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ScienceDirect

Energy Procedia 5 (2011) 2581–2585

Energy Procedia

IACEED2010

Identifying Core Technology Structure of Electric Vehicle Industry through Patent Co-citation Information

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Abstract

Electric vehicles (EV), which have various energy sources and have quite low emission, have come to be one of strategic emerging industries. This article aims to identify its core technology structure so as to understand the recent progress of EV technology innovation. This has important implication for policy-making at governmental level and strategic decision-making at firm level. The authors use a method of patent co-citation information to identify the core technologies of EV industry. Five core technology groups have been shaped up as driving system arrangement & control, energy management & control, battery management, transmission system control, and motor design & control. Core technology assignees are decentralized as the most productive eight assignees possess 55.7% of core patents. None Chinese assignee is listed in these EV core patents.

Keywords: Electric vehicle; Patent co-citation; Core patent; Technology innovation

1. Introduction

The growing urgency of global climate challenge has made electric vehicles (EV) which have various energy sources and have quite low emission, as one of strategic emerging industries and a new developing boom [1], both in China and several developed countries. Different kinds of EVs appear like mushrooms. Prius by Toyota, Insigh by Honda, Prodigy by Ford, and Precept by GM have been on sale so far. Many companies like Volkswagen, BMW and Chevrolet are devoting to produce pure EVs. At the same time, China EV industry is developing rapidly and auto companies like BYD, Chang'an and Chery have

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doi:10.1016/j.egypro.2011.03.443

introduced their own types of EV. However, as this article will show, there is extensive evidence that unclear EV technology roadmap does lead enterprises and governments to promote EV almost blindly, which will increase the risk of EV innovation as well as decrease expected social benefits of EV industrialization.

Identification of EV core technology has a central role to play in making EV technology strategy and pursuing competitive advantage. Core technology can effectively resist imitation and help market penetration [2]. It is obviously necessary for companies to analyze core technology of competitors and the whole industry before they make decision of internal resource allocation and external opportunity determination. Meanwhile, identifying industry core technology will help policy makers to develop effective policies. Entrepreneurs and researchers have concerned core technology identification in recent years. Some researchers [3-8] have proposed different methods to identify core technology of a company. Another cluster of researchers committed to unveil industry core technologies [9-12]. This study aims to identify the core technologies of EV industry and analyze technology development status through patent data. We use patent co-citation method. Our result will be valuable for governments to develop effective measures and for enterprises to design appropriate technology strategies.

2. Method

Concept of co-citation was first proposed by a US information scientist Henry Small in 1973 [13]. The basic idea is: if patents A and B are co-cited, they have correlation on technologies and the correlation increases with the co-cited frequency increases. It was widely used in frontier analysis, domain analysis, research evaluation, and etc. It has also been used on clarification of core technologies. Mogee and Kolar employed patent co-citation information to identify core technologies of Allergan Inc [14] and Eli Lilly & CO. [15]. Lai [16] have established a new patent classification system using patent co-citation information. Wu [8] have used patent co-citation to unveil core technologies of TSMC Co. Based on the prior work, we use patent co-citation method in our study to identify the core technology of EV industry.

Data. A total of 4020 patents issued from Jan.1, 1990 to Dec.31, 2007 were retrieved from USPTO database, including bibliography and citations. We define the period of 1990~2007 because of two folds: one is EV patents issued before 1990 were rare and they have expired; another is patents issued after 2007 have little citations which means less impact on EV industry so far.

Initial screen of core patents. Cited frequency is widely used as an indicator to evaluate the importance of patents [17]. A patent, if often cited by other patents, normally has a great impact on the development of its field [18]. We also considered the influence of patent duration, because older patents have a greater chance to be cited than younger ones. Stratified sampling is used to screen core patens in this article. Patents are classified by their issuing year to nine groups and select the most cited 10% as core patents. Then remove unrelated patents through manual screening. As a result, 343 core patents were got.

Construct core patents co-citation matrix. Co-citation analysis based on the idea that: if patents A and B are co-cited, they have correlation on technologies and the correlation increases with the co-cited frequency increases. Investigating patent co-citation information can extract core technologies. The 343 initial core patents compose a 343*343 co-citation matrix. Samples of the matrix are shown in Table 1.

Table1. Samples of core patents co-citation matrix

PN	US5343970	US5931757	US5561380	US5939861	US6209672	US5558595	US5808469	US5711648
US5343970	220	4	0	13	33	14	0	0
US5931757	4	166	0	0	2	82	0	0
US5561380	0	0	148	98	1	0	103	80

US5939861	13	0	98	135	0	0	97	80
US6209672	33	2	1	0	134	8	0	0
US5558595	14	82	0	0	8	129	0	0
US5808469	0	0	103	97	0	0	129	80
US5711648	0	0	80	80	0	0	80	120

Further screen of core patents. Core patents received after initial screening might not belong to core technology fields. In this procedure, we further screened core patents. Construct a co-citation index τ, shown as follows:

$$\tau = \frac{\sum_{i=1}^{n} \alpha_{ij} - A_j}{A_j}, \quad j=1, 2, 3 \ldots 343 \qquad (1)$$

Where A_j is the frequency patent j is cited, τ is the co-cited frequency of patent i and patent j.

