EVS26
Los Angeles, California, May 6-9, 2012

Foresight Scenario Analysis of Motor System of Electric Vehicle

Yih-Chearng Shiue[1], Chang-Franw Lee[2], Peng-Jen Chen[3], Chih-Chiang Yu[4], Chih-Wei Chen[5]
[1] *Department of Information Management, National Central University, No.300, Jhongda Rd., Jhongli City, Taoyuan County 32001, Taiwan (R.O.C.),Tel: +886-3-4227151, Email: ycs@cc.ncu.edu.tw*
[2,3] *Department of Industrial Design, National Yunlin University of Science and Technology, No.123 University Road, Section 3, Douliou, Yunlin 64002, Taiwan(R.O.C.),Tel: +(886)5-534-2601,Email: leecf@yuntech.edu.tw*
[4,5] *Department of Business Administration, National Central University, No.300, Jhongda Rd., Jhongli City, Taoyuan County 32001, Taiwan (R.O.C.) ,Tel: +886-935-506257, Email: chihwei0927@gmail.com*

Abstract

In order to describe the trend of motor system development of electric vehicle and to figure out the factors that would affect the external drives and the internal resources, the thesis uses scenario analysis method to be the basic framework, adding modified Delphi method to clarify time transition into five categories: changeless, changeable, disappeared, uncertain states and newborn. More precisely, the five factors is used to construct "Scenario Analysis of Markov Modified Delphi Method". The thesis focuses on motor system to do the Foresight analysis, using the transition concept of Markov Chain to clarify the key factors of uncertain states into motor system: brushless DC (BLDC) motor, surface permanent magnet synchronous motor and Switched Reluctance In-Wheel Motor. Moreover, the changeless concept of Markov Chain is used to be background, adding the key factors of changeable and uncertain states to clarify seven kinds of scenario portfolio: basic scenario, scenario assumption I, scenario assumption II, future scenario, breakthrough scenario I, breakthrough scenario II and challenge scenario. It could make the government, industries and related departments realize the development trend of key components about electric vehicle by the scenario descriptions. It can increase their willingness to invest in the related researches to achieve future image, also shape the usable engineering technique and integrated system concepts of electric vehicles in 2020 for public.

Keywords: EV (electric vehicle), motor, market

1 Introduction

Under the trends of energy saving and carbon reduction, electric cars have become an inevitable alternative. Although the mainstream of the power system in vehicles is still internal combustion engine which has gone through one hundred years of development, and its energy conversion efficiency continues to be improved, the oil consumption and carbon dioxide emissions are gradually becoming unacceptable. In fact, only 25% of the energy produced by gasoline is transmitted to the tires. On the contrary, electric motors can convert 80% of the kinetic energy, it is much higher compared with the fuel conversion efficiency. Therefore, whether electric cars can truly replace the existing fueled vehicles, issues such as size, light weight, high efficiency and low cost of the motor drive system became critical.

Therefore, this research mainly studied the development status of electric car motor system and it used the Markov chain time state transfer views to carry out the scenario analysis of modified Delphi and Markov transition. It speculated the possible motor technology development and potential by 2020. Some key factors were analyzed and an engineering development approach was used to build a combination of future life scenarios. They provide decision making references in the R&D direction for industries, research institutes, and government organizations.

2 Literature Review

If motors are differentiated by electric current, they can be divided into two broad categories: DC motors and AC motors. AC motors have the characteristics of high efficiency, high output, regenerative braking capacity, etc. In addition to being widely used in industrial products, some are also being used on electric vehicles. If classified according to magnetic fields, there are four kinds of motors: brushed DC motor, AC induction motor, brushless motor, and reluctance motor, etc. (Wen-Hai Liu, Sheng-Lung Lee, 2007).

Brushless motor has the highest operating efficiency and power density. However, its cost of unit power is higher; reluctance motor has the lowest cost of unit power, but its cost of drive is apparently higher; AC induction motor has many advantages, but its power density is the lowest among these four motors, and its volume and weight are less than ideal; brushed DC motor is constrained by its maximum speed limit and its relatively poor reliability, it's difficult to be developed for high speed, and as a result, its use in electric cars has gradually been eliminated; induction motor has a better torque output in high speed, it's suitable to be used in wider, faster-speed suburban areas, and it also has a lower demand for magnetite ore; brushless motor has a better torque output at low speed, and it's suitable to be used in short distance, slow speed urban areas. However, it's difficult to acquire the permanent magnet material (NdFeB magnets); reluctance motor is constrained by factors such as the high controller cost, low conversion efficiency, and so on. Currently, there is not a breakthrough in this technology.

