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Department of Electrical Power Engineering
Wrocław University of Science and Technology
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland
phone: +48 71 320 35 41
www: http://www.weny.pwr.edu.pl/instytuty,52.dhtml; http://www.psc.pwr.edu.pl
e-mail: wydz.elektryczny@pwr.edu.pl

OFICYNA WYDAWNICZA POLITECHNIKI WROCŁAWSKIEJ
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław
http://www.oficyna.pwr.edu.pl
e-mail: oficwyd@pwr.edu.pl
zamawianie.ksiazek@pwr.edu.pl

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CONTENTS

Proton Exchange Membrane (PEM) Fuel Cell,
DC/DC boost converter, Distributed Generation (DG),
polarization curve, efficiency

Sunny KATYARA*, Jan IŻYKOWSKI**,
Łukasz STASZEWSKI**, Fawad SHAIKH*

TECHNICAL AND ECONOMICAL EVALUATION OF PROTON EXCHANGE MEMBRANE (PEM) FUEL CELL FOR COMMERCIAL APPLICATIONS

The green energy sources are the utmost needs of today's world where the reserves of fossil fuel are depleting day by day. The Distributed Generation (DG) has become integral part of power system at commercial level. The most efficient among all DGs and Renewable Energy Sources (RES) is the Fuel Cell (FC) power generation. The fuel cell invariably converts chemical energy directly into electricity. The Fuel cells have normally 60 to 70% efficiency at working conditions. The polarization curve of fuel cell plays important role in improving its efficiency.

This research presents the mathematical and Simulink modeling 6 kW, 45 V_{dc} of Proton Exchange Membrane (PEM) fuel cell. The input thermodynamic parameters of fuel cell are varied and their effects on the output electrical variable are observed. The DC/DC boost converter is used to step up the voltage of fuel cell to 100 V_{dc} at commercial usable level. A new mathematical equation is presented to improve the efficiency of fuel. The mathematical results are then varied through Simulink results.

1. INTRODUCTION

The fuel cell is an electromechanical device which transforms the chemical energy into electricity. Due to its higher efficiency, fuel cell is widely being accepted for power generation as compared to electromechanical devices. The fuel cell does not involve any intermediate link between the conversion processes [1]. However the growing issues of global warming has resulted in the alarming situation for the world

* Electrical Engineering, Sukkur IBA University, Pakistan, e-mail: sunny.katyara@iba-suk.edu.pk, mfawad.be14@iba-suk.edu.pk

** Department of Electrical Power Engineering, Wrocław University of Science and Technology, Poland, e-mail: jan.izykowski@pwr.edu.pl, lukasz.staszewski@pwr.edu.pl

to use clean energy sources for power generation [2]. The fuel cell generation is free from CO_2 emissions.

Figure 1 shows the basic construction and working of fuel cell. Basically a fuel has three adjacent segments:

a.Anode;

b.Cathode;

c.Electrolyte.

The fuel used in cell is the hydrogen gas, which is being supplied to the anode. At anode the catalyst oxidizes the hydrogen into positive ion (H^+) with release of electron. The electrolyte is the substance especially designed so that ions can pass through it but electrons cannot. The free electrons then pass through load thus creating electricity. The positively charged hydrogen ion (H^+)

The Proton Exchange Membrane (PEM) fuel cell is the most commonly used fuel cell for commercial applications due to its best voltage and current characteristics. It is small in size, weighs low and has least corrosion. The PEM fuel cell operates at temperature range between 35 °C to 100 °C. Its transient response is quick as compared to Solid Oxide fuel cell which works at temperature above 700 °C.

