Research on matching strategy of hybrid power with fuel cell

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Abstract. The hybrid power is an important research in the research field of new energy power system, and its strict operating process and running status influence the performance and life greatly. To aim at the problem, the structure of hybrid power was given out at first. Secondly, the modeling of hybrid power fuel cells was advanced based on electrochemistry. Then the modeling structure, algorithm, and simulation of electrical characteristics of hybrid power fuel cells were particularly presented. Finally, the 1kW experiment of hybrid power fuel cells was finished for the operating and running process. The research result is provided for the suitable engineering model of matching and control of hybrid power system at the view of application.

1. Introduction
The automobile, which is driven by the fuel oil engine, has passed the history of nearly one hundred years [1]. At present, the energy crisis and environmental pollution make the hybrid electric vehicle initially occupy a certain market share, and promote the development of various electric vehicles. Whether it is a hybrid electric vehicle or an electric vehicle, the battery plays a major role as a power source. However, the performance price ratio and reliability of power battery have always been the constraints of electric vehicles and become the bottleneck of technology.

Hybrid power is a hybrid device that connects two or more than two different types of power or batteries in different ways to provide kinetic energy or electrical energy [2]. Its biggest feature is to make full use of the characteristics of different types of power or battery in a certain range of the performance price ratio, learn from others' strong points and close the gap, and improve the comprehensive performance and reliability. Therefore, it has become an important research direction in the research field of new energy power system. Because the energy and power system works under various conditions, its strict working process and operation state is very important for the performance and life of hybrid power. In the research process of hybrid power, its input and output performance matching is quite strict, so there are many difficulties in matching strategy and modeling. Thus, it has always been an important topic in the research and development of hybrid power. This paper mainly research the modeling, simulation and matching of hybrid power fuel cells.

2. Hybrid power system
A set of hybrid power system is composed of multiple power sources with different structures and different types. At present, the EV hybrid power system is mostly formed on the basis of the fuel oil engine with the power battery. The combination form of the EV hybrid power system has three types that are series type, parallel type and mixed type [3]. The basic structure is shown in Figure 1.
In general, the modern electric vehicle (the abbreviation is EV) according to different sources, mainly divided into four categories: hybrid electric vehicle (the abbreviation is HEV), plug-in hybrid electric vehicle (the abbreviation is PHEV), pure electric vehicles (the abbreviation is PEV) and fuel cell electric vehicles (the abbreviation is FCEV) [4].

The power ratio of the power battery to the fuel oil engine is defined as the mixing degree. when the mixing degree is more than 50%, the hybrid power system has the function of pure battery power driving for most of the vehicle working conditions under the ideal conditions. At present, the mixing degree of belt driven starter generator, which is the plug-in belt drive starting power generation technology (the abbreviation is BSG), is less than 10%, and the power battery can only achieve the condition of the idle speed, the low speed start, the light load, the low speed and the reverse operation. The blending degree of integrated starter and generator, which is the installed crankshaft drive electric power-generation disc motor technology (the abbreviation is ISG), is about 30%. The research shows that the PHEV, which is developing vigorously in Europe and America, has a mixing degree of 30% to 50%. Therefore, it can be said that PHEV will become a transition product of HEV and PEV from the current trend of development.

Here the fuel cell is designed as a power battery for the hybrid power system. The following will be carried out for the research of hybrid power fuel cells.

3. Hybrid power fuel cells mechanism
A set of fuel cell, which is used for hybrid power, is composed of many fuel cell units which structure is same. Figure 2 shows the structure of the basic fuel cell unit.

In the fuel cell, its outer layer is the separator plate, its inner layer is the bipolar plate, and its center part is the electrolyte plate where the outer parts are the anode and cathode. When the fuel gases and oxidant gases enter at the gas inlets, they flow in the gas channels of the bipolar plates and filter into the porous anode/cathode, and then react with the aid of the catalyst that is nickel and nickel protoxide in the certain condition. The electrolyte plate obstructs the gases and the electron of the anode, and
only permits the carbonic acid ion of the cathode to pass. The electron of the anode can flow across the load of the circuit to the cathode. Thus, the fuel cell produces direct current electricity.

