Development Status and Trend of Electric Vehicles in China

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Abstract: Due to pressures from both energy and environment, electric vehicles (EVs) and their related technologies have experienced considerable achievements in China in recent years. This paper firstly presents the EV development status in China with key statistics including EV market status, mainstream technical indicators, charging infrastructure, and key components (battery, motor drive systems). Then, the developmental driving forces of EVs in China are reviewed and analyzed with an emphasis on government policies such as subsidy rules, research investment, and standards. Finally, the development trend of EVs in China is prospected from aspects of industry, technology and policy, opportunities and challenges, with an expectation that more attention from academia, industry and government will be attracted into the area of EVs.

Keywords: Electric vehicles, BEV, HEV, PHEV, development status, EV technology, EV policy, review.

1 Introduction

With the rapid development of the Chinese economy, China has become the largest passenger car market in the world since 2009. Although the fast growth of the Chinese automobile industry has made great contribution to the whole Chinese economy and provided many job opportunities, it also presents substantial challenges to the nation.

By the end of 2015, the total number of civil vehicles in China has reached 162.84 million[1], which means more and more petroleum is being consumed. The percentage of transport oil consumption rose from 14.65% to 37.72% during the 25-year period from 1990 to 2014 in China.

On the other hand, the emission of ICE vehicles makes a considerable contribution to air pollution in most cities in China[2].

Hence, to relieve the pressures from both energy and environmental aspects, China has already made great efforts in the development of electric vehicles (EVs), which have accelerated the transformation of Chinese automobile industry and received some considerable achievements in recent years.

2 Present state of electric vehicles in China

2.1 EV Market in China

China started research of EVs since the 1990s. After years' of striving by the government, companies and research institutes, great achievements have been made. As is demonstrated in [3], in the "863" special item of developing electric vehicles during the Chinese tenth Five-Year Plan, EVs are classified into three different types, namely battery EV(BEV), hybrid EV(HEV), and fuel cell EV(FCEV), among which BEVs and plug-in HEVs(PHEVs) are the mainstream in recent years in China.

2.1.1 EV sales in China

Fig.1 shows the sales of BEVs and PHEVs in the past 5 years. More than 507 thousand EVs were sold in 2016 and the cumulative sales have reached 943 thousand units in China. It can be illustrated from Fig.1 that 2015 is a key year for China EV market[4], beginning a period of rapid development in China. Nevertheless, there has been no news about mass production of FCEVs in China recently, though they were running as demo in 2008 Beijing Olympic Games and 2010 Shanghai Expo (23 units and 173 units, respectively[4]).

Taking advantage of the momentum of EV industry's rapid development, many outstanding EV enterprises have been founded in recent years. In terms of passenger EVs, BYD, Geely, BAIC BJEV, Zotye and Chery are the top five sellers in 2016, and BYD is the only company with over 100 thousand annual sales. On the other hand, Yutong, Zhongtong, BYD, Higer and BAIC Foton take the first five places in EV bus sales. Table 1 lists sales of the representative Chinese EV enterprises in 2016.

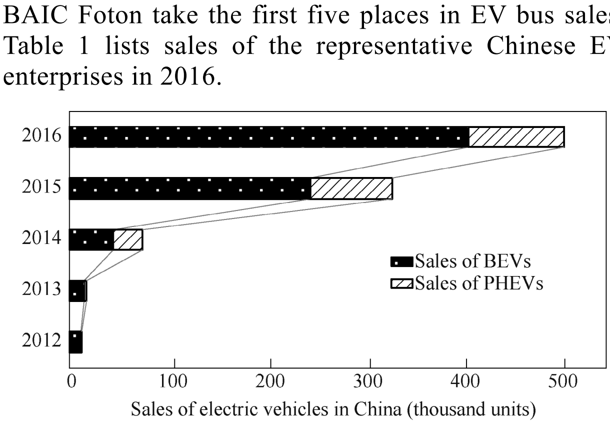

Fig.1 Sales of electric vehicles in China. source: china association of automobile manufacturers

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Table 1 Sales of Chinese EV enterprises in 2016*

Enterprise	Sales	Representative Products
Passenger EVs		
BYD	100178	E5, E6, Tang, Qing
Geely	49218	Emgrand EV, ZD D1/D2/D2S
BAIC BJEV	47048	EC180, EU260, EX260, ES210
Zotye	36999	E30, E200, Yun 100S
Chery	20963	Arrizo 7e, eQ
SAIC	20017	Roewe e50, eRX5, e750 Hybrid
JAC	18369	iEV4, iEV5, iEV6S
JMC	15608	E100, E200
Chang'an	4931	Benben mini, C303, Zhixiang
DFM	4347	e30, A60EV
Electric Buses		
Enterprise	Sales	Representative Products
Yutong	26856	E8 mini, E8, E10, E12
Zhongtong	14105	LCK6108EV1/EVG4, LCK6809EVG
BYD	13278	K6/7/8/9, C6/8/9
Higer	7042	KLQ6702EV, KLQ6125ZAEV
BAIC Foton	6754	BJ6127/6852/6851/6760
Golden Dragon	5327	XML6105/6115/6125, XML6809
Yinlong	5285	City BRT, 13m Double-layer Bus, 18m Bus
Wuzhoulong	5103	FDG6105EVG1/G4/G5
Ankai	4950	HFF6850K10EV, HFF6101K10EV
Skywell	4893	D11, D12

*Source: Official websites of corresponding enterprises.

EV sales of foreign brands are not as desirable as local brands in China. In fact, with the exception of Tesla which sold the 6824 Model S and 4904 Model X, there is no other foreign companies which has achieved mass saleroom in 2016 in China. This situation is likely caused by two reasons: one is that the positioning of the foreign EVs is usually too high for Chinese market (BWM i3 and i8, for example); the other is that the products from foreign brands can hardly satisfy the subsidy conditions of government. For these reasons, joint ventures are a reasonable solution for foreign brands. Consequently, several joint venture enterprises have been founded recently, Denza (founded by BYD and Daimler AG) and Venucia (founded by DFM and Nissan Motor) for example. Based on the vehicle technology from Daimler and the battery and electrical drive technology from BYD, the Denza 400 was proposed in 2016. Similarly, based on Nissan Leaf platform, Venucia redesigned a new car called e30 in 2015. Thanks to being listed in the promotion directory, Denza 400 and Venucia e30 are the only two foreign brand EVs selling more than 2000 vehicles in 2016.

2.1.2 Unbalance distribution of EV sales

With the rapid development of the electric vehicle industry however, some defects also have come out and several unhealthy trends can already be found in Chinese EV market.