In-wheel motors are divided into four major categories, permanent magnet brushless motor, induction motor, switched reluctance motor, and transverse flux motor. Among them, the application of permanent magnet brushless motor is most common, and the transverse flux motor is a very competitive new low speed high torque motor. Currently, the in-wheel motor technology of Mitsubishi Motors is the most mature. It has the direct function of reducing vehicle weight, increasing range, and improving handling (Wen-Hai Liu, Sheng-Lung Lee, 2009).

3 Methodology

The research flow followed the steps in the modified Delphi method, the key factors of motor system through the consensus from the experts group were used as a basis, finally, the key factors were developed and the Markov modified Delphi method scenario analysis was used to conduct analysis of each step, the development scenarios of motor system of electric cars were then built.

3.1 Questionnaire design

The first survey was a structured questionnaire which was designed by researchers according to literature. It asked the participants to choose the significance of each item, and to provide other opinions or views as the reference basis of feedback. However, in the second questionnaire, the collective measure of each item from the first questionnaire was attached as a percentage. There are pros and cons of publishing experts' agreement percentage, i.e., it enables fast convergence, making participants understand the opinions of most experts, and avoiding the same views as the previous survey, and lost the meaning of the second survey. Similarly, after the second questionnaire was received, the data must be sorted and analyzed to provide the collective measurement to participants as a reference, then the participants were asked to complete the third questionnaire, the process continued like this until the consensus has been reached.

3.2 The selection of experts

As to the number of experts to be selected, the Delphi method requires the number to be at least 10 persons, but not more than 30 persons. If the number of experts exceeds 30, their contribution to the research will be limited, and if there are too many experts, the workload increases such that it's difficult to achieve an effective conclusion.

Based on the above criteria and taking into consideration that the background of the participating members should be diverse, have different ideas or status, and be able to strengthen the Delphi method in the process.

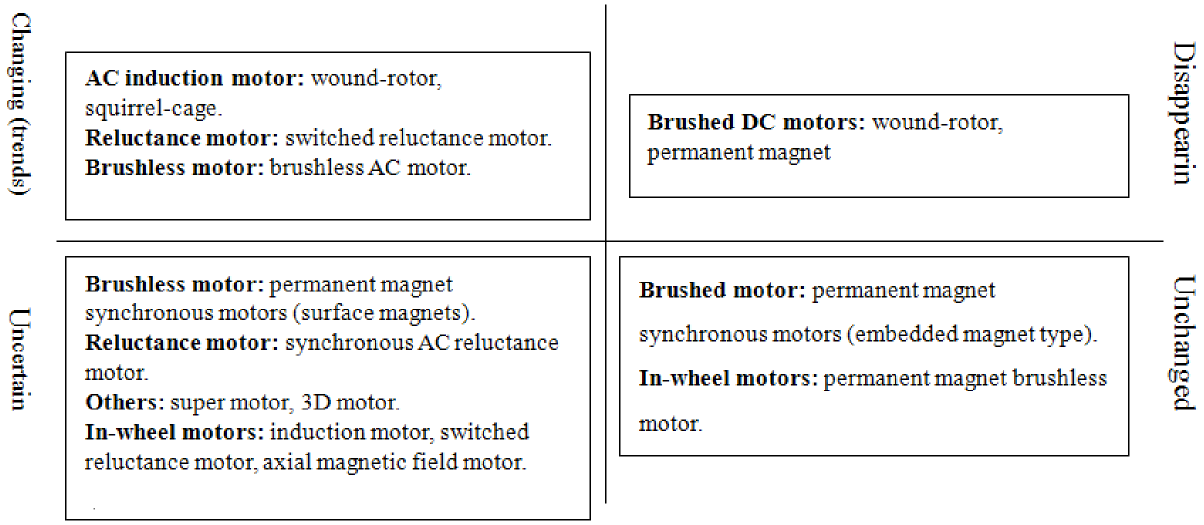

Figure1: The four-state Markov integration diagram of motor systems through sorting the literature

As a result, certain R & D personnel of the industries and government agencies, and so on in the research area were invited, and the issues such as funding and feasibility were also considered. In total, 10 experts participated in the research survey and integration of views.

3.3 Scenario analysis of Markov modified Delphi method

The scenario analysis of Markov modified Delphi method integrates scenario planning and the Markov chain's theory and concept, and it analyzes the changes in factor transition and causal relationship from a long term perspective. According to the views of the Markov transition process, the key factors would develop five states with respect to the change in time: unchanged, disappeared, new, changed, uncertain. In order to view many years into the future more precisely, one should consider that each key factor could change during the conversion period. After identifying each key factor in the transition period, it can be speculated from historical information that certain significant factors could be influenced by the external forces to become events, the events that have higher probability were examined to develop the chronicle of future events, and to be used as an index of reference in the selection and implementation of future strategy, after identifying the combination of influencing factors during each conversion period, assessed internal capabilities and resources at the same time, and after getting internal resources and changes that could be faced externally under control, a state that could occur can be established.

