AC Impedance Calibration Research Landscape: A Bibliometric Study of Scopus Publications (2010-2024)

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Abstract. AC impedance calibration plays a vital role in ensuring measurement accuracy across electrical engineering applications, particularly in energy storage systems, biomedical instrumentation, and precision electronics. As technological demands grow, understanding the evolution of research in this field becomes essential for guiding innovation and standardization. This bibliometric study maps global trends in AC impedance calibration research from 2010 to 2024, based on 4,227 Scopus-indexed publications. The analysis reveals a 30% surge in publications (1,262 papers) between 2022 and 2024, largely driven by industrial demand in energy storage and precision instrumentation. China leads the field with 37% of total output, with key contributions from institutions such as Southeast University and authors like Yin Xiaokang. Keyword analysis highlights dominant themes including electrical impedance measurement (3,215 occurrences), electrochemical impedance spectroscopy (EIS), and emerging applications in lithium-ion batteries. While strong national collaborations are evident particularly in China international partnerships remain limited. The study emphasizes the need for standardized methodologies and the integration of AI-enhanced calibration techniques to address persistent measurement uncertainties.

1 Introduction

Alternating current (AC) impedance calibration is a fundamental process in ensuring accuracy across various electrical engineering applications[1]. It plays a critical role in advancing technologies such as renewable energy systems[2], biomedical instrumentation[3], and high-performance electronic devices[4]. Accurate impedance measurement is essential for maintaining the integrity of power grids, optimizing energy storage systems particularly lithium-ion batteries and ensuring the safety and reliability of diagnostic medical equipment[5][6][7]. Despite its growing importance, research in AC impedance calibration remains fragmented, with diverse methodologies, applications, and standards. While numerous technical studies address specific aspects of impedance measurement, there is a lack of comprehensive insight into the global research landscape, including key contributors, thematic priorities, and emerging trends. This study aims to fill

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that gap through a bibliometric analysis of 4,227 Scopus-indexed publications from 2010 to 2024. The main objectives are to:

1. Analyze publication trends and geographical distribution.
2. Identify the most influential authors, institutions, and journals.
3. Map emerging research themes and collaboration networks using VOS viewer.

The originality of this work lies in its systematic and visual approach to understanding the evolution of AC impedance calibration research. By highlighting regional strengths, collaboration patterns, and thematic developments such as the rise of electrochemical impedance spectroscopy and AI-enhanced calibration this study provides a strategic overview for researchers, policymakers, and industry stakeholders. It also offers a foundation for future research directions and standardization efforts in precision metrology.

2 Materials and methods

This review aimed to reveal the most prolific studies carried on AC impedance calibration area. To achieve this bibliometric analysis review was conducted in this study. This research was conducted on 12th January 2025. Scopus database was used in this study. The initial search revealed 7902 articles in AC impedance calibration research area. The keywords were used KEY((calibration OR measurement) AND (impedance) AND (ac OR alternating AND current)) this research covered the last 15 years from 2010 to 2024. The document type included in this review are just the articles in a final publication stage. Finaly the research language used only articles published in English language excluded any other languages.

