and policymakers to foster collaboration, drive innovation, and enhance the development of sustainable power infrastructure.

Keywords: Cluster analysis, power cables, research analysis, scientometric, Web of Science

INTRODUCTION

Power cables are integral to the functioning of power utility companies and national grids, primarily due to their role in transmitting electrical power. These cables, often made of copper or aluminum conductors with electrical insulation (Powers, 1994), are crucial for maintaining a stable supply of electricity. Notably, cross-linked polyethylene (XLPE) cables are widely used for their mechanical and electrical advantages, including superior heat resistance and flexibility in installation (Illias et al., 2016; Z.-P. Zhang et al., 2020). However, the increasing global demand for electricity and the integration of smart grid systems (M.-F. Chen et al., 2019; R. Huang et al., 2013) present significant challenges in terms of maintaining an uninterrupted energy supply and managing the escalating costs associated with power cable infrastructure. Concerns over energy security compound the growing reliance on power cables (Nick et al., 2016) and the affordability of electricity. This is particularly pertinent considering the United Nations' SDG of ensuring accessible and clean energy for all (Arora & Mishra, 2019). Natural disasters and global events like the COVID-19 pandemic further exacerbate the situation (Carere et al., 2020), which has heightened the need for a robust and sustainable electricity supply, underscores the critical role of power cables in the energy sector.

Despite the evident importance of power cables and extensive research on theoretical and practical aspects since 1994, there has been a lack of scientometric analysis or quantitative view in this field (Xu et al., 2022). Bibliometric analysis has gained popularity in recent years in social science and commercial studies (Donthu et al., 2021). There are also articles focusing on the role of scientific research in advancing sustainable development, particularly through energy and engineering disciplines (Kumar et al., 2023; Raman et al., 2024). Thus, this study aims to fill this gap by employing scientometric methods (Sarquah et al., 2022) to analyze scientific research and publications related to power cables systematically. Specifically, the study aims to address the following research question: i. What are the overall trends in research publications on power cables? ii. What are the central topics or clusters within this research domain? iii. Which publications have been most influential in these areas? and iv. What are the key publications and keywords that have had a significant impact in the field? This scientometric analysis represents the first of its kind in the power cable industry. It provides a novel perspective by examining the relationships between data, mapping, and clustering networks, analyzing publication output by countries, identifying the most productive authors, and exploring international collaborations (Hwalla et al., 2023). This approach offers a comprehensive understanding of the evolving trends and pivotal elements in power cable research, thereby addressing the identified research questions and contributing valuable insights into this rapidly developing field.

This paper is structured into five main sections: Introduction, Methodology, Results, Discussion, and Conclusion, to provide a comprehensive scientometric analysis of power cable research. The Introduction Section highlights the significance of power cables in the energy industry, as well as their contribution and novelty in addressing the current scientometric study gap. The Methodology Section outlines the approach employed, including database searches conducted within the WoS and the analysis techniques used, which comprise descriptive and scientometric analyses, as well as visualization techniques utilizing CiteSpace. The Results Section presents key findings from the descriptive analysis, including the most cited articles, publication trends per year, publication affiliations, research trends across countries, and author productivity. Meanwhile, the scientometric analysis results include cluster mapping, document co-citation analysis, article burst trends over the years, author co-citation analysis, and keyword burst trends over the years. The Discussion Section synthesizes these findings, linking them to broader technological and policy trends, such as the adoption of renewable energy and advancements in cable insulation and diagnostics. Lastly, this paper concludes by emphasizing the value of scientometric analysis in identifying research gaps and guiding future studies. It also suggests areas for further exploration, including collaborations between leading institutions and comparative analyses using alternative bibliometric tools.

METHODOLOGY

The methodology of this study employs a two-pronged approach, combining both descriptive and scientometric analyses, which draws upon data from the WoS database. The aim of the overarching is to present a comprehensive picture of research trends, influential authors, and key themes within the domain of power cable research.

Database Searches

The foundational step in this study involved a systematic search of the WoS Core Collection database. This is a widely acknowledged resource in scholarly research because of its thorough coverage, excellent citation records, and strict indexing guidelines. The WoS is well known for providing reliable and trustworthy data for bibliometric research, particularly in ensuring consistency in impact analyses and citation metrics. To preserve the accuracy and dependability of our findings, our paper aimed to prevent potential redundancies and inconsistencies that could arise from using multiple databases.

To ensure a comprehensive search, the study utilized the term "TS" for topic search in WoS, targeting titles, abstracts, keywords, and author details. The search phrase employed was "TS= ("power cable*")," including an asterisk to capture variations of the term. The time frame for the search spanned from 2006 to 2023, with a focus exclusively on original research articles. Exclusions were made for non-research-based publications such as editorials, book chapters, and discussion papers. The search, conducted on December 22, 2023, aimed to create a diverse dataset encompassing a range of research methodologies.

Data Analysis

Data analysis in this study is bifurcated into descriptive analysis and scientometric analysis, detailed as follows:

Descriptive Analysis

The descriptive component focused on quantifying the annual publication output, identifying prominent journals, and pinpointing the most productive authors and institutions. Additionally, it included an analysis of geographical distribution by determining the countries with significant contributions to the field.

Scientometric Analysis

Utilizing CiteSpace 6 (version 6.2 for Windows), the study engaged in a scientometric evaluation through dual map overlay and document co-citation analysis. The dual map overlay method differentiated between cited and citing journals, creating a visual representation of inter-journal relationships. It highlighted the flow of citations, with the size and thickness of map elements reflecting the volume of publications and the frequency of citations, respectively. document co-citation analysis (DCA) was conducted to identify patterns of co-citation among articles. It provided insights into the interconnectedness of publications, revealing key research articles through metrics like burstiness, centrality, and sigma. Burstiness highlighted articles with sudden increases in citations, centrality identified influential papers within the network, and sigma combined these factors to assess the novelty and impact of the research.

