EVS25

Shenzhen, China, Nov 5-9, 2010

The Research of Fault Processing Strategy for Fuel Cell Vehicle Based on Classification Principle

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Abstract

The paper proposes a fault processing strategy based on classification principle. Detail the realization of the strategy for a fuel cell vehicle which is developed by Tongji University and shanghai fuel cell vehicle powertrain Co., Ltd. Emphasis on the definition of fuel cell vehicle fault classification and the processing strategy of three grade faults. The practicability of the fault processing strategy has been proved by the application in fuel cell vehicle of Shanghai Fuel Cell Vehicle Powertrain Co., Ltd (Copyright 2010 EVS25).

Keywords: fuel cell vehicle, powertrain, fault processing based on classification principle

1. Introduction

Environmental pollution and energy shortage have become two prominent contradictions of threatening the human survival. International Energy Agency statistics show that 57% of world oil is consumed in the transportation field. Now the total number of vehicles has reached 800 million. And the number increases by 30 million every year. The vehicle ownership will reach 1 billion in 2010. U.S. Department of Energy forecast: the net gap between global oil demand and conventional supply will appear after 2020. The gap will reach 500 billion barrels in 2050. In order to solve the energy crisis, the world's major automakers are working on new energy vehicles using alternative energies for oil. The new energy vehicles refer to vehicles using clean energy as an alternative fuel except to gasoline and diesel. Now, new energy vehicles such as natural gas, methanol and ethanol have been successfully developed. New energy with hydrogen, propane, methane, vegetable oil, electricity and solar energy are experimenting.
Fuel cell vehicle is a kind of electric vehicles. The battery's energy is the chemical reaction of hydrogen and oxygen directly into available electrical energy. The experts believe that fuel cells are the ultimate direction of vehicle energy development. Conventional vehicles and other new energy vehicles compared to fuel cell vehicles have the following advantages: zero emissions, reduced greenhouse gas (CO₂) emissions, improve fuel economy, and can carry hydrogen fuel to generate electricity directly without external charge.

However, compared to conventional diesel, the fuel cell vehicle is still under development. Its failure rate is relatively high. Therefore, to ensure vehicles running safety, stability and reliability, the proper fault processing in the operation process becomes a key point of fuel cell vehicle research and development. This paper proposes a fault processing strategy based on classification principle. The fault classification based on Failure Mode and Effects Analysis theory. And the processing strategy of three grade faults as an example, expounds the fault processing strategy of fuel cell vehicle.

2. Fuel Cell Vehicle

Based on the new generation of fuel cell vehicle which is developed by Tongji University and Shanghai fuel cell vehicle powertrain Co., this paper briefly introduced the working principle of fuel cell vehicle and the key components of fuel cell vehicle.


The fuel cell and battery power, ‘electric – electric’ hybrid program is used in fuel cell vehicle. The basic working principle is: hydrogen and oxygen chemical reaction to produce electricity energy in fuel cell stack at normal temperature, through the DC / DC converter impedance matching and voltage transformation, parallel with power battery, and provide energy to the motor that converts electrical energy into mechanical energy to drive vehicles. ‘Electric – electric’ hybrid powertrain adapt to a variety of operating conditions, not only energy-saving environmental protection, but also excellent economy and power performance.

The fuel cell deliver the extra power to battery at load, fuel cells and batteries output power to the motor at heavy load. This allows power to maintain the best battery charge and discharge levels. In addition, the use of the "electricity - electric" hybrid program, vehicles with regenerative braking function, can significantly improve vehicle economy. The working principle of the fuel cell vehicle is shown in Figure 1.

![Figure 1: Fuel cell vehicle principle diagram.](image)

2.2. The Key Components of Fuel Cell Vehicle

The new generation fuel cell vehicle using fuel cell as the main power, power-type battery as the auxiliary power to realize excellent economy and power performance. According to the function, powertrain mainly consists of the following six parts:

2.2.1 Fuel Cell Engine System(FCE)

Fuel cell engine system is the main power of fuel cell vehicle. It consists of fuel cell stack, hydrogen and air supply system, cooling system and control system. Fuel cell engine work principle is shown in Figure 2.
2.2.2 Battery Management (BM)

Battery Management is the auxiliary power of fuel cell vehicle. The battery provides instant power in the peak load, recycles energy under the condition of brake, and can provide electric mode in a short time. Battery packs are shown in Figure 3.

2.2.3 Power Control Unit (PCU)

PCU is formed by the following components: DC/DC converter is used to realize the current output impedance matching and fuel cell voltage transform, Motor actuator (DC/AC) drive torque output unit, it also includes air conditioning, water drive controller, and on-board 12volt battery charger, etc. PCU is shown in Figure 4.

2.2.4 Power Transmission System

Different from traditional internal combustion engine vehicles, fuel cell vehicles have a fixed transmission ratio of the reducer and the differential and the associated couplings for power transmission, no more gear transmission and clutch.

