Maximum Load Behaviour of a Fuel Cell Stack under Different Ambient Temperatures

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Abstract

We studied the full load behavior of a proton exchange membrane fuel-cell(PEMFC) stack at under different ambient temperatures. We switched a load to the FC system and observed the system parameters as FC temperature, current and voltage under two different ambient temperature. We extracted to ambient temperature effects on the power transferred to load. We also investigated the effect of hydrogen tube temperature and hydrogen tube pressure relation on FC system.

1. Introduction

Fuel-cells generate electrical power guietly and efficiently without pollution. Aims to develop hydrogen fuel cell technologies to make fuel cell vehicles will be practical and cost effective in the future. A lot of countries have dedicated billion dollars to fuel cell research and devolopment so far[1-2].

Fuel cells are static energy conversion devices that convert the chemical energy of fuel into the electrical energy directly. They have many advantages over the conventional power plants, including having high efficiency and modular structure, and being scalable and environmentally friendly. The proton exchange membrane fuel cell has been considered as a promising kind of fuel cell during the last 15 years because of its low working temperature, compactness, and easy and safe operational modes. PEMFC is very simple and uses a polymer based membrane as the solid electrolyte and a platinum catalyst. Electric vehicles are one of the major applications of PEM fuel cells. The increased desire for vehicles with less CO_2 emission has made PEM fuel cells as an attractive option for vehicular applications due to their zero-emission property, high power density and quick start[3-8].

The schematic representation of a PEMFC is shown in Figure 1. A PEMFC depends primarily on a modified polymer membrane, coated with highly dispersed catalyst particles[9].

The electrochemical equations are given by:
At Anode: H2 → 2 H+ + 2e-
At Cathode: 2 H+ + 2e- + ½ O2 → H2 O + heat
Overall reaction: H2+ ½ O2 → H2 O + heat
Where: first equation determines amount of hydrogen needed to be fed to anode to meet a load, second equation determines amount of oxygen needed to cathode to maintain reaction, while the third equation determines water produced[9].

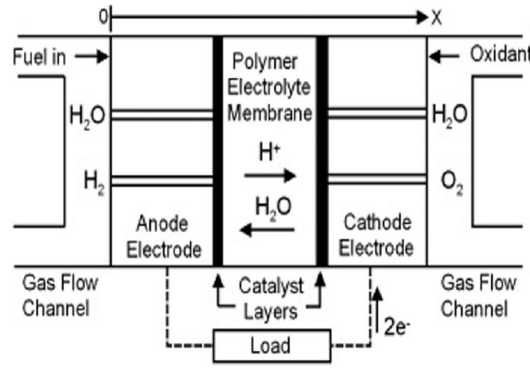

Fig.1. Schematic representation of PEMFC[7]

PEM fuel cells are good energy sources to provide reliable power at steady state, but they cannot respond to electrical load transients as fast as desired. This is mainly due to their slow internal electrochemical and thermodynamic responses. The transient behavior of PEM fuel cells needed to be studied and analyzed under different conditions, such as electrical faults on the fuel-cell terminals, motor starting, electric vehicle starting and acceleration[3].

A fuel cell stack is composed of several fuel cells connected in series separated by bipolar plates and provides fairly large power at higher voltage and current levels[4].

In this work, we studied the ambient temperature induced failure conditions of Nexa 1200 PEMFC which is used for the Hidromobile of İstanbul University Electrical&Electronics Dept.. We investigated the fuel cell performance at 20^oC and 30^oC ambient temperatures under maximum load conditions. The FC optimally operates around 60^oC[10] and we aimed the determine the ambient temperature effects on the FC operating temperature. We also aimed to determine the FC operating temperatures effects on the system parameters as FC voltage, FC current and delivered power in the system. We made an electrical load by using resistors. We switched the load as fast as possible to the system. We also investigated the effect of hydrogen tube temperature on the fuel cell performance.

