TELKOMNIKA Telecommunication Computing Electronics and Control
Vol. 23, No. 6, December 2025, pp. 1687~1695
ISSN: 1693-6930, DOI: 10.12928/TELKOMNIKA.v23i6.26976

Lightning studies on effects on distribution lines: a bibliometric analysis

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Article Info

Article history:

Received Feb 8, 2025
Revised Sep 17, 2025
Accepted Oct 19, 2025

Keywords:

Bibliometry
Distribution line
Induced voltage
Lightning
PRISMA

ABSTRACT

The study of lightning effects on distribution lines is of vital importance for the reliability and safety of electrical systems, as lightning is one of the main causes of failures. The purpose of this study is to perform a bibliometric analysis to evaluate academic productivity trends and research trajectories in this field. The methodology was based on a comprehensive search of the Scopus database, from which a total of 545 articles published between 1932 and 2024 were analyzed. For the analysis, the VOSviewer tool and the Bibliometrix library in R were used. The results reveal a constant increase in productivity since the 1970s, with Japan and China emerging as the most prolific countries. The research has evolved from early theoretical and experimental studies toward the use of advanced computational models and, more recently, the application of machine learning techniques for fault detection. In conclusion, the findings of this study provide a consolidated view of the field, which is fundamental for engineers to be able to design more robust protection systems and to guide future research toward model validation and the integration of renewable energy technologies.

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1. INTRODUCTION

The study of lightning's impact on distribution lines is of significant interest because these aerial infrastructures are inherently exposed to the effects of thunderstorms [1]. Lightning is identified as a primary cause of network failures, causing damage through both direct strikes and overvoltages induced by indirect discharges. Induced overvoltages that exceed a line's critical flashover voltage (CFO) can lead to a series of serious consequences. These include power service interruptions [2]–[5], significant infrastructure damage due to the low CFO of distribution systems [6], impacts on the stability and reliability of the power supply [7], and risks to users who interact closely with these networks [8]. Therefore, understanding the effects of lightning-induced voltages is crucial for implementing effective protection measures that maintain an acceptable level of reliability in distribution systems [9]. Achieving this reliability optimization is fundamental for mitigating economic losses for both consumers and service providers [10].

Some pioneering studies in this field were those carried out in 1908 by Wagner [11], who assumed that the charge of a storm cloud situated over a transmission line could induce charges of opposite polarity in the line and that when the cloud was discharged by the effect of lightning, traveling waves were produced through the line, thus generating the induced voltage on the line. Wagner's study is based on the concept of electrostatic induction generated by a charged cloud [12]. His model postulates that, following a lightning strike, the charge initially distributed on the line dissipates into two waves that propagate in opposite directions. Since Wagner assumes a line with open ends, these waves are reflected at the terminals, creating a superposition phenomenon that results in transient overvoltages. Another relevant study, whose model has been incorporated into the IEEE Std 1410 standard, was developed in 1958 by Rusck [13]. This work proposed a theory to calculate the induced voltage from indirect strikes, considering both the vector and scalar potentials. For his model, Rusck conceptualized the distribution line as a single, lossless, infinitely long conductor over a perfectly conducting ground. Based on this simplification, he calculated the induced voltage at the point on the line closest to the lightning strike, using the scalar potential as the primary variable.

$$V \frac{Z_O I_O h}{d}\left(1+\left(\frac{1}{\sqrt{2}}\frac{v}{c}\frac{1}{\sqrt{1-\frac{1}{2}\left(\frac{v}{c}\right)^2}}\right)\right)_{max} \quad (1)$$

where:
- Z_0 = 30 Ω
- c = speed of light
- v = velocity of the return stroke
- h = average height between the ground and the line conductor
- d = distance between the line and the lightning strike point
- I_0 = peak current of the return stroke

The study of the effect of lightning on distribution lines is essential to ensure the reliable and safe operation of electric power systems. The results of these studies allow engineers to design more resilient systems, implement effective protection measures, and optimize system performance in areas prone to lightning. For this reason, and considering the evolution of technology that has taken place since 1958, when Rusck presented his model to calculate induced voltage, this article seeks to answer the research questions: What has been the behavior of academic productivity on the effects of lightning on distribution lines? What trends can be observed? To answer these questions, the proposed method is to perform a bibliometric analysis. This analysis is justified by the need to consolidate the most relevant works into a single document and identify new research areas. This consolidation will enable researchers and electrical distribution line designers to implement protective measures and identify areas for further investigation. Finally, this article aims to analyze academic production trends, identify the most relevant authors, and examine the most impactful articles.

