ECONOMIC CONSIDERATIONS FOR AN INNOVATIVE HIGH TEMPERATURE BATTERY IN POWER PLANT APPLICATIONS

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Abstract

A novel high temperature battery based on the concept of the solid oxide fuel cell (SOFC) is presented. Due to the use of cheap iron- and calcium-based storage materials providing a high theoretical capacity of roughly 1,300 Wh/kg the battery could be used to optimize the part load properties and the long term durability of conventional power plants. The elevated working temperature of 800 °C makes the battery applicable where high quality heat is available and needed. In this paper an economical consideration leads to general design recommendations for this battery which at the moment operates with current densities of 150 mA/cm^2 and approximately one hour charging/discharging time at cell voltages between 0.7-1.2 V.

Introduction

Any technology for storing electrical energy provides the opportunity of decoupling generation and usage of electricity. This can be beneficial whenever there is a temporal change of electricity generation cost due to load variation or fluctuating availability. Latter becomes especially true, when augmenting the grid with power sources (renewables) with a possibly large discrepancy between actual and rated power input. In this case, energy storage can substitute the increase of rated power or even render additional flexible power plants unnecessary.

Since conventional storage technologies (e.g. pumped hydro) lack the possibility of considerable expansion, electrochemical storage can be an alternative. However, due to high investment cost this option has not been implemented on large scale so far. Therefore technological alternatives with low investment cost are needed. A very innovative concept that fulfills these requirements is the Rechargeable Oxide Battery (ROB) which will be presented in this paper.

General Overview

The Rechargeable Oxide Battery (see Fig. 1) is based on a solid oxide cell (SOC) that operates in turns as fuel cell (SOFC) and as electrolyzer (SOEC). The SOC is coupled with a storage material which provides and absorbs reactants at the fuel side. Whereas a classical fuel cell or electrolyzer system needs continuous delivery and removal of fuel gases the integrated storage material enables the system to be operated as a battery in a semi-closed system, which saves all cost related to gas delivery and conditioning. At the air side a simple passive air vent or a small fan suffices.

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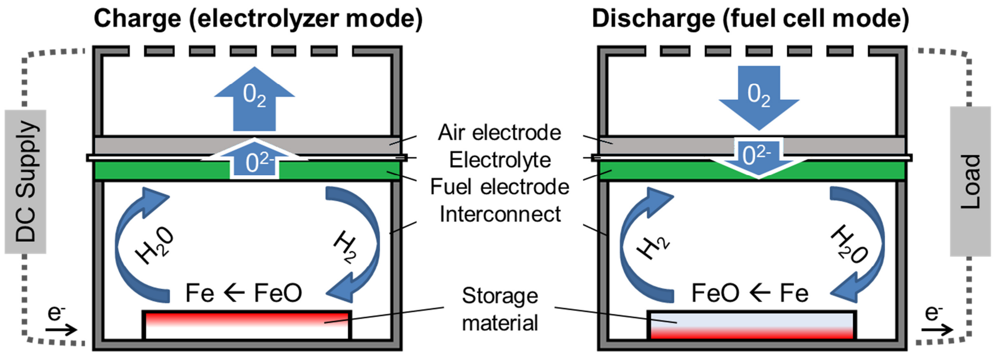

Fig. 1 Schematic of working principle of a ROB in discharge and charge operation according to [Tokariev et al., J. Power Sources, submitted 11-13]

As depicted in Fig. 1, in charge operation (electrolyzer mode) electrons are used to split steam into hydrogen and oxygen ions. Whereas the oxygen ions diffuse through the electrolyte to the air electrode hydrogen is used to reduce iron oxide. The thereby generated steam is ready for further electrolysis. The ROB is charged when all of the iron oxide based storage material is reduced to metallic iron. Vice versa, in discharging operation iron is oxidized with steam, leading to hydrogen which can be used in fuel cell operation.

Using iron based storage the battery provides a cheap way of storing large amounts of energy in a relatively low amount of storage material. Below, the governing chemical equations of the system are shown, where Eq. 1 describes the reversible reaction of the atmosphere with the storage material and Eq. 2 and Eq. 3 represent the well-known reactions at the respective electrodes of the SOC.

$$3Fe + 4H_2O \leftrightarrows Fe_3O_4 + 4H_2 \qquad \text{Eq. 1}$$

$$H_2 + O^{2-} \leftrightarrows H_2O + 2e^- \qquad \text{Eq. 2}$$

$$O_2 + 4e^- \leftrightarrows 2O^{2-} \qquad \text{Eq. 3}$$

The iron based storage material yields a theoretical capacity of roughly 1,300 Wh/kg. First experiments show that the battery in the current design displays charging/discharging durations of about one hour and current densities of 150 mA/cm^2 at a cell voltage of approximately 0.7-1.2 V. Further experimental work is conducted with the aim to increase capacity and kinetics and at the same time reduce degradation effects, operating temperature and cost. For this material research as well as manufacturing issues are improved.

Possibly, the main advantage over other electrochemical storage devices such as lithium-ion batteries is the lower investment cost of used materials. Compared to conventional SOEC/SOFC systems, especially the operating cost will be lower mainly due to avoided gas conditioning (purity, storage, pumping, metering and thermal losses).

From the specific technical operation conditions of the battery – especially the temperature - two applications are most promising: 1. the operation of the battery in high frequency for stabilization purpose of the electricity network and 2. the operation in combination with conventional power plants. The economical prospect of these applications is estimated on the basis of cost and revenue considerations that include an energy market analysis and an optimized operation management. Thereby the analysis also reveals requirements for the technology development.

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