Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Stanislav Bogdanov

PhD Program: Engineering Systems

Title of Thesis: Modeling and operation optimization of vanadium redox flow batteries

Supervisor: Dr. Mikhail Pugach, Skoltech

Co-supervisors: Associate Professor Federico Martin Ibanez, Skoltech
Dr. Sergei Parsegov, Skoltech

Name of the Reviewer: Sun Chuanyu

I confirm the absence of any conflict of interest Yes	 **Date: 10-10-2024**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

The thesis develops a real-time VRFB simulation model suitable for different system sizes and operating conditions. It can be employed to enhance understanding of internal VRFB processes, supporting effective control and monitoring. In detail, the most appropriate model for real-time VRFB simulation is highlighted based on general principles of mass and energy conservation. Moreover, a new parameter identification algorithm is developed to enhance model accuracy and predictive capability. The proposed model has been successfully validated on both laboratory-scale setups and industrial-scale setups (10 kW, 100 kWh), demonstrating a relative modeling error of less than 2%. The developed model is helpful to find the optimal operation strategy for VRFB in residential grid, minimizing its annual operational cost. Overall, this thesis makes great contributions for development of reliable and efficient simulation tools for large-scale VRFB systems, and it devotes to designing advanced control strategies for the safe operation of VRFB systems.

The thesis quality is very good, and the overall structure of the thesis is complete and comprehensive enough. The actual content of the thesis is completely consistent with the title of the thesis. It includes not only model simulation but also actual operation test verification of VRFB systems of different specifications. The relevant characterization and test methods are comprehensive and reliable. The scientific and engineering significance of the results obtained are significant, which will help guide the design optimization of future large-scale energy storage RFB systems. Compared with the international level, they are at the cutting-edge technology level.

The results obtained are closely related to the engineering application of VRFB systems and the large-scale promotion of MWh scale. The quality of doctoral publications is extremely high. Two are published in Journal Of Power Sources (IF=8, JCR Q1 Journal) and one is published in Journal of Energy Storage (IF=9, JCR Q1 Journal), and the candidate was the first/second author. This fully confirms the cutting-edge nature of their academic achievements and has been widely recognized in peer review.

For the summary of issues to be addressed before/during the thesis defense, I list them as follows:

1. Page 18, 'This structure provides several advantages: a very long lifecycle of up to 20,000 cycles, flexible scalability, and a high depth of discharge.' I consider the lifespan by years should also be given. For example, 15-20 years.

2. Page 23, Table 2.1, 'Low energy density and high cost' for RFB may not be accurate. For example, iron-chromium and all-iron RFB are quite cheap, and the high cost is more commonly for VRFB. And for the low energy density, it has been reported that zinc–Iodine hybrid flow batteries possess an exceptional energy density based on the solubility of zinc iodide (up to 5 M or 167 Wh L^{-1}). So low energy density is more suitable for VRFB as the disadvantage, not all RFBs.

3. Page 42, 'The membrane in the cell serves as a separator of the different electrolytes, while conducting the protons to close the electrical circuit and ensure the continuous flow of the current.' I consider the membrane can only ensure the transportation of protons, not flow of the current. The current flow should be realized in the metallic cable/wires in the external circuit, not the membrane inside the VRFB system. The descriptions should be modified to be more accurate and reasonable.

4. At present, there are many works on modeling of all-vanadium liquid flow battery (VRFB). The model and indicators proposed in this paper should be compared with the key indicators of the model reported in the literature to highlight the superiority of the proposed new model. At present, the main text and chapters seem to mainly describe the results of applying the model to VRFB systems of different power levels, but lack comparison with the indicators in the existing literature. Therefore, it is recommended to further supplement and improve this part.

5. The contents in Chapter 5 are a bit short in terms of the length of the chapter. Moreover, the investigation contents in this part should be further enriched. Now compared to other two chapters, this part is quite simple and the conclusions obtained is also quite basic.

Provisional Recommendation

√ ☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*
☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*
☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*