

Development of Electric Power Control using the Capacitance Characteristics of the Fuel Cell

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ABSTRACT

Cold weather operation has been a major issue for fuel cell vehicles (FCV). In order to counteract this effect on FCV operation, an approach for rapid warm-up operation based on : concentration overvoltage increase and conversion efficiency decrease by limiting oxygen or hydrogen supply, was adopted in a running fuel cell hybrid vehicle. In order to adjust the output power response of the fuel cell to the target power of the vehicle, -the inherent capacitance characteristics of the fuel cell were measured- based on the oxidation-reduction reaction and an electric double-layer capacitor, and an equivalent electric circuit model of a fuel cell with the capacitance was constructed. This equivalent electric circuit model was used to develop a power control algorithm to manage absorption of the surplus power, or deviation, to the capacitance. It was confirmed that the rapid warm-up operation could follow the output power response and warm-up performance reasonably well, and this control was applied to the new Toyota FCHV-adv, released in June 2008.

INTRODUCTION

Toyota Motor Corporation is proactively developing various environmentally friendly technologies to help resolve energy-related issues such as atmospheric pollution, global warming, and the depletion of fossil fuels. Of these technologies, the fuel cell hybrid vehicle (FCHV) offers the lowest well-to-wheels carbon emissions (zero local emissions) and longest driving range compared to all other electric powertrain types.

As the World's hybrid, fuel cell vehicle, the Toyota FCHV was released on a limited lease basis in December 2002. Since then, various improvements have been made based on issues identified in real world driving. However, the following points are to be addressed to ensure FCHVs gain widespread acceptance in the market: 1) driving range, 2) cold start capability, 3) stack durability, 4) cost reduction, and 5) hydrogen infrastructure creation.

With the Toyota FCHV-adv (see Fig. 1), which became available for leasing in 2008, progress has been made toward resolving the issues of driving range [1], cold start capability [2], and stack durability [3, 4]. The range of the Toyota FCHV-adv is equivalent to the 500 km range of a gasoline vehicle, and stack durability has been enhanced by greatly improving crossover performance in particular. In addition, adopting a rapid warm-up operation strategy for vehicle systems drastically improved the speed of temperature increase of the fuel cell, enabling start at -30°C [5, 6].

Rapid warm-up operation increases the temperature of the fuel cell above freezing point and enables the vehicle to be driven. Subsequently, it is preferable for the fuel cell to operate at approximately 70°C to allow operation at the highest efficiency (see Fig. 2). However, in below-freezing environments, it takes some time for the fuel cell temperature to reach 70°C , which means that the fuel cell does not operate efficiently before reaching this temperature.

This paper describes the concept behind a fuel cell operation control that supports both the running of the vehicle and the warming-up of the fuel cell, after the temperature of the fuel cell has been increased above freezing point (see Fig. 3). It also details an electric power control method that uses the capacitance characteristics of the fuel cell to enable the power of the fuel cell to follow constantly changing accelerator response requirements (i.e., the power required by the vehicle). Finally, this paper presents the results of application of this control to the vehicle systems.



Fig. 1. Toyota FCHV-adv under Cold Testing

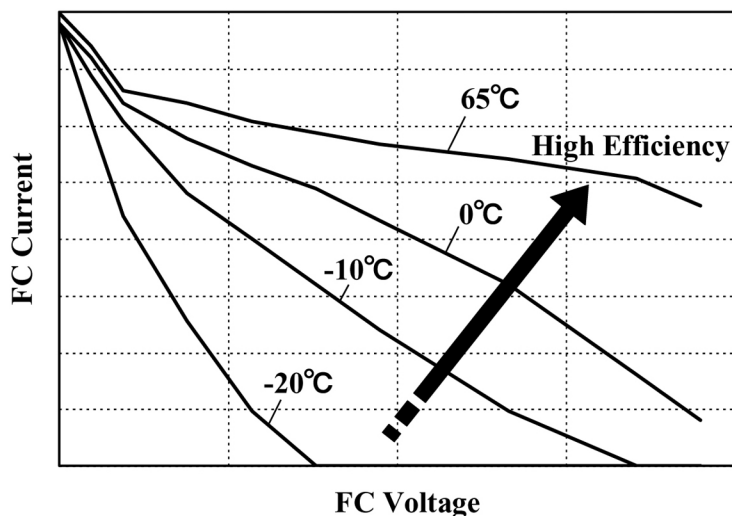


Fig. 2. Temperature-Dependant Change of Fuel Cell Voltage-Current (IV) Characteristics