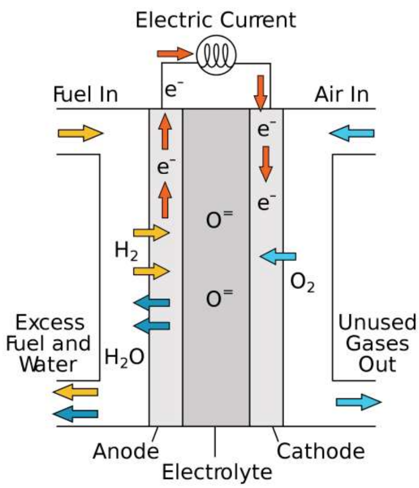

Fig. 1. Proton Exchange Membrane (PEM) Fuel Cell

In this area, the work has been done to certain extent. Aziz et. al (2011) analyzed the working performance of 3.757 kW PEM fuel cell at load current of 261.4 A. The cell was investigated under the transient as well as under steady states. Outeiro et. al (2011) developed the Simulink model of PEM fuel cell and evaluated the optimization of cell using Simulated Annealing (SA) algorithm. The design specifications of DC/DC converter were also considered for boost up process at commercial level. Ibrahim et. al (2015) deduced the new mathematical model for investigating the characteristics of PEM fuel cell. The input parameters to the model were thermodynamic and outputs were electrical. Wee et al (2006) applied PEM fuel cell in the real time applications such as automotive vehicles. He also enumerated the working merits of fuel cell technology for energy production.

This research work develops an electrochemical model of PEM fuel cell based on ballard group to simulate and analyze the transient response of cell voltage, flow rates of hydrogen and oxygen, temperature of fuel cell and pressure at anode and cathode under sudden changes in the load current of PEM fuel cell. The MATLAB model of PEM fuel cell helps to estimate the maximum power produced by the cell and to prevent cell from excessive heat, thereby notifying the temperature limits.

2. RESEARCH METHODOLOGY

A. Mathematical Model

The mathematical model for PEM fuel cell is shown in Fig. 1. The model is used to analyze the static and dynamic characteristics of PEM fuel cell.

According to Kirchhoff's voltage law, the output voltage of single PEM fuel cell can be found by Eq. (1)

$$V_F = E_{NL} - V_{RA} - V_{RC} - V_{RO} \qquad (1)$$

where:

V_F – output fuel cell voltage,
E_{NL} – no load voltage of fuel cell,
V_{RA} – voltage drop due to activation loss,
V_{RC} – voltage drop due to concentration loss,
V_{R0} – voltage drop due to ohmic loss.

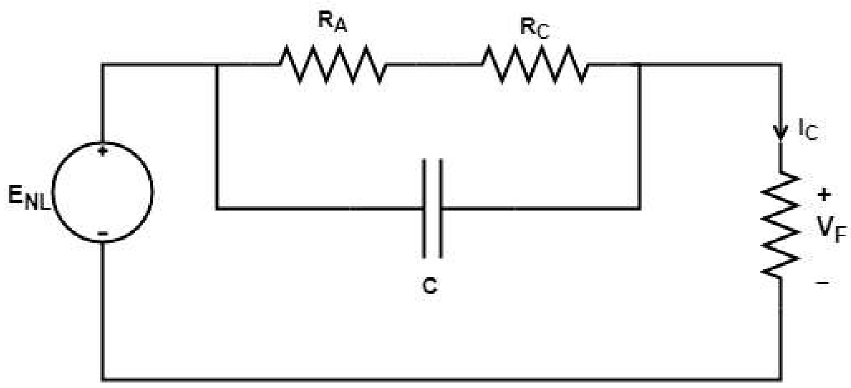

Fig. 1. Simplified electrochemical model of PEM fuel cell

The no load voltage of fuel cell defines its reversible voltage and is given by Eq. (2)

$$E_{NL} = 1.23 - 8.5 \times 10^{-3} \times (T - 298) + 4.31 \times 10^{-5} \times \left[\ln(P_1) + \frac{1}{2}(P_2) \right] \tag{2}$$

where:

P_1 – partial pressure of hydrogen,

P_2 – partial pressure of oxygen,

T – temperature of cell.