As is reported in [6], up to the end of 2015, only about 1/3 of EVs are sold to private users and the left are shared by public purchase in which rental vehicles and city buses take more than half. Fig.2 shows the detailed sale distribution in 2015. Considering the strong policy encouragement from the government, Chinese residents' recognition of EVs is not as desirable as the increasing market sales indicates.

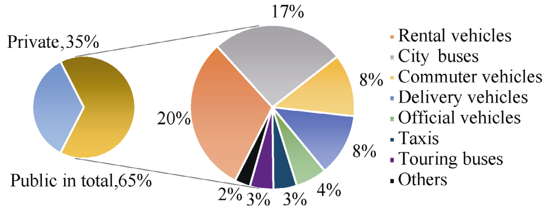


Fig.2 Sale Distribution of EVs in China up to the end of 2015[6]

In addition, when looking into the private market, it can be found that Shanghai (26%), Beijing (14%) and Shenzhen (8%) contribute nearly half of the total sales, where both the purchase and registration are limited for ICE cars, and purchasing an EV is the only way to get a car quickly.

Except for the unbalance of distribution in different districts, the monthly EV sales also show unbalance in recent years as shown in Fig.3[7-8]. The reason for all the unbalanced development will be discussed in following sections.

2.1.3 New trends of Chinese EV market

Fortunately, some new encouraging trends can be found in Chinese EV industry as well, including participation of internet companies, active cooperation with scientific enterprises of traditional automobile factories and overseas development of Chinese automobile companies.

With the growing recognition of EVs in society and people in different fields, more and more scientific or internet enterprises are announcing to take part in the EV industry with their strong capital, technology and talent reserves. Several representative enterprises are listed in Table 2.

Moreover, for the traditional automobile companies, they have the essential superiority to transform into EV industry. Consequently, nearly all the automobile factories have set up their own EV projects and many of them have been seeking for cooperation with strong partners in emerging fields. For example, SAIC Motor and Alibaba Group initiated $161 million fund for internet cars in March 2015, and jointly released the first mass-produced internet car (Roewe RX5) in the world that carried the YunOS in July 2016. On the other hand, Baidu and China Chang'an Automobile Group, BAIC Motor and Daimler AG have built similar cooperation relationship, respectively.

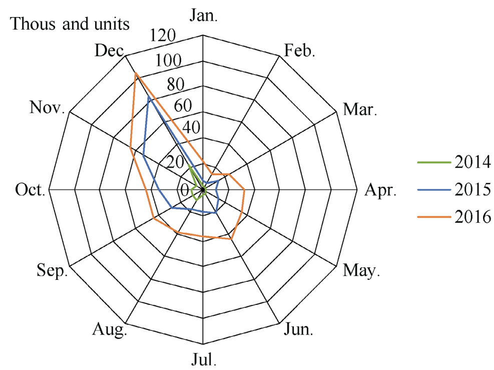


Fig.3 Monthly EV sales in 2014, 2015 and 2016 (Source: Xinhuanet.com and Qianzhan.com[8])

Table 2 Representative Internet enterprises joining EV industry

Enterprise	Founder	Investor	Products	Investment/(million)	Entry time
Nio	Li Bin (Founder of BitAuto)	Baidu, Tencent, JD.com, Hillhouse Capital	EP9 (Released in Nov. 2016), EVE (Released in Mar. 2017), ES8 (Released in Apr. 2017)	¥7000	Nov. 2014
Chehejia	Li Xiang (Founder of AutoHome)	Leo Group, Source Code Capital, Government of Changzhou	Not released	¥780	Oct. 2015
ZhicheAUTO	Shen Haiyin (Former VP of 360)	Intel Capital, Government of Tongling	Singulato Motor (Released in 2016.3)	¥600	Dec. 2014
XPENG Motors	He Xiaopeng (Founder of UC)	UC, YY, Cheetah Mobile	Xiaopeng Motor's Beta Version (Released in Nov. 2016)	¥600	Jan. 2015

*Source: Official websites of corresponding enterprises and *Itjuzi.com*.

Meanwhile, building overseas centers is becoming more and more popular for Chinese automobile companies. BJEV, held by BAIC, has built seven R&D centers in Silicon Valley, Aachen, Detroit, Barcelona, Dresden Tokyo and Turin since 2015. Coincidentally, Nio has arranged three R&D or design center in San Jose, Munich and London.

2.2 Mainstream technical indicators of EVs in China

To clearly present the mainstream technical indicators of passenger EVs in China, several representative EVs (having considerable sales around the world) from local and foreign companies in different category are selected for comparison, whose main indicators are shown in Table 3. We can conclude that the NCM battery and permanent magnet synchronous motor (PMSM) are mainstream for EV's electric propulsion system. Moreover, 150km range and 100km/h max speed are the basic performance for EVs in all levels.

In China, EVs under A-class hold the majority of the market, which are nearly all BEVs. For A00 and A0 EVs, they usually have 150km range and over 100km/h maximum speed and are equipped with about 20kWh battery. From the point of view of vehicle technology, Chinese local EVs are on the same level as foreign ones and at a more competitive price for A00 and A0 classes. For A-class EVs, Emgrand EV and Leaf S are the most popular A-class EV in China and around the world in the first half of 2017, respectively. In terms of technical indicators, Emgrand EV has a 330km battery range, 140km/h maximum speed and 9.9s 0~100km/h time, which has distinct advantages over Leaf S while the price is almost the same. This is also a reason why there are rarely foreign brands selling well in China.

In addition, in the B-class EV market, PHEV takes absolute percentage. BYD Tang is the sales champion of all EVs in China in 2016, with outstanding performance (4.9s 0~100km/h time) even compared with ICE cars with an extremely low oil consumption (1.8L/100km). Thanks to the subsidy from both nation and cites, customers can own a high-performance vehicle equipped with advanced intelligent technology for a reasonable low price by purchasing a PHEV.

However, in the high-level market, Chinese EVs achieved little progress in recent years. It is hard to find a Chinese EV having similar performance to Tesla or any other famous EVs from foreign companies except for the concept cars issued by the emerging Internet companies discussed above. This may be due to the weak demand and recognition of high-level EVs in China.

2.3 Infrastructure construction.

For EV customers (including potential customers), the largest concern is the amount and location of available charging facilities rather than intensity of support policies or other factors[6]. Therefore, charging infrastructure construction is so important that it directly relates to EV acceptance for normal customers.