For clustering analysis, the study employed a multidimensional clustering approach using the log-likelihood ratio (LLR) for label extraction. Cluster visualization was achieved through a timeline view, illustrating the chronological development of the research field, and a spatial network representation, showcasing the thematic structure of the dataset. Cluster quality was assessed using the modularity index (Q) and the silhouette metric to evaluate the reliability and coherence of the identified clusters. The methodology's flow and sequence are encapsulated in the framework provided in Figure 1. This structured

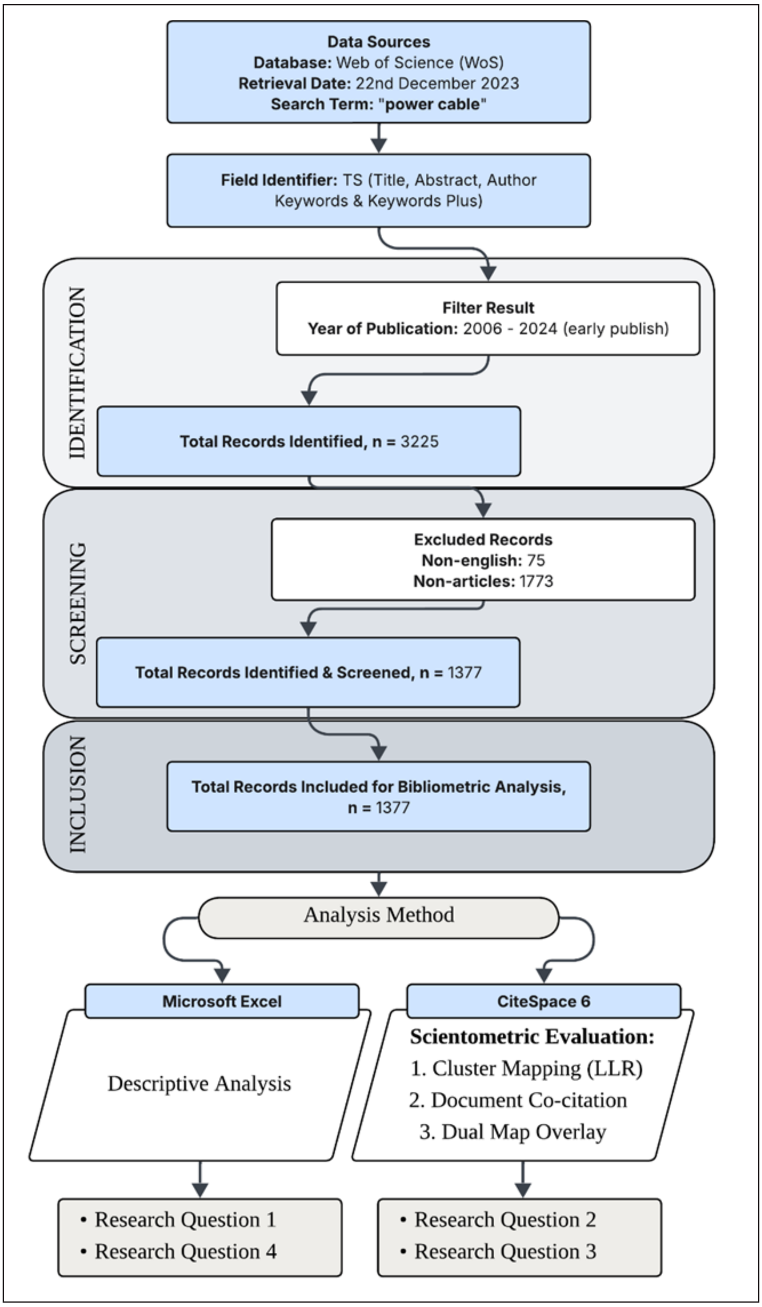

Figure 1. Methodology flow for descriptive and scientometric analysis in this study, consisting of the identification, screening, and inclusion stages
Note. LLR = Log-likelihood ratio

approach ensures a comprehensive and systematic exploration of the power cable research landscape, aiming to uncover patterns, trends, and influential contributors in the field.

RESULTS

Based on the methodology part, the general data gathered has been tabulated as shown in Table 1. As in the methodology section, 1,377 articles retrieved on 22nd December 2023, and published between 2016 and 2024, will be analyzed in this work. The total number of citations recorded is 15,204, and the average number of citations per article is 11.04, which highlights the notable impact of the research over the specified timeframe. Furthermore, the Hirsch index (*h*-index), which measures the number of papers in which other writers have cited a writer, is 52, showing the significance of the potential for co-citations in multidisciplinary domains.

Table 1
General statistics from selected records

Publication titles	Record count
Articles	1,377
Sum of the times cited	15,204
Average citations per item	11.04
h-index	52

This paper presents a scientometric examination of articles published between 1970 and 2024, which serves as the basis for the findings, revealing how references were distributed over time. Older references should also be included to document the changes and patterns that have occurred in the field over the past fifty years. Additionally, since this research was conducted and written at the early stage of data availability from 2024 publications, only one article from 2024 is included. The following section utilizes these general statistics to present the most significant and often cited articles, annual trends in article citations, affiliations, and record trends across the country, as well as notable writers and their record counts.

Most Cited Articles

Table 2 shows the top ten articles (Hammerl et al., 2000; Sun et al., 2012) with their total citations, respectively. From this result, the most influential paper in the power cable research field is cited (Hammerl et al., 2000) with a total of 225 citations, the research demonstrated that calcium doping of grain boundaries in polycrystalline $YBa_2Cu_3O_7$ significantly enhances its supercurrent density at 77 K. Next, the fewest citations among the articles is (Sun et al., 2012), which is 98 citations recorded. These 10 articles, overall, focus on advancements in high-temperature superconductors, electrical insulation, power electronics, fault detection, and biomedical engineering. The key themes include enhancing supercurrent density, optimizing charge injections, improving insulation properties and fault detection methods, and developing efficient power systems for industrial and biomedical applications.

Table 2
Number of citations from the top ten most cited papers

Titles	Total citations
Enhanced supercurrent density in polycrystalline YBa_2Cu_3O(7-delta) at 77 K from calcium doping of grain boundaries (Hammerl et al., 2000)	225
Electrodes and charge injection in low-density polyethylene - Using the pulsed electroacoustic technique (G. Chen et al., 2001)	147
Effect of insulation properties on the field grading of solid dielectric DC cable (Boggs et al., 2001)	143
An efficient method based on the electromagnetic time reversal to locate faults in power networks (Razzaghi et al., 2013)	140
Evaluation of switching performance of SiC devices in PWM inverter-fed induction motor drives (Z. Zhang et al., 2015)	117
Feature extraction of partial discharge signals using the wavelet packet transform and classification with a probabilistic neural network (Evagorou et al., 2010)	113
A distributed optical fibre sensor for temperature detection in power cables (Yilmaz & Karlik, 2006)	109
An integrated driving/charging switched reluctance motor drive using three-phase power module (H.-C. Chang & Liaw, 2011)	100
Electrical treeing characteristics in XLPE power cable insulation in frequency range between 20 and 500 Hz (G. Chen & Tham, 2009)	100
A two-hop wireless power transfer system with an efficiency-enhanced power receiver for motion-free capsule endoscopy inspection (Sun et al., 2012)	98