The voltage drop due to activation loss is given by the Eq. (3)

$$V_{RA} = -[\ell_1 + \ell_2 \times T + \ell 3 \times T \times \ln(\mathrm{CO}_2)] \tag{3}$$

2. RESULTS AND DISCUSSION

Figure 1 shows the complete model of fuel cell stack that produce 6 kW and 45 V DC. The DC to DC Boost converter regulates the voltage up to 100 V and it is loaded with RL load to visualize the real time scenario. The simulation was performed to obtain the results of variations in the efficiency of fuel cell when input parameters to fuel cell get changed. Initially for 10 sec, the input to fuel cell was constant but after 10 sec switch changes the position and input parameters started changing such as fuel flow rate changes from 50 lpm (liter per minute) to 85 lpm.

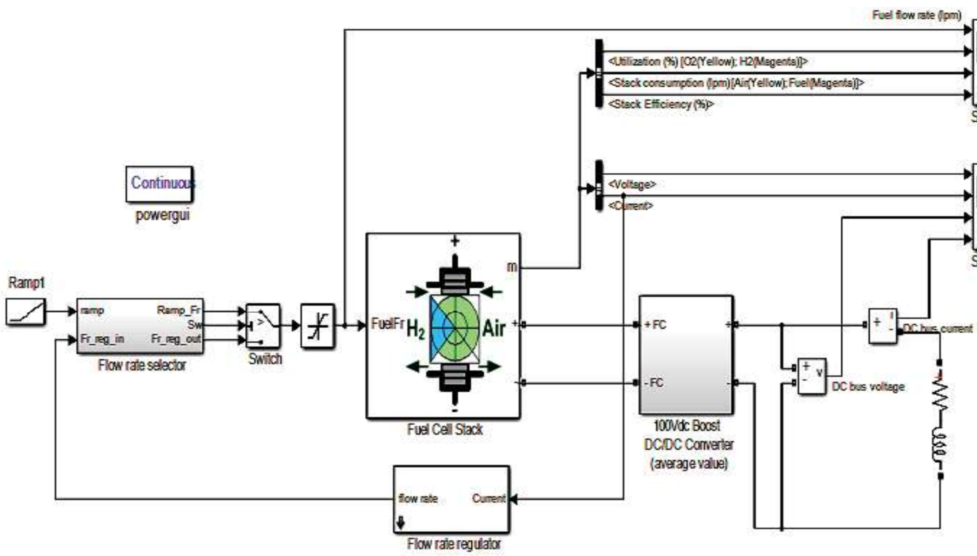

Fig. 2. Simulink model of PEM fuel cell stack

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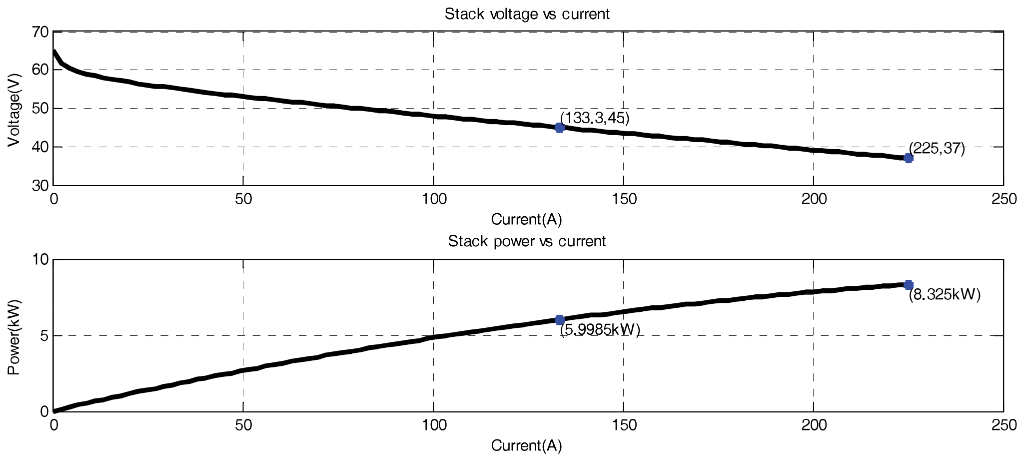