Namely, the fuel cell anode consumes 1mol hydrogen, at the same time the fuel cell cathode consumes 0.5mol oxygen and 1mol carbon dioxide, as a result, the fuel cell can produce 2mol electron, and give out the heat of 246KJ and the standard potential of 1.19V [5].

In conclusion, the fuel cell can generate electricity continuously as long as the fuel gas and oxidant gas are supplied in the definite operating condition. The main factors that determine the amount of the fuel cell generating power are the active working area and working status of the electrolyte plate. The amount of electricity that a single fuel cell produces is very low commonly (A fuel cell unit has only a potential of 0.5~0.8V when generating a current density of approximately 0.15~0.25A/cm²). However, many fuel cells are connected in series to form a fuel cell stack to meet the required power for a specific application. The keys that determine fuel cell running normally rest with the internal working status and external operating condition of fuel cell stack.

4. Hybrid power fuel cells modeling

The fuel cell modeling is mainly studied for the fuel cell internal relations about the working status, in which the researchers analyze the relations about the fuel cell performance with the operation variable, the working condition, and the internal part condition [6]. The goal of the modeling is to promulgate the fuel cell internal transmission distribution mechanism, to predict the fuel cell performance, to optimize the fuel cell design, and to actualize the effective fuel cell control.

In order to model the fuel cell, the supposition is as following firstly: (1) the gas is the laminar flow in the channel; (2) the anode, the electrolyte and the negative are all of the homogeneous phase porous medium; (3) the gas dissolution is ignored in the liquid water; (4) the distribution of the temperature and the pressure are even; (5) the fuel cell operates under the steady state conditions.

According to Nernst equation [7], regarding as the multi-component fuel gas of H₂/H₂O/CO₂/CO, its equation is,

\[ E_{eq}(u) = E_{eq}(0) - \frac{RT}{2F} \ln \frac{p_a(0)}{p_a(u)p_{co}(0)} - \frac{RT}{2F} \ln \frac{p_a(u)}{p_{a,x(u)p_{co}(u)}} \]  (1)

where, \( E_{eq}(u) \) is the open-circuit voltage (V), \( E_{eq}(0) \) is the standard potential (V), \( R \) is the universal gas constant (J/molK), \( T \) is the absolute temperature (K), \( F \) is the Faraday's number (C/mol), and \( p_i \) is the differential pressure of the gas (atm).

Supposed \( x_i \) is the mole component of the gas, the above equation is rewritten as,

\[ E_{eq}(u) = E_{eq}(0) - \frac{RT}{2F} \ln \frac{x_a(0)}{x_a(u)x_{co}(0)} - \frac{RT}{2F} \ln \frac{x_a(u)}{x_{a,x(u)x_{co}(u)}} \]  (2)

Meanwhile, under the certain temperature conditions, the fuel gas has the reversible moisture transformation reaction [8]. That is,

\[ H_{2} + CO_{2} \leftrightarrow H_{2}O + CO \]  (3)

where, its enthalpy is \( \Delta H_{298}^{0} = -41kJ / mol \).

Thus it causes the change of the fuel gas component, and the change \( \Delta n \) may be calculated according to the equilibrium constant K formula of the reaction,

\[ K = e^{\frac{\Delta G}{RT}} = \frac{(x_{CO_2}(0) + \Delta n) \cdot (x_{H_2}(0) + \Delta n)}{(x_{CO}(0) - \Delta n) \cdot (x_{H_2O}(0) - \Delta n)} \]  (4)

where, \( e \) is the natural index, \( \Delta G \) is the Gibbs free energy changes (J/molK), \( x(0) \) is the gas density before the moisture transformation reaction (mole percentage), and \( \Delta n \) is the change of the gas component (mole percentage).