In the early years when China first started promoting EVs, the construction of charging stations and points exhibited some confusion and disorder[6,9]. Until late 2015, three key policies were issued, namely Guiding Opinions of the General Office of the State Council on Accelerating the Construction of Electric Vehicle Charging Infrastructure by General Office of the State Council, Notice on Issuing the Guidelines for the Development of Electric Vehicle Charging Infrastructure (2015~2020) by National Energy Administration and Notice on Enhancing the

Table 3 Technical indicators of representative EVs

EV model	Producer	Category	Max		Battery*		Electric machine			Charging time/h		Oil/electricity consumption/ (kWh/ km)	0~100 time/s	Intelligent device
			Pure battery range/km	Speed/ (km/h)	Type	Capacity/ (kWh)	Type	Power/ kW	Torque/ (N·m)	Fast	Slow			
Yun 100S	Zotye	A00/BEV	155	105	NCM	22	IM	27	140	1.5	8	10/100	-	○
Smart fortwo	Smart	A00/BEV	145	125	NCM	17.6	PMSM	55	130	3.5	7	14.4/100	-	○
EV160	BAIC BJEV	A0/BEV	150	125	LFP	25.6	PMSM	45	144	1	8	15/100	-	○
ZOE	Renault	A0/BEV	240	135	NCM	22	PMSM	68	220	1	9	13.3/100	13.5	●
Emgrand EV	Geely	A/BEV	330	140	NCM	45.3	PMSM	95	240	0.8	14	15.8/100	9.9	●
Leaf S	Nissan	A/BEV	175	150	NCM	30	PMSM	80	254	0.5	4	18.7/100	9.9	○
Tang 100	BYD	B/PHEV	100	180	NCM	22	PMSM	220	500	-	6.9	1.8 /100	4.9	●
Model S 75	Tesla	C/BEV	480	225	NCM	75	IM	285	440	4.5	10.5	21/100	5.8	●

*NCM = Lithium Nickel Manganese Cobalt Oxide battery ($LiNi_xMn_yCo_zO2$), LFP = Lithium Iron Phosphate battery ($LiFePO_4$).

Urban-Rural Development[10-12]. In these policies, it was planed that the construction of 4.3 million charging points and 2397 public charging stations were going to be completed before 2020. Meanwhile, the demand or modification work for new constructions or existing constructions was clearly confirmed.

It was the first time that the government gave a specific plan for the development method, construction mode and quantity for a EV charging infrastructure. The effects of these policies are obvious. The numbers of existing and incremental charging facilities from 2012 to Feb. 2017 are shown in Fig.4[6,13-15]. It can be fund that a sharp spike occurred between 2015 and 2016 after the policies were issued, and there were as many incremental charging spots in Jan. 2017 as that of the whole year in 2014. Also, besides the local charging spots, charging stations between different cities are growing at a rapid pace. The State Grid has already built 1224 expressway charging stations up to Jan. 2017, covering most areas in East China[17]. The main operating companies of charging facilities include the State Grid, China Southern Power Grid, Potevio, Teld and Star Charge, while Nari of State Grid, XJ Electric, Auto Electric Power, UTEK and TGood are the major charging piles producers[6].

However, it may be a little late for charging facilities' construction to catch up with the increasing speed of EV sales. The ratio of charging points and EV sales at the same time is also depicted in Fig.4, showing a rapid decline from 2013, which means that the construction speed of charging facilities is far behind that of the increasing EV sales. Although the encouraging policies changed the declining trend, the ratio just climbed to less than 16% in Feb. 2017, indicating that more than six EVs shared one charging pile.

2.4 Key components

2.4.1 Battery technology

Compared with the lag of development of charging facilities, the Chinese power battery industry can satisfy the demand of EV production easily in 2017. What is of concern now is how to absorb the excess capacity. In fact, encouraged by sequential support policies, massive capacity expansion has been operated by many Chinese battery companies in the past two years. Now, if all the battery capacities are released, the production can reach 170GWh per year while just 28GWh per year can satisfy the demand of the EV market in 2016[18].

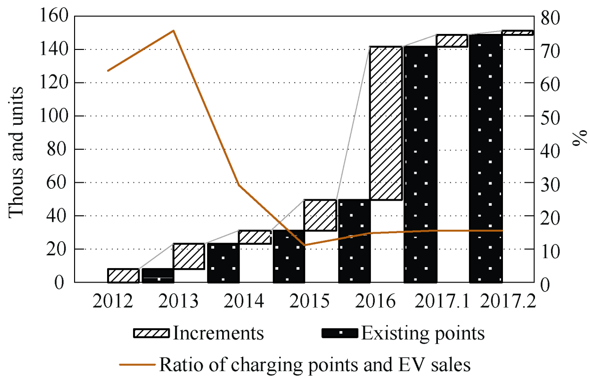


Fig.4 Existing and incremental charging points from 2012 to Feb. 2017 and the ratio of charging points and EV sales in each period[6,13-15]

Lithium-ion battery is the main stream power battery of EV and can be categorized by its cathode material. In terms of distribution of different kinds of batteries, Lithium Iron Phosphate (LFP, $LiFePO_4$) battery and Lithium Nickel Manganese Cobalt Oxide (NCM, $LiNi_xMn_yCo_zO_2$) battery are taking the major part of the whole market shown in Fig.5[19-20]. Other types of batteries include Lithium Manganese Oxide (LMO, $LiMn_2O_4$) battery and Lithium Cobalt Oxide ($LiCoO_2$) battery. On the other hand, for producers, BYD, CATL, Optimum Nano and Guoxuan High Tech take 66% of the whole market in 2016[20].

Another challenge for the Chinese power battery industry is that many foreign battery companies have built or plan to build battery factories in China. In fact, Samsung SDI has completed its battery factory in Xi'an in Oct. 2015 as well as LG Chem has also built a factory in Nanjing at the same time. Moreover, Panasonics, Bosch, SK and Volkswagen have all confirmed plans for their battery factories in China[6].

2.4.2 Motor drive system

As the heart of EVs, the propulsion motor is one of the key technologies of EVs. The special operating modes and working conditions of EVs present special demands for the electric motors used in them, which has made academics regard EV motors as a special category[21]. The main differences between EV motors and conventional industrial motors are listed in Table 4.

