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The Application of Battery Charging Circuit using PEM Fuel-Cell

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Abstract – In this study, the experimental application of polymer electrolyte membrane fuel cell (PEM-FC) with dc-dc boost converter is realized for compact design of electric vehicle (eV). The PEM-FC is an electro-chemical device which combines hydrogen with oxygen to produce electricity for charging batteries which drive an electric motor. The performance of the DC-DC boost converter as power modulator for fuel cell is analyzed for varying loads in order to control dc compound motor for enhancing performance. This PEM-FC can produce max 40V electricity to charge the six 12V lead-acid batteries that are connected series are used to power the dc compound motor of eV. In order to charge these batteries, a dc-dc boost converter is used to increase the PEM-FC voltage to 72V that batteries need for charging. During the charging process, the system is feedback itself with current and voltage sensors. The power system is controlled by Arduino ATmega16U2 microcontroller that is able to decide the desired duty cycle of the boost converter. The experimental results prove the robustness of control algorithm.

Keywords – Fuel-Cell, Lead-Acid Battery, Electric vehicle, PEM, Boost converter

I. Introduction

As an energy source, the engines of transportation vehicles use petroleum products such gas and diesel. Also, these engines require oil, which is another petroleum product, to protect metal parts of the engine from the corrosion. The number of the transportation vehicles increase gradually, so the consumption of petroleum products increases fast. All these products are the part of the environmental pollution, and also they become an expensive way of energy because of decreasing reserves. Therefore, electrical vehicles become an important alternative. They only consume electricity and the electricity is supplied by batteries. These batteries can be charged by either grid-connected charging stations or an external DC source connected charging devices. The grid-connected charging stations are a type of harmonic source and so negatively affect the power system quality [1]. This adverse effect cannot be negligible when thousands of vehicles are charging at the same time. In order to separate the electrical vehicle and the power system, the only solution is to focus on the external DC source connected charging devices and the most common external DC source is Fuel Cells.

Fuel cell technology, which converts the chemical energy of hydrogen to electrical energy, is used as an alternative way of clean and economical 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) [2]. Although each one has advantages and disadvantages for different kind of use, PEM fuel cells are the best for vehicle applications [3]. Therefore, this paper only considers PEM fuel cell stack for the production of clean 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 [4]. This type of batteries has been used for different practices over the past 50 years and so they have a well-experienced technology [5]. Hence, lead acid batteries are used in the application of electric vehicle.

The aim of this paper is to evaluate the application of battery charging circuit using fuel cell systems in the case of an electric vehicle application. Consequently, a charging circuit is developed and experiments are performed.

II. Materials and Method

In this study, there are four main parts; a polymer electrolyte membrane fuel cell (PEM-FC), a dc-dc boost converter, a battery block consists of six batteries, and a controller. These four parts are performed together for compact design of electric vehicle (eV). The block diagram is shown in Figure 1.

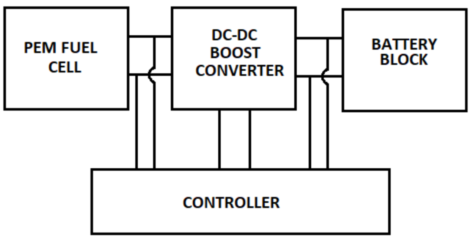

Fig. 1 Block diagram of the circuit

The first part is PEM-FC (see Fig. 2). This fuel cell has 40 cells. The rated current is 100A, rated voltage is 24V, and rated power is 2.4kW. I-V and I-P characteristics are shown in Figure 3 [6]. Dashed lines in the figure indicate the stack to stack manufacturing variability. When the output current increases, the output voltage decreases. This change is also related to the hydrogen flow rate. Therefore, output voltage of the PEM-FC should be observed for the controlling purpose.

Fig.2 DuraPEM W240 fuel cell stack

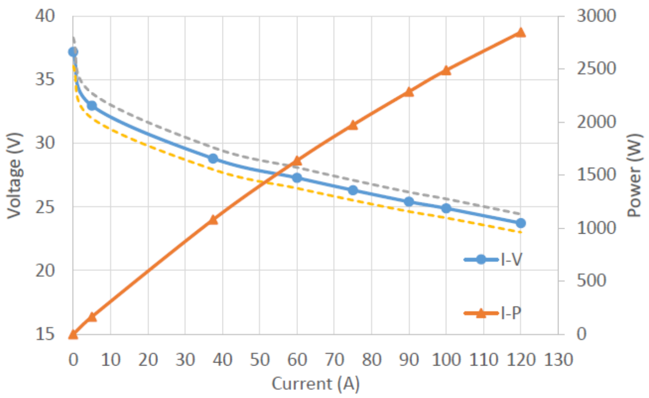

Fig. 3 DuraPEM W240 fuel cell stack steady state I-V and I-P characteristics

The second part is dc-dc boost converter. It consists of an inductance, an IGBT, a power diode, and a capacitor. The converter is in continues conduction mode (CCM) and increases the fuel cell output voltage into desired level. Thus, the inductance value 'L' is determined as 4mH and the capacitor value 'C' is determined as 470uF.

