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Fuel Cell Electric Vehicle Energy Storage Control Based on Fuzzy Algorithm

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The fuzzy algorithm is used to conduct an in-depth study on the energy storage control of FCEV. Based on the fuzzy algorithm, the author establishes an accurate mathematical model and optimizes the fuel cell system so as to test and study the energy storage control. When applying the fuzzy algorithm to control the energy storage of FCEV, its economic and dynamic performance has been significantly improved. The results of FCEV energy storage control based on fuzzy algorithm make up for the deficiency of switch control strategy. Therefore, this intelligent fuzzy control strategy is of certain value for promotion and application.

1. Introduction

A fuel cell electric vehicle (FCEV) is a new energy vehicle that consumes fuel. Its main mode of generating electricity is to contact the proton exchange membrane fuel cell (PEMFC) with hydrogen and oxygen electrodes so as to produce a chemical reaction and generate electricity during the contact process. Judging from the actual situation of foreign researches, although the power performance of the new type FCEV has been greatly improved compared with those in previous years, it gradually develops towards driving for short distances and the structure of the entire vehicle is mainly based on multi-energy, in actual operation, the entire vehicle structure is often too complicated and affects the efficiency of the vehicle control. Therefore, the vehicle control strategy is more demanding. According to the domestic research status, FCEV is not only very easy to implement and has a very large space for promotion, but also it can also be studied from various aspects. At present, the domestic research on new energy vehicles is equivalent to foreign technology and the economic performance of FCEV is constantly improving. Because the foreign control strategy has a longer development compared with the domestic control strategy, intelligent optimization strategies have become a hot topic in domestic vehicle performance research. In the implementation of intelligent optimization strategies, the application of fuzzy algorithm to achieve intelligent fuzzy control can not only meet the vehicle demand power, but also provide important guarantees for the performance of energy devices, thus the fuel economy of vehicle has also been significantly improved.

2. Literature review

In recent years, the enthusiasm of various companies in the world for the research of new energy vehicles has increased. In particular, good results have been achieved in hybrid vehicles for fuel cell vehicles. In the United States and Canada, with the support of powerful technology, General Company's Chevrolet made a Equinox fuel cell vehicle. In 2006, Ford of the United States also introduced a new type of fuel cell vehicle. Its maximum output power can reach 60kw, and it is equipped with a high-pressure hydrogen storage tank and battery as an auxiliary energy source. The mileage can reach 560km. In Europe, Mercedes-Benz Germany, in 2011, introduced the new B-grade fuel cell car F-CELL. The actual maximum speed of the car can reach 170km/h and the mileage can reach 400km. In 2014, Audi also introduced the new Sportback h-tron quattro concept. It has four high-pressure hydrogen storage tanks. The hydrogen consumption per 100 kilometers is about 1kg. In about 3 minutes, the car can be filled with hydrogen. The 100-meter acceleration is less than 8 seconds and the maximum speed can reach 180km/h. It brings major guiding significance to the development of fuel cell vehicles. In 2014, Toyota Motor announced that its "Future" car began commercial application. Its

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mileage has reached 820km, and it can maintain good performance in low temperature environments below 30 degrees (Hu et al., 2015).

From the research status of foreign countries, the dynamic performance of fuel cell vehicles has been continuously improved, and mileage can also meet the needs of short and medium distance driving. El Fadil et al. pointed out that the vehicle structure gradually adopts a multi-energy structure, which further improves the vehicle performance. However, the more complex vehicle structure will increase the difficulty of vehicle control and impose higher requirements on the vehicle control strategy (El Fadil et al., 2014). D. Buntin et al. kept the SOC of the battery pack as high as possible. Under the condition of maintaining the power of the entire vehicle, the autonomously established strategy of switching control based on the vehicle torque requirement was adopted. Torreglosa et al. adopted the same output strategy for all three energy sources to reach the battery pack with the highest efficiency. The FCEV was studied. It has three energy sources: PEMFC, battery, and super capacitor (Torreglosa et al., 2014). Aouzellag et al. used Advisor modeling simulation software to optimize the energy output of PEMFCs and batteries (Aouzellag et al., 2015). Larcher et al. used experimental methods to verify the relationship between energy sources and the vehicle. It can use multiple energy sources in the FCEV (Larcher et al., 2015). Ansarey et al. designed the FCEV vehicle simulation model in the SPS environment of Matlab software, using the common battery model (Ansarey et al., 2014).

