

Realization of an Electronic Load for Testing Low Power PEM Fuel Cells

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Abstract—A realized electronic load system intended for testing and characterization of hydrogen fuel cells is described. The system is based on microcontroller PIC16F877 by applying the concept of virtual instrumentation. The accomplished accuracy of the developed electronic system allows performing efficiently investigations of the electro-chemical phenomena involved in the process of designing hydrogen fuel cells.

Index Terms—Programmable current source, microcontroller, fuel cell.

I. INTRODUCTION

Hydrogen is an almost ideal medium for energy conservation and potentially it could be a part of the basis for further development of the present day civilization. The ever increasing demand for energy is an incentive for investing additional efforts in developing the production methods, storage systems, as well as the methods of releasing the stored energy of hydrogen and its conversion to electricity or heat. Fuel cells are used for obtaining electrical energy from hydrogen [1]. At present, depending on particular application, several types of fuel cells are in use: Proton Exchange Membrane Fuel Cells (PEMFC), Solid Oxide Fuel Cells (SOFC), Alkaline Fuel Cells (AFC), Direct Methanol Fuel Cells (DMFC), Metal hydride Fuel Cells (MHFC), etc.

For the purpose of characterization of fuel cells, investigation, and understanding of the phenomena involved, different methods and specific electro-chemical instrumentation are used. A most frequent instrument used for characterization of current-voltage characteristics of fuel cells is electronic load [2]. In essence, electronic load is a programmable current source fed by a chemical power source, a fuel cell in this case. The main requirement concerns measurement of the cell voltage while its current is modulated by the programmable current source. In this way, one obtains the current-voltage characteristic which contains numerous data as regards electro-chemical processes involved in a fuel cell.

II. BASIC ELEMENTS OF AN ELECTRONIC LOAD

An electronic load consists of two main parts: master application of a virtual instrument [3] on a PC and microcontroller system accompanied by a programmable

current source. Block diagram of an electronic load is shown in Fig. 1.

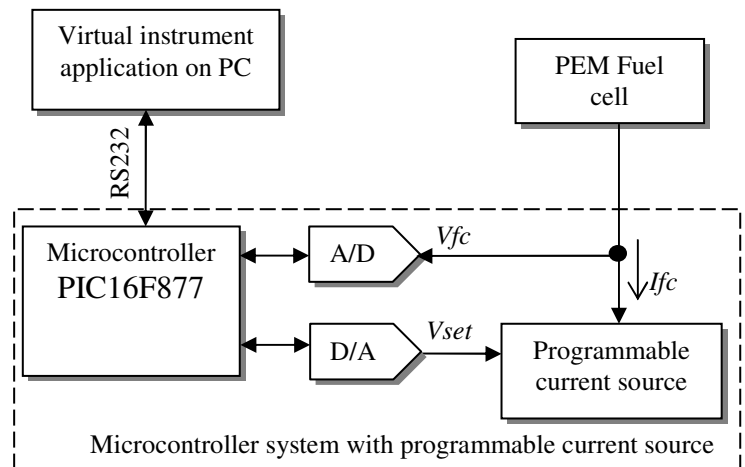


Fig. 1 Block diagram of electronic load.

The microcontroller system consists of an 8-bit PIC16F877 microcontroller [4], a 12-bit A/D converter MCP3204 together with an input circuit, a 12-bit D/A converter MCP4921 together with an adaptation circuit, and a programmable current source. Essentially, the microcontroller system is designed as a slave instrument fully controlled by the master virtual instrument application. The task of the microcontroller system is to load the examined fuel cell by the current which is defined by the master PC application and then to measure voltage across the fuel cell. The master-slave data exchange is realized a series RS232 channel. The communication protocol is very simple. The master application sends two bytes carrying information on the 12-bit value of the required current, and the slave microcontroller system returns four bytes, two repeating the required current value (confirmation of the received message) and two carrying 12-bit value of the voltage measured across the cell.

The programmable current source is realized according to the block diagram shown in Fig. 2. Basically, the source consists of the high power MOSFET BUZ11A and operational amplifier LM4250. The programmable current source is controlled by the control voltage V_{set} . Resistor R_{set} defines the maximum current of the source. In order to accomplish an improved measurement of IU characteristic of fuel cells, it is required that the value of R_{set} is as low as possible which would reduce its influence on measurement of the cell voltage at short circuit (diffusion region).

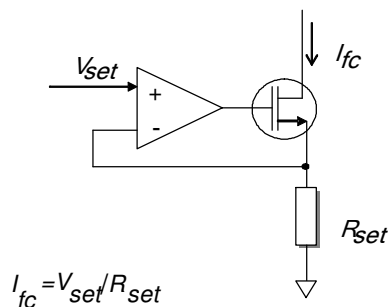


Fig. 2 Block diagram of the programmable current source.

