Control Strategy in Electric Vehicle: A Visualized Bibliometric Analysis

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Abstract

Control strategy has an important role in electric vehicles. It determines the efficiency and performance of electric vehicles. This study analyzes the control strategies on electric vehicles by a bibliometric analysis using VOSviewer, Open Refine and Tableau Public software. In this study, the dataset was taken from Scopus. The number of articles used is 1403 documents. The keywords used in Scopus database based on TITLE-ABS-KEY (title, abstract, keyword) are "control strategy" AND "electric vehicle" OR "EV". Based on the result analysis, the number of studies on control strategies in electric vehicles continues to increase from 2013 to 2022. Result analysis of this study provides information that the latest research trend related to control strategies in electric vehicles is wireless power transfer, switched reluctance motor, energy consumption, robust control, disturbance observer, battery life, deep reinforcement learning, reinforcement learning, ECMS and fuzzy logic control. We find that the most influential and productive authors are from China.

Keywords

Bibliometric analysis; Control strategy; Electric vehicle; Scopus; VOSviewer software.

1   Introduction

There are 3 important components in electric vehicles (EV) that support the vehicle to run properly, those are the battery as a power source of the EV, the electric motor as a driver that produces mechanical energy, and the drive system to transfer the mechanical energy to the wheels [1]. The battery as the main power source has a characteristic of large energy density which stores amounts of energy electricity to supply the motor [2]. Electric motors have high torque for starting and uphill propulsion and high power density for speeding when driving [3-4]. The drive train system with various configurations such as battery electric vehicle (BEV), hybrid electric vehicle (HEV), and plug-in hybrid electric vehicle (PHEV), determines the energy transfer process to maintain the EV performance [5]. Since these components play an important role for the EV, they require an optimal control strategy to achieve good efficiency and better performance of electric vehicles.

Control strategy in EV is very complex, generally managing all processes related to the functional aspects of every support system such as managing power modes for EV (e. g. start-up, driving, charging) [6], torque request acquisition and validation, torque management on EV (e. g. calculation of driver torque demand, drivability filtering and torque limitation) [7-8], vehicle powertrain control, transmission gear control, battery charge (AC & DC) [9-11], thermal management, energy management [12-13], and safety monitoring unit.

The complexity of strategy control is an opportunity for researchers to lead research in this field. On the other hand, the issues emerge for the researchers to figure out which gaps can be placed to conduct research, and what topics are currently being discussed in tackling issues related to EV, especially strategy control. This encourages extensive research on EV especially strategy control has been increasingly conducted. Therefore, a state-of-the-art reference is needed to take care of the issue by responding to several questions related to it.

1. How are the global EV trends and research directions that have appeared over the years?

2. How is a holistic map of the EV research themes aligned with strategy control perspectives?

3. What are the correlations, and connection patterns among the keywords identified in the EV control strategy analysis?

4. Who is the most influenced and the most productive author, country, and research center in the topic of control strategy in EV?

Bibliometric analysis assists the researchers in dealing with numerous publications and quantitatively analyzing the research papers concerned about the research area [14]. Therefore, the author is using bibliometric analysis to analyze the key areas of EV control strategy research and to predict the direction of future studies. The present study aims to provide a body of knowledge for EV research themes such as trends, the most influenced author, the most publication, and a holistic map of EV research regarding control strategy over the last decades (2013–2022). The last decade's articles (the last 10 years) are selected based on the Publication manual of the American Psychological Association, 7th ed. It stated that the ideal publication is compiled within the last 5 - 10 years [15]. In order to maximize the data, the articles are selected from the last 10 years. To achieve the aim of this study, a mixed-method approach, including bibliometric analysis, text mining, data extraction, and content analysis & interpretation are applied.