Article Publication Per Year

As shown in Figure 2, early research publications in the power cable field began to appear in 1970. The number of records did not exceed 20 articles until 2006, indicating that this

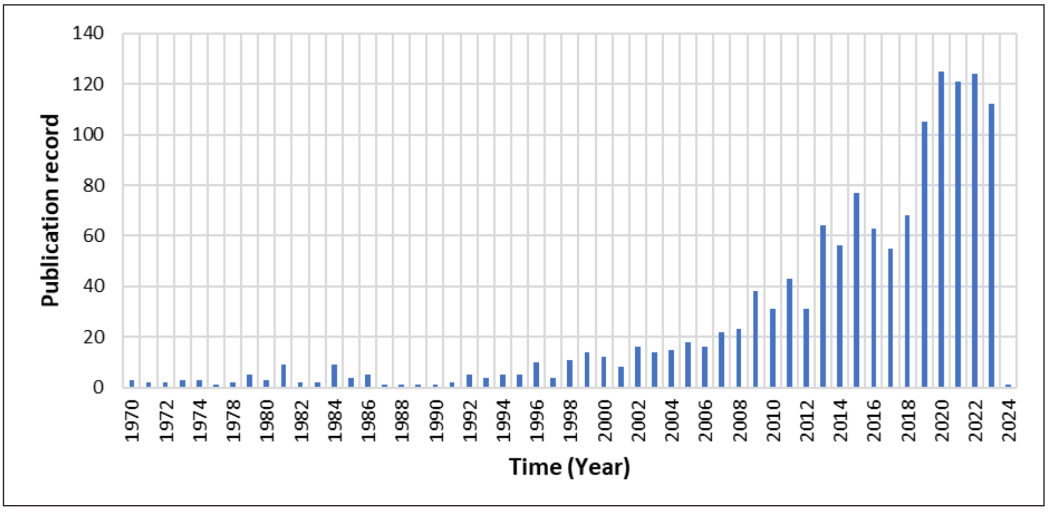

Figure 2. Yearly article publications trend from 1970 to 2024 regarding power cables

study was still in the exploratory stage. However, it was found in an article published in 1970 (Kortschinski & Leslie, 1970). References have been cited from papers published as early as 1931, which observed cable temperatures. Based on that reference, this paper highlights the design features and installations of a thin, liquid-filled coaxial sensing cable for detecting and locating hot spots in underground power cables.

Moving forward to 2013, the number of research publications increased significantly until 2023, indicating that many research studies were conducted widely during this period. Within this period, the year 2020 reached the highest value, which is 125 publications. This increment in number can be observed to be affected by the outbreak of the COVID-19 pandemic that started in 2019, where globally, most activities were carried out online, which then led to unpredictable load changes (Carere et al., 2020; H. Zhong et al., 2020; Zarbakhsh et al., 2022). Besides, the expansion of renewable energy generation and smart grids (Bonnard et al., 2020; Colin & Pilgrim, 2020; Lecuna et al., 2020; Wang et al., 2020), those who rely on intermittent weather conditions also contribute to this number. As one of the essential components of the power system, the power cable became a popular subject during this period. The focus was on enhancing the reliability of power cables to withstand realistic dynamic loads and weather conditions, thereby optimizing conservative cable sizing and rating, and preventing cable failure. Lastly, in 2023, power cables remain a topic of discussion, with 112 publications, indicating that the topic of power cables is still relevant.

Publication Affiliations

Throughout the period of the subject, Table 3 displays the top ten influential affiliations that have contributed to the publication of power cable studies. Affiliations from China have contributed the highest number of publications, followed by Korea, Egypt, and then Italy.

Table 3
Top ten influential affiliations with record numbers

Affiliations	Records count	Country
Xi'an Jiaotong University	**44**	China
State Grid Corporation of China	**36**	China
Changwon National University	**34**	South Korea
Egyptian Knowledge Bank EKB	**31**	Egypt
China Southern Power Grid	**30**	China
Chongqing University	**30**	China
Korea Electrotechnology Research Institute Keri	**29**	Korea
University of Bologna	**29**	Italy
Korea Electric Power Corporation - KEPCO	**27**	Korea
North China Electric Power University	**27**	China

According to the table, Xi'an Jiaotong University in China has the highest productivity in publications, with 44 records. The State Grid Corporation of China, the world's largest power company and a government-owned entity, has 36 records, making it the second highest. Korea's Changwon National University, which currently owns 34 records, came next. The list continues, totaling 317 records. With just 27 records, the two lowest-ranked institutes demonstrate their ongoing improvement. Thus, China appears to be the home of the major research institutes, which have had a significant impact on the field of power cable research.

Records Trend Across Countries

Figure 3 illustrates the global trend in publications. Referring to the blue scale, which ranges from 1 to 363 records, China has the highest number of publications, with 363 records. The United States of America (USA) follows with almost half that number, at around 163 records. Japan and South Korea come next, with 136 and 126 records, respectively. This trend reflects the fact that these countries are among the world's largest economies. The list then continues with countries such as England, Italy, Germany, France, Poland, Canada, Sweden, Taiwan, and Egypt, arranged according to the color concentration on the blue scale.

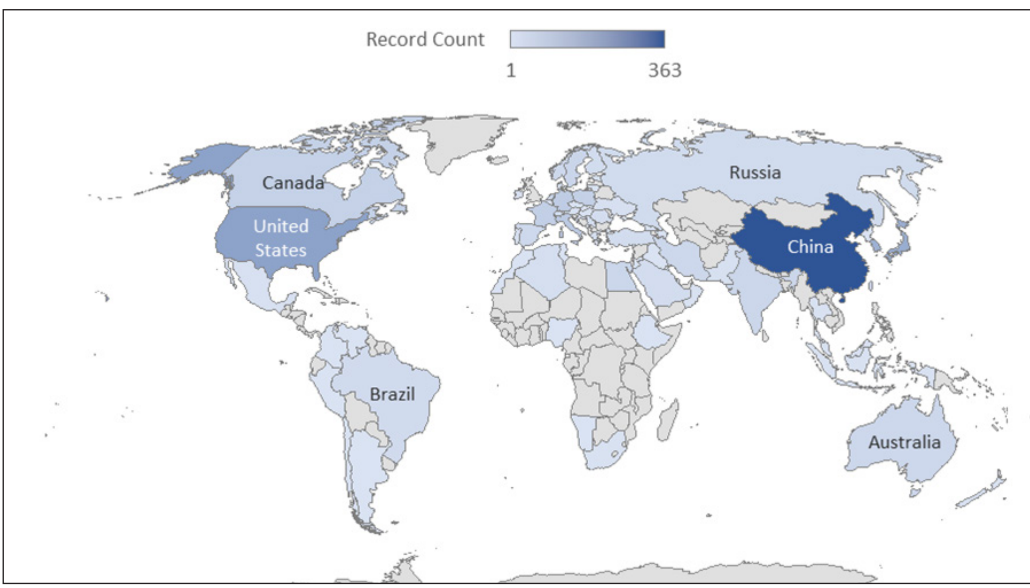

Figure 3. Publications trends across countries are represented by the concentrations on the blue scale, as shown in the legend