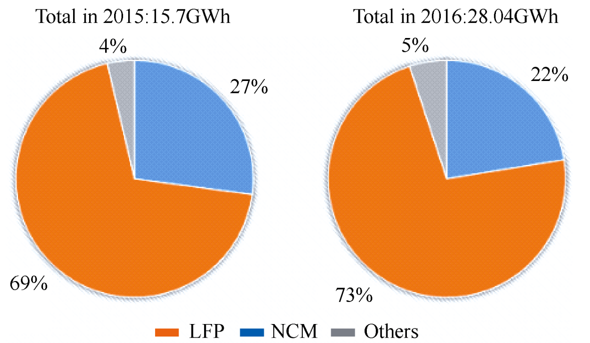


Fig.5 Distribution of different kinds of batteries in 2015 and 2016[20]

Table 4 Comparison of EV's and traditional motors[21]

Item	EV motors	Traditional motors
Ambient temperature	–40~140℃	20~40℃
Operation environment	Adverse	Indoor
Coolant temperature	<70~150℃*	<40℃
Winding temperature	160~200℃	75~130℃
Speed range	0~15000r/min	<3000r/min
Noise level	Very low	Low
Speed demand	Frequent changes	Keep uniform
Installation space	Very limited	Loose
System voltage	Independent/variable	Static grid
Efficiency	High efficiency over a wide area	High efficiency at a certain point

*<70℃ for BEV, <150℃ for HEV.

Planning and Construction Work of Electric Vehicle Charging Infrastructure by Ministry of Housing and considering electrical machines used in EVs, the permanent magnet synchronous machines take the distinct advantage where production reached 450 thousand and 77% of the whole market in 2016 while the numbers of induction machines are 140 thousand and 23%, and others, DC machines or switched reluctance machines for example, hold the remaining 1%[23].

2.4.2.1 Permanent magnet motors

For the PMSMs, interior permanent magnet (IPM) motors are still dominating the market. The typical topology and prototype of IPM motor is shown in Fig.6. Due to the relatively mature structure and design method, academic research about IPM motors in China is focused on noise characteristics, demagnetization fault diagnosis, fault mode recognition, analysis of natural frequencies, and so on, which are mainly concerning the operation reliability[26]. In addition, the advanced control strategies for IPMs, the deadbeat- direct torque and flux control or sensorless control for example, are also popular research directions.

2.4.2.2 Induction motors

Although with lower efficiency than that of PM motors, induction motors account for 23% of the whole market in China due to their robust structure, low cost, high reliability and mature processing technology, especially for applications which are not sensitive to volume but strict with regards to cost, such as electric buses and trucks.

Moreover, to improve the efficiency and power density and reduce noise, die-cast copper rotor IMs are attracting more and more attention from both academia and industry[27]. Compared with the aluminum rotor, cast copper rotor IMs can reduce rotor loss with the advantage of higher electrical conductivity. Another attractive feature of the copper rotor IMs is the relatively flat efficiency curve over a wide range of output power, which can well satisfy demand for EV applications.

The main obstacle for the application of copper rotor IMs is that the manufacturing requirements of cast copper rotor for the high melting point and poor flow ability of copper. There are two directions to deal with the problem, namely improving the die material and optimizing the assembly method of rotor bars and rings. A heated nickel-base alloy die technology was reported in [27], which is intended to be a method to solve the manufacturing problem. On the other hand, Tesla Motors, the world-famous EV enterprise, presented a novel rotor assembling method, which could fabricate a copper rotor easily while minimizing rotor weight and maximizing conductivity between rotor bars[29].

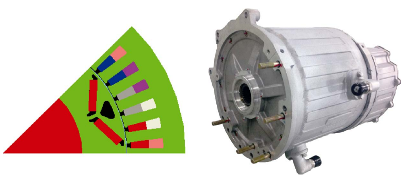


Fig.6 Typical topology and prototype of IPM motor

2.4.2.3 Industry status

Table 5 shows the top ten sellers in motor and motor controller market. It can be seen that Shanghai Edrive, UAES and JEE take the first three places with the exception of the EV companies. Furthermore, a clear trend in motor and drive industry is industrial integrity, evidenced by remarkable events such as the purchase of Shanghai Edrive by Broad-Ocean Motor and the cooperation of Dajun Tech and Wolong in 2015[6]. Meanwhile, the participation of traditional inverter companies is also a new change. In fact, Inovance in Shenzhen, Sungrow in Hefei, FDM in Zhejiang and V&T in Shenzhen are all taking part in the motor and controller industry for EV through technology extension and purchase.

Simply stated, the status of today's Chinese EV industry is caused by many complex factors. Beyond the technology development, operation of capital markets, residents' recognition, international environmental factors, and government policies are also crucial factors for EV development.

3 EV policies in China: summary and analysis

3.1 National and regional policies

To keep the development of EV industry stable and healthy, many policies have been issued by governments. The main departments of the central government responsible include the State Council and its General Office, the Ministry of Industry and Information Technology (MIIT), the National Development and Reform Commission (NDRC) and its National Energy Administration (NEA), the Ministry of Science and Technology (MOST), Ministry of Finance (MOF), the State Administration of Taxation (SAT), Ministry of Housing and Urban-Rural Development (MOHURD) and the Ministry of Transport (MOT), which were clearly confirmed in Notice on Issuing the Planning for the Development of the Energy-Saving and New Energy Automobile Industry (2012-2020) by the State Council[31]. Most of the important national policies are listed chronologically in Fig.7[31-47] and are classified into four different categories, namely the macro guidance policies, the finance support policies, the policies related to charging facility and battery and the supervision policies.

Table 5 Top ten sellers in motor and controller market[30]

Electrical Machine		Motor Controller	
Enterprise	Shipments	Enterprise	Shipments
BYD	140197	BYD	140197
BAIC BJEV	51831	BAIC BJEV	51831
Yutong	26851	UAES	39144
Shanghai Edrive	22705	Shanghai Edrive	19603
UAES	20189	JEE	18371
JEE	18371	Deyang	17610
JMC	17362	JMC	17362
Deyang	17206	Zotye	15314
JJE	17072	Sikeruo	10883
Zotye	15314	Genwell	10839

* EV companies are included.

