Measurement 42 (2009) 1497–1501

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Uncertainty of measurement by Monte-Carlo simulation and metrological reliability in the evaluation of electric variables of PEMFC and SOFC fuel cells

Sergio P. Oliveira [a,*], Adriana C. Rocha [b], Jorge T. Filho [a], Paulo R.G. Couto [a]

[a] INMETRO, Brazil
[b] COPPE/POLI/LNDC/UFRJ, Brazil

ARTICLE INFO

Article history:
Received 27 October 2008
Received in revised form 16 July 2009
Accepted 18 August 2009
Available online 3 September 2009

Keywords:
Monte Carlo
PEMFC
SOFC
Uncertainty of measurement
Traceability

ABSTRACT

The aim of this work is presenting results of uncertainty of measurement calculations applied to both a low temperature PEMFC (proton exchange membrane fuel cell) and a high temperature SOFC (solid oxide fuel cell) by using Monte Carlo method simulations. The intention is correlating electric voltage, obtained in the technical literature, and energetic efficiency of the fuel cells studied in this work. In order to validate the Monte Carlo results achieved a comparison with the procedure for the evaluation of the uncertainty of measurement existing in the GUM 95 "Guide to the Expression of Uncertainty in Measurement" (by BIPM, IEC, IFCC, ISO, IUPAC, IUPAP and OIML) is made. A reasoning of the balancing of the sources of uncertainty is presented as well. In last, it is discussed why the calibration process and traceability of the voltmeter are key factors in providing reliable metrological results in the production of electricity by fuel cell technology. This work is the first part of a broader study from which the next steps will be the validation of these presented simulations by fuel cell bench tests and the planning and development of Brazilian Conformity Assessment programs for PEMFC and SOFC fuel cells afterwards.

1. Introduction

At a time when the world worries about the global energy resources – fossil fuels reserves depletion, global warming by greenhouse gases effect – a solution to solve these problems is the development of the hydrogen economy [1]. This concept means the use of the hydrogen as a source of non-pollutant (clean), non-toxic and quasi-infinite available energy. The most studied hydrogen application is its use as a fuel cell.

Fuel cell is an electrochemical device that produces electrical energy that uses the hydrogen gas as the input fuel and as a consequence of the chemical reaction of a proton with the oxygen gas yielding water as the output. There is also the generation of heat as a by-product which could be used in co-generation energy processes enhanced the overall energy efficiency.

Two kind of fuel cells are most used nowadays: PEMFC (proton exchange membrane fuel cell) and SOFC (oxide solid fuel cell). The former is used in low temperatures applications (around 80 °C) and the last is used in the high temperature range (near 1000 °C), it is important to evaluate energy efficiency of the fuel cells and the correct way to measure their efficiency [2].

One of most important parameters to be controlled in a fuel cell is the calculation of its energy efficiency. To do so it is necessary to know both the thermodynamic and the enthalpy variation of the energy generation process.

The system of fuel cell technology is composed of a series of stacks, each of them with some unitary fuel cells. And

* Corresponding author. Address: INMETRO, Av. Nossa Senhora das Graças, 50 – Prédio 3, Lafor, 25250-020 Duque de Caxias, RJ, Brazil. Tel.: +55 21 2679 9050; fax: +55 21 2679 1505.

E-mail addresses: spoliveira@inmetro.gov.br (S.P. Oliveira), adrirocha@metalmat.ufrj.br (A.C. Rocha), jtfilho@inmetro.gov.br (J.T. Filho), prcouto@inmetro.gov.br (P.R.G. Couto).