The developed electronic load is intended for testing fuel cells, either mono-blocks or stacks up to 5 cells, thus for the purpose of input circuit protection, the voltage range is limited to 10V.

III. MASTER APPLICATION OF A VIRTUAL INSTRUMENT

The main task of the master application of a virtual instrument is control of the microcontroller system of the electronic load. In the process of the IU characterization of a fuel cell, several different measurements have to be carried out: measurement of the IU characteristic by varying a range of currents from I_{min} to I_{max} within a predefined number of measuring points, measurement of the IU characteristic during a long term load of the fuel cell by a load current I_{const} , and measurement of the IU characteristic during a long term load of the fuel cell by a constant voltage V_{const} .

Measurements of the IU characteristic by varying the value of current over a range from I_{min} to I_{max} , within a predefined number of measurement points, is realized by an open loop control algorithm. The master application of a virtual instrument determines the value of current of the microcontroller system by the RS232 serial interface. Variation of the current is updated each 0.5s within the range from I_{min} to I_{max} . The voltage measured across the fuel cell, together with the value of the preassigned current, are stored in a separate file for further analysis. On the basis of the obtained IU characteristic, the current-power (IP) characteristic is formed. This type of measurement serves for determination of the three regions of fuel cell operation: activation, ohmic, and diffusion regions which is significant for defining operating regime of a fuel cell.

For measurement of IU characteristic of a fuel cell during a long-term loading by a constant current I_{const} , the virtual instrument application is also realized by an open loop control algorithm. The master application defines the value of current I_{const} and passes it to the microcontroller system. The master application also determines the length of time of the fuel cell voltage measurement. This measurement serves for testing stability of the fuel cell and of its constituents: electrodes, membrane, catalyst, and activator.

For measurement of IU characteristic of a fuel cell during a long-term loading by a constant voltage V_{const} , the virtual instrument application is realized by a proportional control algorithm. The feedback is closed in the master application in order to avoid change of the microcontroller system and software of the slave. Each 0.1s the master application takes measurement of the voltage across the fuel cell, makes a

comparison with the pre-assigned voltage V_{const} , and modifies current I_{fc} in order to ensure the pre-assigned voltage across the cell. Since the speed of control is not specified, the algorithm of proportional control is applied.

IV. THE REALIZED ELECTRONIC LOAD

The microcontroller system of the electronic load is based on PIC16F877 microcontroller made by Microchip, while the corresponding software has been developed by using the development tools EASYPIC5 and MicroC Pro made by Mikroelektronika [5,6]. The realized hardware has been optimized for a series production with the aim of offering this product as a part of the experimental set intended for education in the area of application of hydrogen for energy conservation.

The master application of virtual instrument has been realized by using software package made by National Instruments CVI. The realized application consists of three parts: IU characterization of fuel cells within current range from I_{min} to I_{max} called EASY eLOAD, IU characterization of fuel cells long-term loaded by a constant current I_{const} called EASY eGalvanostat, and IU characterization of fuel cells long-term loaded by a constant voltage V_{const} called EASY eVoltstat.

The obtained characteristics of the electronic load have been examined by measuring a set current I_{fc} and by making a comparison of the voltage V_{fc} measured across the fuel cell by the microcontroller system and by a reference voltmeter. Fig. 3 shows block diagram of the system for measurement of the electronic load characteristics.

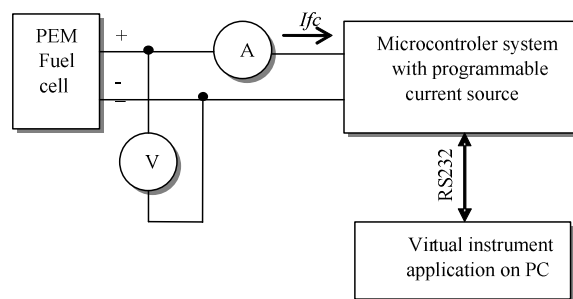


Fig. 3 Block diagram of the system for measurement of the electronic load characteristics.

The reference measurements of the current I_{fc} and voltage V_{fc} , which control operation of the electronic load, have been made by a Hp3457A multi-meter.

A PEM fuel cell has been tested. The Membrane Electrode Assembly (MEA) consists of two electrodes made of carbon paper having a thin layer of the catalyst deposited on the paper surface (0.2mg/cm² of Pt), Nafion 117 membrane, and all pressed to make a compact whole.