In China, research and development of fuel cell vehicles is also continuing. The Chinese government also supports the research work on fuel cells and lists them in the national 863 project plan. The project research vehicle power is 36k W. The Chutian-1 fuel cell hybrid vehicle jointly developed by Dongfeng Motor Corporation and Wuhan University of Technology has a power of 25k W. In 2008, the fuel cell bus with 100k W power was developed by Beijing Institute of Technology. It was used for road transport during the Olympics. In 2010, CRRC began researching new energy vehicles that combine fuel cells and super capacitors. In 2012, Yutong's new-generation fuel cell city bus was launched, and its full-load hydrogen consumption was only 8.3kg/100km. Compared with imported Mercedes-Benz fuel cell bus Benz/Ballard, the performance is comparable and fuel consumption is greatly reduced. In 2014, SAIC Motor Group introduced the Roewe 950 fuel cell vehicle and launched an innovative journey with outstanding results. The power follow-up control strategy was used to complete the energy allocation of the PEMFC and the power battery under different working conditions, and the specific implementation condition rules were described. A multiple model control strategy is proposed to optimize the structure and mixing degree of FCEV power system. Li Qi et al. proposed a multi-energy management strategy based on a fuzzy logic control method to reduce the FCEV's hydrogen consumption and thus improve its continued ability. For the FCEV energy system, a real-time control algorithm based on fuzzy control is designed. A real-time fuzzy control strategy was designed for the FCEV energy system. Through modeling and simulation analysis, the vehicle performance and operating costs under the three energy distribution strategies of battery power consumption, maintenance, hybrid mode, and dynamic planning were compared. An energy management strategy that balances the output of the PEMFC and allows the power battery to compensate is used (Song et al., 2015).

At present, more commonly used energy storage devices are: lead-acid batteries, nickel-cadmium batteries, flywheel batteries, lithium-ion batteries and super capacitors. Although the lead-acid battery is stable and the price is low, it is relatively bulky and harmful to the environment. It has gradually been replaced. Nickel-cadmium batteries also have the same problem. Flywheel batteries are expensive and rarely used in electric vehicles. Lithium-ion batteries have a higher energy density than supercapacitors. The super-capacitor power density is higher, the discharge speed is faster, overcharge and over-discharge have no effect on its life, and no special charge/discharge control circuit is needed. At the same time, the combination of the fuel cell has a higher energy density, and the super capacitor has a better auxiliary energy device characteristic. Supercapacitors are used as auxiliary energy storage devices (Xu et al., 2015). The supercapacitors are classified into three types according to the different electrode materials: Capacitors of double-layer capacitors, Faraday pseudocapacitors, and organic polymer electrodes. At present, the electric double layer capacitor is widely used. It consists of two electrodes and is separated by a separator in the electrolyte. The electrode is deposited from a porous material on a thin metal film. Compared to conventional capacitors, the supercapacitor has a smaller charge distance and the activated carbon electrode has a larger surface area. Therefore, the super capacitor has a very large capacitance. The super capacitor's charge and discharge have no chemical reaction, so its response speed is very fast and its service life is very long. Super capacitors have a high-power density. It can achieve high current charge and discharge and high-power conversion in a short time.

To sum up, the foreign control strategy developed earlier and the domestic control strategy developed late. Intelligent optimization strategy has gradually become a research hotspot. Various experts have done a lot of research on the rational allocation of fuel cells and auxiliary energy output power. Its purpose is to improve the vehicle's dynamic performance and economy. However, the current fuel cell cost is high and its lifetime is low. At the same time, the start-up speed of fuel cell vehicles is insufficient, and the hydrogen stored in the vehicles is limited, resulting in limited vehicle mileage. Moreover, fuel cells cannot recover energy. Fuel cells are used as the main energy source. The super capacitor is used as a composite energy source for auxiliary energy. It gives full play to the characteristics of super capacitors and improves the performance of cars. At the same time, it can also recover energy. In addition, combined with the fuzzy algorithm and particle swarm algorithm, the control strategy for fuel cells is further optimized and improved. The hydrogen consumption of the entire vehicle is saved and the economy is improved.