0263-2241/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.measurement.2009.08.005

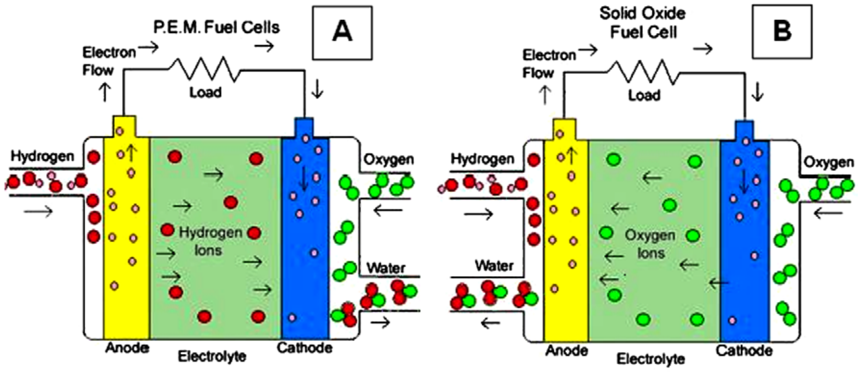

Fig. 1. Unitary fuel cell system – (A) PEMFC and (B) SOFC.

the number of stacks depends on the electric characteristics of the electric devices (electric load) that will be receiving electric energy from the grid. So the voltage and the electric current are directly related to the number of stacks and the energy efficiency as well.

In accordance with the requirements of the standard ISO/IEC 17025:2005 [3], if a measurement result is considered to be trusted and reliable, it shall show evidence of traceability to international standards and metrological reliability. These evidences are established as important properties for assessing the quality of any measurement. But often, the results of measurements are presented and used without the concern of the existence of these important requirements of the standard. Therefore, under these circumstances, any decision on the basis of these results of measurement can cause wrong conclusions whose consequences are unpredictable.

The basic action in order to establish mutual recognition between metrological systems is the existence of frequent comparisons between the results of measurement among these systems, in such a way the compatibility be attained. The ISO GUM 95 may also be used as an important tool in establishing the accuracy required prior to any variable of a process, aimed at mitigating the cost/benefit aspect [4].

The Monte Carlo modeling appeared as a solution to minimize the limitations of the classical methods of calculating the uncertainty of measurement proposed by ISO GUM 95. These limitations are the linearization of the model, the normal distribution assumption for the measurand data and the calculation of the effective degrees of freedom [2,4–7].

In this paper, an example is presented. It deals with the analysis of the accuracy classes of a multimeter used to measure the difference in electrical potential provided or consumed by a particular by fuel cell stacking. The better the class of accuracy of a multimeter the greater the number of digits of its display. Consequently, the greater the number of digits in this equipment, the higher its sales cost. Through the implementation of ISO GUM 95 [5] one can select a multimeter class of accuracy suitable for the measurement of the difference in potential provided or consumed by a particular stacking of fuel cells.

In Fig. 1 are represented schematically the functioning of cells with the type of fuel-PEMFC and SOFC [8].

2. Objectives

This study aimed to:

(i) To compare the correlated and non-correlated aspects of uncertainty of measurement by Monte Carlo method.
(ii) Presents the analysis of the sources that most influence the estimate of the uncertainty of measurement the efficiency of the fuel cell.
(iii) Submit an estimate of the uncertainty of measuring the efficiency of a fuel cell by using the method of Monte Carlo.
(iv) Establish the appropriate class of accuracy for the measurement of the difference in potential provided or consumed by a particular stacking of the fuel cells, aiming to optimize the cost/benefit of the process.

3. Methodology

The sources of measurement uncertainty of the energy efficiency of a fuel cell have been estimated from data cited in the literature [9–13]. In the calculations of uncertainty of measurement for measuring the result of "an energy efficiency of the fuel cell" it was used the method of Monte Carlo, described in Supplement 1 of the ISO GUM 95 [6]. Two approaches were considered: input variables with and without correlation. The input variables were: thermodynamic efficiency and actual efficiency.

The actual efficiency of both the PEMFC and SOFC used here is calculated according to the Eq. (1), taking into account the input quantities are non-correlated

$$\eta_{\text{real}} = \frac{\eta_{\text{therm}} \cdot E_{\text{actual}}}{E_{\text{ideal}}} \tag{1}$$

where η_{actual} is the actual efficiency, η_{therm} is the thermodynamic efficiency, E_{real} is the actual electric voltage, and E_{ideal} is the ideal electric voltage.

For correlated input quantities, and as a consequence of some manipulation, the Eq. (1) changes into Eq. (2) below:

$$V = N \cdot \frac{\eta_{\text{actual}}}{\eta_{\text{thermod}}} \cdot E_{\text{ideal}} \tag{2}$$