ISMSIT 2017
1st International Symposium on Multidisciplinary Studies and Innovative Technologies Proceedings
(November 2-4, 2017, Tokat, Turkey)
Symposium homepage: www.ismsitconf.org

The Hybrid Control Method of Compound DC Motor using Fuel-Cell and Battery

Rasim DOĞAN[1] and Ahmet KARAARSLAN[2*]

[1]*Electrical Engineering Department, Afyon Kocatepe University, Turkey*
[2]*Energy System Engineering Department, Yıldırım Beyazıt University, Turkey*
[*] *akaraarslan@gmail.com*

Abstract – In this study, we focused on to drive a compound DC motor with a Fuel-Cell and battery, which uses hydrogen as a fuel. A fuel cell can supply maximum 40V electric. In order to drive a DC motor, it needs 200Vdc. Therefore, a microcontroller controlled boost converter that is used to increase the voltage for desired level that is supplied with fuel cell and battery. During the powering process, the feedback control is implemented into the system with current and voltage sensors. So, the ATmega16U2 microcontroller is able to decide the desired duty cycle of the boost converter which is used for the gate of IGBT. Thus, the results presented in this paper with laboratory experiments.

Keywords – Fuel-Cell, compound DC motor, Electric Car, hybrid system

I. INTRODUCTION

The needs for a mechanical energy of transportation, fossil fuels are converted their high density chemical energy to mechanical energy for years. However, environmental effects, higher prices, and lower reserves of fossil fuels become a serious problem for today's world [1]. In order to achieve this problem, electric motors are the best option. The only difference from fossil fuel motor, an electric motor converts the electrical energy to the mechanical energy. Therefore, it needs an electrical source and the well-known electrical energy source is a battery. Conversely, it has a limited storage capacity. So, the battery must be charged after it is used.

There are two options to charge a battery. One is grid-connected charging stations. The other one is an external DC source connected charging devices. The first one has advantages and disadvantages. The grid-connected charging stations are easy to charge but they are still not common and they produce harmonics at the power system [2]. The second one also has advantages and disadvantages. The external electric source can supply energy anytime needed also it decreases the travel time and increases the distance without stop.

Fuel cell technology, which converts the chemical energy of hydrogen to electrical energy, is used as an alternative way of clean and economical alternative energy. There are different types of fuel cells such as polymer electrolyte membrane (PEM), solid oxide fuel cells (SOFCs), alkaline fuel cells (AFCs), phosphoric acid fuel cells (PAFCs), and molten carbonate fuel cells (MCFCs) [3]. PEM fuel cells are the best for the vehicle applications [4]. Therefore, this paper considers PEM fuel cell stack for the production of electric energy.

In order to store and supply electricity, lead acid batteries are the most common energy storages. As a result, their prices are low and it is easy to access for different battery voltage and the capacity [5]. This type of batteries has been used for different practices over the past 50 years and so they have a well-experienced technology [6]. Hence, lead acid batteries are used in the application of electric vehicle for the electric energy storage.

The main objective of the study is to drive a Compound DC motor of an electric car using fuel cell and battery as energy sources. The hybrid control method for these two energy sources is developed and experiments are performed.

II. MATERIALS AND METHOD

In this study, there are two main parts; charging the battery block with PEM fuel cell and drive the motor from the battery block. These two parts are performed together for compact design of electric vehicle (eV). The block diagram is shown in Figure 1.

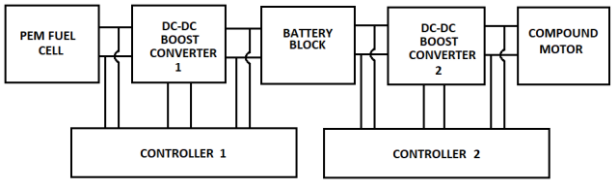

Fig. 1 Block diagram of the circuit

A. Charging the Battery Block with PEM-FC

A PEM fuel cell (see Fig. 2) produces DC voltage when hydrogen gas flows between its cells and the magnitude of the DC voltage depends on the flow rate of the hydrogen and the drawn current from the output as seen on the Figure 3 [7].

The lead acid battery block consists of six 12V 42Ah batteries that are connected series and this block is used both to storage energy and to power the dc compound motor of eV.

Between the PEM fuel cell and the battery block, there is a DC-DC boost converter. Since the electrical energy produced by Fuel cell needs to be stored into the battery block, this

converter increases the output of the fuel cell voltage to the desired level for charging the battery block. It consists of an inductance, an IGBT, a power diode, and a capacitor. The converter is in continues conduction mode (CCM). Thus, the inductance value 'L' is determined as 4mH and the capacitor value 'C' is selected as 470uF.

Fig.2 DuraPEM W240 fuel cell stack

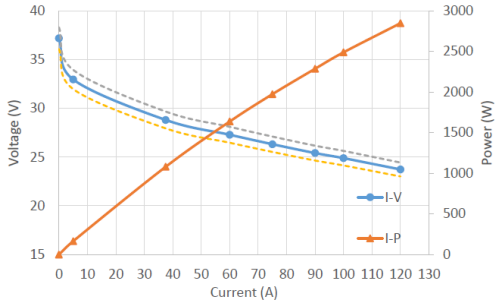

Fig. 3 DuraPEM W240 fuel cell stack steady state I-V and I-P characteristics

The power system is managed by Arduino ATmega16U2 microcontroller which is shown as Controller 1. This controls the first dc-dc boost converter switching. The controller receives the current information from the output terminal point and voltage information from the both terminal points of the dc-dc boost converter (see Fig. 4). Then, the information processed by Controller 1 and created a PWM signal to drive IGBT which is located in the dc-dc boost converter.