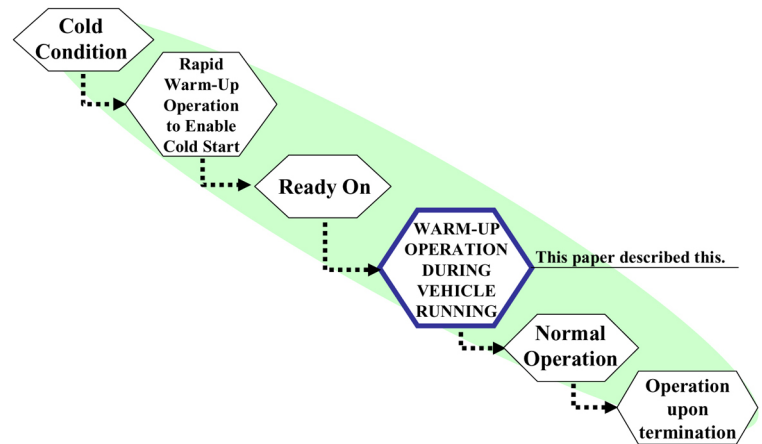


Fig. 3. Scenario of Fuel Cell Hybrid Vehicle Starting-up from Sub-freezing Temperature

RAPID WARM-UP OPERATION TO ENABLE COLD START

The challenge of starting and operating a fuel cell in a freezing environment is to process the water produced by electric power generation. Various methods of cold starting a fuel cell have been proposed to resolve this issue [7]. The Toyota FCHV-adv uses a method that limits the supply of oxygen to the fuel cell to increase the concentration overvoltage and lower the reaction efficiency. This intentionally reduces the efficiency of power generation and increases the amount of self-generated energy to stimulate warming up of the fuel cell [5, 6]. Figure 2 shows the voltage-current (IV) characteristics of a fuel cell comprising a stack of 400 cells. To satisfy the fuel cell requirement power under normal operation, an operation point is determined based on normal IV characteristics (the normal operation point shown in Fig. 4). However, under rapid warm-up operation, to increase the self-generated energy while satisfying the requirement power, the fuel cell is operated at the “rapid warm-up operation point”, which is several tens of volts lower than the “normal operation point” on the constant power curve. Increasing the self-generated heat in this way rapidly warms up the fuel cell beyond the freezing point.

WARM-UP OPERATION DURING VEHICLE RUNNING

OPERATION POINT OF FUEL CELL

After the temperature of the fuel cell has been increased above freezing by the rapid warm-up operation, the warm-up phase is continued during vehicle operation, until approximately 70°C, to enable efficient fuel cell operation. In the rapid warm-up operation below freezing point described above, the voltage is reduced by several tens of volts to increase the temperature above freezing. However, unlike the