2. Material and Method

In this study, experiments are conducted with Heliocentris Ballard Nexa 1200 fuel cell module. The FC module's maximum output power 1200W, maximum output current 60A and output voltage between 20-36 VDC. It is an air cooled module. It' s weight is 22 kg and has 47 serial cells. Cell area is 120 cm^2. The membranes are Nafion 117 membrane with 122 µm thickness[10].

We composed a test circuit including Nexa 1200 fuel cell. The schematic representation of test circuit given in Figure 2. The electrical loads composed of five pieces of 10 Ω 300 W rated resistors are connected in parallel via mechanical on/off switches. All resistors are mounted on an aluminum plate and a cooling fan is used in order to prevent the resistor overheating.

In our tests, we started the FC and switched the full load as fast as possible to the system. We observed the system parameters during a while by computer programme. We performed our tests under two different ambient temperatures around 20^{o}C and around 30^{o}C, respectively. We investigated FC temperature, FC current, FC voltage, system current and produced-wasted powers as system parameters.

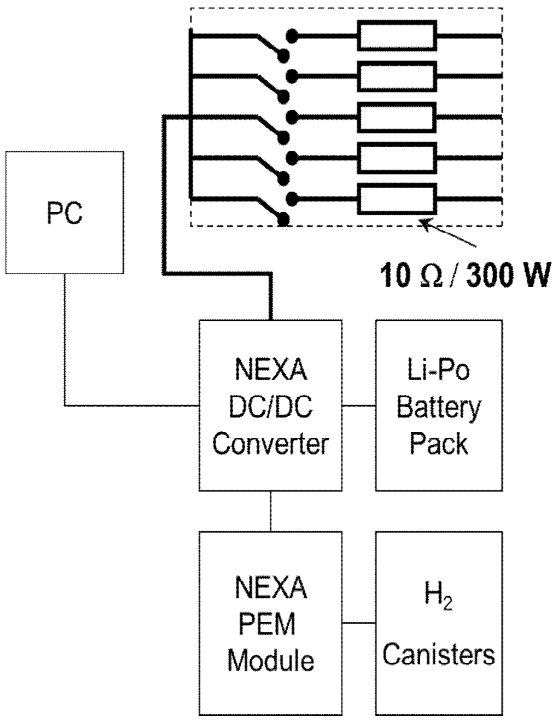

Fig.2. Schematic representation of test circuit

We used metal hydride canisters as hydrogen tank. Metal hydride canisters utilize metal hydride technology to safely store hydrogen in a compact manner at low pressure[11].

3. Experimental Results

We presented the FC temperature change for different ambient temperature. In Figure 3, ambient temperature around 20^{o}C(blue line-1) is our first test condition(test#1). In this condition, the FC temperature is around 58^{o}C(red line-3). The ambient temperature around 30^{o}C(purple line-2) is our second test condition(test#2). In this condition, the FC temperature is around 60^{o}C(dark blue line-3). There is a temperature difference of 10^{o}C between ambient temperatures; however, FC changes ıts operating temperature only 2^{o}C.