2 Method

Bibliometric analysis is the method to identify the scientific research trends with a special topic statistically [14,16]. Bibliometric is very useful to synthesize the research findings and trends that can give the insight for the empirical researcher to find the originality and novelty of their own research [17-18]. The dataset of bibliometric analysis can be accessed from various sources such as Scopus, Web of Sciences and Google Scholar [19-20]. In this paper, the dataset from Scopus is selected because it gains the most trusted journal and presents a variety of information from all over the world [21].

The method of the research is shown in Figure 1. The explanation of Figure 1 in detail is provided in the next subsection.
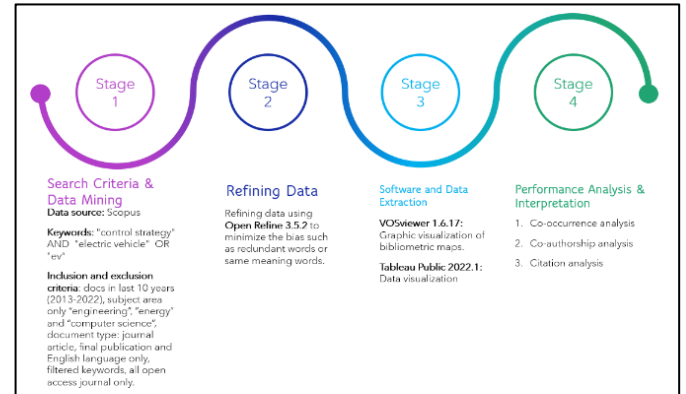

Figure 1 Step by step of the bibliometric analysis

2.1 Search criteria and data mining

In stage 1 (Figure 1), the author defines the search criteria to get the useful and matching data [22]. Data mining was carried out on March 10, 2022, in the Scopus database. The keywords used in Scopus database based on TITLE-ABS-KEY (title, abstract, keyword) are "control strategy" AND "electric vehicle" OR "EV". The inclusion and exclusion criteria are documented in the last 10 years (2013-2022) because authors want to reveal the latest research streamline in the main topic of "Control Strategy in EV". The subject areas included are only engineering, energy, and computer science. Authors exclude subject areas such as social science, chemical engineering, and mathematics since they do not fit to this research topic. The authors also selected journal articles and final publications only. Generally, the journal article has a tight and rigorous review process to produce articles in good quality [18].

Table 1. Inclusion and exclusion criteria of Scopus dataset

No	Inclusion and Exclusion Criteria	Amount of Scopus Documents
1	Keywords: "control strategy" AND "electric vehicle" OR "EV"	7089
2	Limit to last 10 years (2013-2022)	5120
3	Filter by subject area: engineering, energy, computer science	4873
4	Limit to: Document type: article only Source type: journal only Language: English only Publication stage: Final	1845
5	Filter by keywords: electric vehicles, control strategies, electric machine control, electric vehicle, fuel economy, controllers, energy efficiency	1403
6	Final Dataset	1403 documents

The inclusion and exclusion criteria are more detailed in Table 1. After applied the inclusion and exclusion criteria, authors exported the dataset into a CSV file with the detail as in Figure 2.

Figure 2 Exported dataset detail (orange marked).

2.2 Refining dataset

In refining dataset stage as in Figure 1, the Scopus raw dataset needs to be refined because there is bias such as redundant or same terminology that split differently [17]. The author use Open Refine 3.5.2 to minimize the bias. After uploaded the dataset to Open Refine, the result is shown in Figure 3.

Figure 3 Screen display of Open Refine 3.5.2 after the dataset is uploaded.

There are 1403 data rows, the same amount of final Scopus dataset (Figure 3). The data in the author keywords and index keywords column are refined because there are several words that have the same meaning but separated. The example words with the same meaning are shown in Figure 4.

Figure 4 Refining the same meaning words

The refining data process shown in Figure 4 is exported to the CSV extension file. The refined final dataset will be visualized by VOSviewer and Tableau Public for analysis and interpretation.

2.3 Software and data extraction

In software and data extraction stage, to make graphic and data visualization of the refined data based on the research question, we use VOSviewer 1.6.17 and Tableau Public 2022.1 software. Each software is open access and easy to use, they also can visualize the refined data in incredibly good [23].