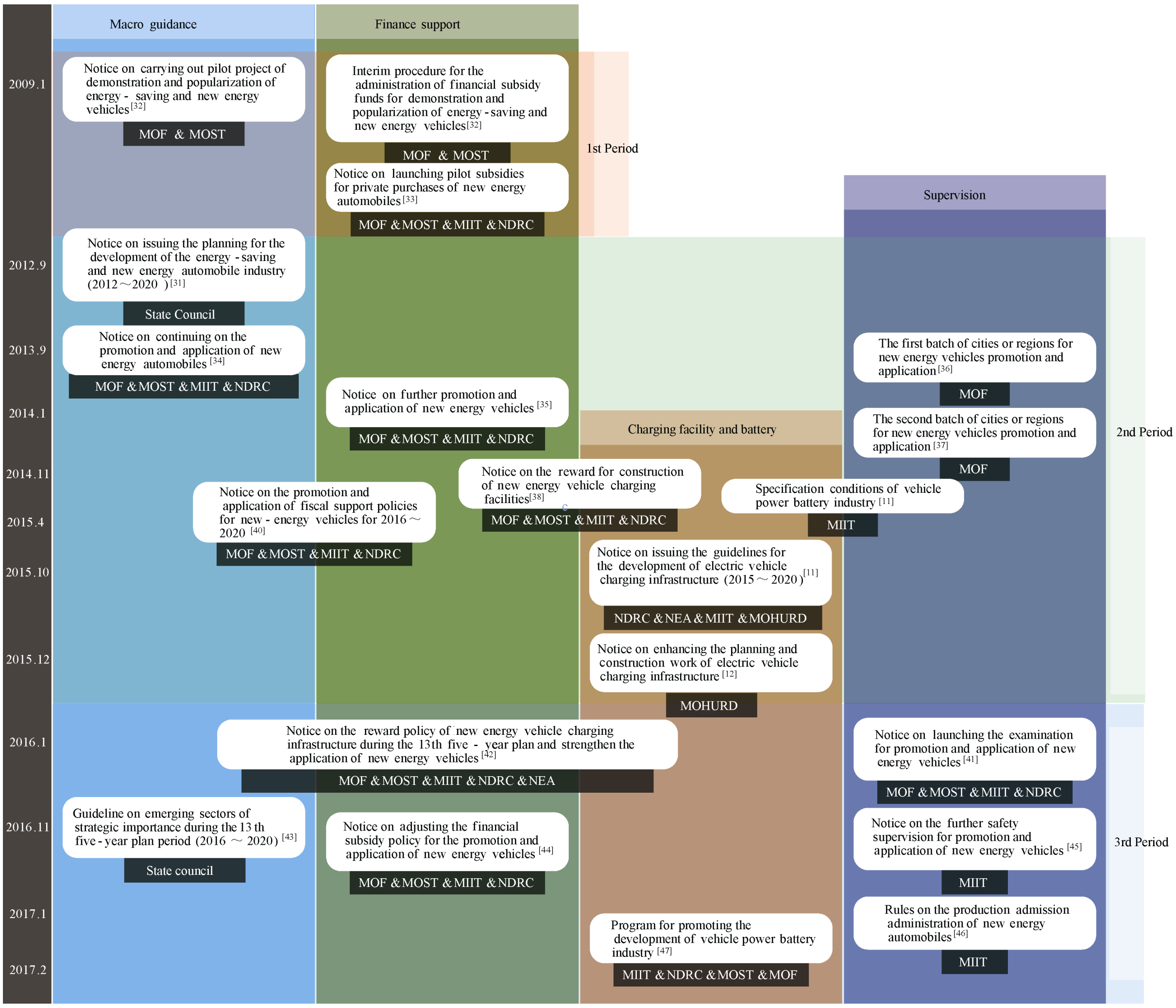


Fig.7 Summary of EV policies in China from 2009 to Feb. 2017. Source: Websites of the State Council, MOF, MOST, MIIT, NDRC, MOHURD and SAT[11-12, 31-47]

The massive development of EVs in China began from the issuing of Notice on Carrying out Pilot Project of Demonstration and Popularization of Energy-Saving and New Energy Vehicles in 2009[32], when the "10 Cities 1000 EVs" project was started, which planned to implement demonstration of 1000 EVs in ten cities each per year[48]. We define it the first period of China EV development and this period lasts for nearly four years from 2009 to 2012.

The second period began from the presentation of the Planning for the Development of the Energy-Saving and New Energy Automobile Industry (2012~2020) in July 2012, in which BEVs were confirmed to be a priority strategy for the first time, and EV production and sales plans of 500 thousand in 2015 and 5 million in 2020 were drawn up while that of the US were 1 million and 3 million, respectively[31]. Another important policy was the Notice on Continuing on the Promotion and Application of New Energy Automobiles issued in Sep. 2013, where the city-based developing strategy, the phase-out mechanism of subsidy and the clear subsidy standard were proposed[34].

The subsidy standards in different periods direct not only the market but also the technology orientation. Comparison of the subsidy standards between the two periods is shown in Table 6. We could conclude that the target of the first period was fuel savings, when the fuel-saving ratio was first considered for the subsidy level evaluation. Meanwhile, although the amount of subsidy for BEVs is relatively high compared with that of HEVs, the subsections of HEVs were regulated in more detail, which meant there was not a clear emphasis on the EV development at that period. In addition, the subsidy strategy was changed following the evolution of the development idea in the second period, when the EV industry was not regarded as a simple update of traditional vehicle industry but a brand new field. Instead of the fuel-saving ratio, pure electric driving range had become the main factor for subsidy level assessment and subsidy for BEVs much more than that of HEVs, showing the priority developing position of BEVs. In terms of buses, subsidy in the second period was more comprehensive than the first. For FCEVs, considering the technology threshold and developing potential, support from government was always strong.

To supervise and urge the promotion of pilot cites, the elimination mechanism was also regulated in [34], which indeed accelerated the growth of the EV industry

Table 6 Comparison of subsidy in different periods[32]

Period	Type	Fuel-saving ratio(%)	Electrical power ratio(%)	Subsidy(¥) Passenger vehicles	Subsidy(¥) Buses (＞10m)
2009 ~ 2012	HEV	10~20	10~20	28,000	-
			20~30	32,000	200,000
			30~50	-	
		20~30	10~20	32,000	-
			20~30	36,000	250,000
			30~50	42,000	
			＞50		300,000
		30~40	20~30	42,000	300,000
			30~50	45,000	
			＞50		360,000
		＞40	30~50	50,000	35,000
			＞50		42,000
	BEV	100	-	60,000	500,000
	FCEV	100	-	250,000	600,000
2013 ~ 2015	HEV	Pure electric driving range	Vehicle length	Passenger vehicles	Buses
		＞50 km	-	35,000	-
		-	＞10 m	-	250,000
	BEV	80~150km	-	¥35,000	-
		150~250km	-	¥50,000	-
		＞250km	-	¥60,000	-
		-	6~8m	-	¥300,000
		-	8~10m	-	¥400,000
		-	＞10m	-	¥500,000
	FCEV			¥200,000	¥500,000

but might be the reason for the unbalance distribution of EV development mentioned in Section 2 as well. As well as subsidy policies, the tax exemption for EV purchases is also given[50].

Meanwhile, it should be noted that the government arranged some support policies for the development of charging infrastructure and battery late in this period, which boosted considerably the construction and research of charging facilities and the capacity extension of the battery enterprises[10]. Moreover, the presenting of Provisions on the Administration of Newly Established Pure Electric Passenger Vehicle Enterprises in June 2015 showed the determination of the government to regulate the EV industry[52], and the Notice on Launching the Examination for Promotion and Application of New Energy Vehicles issued in Jan. 2016 indicated the end of the second period[41].