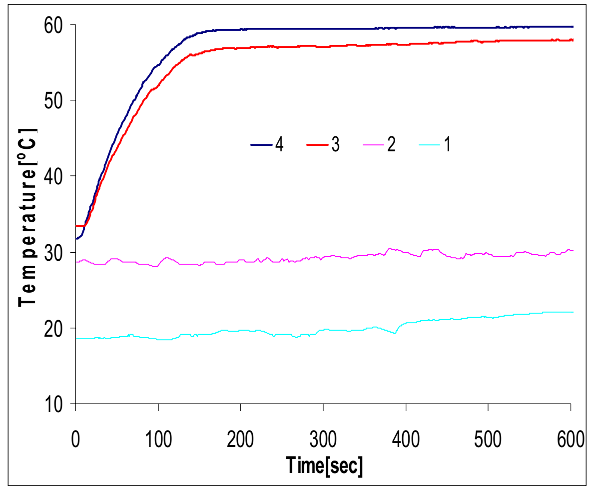

Fig. 3. FC temperatures and ambient temperatures

The FC uses its internal fan to set the initial temperature at a safe level. We also investigated the system current to analyze the current that is consumed by the FC, at different ambient conditions. As shown in Figure 4, the current consumed by the FC system is increased at higher ambient temperature. Inrush current of internal fan causes distinct peaks in FC system current. As ambient temperature increases, internal fan rotates much faster and power consumed by fan, and thus, system current increases approximately 2A.

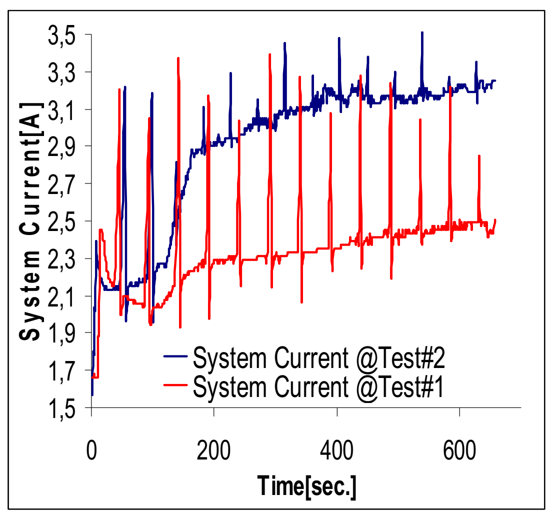

Fig. 4. FC system current change under different ambient temperatures

We also examined the FC output current and voltage at different ambient temperatures. In Figure 5, change of output voltage with respect to time at electrical load is switched. It is seen that output voltage decreases with the increasing ambient temperature. In Figure 5, there is also a minimal pick point for both ambient temperatures that is occurred caused by sudden switching of load. This minimal pick can cause the system shut down because of safe operating conditions of PEMFC stack.

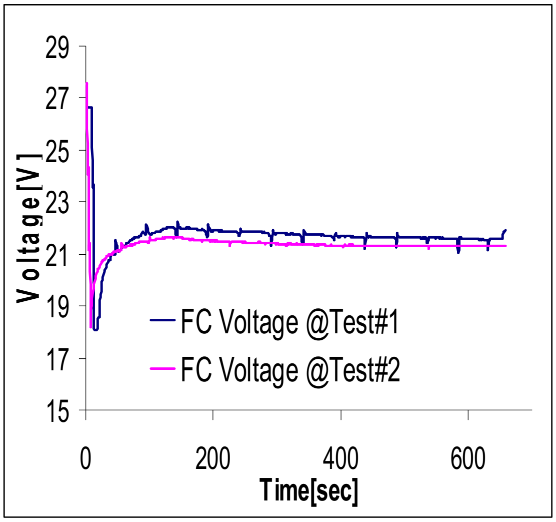

Fig. 5. FC output voltage change under different ambient temperatures

In Figure 6, change of output current with respect to time is given. The output current increases with the increasing ambient temperature approximately 5A. There is a transient pick point for test#1 condition. It is occurred in the case of sudden load switching as voltage change. The transient pick point is also occurred for first test#2 condition, however, its maximum value exceed the maximum current limit of FC and causes the system shutdown. To avoid the system shutdown, we limited the maximum current of FC for test#2, repeat the test and get the given results.