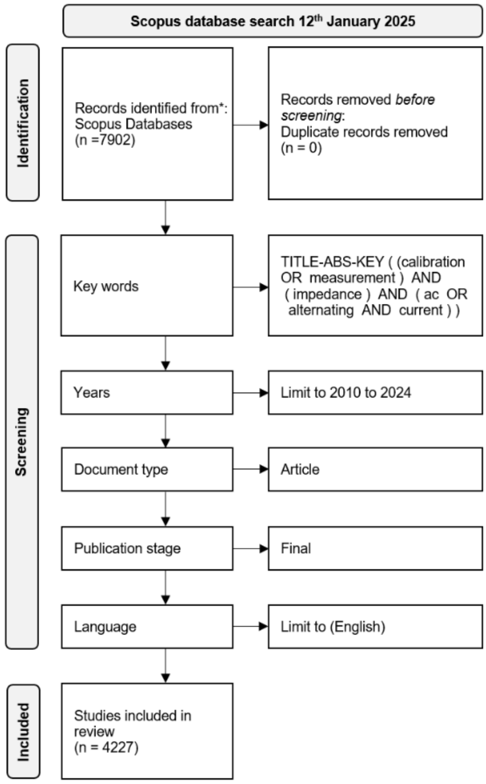

Fig. 1. Analytic framework of the study

3 The bibliometric analysis

The bibliometric analysis method was also used in the study. With bibliometric analysis, the most used keywords, the most cited journals, the most published journals, the journals that published the most studies on the subject, the countries that did the most studies on the subject, the keywords used and the relationship between them, the most cited authors, the journals that were jointly cited and the most published areas were examined. The VOSViewer software, one of the widely used programs in visualizing bibliometric networks, was used to reveal the network visualization in the analysis. This review is being carried out based on the following purposes. First, online learning has evolved into a compelling research area with growing research numbers. Thus, it is required to investigate the thematic structure of such a study area by utilizing an accurate machine learning method that could spontaneously examine sizeable, documented literature data. Then, the current research is being carried out to help provide insights concerning what has been discussed and the trends in AC impedance calibration.

4 Findings

The aim of the study was to identify the studies profile of AC impedance calibration research over the last 15 years. The results of this review were discussed based on the research questions.

4.1 Research question 1

What is the distribution of AC impedance calibration publications by years for the last 15 years? To address the first finding, an analysis was conducted of the publication year of the articles over the previous 15 years. It was seen that the papers were mainly published in the last three years, in 2024, a total number of 407 publications were published concerning AC impedance calibration: in 2023, a total number of 430 publications, following by a total number of 425 publications in the year of 2022. The other publications are distributed over the remaining years as shown in Figure 2.

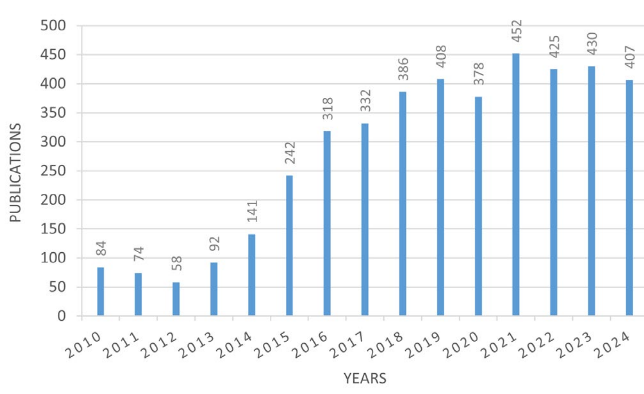

Fig. 2. Distribution of publications by years (2010-2024)

Figure 2 shows the distribution of the article among the years starting from 2010 until 2024. The figure shows that in 2010, 84 articles were published in the topic of AC impedance calibration. In 2024 there were 407 articles published, which shows the increment in this research area.

4.2 Research question 2

What are the most relevant Journals and authors in online learning readiness research? In the content analysis made for the most cited journals, “Total Publication,” “Total Citation,” “Cite Score of the journal,” “The most cited article,” “Times cited,” and “Publisher” was chosen as the analysis criteria as presented in Table 1.

Table 1. Top 15 sources journals in AC impedance calibration in the years (2010 - 2024)