Authors' Productivity

As shown in Table 4, the top 10 authors are involved in the areas of electrical power engineering and cable research. For example, Minwon Park, who has 21 publications and studies in the fields of magnetic fields, superconductors, and critical current, is affiliated with Changwon National University. Next is Peter A. A. F. Wouters, a major in power cables, phase velocity, and dielectric constant, who has published 17 papers with Eindhoven University of Technology. After that, in third and fourth positions, Takato Masuda and Giovanni Mazzanti have each produced 16 publications, specializing in cable systems and thermal stress research. Lastly, the fewest publications are from Dardan Klimenta, a University of Pristina, Kosovo-affiliated author of 11 papers on energy systems, renewable energy sources, and capital costs.

Table 4
Top ten authors with publications retrieved from the Web of Science database

Researcher profiles	Records count	Research areas	Affiliations	Countries
Minwon Park (Park, Minwon)	21	Magnetic field, superconductors, critical current	Changwon National University	South Korea
Peter A. A. F. Wouters (Wouters, P. A. A. F.)	17	Power cables, phase velocity, dielectric constant	Eindhoven University of Technology	Netherlands
Takato Masuda (Masuda, T.)	16	Superconducting cable, cable system, power cable	Sumitomo Electric Industries Ltd.	Japan
Giovanni Mazzanti (Mazzanti, Giovanni)	16	Space charge, cable system, thermal stress	University of Bologna	Italy
In-Keun Yu (Yu, In-Keun)	15	Renewable energy, power system, photovoltaic power	Changwon National University	South Korea
Sastry Pamidi (Pamidi, Sastry)	13	Superconductors, cryogenics, electrical insulation	FAMU-FSU College of Engineering	Florida
Atsushi Ishiyama (Ishiyama, Atsushi)	12	Magnetic field, current flow, superconductors	Waseda University	Japan
Masayoshi Ohya (Ohya, M.)	12	Superconductor, liquid hydrogen, critical current	Sumitomo Electric Industries	Japan
Chul Han Kim (Kim, C. H.)	12	Superconductor, magnetic field, power cables	Florida State University	USA
Dardan Klimenta (Klimenta, Dardan)	11	Energy system, renewable energy, capital costs	University of Pristina	Kosovo

Scientometric Analysis

In this section, the scientometric results, including cluster mapping, references, document burst trend, author co-citations, and keyword trends, are analyzed and briefly described.

CiteSpace, a data visualizer software, is used in this study to visualize or plot the extracted data. Furthermore, CiteSpace can cluster the items identified by optional algorithms such as LLR and evaluate the burst of items to identify keywords with long-term burst and high strength (Liang et al., 2017).

Cluster Mapping Analysis

Figure 4 displays the clusters of records related to the keyword used in this paper. Most academic records were published in top-tier articles in the research area of power cables, including underground transmission lines, underground power cable systems, fault location, material advancements, overcurrent characteristics, and high-temperature applications.

Based on the size of clusters, the top three clusters, Cluster #0, Cluster #1, and Cluster #2, can be considered articles that have a significant influence in this area. They are studied under the topics of underground transmission lines, underground power cable systems, and fault locations, respectively, which are the three key elements in the study of electrical power systems. As shown in Figure 4, the label indicates the item, and the size of clusters is directly proportional to the number of publications in each cluster that included the keyword (Li & Li, 2018). The red spots on each label show the largest cluster in which the most articles were published in relation to their label in the average years.

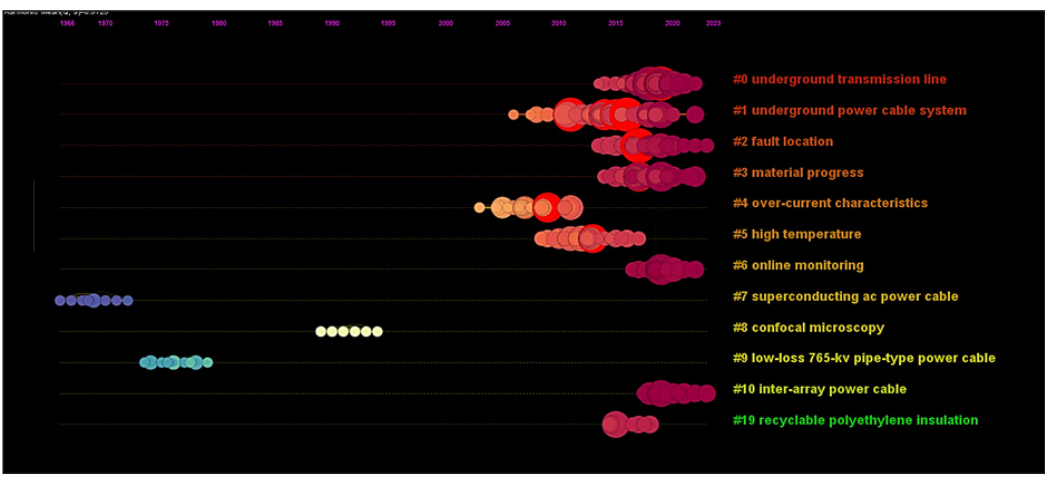

Figure 4. Cluster mapping based on cluster labels

Table 5 is shown to detail the information illustrated by Figure 4. The homogeneity of a cluster is represented by the "silhouette" in the table, the larger the silhouette, the stronger the relationship between the items in the clusters. Cluster #0, with the label “underground transmission line”, is the largest cluster, consisting of 63 articles, and is one of the hotspots in the research area in the 2018 average year. The second cluster, Cluster #1, labeled as the "underground power cable system", had an average of 50 articles per year in 2014. The next cluster, Cluster #3, has 44 articles published in the average year of 2017. This was followed by the other nine clusters, each with its respective label, as shown in Table 5. Lastly, the top three often cited articles for the top three largest clusters are shown in Tables 6-8.