4 Data Analysis

4.1 The generalization of factor dimensions

This research gathered the information from the status of electric car technology development to formulate the options of development dimensions of motor systems, and to conduct the analysis of the modified Delphi questionnaire and to generalize the development dimensions and factors into a four-state Markov as shown in Figure1.

4.2 Analysis of questionnaire results from the modified Delphi method

In the first round questionnaire, 14 sets of questionnaire were sent, 10 experts replied, the rate of return was 71.43%; in the second round, questionnaires were sent to the experts and scholars who replied in the first round, a total of 10 sets of questionnaire were sent, 10 experts replied, the rate of return was 100%.The questionnaire content that did not reach a significance level in the first round was included and new factors suggested by the experts in the second round questionnaire for selection, conduct the second round questionnaire.

4.3 Analysis of the external driving forces

The changes of issues in the key factors from the past until the present were analyzed through five kinds of forces, including social forces, political forces, economic forces,

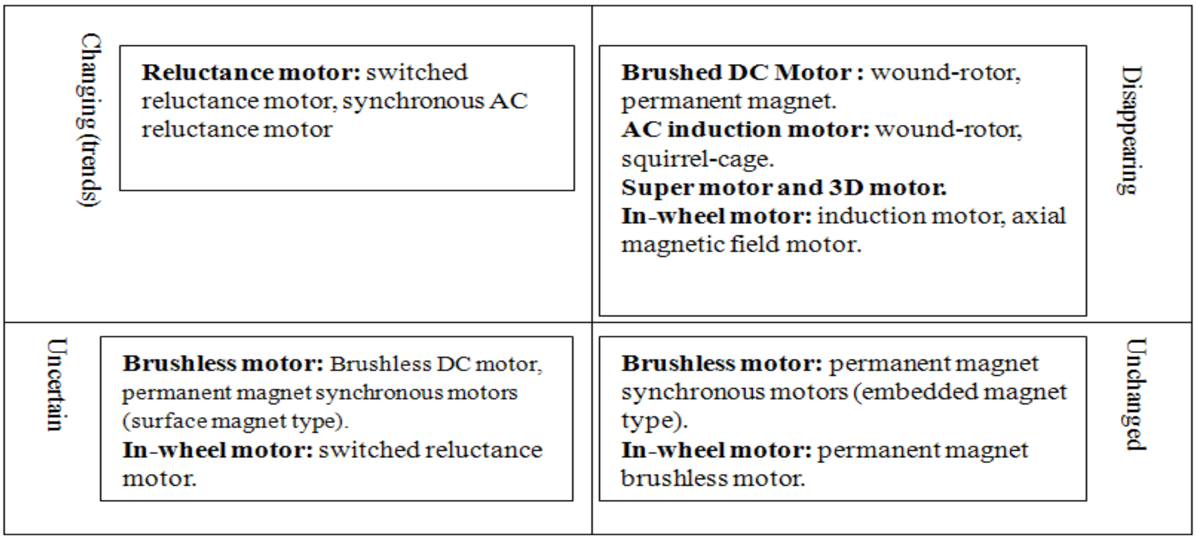

Figure2: The integration diagram of a four-state Markov in 2020

scientific and technological forces, environmental protection forces.(Hsu-Chiang Yu et al., 1989), this would help the understanding of the development trends of the future motor systems.

Having integrated the analysis of the five external driving forces, it's shown that the social, economic, and environmental forces will drive the development of motors toward the direction of permanent magnet synchronous motors (embedded magnet).

In addition, the social and technological forces will drive the development of brushless DC motor, permanent magnet synchronous motors (surface magnet), in-wheel switched reluctance, toward a uncertain state, and brushed DC motor (wound-rotor, permanent magnet), AC induction motors (wound-rotor, squirrel cage), in-wheel induction motor, and in-wheel axial magnetic field motor were all in a disappearing state due to social, economic, technological, environmental forces.

4.3.1 The chronicle of future events

This checklist of the external driving force was used to find the related events in the motor system. To understand the changes of key factors in the four-state Markov, these events that could have significant impact in the future were assembled in a "chronicle of future events".The external forces were used to build the chronicles of future events, to find the developing trends of future motor and battery systems, finally, the results of the second round of questionnaire from the experts were added, and the key factors are shown in Figure 2.