Journal	Total publications	Total citations	Cite Score (2023)	The most cited Article (Reference)	Times Cited	Publisher
Energies	32416	201848	6.2	Increasing the Efficiency of Diagnostics in the Brush-Commutator Assembly of a Direct Current Electric Motor	49	Multidisciplinary Digital Publishing Institute (MDPI)
Journal of Electronic Materials	3034	12467	4.1	The Impact of Bi Content on the Coarsening Kinetics of IMC Particles and Creep Deformation Under Thermal Cycling	16	Springer Nature
Materials	30074	173808	5.8	Biomedical Applications of Titanium Alloys: A Comprehensive Review	46	Multidisciplinary Digital Publishing Institute (MDPI)
IEEE Transactions on Applied Superconductivity	2764	9589	3.5	Experimental Assessment and Model Validation of the SPARC Toroidal Field Model Coil	28	IEEE
Electrochimica Acta	6406	72519	11.3	Role of bicarbonate in CO2 corrosion of carbon steel	42	Elsevier
Ceramics International	15239	142644	9.4	Structural color tunable intelligent mid-infrared thermal control emitter	86	Elsevier
Applied Physics Letters	8748	55606	6.4	Hierarchical piezoelectric composite film for self-powered moisture detection and wearable biomonitoring	85	American Institute of Physics
IEEE Transactions on Power Electronics	4929	74843	15.2	Nonisolated High Step-Up DC-DC Converters: Comparative Review and Metrics Applicability	73	IEEE
Journal of Applied Physics	7077	37912	5.4	Effects of different atomic passivation on conductive and dielectric properties of silicon carbide nanowires	25	American Institute of Physics
Micromachines	7079	36875	5.2	Perovskite Solar Cells: A Review of the Latest Advances in Materials, Fabrication Techniques, and Stability Enhancement Strategies	31	Multidisciplinary Digital Publishing Institute (MDPI)
IEEE Access	49687	484743	9.8	The Optimization of Carbon Emission Prediction in Low Carbon Energy Economy under Big Data	108	IEEE
IEEE Transactions on Instrumentation and Measurement	6644	59531	9.0	YOLOv8-QSD: An Improved Small Object Detection Algorithm for Autonomous Vehicles Based on YOLOv8	37	IEEE
Journal of Materials Science: Materials in Electronics	8893	44348	5.0	A green and simple procedure to synthesize dysprosium cerate plate-like nanostructures and their application in the electrochemical sensing of mesalazine	29	Springer Nature
Dalton Transactions	7248	47818	6.6	Recent advances in lanthanide-based POMs for photoluminescent applications	31	Royal Society of Chemistry
Journal of Power Sources	5080	83084	16.4	Review of next generation hydrogen production from offshore wind using water electrolysis	43	Elsevier

Note : TP = Total Publications, TC = Total Citations

Table 1 identifies Energies as the most productive journal on AC impedance calibration (32,416 publications, 201,848 citations), followed by Journal of Electronic Materials (3,034 publications) and Materials (30,074 publications, 173,808 citations). It also outlines the thematic distribution of journals contributing to the field. Table 2 addresses RQ2 by analyzing the most prolific authors, based on total publications, h-index, citations, current affiliation, and country of origin.

Table 2. List of the 15 most prolific authors in the AC impedance calibration research area

Author	Year of 1st publication	Total Publications	h-Index	Total Citation	Current Affiliation	Country
Yin, Xiaokang	2009	18	19	1,224	China University of Petroleum	China
Li, Wei	2007	18	18	1,147	China University of Petroleum	China
Yuan, Xin'An	2014	18	14	685	China University of Petroleum	China
Bond, Alan M.	1996	16	79	32557	Monash University	Australia
Wang, Zhong Lin	1996	13	295	382790	Chinese Academy of Sciences	China
Gao, Chunxiao	1996	13	32	3973	Jilin University	China
Zhao, Jianming	2018	13	11	246	Qingdao University of Science and Technology	China
Zhang, Jie	1995	12	55	11427	Monash University	Australia
Zhu, Min	2006	12	16	1079	Zhejiang Sci-Tech University	China
Wei, Xuezhe	2004	11	56	9646	Tongji University	China
Dai, Haifeng	2006	11	54	9684	Tongji University	China
Du, Cuiwei	1996	11	50	11231	University of Science and Technology Beijing	China
Zhang, Yiquan	2002	11	48	8256	Nanjing Normal University	China
Sun, Cheng	1999	11	28	2410	Institute of Metal Research Chinese Academy of Sciences	China
Xu, Jin	2001	11	27	2213	University of Science and Technology	China

Table 2 shows 10 prolific authors in the research area of AC impedance calibration. Furthermore, the most prolific author was "Yin, Xiaokang" with a total number of publications of 18, with the most h-index of 19, in addition to a total of 1224 citations, and the author is from China. Followed by "Li, Wei" with a total number of publications of 18, with an h-index of 18, in addition to a total of 1147 citations, and the author is from China. Followed by "Yuan, Xin'An" with a total number of publications of 18, with an h-index of 14, in addition to a total of 685 citations, and the author is from China as well. Furthermore, from an H-index standpoint, the top three remained the same as ranked by the publishing count. Moreover, other prolific authors in AC impedance calibration research area data were presented in Table 2.