2.4 Data analysis and interpretation

The visualized data is analyzed and interpreted to answer the research questions that consist of research development in control strategy of EV, the most productive country regarding control strategy of EV research, research center / university involved in the topic, the most productive and influence author in the topic and the research trend of control strategy in EV.

3 Results and Discussion

3.1 Research development in "control strategy in electric vehicle

As mentioned before, the 1403 articles published in reputable journals indexed by Scopus. The number of publications in the last 10 years (2013-2022) is presented in Figure 5.
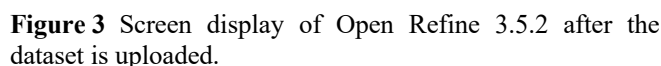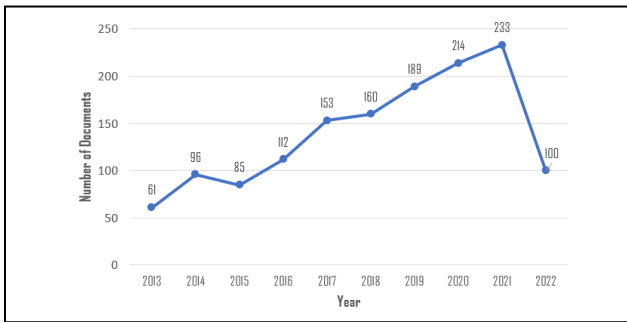
Figure 5 Number of publications regarding the main topic in the last 10 years.

Based on Figure 5, there are an increasing number of publications in every year, except from 2014 to 2015. In the first quarter of 2022, there were one hundred publications regarding the topic. Therefore, the average from the number of publications by the end of 2022 based on the first quarter approximately in three hundred publications. The interesting fact is that the covid-19 pandemic did not affect the productivity of the researchers in the field of control strategy of electric vehicles. From 2019 to 2021, the number of publications will keep increasing. The covid-19 pandemic impact to the stability of global electric vehicles supply chain [24].

3.2 The most productive country regarding topic "control strategy of electric vehicle"

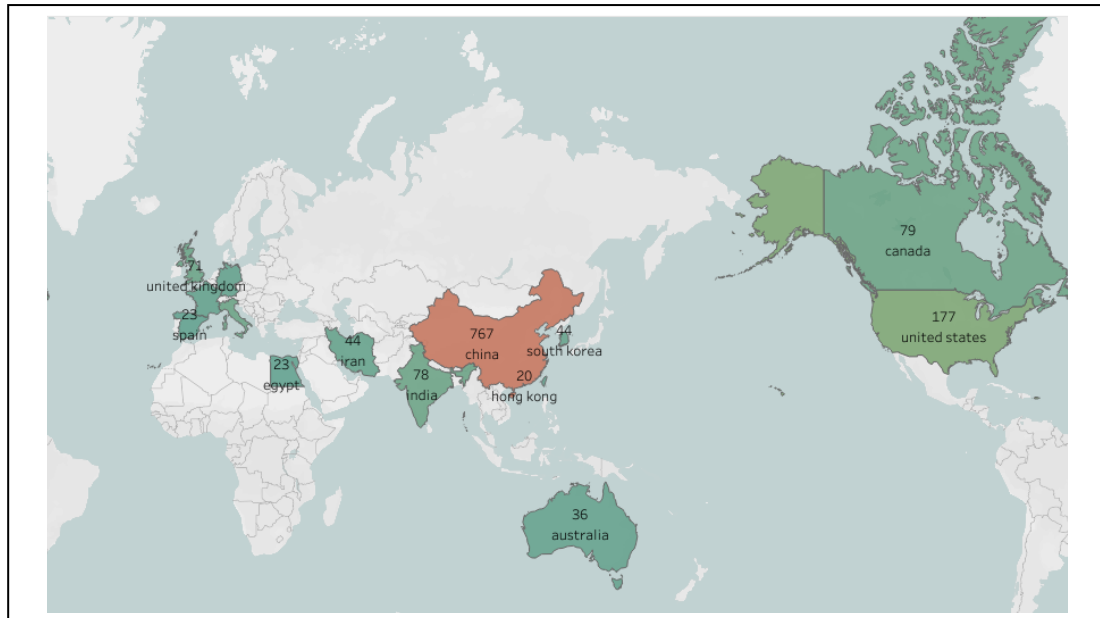Figure 6 shows the most productive country in publication regarding the topic.