4.4 The development of scenarios

Analyze the impact on key factors by external driving forces and the chronicle of future events, and the positioning of all key factors in future changing state of Markov chain can be seen clearly in Table1.

Table1: The integration table of a four-state Markov of motor system key factors

Markov states	Motor systems
Disappearing state	Wound-rotor brushed DC motor, permanent magnet brushed DC motor, wound-rotor AC induction motor, squirrel-cage AC induction motor, super motor, 3D motor, in-wheel induction motor, axial magnetic field in-wheel motor.
Unchanged state	Permanent magnet synchronous motor (embedded magnet type), permanent magnet brushless in-wheel motor.
Changing state	Switched reluctance motor, synchronous AC reluctance motor.
Uncertain state	Brushless DC motor, permanent magnet synchronous motor (surface magnet type), in-wheel switched reluctance motor.

4.4.1 Content description of the scenario combination

1. The basic scenario

Little Wang is a design engineer of a certain car manufacturer. In order to identify an electric car motor suitable for use in Taiwan's high temperature environment, little Wang considered the following motors: Permanent magnet brushed DC motors, embedded permanent magnet synchronous motors, switched reluctance motor, synchronous AC reluctance motor and in-wheel permanent magnet brushless motor. First of all, because the brush of a permanent magnet brushed DC motor must be replaced often, it was quickly disqualified by little Wang. Embedded permanent magnet synchronous motors have the risk of magnet becoming demagnetized easily due to high temperature, and it's relatively costly to replace permanent magnets, thus, it is not a suitable motor. The advantage of either switched reluctance motor or synchronous AC reluctance motor is the maintenance is very fast and cheap, but the drive controller is very expensive, if, after the vehicle warranty period, the controllers malfunction, it would be a costly expense by that time, and it does not meet the durability requirement of the people in Taiwan. Later, little Wang decided to adopt a permanent magnet brushless in-wheel motor. Although in-wheel motor is a little more expensive, but its reliability, transmission efficiency and weight are all better than the above-mentioned motors.

2. Hypothetical scenario I

Little Wang would like to design a vehicle with a high weight bearing capacity to replace the current truck. According to the truck usage characteristics, it must be designed to meet the needs of stop-go deliveries, the long-distance truck usage, and the climbing ability. Therefore, the motor must meet the requirements of having a great torque and long high-speed operation. Finally, little Wang adopted permanent magnet brushless in-wheel motor, other than satisfying these features, due to the design of in-wheel motors, the mechanical shift control device, clutch, transmission, drive shaft, differential, and so on used in traditional vehicles were all omitted. This greatly simplifies the drive system, the whole vehicle, and the chassis structure, and the effective use of space and the transmission efficiency have both been improved.

3. Hypothetical scenario II

Due to the improvement in semiconductor technology in the future, the costs of controllers for the reluctance motors are significantly reduced. In the future, a large number of cars will start using switched reluctance motors and synchronous AC reluctance motors. Relative to the previous generation of electric cars, the switched reluctance motors has a simple design in construction and inexpensive maintenance, and it does not have the demagnetization issues due to high temperature as found in embedded permanent magnet synchronous motors and permanent magnet brushless in-wheel motors.

4. The Future scenario

As electric cars become popular, the consumers are gradually getting used to and accepting the performance of electric cars. In response to the requirement of an electric car that has low maintenance and is durable, little Wang, therefore, launched a cheap electric car design, and selected a switched reluctance motor. In addition to having simple maintenance, the motor can operate normally in high temperature which satisfies the vehicle requirement of the general public.

5. The challenging scenario

Sales of an electric car with in-wheel switched reluctance motor designed by little Wang was discontinued due to poor sales, and the car manufacturer carried out a series of review meeting. In the selection of a motor, the in-wheel switched reluctance motor was already adopted due to its ability to meet the needs of long-distance use and the weight-bearing requirement, but it was not very much accepted by the market. After a series of customer surveys, it was discovered that parts can be stolen from the electric car easily, and the stolen parts were not the motors, but the motor controllers. The electric car with in-wheel switched reluctance motors can be identified easily from its appearance, and the components that have the highest values in the vehicle are the controllers which not only can be stolen easily, but they can also be sold easily. Because the vehicle cannot be used without the controllers, having become famous with the high theft rate, the electric car model resulted in poor sales. As a result, the car manufacturer had to re-design to consider whether to replace the motor with brushless DC motor.