3. Research methods

At present, for different kinds of EVs, they all have one thing in common - they all need energy storage devices, which can not only supply vehicle power, but also absorb braking energy. Because fuel cell energy is in a one-way transmission, FCEVs must have energy storage devices to absorb energy. To a large extent, energy storage devices determine the performance of an EV. To inspect the automobile in the factory is to meet the dynamic performances such as starting, acceleration and braking, the energy storage devices of the electric vehicle must have a high power density; in order to meet the requirements of mileage, vehicle weight and the times of cycle charging, energy storage devices must have a high specific energy density and a long service life. Therefore, the requirements for ideal EV energy storage devices are: high power density, high energy density, long life and low cost. The super-capacitor has a large capacitance and its charge and discharge has no chemical reaction, so its response is very fast and its service life is very long. The super-capacitor has a high power density and can realize high-current charge and discharge and high-power conversion in a short time. In this paper, the author establishes a FCEV simulation model with super-capacitor. The super-capacitor can not only recover the braking energy and improve the economic efficiency of vehicle, but also overcome the disadvantages of poor dynamic response of the fuel cell and can not fully satisfy the high power demand for starting, acceleration and climbing due to its rapid charge and discharge and instantaneous high power. The author has designed a fuzzy energy control strategy to ensure the normal driving dynamics of vehicle. The super-capacitor provides high power for vehicle when it starts and accelerates, optimizes the fuel cell's working efficiency, reduces the fuel consumption and improves the vehicle's power and economy. In the Matlab/Simulink environment, the author uses the vehicle simulation software ADVISOR2002 for secondary development. The particle swarm optimization algorithm is used to optimize the fuzzy control strategy. The simulation results are compared and analyzed to verify the effectiveness and feasibility of the control strategy. The super-super-capacitor simulation module diagram is shown in Figure 1.

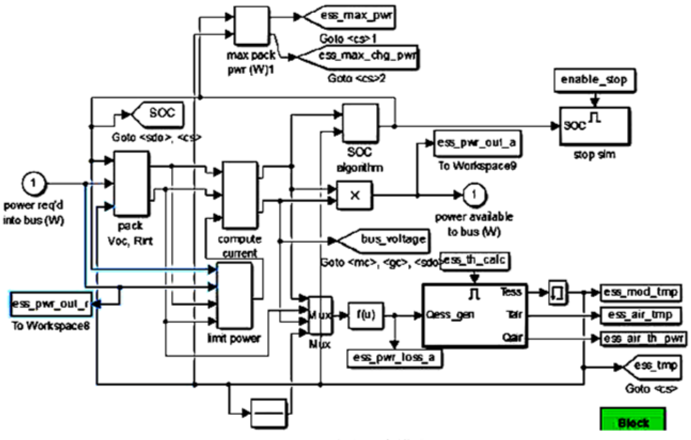

Figure 1: Super-capacitor simulation module diagram

4. Results and discussions

4. 1 Fuel cell analysis and modeling

The principle of a fuel cell is very similar to that of a storage battery, but it has the advantage of being able to directly convert the chemical energy of the fuel and oxidant stored in the fuel tank into electrical energy. This process does not have a Carnot cycle and also has high efficiency and no emission pollution. There are many kinds of fuel cells. Common ones are: proton exchange membrane fuel cell (PEMFC), alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC). However, not all the above five types of fuel cells are suitable for use in EVs. AFCs and PAFCs were used in vehicles. After many tests, the performance indexes of fuel cells were found low. The current fuel cells on vehicles are mainly proton exchange membrane fuel cells, i.e. PEMFCs. The anodes, cathodes and solid electrolytes of PEMFCs participate in reaction. The hydrogen side loses electrons, electrons flow to the oxygen side, oxygen gets electrons and hydrogen ions turn into water. When a chemical reaction occurs on a PEMFC, a "double charge layer" occurs. Electrons accumulate on the surface of the electrode. Hydrogen ions accumulate on the surface of the electrolyte. A voltage is generated between them and charges and energy are stored. This is equivalent to an equivalent capacitance. The PEMFC equivalent circuit diagram is shown in Figure 2 below. Where En is the PEMFC Nernst voltage, Ra is the sum of the equivalent internal resistances of the active polarization and the concentration polarization, Ro is the ohmic polarization resistance, C is the equivalent capacitance and E is the PEMFC output voltage.

