

Research on Electric Power System for Honda FCX Fuel Cell Vehicle

Hidekazu TAKENAKA*

ABSTRACT

An ultra capacitor has been utilized as a back up power source to give the Honda fuel cell vehicle acceleration performance rivaling that of a conventional vehicle. To control the difference in voltage between the two power sources at system start-up or takeoff from idle stop, a VCU (Voltage and current Control Unit) has been set between the fuel cell and the high-voltage device for the traction motor. The VCU charges the ultra capacitor gradually by chopping control of the current from the fuel cell, equalizing the voltage of the fuel cell and the ultra capacitor. This prevents the occurrence of over-current at system start-up or takeoff from idle stop. When the ultra capacitor is being charged with regenerated braking energy, chopping control of the current from the fuel cell by the VCU electrically separates the fuel cell and the ultra capacitor, and the current from the fuel cell is restricted. This enables the energy provided by regeneration to be utilized for charging the ultra capacitor.

1. Introduction

In December 2002 the Honda FCX fuel cell vehicle became the world's first fuel cell vehicle to be marketed in Japan and the U.S. The vehicle is fueled by pure hydrogen, and represents an attempt to exploit an alternative energy source in consideration of the future exhaustion of the world's oil reserves. By utilizing pure hydrogen as a fuel, the vehicle produces no CO₂ and achieves a zero level of emissions. Vehicles employing a fuel cell, which produces no pollutants, are being focused on as the way of the future in the automotive field, and the FCX is designed as one ideal form in which a zero-emission vehicle should be realized⁽¹⁾.

Development of the FCX did not focus solely on the environmental performance of the vehicle. The aim of the development was to produce a vehicle that matched the performance of conventional vehicles, for example, acceleration performance, high responsiveness, and smooth drivability, which tend to be sacrificed when environmental performance is a development focus.

The transient power performance of a fuel cell is not as rapid as that of a gasoline internal combustion engine. A level of acceleration performance equivalent to that of a vehicle employing a gasoline engine cannot currently be obtained in a vehicle which relies only on a fuel cell as its power source. Therefore, a Honda ultra capacitor has been used in combination with the fuel cell in the

* Tochigi R&D Center

FCX as the electric power system to improve acceleration performance.

When the fuel cell and the ultra capacitor are used in combination, the difference in voltage between the two power sources becomes an issue. To eliminate this voltage difference, a voltage and current control unit (VCU) that regulates the output of the fuel cell has been set between the fuel cell and the high-voltage device for the traction motor.

This paper will discuss the principle of operation of the VCU and the actual performance of electric power control.

2. Study of the Power Train System

Table 1 shows the results of a comparison of power supply systems⁽²⁾. The simplest of these systems is that in which the motor is driven directly by the output of the fuel cell. In addition to this type of system, there are also systems providing power assist and braking energy regeneration mechanisms, in which a battery or an ultra capacitor is used in combination with the fuel cell.

When only the output of the fuel cell provides the driving force, driving performance depends entirely on the output characteristics of the fuel cell. The transient power performance of the fuel cell is inferior to that of a gasoline engine. In particular, it is difficult to ensure equivalent driving force during acceleration to that provided by a conventional gasoline engine vehicle when using this type of system. In addition, this type of system requires a startup device for starting the generation of power in the fuel cell from system shutdown status.

The types of systems that utilize a battery or an ultra capacitor as an energy storage unit in combination with the fuel cell were studied next. Here, the use of a nickel

metal-hydride (Ni-MH) battery was taken as the base case, because this battery is at present conventionally employed in high-voltage applications. A comparison of the output characteristics of the Ni-MH battery and the ultra capacitor is shown in Fig. 1. It is clear from Fig. 1 that the ultra capacitor has a very high power density in comparison with the Ni-MH battery⁽³⁾. This output characteristic is particularly desirable for automotive dynamic performance, which requires high acceleration performance over a short period of time.