2. METHOD

A bibliometric analysis was performed to understand research trends, productivity, and establish metrics [14], [15]. This analysis utilized VOSviewer (version 1.6.19) [16] and the Bibliometrix library (version 5.1.0) in R software [17]. These tools employ robust algorithms to create networks and clusters, which ensures that the graphical representations are reliable and accurate.

The Scopus database was consulted in 2025. The data cleaning process involved two main exclusion criteria: i) non-article records were discarded and ii) documents written in languages other than English were eliminated. This process was essential to ensure that the final dataset of 545 records was homogeneous and relevant for analysis.

Given the need to observe the entire temporal trajectory of productivity, no temporal restriction was applied. The search equation used was: lightning AND “distribution lines”. A total of 545 records were obtained, made by 979 authors, and published in 115 journals, in a time window from 1932 to 2024. Finally, the 10 most cited articles in the entire time window were analyzed, and then the 10 most cited between the years 2014-2024 to identify more recent trends.

3. RESULTS AND DISCUSSION

3.1. Publications by year

Figure 1 shows the temporal distribution of scientific productivity. The growth rate has been 3.65%, a value obtained by excluding data from 2024. Publications began in 1932 with a single document, followed by a gap until 1953, when two articles were published. The years 1967, 1968, and 1970 marked the earliest period of notable productivity, with four documents published. Since 1979, a consistent increasing trend in productivity has been observed, continuing to the present day, with no subsequent years having zero article production. It should be noted that the productivity for 2024 is understated, as not all records for that year had been consolidated in Scopus at the time of the search.

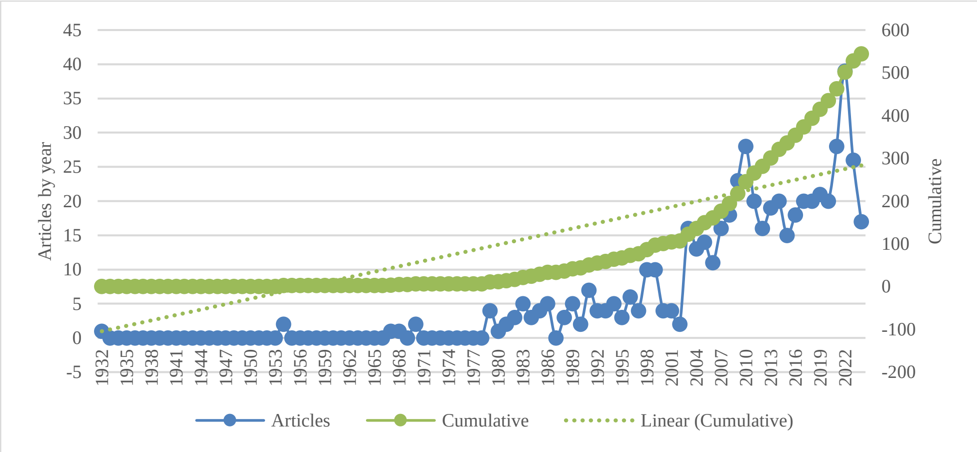

Figure 1. Temporal evolution of productivity

The first paper on this topic, published and indexed in Scopus in 1932, was by Harding and Sprague [18]. In it, the authors analyzed various possible connections for transformers and protection devices in 4,000 V and 115-230 V overhead power distribution systems. To do so, they built an experimental five-span distribution system with an isolated artificial cloud. This cloud was charged using a surge generator to induce steep-wavefront transient potentials in the distribution system, simulating the effects of lightning.