Fig. 2. Polarization curve of fuel cell

Figure 2 shows the polarization curve of fuel cell which indicates variation of its resistance with its charge flows. Due to inverse characteristics of fuel cell, causes increased voltage drop due to increased internal chemical losses. In the first region, which is called activation region, the drop of voltage is due to slowness of chemical reaction at the surface of electrodes. The width of activation region depends upon the temperature and operating pressure in the system and so as the electrode types and catalyst are selected. The second region, which is called ohmic region indicates the resistive losses due to internal resistance materials used in fuel cell stack like; anode,

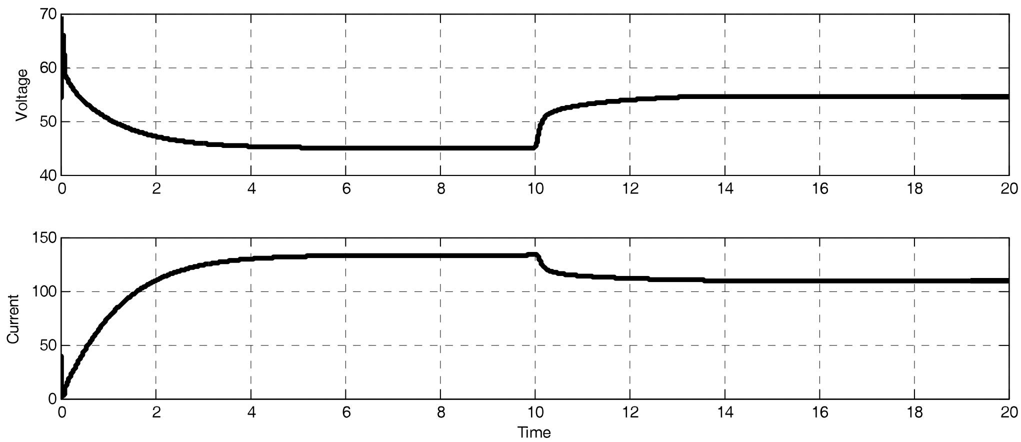

Fig. 3. Fuel cell stack voltage and current

cathode and electrolyte. Finally, the third region is called concentration region, which indicates mass transport losses due to change in concentration of reactants, as the fuel get used up in the stack. Figure 3 shows the output voltage and current of fuel cell.