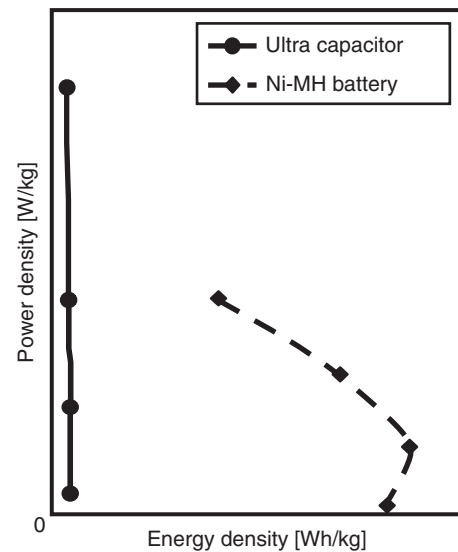
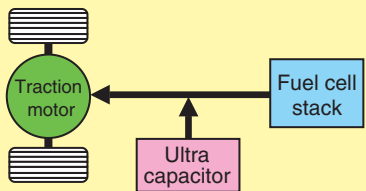
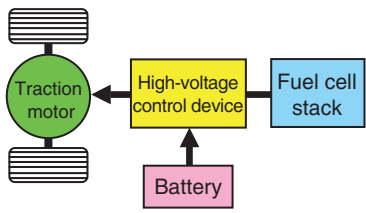
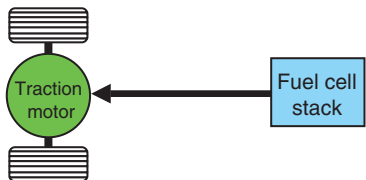


Fig. 1 Comparison of power density of Ni-MH battery and ultra capacitor

Table 1 Comparison of system configurations

	Basic configuration	High-voltage distribution system	Transmission efficiency	Braking regeneration	Power performance
Capacitor-assisted system		Not required	High	Yes	Instantaneous high-power assist
Battery-assisted system		Required	Medium (Losses of high-voltage controllers)	Yes	Power assist
Fuel cell direct-supply system		Not required (Startup device required)	High	No	Power and responsiveness depend on fuel cell stack

Voltage differences between the power sources become an issue when the fuel cell and the Ni-MH battery are used in combination. The fuel cell and the Ni-MH battery have specific current-voltage characteristics which are different from each other. It is therefore necessary to employ a high-voltage control mechanism which enables the voltage of the Ni-MH battery to be constantly maintained at the same voltage as the fuel cell in order to provide power assist and charge the battery with regenerative braking energy in accordance with the current-voltage characteristic of the fuel cell. On the other hand, the voltage of the ultra capacitor can be varied according to the current-voltage characteristic of the fuel cell, and the output current characteristic is very stable. Therefore, when electrically connected to the fuel cell, the ultra capacitor is capable of constantly maintaining the same voltage as the fuel cell. This makes the use of the high-voltage control mechanism unnecessary when the ultra capacitor is employed.

The comparison discussed above led to the selection of the ultra capacitor as the backup power source for the FCX, given its superiority to the Ni-MH battery in (1) enabling instantaneous high-power assist, and (2) eliminating the requirement for a high-voltage control mechanism.

3. Principle of Electrical Control Using VCU

When the system is shut down, and the fuel cell and the ultra capacitor remain connected with the high-voltage device, electricity gradually leaks away as dark current from the vehicle. At this time, as the hydrogen storage tank valve has closed, electric power is generated by the fuel cell from the hydrogen remaining in the hydrogen supply pipes. This may cause negative pressure in the pipes and have a bad influence on the fuel cell stack. In addition, the ultra capacitor continues to discharge, and if its voltage falls below the threshold level, the system will not start-up.