The 13th Five-Year Plan for the National Economic and Social Development of China listed the new energy vehicles as one of the six strategic emerging industries in Chapter Twenty-three in Mar. 2016, which marked the opening salvo of EV development's new period[53]. The following policies focused on the subsidy adjustment and safety supervision, indicating the healthy and orderly development is the target for the next period of the EV industry[44].

For regional policies, to coordinate the guidance of the central government, the pilot cities or city groups issued massive corresponding regional policies and the detailed analysis can be found in [6]. It needs to be noted that registration of EV licenses are allowed to be applied for directly without lottery or biding and the traffic control policies are also inapplicable to EVs in the eight vehicle purchase-limited and traffic-control cities.

3.2 Research and development investment

The beginning of Chinese research on EVs can be traced back to 1992, when the Research on Key Technology of Electric Vehicles was listed into the National Science and Technology Project during the Eighth Five-Year Plan[54]. In fact, EV technology research has always been included in the top research plans since then, and can be found in Table 7. During the 8th and 9th Five-Year Plan periods, the design and manufacture of a concept EV was completed and a national electric vehicle demonstration area was built, which laid the foundation for the following research projects[55]. When the time of the 10th Five-Year Plan period came, a comprehensive R&D framework was in place, focusing on three core technologies, namely the powertrain, drive motor and power battery for HEV, BEV and FCEV[3]. Based on this R&D framework, the research scope was further extended to electricity-based vehicles (BEVs and PHEVs), energy-saving ICE vehicles and gas-fuel-based vehicles (FCEVs and CNG vehicles), and construction of technology, R&D and production platforms become the core target during the 11th Five-Year Plan. Moreover, in the next Five-Year Plan, BEV technology was determined to be the priority, and the research scope was categorized more effectively into the electricity based vehicles (BEVs and PHEVs), the FCEVs and hybrid vehicles (CNG vehicles and others). In addition, the platforms of standard and test, energy supply and demonstration were established during this period[56]. Due to the successful implementation of the top research projects, great achievements have been made in the promotion and application of EVs.

Additionally, according to incomplete statistics, more than two hundred and fifty projects have been established by the National Natural Science Foundation of China from 2008 to 2016, which also provide strong support for the R&D process of China.

3.3 State standard

The EV industry is developing rapidly, but standards can play a crucial role to coordinate the relationship between the products, technology, market and industry. Standards are a requirement of government and industry development. The first batch of EV-related state standards was issued in July 2001, focusing on the approval evaluation program and safety specifications. Up to Mar. 2017, 121 state and industrial standards have been issued and eighteen of them are replaced by the subsequently modified ones, so that there were 103 state and industrial standards being valid at that point. Fig.8 shows the state and industrial standards issued in different years, and

Table 7 Top research plans of EV technology in China

Period	Project
8th Five-Year Plan	National Science and Technology Project
9th Five-Year Plan	National Science and Technology Project
10th Five-Year Plan	National Science and Technology Major Project
11th Five-Year Plan	National High Tech Research and Development Program (863 Program): Energy-saving and New Energy Vehicle Major Project
12th Five-Year Plan	EV Technology Development Key Specialized Project
13th Five-Year Plan	National key Research & Development Plan

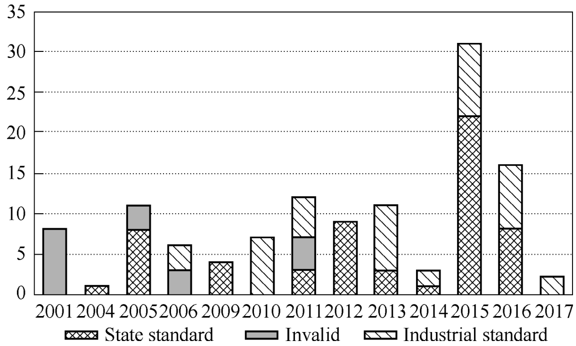


Fig.8 EV-related state standard in China. Source: National Standard Information Sharing Infrastructure[57]

invalid standards are presented to show the real volume of standards issued as well. It should be noted that all the invalid standards are state standards. It can be easily observed that the industrial standards always follow the issuing of state standards and the time between them has been reduced.

The annual distribution of standards in different fields is shown in Fig.9. It can be seen that the standards published in the early years mainly regulated the vehicle itself. As time went on, more and more standards were related to the components and charging infrastructures after 2009. Moreover, due to the demand of the rapid developing industry, all types of standards increased sharply over recent years. The reason for the rise of vehicle standards is that the modifications of the old standards do not satisfy the current situation anymore. However, the requirement from the EV components and charging facilities fields shows no decrease at all, and more than fifty related standards were issued in recent five years.

To keep a leading position in the EV standard field all over the world, China held the US-China Workshop on Electric Vehicle Technology and Standardization in Beijing, 2015. The Standardization Roadmaps of Electric Vehicle in China and US were discussed and cooperative intention was achieved. In addition, cooperation in the field of EV standards with Germany is also being implemented[58].

4 Trend of EV development in China

4.1 Industry trend

The annual EV production and sales are planned to be 200 million with total ownership of EVs expected

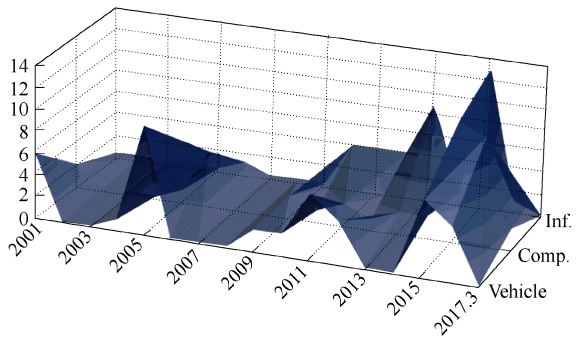


Fig.9 Annual distribution of standards in vehicle, components and charging infrastructure fields

to reach 500 million by 2020[31]. Continuing with the well implementation of the EV promotion these years, it can be expected to achieve the target successfully.

Along with industry development, the imbalance in distribution of EV sales will change gradually. It can be predicted that the portion of private EVs is going to increase even if the subsidy is reduced, which can be deduced for two reasons. Firstly, more and more cities are going to implement the purchase limit and traffic control policies, which will push customers to take EVs into consideration. Secondly, the fuel consumption regulations are getting increasingly strict all over the world, which will compel the automobile industry to focus more attention into EVs and will undoubtedly create more incentive for production of EVs at a reasonable price to customers. However, the increasing speed of the EV market may experience a slow down period at the beginning of modification of policies, which can be observed in Jan. 2017.