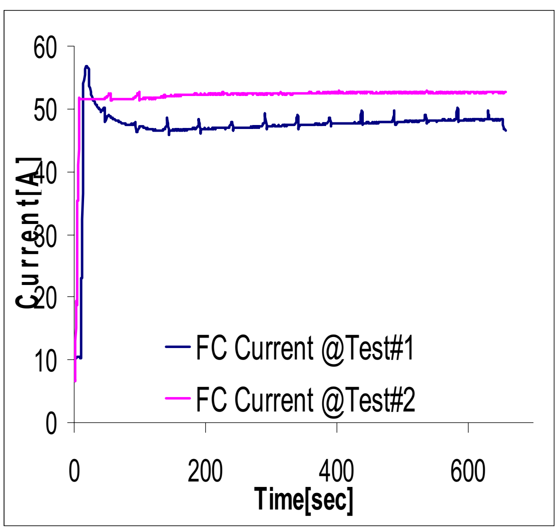

Fig. 6. FC output current under different ambient temperatures

If we consider the Figure 4 and Figure 6, the increasing ambient temperature causes an increase in both system current and FC current. The system current is wasted by the system but totally, FC current increases much more than the system current and the current transferred to load increases.

We investigated the FC output power under different ambient temperatures. In Figure 7, it is seen that the ambient temperature causes an increase at FC produced power(P_{FC}).

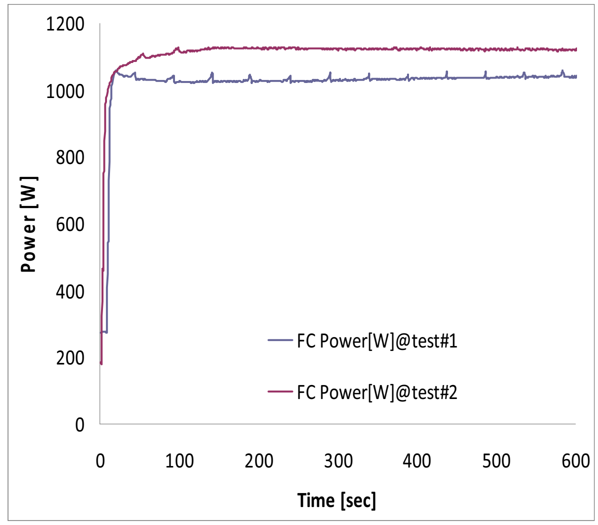

Fig. 7. FC produced power under different ambient temperatures

In Figure 8, the wasted power is presented. The wasted power(P_{WASTED}) is spent by the FC stack and can not be transferred to load. The ambient temperature causes also an increase at the wasted power.

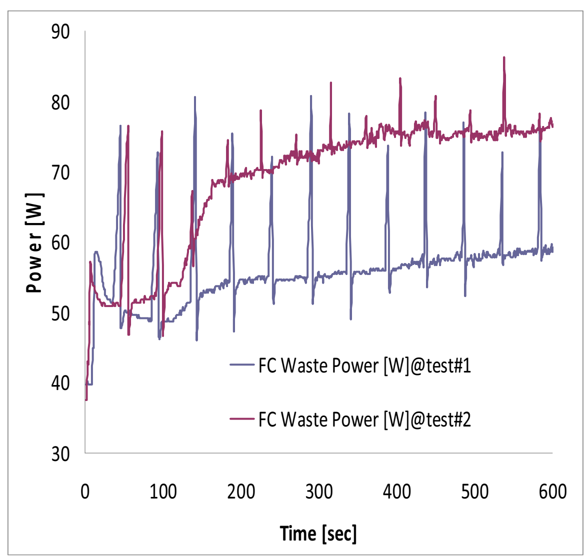

Fig. 8. FC wasted power under different ambient temperatures

We calculated the net power(P_{NET}), that is transferred to load using Equation (1),

$$P_{NET}=P_{FC}-P_{WASTED} \qquad (1)$$

The net power transferred to load is seen in Figure 9. The ambient temperature causes an increase at the net power.

