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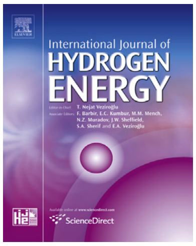

Effect of temperature uncertainty on polymer electrolyte fuel cell performance☆

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ABSTRACT

The temperature of operation is a key parameter in determining the performance and durability of a polymer electrolyte fuel cell (PEFC). Controlling temperature and understanding its distribution and dynamic response is vital for effective operation and design of better systems. The sensitivity to temperature means that uncertainty in this parameter leads to variable response and can mask other factors affecting performance. It is important to be able to determine the impact of temperature uncertainly and quantify how much PEFC operation is influenced under different operating conditions. Here, a simple lumped mathematical model is used to describe PEFC performance under temperature uncertainty. An analytical approach gives a measure of the sensitivity of performance to temperature at different nominal operating temperatures and electrical loadings. Whereas a statistical approach, using Monte Carlo stochastic sampling, provides a 'probability map' of PEFC polarisation behaviour. As such, a polarisation 'area' or 'band' is considered as opposed to a polarisation 'curve'. Results show that temperature variation has the greatest effect at higher currents and lower nominal operating temperatures. Thermal imaging of a commercial air-cooled stack is included to illustrate the temporal and spatial temperature variation experienced in real systems.

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1. Introduction

A polymer electrolyte fuel cell (PEFC) is a device that converts chemical energy in fuels directly into electricity with high efficiency, no combustion or moving parts [1]. The advantages of this type of fuel cell includes low operating temperature, quick start-up, planar configuration and easier sealing due to the use of a solid electrolyte [2–9]. However, water management issues require careful consideration to ensure good protonic conductivity in the electrolyte while avoiding electrode flooding that limits reactant access and results in mass

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transport limitations [10]. To achieve this, it is important to run the system at the optimum operating conditions by applying efficient control methodologies. There are many factors which affect performance, ranging from fundamental thermodynamic properties; ionic, electronic and mass transport mechanisms; heat transfer and electro-kinetics [11–13]. For all these processes, temperature is a major determining factor and control is essential for understanding how fuel cells operate, optimising performance, and developing better and longer lasting devices.

When operating fuel cells, there is always a level of 'uncertainty' in the operating parameters and physical state of the system that leads to variable and unpredictable performance. This uncertainty can be due to fluctuations and distribution of operating parameters, measurement accuracy, random errors, unoptimised/unstable control, etc. [14]. Temperature is one of the parameters with the highest uncertainty as it is a function of operating point, reactant flow rate and ambient conditions; it is also temporally variant under dynamic conditions and spatially heterogeneous.

The sensitivity of fuel cell operation with respect to temperature has been reported in the literature [15–17]. Studies have focussed on the impact of operating temperature on fuel cell performance, and also uncertainty as a part of the control system [18,19].

Temperature is an important component in fuel cell operation, and plays a key role in cell performance [20,21]. Water transport is directly influenced by temperature, affecting the mobility of species in the electrolyte and access and removal of water at the electrodes and propensity to flooding [10]. Thermal imaging has increasingly become a popular tool for the investigation of fuel cells. It provides high spatial resolution imaging and allowing non-contact measurements, so avoiding potential interference with fuel cell operation. Thermal imaging can be used to identify defects and/or areas of unusually low or high activity on the surface of fuel cells. Aieta et al. have shown how catalyst loading defects can be investigated using thermal imaging [22]. Hakenjos et al. measured the current and temperature distribution using IR thermography in order to obtain the temperature distribution along the GDL of a PEMFC [23]. They also observed flow-field flooding through images taken from temperature distribution. Daino et al. have performed similar work aimed at identifying temperature gradients along GDL layers within PEMFCs [24].

In this paper, a simple mathematical lumped model is used to examine the effect of temperature on the parameters and fundamental physical and chemical properties that determine PEFC performance. First, an analytical approach is adopted that examines the sensitivity of the equations to small changes in temperature by using the differential dV/dT to map the operating range of polarisation and nominal operating temperature. However, this does not capture the stochastic nature of the uncertainty associated with practical operation, so a second analysis is performed that applies a statistical treatment to develop a 'probability map' of fuel cell polarisation performance.

In order to support the statistical study, an experimental characterisation of a commercial air-cooled stack is performed that uses high-resolution thermal imaging to characterise the kind of spatial and temporal temperature uncertainty that can be expected in a practical operating system.

The intention of this study is to provide fuel cell developers with a basis for estimating the expected level of uncertainty in polarisation performance based on a given uncertainty in the temperature of the system (spatial and temporal). A key outcome is that conventional polarisation curves should be considered as 'polarisation areas' or 'bands' with variable uncertainty across their operating range.

1.1. *Temperature uncertainty in fuel cell operation*

Temperature distribution within fuel cells has been modelled using a range of techniques and length scales; for example, Shimpalee and Dutta describe the temperature variation across the flow channel width [21] and Pharoah and Burheim at the cell level [20]. However, models rarely consider the effect of measurement and physical uncertainty on cell performance.

Mawardi and Pitchumani investigated the impacts of uncertainty in materials and operating parameters on fuel cell performance by using a one dimensional, non-isothermal mathematical model [14]. Parametric analysis was used to determine how cell voltage and power density change with uncertainty, where the input samples were generated stochastically using the Latin Hypercube Sampling (LHS) method.

To show the significance of temperature on other variables like degradation rate, Placca et al. demonstrated the effect of the interaction between temperature and degradation rate on overall performance of fuel cells [25]. The Response Surface Method (RSM) was applied in this study to analyse the effect of uncertainty in these variables on polarisation (V–I) curves. However, no attempt was made to quantify the association between the measurement uncertainty and temporal and spatial temperature distribution.

2. Model development

For the purpose of analytical and statistical analysis, a mathematical model is required to describe the thermodynamics of the system, kinetics, mass and charge transfer as a function of temperature.

2.1. *Model assumptions and equations*

A lumped, semi-empirical, mathematical model is used to simulate PEFC operation [10,11]. The purpose of using this model is to indicate the effect of temperature on different parameters and identify their impact on overall performance. Therefore, some of the parameters, such as exchange current density and conductivity, which are usually measured experimentally, are expressed using empirical equations, which themselves can generate discrepancy due to model uncertainty. However, the focus of this work is the impact of temperature uncertainty on cell performance, whereas model uncertainty is assumed negligible. The following assumptions are applied: (i) steady state system; (ii) incompressible and ideal gases; (iii) single phase vapour water; (iv) heat loss is

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