4.3 Research question 3

What are the most productive countries in AC calibration impedance research area? In the content analysis made for the most productive countries in AC calibration impedance research area, "country," "Total Publications," "and "most productive academic institution" were selected as the analysis criteria as shown in Table 3 and Figure 3.

Table 3. List of the 15 most prodective countries in AC impedance calibration research area

Rank	Country	Total Publications	Most Productive Academic Institution
1	China	1542	School of Automation, Southeast University
2	United States	609	Massachusetts Institute of Technology

3	India	335	Variable Energy Cyclotron Centre
4	Japan	277	Graduate School of Science and Engineering
5	South Korea	238	Pohang University of Science and Technology
6	Germany	192	Massachusetts Institute of Technology
7	United Kingdom	170	Loughborough University
8	Iran	108	Engineering Faculty, Razi University
9	Russian Federation	96	National University of Science and Technology MISiS
10	Turkey	95	Kırıkkale University
11	Australia	94	Australian Energy Research Institute
12	France	92	Université de Picardie Jules Verne
13	Taiwan	89	National Cheng Kung University
14	Canada	83	School of Automotive Engineering
15	Saudi Arabia	82	King Abdullah University of Science and Technology

Table 3 highlights the top 10 most productive countries in AC impedance calibration research, along with thematic focuses by region and institution. While most countries show broad engagement with the field, others emphasize specific trends. China leads with 1,542 publications, primarily from Southeast University, followed by the United States (609, MIT) and India (335, VECC). Additional contributing countries are also listed in the table.