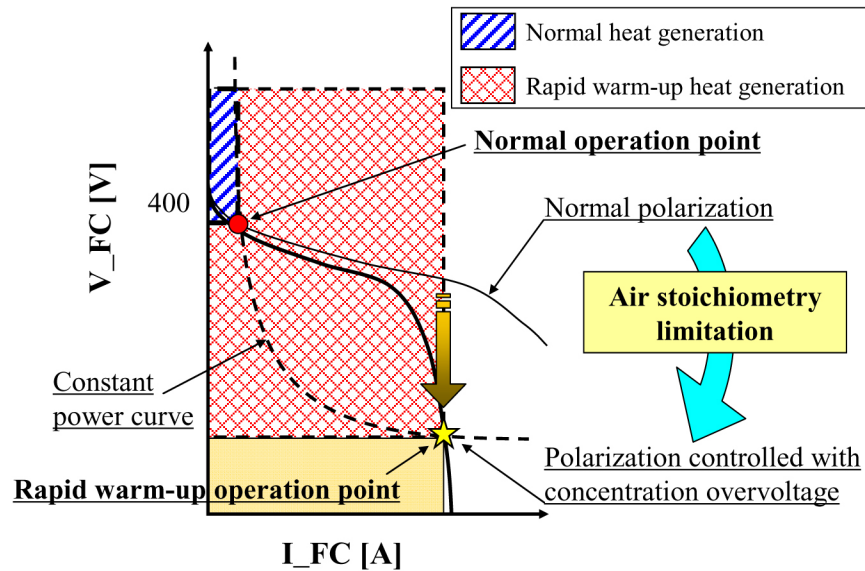


Fig. 4. Rapid Warm-Up Operation Point of Fuel Cell

rapid warm-up concept, the warm-up operation of the fuel cell while the vehicle is running must also consider the power demand specifications (minimum drive voltage and current) of the traction motor and inverter, the required vehicle dynamic performance, and other factors. In the Toyota FCHV-adv, the fuel cell voltage for warm-up operation while the vehicle is running was set to 180 V based on the two rate determining conditions described above. Thereafter, it was attempted to control the fuel cell power to follow accelerator response by varying the current through controlling the amount of air.

ISSUES OF FUEL CELL POWER RESPONSE

The vehicle systems were evaluated to confirm whether the fuel cell control method described in the previous section could adjust the fuel cell power in line with that required by the vehicle. From a state of equilibrium, where vehicle requirement power = fuel cell power (35 kW), Fig. 5 shows the fuel cell voltage and power when the accelerator is released, and the deviation between the fuel cell requirement power and actual power. Immediately after the accelerator is released, the requirement power drops sharply, but the actual power of the fuel cell does not follow this value, and surplus power continues to be generated. In the high voltage system structure [8] of the Toyota FCHV-adv shown in Fig. 6, this surplus power is used to charge the secondary battery. Under these conditions, the generated surplus power is approximately 20 kW.

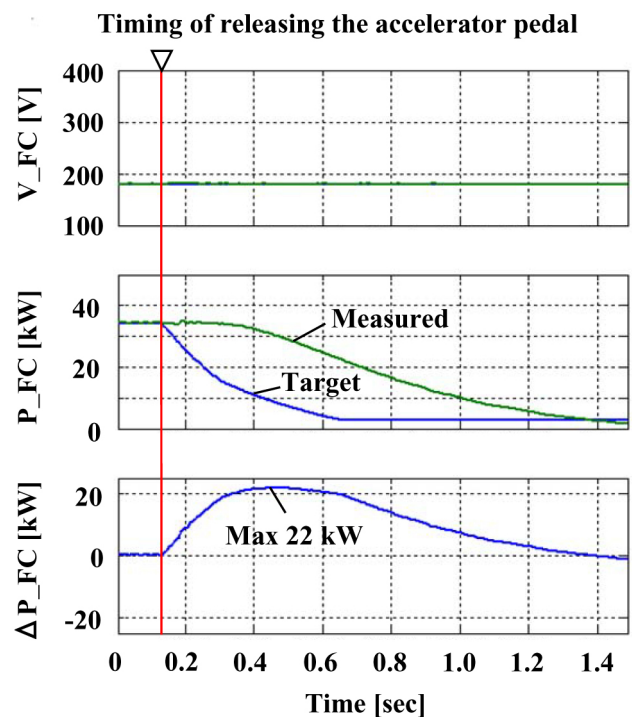


Fig. 5. Fuel Cell Power Behavior when Accelerator Pedal is Released under Rapid Warm-Up Operation