Figure 6 Mapping of the top ten most productive countries in publication regarding the topic.

Based on Figure 6, China became the most productive country with 767 documents (54,66%). The second to the fifth are the United States with 177 documents (16,97%) and Canada with 79 documents (7,57 %), India with 78 documents (7,47%) and the United Kingdom with 71 documents (6,8%) respectively. Compared to other countries, China is leading in publication regarding the topics by a large number. It happens because China's government gives incentives to the researchers that do the research in EV development since 2005 [16,25]. The research productivity in a country related to the country's intellectual and economic wealth. By the further analysis, it has the possibility to present the status of countries in other aspects [26].

3.3 Research center / university involved in the topic

Figure 7 indicates the research center involved in the topic "control strategy in electric vehicles". Unsurprisingly, the top 10 research centers / universities are all from China. Research center / university with the greatest number of publications in the topic is State Key Laboratory of Automotive Safety and Energy, Tsinghua University Beijing, China with 26 documents. They did a lot of research on EVs, for example Energy efficiency optimization of EV [27], implementation of EV in China and the US [28], design and control of a novel two-speed uninterrupted mechanical transmission for EV [29], and PI antiwindup speed control for EV [30].
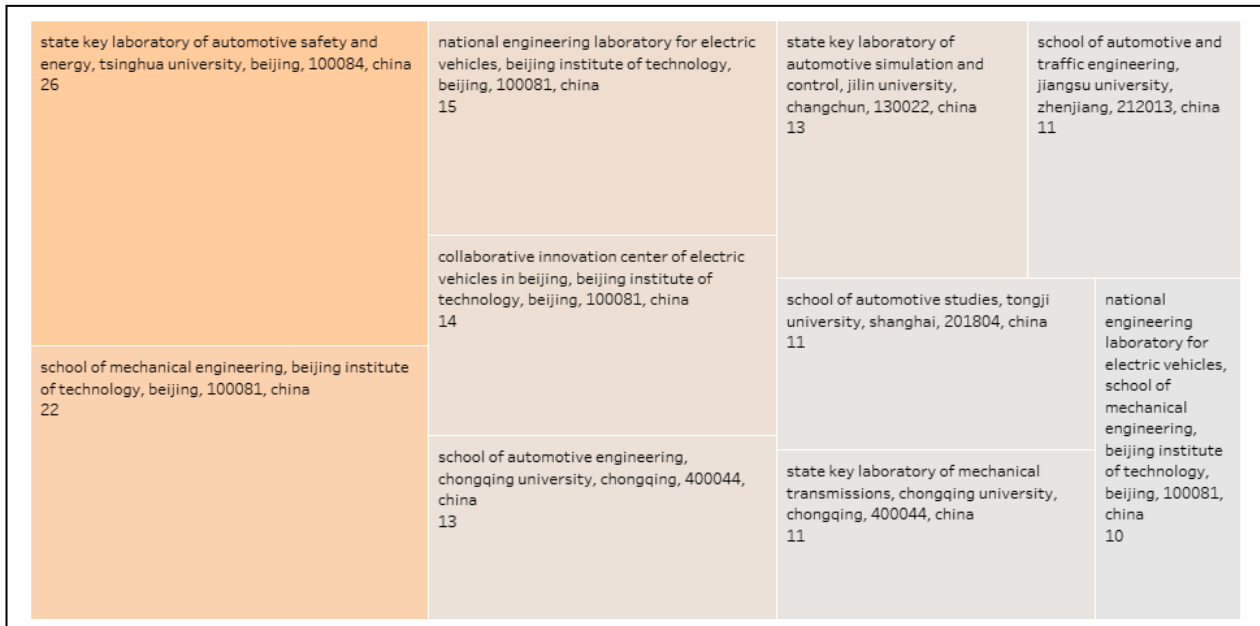
Figure 7   Tree map of research center / university that published the most paper in the topic.