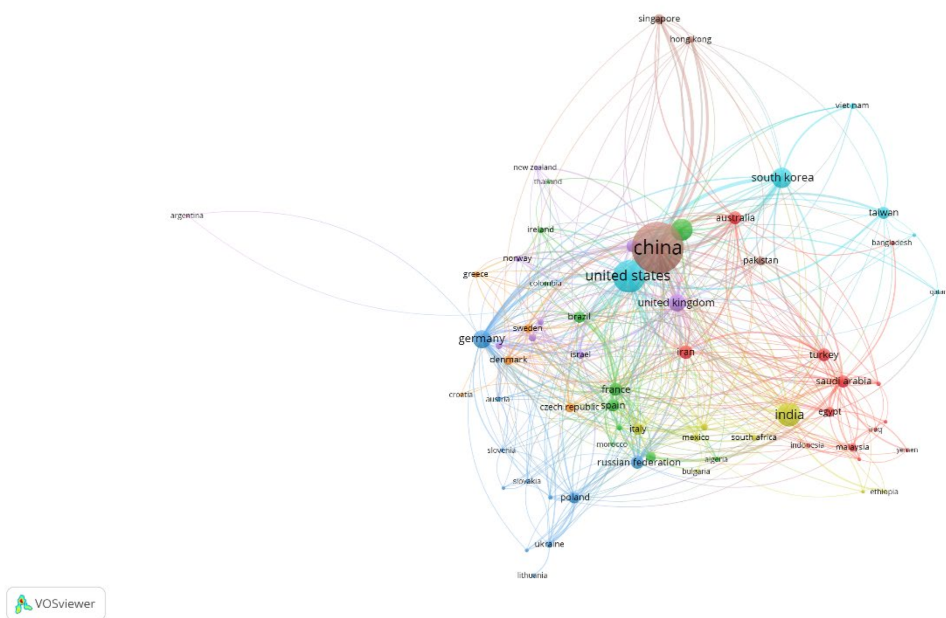

Fig. 3. Analysis results of productive countries in AC impedance calibration

Figure 3 illustrates the analytical results of productive countries in AC impedance calibration research. Thus, in contrast to countries, institutes listed in the figure presented more interest in specific matters, the most productive country was China, followed by United States followed by India Moreover, Japan, South Korea, Germany, United Kingdom, Iran, Russian Federation, Turkey were listed as top 10 countries in the research field. Beginning With the analysis, it was evident that the countries from within the same institutions and continents from within the same countries with comparable study interests tend to collaborate more in AC impedance calibration research areas.

4.4 Research question 4

What are the main research Keywords related to AC impedance calibration over the last 15 years? For the bibliometric analysis of the most used keywords, "Co-occurrence" was selected as the analysis type, and "Authors keywords" was marked as the unit. In this context, 1000 keywords were identified from the data set, as shown in Figure 4.

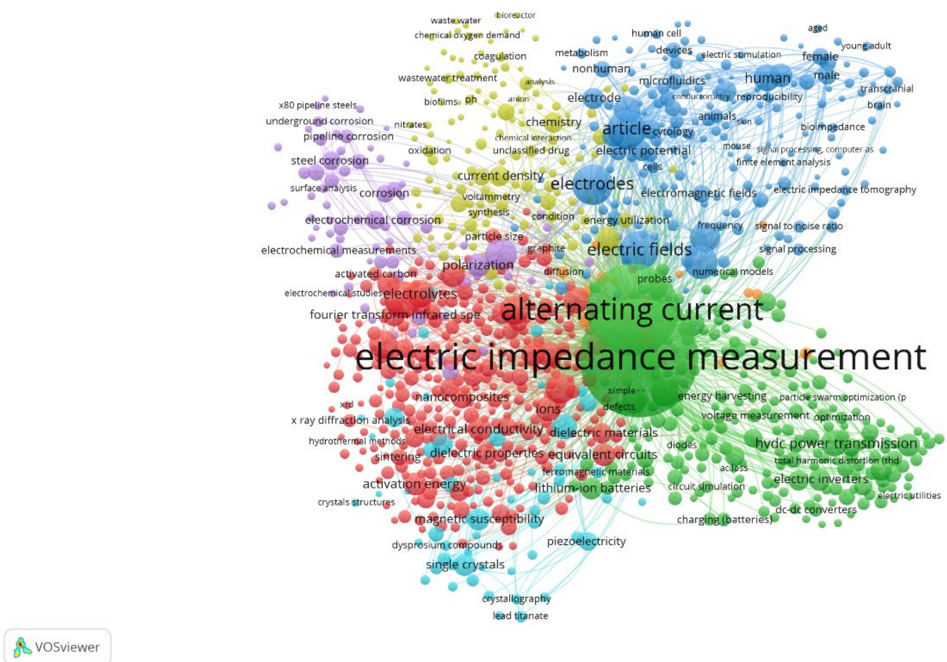

Fig. 4. Analysis results of publications by keywords

When Figure 4 is examined, the keywords used in the studies listed as "electric impedance measurement" (Occurences "Oc" = 3215), "Alternating current" (Oc = 1931), "Electric field" (Oc = 354), "Electric impedance" (Oc = 255), "Electrochimical impedance spectroscopy" (Oc = 231) and "capacitance" (Oc = 207). These were followed by impedance, impedance spectroscopy, direct current, Electric discharges, and impedance measurement. When the keywords of the publications are examined, it is seen that approximately 53,4% (n = 534) use words such as AC impedance calibration and electric current measurement. In addition, keywords such as AC voltage, AC impedance and current density of lithium ion batteries are favoured in the bibliometric analysis.