5 Conclusion

In recent years, various countries raced to develop green energy-related industries, and they're seizing the electric car markets actively. However, the current price of electric vehicles is still too high, the most important factor is the motor which accounts for more than 25% of vehicle cost. Therefore, in order to make electric cars become popular sooner, the investment in the R&D of motors must be continued to achieve scale production as soon as possible, so the production costs can be reduced, and the production efficiency can be improved. This research conducted in-depth study of structure, functions, characteristics and the future development direction of the motor

system through literature review. The modified Delphi method was used to integrate the opinions of electric car arena, and key factors were developed to understand the key technical trends of current motor systems in electric cars. This was the first contribution.
"Markov modified Delphi scenario analysis" was developed by using the scenario planning as the basic framework, then adding the classification of Markov transition key factors in various space time states. In addition to identifying the trends in key technologies, the key technical factors of motor system were used to focus on the possible types of scenario and to develop the trends of electric car motors by 2020. The Markov chain concept was used to describe the technical factors in the five states of the chronicle of future events: changed, unchanged, disappeared, uncertain, and new. That was the second contribution.
Finally, the concept of proper combination of the future as proposed by Heiko was used as the basis to develop the scenarios. The combination of a five-state Markov was made to form five scenarios: "basic scenario", "hypothetical scenario I", "hypothetical scenario II", "future scenario", "challenging scenario", etc. The application simulation of future electric cars was depicted through life scenarios. It can accomplish the objectives of integrating electric car's practical engineering technology and system integration. That was the third contribution.

6 References

[1] Yu, Hsu-Chiang, Hsu, Chih-I, Chen, Tse-I, *Introduction to technology management*, ISBN：9572143522, Taipei City: Wu-Nan Book Inc., 1998.

[2] Bureau of energy, Ministry of Economic Affairs, *The promotional strategy of the application of high efficiency motors*, Taipei City: Ministry of Economic Affairs, 2008.

[3] Liu, Wen-Hai, Lee, Sheng-Lung, *Development prospects and business opportunities of Key components for light electric vehicles*, Kaohsiung City: Metal Industries Research & Development Centre, 2009.

[4] Hsu, Yeh-Liang, *Putting the motors in wheels – On in-wheel motors.* Taipei City: Car Buyers Guide, 2010.

[5] Department of Industrial Technology, Ministry of Economic Affairs, *Technical white paper of energy industry,* Taipei City: Ministry of Economic Affairs, 2010.

[6] Kan, Wen-Jui, Chang, Hui-Kuan, Chang, Hung-Hsi, Lo, Ying-Chao, Hsiao, Jui-Sheng, *The research of transition of automotive industry under the trend of green environment,* Taipei City: Industrial Economics & Knowledge Center, Industrial Technology Research Institute, 2010.

[7] Dalkey, *N., Delphi report. Santa Monica*, CA: Rand Corporation, 1967

[8] Brook K. W., *Delphi technique: Expanding Application,* North Central Association Quarterly, 53(3), 377-385, 1979.

[9] Simpson, R. D., and Smith, K. S., *Validating Teaching Competencies for Graduate Teaching Assistants: A National Study Using the Delphi Method*, Innovative Higher Education. 18(2), 133-146,1993.

[10] IBC Asia, *Exploring commercial opportunities for Electric Vehicles in Asia,* In Electric Vehicles Asia 2010, in Hong Kong,

[11] Postma, T., Liebl, F., *How to Improve Scenario Analysis as a Strategic Management Tool, Technological Forecasting & Social Change*, 72(2), 162-173, 2005.

[12] Murry, J.W., and Hammons, J. O., *Delphi: A Versatile Methodology for Conducting Qualitative Research. Review of Higher Education*, 18(4), 423-436,1995.

[13] Sackman, H., *Delphi Assesment：Expert Opinion, Forecasting, and Group Process. A Report prepared for United States Air Force Project Rand.,*1974.

Authors

Yih-Chearng Shiue
A Professor in the Department of Information Management at the National Central University, Taiwan (R.O.C.) His research interests include knowledge management and strategy management.

Chang-Franw Lee
A Professor in the Department of Industrial Design, National Yunlin University of Science and Technology (YunTech), Taiwan. His research interests include Ergonomic Design, User Interface Design, and Universal Design.

Peng-Jen Chen
An Instructor in the Department of Industrial Design, National Yunlin University of Science and Technology (YunTech), Taiwan. His research interests include Design Semiotics, Design Patent, and Design Sketching.

Chih-Chiang Yu
Chih-Chiang Yu is a master of the Department of Business Administration at National Central University. His research interests include management and Financial.

Chih-Wei Chen
A PhD student in the Department of Business administration at the National Central University, Taiwan(R.O.C.). His research interests include knowledge management and information management.