Based on Figure 7, it informs that if someone want to pursue the master or doctoral degree or do the collaboration research in control strategy in EV, China can be considered as one of the best choices.

3.4 The most influenced and most publication author in the topic

Based on the refined dataset, there are 3011 authors in the total 1043 documents. The author with a minimum 5 or more documents linked to their name in VOSviewer software is analyzed to see the list of top cited author or it can say "the most influenced author" in the topic [31]. The most influenced author measure the capability of their field or discipline [32]. There are only 203 authors (6,74%) meet the threshold. Figure 8 shows the most cited author in the topic. The author "Xiong R" is the most cited author, although the author "Xiong R" only has 12 documents.
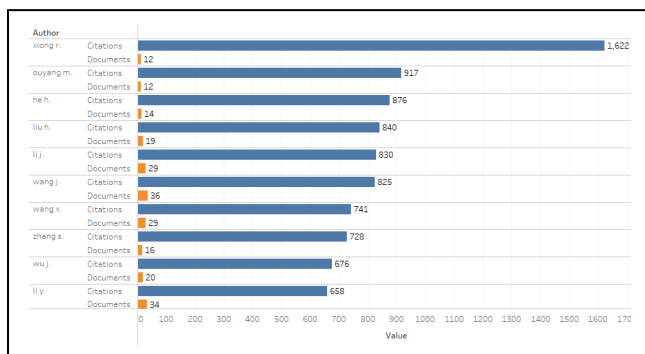

Figure 8   The most cited author in the topic

Figure 9 shows the author with the most publication in the topic. The author "Zhang Y " is the author with the most publications compared to the others. The interesting fact is the author with the most publications does not automatically become the most cited author. Based on Figure 8 and 9, it can be concluded that the most influential author in the topic is "Xiong R" and the most productive author in the topic is "Zhang Y".
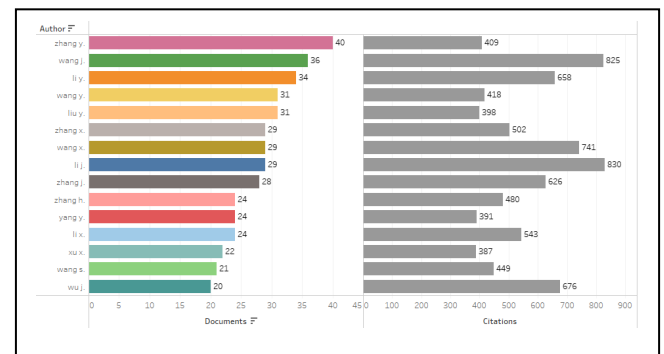