2.2.5 Hydrogen Storage and Supply System

Hydrogen storage and supply system, including hydrogen storage and supply system, mainly by high-pressure hydrogen storage bottles, valves, sensors, plus air intake, high-pressure pipeline, and hydrogen leak alarm, etc. Hydrogen storage and supply system is shown in Figure 5.

2.2.6 Powertrain Control System

Powertrain control system whose main functions include energy management, fault diagnosis, vehicle control.
3. Definition of Fault Processing for Fuel Cell Vehicle Based on Classification Principle

Similar to the traditional internal combustion engine vehicles, fuel cell vehicles can appear all sorts of fault in the operation process. The effect of different fault is very different, so it is necessary to classify the fault according to the effect. The following will introduce the concept of Failure Mode and Effects Analysis (FMEA), and define the fault of the fuel cell vehicle based on FMEA.

3.1. Definition of FMEA

Failure Mode and Effects Analysis (FMEA) is an inductive analysis method which is to analyze each product for all possible failure modes and all possible influence, and to classify the severity, detecting degree of difficulty and frequency of every failure mode. Failure Mode, Effects and Criticality Analysis (FMECA) is the Portfolio analysis method of FMEA and Criticality Analysis-CA. In this paper, the FMEA and FMECA collectively referred as "FMEA" except for designation.

FMEA as a reliability analysis method originated in the United States. Back in the early 50s, the U.S. Grumman Aircraft Corporation used FMEA method in the development of the main control system to obtain good results. To the late 60s and early 70s, FMEA method used extensively in aviation, aerospace, ships, weapons and other developed military systems, and gradually penetrate into the machinery, automotive, medical equipment and other civilian industries, achieved significant results. In the early 80s, with the reliability of technology in engineering, FMECA concepts and methods have gradually been accepted in China. Currently in the aviation, aerospace, weapons, ships, electronics, machinery, automobiles, household appliances and other industries, FMEA have a certain degree of popularity.

3.2. Fault Classification Based on FMEA

Currently, FMEA in product design and manufacture an extensive range, it brings great benefit to most people. In this paper, fuel cell vehicles have possible fault classification; also have a positive impact based on FMEA. Based on the method of FMEA, fault classification of the system as well as key parts will be involved in all aspects of the new generation of fuel cell vehicle which is developed by Tongji University and Shanghai fuel cell vehicle powertrain Co. Here focus on fuel cell vehicle model of powertrain fault, which mainly include the PCU (Power Control Unit) and its cooling system, fuel cell and auxiliary systems, hydrogen storage and transportation systems, batteries and its management systems, air conditioning system, DC/DC and DC/AC converter, drive motor and its wiring harness, and the vehicle electrical appliances. Hydrogen transport system as an example of the FMEA analysis in Figure 6.

Figure 6: FMEA analysis of hydrogen transport system.

3.3. Fault Definition of Fuel Cell Vehicle

According to the nature of fault classification, it is necessary to define the corresponding
diagnostic code (DTC) of the components. Depending on the different needs, the DTC will not only upload to the vehicle management system, display, gateways, and also stored in each fault memory cell to facilitate online real-time display and processing, as well as off-line fault analysis and diagnosis. The definition of DTC is shown in Table 1-5.

Table 1: Diagnostic code definition table

<table>
<thead>
<tr>
<th>DTC</th>
<th>The first byte of data field</th>
<th>The second byte of data field</th>
<th>The third byte of data field</th>
<th>The fourth byte of data field</th>
</tr>
</thead>
</table>

Table 2: The first byte of data field

<table>
<thead>
<tr>
<th>Fault level</th>
<th>Systematic classification code</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 6 5 4 3 2 1 0</td>
<td></td>
</tr>
<tr>
<td>0 0 1 1 0 0 0 1</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: The second byte of data field

<table>
<thead>
<tr>
<th>Diagnostic code</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 6 5 4 3 2 1 0</td>
</tr>
<tr>
<td>0 0 0 0 0 1 1</td>
</tr>
</tbody>
</table>

Table 4: The third byte of data field

<table>
<thead>
<tr>
<th>Diagnostic code</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 6 5 4 3 2 1 0</td>
</tr>
<tr>
<td>1 0 0 0 1 0 0</td>
</tr>
</tbody>
</table>

Table 5: The fourth byte of data field

<table>
<thead>
<tr>
<th>Fault occurred frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 6 5 4 3 2 1 0</td>
</tr>
<tr>
<td>0 0 0 0 1 1 0 0</td>
</tr>
</tbody>
</table>

Table 1-5: DTC from 4 parts, fault level, system classification code, fault code and the fault occurred frequently. Among them, the systematic classification code have corresponding reference standard, the diagnostic code and fault occurred frequency based on the actual situation. Here the DTC on the fuel cell vehicle in a brief description of the fault level.

The first byte of data packets DTC 7 ~ 5 is used to identify fault level (binary), specific as follows: 001, Level 1, risk fault; 002, Level 2, serious fault; 011, Level 3, general fault; 100, Level 4, slight fault; 101~111, system reserved.

