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: Elena Gryazina

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Date: 06-10-2024**

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

- **Brief evaluation of the Thesis quality and overall structure:**

The thesis presents a well-structured and in-depth investigation into the real-time simulation of Vanadium Redox Flow Batteries (VRFBs). The author focuses on developing accurate, efficient models for real-time applications, emphasizing the essential trade-offs between computational speed and precision. The research is organized systematically, beginning with an overview of current VRFB modeling techniques, progressing through the development of a comprehensive simulation model, and concluding with a practical case study involving peak shaving for residential grid systems.

The quality of the work is commendable, featuring rigorous experimental validation and model development that balances both theoretical advancements and real-world application considerations.

- **Relevance of the topic to the dissertation content and methods used**

The topic of the thesis, which revolves around creating a comprehensive model for VRFB simulation, aligns closely with the content of the dissertation. The research explores the detailed modeling and validation of VRFB behavior, emphasizing its real-time application. This focus makes it particularly relevant to researchers and engineers involved in energy storage systems and grid applications. The clear linkage between the thesis's objectives and content ensures that the work stays focused on its primary goals throughout.

The methods used in the dissertation, including advanced modeling techniques and parameter identification algorithms, are highly appropriate for addressing the research objectives. The author employs a range of mathematical tools, including simplified models for control-oriented applications and detailed models for accuracy-focused applications. The use of experimental validation, along with error analysis, provides a robust framework for ensuring the relevance and correctness of the proposed models. The parameter identification algorithm, applied to long-term operational data, significantly enhances the models' predictive capability.

- **Scientific significance of results and international relevance**

The results of the thesis demonstrate significant scientific value, particularly in advancing the state-of-the-art in VRFB modeling. The proposed models, particularly the 8-th order model, achieve impressive accuracy, with validation errors remaining under 5% during extensive charge-discharge cycles. The degradation studies further emphasize the model's utility in predicting long-term performance, making it applicable for real-world scenarios such as grid management and renewable energy storage.

The methods and findings of this research are competitive at the international level, meeting the current needs in energy storage systems for precision and real-time control. The focus on both computational efficiency and long-term predictive accuracy makes the results highly relevant to industries adopting energy storage technologies globally.

The thesis outcomes are highly relevant to practical applications, particularly in the context of grid energy management. The application of the VRFB model to peak shaving in distribution grids showcases its utility in real-world scenarios, where accurate control and predictive capabilities are critical. The modeling approach, which incorporates the effects of degradation and performance over time, provides essential insights for industries using VRFBs for long-duration energy storage. The electrolyte rebalancing technique presented in the thesis could have significant implications for extending VRFB lifespan in practical applications.

7. Summary of Issues to Be Addressed Before/During Defense:

- In Fig. 5-1 the units for vertical axes should be in kW not in kWh.
- The model could benefit from additional validation on larger industrial-scale VRFB systems, which would enhance its credibility for real-world industrial applications.
- The thesis could be improved by offering more specific guidelines for industries aiming to implement the proposed models in practical VRFB systems, particularly regarding the cost-effectiveness of electrolyte rebalancing procedures.

In conclusion, this thesis offers significant scientific contributions, with practical relevance and strong alignment to current technological demands in energy storage systems. The work could have substantial impact if the recommendations above are addressed before the defense.

Provisional Recommendation

X *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*