Table 5
Cluster IDs and details based on cluster label

Cluster ID	Size	Silhouette	Label	Average year
0	63	0.927	Underground transmission line	2018
1	50	0.972	Underground power cable system	2014
2	44	0.976	Fault location	2017
3	43	0.994	Material progress	2017
4	37	1	Over-current characteristics	2007
5	37	0.99	High temperature	2012
6	34	0.975	Online monitoring	2018
7	29	1	Superconducting AC power cable	1968
8	20	1	Confocal microscopy	1990
9	20	1	Low-loss 765 kv pipe-type power cable	1976

Note. AC = Alternating current

Cluster #0**.** In this cluster, the most cited articles are listed in Table 6, with two published in 2018 and one in 2019. The research (Shabani & Vahidi, 2019) introduces an algorithm designed to calculate the most efficient cable ampacity. By utilizing heuristic optimization (ICA) and a probabilistic approach (Monte Carlo), the algorithm's objective function considers cable arrangement and backfill dimensions, incorporating parameter uncertainties to optimize ampacity and load current conformity while minimizing installation costs.

Similarly, the second paper (Cichy et al., 2018) employed a genetic algorithm to address the optimization of the underground power cable conductor. It considered factors such as ampacity, material, and labor costs in cable production, as well as the expenses associated with losses during its operation. Lastly, the next paper (Bustamante, Mínguez, et al., 2019) computed the ampacity of underground cables, incorporating variables such as soil resistivities and depths. The aim was to assess the risk of exceeding the maximum permissible cable temperature based on these variables, which is necessary to determine the cable's longevity.

Cluster #1**.** Table 7 lists the articles that have been the highlights in Cluster #1. Published in 2011, 2014, and 2016, respectively, the publications discuss the thermal analysis and performance analysis of underground electrical power cables. In order to ascertain the thermal resistance that exists between an underground electrical power cable and the ground

Table 6
Most cited articles in Cluster #0

Titles	Year
A probabilistic approach for optimal power cable ampacity computation by considering uncertainty of parameters and economic constraints (Shabani & Vahidi, 2019)	2018
Economic optimization of an underground power cable installation (Cichy et al., 2018)	2018
Thermal behaviour of medium-voltage underground cables under high-load operating conditions (Bustamante, Mínguez, et al., 2019)	2019

surface, the first paper (de Lieto Vollaro et al., 2011) carried out a significant number of numerical simulations for various values of the trench depth and width, the burial depth of the cable, the thicknesses of the two backfilling layers, and the cable bedding, along with their respective thermal conductivities and the thermal conductivity of the mother soil.

Aside from that, a new thermal backfill material, Lafarge Gruntar, is suggested in the following research (Ocłoń et al., 2016). Its performance in relation to water content and time is analyzed for various mass fractions, such as 5%, 10%, and 15%, to maximize the underground power cables' thermal performance. The next paper (Kroener et al., 2014) also investigated the thermal behavior of the underground cables. The heat dissipation from the cables was described by a computational model of linked liquid water, vapor, and heat.

Table 7
Most cited articles in Cluster #1

Titles	Year
Thermal analysis of underground electrical power cables buried in non-homogeneous soils (de Lieto Vollaro et al., 2011)	2011
The performance analysis of a new thermal backfill material for underground power cable (Ocłoń et al., 2016)	2016
Numerical simulation of coupled heat, liquid water and water vapor in soils for heat dissipation of underground electrical power cables (Kroener et al., 2014)	2014

Cluster #2**.** In this cluster, Cluster #2 has three other articles published, as shown in Table 8, that discuss cable durability and lifetime. To maximize the operational value of cable assets while maintaining the cable life cycle, a 2017 paper (Zhou et al., 2017) offers a thorough analysis of current research and development in the areas of cable fault diagnosis, condition monitoring and diagnosis, life assessment techniques, fault location, and optimization of maintenance and replacement strategies.

Finally, the following two studies (C.-K. Chang et al., 2019; Dong et al., 2017) demonstrated the simulation of sheath system currents in a cross-bonded cable system analysis and offered affordable and workable decision tree rules for an online partial discharge (PD) monitoring device to assess the viability of fault diagnosis and accomplish condition-based maintenance in distribution power cables.

Table 8
Most cited articles in Cluster #2

Titles	Year
Review of recent research towards power cable life cycle management (Zhou et al., 2017)	2017
Online monitoring and diagnosis of HV cable faults by sheath system currents (Dong et al., 2017)	2017
Decision tree rules for insulation condition assessment of pre-molded power cable joints with artificial defects (C.-K. Chang et al., 2019)	2019

References Analysis (Document Co-citation Analysis)

Researchers might access several of the most relevant articles with creative concepts and trustworthy experimental results. Thus, this document's co-citation analysis is performed to assist in identifying important literature for cross-disciplinary concepts. Figure 5 illustrates the interaction between high-citation articles. The node's label represents the name and publication year of the author, and the thickness of the node is determined by the frequency of its mention.

According to Figure 5, studies by Bicen (2017), Bustamante, Manana, et al. (2019), and Dinmohammadi et al. (2019), are among the highly cited articles based on the node size. Briefly, their papers highlight the monitoring of underground power cable lifetimes using a trend-adjusted methodology, calculate dissolved gas analysis (DGA) limit values and optimal sampling intervals, and develop predictive models for assessing damage and

