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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Mikhail Pugach

PhD Program: Engineering Systems

Title of Thesis: Vanadium Redox Flow Batteries modeling and performance analysis

Supervisor: Assistant Professor Aldo Bischi

Name of the Reviewer: Prof. Hubert Girault, EPFL Lausanne, Switzerland

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Signature:**  **Date: 27-09-2020**

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

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

It is my pleasure to recommend the thesis of Mikhail Pugach entitled: Vanadium Redox Flow Batteries Modeling and Performance Analysis

The work of Mikhail Pugach is dedicated to the study of vanadium redox flow batteries (VRFB). Indeed, megabatteries are increasingly playing an active role for the integration of renewable electric sources in the grid, and it is important to understand some of the key aspects of this type of batteries, which are becoming more widely commercially available.

The work presented in this thesis is original and of high-quality, showing that the candidate has a very strongly background in electrochemistry and electrochemical engineering. It is very well and carefully written.

Chapter 1 presents the objectives of the work and the global world energy background.

Chapter 2 provides an excellent review of electricity storage systems (ESS) detailing the technical indicators, and introduces the advantages of redox flow batteries with respect to other ESS technologies. It describes in particular the Vanadium redox chemistry and its use to develop VRFBs.

Chapter 3 introduces the field of mathematical modelling of VRFBs using a multi-level simulation and introduces a key aspect of the present work, namely the 0-D dynamic model aimed at understanding the cross-over phenomena. The results obtained are compared with literature data showing that the model is quite powerful in predicting battery behaviour. Indeed, the candidate shows clearly the role of convection with respect to diffusion and migration.

Chapter 4 is dedicated to the important problem of energy loss. The work presented in this chapter is very comprehensive and shines new light on the operating performances of VRFBs. The model developed by the candidate provides interesting conclusions regarding the voltage and coulombic efficiencies during charging and discharging, namely the role of ohmic losses in charging and the role of cross-over whilst discharging. The candidate also addresses the usual battery capacity aspects which are often over-looked.

Chapter 5 is dedicated to the main characteristics of VRFBs, namely the flow and the associated hydrodynamic aspects and more importantly the flow management system. The candidate has developed a strategy for a control system able to adapt the flow to the operations of the battery. This work clearly shows the importance of controlling the electrolyte flow rates in running the battery management systems, as many commercial VRFBs have often a flow control limited to the on-off of the pumps.

Chapter 6 summarises all the work and presents some future perspectives.

The work has led to four interesting publications in the international literature.

All in all, Mikhail Pugach has carried out an excellent modeling of RFBs addressing different keys aspects. Of course, VRFBS are complex systems and some other aspects such as the role of the protons, the shunt current or even the temperature could be further considered. But the present work clearly shows that the boundary conditions chosen are relevant to obtain key information. The power of a model is not its complexity but its predictive ability in a relatively short time. As such, the present work achieves these goals.

It is without any hesitation that I recommend acceptation without reservation of this thesis and congratulate the candidate for the quality of his work.

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*