Figure 9   Author with the most publication in the topic

3.5 The most cited journal in the topic

Another important category to be analyzed by bibliometric is the amount of citation of the journals. It is important because it presents the key areas or scope of the research involving control strategy in electric vehicles. It also measures the impact in the scientific community of an article, and cumulatively [33]. Based on the refined final dataset, there are 274 journals and only 34 journals meet the threshold with the minimum number of documents of a journal to 10 or more.
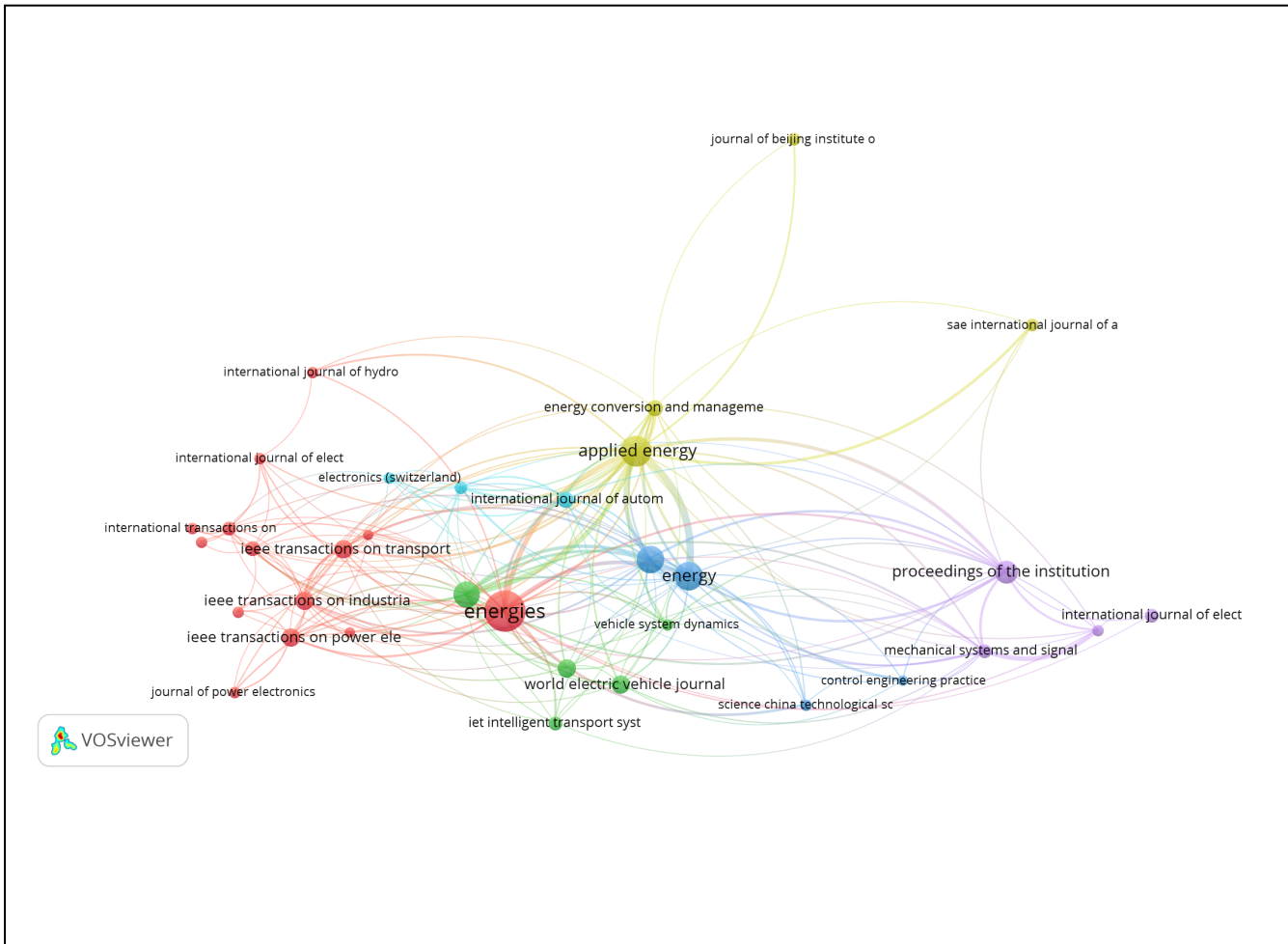
Figure 10 Visualization of journals based on the number of documents of a journal and total link strength.

Based on Figure 10, the bigger node of the journals, the bigger the number of the documents of the journals. Journal "Energies" has the most documents with 134 documents (9,55%). The second and the third journal with the most documents in the topic are journal "Applied Energy" with 75 documents (5,34%) and journal "Energy" with 68 documents (4,84%) respectively. The closer two journals are located to each other, the relatedness between them is stronger. Based on this data, the scope of the journal involving control strategy in electric vehicles can be checked as the main topic. Generally, the journals are in the scope of multidisciplinary subjects such as engineering, transportation, energy, and computer sciences. As the researcher, it can be an optional choice to publish the research paper that suits the topic of control strategy in EV.