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

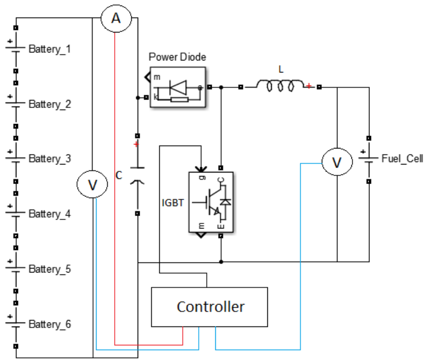

Fig. 4 Battery charging system configuration

The last part is the controller. The power system is controlled by Arduino ATmega16U2 microcontroller. This controls the dc-dc boost converter switching. The controller receives the current information from the output terminal and voltage information from the both terminal points of the dc-dc boost converter. This information processed by controller and created a Pulse Width Modulation (PWM) signal to IGBT which is located in the dc-dc boost converter.

The charging process is limited by the charging current with 8A and the charging voltage with 82V. These are main limits for the secure charging and can be altered by the user.

Electric vehicle uses the battery-block as a first energy source. Therefore, battery block should be charged all the time or at least when the vehicle is OFF. This study focused on only charging the battery block when the vehicle is OFF as seen on Figure 4.

III. Results

The experimental application of the circuit is seen on Figure 5 and the setup is performed in Afyon Kocatepe University Renewable Energy Lab.

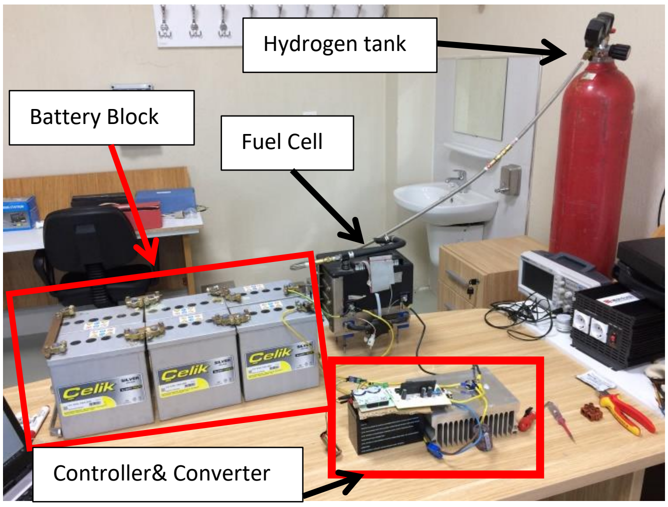

Fig. 5 Experimental charging system

At the beginning of the experiment, it is verified that batteries are fully discharged. Then, hydrogen gas starts to flow into the fuel cell and it generates electricity. At the same time, the output of the fuel cell is measured by controller. When the voltage is more than 24V, the boost converter starts to run. The output voltage of the converter depends on the duty cycle of the IGBT and it changes by controller to regulate the output voltage. The duty cycle can be any value between 0 and 255. It starts from 0 and increases 1 by 1. Each addition of duty cycle increases the output voltage of the converter. There is not any current in both directions until the converter voltage is higher than battery block voltage. After this point, the charging current flows into the battery block. The converter voltage continues to increase and also the current increases. This will rise up to 8A. When the current reaches 8A, the duty cycle of the converter is regulated by controller. Meantime, controller measures the output current and does not let exceed the predetermined value.

This procedure ends whenever the no-load voltage is equal 82V and current decreases to very low level which is 100% charged. The effective charging time is 4 hours. But this time can be shorter when we increase the charging current limit.

IV. Discussion

The study is focused on charging the batteries. The setup cannot be run more than 4 hours due to time restriction. This study should also be repeated with Li-ion batteries and compare these two kind of batteries.

V. CONCLUSION

As a result of the study, batteries are successfully charged by Fuel-Cell and experimental results prove the robustness of control algorithm.

This charging circuit gives a solution when there is not any charging station around because charging stations for electric vehicles are not common in most countries including Turkey. Furthermore, this charging system is very important on power system quality because the electric vehicle is separated from the power grid. Thus, the system quality standards are not affected by millions of vehicles.

The charging circuit gives another solution for air pollution. The exhaust of the circuit is only water, hydrogen, and oxygen. Comparing the fossil fuel generators, this is the cleanest one.

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REFERENCES

[1] W. Guoliang, X. Bingliang, Y. Haiyang, D. Erjia, "Power quality analysis and harmonic suppression of high latitude and high alpine region electric vehicles charging station", *2013 World Electric Vehicle Symposium and Exhibition (EVS27)*,p. 1-5

[2] YunWang, Ken S.Chen, Jeffrey Mishler, Sung Chan Cho, Xavier Cordobes Adroher," A review of polymer electrolyte membrane fuel cells: Technology, applications, and needs on fundamental research", *Applied Energy,* vol.88, no.4,pp.981-1007, Apr. 2011

[3] Kunusch C., Puleston P., Mayosky M., *PEM Fuel Cell Systems. In: Sliding-Mode Control of PEM Fuel Cells. Advances in Industrial Control*. London, England: Springer, 2012.

[4] M. Dürr, A.Cruden, S. Gair, and J.R.McDonald," Dynamic model of a lead acid battery for use in a domestic fuel cell system", *Journal of Power Sources,* vol.161, no.2, pp.1400-1411,Oct. 2006

[5] J. B. Olson and E. D. Sexton, "Operation of lead–acid batteries for HEV applications*," in Proc. 15th Battery Conf. Appl. Adv.*, pp. 205–210. Jan. 2000

[6] *DuraPEM W240*, APFCT,Taiwan