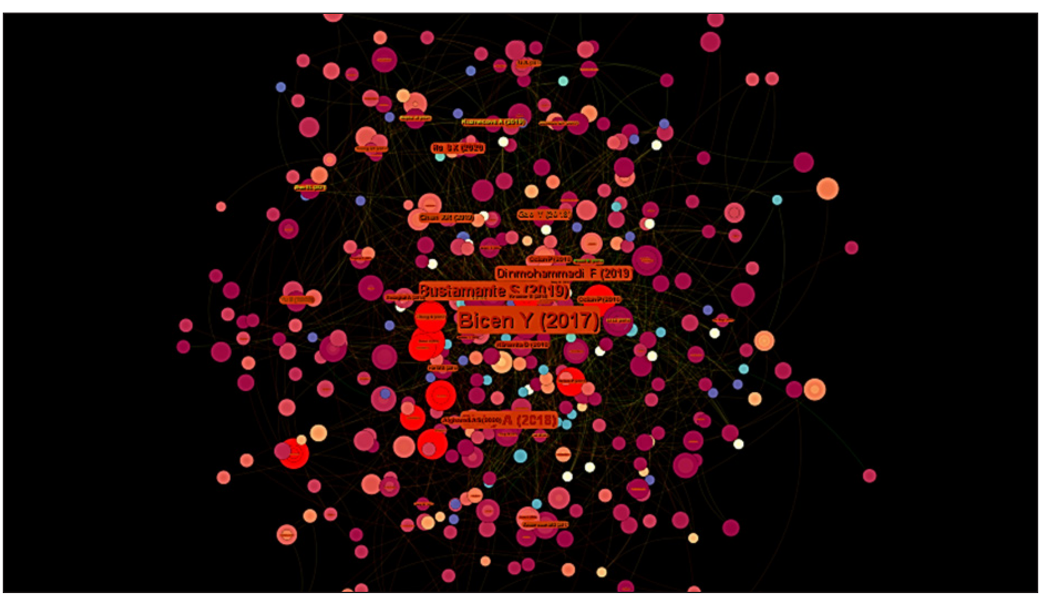

Figure 5. Articles' co-citation analysis on power cables research

estimating the life expectancy of subsea power cables, aiming to enhance reliability and inform maintenance planning.

To provide better clarity for analysis, Table 9 shows the centrality and sigma values of each article that cited authors' articles (displayed in Figure 5). The centrality of 0.01 for each article means that the same factors have the same values in terms of how close they are to one another and how information flows through them. Sigma, on the other hand, is the total of the burstiness and centrality scores, with the highest value corresponding to high-value research publications. Therefore, the top three articles, with a sigma value of 1.04, are the most influential ones, followed by the two articles with a sigma score of 1.03.

Collectively, the research in Table 9 encompasses advancements in thermal management and diagnostic techniques for underground power cables. Studies on novel thermal backfill materials and coupled heat, liquid water, and vapor movements in soils demonstrate significant improvements in heat dissipation and cable performance. The reviews of power cable life cycle management highlight emerging diagnostics and maintenance strategies enhancing reliability. Next, innovations in online monitoring using sheath system currents provide real-time fault detection for high-voltage cables. Lastly, numerical simulations of heat dissipation processes in thermal backfills and multilayered soils underscore the importance of material and design choices in optimizing underground cable efficiency and lifespan.

Table 9

The top five co-citation articles score

Title	Centrality	Sigma
Numerical simulation of coupled heat, liquid water and water vapor in soils for heat dissipation of underground electrical power cables (Kroener et al., 2014)	0.01	1.04
The performance analysis of a new thermal backfill material for underground power cable system (Ocłoń et al., 2016)	0.01	1.04
Review of recent research towards power cable life cycle management (Zhou et al., 2017)	0.01	1.04
Numerical simulation of heat dissipation processes in underground power cable system situated in thermal backfill and buried in a multilayered soil (Ocłoń et al., 2015)	0.01	1.03
Online monitoring and diagnosis of HV cable faults by sheath system currents (Dong et al., 2017)	0.01	1.03

Note. HV = High-voltage

Document Burst Trend Over the Years

Table 10 depicts the trend of top publications with the most powerful citation bursts, where the period of each burst is represented by the red line on the blue timeline (from 1970 to

Table 10
The burst trend of the most influential documents between 1970 and 2023

References	Year	Strength	Begin	End	1970 - 2023
A new HTS cable project in Japan (Masuda et al., 2009)	2009	5.49	2011	2013	
Phase II of the Albany HTS cable project (Yumura et al., 2009)	2009	4.26	2011	2013	
Thermal analysis of underground electrical power cables buried in non-homogeneous soils (de Lieto Vollaro et al., 2011)	2011	5.85	2013	2016	
Numerical simulation of coupled heat, liquid water, and water vapor in soils for heat dissipation of underground electrical power cables (Kroener et al., 2014)	2014	5.26	2015	2018	
Update of YOKOHAMA HTS cable project (Yumura et al., 2013)	2013	4.54	2015	2017	
Numerical simulation of heat dissipation processes in underground power cable system situated in thermal backfill and buried in a multilayered soil (Ocłoń et al., 2015)	2015	5.85	2016	2018	
The performance analysis of a new thermal backfill material for underground power cable system (Ocłoń et al., 2016)	2016	4.55	2017	2021	
Linescout Technology opens the way to robotic inspection and maintenance of high-voltage power lines (Pouliot et al., 2015)	2015	4.74	2018	2019	
Review of recent research towards power cable life cycle management (Zhou et al., 2017)	2017	4.82	2019	2023	
Online monitoring and diagnosis of HV cable faults by sheath system currents (Dong et al., 2017)	2017	4.42	2019	2023	
A probabilistic approach for optimal power cable ampacity computation by considering uncertainty of parameters and economic constraints (Shabani & Vahidi, 2019)	2019	5.57	2020	2023	
Polypropylene based thermoplastic polymers for potential recyclable HVDC cable insulation applications (X. Huang et al., 2017)	2017	4.17	2020	2023	

Note. HTS = High-temperature superconducting; HVDC = High voltage direct current

2023). A burst reflects the emergence of a keyword in a publication during a specific time. As some of the articles from this table have been reviewed in the previous subsection, the remaining articles (Masuda et al., 2009; X. Huang et al., 2017) will be reviewed in this subsection first, and then the burst trend will be explained.

The articles focus on advancements in high-temperature superconducting (HTS) and high-voltage power cable technologies. Masuda et al. (2009) discuss a new HTS cable project in Japan aimed at enhancing power transmission efficiency using superconductors. Yumura et al. (2009) cover Phase II of the Albany HTS Cable Project, emphasizing improvements in cable performance and reliability. Their 2013 update (Yumura et al., 2013) on the Yokohama HTS Cable Project highlights progress in the deployment and operational testing of HTS cables.

Next, Pouliot et al. (2015) introduce LineScout Technology, a robotic system for inspecting and maintaining high-voltage power lines, aiming to increase safety and efficiency in power line maintenance. Lastly, X. Huang et al. (2017) explore polypropylene-based thermoplastic polymers for HVDC cable insulation, focusing on the potential for recyclability and improved electrical properties. Together, these studies aim to enhance power transmission infrastructure through innovative materials and technologies.