To prevent this situation, relay units are set between the fuel cell and the high voltage devices, and the ultra capacitor and the high voltage devices. When the fuel cell and the ultra capacitor are electrically disconnected by the

relay units, their voltages have a difference. If these relay units are connected while there is a difference in voltage between the two power sources, it is possible that an over-current could occur in the circuit connecting the fuel cell and the ultra capacitor. A VCU, which regulates the output current of the fuel cell by chopping to gradually reduce the difference in voltage with the ultra capacitor, is therefore required. In this system, the VCU is set between the fuel cell and the high-voltage devices for the traction motor. Figure 2 shows a system diagram of the VCU and the high-voltage devices.

The operation of the VCU and a diagram of the current-voltage control waveforms are shown in Fig. 3. IGBT is switched on or off by a control signal, which enables chopping of the output current from the fuel cell. In other words, IGBT functions as a switch. When IGBT is on, the current from the fuel cell, I_{FC} , becomes the current to the high-voltage devices, I_{OUT} . The current I_{OUT} becomes the current flowing into IGBT, I_{sw} , and finally returns to the negative side of the fuel cell. Therefore, $I_{FC} = I_{OUT} = I_{sw}$.

When IGBT is off, the current path from the fuel cell is closed and the current I_{FC} does not flow. Instead, the inductor placed in the current path charges electromagnetic energy by its inductance, and the discharge of this energy supplies the current when IGBT is off. This discharged current becomes the current flowing to diode 2, I_D , and flows into the high-voltage devices. In other words, $I_D = I_{OUT}$. The inductance of the inductor is designed to charge an amount of electromagnetic energy corresponding to the amount required for the current when IGBT is off. The total current flowing to the high-voltage devices becomes $I_{OUT} = I_{sw} + I_D$. The ability to vary the ratio of on to off in IGBT enables the output current of the fuel cell to be continuously varied.

At the same time, the current from the fuel cell is used to charge the ultra capacitor. The voltage of the ultra capacitor, V_{CAP} , increases as charging proceeds, until it becomes the same level with V_{FC} , the voltage of the fuel cell. V_{FC} becomes smaller as I_{FC} becomes greater. When $V_{FC} = V_{CAP}$, the VCU stops chopping and remains constantly on.