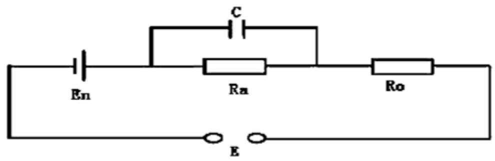

Figure 2: Fuel cell equivalent circuit diagram.

In general, when the inverter is working at the maximum power of motor, the working efficiency is 95%, the working efficiency of the one-way DC/DC converter is 96% and the automobile has a load of 2 kW. By entering the above parameters into equation (1), the fuel cell system power, approximately 26.13 kW, can be calculated, so it can be determined that the fuel cell's rated power is 30 kW and the peak power is 50 kW. Its concrete simulation structure diagram is shown in Figure 2. As it can be seen from Figure 2, the input is the bus demand input power and the output is the fuel cell power, fuel consumption and its emissions.

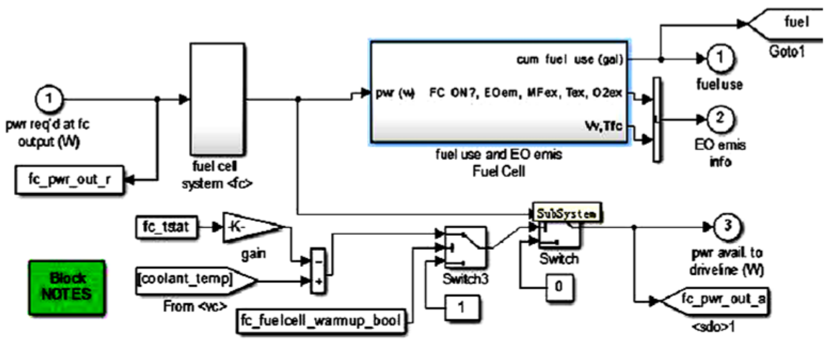

Figure 3: Fuel cell simulation structure model diagram.

The fuel cell power sub-module limits its input based on the maximum power that the fuel cell can provide. The structure of the sub-module is shown in Figure 3. Fuel cell efficiency is shown in Figure 4.

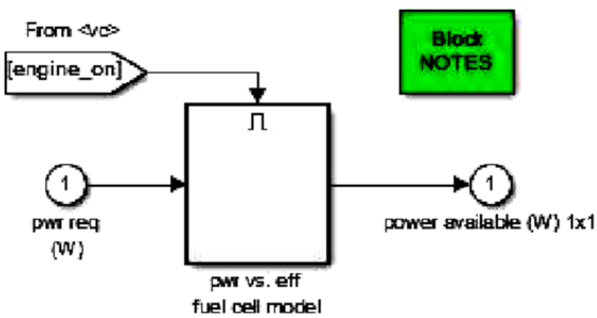

Figure 4: Fuel cell power submodule diagram.

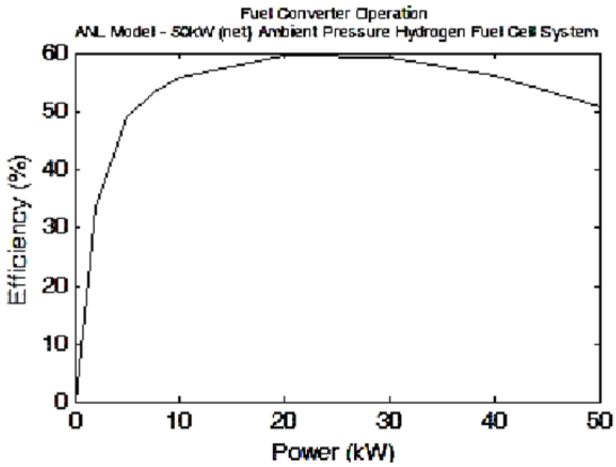

Figure 5: Fuel cell efficiency diagram.

