Band-Gap Reference Voltage Control Strategy for Fuel Cell Hybrid Vehicle

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Abstract

Generally, the power management system of fuel cell hybrid vehicle (FCHV) requires a unidirectional DC/DC converter for the fuel cell (FC) and a bidirectional DC/DC converter for the battery. To manage the various power flows between these modules with a simple way, a new band-gap reference voltage (BGRV) control strategy is proposed. The proposed method easily controls this variable power flow by setting the reference voltages of each converter to slightly different values, and it can be simply implemented by commercial controllers as well. The operational principle of proposed method is presented and verified experimentally by the 400W prototype.

I. Introduction

Recently, it is concerned that the environmental pollution and the depletion of petroleum. Accordingly, in order to improve a fuel efficiency and to meet a emission regulation, an automobile industry tries to find the alternatives to the internal combustion engine, such as electric vehicle (EV), hybrid electric vehicle (HEV), and fuel cell vehicle (FCV) [1]. Among them, FCV is the most attractive solution, since it utilizes the hydrogen as a fuel which makes no pollution and reduces the consumption of petroleum. However, a high cost and a slow transient response are the main technical obstacles for the commercialization of FCV. Moreover, it cannot recycle the regenerated energy from the motor since the fuel cell system does not have the storage capability. To make up for these week points, FC can be used with the energy storage components such as a super capacitor (SC), battery or both [2]. Among them, FC with SC suffers from the start-up problem due to the self-discharge of SC, and utilizing both SC and battery increases the system complexity and cost. By the reason of that, the research of operating FC with battery has been mainly progressed.

Generally, the power management system of FCHV requires the unidirectional DC/DC converter, converter 1, to transfer the power from FC to the inverter and the bidirectional DC/DC converter, converter 2, to handle the surplus or regenerative power as can be seen Fig. 1. For the efficient operation of this system, the power flow between these modules should be properly managed and many control strategies have been proposed in the literatures [3,4]. The control strategy using DSP or MICOM can improve the dynamic load response, however it features complex and high cost which make the commercialization difficult. To solve these problems, a new BGRV control strategy is proposed in this paper. By simply adjusting the reference voltages of each converter to the slightly different levels, the power flow between FC, battery, and inverter can be effectively controlled and it is easily implemented using widely used commercial controllers such as TL494 as well.

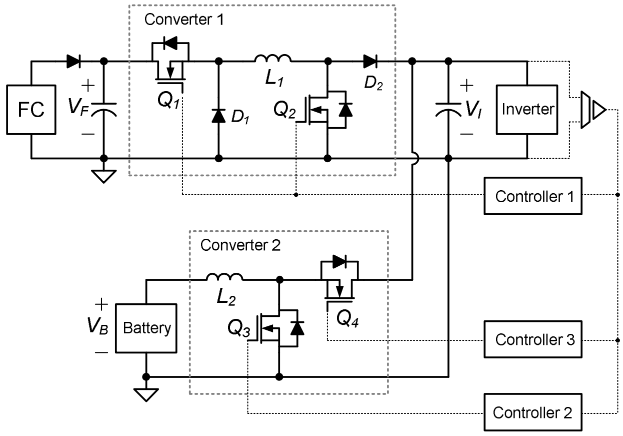

Fig. 1 Circuit diagram of power management system

II. Operational principle

In our power management system, the maximum power which can be supplied by FC is limited to P_{FCmax}, therefore FC supplies the power under its capability using converter 1. Since FC has a low dynamic response, no storage capability, and the limitation of supplying power, the surplus power or regenerated power from the inverter is handled by the battery using converter 2. The flow chart and operational modes of power management system are as follows

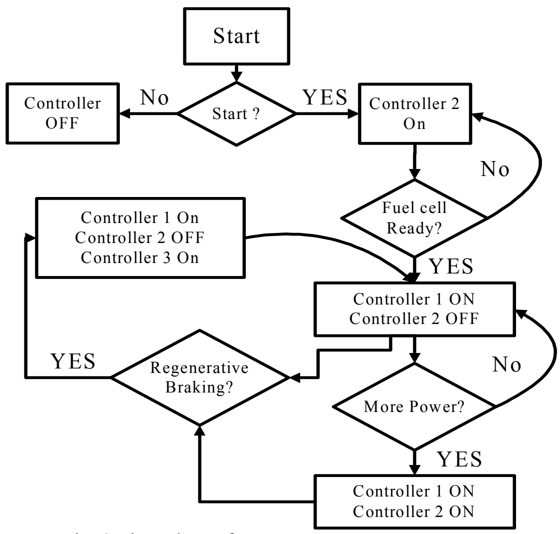

Fig. 2 Flow chart of power management system

1) start-up mode : At the start-up period, only the battery supplies the power to the inverter for the preparing of FC.

2) normal mode : In the normal driving, FC supplies the power to the inverter under the power limit of FC.

3) excessive mode : When the vehicle is accelerated, the motor requires a more power than usual. If the required power is exceed over the FC's capability, FC works at its maximum power and the battery fills the surplus.

4) regenerative mode : When the vehicle is braked, the power is regenerated from the inverter to the battery.

To regulate the inverter voltage V_I under the mode variations, three controllers are required basically, i.e., controller 1 for the forward power flow of converter 1, controller 2 for the forward power flow of converter 2, and controller 3 for the backward power flow of converter 2 as can be seen in Fig. 1. The main concern is how it can be effectively managed that the various power flows between the converters in a simple way using these three controllers. The proposed BGRV control strategy simply manages the power flow by only setting the slight band-gap between the reference voltages of each controller.