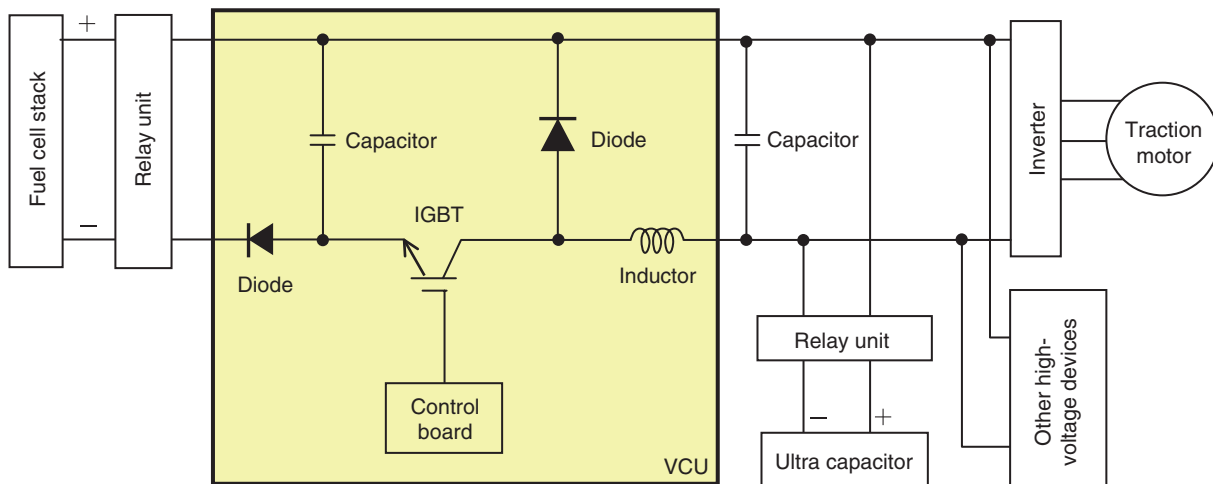


Fig. 2 System diagram of VCU and high-voltage devices

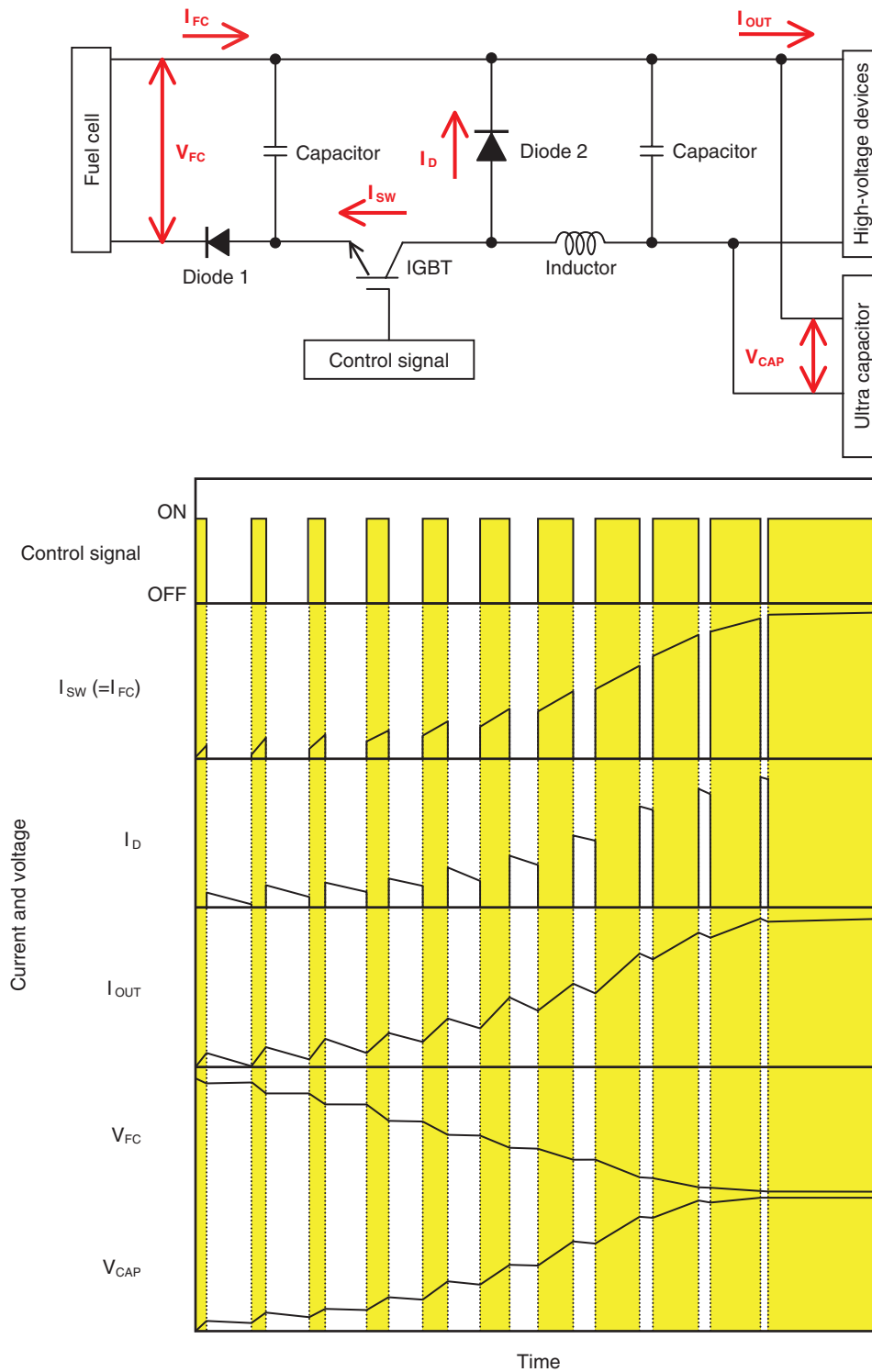


Fig. 3 Diagram of VCU current control mode

4. Verification of the VCU Operation in a Vehicle

4.1. Operation at System Start-up

Figure 4 shows fuel cell voltage, V_{FC} , and current, I_{FC} , ultra capacitor voltage, V_{CAP} , and current, I_{CAP} , when the system is started up and the fuel cell begins generating power from system shutdown status. When the system