Supposed \( u \) is the fuel gas use factor (percentage), \( v \) is the occupy proportion of CO in the moisture transformation, namely \( x(0) \cdot \Delta n \), in the electrochemical reaction process the gas density (mole percentage) \( x(u) \) of the fuel gas is as follows,
\[
\begin{align*}
X_{H_2}(u) &= \frac{x_{H_2}(0) + \left[ x_{H_2}(u) + x_{CO}(u) \right] u + x_{CO}(0) v}{1 + (x_{H_2}(0) + x_{CO}(0)) u} \\
x_{CO}(u) &= \frac{x_{CO}(0) + \left[ 1 - v \right] u}{1 + (x_{H_2}(0) + x_{CO}(0)) u} \\
x_{H_2,O}(u) &= \frac{x_{H_2,O}(0) + \left[ x_{H_2}(u) + x_{CO}(u) \right] u + x_{CO}(0) v}{1 + (x_{H_2}(0) + x_{CO}(0)) u} \\
x_{CO_2}(u) &= \frac{x_{CO_2}(0) + \left[ x_{H_2}(u) + x_{CO}(u) \right] u + x_{CO}(0) v}{1 + (x_{H_2}(0) + x_{CO}(0)) u}
\end{align*}
\]  

(5)

If the moisture transformation reaction is not considered, the relation of the current density \( i \) (A/m²) and the reactant production rate or the resultant production rate \( m \) (mol/m² s) of the unit area is:

\[
i = 2F \frac{m}{n}
\]

(6)

where, \( F \) is the Faraday's number, \( n \) is the equivalent number of the gas component \( H_2, CO, CO_2, O_2, \) and \( H_2O \). The anode is \( n_a = (-1,0,1,0,1) \), and the cathode is \( n_c = (0,0,-1,-0.5,0) \).

But, in the flow direction \( l \) of the fuel gas from the input to the output, the fuel cell internal electrochemical reaction causes the change of the fuel gaseous component. Thus fuel cell current density distribution of the \( t \) time may obtain through the equation below:

\[
i(l,t) = I_{in}(t) \frac{\partial u}{\partial l} \quad (0 < l < 1)
\]

(7)

Therefore, the relation of the fuel cell average current density and the fuel gas use factor is:

\[
I(u) = I_{in}(t) \cdot u(t)
\]

(8)

where, \( I_{in}(t) \) is the equivalent input current, and it is the current when the fuel gas is completely used.

5. **Hybrid power fuel cells simulation**

The fuel gas use factor of the fuel cell is changed along with the fuel gas component. When the reactant gas consumes gradually, the fuel cell voltage will drop as a result of polarization and the gas component change. Generally, the increasing of the fuel gas use factor can cause the reducing of the fuel cell performance. Here, the fuel gas use factor is set as 75%–85%, and the oxidant gas use factor is set as 50%.

Of course, the fuel cell output voltage, the average current density and the internal resistance vary with the fuel gas use factor of the fuel cell, and the relationship is coupled with each other. When the average current density of the fuel cell is different, the output voltage of the above modeling is different. The change of the output voltage is linear in the different flow direction \( l \) of the fuel gas. The computer simulation result of the fuel cell output voltage to the average current density is shown as the Figure 3.
6. Hybrid power fuel cells experiment
To operate the hybrid power fuel cell experiment, the average porosity factor of the electrolyte board is 60%, the average aperture is 0.5μm, the electrolyte board assumes the level laying aside via assemble contracts, and the anode and the negative passes over 0.05MPa oxygen. The electrolyte board starts the agglutination after the heat start for 18 hours. 40 hours later, the fuel cell runs stably, and then test.

The open-circuit voltage of the fuel cell reaches to 34V. When the current density is 150~200mA/cm², the output voltage obtains the steady change in 21.37~19.46V scope, namely the unit average output voltage maintains 0.7V. Figure 4 shows the output power characteristic curve. The maximum power output achieves 1.1kW, while the power density is 0.1W/cm².

7. Conclusion
The running process of hybrid power fuel cells is related with the material quality, start process and operating condition. The fuel cell mathematical modeling is extremely difficult, moreover is difficult to use in the real-time control. Here the electrical modeling is established through applying the electrometrical characteristics. Its modeling structure is simple, the algorithm is concise, and the
accuracy is high. Its prominent merit is that the major effect factor of the operation process is considered, meanwhile the secondary influence factor is processed as the non-linear disturbance factor, and therefore it has the certain environment adaptation. The computer simulation and experiment result provided for the suitable engineering model of matching and control of hybrid power system at the view of application.

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