Another predictable trend is the improving and completing of charging infrastructure. No matter what opinions are held by different groups, society has already become familiar with and is getting to appreciate the concept of EVs. Therefore, the construction of charging installations will become standard providing for facilities in different places.

The safety and compatibility will become a new developing direction as well. As the demand for basic performance is being satisfied for the costumer, the safety requirements will become more of an issue and the newly issued supervision policy confirms this trend[45]. Besides, with the implementation of EV standardization process, compatibility between EV-to-EV, charging pile to charging pile, EV to charging facility and EV to other newly developed accessories will be enhanced greatly.

In a word, with the environmental pressures and numerous advantages of EVs, China will keep pace to in development for the EV industry, which will undoubtedly lead to a bright future.

4.2 Technology trend

For the EV technologies, the research layout of next period has been presented in [60]. The BEV and PHEV will still be the priority while the implementation of new energy, new material and informatization are considered brand-new opportunities to be seized.

4.2.1 Trend of vehicle technology

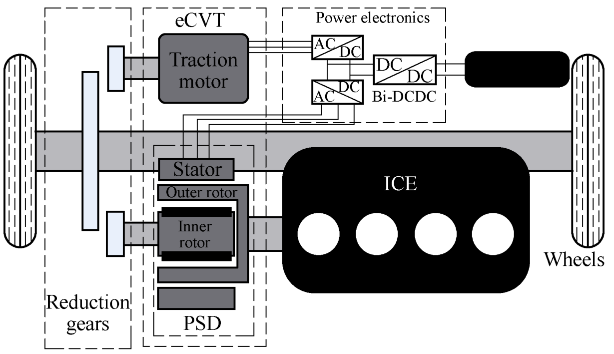
The detail technical indicators for the next generation BEV and PHEV determined in [60] are listed in Table 8.

For PHEV, novel vehicle technology and optimization for existing PHEV are required at the same time, and the main purpose is to improve performance as well as reduce oil consumption to an extremely low level (1.3L/100km). The main solution can be aided through research on advanced electromechanical coupling technique, cost-benefit power train, battery management system and optimum control techniques for vehicle power.

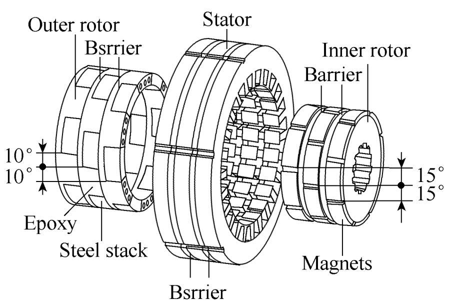
Table 8 Vehicle technical indicators

Field	Item	Technical Indicator
Novel cost-benefit PHEV	0~100km/h time	<5s
	0~50km/h time (pure battery)	<2.5s
	Pure battery range	>70km
	Oil consumption	<1.3L/100km
Optimization for normal PHEVs	0~100km/h time	<8s
	0~50km/h time (pure battery)	<3.5s
	Pure battery range	>70km
	Oil consumption	<1.3L/100km
Distributed drive BEV	0~100km/h time	<6s
	Max gradeability	>30%
	Pure battery range	>300km
	Max speed	>140km/h
	Electricity consumption	<10kWh/100km
High-performance low-cost BEV	0~100km/h time	<6s
	Lightweight of body	>10%
	Pure battery range	>400km
	Max speed	>160km/h
	Electricity consumption	<10kWh/100km

To satisfy this demand, a novel power split system based on a magnetic-geared dual-rotor machine (MGDRM) may be a good solution and has attracted increasing research attention[61]. Fig.10(a) shows the diagram of the power split system made of the MGDRM. The mechanical power of the ICE output can be split into two parts by the MGDRM. Part of the mechanical power is directly transmitted to the drive axle by the inner rotor; the rest of the power is converted to electric power by the armature windings to support the traction motor and/or to charge the battery. Because vehicles have several complex operation patterns, such as regenerative braking mode and rapid acceleration mode, the output mechanical power flow and the electric power flow are both bidirectional.



(a) Power split system



(b) Topology of MGDRM

Fig.10 MGDRM-based power split device system and the utilized motor

The utilized MGDRM is presented in Fig.10(b), where both outer rotor and inner rotor are divided into three equal modules with a particular angular displacement, called the complementary structure, with which the symmetrical and sinusoidal phase back-EMF waveforms and low cogging torque are achieved.

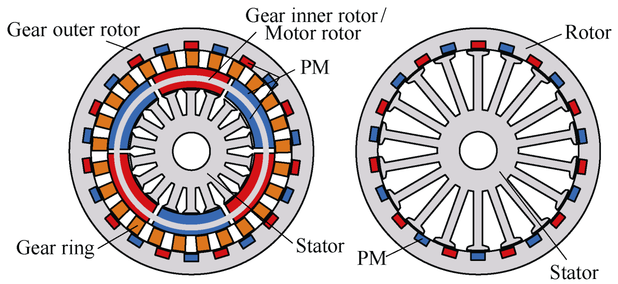
For BEV, distributed drive system is a new attempt while high-performance, low-cost and lightweight body are the main requirements for normal BEV. In particular, the electricity consumption is the biggest challenge to reduce to under 10kWh/100km.

The in-wheel motor drive system can achieve accurate torque distribution in all EV wheels without gearbox and differential mechanisms. Therefore, the complexity and mass of EVs can be reduced significantly by implementing in-wheel motor drive systems. In fact, FAW launched a new lightweight BEV with carbon fiber crew compartment, cast aluminum alloy chassis, and double front in-wheel motor drives.

To satisfy demand without mechanical speed reduction element in the in-wheel motor drive, the magnetic gear is taken into consideration for its no-contact torque transmission and inherent overload protection abilities. By simply integrating a coaxial magnetic gear into a PM motor, a magnetic-geared outer-rotor PM brushless motor is obtained as shown in Fig.11(a), which can offer higher torque density and less cogging torque[63]. Nevertheless, the proposed magnetic-geared in-wheel motor has such a complicated structure that three air gaps exist and tend to be higher in cost and low reliability. To overcome the problems, an improved flux-modulated PM (FMPM) in-wheel motor is presented in [64], as shown in Fig.11(b). Due to the omission of the inner rotor and stationary ring, there is only one air gap between the stator and outer rotor. With similar performance, the highly simplified FMPM in-wheel motor is much more competitive than the former one.