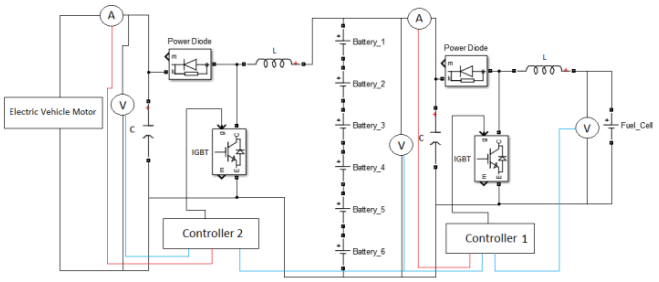

Fig. 4 Overall system configuration

B. Driving the DC Motor

The compound DC motor requires 200Vdc and this cannot directly be supplied by the battery block without any transform since their output voltage is 72Vdc. Therefore, there should be another DC-DC boost converter between the motor and the battery block. This converter increases the battery output voltage up to the 200Vdc. This could be higher or lower depending on the loading conditions and the motor tolerance. The system is managed by another Arduino ATmega16U2 microcontroller which is Controller 2 (see Fig. 4). It controls the second dc-dc boost converter switching. The controller receives the current information from the output terminal point and voltage information from the both terminal points of the dc-dc boost converter as same as Controller 1.

Electric vehicle uses the battery-block as a first energy source and the current path is shown in Figure 5a. But, when the battery charge level is low fuel cell directly supplies energy to the motor with two series boost converters and also charge the battery at the same time. The current path is shown in Figure 5b.

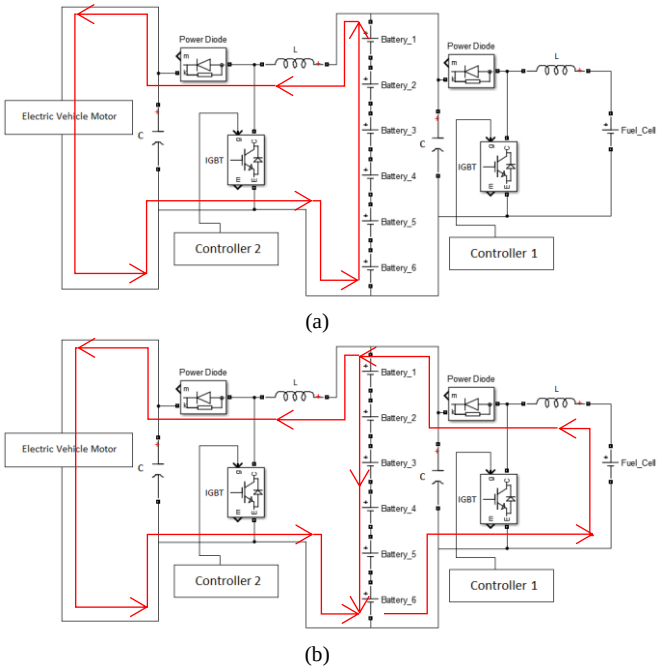

Fig. 5 (a) Battery supplies energy into the motor and (b) Fuel cell both charges the battery and drives the motor

III. RESULTS

The experiment is performed in Afyon Kocatepe University Renewable Energy Lab and the setup is shown on the Figure 6. DC motor is used to emulate the Electric vehicle motor.

Fig. 6 Experimental Setup.

At the beginning of experiments, it is verified that batteries are fully charged. First, energy stored in battery is used for driving the motor. Therefore, boost converter rises up the battery voltage from 72Vdc to 200Vdc. Converter output

voltage is depending on the duty cycle of the IGBT. This cycle is controlled by PWM signal created by Controller 2 to regulate the output voltage. Meantime, it measures the output voltage and input current. The input current is limited to 42A by controller 2. The reason of the limitation is the Fuel Cell rated power.

When the battery voltage is lower than 72V, hydrogen gas starts to flow into the fuel cell and fuel cell generates electricity. This fuel cell injection is controlled by an electronic valve. At the same time, the output of the fuel cell is measured by Controller 1. When it senses the output voltage of Controller 1 more than 24V, the boost converter starts to increase voltage. Then, battery starts charging and also the electric motor is fed by fuel cell as seen on Figure 5b.

The experiments are performed with and without load connection.

IV. DISCUSSION

The project only focused on the interaction of two separated system and control. Therefore, this still needs improvement. The hydrogen consumption and the heat change on the critical parts of the projects are neglected.

V. CONCLUSION

As a result of this study, the hybrid control method proposed and tested. After the test, a compound DC motor is successfully driven by the Fuel-Cell and battery.

This hybrid solution increases the travel distance range and also decreases the travel time. For example, if an electric vehicle consumes only battery energy, it will have a limited travel distance such as 300-400km depending on the vehicle and road conditions. However, if the vehicle uses an alternative source together with the battery, its distance range will be increased. This, also, saves time for electric vehicle users. Otherwise, they have to stop every 300-400 km to charge the battery and charging time may not be short.

ACKNOWLEDGMENT

This project is supported by Afyon Kocatepe University Scientific Research Project Department which is numbered 16.MUH.04.

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