The most recent publication [19] proposed a method to assess the lightning risk on active distribution lines with distributed photovoltaic (PV) systems. The authors built a lightning simulation model in alternative transients' program (ATP) based on lightning activity information and line parameters of a PV system connected to a 10-kV distribution system. From this model, they calculated the annual power loss rate of the PV system and the lightning trip rate of the line-side towers. Relevant findings indicate that the tower closest to the PV side experiences the highest lightning risk and the highest lightning trip rate. They also observed that a lightning strike on one side of an active distribution line will affect the other side.

A significant change in the analysis technologies used can be observed between the first publication (1932) and the last (2024). In 1932, the research was based on physical experiments, while the 2024 study utilized software simulations and applied them to a modern renewable energy technology like PV systems.

3.2. Distribution of publications by journal

Table 1 shows the 10 most relevant journals in terms of the number of articles related to the effects of lightning on power distribution lines. The most representative journal is IEEE Transactions on Power Delivery, which is in the first quartile (Q1 of the Scimago Journal Ranking SJR) and accounts for 17% of the published articles. From the Table 1, it is possible to conclude that 39% of the published articles are in Q1 journals, 5% in Q2, 17% in Q3, and 9% in Q4. Geographically, China is the country with the largest number of journals located among the 10 most relevant.

Table 1. Main sources of publications

Sources	Articles	%	SJR[1]	Country
IEEE Transactions on Power Delivery	94	17%	Q1	United States
IEEJ Transactions on Power and Energy	81	15%	Q3	Japan
IEEE Transactions on Electromagnetic Compatibility	60	11%	Q1	United States
Electric Power Systems Research	49	9%	Q1	Netherlands
Electrical Engineering in Japan (English Translation of Denki Gakkai Ronbunshi)	28	5%	Q4	Japan
Gaodianya Jishu/High Voltage Engineering	27	5%	Q2	China
Dianwang Jishu/Power System Technology	12	2%	Q1	China
Transactions of the Korean Institute of Electrical Engineers	11	2%	Q4	South Korea
Gaoya Dianqi/High Voltage Apparatus	10	2%	Q3	China
IEEE Transactions on Power Apparatus and Systems	9	2%	Q4	United States

[1]Scimago journal rank

3.3. Author productivity

Table 2 shows the 10 authors with the highest number of published articles. The top four authors are from Japan, and the country has a total of six authors in this ranking. China follows with two authors, while Brazil and Italy each have one.

Table 2. Most relevant authors

Authors	Articles	Institution	Country
Yokoyama Shigeru	44	Shizuoka University	Japan
Asakawa Akira	43	Electric Power Engineering Research Lab	Japan
Okabe Shigemitsu	33	Tokyo Electric Power Company Holdings, Inc	Japan
Ishimoto Kazuyuki	28	Grid Innovation Research Laboratory Central Research Institute of Electric Power Industry	Japan
Wang Jianguo	26	Wuhan University	China
Miyazaki Teru	22	Tokyo Electric Power Company Limited	Japan
Piantini Alexandre	21	University of São Paulo	Brasil
Nucci Carlos Alberto	20	University of Bologna	Italia
Cail Li	17	Wuhan University	China
Sekioka Shozo	17	Shonan Insttute of Technology	Japan

3.4. Productivity geographic distribution

Figure 2 shows the geographical distribution of productivity. Japan leads with 16%, followed by China (15.4%), Brazil (6.4%), and Italy (5.3%). This is consistent with the findings on the most productive authors, where six of the top 10 authors are from Japan, followed by China, Brazil, and Italy, in that same order. This indicates a direct relationship between the location of the most productive authors and the overall geographical distribution of academic productivity.