From the table, the third (de Lieto Vollaro et al., 2011) and sixth (Ocłoń et al., 2015) publications that studied the underground power cable thermal analysis and heat dissipation have the same strongest burst, 5.85, which were published in 2011 and 2015, respectively. The papers were maintained as popular publications for four years, from 2013 to 2016, and for three years, from 2016 to 2018, respectively. Next, the second last paper that was published in 2019 (Shabani & Vahidi, 2019) is one of the highest strengths of burst, 5.57. This paper started to call out a year after its publication, that is, 2020, and remained the hot topic in power cable research until 2023, along with the last paper that was published in 2017 (X. Huang et al., 2017) with the strength of the burst is 4.27. The other two papers that are still bursting until 2023 are Zhou et al. (2017) and Dong et al. (2017), which were both published in 2017 with burst strengths of 4.48 and 4.42.

Authors Co-citation Analysis

The network of authors' co-citations is shown in Figure 6, with the thickness of the lines connecting authors' names signifying the degree of collaboration. The font size corresponds to the number of published articles on which the other authors have collaborated, and the publication date determines the color of the ring. Since the author's name stood out the most among the others, it is evident that R. Bartnikas et al. is the most closely linked author. Next, G. Mazzanti came in second, followed by A. Ametani in third.

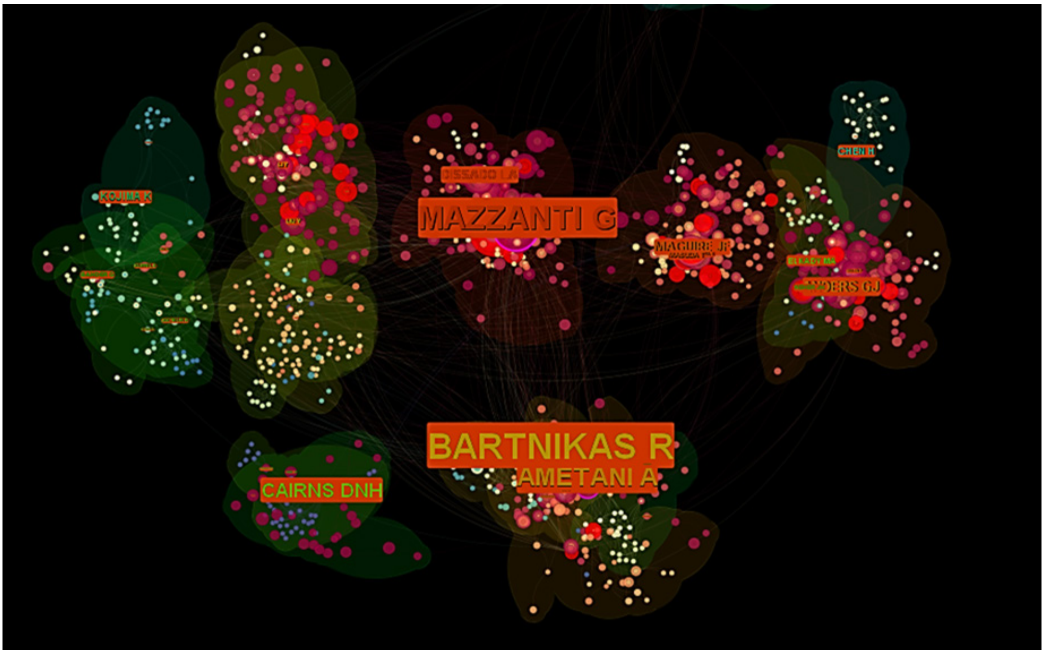

Figure 6. Networks of authors' co-citations

Nevertheless, the authors listed in Table 11 below are the most pertinent, as they are the top co-citation authors related to this field after narrowing the search parameters. James F. Maguire came in first with 0.07 centrality and a 1.84 sigma value. Given that J. F. Maguire's papers have the greatest sigma value, which presents a high degree of centrality, this indicates that he is a highly valued author of research articles.

Although Gian Carlo Montanari placed second with a 1.67 sigma value, Gian Carlo Montanari has the highest centrality, 0.09, which has a significant impact on the behavior of the research area since the centrality indicates the degree of influence one author has over another. Next, Takato Masuda, who also has a 1.67 sigma value, has a centrality of 0.04. Steven A. Boggs followed this with 0.04 and 1.44 for centrality and sigma value. Finally, Shinichi Mukoyama has the lowest centrality and sigma values, which are 0.02 and 1.32.

Table 11
The authors with the highest score of co-citation

Author	Centrality	Sigma
James F. Maguire	0.07	1.84
Gian Carlo Montanari	0.09	1.67
Takato Masuda	0.04	1.67
Steven A. Boggs	0.07	1.44
Shinichi Mukoyama	0.02	1.32

Keyword Burst Trend Over the Years

The top 20 related keywords with the strongest citation bursts are displayed in Table 12, which displays the concentrations in study areas and new trends over the years. In this keyword analysis, the keywords that the burst line represents an outburst in each field of study at a given time. The time span of each keyword burst is indicated by the corresponding red line on the blue timeline (from 1970 to 2023), as shown in the burst analysis above. From the table, the term "XLPE", which stands for cross-linked polyethylene, a thermoset insulation material commonly used in electrical cable for power transmission and distribution, has the longest burst duration among others.

From 1999 to 2013, the term was used widely for 14 years, with a burst strength of 4.4. Moreover, in 2016, the same keyword, "XLPE insulation", was used and had the second strongest burst strength, which is 11.15, for two years, beginning from 2018 to 2020. The term "power cable insulation" has been in use for 4 years, from 2019 to 2023, and has the highest burst strength, which is 13.3, indicating that it has been widely used in many research documents to date. Besides that, the term "power cables" holds the third-highest burst strength, which is 11.05, and has also become the central topic of research until 2023, along with the terms "cable shielding", "temperature measurement", and "diagnosis", with the burst strengths of 5.77, 4.3, and 4.19, respectively.

DISCUSSION

In this section, the results obtained from the scientometric analysis performed in this paper are briefly described. This discussion answers the research questions stated in the introduction above.

The Overall Publication Trends in Terms of Output

From a general analysis, the fact that the total number of citations from 1,377 retrieved articles was 15,204, and the average number of citations per article was 11.04, indicates the significant impact of the research over the period. The most cited article, which has made the most impactful contributions to the field of power cable research, was identified with 225 citations. Furthermore, from 2013 to 2023, the total number of articles published has grown dramatically, and this trend is expected to continue in the coming years. The results section discusses these trends, highlighting factors like COVID-19 and the integration of renewable energy and smart grids. These are driven by rapid technological advancements, the urgency to address climate change, and policies, subsidies, and incentives promoting renewable energy and smart grids to achieve SDGs such as SDG 7, SDG 9, SDG 11, SDG 12, and SDG 13 (Arora & Mishra, 2019).