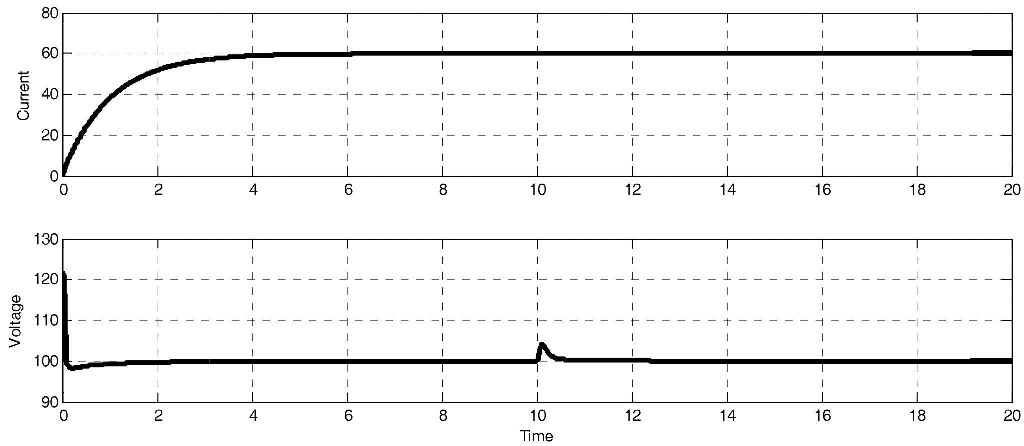

Fig. 4. Voltage and current for DC/DC boost converter

The output voltage of fuel cell is low therefore boost converter is used to step up the DC voltage and also to regulate its output as shown in Fig. 4. Initially at the of start of simulation there is a peak up to 122 volts due to least drop but as inductor opposes change in current and also transfer function interfaced with the pulses of IGBT, makes it stable and voltage remain constant. After 10 sec, the fuel supply is being

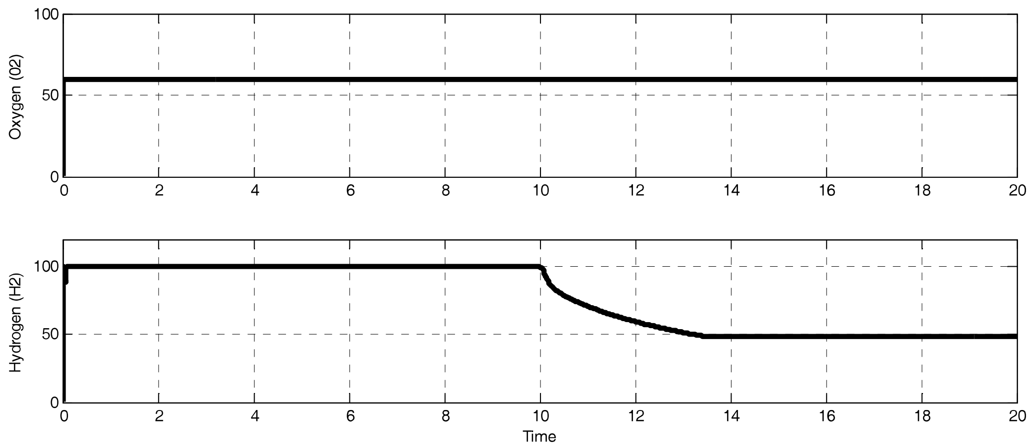

Fig. 5. Utilization of hydrogen and oxygen

increased resulting increase in voltage but regulator makes it stable within 10th sec and voltage at the load.

Figure 5 shows that how much oxygen and hydrogen is being supplied to the stack. Since 99.56% of hydrogen from tank is being supplied to the fuel cell with a constant use of 60% oxygen as shown in Fig. 6. It shows that how much H_2 and O_2 are consumed to give output. As flow rate varies then there should be variations.

The slow reaction in fuel cell gave more voltage so its flow rate increases and its stability reaction decreases. Therefore, due to this consumption of hydrogen, the efficiency of fuel reduces as shown in Fig. 7.