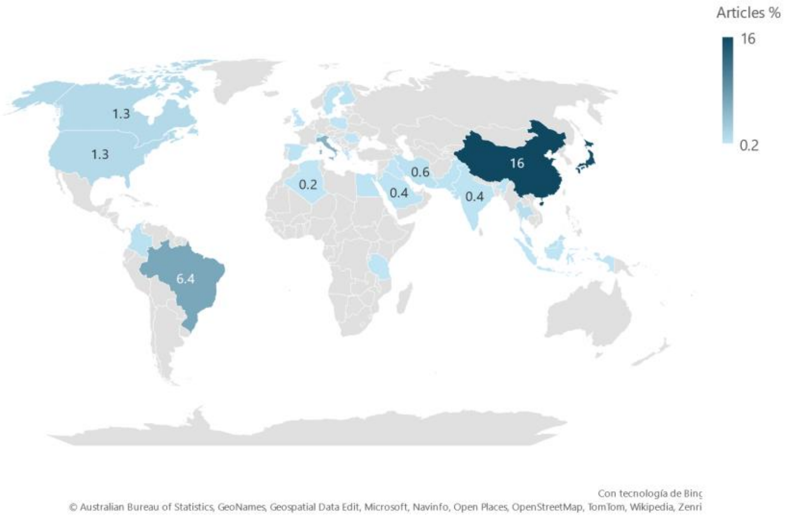

Figure 2. Geographical distribution of productivity

3.5. Keyword co-occurrence

For the author’s keyword co-occurrence analysis, the minimum occurrence threshold was 7, resulting in 6 groups, which are presented in Table 3 and visually in Figure 3. The analysis of the keyword co-occurrence network, shown in Figure 3, visually validates the field’s thematic structure and confirms the existence of well-defined research areas. The blue cluster, with the highest centrality, highlights the primary relevance of studying induced overvoltages and the characteristics of the lightning return stroke, employing mathematical tools like the discrete fourier transform (DFT). The other main clusters green, yellow, and purple focus on the mitigation of lightning effects, covering everything from protection measures like surge arresters and shield wires to statistical analysis methodologies such as the Monte Carlo method. Finally, the red and aquamarine clusters complement this structure by focusing on fundamental concepts of the phenomenon, such as flashover and the distinction between direct and indirect strikes.

Table 3. Cluster

Cluster	Color cluster	Palabras
1	Red	Flashover, insulation, lightning impulse, lightning surge, pole, software
2	Green	Direct lightning, electromagnetic transient, indirect lightning, lightning protection, overhead distribution lines, shield wires
3	Blue	Discrete fourier transform (FTTD), induced overvoltage, lightning current, return stroke, triggered lightning
4	Yellow	Arresters, grouding, overhead ground wire, power system lightning
5	Purple	Lightning performance, mote carlo method, overvoltage protection
6	Aquamarine blue	Direct lightning stroke, indirect stroke

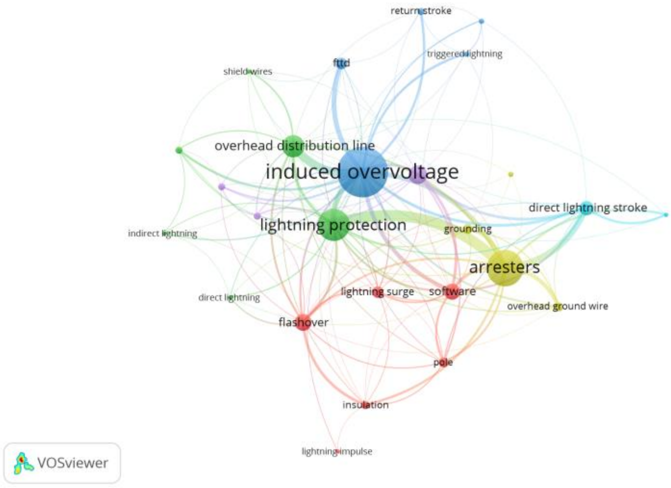

Figure 3. Keyword co-occurrence network

3.6. Most relevant articles

Table 4 shows the most relevant articles (highest number of citations) in the window from 1932 to 2014, with their respective title, DOI year, and total citations. Some of the articles have had the same author as their main author; to visualize this in Table 4 the articles by each author have been highlighted with a color code. In Table 5 the code in question can be seen. The author Yokoyama Shigeru has 3 of the most cited articles on the subject, followed by Piantini Alexandre and Paolone Mario (2 articles) and finally by Barker Philip and Borghetti Alberto (1 article).