Table 12
The burst trend of the notable keywords from 1970 to 2023

Keywords	Year	Strength	Begin	End	1970 - 2023
XLPE	1999	4.40	1999	2013	
Dielectric breakdown	2001	5.86	2001	2009	
AC loss	2004	6.56	2004	2013	
Superconducting cables	1992	7.33	2006	2011	
Superconducting power cable	2007	5.11	2007	2017	
Transmission lines	2008	5.24	2008	2015	
System	2008	4.23	2008	2018	
High-temperature superconductors	2009	5.93	2009	2016	
HTS power cable	2002	4.94	2009	2014	
Fault current	2009	4.52	2009	2016	
Power cable connecting	2009	4.28	2009	2014	
Partial discharge	1996	4.58	2012	2014	
Transients	2013	4.49	2013	2017	
Space charge	2001	4.97	2017	2020	
XLPE insulation	2016	11.15	2018	2020	
Power cable insulation	2011	13.30	2019	2023	
Cable shielding	2009	5.77	2020	2023	
Temperature measurement	2020	4.30	2020	2023	
Power cables	1992	11.05	2021	2023	
Diagnosis	2018	4.19	2021	2023	

Note. XLPE = Cross-linked polyethylene; AC = Alternating current; HTS = High-temperature superconducting

Next, China is the leading country in the field of research on affiliated power cables, as evidenced by the contributions of five institutions to research publications. This is due to the Chinese government's implementation of strong policy initiatives and substantial funding to support research and development (R&D) in the energy sector (Sandalow et al., 2022). However, the USA has published the most resourceful records in the world, followed by Japan and South Korea. This statement is then supported by the fact that the top ten authors are mainly from Japan, Korea, and the USA, having published the most relevant records, totaling 101 publications. This indicates that advanced-economy countries, such as the USA, Japan, and Korea, are at the forefront of this industry, as these countries have dedicated significant government and industry funding to energy research, fostering collaboration on low-carbon and carbon-free energy technologies (U.S. Department of Commerce, 2024).

The Central Topics and Their Temporal Evolution

According to the cluster analysis, "underground transmission line", "underground power cable system", "fault site", and other terms were the most popular study subjects and directions. The focus of research has been on improving cable ampacity and its durability against critical environmental and load conditions.

Moreover, in the past decade, power cable research has focused on improving superconducting cables and power (2010-2017), enhancing insulation (2019-2023), and advancing diagnostic and measurement technologies (2020-2023). Efforts in superconducting materials aimed to increase efficiency and capacity, while insulation research focused on durability and performance. Diagnostic advancements are geared towards predictive maintenance and real-time monitoring. High-temperature superconductors (2016-2023) also received attention for their potential to overcome conventional limitations.

Looking ahead, research will likely concentrate on diagnostic systems, high-performance insulation materials, renewable energy integration, and smart grid technologies soon. In the far future, advancements in superconducting technologies, nanotechnology, eco-friendly materials, and cyber-physical systems will be crucial. Dynamic Line Rating (DLR) or Dynamic Current Rating (DCR) are recent instances of technologies that have been acknowledged as a continuing trend (Fariz et al., 2024). In addition to these advancements, future research is expected to focus on the integration of sensors, artificial intelligence (AI), and machine learning (ML) for real-time grid optimization, fault detection, and predictive maintenance of power transmission systems, as in a study by Radzi et al. (2021), where an ultrasonic sensor is used for detecting partial discharges.

Moreover, the application of advanced thermal modelling techniques, including computational fluid dynamics (CFD) simulations, will improve the accuracy of cable rating assessments, particularly for cables installed in tunnels or densely populated urban areas. Research into high-voltage direct current (HVDC) transmission and flexible AC transmission systems (FACTS) will also gain momentum, as these technologies provide enhanced efficiency and stability for long-distance power delivery. These evolutions reflect the ongoing drive for efficient, reliable, and sustainable power transmission solutions. Research on these targeted topics has also been ongoing for a substantial period, as the results of this study could have long-term benefits for the national grid and power utility companies, including lower installation, maintenance, and operating costs, while also contributing to the achievement of the SDGs.

The Most Influential Publications in These Domains

The analysis of document co-citation reveals that articles by Bicen (2017), Bustamante et al., and Dinmohammadi et al. (2019) are among the most cited, indicating that their publications have made significant contributions to various studies related to power cables. After the scope of data has been constrained, the most relevant and influential publications are those that study heat and thermal analysis, which influence the cables' lifecycle and cable fault diagnosis. These publications have recently become the focus of interest in the power cables domain. Additionally, since James F. Maguire and Gian Carlo Montanari have a greater degree of influence than other authors, based on their centrality and sigma values in author co-citation analysis, their publications have a substantial impact on the behavior of the research area.

The Most Impactful Publications and Keywords

The concentrations in power cable research areas and new trends over the years have been discovered using document and keyword burst trend analysis. From the results, both articles, which have the strongest burst in document burst analysis, are the most impactful publications, providing clear insight into the thermal and heat dissipation analysis of underground power cables with variable soil parameters. These studies may have catalyzed numerous existing research projects or further potential publications on the thermal behavior of underground power cables.

Apart from that, the most impactful keyword, as indicated by the keyword burst trend analysis, is power cable insulation, a crucial component in the design of power cables that is necessary for the reliable transfer of energy under various load conditions. This keyword may have been applied in conjunction with other keywords mentioned in the results section, as it refers to a common component that prevents heat, sound, or electric current from escaping or entering the cables.

CONCLUSION

Power cables are among the crucial parts, particularly in the field of electrical engineering, that require extensive research to ensure the most dependable and economical installation, maintenance, and use of cables, given their importance as a national grid and electrical utility company asset. In this paper, the scientometric analysis is performed to identify significant research gaps and suggest future paths by assembling a collection of relevant studies from different power cable studies.

Thus, this study has provided a thorough overview of the existing research collection, illustrating the chronological evolution of power cables over time, as well as the influential papers, countries, and authors recognized in this discipline. Furthermore, the core content of this paper is how to use an appropriate search scheme to develop cable from a literature perspective. For future studies, authors could map these research topics and possibly pinpoint missing relationships by comparing other databases with WoS. Subsequent studies may also examine the significant partnerships between nations and writers, as well as compare outcomes utilizing the widely used scientometric analytic software, such as VOSviewer.

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