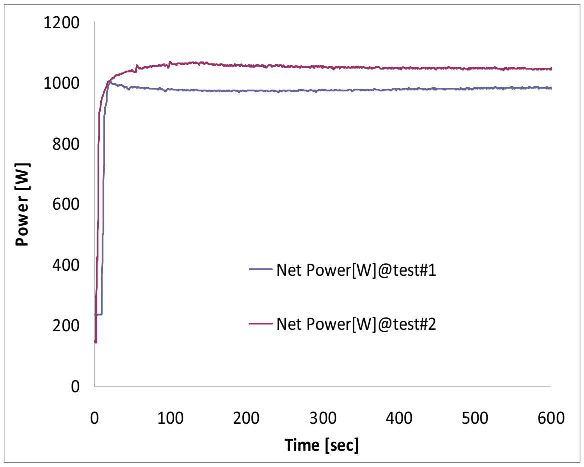

Fig. 9. FC net power under different ambient temperatures

Low hydrogen pressure approximately 1 bar cause the system shut down[10]. We also examined the relation between hydrogen tube pressure and tube temperature. A thermal camera (Fluke Ti35) is used to take temperatures and thermal images during the tests (Figure 10). Pressure values are obtained using the computer programme.

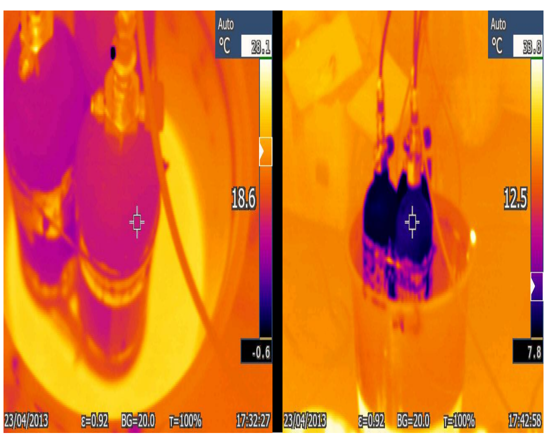

Fig. 10. Hydrogen tube temperatures thermal images

In Figure 11, it is seen that, when the tube temperature goes down to the 12°C, the hydrogen pressure decreases to 1 bar and it causes the system shut down. The lower temperatures are improper for hydrogen tubes. Because, it decreases the tube pressure and causes the system shut down.

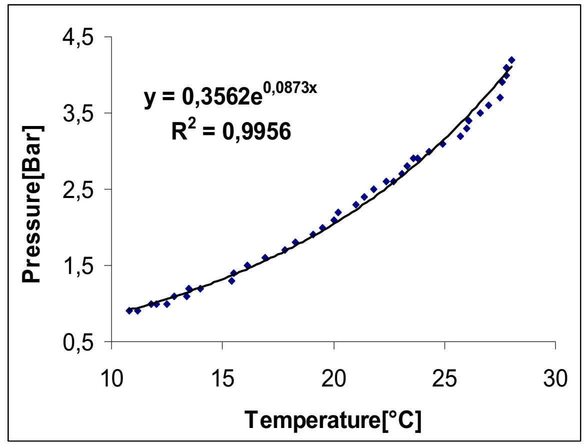

Fig. 11. Hydrogen tube temperature and pressure relation

The tube temperature and tube pressure relation can be given in Equation (2).

$$P_{TUBE}=0{,}3562xe^{0{,}0873T} \qquad (2)$$

Where, P_{TUBE} is the tube pressure and T is the temperature in Celcius.

4. Conlusion

In this work, we investigated the full load behavior of a proton exchange membrane fuel-cell stack under two different ambient temperatures around 20°C and 30°C. When the ambient temperature changes 10°C, FC changes its operating temperature only 2°C. This FC temperature change causes output voltage decrease, the output current increase. Increasing current can be exceeded the maximum current limit and cause system shut down. The system current that is wasted by the FC system also increases with the ambient temperature to keep constant the FC temperature. The wasted power increases with the ambient temperature but the net power that is transferred to load also increases with the increasing ambient temperature. The hydrogen tube temperature is also considered for preventing system shut down.

5. References

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