Analysis of V-A characteristics of the hybrid photovoltaic system

***Pavel Tošer*[1], *Pavel Abraham*[1], *Petr Bača*[1] *and* *Peter Tauš*[2]**

The Alternative energy sources become more and more important. The Energy of sun is for sure much more appropriate and ecologic source of power than the fossil fuels. This topic cannot be actual more at least in the Czech Republic and Slovakia also where official authorities refuse to allow connection of new the PV power plants to supply network. This is because PV power plant is unstable source of power and prediction of supplied power amount is problematic. This could lead to overload of a grid or even total black out of system. Possible solution is to accumulate electric energy from PV to another form of energy. Possibility of energy stored in hydrogen is presented in this paper.

Key words: *Fuel cell, electrolyser, photovoltaic cell, PEM, energy efficiency, ideal efficiency*

Introduction

Electricity is produced in quite a complicated manner these days. Chemical energy of the fuel that burns (i.e. chemically reacts with oxygen) is transformed to heat. The heat is then transformed into mechanical energy. Efficiency of these transformations is limited on principle. Mechanical energy is then transformed to electrical energy in electric generator. This is why direct transformation of chemical energy of fuel to electrical energy seems to be so interesting.

Basic principles OF the fuel cell with pem membrane

Electrolyte of PEM (Proton Exchange Membrane or Polymer Electrolyte Membrane) fuel cell is made of solid polymer membrane with proton conductivity. These fuel cells operate at the relatively low temperatures about *80°C*. Quick start and long lifetime are most important properties of this technology. The power to weight ratio is also quite good however high cost of *Pt* (platinum) catalysts used at anode is big disadvantage.

Fig. 1 shows principle of such fuel cell. Membrane *100 μm* thin is it's the most important part and protons unlike electrons can freely diffuse through it. On each side of the membrane porous conductive electrodes are placed containing catalyst layer of platinum. Hydrogen is supplied to anode and pure or atmospheric oxygen is supplied to anode. Hydrogen is dissociated and freed protons can diffuse through membrane toward cathode. Cathode starts to gain the positive charge. Equation 1 describes oxidation at anode:

$$2H_2 \rightarrow 4H^+ + 4e^-. \quad (1)$$

Electrons which can't pass through membrane are forced to move through external electric circuit to restore charge equilibrium. Protons are reduced again at cathode. Energy that is supplied to the external circuit is provided by chemical reaction of hydrogen and oxygen. This reaction is follows.

$$4H^+ + 4e^- + O_2 \rightarrow 2H_2O \quad (2)$$

Overall reaction in fuel cell:

$$2H_2 + O_2 \rightarrow 2H_2O \quad (3)$$

Energy produced by this chemical reaction has two forms – electric energy and heat. In the work [4] are described these processes.

The operation principle of PEM electrolyser is basically reversed operation of fuel cell and it is also shown at Fig. 1. Electric current is flowing from external source through electrodes which are sunken in water. Water dissociates at anode. Oxygen gas flows freely to atmosphere. Volumes of originated gases are in 2:1 ratio.

[1] *Ing. Pavel Tošer, Ing. Pavel Abraham, doc. Ing. Petr Bača Ph.D.*, Brno University of Technology, 616 00 Brno, Czech Republic, Department of Electrotechnology, xtoser00@stud.feec.vutbr.cz , xabrah02@stud.feec.vutbr.cz , baca@feec.vutbr.cz

[2] *doc. Ing. Peter Tauš, PhD.*, Ústav podnikania a manažmentu, Fakulta baníctva, ekológie, riadenia a geotechnológií, Technická univerzita v Košiciach, Letná 9, Košice,.SK, peter.taus@tuke.sk