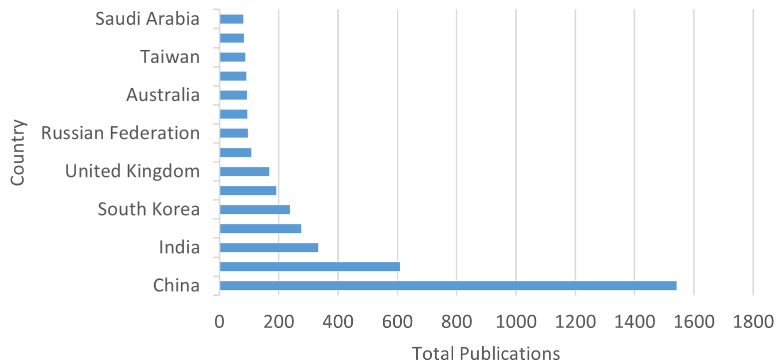

Fig. 5. Country distribution and total publications

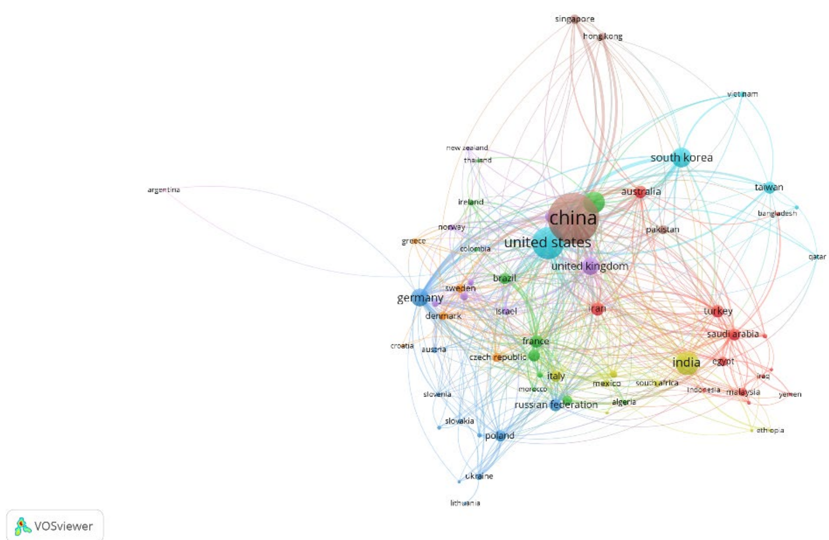

Fig. 6. Country distribution and publications

The China has contributed roughly 37% of the analyzed literature, with School of Automation, Southeast University. Moreover, Scientific cooperation analysis shows that countries/regions (e.g., the China, Hong kong, Pakistan, and Singapore) presenting more interest in global cooperation are likely to develop faster.

5 Discussions

The bibliometric landscape of AC impedance calibration research from 2010 to 2024 reveals significant growth and transformation, particularly in the last three years. This surge in publications reflects the increasing relevance of impedance calibration in emerging technologies such as renewable energy systems, electric vehicles, and smart grids. The rapid expansion is not merely quantitative—it signals a shift in research priorities toward precision, reliability, and interdisciplinary integration. China's dominant position, contributing 37% of

the total publications, can be attributed to strategic national initiatives like "Made in China 2025," which emphasize technological self-sufficiency and innovation in metrology and materials science. Institutions such as Southeast University and the Chinese Academy of Sciences have played a central role in this expansion, supported by substantial government funding and policy alignment. The prominence of journals like Energies and Materials (MDPI) underscores the interdisciplinary nature of AC impedance calibration, bridging electrical engineering, materials science, and energy storage. The frequent appearance of keywords such as electrochemical impedance spectroscopy (EIS) and lithium-ion batteries reflects the growing industrial demand for accurate diagnostics and efficient energy systems. These trends suggest that impedance calibration is increasingly being integrated into real-time monitoring systems, including IoT-enabled devices and wearable technologies. However, the analysis also reveals a fragmented global research ecosystem. While intra-national collaboration—especially within China—is strong, international cooperation remains limited. This lack of cross-border collaboration may hinder the development of universally accepted standards and methodologies, potentially exacerbating issues of reproducibility and measurement uncertainty. The case of Alan M. Bond, a highly cited Australian researcher, illustrates the impact of individual excellence but also highlights the absence of sustained institutional partnerships across regions.
Furthermore, the reliance on Scopus and English-language publications introduces limitations. Important regional innovations published in other languages or indexed in alternative databases may be underrepresented, leading to a skewed understanding of global research dynamics. Additionally, the 2024 dataset may be incomplete, as year-end publications were not fully captured at the time of analysis. In light of these findings, future research should prioritize: Expanding data sources to include platforms like Web of Science and regional databases; Fostering international collaboration to harmonize calibration practices and enhance knowledge exchange; Integrating artificial intelligence to improve calibration accuracy and automate measurement processes; Encouraging interdisciplinary approaches that combine electrical engineering, data science, and materials research. By addressing these gaps, the field can move toward more robust, standardized, and globally relevant calibration frameworks that support innovation across industries reliant on precise impedance measurement.