4. 2 Super-capacitor analysis and modeling

Super-capacitors are divided into two types according to the principle of energy storage mechanism: double-layer capacitors and faradic pseudo-capacitors. A double-layer capacitor is selected , because the double-layer capacitor is a fully charged physical process, there is no chemical reaction in the process, so the storage speed is faster, the charge-discharge loss is small and the performance is stable. The commonly used carbon electrode double-layer capacitor structure has two fixed porous plates on both sides of the electrolyte. When a voltage is applied to both plates, a potential is formed on the positive plate to attract negative ions in the electrolyte. A potential is formed on the negative plate to attract positive ions in the electrolyte. Thus, an electric double layer capacitor is formed on the surfaces of the two electrode plates. In ADVISOR2002, there are two types of super-capacitor models: RC model and Rint model. The Rint model mainly analyzes the chemical reaction process inside the capacitor. The RC model is mainly used to analyze the instantaneous working state of the model. This author uses the RC model in this paper, as shown in Figure 5. Super-capacitor RC model is mainly divided into 5 modules, including open circuit voltage calculation module, internal resistance calculation module, current calculation module, power limit module and SOC estimation module.

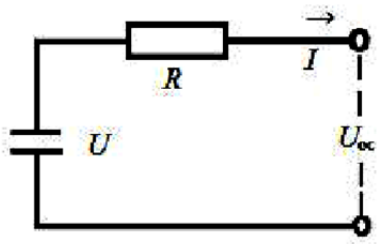

Figure 6: Super-capacitor RC model diagram.

4. 3 EV motor analysis and modeling

The motor is the only power output of a FCEV and is also a key component for energy recovery. There are two working states, one is to provide the motor with the required power for running the motor and the other is to use the generator as the generator for decelerating and braking, so that the auxiliary device can recover energy. The following is a comparative analysis of several motors commonly used in EVs. Since the permanent magnet brushless motor is excited by a permanent magnet, there are only two speed control methods. One is to change the armature loop resistance and the other is to adjust the armature terminal voltage to adjust the speed. In this paper, the method of adjusting the armature voltage is used to adjust the speed, which is realized by a pulse width modulation (PWM) converter. With the PWM speed control system of the fully-controlled device, the switching frequency can be as high as 20KHz or more, so the system response becomes faster and the dynamic disturbance capability increases. In this paper, the current-speed double closed-loop PWM speed control system is adopted, the speed adjustment is controlled by PID and the current adjustment is controlled by a hysteresis comparison PWM. The conventional PID control can obtain the response curve of the system by adjusting the three parameters of Kp, Ki and Kd. After using fuzzy PID control, the fuzzy controller is used to adjust the parameters of PID and the dynamic performance and steady-state performance of the system can achieve ideal results. As for the fuzzy PID control idea, it firstly finds out the fuzzy relationship between the 3 parameters of the PID and the deviation E and the rate of change of the deviation EC. When the control system is working, it constantly detects E and EC and according to the situation of E and EC at different times, it comes to the real time in adjusting the 3 parameters, namely, Kp, Ki and Kd of the fuzzy PID controller to complete the control, so that the controlled object has better static and dynamic performance. The inputs to the fuzzy controller are the deviation E and the rate of change of deviation EC and the parameters of the output PID controller Kp, Ki and Kd. They are all represented by 5 fuzzy linguistic values. The fuzzy subsets are defined as {NB, NS, ZE, PS, PB}. NB is negative, NS is negative, ZE is zero, PS is positive and PB is positive. For convenience, the universe of discourse is defined as [-1, 1], the membership function uses a triangular distribution function.

5. Conclusions

In this paper, the discharge of PEMFC is an electrode reaction, which does not require combustion to work. Therefore, the energy conversion rate is very high and the maximum can be more than 60%. The fuel cell is widely used in energy development and reuse due to its short filling time, convenient hydrogen filling, noise pollution during operation, water being its only product, clean working environment and a wide range of hydrogen sources. In the construction of super-capacitor fuel cell model, the introduction of fuzzy algorithm and the performance and indexes of the main components of the power system are comprehensively analyzed. Based on this, the technical parameters of each component and energy structure are also involved. The system model is built by using the simulation software Matlab, which mainly includes permanent magnet brushless motor, super-capacitor and fuel cell. In addition, the author uses the simulation software Matlab to simulate the operation efficiency of EV motor and the energy storage device function, using the modular and traditional PID speed regulation, and the final experimental results prove that the fuzzy PID speed regulation is conducive to optimizing the energy storage device control strategy of FCEV and its dynamic and static characteristics have been significantly improved.

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