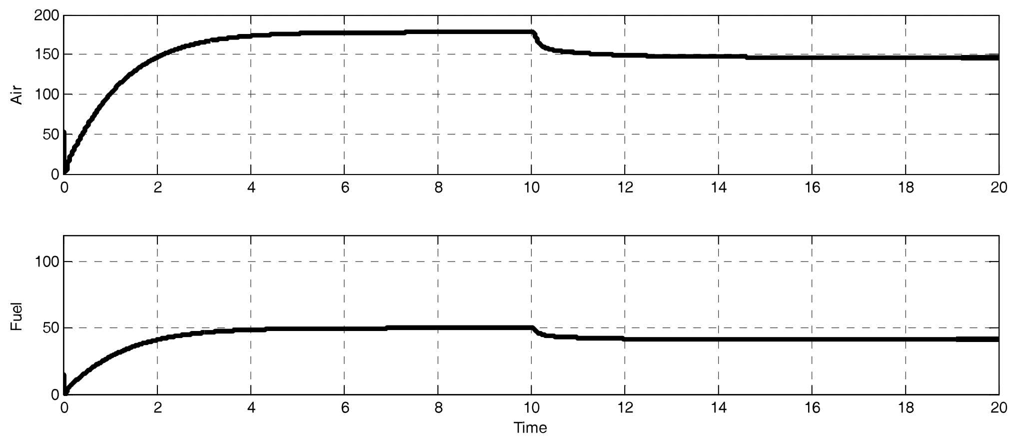

Fig. 6. Fuel stack consumption for air and fuel

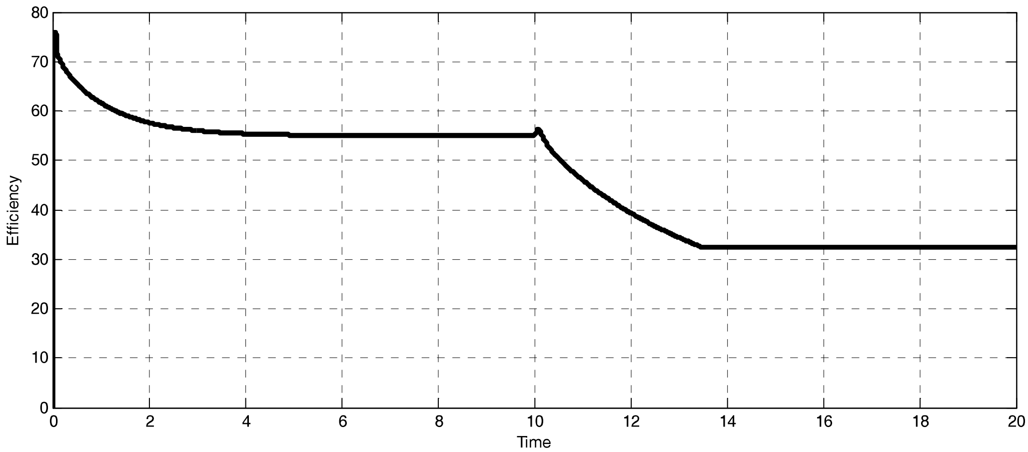

Fig. 7. Fuel cell efficiency

The efficiency of tested PEM cell is 55% but when fuel flow rate is slow, its efficiency reduces up to 32%. When fuel flow rate is slow, the rate of reaction is low and the stack does not get fully activated as shown in Fig, 7. Also, if the rate of fuel is increased, the fuel cell is not capable of utilizing the entire fuel simultaneously resulting input fuel is high and output is low, so overall efficiency is reduced. Therefore, the fuel cell should be operated within the saturation dome of its characteristics, in order to get the maximum efficiency,

3. CONCLUSION

The fossil fuel reserves are depleting day by day and they also badly effect the environment because they are the major cause of CO_2 emission. Renewable source is the best way to overcome from these problems. The renewable resource with the highest efficiency is fuel cell we can get up to 60% to 70% efficiency from the fuel cell. In this paper mathematical model is observed to improve the efficiency of fuel cell and equations are defined to analyze the fuel cell from different aspect this model is capable to analyze the dynamic and static characteristics of PEM Fuel cell. We use MATLAB Simulink to model the PEM fuel cell and vary the different parameter like increase the amount of fuel and then different output parameter are observed such as fuel consumption and utilization, voltage, current and efficiency. We observed that increase the amount of fuel cause the efficiency negatively because fuel cells are defined for particular fuel flow rate, to overcome from this problem fuel flow rate should me with in permissible limits to get the highest efficiency

FUTURE RECOMMENDATIONS

The fuel cell with its portable nature can be used for Army purposes to power the auxiliaries of jets and tanks during the war when national grids are inaccessible. Also, fuel cell with its high efficiency can be used in small scale automobiles to beat the increasing process of fossil fuels. In future, the fuel cell technology will play an important in energy harvesting. It will recycle its own exhaust with pyrolyses, to generate additional energy.

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