τ can indicate the correlation between core patents. If τ is comparatively big, it means they correlate closely; if τ is comparatively small, it means they correlate loosely. τ of EV core patens is 0.06-26. We removed patents whose τ is less than 6.

Factor analysis. The bibliometrics generally employs factor analysis to classify documents, journals and authors. Factor analysis is also used in patent classification. This study aims to classify patents by their correlation which reflected in the matrix is the linear correlation between variables. So factor analysis is suitable for this study. The result of KMO and Bartlett's Test verified the applicability of factor analysis. As shown in Table 2, value of KMO is 0.965, the observed value of test statistics of Bartlett's Test is 32560 and p- is far less than 0.05. Both these tests show factor analysis is suitable for the study.

Table 2. KMO and Bartlett's Test

KMO and Bartlett's Test		
KMO Measure of Sampling Adequacy.		0.965
Bartlett's Test of Sphericity	Approx. Chi-Square	3.256E4
	df	12090
	Sig.	0.000

Result of factor analysis shows that extract five factors can explain about 60% of total variance, while extract five more factors only can explain variance 10% more. So, in this study we classify core EV patent to five groups.

Determine core technologies. Classify core patents to five groups according to the correlation coefficient between variables and factors. Then make necessary adjustment after examining the results. Results are shown in Table 3. Five core technologies of EV are driving system arrangement and control, energy management and control, battery management, transmission system control, motor design and control.

Table 3. Core technologies of EV

Group	Number of patents	Core technologies
1	78	Driving system arrangement and control
2	18	Energy management and control
3	11	Battery management
4	11	Transmission system control

5	7	Motor design and control

3. Result analysis

Hybrid EV technology innovation is dominant. From the study above, we find hybrid EV technology innovation is dominant in EV R&D, which accounts for about 54% of core patents. Then is battery vehicle, which accounts for 30% of core patents. Fuel cell EV accounts for less than 10% of core patents. So, we can obtain a result that EV technology innovation in the past 17 years mainly focused on hybrid EV. This is consistent with the reality that most of EVs on road are hybrid.

Driving system arrangement and control technology is most important. As shown in Table 3, the first group accounts for 62% of all core patents, far more than the second group. All these patents are about driving system arrangement and control technology, which means this technology filed is most important. Energy management and control technology is the second important technology area. Technologies for controlling internal combustion engine, motor and other apparatus to achieve maximum energy efficiency and regenerative braking for energy recovery are all in this group. The third group represents battery management technologies, which include battery charging, discharging, monitoring and load balancing technologies. The fourth group is transmission system control technology. The fifth group is motor design and control technology.

Assignees are decentralized. The most productive eight assignees are Toyota, GM, Ford, Honda, Nissan, Hitachi, Aisin and Kabushikikaisha Equos Research. Two are from America and six are from Japan. These assignees possess 55.7% of all core patens. Other 74 assignees possess 44.3% core patents. Core technologies are not centralized. Organizations from other field are actively involved in EV development, for example, Engelhard Corporation (US4962462, US4931947) from USA is a manufacturer of auto exhaust gas catalyst, and Hydro-Quebec (US5418437) from Canada is a power company. Opportunities exist for small and medium entrepreneurs and variety kinds of organizations.

China has weak EV R&D performance. There is no Chinese assignee among more than 300 EV core patents. Chinese technologies of EV haven't entered the world stage before 2007. Chinese government, corporations and research institutes are all active in developing EV and several corporations have produced end products. Yet it is need to recognize that gap still exists between Chinese and abroad participants.

4. Conclusion

This article investigates core technologies of EV industry using patent co-citation information. Our results give a whole picture of EV technology innovation, which may be useful for policy-making and decision-making of EV firms.

We find that hybrid EV gets more attention than battery and fuel cell EV, and be the main stream so far. We extract five EV core technology groups as: driving system arrangement and control, energy management and control, battery management, transmission system control, motor design and control. Among the groups, driving system arrangement and control is the most important R&D field, which accounts for more than 60% of core patents. Core technology assignees are decentralized as the most productive eight assignees possess 55.7% of all core patens and other 74 assignees possess 44.3%. Opportunities exist for small and medium entrepreneurs and variety kinds of organizations. However, there is no Chinese assignee. It is need to recognize the gap between Chinese and abroad participants.

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