6 Conclusion and implications

This bibliometric analysis of 4,227 Scopus-indexed publications (2010–2024) underscores the dynamic evolution of AC impedance calibration research, marked by a notable surge in output, peaking at 430 publications in 2023. China dominates the field (37% of publications), followed by the U.S. and India, reflecting concentrated scientific efforts. Leading journals (Energies, Materials) and authors (e.g., Yin Xiaokang, China) highlight the intersection of materials science and electrical engineering. Prevalent keywords "electric impedance measurement" and "alternating current" emphasize applications in precision metrology and industrial technologies. The study reveals robust institutional collaborations, particularly within regions, fostering innovation in calibration methods. However, reliance on Scopus alone risks overlooking contributions from other databases, while restrictive search terms may exclude relevant studies. Future research should integrate artificial intelligence to enhance calibration accuracy and broaden data sources (e.g., Web of Science) for comprehensive insights. Strengthening global partnerships and diversifying interdisciplinary approaches will advance standardized AC calibration frameworks, addressing emerging industrial demands. This work provides a foundational roadmap for prioritizing R&D investments and fostering technological resilience in metrology, which is essential to sustain progress in sectors reliant on accurate impedance measurement.

References

[1] S. Amzil, A. Zamma, S. El Ouardi, and H. Samri, “Exploring the Potential of Artificial Intelligence in the Development of a New AC Resistor Calibration Bridge at the National Metrology Laboratory of Morocco LPEE-LNM,” *2025 5th International Conference on Innovative Research in Applied Science, Engineering and Technology, IRASET 2025*, 2025, doi: 10.1109/IRASET64571.2025.11008343.
[2] H. Kolavada, P. N. Gajjar, and S. K. Gupta, “Unraveling quantum capacitance in supercapacitors: Energy storage applications,” *J Energy Storage*, vol. 81, Mar. 2024, doi: 10.1016/J.EST.2023.110354.
[3] F. Aumer and T. Hinz, “Electrical Impedance Spectroscopy on 8-channel PSoC-Based Miniaturized Board to Enable Data-Rich Environmental Sensing,” *2021 Smart Systems Integration, SSI 2021*, Apr. 2021, doi: 10.1109/SSI52265.2021.9466999.
[4] M. Meisser, K. Haehre, and R. Kling, “Impedance characterization of high frequency power electronic circuits,” *IET Conference Publications*, vol. 2012, no. 592 CP, 2012, doi: 10.1049/CP.2012.0240.
[5] P. H. Wagner *et al.*, “Electrical Impedance Tomography: From the Traditional Design to the Novel Frontier of Wearables,” *Sensors*, 2023, doi: 10.3390/s23031182.
[6] S. Um, J. Lee, and H. J. Yoo, “A 3.8-mW 1.9-mΩ/√Hz Electrical Impedance Tomography IC With High Input Impedance and Loading Effect Calibration for 3-D Early Breast Cancer Detect System,” *IEEE J Solid-State Circuits*, vol. 59, no. 7, pp. 2019–2028, Jul. 2024, doi: 10.1109/JSSC.2024.3386681.