Multiphysics Finite-Element Modelling of an All–Vanadium Redox Flow Battery for Stationary Energy Storage Applications

Federico Moro, Alberto Bertucco, Valentina Fiorenzato, Monica Giomo, and Massimo Guarnieri

Dipartimento di Ingegneria Industriale
Università di Padova
Via Gradenigo 6/A, 35131 Padova, Italy
e-mail: federico.moro@unipd.it

ABSTRACT

The growing penetration of renewable energy power in the electric grid has boost the development of new technologies for stationary energy storage. All-vanadium redox flow batteries (RFB) exhibit a very high potential for both medium and large scale applications. This is due to power/energy independent sizing, high efficiency, room temperature operation, and long charge/discharge cycle life. A number of challenges need to be tackled before commercialization, i.e. cell and stack design, highly efficient materials, and optimal power management and control operations [1].

Numerical models are very important for designing control and monitoring systems, which are needed for the electric grid interfacing. Both 1D and 2D finite element models have been developed in order to reduce computing cost and allow for a real-time simulation of RFB operations [2]–[4]. In this work a novel 1D steady-state finite-element model of an all-vanadium redox flow battery is proposed. The reference cell geometry include: current collectors, positive and negative porous electrodes where chemical reactions occur, and the polymer membrane for proton conduction. The FEM model incorporates the following multiphysics phenomena: momentum, charge and species conservation, mass transport (Nernst-Plank equation), electric conduction, charge generation (Butler-Volmer equation) inside the porous electrodes, and the proton conduction inside the membrane. In particular, for charge generation the effect of mass transport is taken into account by considering surface concentration of the electrolytes, which differs from bulk concentration. This is of basic importance for a proper representation of the actual RFB performance. The independent variables of the model are: the electrode and electrolyte potentials and the ionic species concentrations in the porous electrodes. From potentials the overall cell voltage is derived as a function of the State of Charge (SoC) during charge and discharge cycles. Numerical results, showing the behaviour of the cell voltage under different operating conditions, will be presented in the full paper. The proposed model is expected to be a useful tool in driving and optimizing the stack design.

REFERENCES

[1] P. Alotto, M. Guarnieri and F. Moro, "Redox flow batteries for the storage of renewable energy: A review", *Renewable and Sustainable Energy Reviews*, Vol. **29**, p. 325–335, (2014).

[2] C.L. Chen, H. K. Yeoh and M. H. Chakrabarti, "An enhancement to Vynnycky's model for the all-vanadium redox flow battery", *Electrochemica Acta*, Vol. **120**, p. 167-179, (2014).

[3] D. You, H. Zhang, and J. Chen, "A simple model for the vanadium redox battery", *Electrochemica Acta*, Vol. **54**, p. 6827-6836, (2009).

[4] K. W. Knehr et al., "A Transient Vanadium Flow Battery Model Incorporating Vanadium Crossover and Water Transport Through the Membrane", *Journal of the Electrochemical Society*, Vol. **159** (9), p. A1446-A1459, (2012).