is started up, first the relay unit for the ultra capacitor starts to operate, and then the relay unit for the fuel cell operates. The voltage of the fuel cell is different from that of the ultra capacitor. Chopping by the VCU charges the ultra capacitor with current from the fuel cell, causing the voltage of the ultra capacitor to approach that of the fuel cell gradually. When the voltages are equal, the VCU stops chopping and constantly remains on.

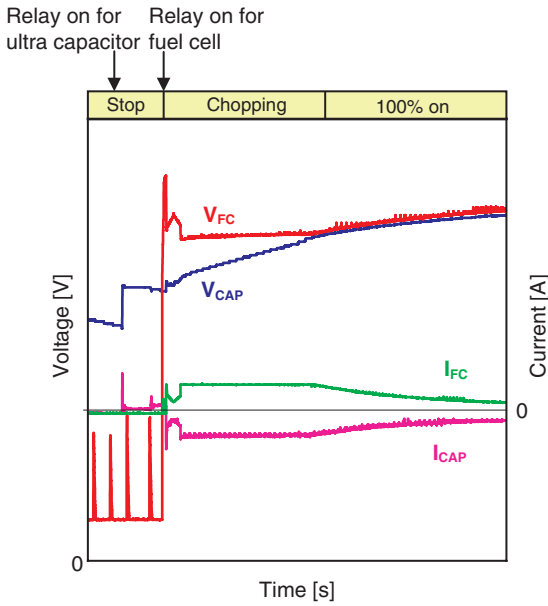


Fig. 4 Voltage and current profiles of fuel cell and ultra capacitor at start-up

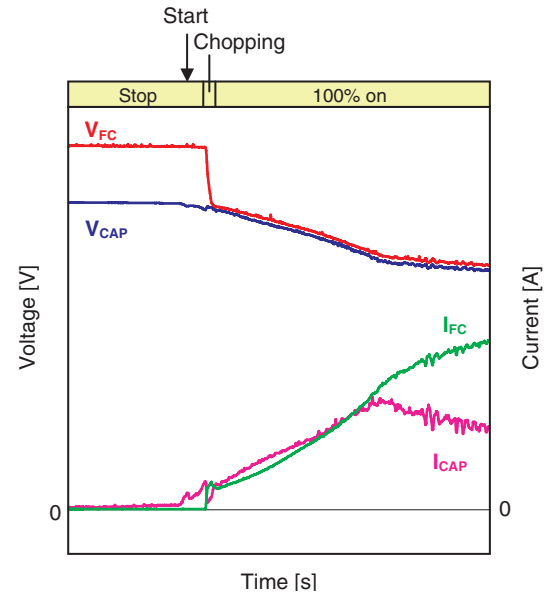


Fig. 5 Voltage and current profiles of fuel cell and ultra capacitor when driving from idle stop mode

4.2. Operation at Takeoff from Idle Stop

To control the consumption of electric power, the fuel cell in the FCX is provided with an idle stop function which goes into operation when a traction command for the motor has not been received for a certain period of time. Because the VCU is 100% off during idle stop, a difference in voltage occurs between the fuel cell and ultra capacitor. Figure 5 shows the voltage and current profiles of the fuel cell and the ultra capacitor when the vehicle takes off from the idle stop mode. When a traction command goes to the motor while the vehicle is in the idle stop mode, the VCU starts chopping. Continuous chopping equalizes the voltages of the fuel cell and the ultra capacitor, after which the VCU stops chopping and constantly remains on.