Fig. 4 shows a photograph of the measurement system associated with the electronic load developed for testing the characteristics of PEM fuel cells during the process of verification of the properties of the electronic load by reference measurements.

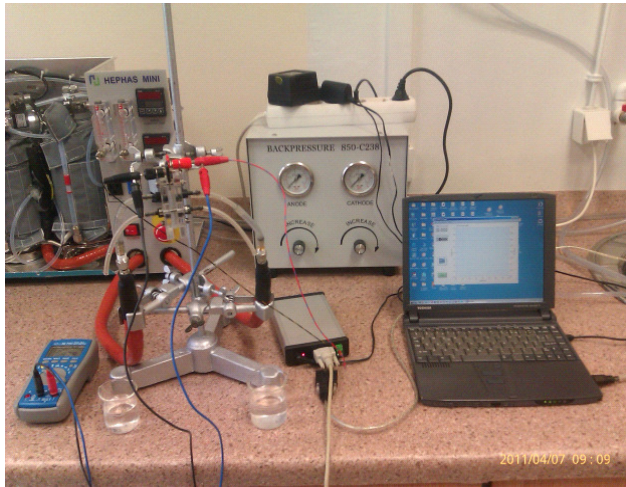


Fig. 4 Measurement system of the electronic load in the process of testing PEM fuel cells.

Fig. 5 shows the application of the virtual instrument during measurements of a PEM fuel cell intended for verification of the electronic load properties

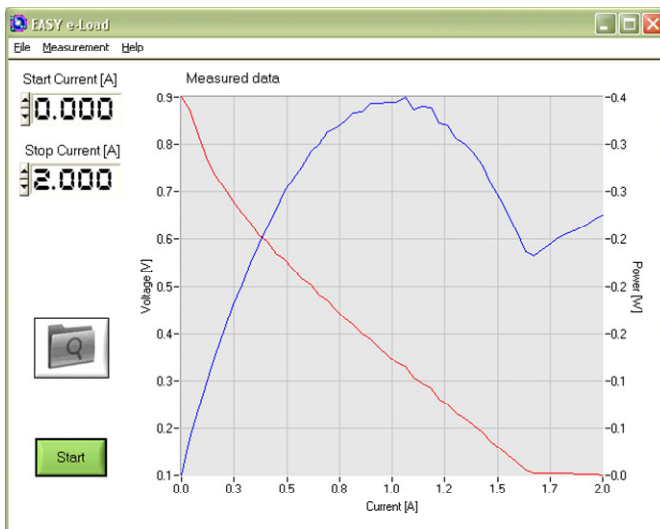


Fig. 5 Application of the virtual instrument of the electronic load.

The obtained measurement results are presented in Table 1. The table shows values of the pre-assigned current I_{set} , the set current I_{fc} measured by the electronic load, the voltage across fuel cell V_{fc} measured by the electronic load, the power P_{fc} measured by the electronic load, the set current I_{ref} measured by the reference meter, the voltage across fuel cell V_{ref}

measured by the reference meter, and the power P_{ref} measured by the reference meter.

TABLE I
RESULTS OF THE MEASUREMENTS OF THE CURRENT, VOLTAGE, AND POWER OF THE ELECTRONIC LOAD OF A PEM FUEL CELL

I_{set}	I_{fc}	V_{fc}	P_{fc}	I_{ref}	V_{ref}	P_{ref}
0,2	0,2343	0,688	0,1612	0,2338	0,6912	0,1616
0,4	0,4296	0,585	0,2513	0,4288	0,5906	0,2532
0,6	0,625	0,504	0,315	0,618	0,5055	0,3124
0,8	0,8203	0,426	0,3494	0,818	0,4289	0,3508
1	1,0156	0,353	0,3585	1,0087	0,3548	0,3579
1,2	1,2109	0,281	0,3402	1,2058	0,2841	0,3426
1,4	1,4062	0,216	0,3037	1,402	0,2202	0,3087
1,6	1,6015	0,143	0,229	1,5989	0,1436	0,2296
1,8	1,7968	0,136	0,2443	1,792	0,1388	0,2487
2	1,9983	0,133	0,2657	1,9922	0,1345	0,2680

On the basis of the presented results one may conclude that the electronic load shows satisfactory characteristics of the set current I_{fc} and measured voltage V_{fc} , therefore it can be used for testing of fuel cells and their constituent parts.

V. CONCLUSION

The realized system of electronic load intended for testing and characterization of fuel cells is based on a microcontroller system and the concept virtual instrument and represents a modern engineering design meeting the requirements for accuracy of the set current and measured voltage across a fuel cell. The electronic load system allows a better insight in electro-chemical processes in a fuel cell and facilitates investigations in this area.

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