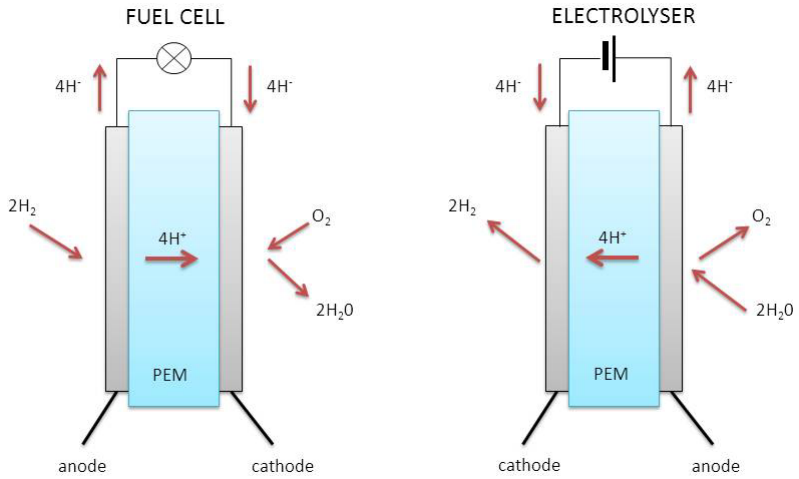

Fig. 1. Principle of PEM fuel cell and PEM electrolyser.

Theory and practical informations

The examples of important efficiencies of PEM fuel cell are presented in following section. Similar equations can be used for electrolyser calculations as well. The output power of the fuel cell depends especially on the load resistance. The slow reaction on changing load is one of the drawbacks of this system. The total energy efficiency called η_{energy} indicates how much of the input energy is dissipated in the system as actual usable energy. The equations for better understanding we can find in [2], [3], [6].

$$\eta_{energy} = \frac{E_{usable}}{E_{input}} = \frac{E_{electric}}{E_{hydrogen}} = \frac{UIt}{V_{H_2} H_I} \tag{4}$$

In general it can be said that the more η_{energy} value is closer to 1 the better efficiency is. The hydrogen consumption/time diagram is in Fig. 2 and the last data from graph are used. If input values are e.g.: U=0,72 V, I=0,21 a t=712 s, then the volume of consumed hydrogen in time t is V_{H_2}=20.10^{-6} m^3. Another needed value is heating value of hydrogen (also called lower heating value) at 20 °C that is 10,8.10^6 J/m^3.

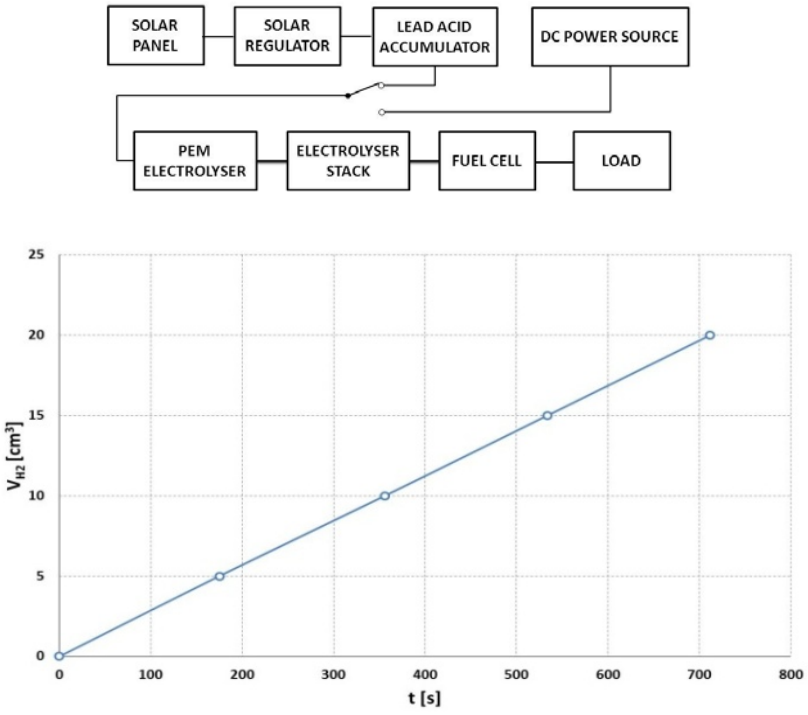

Fig. 2. a) Block diagram of the hybrid photovoltaic system,
b) Hydrogen consumption/time diagram of a fuel cell for calculation parameters.