4. Fault Processing of Fuel Cell Vehicle Base on Classification Principle

Clear definition of fault is the basis for subsequent fault processing. According to various faults of fuel cell vehicle, below the overall strategy for fault processing base on classification principle and in particular describes the control algorithm of limping back is introduced in detail.

4.1. Overall Strategy for Fault Processing Base on Classification Principle

Like traditional vehicles diagnosis and processing, the main objectives of fuel cell
vehicle fault diagnosis and processing are: To ensure traffic safety, reliability and stability. In order to achieve the goal, fault processing base on classification principle is used in fuel cell vehicle. Overall processing strategies are as Table 6.

### Table 6: Fault description and processing

<table>
<thead>
<tr>
<th>Fault level</th>
<th>Fault description</th>
<th>Fault processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Dangerous fault</td>
<td>Emergency shutdown</td>
</tr>
<tr>
<td>Level 2</td>
<td>Severe fault</td>
<td>Request shutdown</td>
</tr>
<tr>
<td>Level 3</td>
<td>General fault</td>
<td>Limit the power</td>
</tr>
<tr>
<td>Level 4</td>
<td>Slight fault</td>
<td>Just Record</td>
</tr>
</tbody>
</table>

### 4.1.1 Level 1 Fault

This level fault is emergency shutdown fault. Vehicle management system receives the status code of vehicle components; determine whether the fault is a level 1 fault. If it is a level 1 fault, vehicle management system immediately issued a shutdown command; all components immediately shut down after the entire system receive instruction, vehicle complete shutdown.

### 4.1.2 Level 2 Fault

This level fault is request shutdown fault. When motor and battery have level 2 faults, vehicle management system will control the accelerator pedal. Pedal is not the output signal, no motor torque output; the vehicle will not be driving. Drivers or technical personnel choose shutdown or not according to specific fault. If DCDC and FCE have level 2 faults, HMS have level 1 or level 2 fault, vehicles will automatically shut down fuel cell system and DCDC controller.

### 4.1.3 Level 3 Fault

This level fault is to limit the power failure. When vehicle management system receives fault, it will limit the output torque to achieve the limit power output. When the vehicles have level 3 fault, driver can continue at low speed. This approach greatly reduces the risk of vehicle breakdown.

### 4.1.4 Level 4 Fault

This level fault is minor fault. Vehicle management system receives the fault without any processing; the fault may disappear in a short time, drivers and engineers only record the fault in the run-time.

### 4.2. Level 3 Fault Processing Strategy of Limping Back

In the process of operation, Level 3 fault is frequent. Level 3 fault processing compared with other levels is more complex, Level 3 fault processing of power train for example.

In the process of operation, power train at Level 3 fault, required to meet the following requirements: To ensure the safety of passengers and drivers; to avoid accidental damage of the key components; eliminate the fault or fault-tolerant operation; with limping back function. In view of the above four requirements, Level 3 fault processing must be relatively flexible.

![Figure 7: Motor torque control diagram after level 3 fault](image)

For example, in the process of operation, fuel-cell have level 3 fault (single battery voltage is low), the fault processing strategy
shown in Figure 7. Suppose at time t1 have problems, first of all, start the power limit mode, record the current motor torque settings (TqSetIn), set as a torque limit (TqSetLmt, assuming before failure occurred is 100) , keep to the time point t2, this period known as the power to maintain phase, which as failure to self-repair, vehicle recovery to normal operation; Otherwise, TqSetLmt gradually decreased and fell to half of the time point t3, and t3 ~ t4 TqSetLmt remain unchanged, the two time periods referred to power down and maintain, hoping for some time to achieve the output power limit troubleshooting purposes; if the program can not eliminate failure, after t4 to adjust the TqSetLmt to smaller constant, to ensure vehicles can limp back. Output power limit by limiting the motor output torque to achieve, the specific control algorithm shown in Figure 8.

Figure 8: Motor power limit algorithm based on the state flow diagram

5. Conclusion

Based on the new generation of fuel cell vehicle powertrain platform, shanghai fuel cell vehicle powertrain Co., Ltd has successively introduced the fuel cell vehicle such as ‘PASSAT’, ‘ROVER’ and the series of ‘EASTAR’. To improve the safety, reliability, stability, the three kinds of models which is used the fault processing strategy have good effect. They had smoothly passed the "863" acceptance criteria. The "PASSAT" fuel cell vehicle served the 2008 Beijing Olympic Games as the leader in the marathon and the official vehicles. The mileage was more than 50,000 km, and the running condition was good. In addition, fuel cell vehicle fault processing strategy has been widely used in many other models, including hybrid vehicles, fuel cell city bus, and a large fuel cell micro-electric car.

In summary, advantage of the fault processing strategy based on classification principle in the following aspects: improving the safety and reliability, significantly reducing the probability of vehicle breakdown; extending the service life of critical components, to avoid damage of components; to enhance the satisfaction of driver and passenger. However, the current fault processing strategies need to be improved. The definition and classification of fault need further refinement. Through continuous improvement, fault processing strategy can be promoted in the field of new energy vehicles.

References

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