Table 4. Most relevant articles in the time window from 1932 to 2014

Paper	Year	DOI	Total citations
An improved procedure for the assessment of overhead line indirect lightning performance and its comparison with the IEEE Std. 1410 method	2007	10.1109/TPWRD.2006.881463	175
Mitigation of lightning-induced overvoltages in medium voltage distribution lines by means of periodical grounding of shielding wires and of surge arresters: modeling and experimental validation	2004	10.1109/TPWRD.2003.820196	173
Induced voltage measurements on an experimental distribution line during nearby rocket triggered lightning flashes.	1996	10.1109/61.489360	134
Lighting - induced overvoltages on overhead distribution lines	1982	10.1109/TPAS.1982.317162	106
A scale model for the study of the LEMP (lightning electromagnetic pulse) response of complex power distribution networks	2007	10.1109/TPWRD.2006.881410	104
Calculation of lightning-induced voltages on overhead multiconductor systems	1984	10.1109/TPAS.1984.318583	95
Lightning induced disturbances in buried Cables—part II: experiment and model validation	2005	10.1109/TEMC.2005.853163	94
Lightning-induced voltages on overhead Lines—application of the extended rusck model	2009	10.1109/TEMC.2009.2023514	90
Experimental study of response of power distribution lines to direct lightning hits	1989	10.1109/61.35653	80
Advanced observations of lightning induced voltage on power distribution lines	1986	10.1109/TPWRD.1986.4307943	78

Table 5. Color code by author

Author	Color
Piantini Alexandre	
Paolone Mario	
Yokoyama Shigeru	
Barker Philip	
Eriksson A. J	
Borghetti Alberto	

A review of the most relevant articles demonstrates the evolution of research on lightning-induced overvoltages in distribution lines. Pioneer studies focused on empirical validation, such as the work by Eriksson *et al.* [20], which used a 10 km experimental line to confirm that simple theoretical models could predict voltage amplitudes. Subsequently, research shifted toward computational modeling, with milestones like the finite-difference program developed by Yokoyama [21] to analyze the effects of surge arresters and shield wires. The work of Yokoyama and his collaborators continued to validate their models, highlighting the importance of simultaneous measurements of lightning parameters [22] and the experimental confirmation of the effectiveness of protections against direct strikes [23].

Later, research focused on improving the precision of existing models. For example, Barker *et al.* [24] showed that the models of the time, such as Rusck's, underestimated induced voltages, which led to a refinement of calculation methods. Authors like Paolone *et al.* [25] proposed advanced models that considered line discontinuities and extended the analysis to phenomena in buried cables [26]. Researchers [27]-[29], validated and refined these approaches, applying statistical methods like the Monte Carlo method and the extended rusck model (ERM) for a more precise evaluation of flashover rates and the mitigation of overvoltages. To explore the most recent advances in the subject, the reference base obtained from Scopus was filtered for the years 2014 – 2024, to obtain the 10 most cited articles in that time window Table 6.

Table 6. Most relevant articles in the 2014-2024 Window

Paper	Year	DOI	Total citations
Three-dimensional FDTD (finite difference time domain) calculation of lightning-induced voltages on a multiphase distribution line with the lightning arresters and an overhead shielding wire	2014	10.1109/TEMC.2013.2272652	76
Fault detection and localization for overhead 11-kV distribution lines with magnetic measurements	2020	10.1109/TIM.2019.2920184	60
Influence of the return stroke current waveform on the lightning performance of distribution lines	2017	10.1109/TPWRD.2016.2550662	52
A full-scale experimental validation of electromagnetic time reversal applied to locate disturbances in overhead power distribution lines	2018	10.1109/TEMC.2018.2793967	51
Evaluation of lightning-induced voltages on multiconductor overhead lines located above a lossy dispersive ground	2014	10.1109/TPWRD.2013.2271516	50
Evaluation of power system lightning performance—part II: application to an overhead distribution network	2017	10.1109/TEMC.2016.2601657	48
Evaluation of the mitigation effect of the shield wires on lightning induced overvoltages in MV distribution systems using statistical analysis	2018	10.1109/TEMC.2017.2779184	45
Analysis of the effectiveness of shield wires in mitigating lightning-induced voltages on power distribution lines	2018	10.1016/j.epsr.2017.08.022	44
Research on distribution network fault recognition method based on time-frequency characteristics of fault waveforms	2017	10.1109/ACCESS.2017.2728015	43
Review of O&M practices in PV plants: failures, solutions, remote control, and monitoring tools	2020	10.1109/JPHOTOV.2020.2994531	39