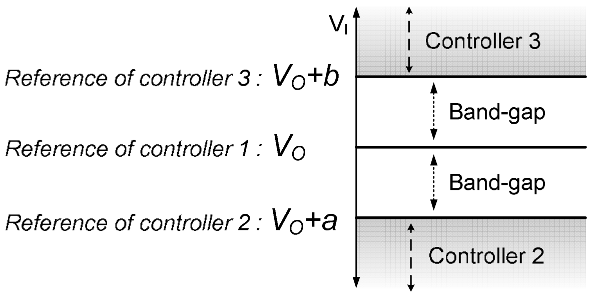

Fig. 3 Reference voltages and operating ranges of controller 2 and 3

As can be seen in Fig. 3, the reference voltage of controller 1 is set to V_O and the reference voltages of controller 2 and controller 3 are set to V_{O-a} and V_{O+b}, respectively. This band-gap between the reference voltages is set in an acceptable range for the operation of inverter. The proper controller according to the certain mode automatically regulates V_I. The operational principle of each mode is presented as follows.

1) start-up mode : At the start-up period, only the battery supplies the power to the inverter until the preparation of FC is finished, i.e., controller 1 is off-state in some duration.

2) normal mode : After the start-up period, controller 1 begins to work. Since the reference voltage of controller 1 is set to the higher value than that of controller 2, the power transfer by converter 1 is gradually increased to regulate V_I to V_O and the power transfer by converter 2 is decreased accordingly. After all, only converter 1 transfers the power and normal mode is operated. If the required load power does not exceed P_{FCmax} or the regenerated power does not come from the inverter, normal mode would be continued.

3) excessive mode : If the required power from the inverter is exceed over P_{FCmax}, V_I would be decreased gradually getting out of the regulation since the supplied power by FC is less than the required power from the inverter. After V_I reaches V_{O-a}, controller 2 starts to regulate V_I to V_{O-a}.. Therefore, the supplementary power is transferred from the battery to the inverter by converter 2 to regulate V_I. That is, excessive mode is operated. If the required power is decreased down to under P_{FCmax}, normal mode would be operated again regulating V_I to V_O.

4) regenerative mode : The transition of regenerative mode is similar to that of excessive mode. In normal mode if the regenerated power comes from the inverter, V_I would be increased gradually getting out of the regulation since converter 1 can not handle the backward power flow. After V_I reaches V_{O+b}, controller 3 begins to regulate V_I to V_{O+b}. Therefore, the regenerative power is handled by converter 2 and is transferred from the inverter to the battery. That is, regenerative mode is operated. If the regenerated power is disappeared, normal mode would be operated again regulating V_I to V_O.

Besides the abovementioned operation, if the dynamic response of FC can not cope with the variation of required power, controller 2 or controller 3 would be operated automatically to regulate V_I.

IV. Experimental Results

To verify the proposed control strategy, the 400W prototype shown in Fig. 1 is built with the following

specification; Fuel cell voltage V_F = 40~45V (open circuit voltage=60V), battery voltage V_B = 24V, rated power of FC = 200W, rated power of battery = 200W, inverter voltage V_I = 48V, band-gap 1, a= 1V, band-gap 2, b = 1V, and TL494 is used as controller 1,2 and 3.

Fig. 4 presents the experimental results of proposed BGRV control strategy. After t_0, start-up mode begins and only the battery supplies the power. After t_1, controller 1 is activated and normal mode begins. Therefore, V_I is regulated to 48V by controller 1 getting out of the regulation by controller 2 and the power is supplied by FC. As the required power exceeds over P_{FCmax} at t_2, FC cannot solely handle the required power. Therefore, V_I is decreased and regulated to 47V by controller 2. After the required power is reduced under P_{FCmax} at t_3, V_I is increased and normal mode is operated again.

In brief, the inverter voltage V_I is well regulated in spite of the mode change. That is, the proper controller regulates V_I effectively according to the mode variation

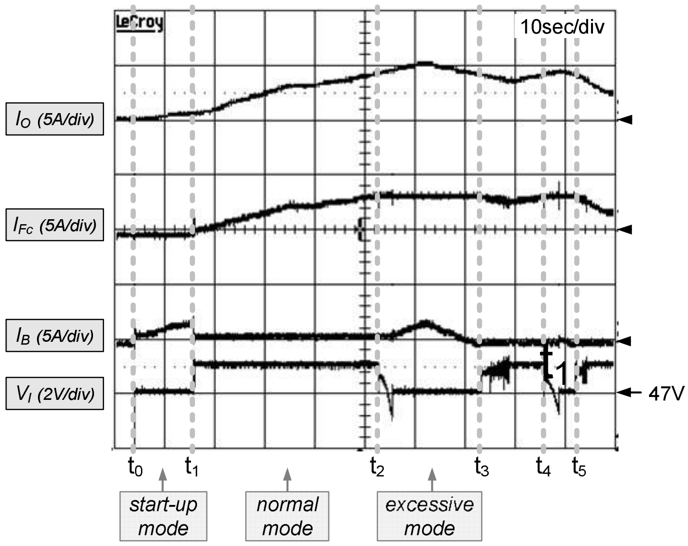

Fig. 4 Experimental waveform with mode variation

V. Conclusion

A new BRGV control strategy for FCHV is proposed. By simply setting the slight band-gap between the reference voltages of each converter, the power management system of FCHV effectively works. Moreover, it is easily implemented by widely used commercial controllers. Therefore, it features a simple and low cost, and is very promising for the commercialization of FCHV.

Reference

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