3.6 Author keywords analysis

Author keywords analysis is important to find out the main topic or theme related to control strategy in EV. The results inform the researcher around the world about the trend of the topic. So, it can be easier for the researcher to find the originality and novelty of their research in control strategy in EV. After making thesaurus terms that consist of the same meaning words, from the total of 3517 author keywords, only 125 keywords (3,55%) meet the threshold with the minimum co-occurrence are 5 or more. Figure 11 shows the results of co-occurrence of author keywords.
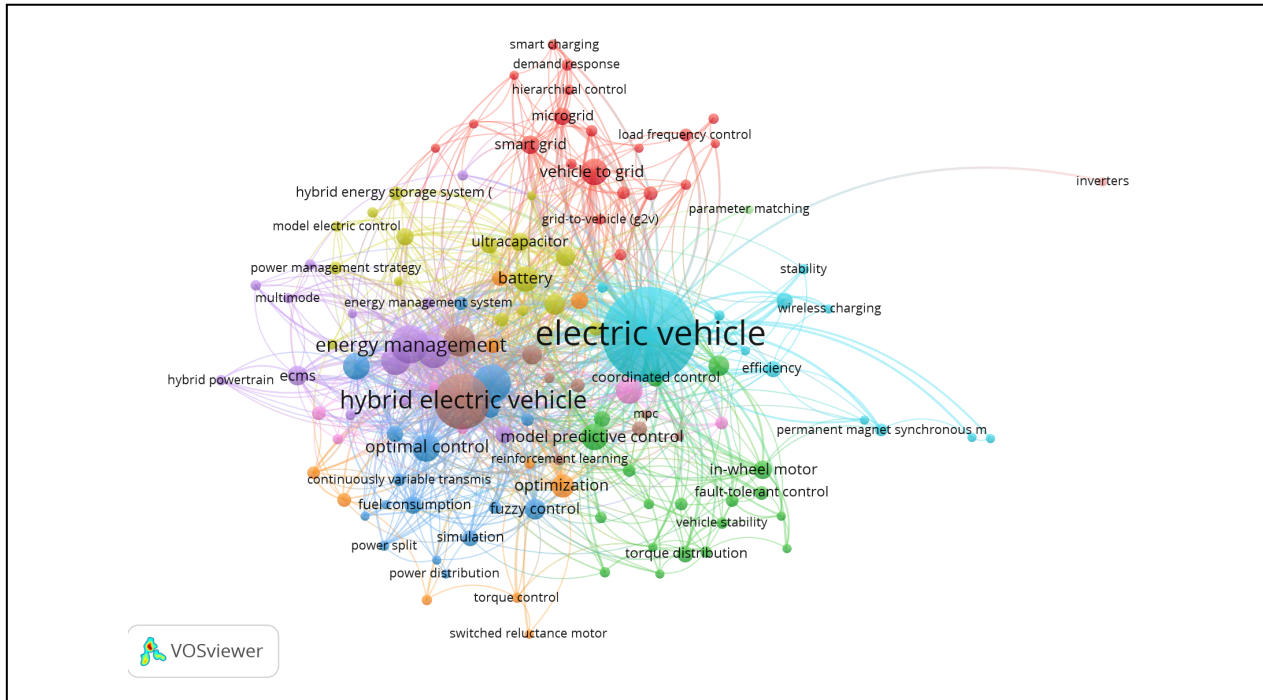
Figure 11 Network visualization of author keywords based on total link strength.