Power assist mode by the ultra capacitor at acceleration from a standstill can also be seen in Fig. 5. The fuel cell attempts to provide current to the motor when the traction command is received, but there is a slight time lag between the idle stop mode and restarting power generation. Current is output from the ultra capacitor to compensate for this output delay. Current continues to be provided from the ultra capacitor even after the fuel cell begins to generate electricity, because it has not generated the level of power required for acceleration. The amount of current from the ultra capacitor gradually diminishes as the amount generated by the fuel cell increases, and power assist stops when the amount of power generated in the fuel cell reaches the required level.

4.3. Operation of Regeneration during Braking

The FCX is able to charge the ultra capacitor with energy regenerated during braking. The voltage and current profiles of the fuel cell and the ultra capacitor in the regeneration mode are shown in Fig. 6. When the vehicle begins to decelerate, the power generated by the

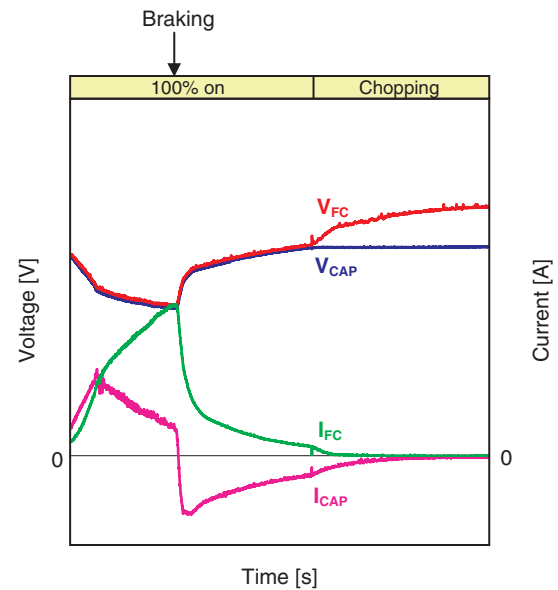


Fig. 6 Voltage and current profiles of fuel cell and ultra capacitor in regeneration mode

fuel cell is controlled to the minimum, and the motor starts regenerating braking energy. As a result, the current from the ultra capacitor becomes negative, and the ultra capacitor begins to charge with regenerated energy. However, because the VCU is constantly on when braking starts, the ultra capacitor is charged with energy from the fuel cell in addition to energy from braking regeneration. To reduce charging from the fuel cell, and to maximize the amount of charging from braking regeneration, the VCU starts chopping to electrically disconnect the fuel cell and the ultra capacitor. This enables output power from the fuel cell to be restricted, and the energy provided by regeneration to be increased.

5. Conclusion

A voltage and current control unit (VCU) has been utilized to control the power provided by the fuel cell in a fuel cell vehicle that also uses an ultra capacitor as a power source. The following results have been obtained:

- (1) Chopping by the VCU when the system is started up and when taking off from the idle stop mode controls the current from the fuel cell, enabling the difference in voltage between the fuel cell and the ultra capacitor to be eliminated.
- (2) In the regeneration mode, chopping by the VCU electrically disconnects the fuel cell and the ultra capacitor, enabling the energy from the fuel cell to be restricted. This enables the energy provided by regeneration to be utilized for charging the ultra capacitor.

References

- (1) Kawasaki, S., Ogura, M., Ono, T., Kami, Y.: Development of the Honda FCX Fuel Cell Vehicle, Honda R&D Technical Review, Vol. 15, No. 1, p. 1-6 (2003)
- (2) Ogawa, T., Kimura, K., Uchibori, K., Fujimoto, S., Shimizu, K.: Development of New Power Train for Honda FCX Fuel Cell Vehicle, Honda R&D Technical Review, Vol. 15, No. 1, p. 7-12 (2003)
- (3) Tamenori, K., Yamamoto, K., Anekawa, A., Taguchi, T., Kubota, S., Kawahara, M.: Development of Electric Double-layer Capacitor System for Fuel Cell Vehicle, Honda R&D Technical Review, Vol.15, No.1, p. 25-30 (2003)

■ Author ■



Hidekazu TAKENAKA