Recent trends in research (2014-2020), documented in the most impactful articles, show a focus on improving the precision and efficiency of simulation models. Tatematsu and Noda [30] applied the finite-difference time-domain (FDTD) method, while Sheshyekani and Akbari [31] investigated the impact of soil dispersion on induced voltages, demonstrating its relevance in low-conductivity soils. Borghetti *et al.* [32] and Brignone *et al.* [33] optimized simulation methods by extending the Monte Carlo method and developing a technique to reduce the computational load, respectively, without sacrificing precision.

Similarly, the development of innovative techniques for fault detection and localization has been explored. Qin *et al.* [34] proposed a supervised learning method based on waveform characteristics, Wang *et al.* [35] experimentally validated the electromagnetic time reversal (EMTR) technique to locate disturbances in real-time. This approach is complemented by studies like that of Kazim *et al.* [36], proposed a novel method to detect short-circuit faults using magnetic field measurements.

Finally, an emerging trend is the evaluation of mitigation measures and the integration of new technologies. Several studies in [37], [38] analyzed the effectiveness of shield wires to mitigate overvoltages, using methods like the response surface methodology (RSM) to optimize their configuration. Lorenzo *et al.* [39] highlighted the lightning risk for PV plants, pointing to the need for specific protection measures for these systems and their sensitive electronic components.

4. CONCLUSION

The findings of this bibliometric analysis confirm a growing research interest in the effects of lightning on distribution lines, with a sustained increase in academic productivity since 1979. This trend reflects a significant evolution in research methodologies, moving from early theoretical and experimental studies with scaled models in 1932 to the incorporation of advanced computational methods. This transition includes the use of finite-difference-based programs and statistical analyses like the Monte Carlo method, which began to appear in 1984. More recent research has expanded the field to include the application of supervised learning for fault classification and the analysis of lightning's impact on PV generation systems.

An analysis of the geographical trends in publications reveals a centralized research pattern, with Japan and China emerging as undisputed leaders in the academic output on lightning effects on distribution lines. Japan tops the list with 16% of the publications, followed closely by China with 15.4%. This geographical concentration is consistent with the findings on author productivity, which identified that six of the ten most prolific authors are from Japan and two are from China. This direct correlation between the location of the most relevant authors and the distribution of productivity highlights the existence of well-established research centers in these countries, which may be driving global research and innovation in this field.

Looking ahead, future research should focus on validating computational models with real-world field data, analyzing the impact of lightning on renewable energy systems particularly PV systems and developing machine learning solutions for fault detection and classification. The research in this field has direct and significant practical applications for designing more robust and reliable distribution networks. Over time, these studies have allowed engineers to develop more effective protection systems, such as the optimized use of shield wires and surge arresters, based on an understanding of induced overvoltage mechanisms. The evolution from theoretical models to computational simulations has provided tools to predict overvoltages with greater accuracy and evaluate the effectiveness of mitigation measures. Furthermore, recent research has extended protection to new technologies like PV systems and has developed machine learning-based fault detection methods to locate disturbances in real time. These advances are crucial for ensuring the continuity of electrical service, reducing economic losses, and improving the safety of networks against the impacts of lightning.

ACKNOWLEDGMENTS

The authors are grateful to: The Universidad Católica de Manizales with the Research Group in Technological and Environmental Developments GIDTA and the Universidad Nacional de Colombia, Manizales with the Research Group in Telematic and Telecommunications GTT.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Vladimir Henao – Céspedes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		
Luis Fernando Díaz – Cadavid		✓				✓	✓		✓	✓				

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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