$$\eta_{energy} = \frac{UIt}{V_{H_2} H_I} = \frac{0{,}72.0{,}21.712}{20.10^{-6}.10{,}8.10^6} = 0{,}498 \cong 50\ \% \quad (5)$$

The energy efficiency of the fuel cell is approximately 50 %. There is also heat and it`s regarded as a lost of energy. We can quantify the value called ideal efficiency. The ideal efficiency was calculated from Gibb`s free energy (ΔG) and reaction enthalpy (ΔH). The reaction enthalpy is the energy released during the reaction.

$$\eta_{id} = \frac{\Delta G}{\Delta H} \quad (6)$$

The difference between ΔG and ΔH is equal to released heat Q. The heat can be calculated from the temperature value and the reaction entropy ΔS.

$$Q = T\Delta S \quad (7)$$

The reaction enthalpy of this reaction can be calculated as follows:

$$\Delta H = \Delta G + T\Delta S \quad (8)$$

The final formula for the ideal efficiency is based on previous equations:

$$\eta_{id} = \frac{\Delta G}{\Delta H} = \frac{\Delta H - T\Delta S}{\Delta H} = 1 - \frac{T\Delta S}{\Delta H} = 1 - \frac{298(-162{,}985)}{-285840} = 0{,}83 = 83\ \% \quad (9)$$

where T=298 K, ΔS=162,985 J/K.mol and ΔH=-28584 J/mol at standard atmospheric pressure and temperature conditions. The ideal energy efficiency is reduced by voltage losses that are manifested as heat (The ideal cell voltage of 1,23 V will never be reached).

The Faraday efficiency

The second Faraday`s law and the ideal gas law are used for determination of relationship between the flowing current and fuel cell`s theoretical volume of gas consumed.

The second Faraday`s law state

$$Q = It = nzF \quad (10)$$

The ideal gas law state:

$$pV = nRT \quad (11)$$

By the combination of equations 10 and 11 we obtain following equation:

$$V = \frac{RITt}{Fpz} \quad (12)$$

where V is theoretical volume of gas consumed in m^3, R is universal gas constant 8,314J/molK, p is the ambient pressure (1Pa), F is the Faraday constant 96485 C/mol, Q is electrical charge in C, n substance quantity in mol, z is number of electrons to release a molecule (for H_2 →z=2).

$$V_{H_2}(calculated) = \frac{RITt}{Fpz} = \frac{8{,}314*0{,}21*298*712}{96485*1{,}013*10^5*2} = 18{,}96\ cm^3 \quad (13)$$

$$\eta_{Faraday} = \frac{\eta_{calculated}}{\eta_{consumed}} = \frac{18{,}96}{20} = 0{,}948 = 95\ \% \quad (14)$$

Properties of the system elements and measured characteristics

The electrolyser power is 15 W at voltage U=4 V. The allowed operating voltage is 3 to 4 V respectively 0 – 4 A. The electrode surface is 2x16 cm^2. The maximum volume of generated gas is up to 65 cm^3/min. The fuel cell stack is composed from 10 fuel cells. Each of them has 200 mW of power. The electrolyser and fuel cell V-A characteristics are presented at Fig. 4.

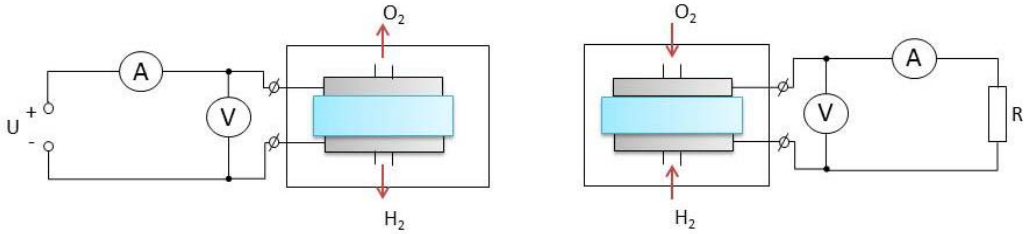

Fig. 3. Scheme for measuring V-A characteristics of a) elektrolyser b) fuel cell.