Based on Figure 11, the strongest keyword is "electric vehicle" as expected. The smaller keywords on the network visualization, the less research conducted about that keyword. It will be great information for researchers to find out the originality and novelty of their future research. The overlay visualization of the author keywords shown in Figure 12 that informs about what topics are the newest of hotspot in control strategy in EV.
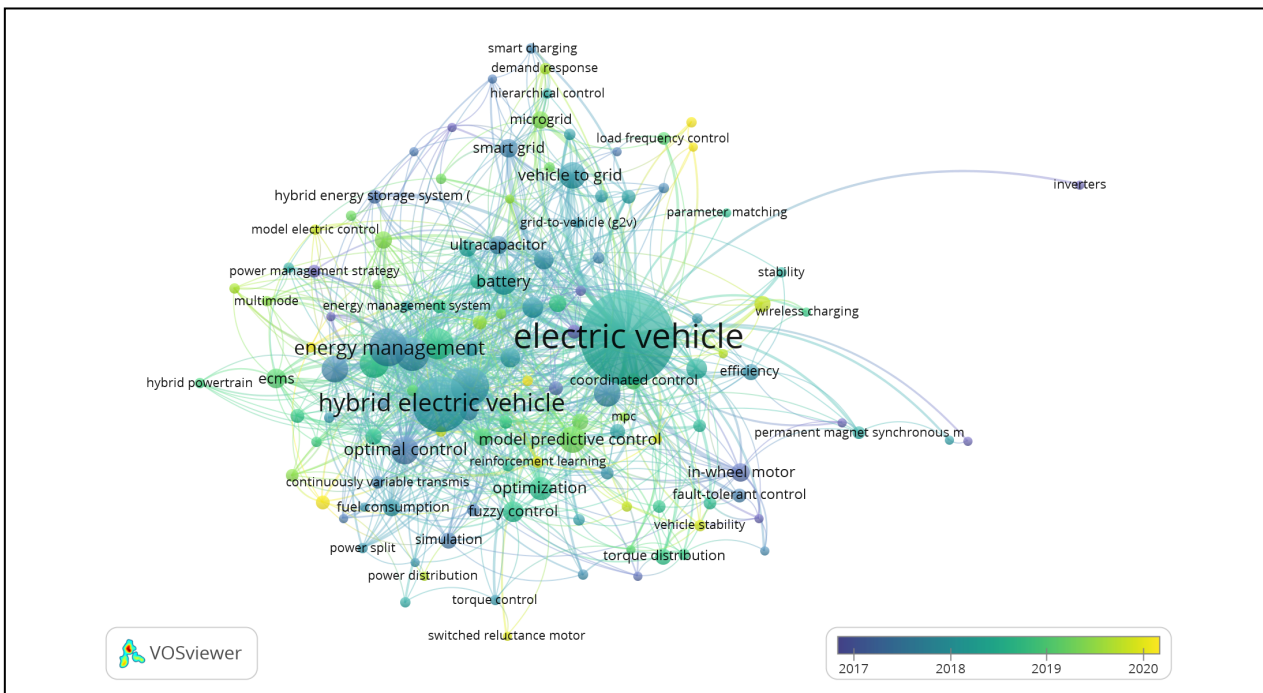

Figure 12 Overlay visualization of author keywords

Based on Figure 12, the keywords used in the newest documents in control strategy in EV are yellow marked. The keywords are wireless power transfer, switched reluctance motor, energy consumption, robust control, disturbance observer, battery life, deep reinforcement learning, reinforcement learning, ECMS and fuzzy logic control. It is great information for the researcher about the latest trends of the research in control strategy in EV.

4   Conclusion

Based on bibliometric analysis using VOSviewer software, in the last 10 years (2013 - 2022), research on control strategies in electric vehicles continues to increase. The most productive country in conducting research on this topic is China, which is 54.66% of the total document dataset used in this study. The results of the analysis of this study provide information about research that is becoming the latest trend related to control strategies in electric vehicles: wireless power transfer, switched reluctance motor, energy consumption, robust control, disturbance observer, battery life, deep reinforcement learning, reinforcement learning, ECMS and fuzzy logic control. Thus, through this research, readers can explore information about potential research ideas to be carried out regarding control strategies in electric vehicles.

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