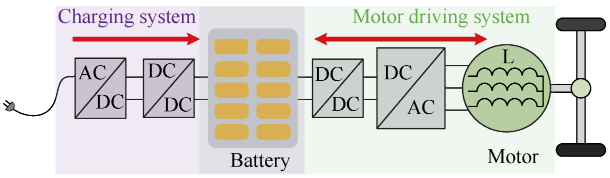
To achieve body lightweight, the integrated charging and driving system may be another good solution. Since the onboard charger gives flexibility to charge anywhere but has the drawback of adding weight, volume and cost, several integrated onboard charging and motor driving systems are reported to realize high performance, compact volume and low cost at the same time[65].

As is shown in Fig.12, by reconfiguring the connection of coils in motor, motor windings are used for filter inductors or an isolated transformer, while the

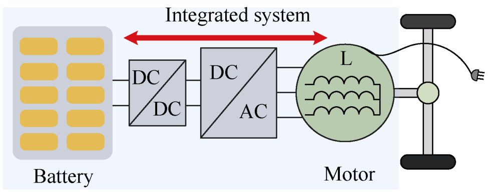


(a) Magnetic-geared outer-rotor PM brushless motor
(b) FMPM in-wheel motor

Fig.11 Magnetic-geared in-wheel motor[63]



(a) Conventional onboard charging system and driving system



(b) Integrated onboard charging system and driving system

Fig.12 Topology of conventional and integrated onboard charging system and driving system

motor drive inverter serves as a bidirectional ac–dc converter. Since the capacity of motor driving inverter is usually much larger than that of battery chargers, the integrated scheme highly feasible. By implementing the integrated system, the separated on-board charger is reduced and nearly all the demand for the electric propulsion system can be satisfied without any loss of performance.

The selection of the high technical indicators mandates that the EV technology in China is at the same level as foreign countries. Guided by the indicators above, great achievements will be achieved. On the other hand, intelligentization and connection to the Internet are also an important trend of EV technology, which may change the market operation mode and drive mode dramatically[6].

4.2.2 Trend of key component technology

At the same time, detail technical indicators for key components are also determined, which are all considerably high in every field as shown in Table 9.

Table 9 Key component technical indicators

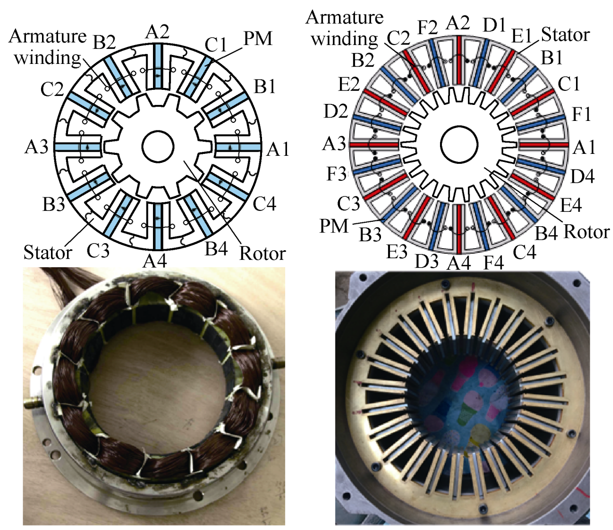
Field	Item	Technical Indicator
High-energy power battery	Monomer energy density	>300 Wh/kg
	Circle life	>1500 times
	Cost	<¥0.8 /Wh
	Annual produce capacity	>100 million Wh
Power battery system	System energy density	>200 Wh/kg
	Circle life	>1200 times
	Cost	<¥1.2 /Wh
Long life power battery	Energy density	>120 Wh/kg
	Circle life	>10000 times
SiC chip , package and controller	Rated current	>400A
	Rated voltage	>750V
	Controller peak power density	>30 kW/L
	Peak efficiency	>98.5%
Motors for passenger cars	Peak power density	>4 kW/kg (>30s)
	Continuous power density	>2.5 kW/kg
	Peak efficiency	>96%
Motors for commercial cars	Peak torque density	>20 N·m/kg (>60s)
	Continuous torque density	>11 N·m/kg
	Peak efficiency	>96%

To satisfy the high-level request for components, some new technologies should be taken into consideration. For example, the stator-PM motors with magnets mounted in the stator, have attracted much attention, as they are deemed a promising solution to overcome the shortages of the rotor-PM motors, such as the risk of irreversible demagnetization caused by the high heating stress and falling off for the magnets in rotor[65]. The operational principle, control strategy and different kinds of extension topologies of stator-PM motors are studied in depth, and it is concluded that the stator-PM motors, especially the flux switching permanent magnet (FSPM) motor can satisfy the demand of EV well and its industrialization is in process[69]. The topology and manufactured prototype of the typical three-phase FSPM motors and the newly presented six-phase FSPM motors are given in Fig.13.

4.3 Policy orientation

Although China will unwaveringly continue in developing its EV industry, the subsidy and tax exemption will inevitably be phased, the market volume continues to expand. Moreover, the infrastructure-related, supervision and management policies will increase to help keep the industry and market stable.

According to the policy published by MIIT in 2016, a new incentive mechanism called parallel credits provision was issued and was planned to be implemented from 2018[75]. In this provision, vehicle companies must earn both oil consumption credits and EV credits by reducing average oil consumption of their ICE products and by producing more EVs. Annually, each vehicle company must keep their oil consumption credits and EV credits to not less than zero, respectively. For companies that cannot earn enough credits, their negative credits should be compensated by purchasing extra EV credits from other companies, otherwise they will be forbidden to sell high consumption products. This mechanism will encourage traditional vehicle companies to transfer their main production into EVs gradually and is also a reward for EV companies.



(a)Three-phase FSPM motor (b)Six-phase FSPM motor

Fig.13 Typical topology and prototype of FSPM motor

5 Conclusion

After years' of technology research, demonstration, operation and market promotion, status of the EV industry in China has achieved rapid and sustainable development. Since 2015, EV sales in China have held first place all over the world. Although imbalance in distribution can be found, the total volume of the EV market and its contribution to the reduction of oil consumption must be acknowledged. The participation of Internet enterprises creates brand new operational patterns and presents great challenge to the industry such that guidance from the government is necessary. Even if related policies are issued in the late second period, construction of charging facilities is still the greatest challenge to promote customers' recognition of EVs. Differing from traditional vehicle industries, nearly all the key components in EVs can be satisfied by independently developed productions in China. Moreover, thanks to the ongoing national research projects, the EV technology in China has made great progress. Plan for the next period of EV development has already been made by the central government, where the high technical indicators are determined, showing confidence in the Chinese EV industry.

With coordination among technology, market and government policies, rapid development of EVs is expected in China for the long term.

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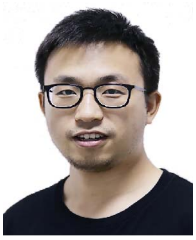

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