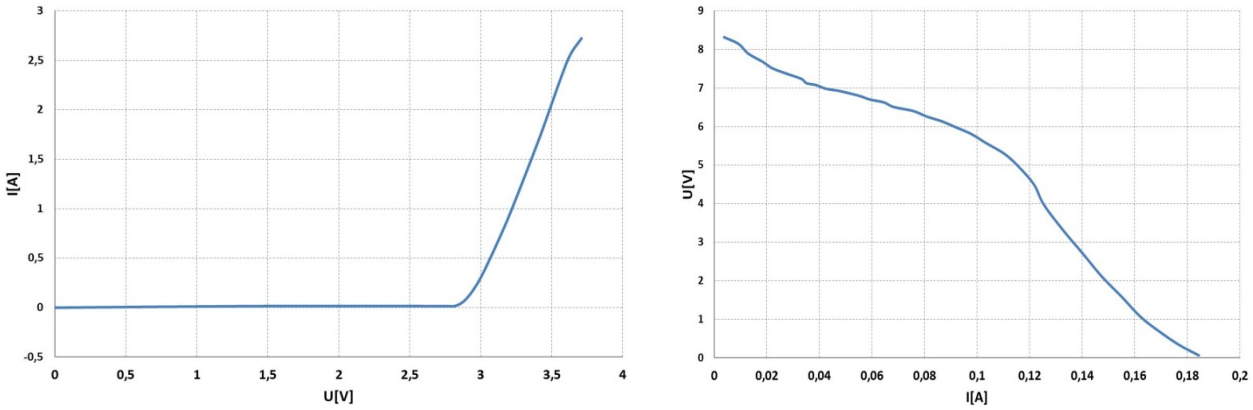

Fig. 4. V-A characteristics of a) electrolyser b) fuel cell.

Conclusions

The paper deals with topic of fuel cells. Experimental workplace for V-A characteristics measurements of fuel cell and electrolyser was assembled. The efficiencies of single elements of the system were measured and compared.

The volume of gas which is actually consumed is slightly greater than calculated volume. Since diffusion losses similar to those with the electrolyser occur in the fuel cell. The main knowledge when we focuse on experiment results is that the Faraday efficiency of the fuel cell is slightly less than that of electrolyser. This is due to a smaller flowing current. It takes much more time to form a given quantity of water than split it. Over a longer time period, more hydrogen diffuses through the membrane and is then no longer available to produce electricity.

Tab. 1. All energy efficiencies in overall.

	η_{energy} [%]	$\eta_{Faraday}$ [%]
Fuel cell	50	95
Electrolyser	82	98

Because the solar panel with the power output 85 W was used the energy efficiency can be quantified. The panel has several specifications as open circuit voltage V_{OC}=21,6 V and short circuit current I_{SC}=5,2 A. The maximum irradiance under sunny summer conditions is 1000W/m^2. The maximum value of short-circuit current was measured at this irradiation. The test conditions were standard at 25 °C. Based on these parameters the energy efficiency of the solar panel is approximately13 %. This value corresponds with the theoretical assumptions. By multiplying the energy efficiencies of all the parts of the system we receive very small value. But the efficiency can be increased by using new technologies etc [1], [5].

Acknowledgement: *This paper was supported by the EU project CZ.1.05/2.1.00/01.0014 and by the FRVŠ project No. 3226.*

References

[1] Dostál Z., Bobek M., Župa J.: The measuring of global solar radiance, *Acta Montanistica Slovaca 13 (2008), 3, 357-362, ISSN 1335-1788.*
[2] Halliday D., Resnick R., Walker J.: Fyzika, Brno University of Technology, *Vutium, Prometheus Praha, 2000, 2003, 2006.*
[3] Lide, D.R.: Handbook of Chemistry and Physics*, 77th edition, section 1-43, 5-93(1996).*
[4] Quashching V.: Understanding renewable energy systems, *Earthscan, 2005, ISBN: 1844071286.*
[5] Tkáč J., Hvizdoš M.: Meranie intenzity slnečného žiarenia; *Elektroenergetika, 4 (2011), 4, 20-24, ISSN 1337-6756.*
[6] H-Tec Operating Instructions and experiments, *manual supplied with hardware.*