Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Álvaro Gonzalez

PhD Program: Engineering Systems

Title of Thesis: Flexibility characterization in power systems

Supervisor: Assistant Professor Aldo Bischi, Skoltech

Co-supervisor: Assistant Professor David Pozo, Skoltech

Name of the Reviewer:

I confirm the absence of any conflict of interest  Audun Botterud	**Date: 04-10-2021**

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

The doctoral thesis of Álvaro Gonzalez addresses flexibility needs in power systems with increasing levels of variable renewable energy (VRE) resources. The topic is of high relevance to ongoing challenges in the electricity industry, as electric power systems transition towards low-carbon solutions in many parts of the world. The thesis consists of three main chapters along with an introduction and concluding remarks.

The introduction discusses flexibility needs in power systems and how flexibility can be provided by through different means, including generation, demand, storage, and networks along with connections to other energy infrastructure as well as through improved market solutions. The introduction also introduces metrics for flexibility and how they can be measured, and identifies relevant research gaps and the corresponding motivation and contributions of the thesis.

Chapter 2 proposes a new approach to represent Li-ion batteries within power system optimization models, with a focus on improved modeling of power limits and efficiencies in such batteries. The chapter is addressing emerging needs in power systems as energy storage devices are being installed to address the variability and uncertainty stemming primarily from VRE such as wind and solar. Using a non-linear equivalent circuit model as a starting point, an elegant convex representation of the operating region of the battery is developed. The proposed representation is tested on a transmission-level network-constrained economic dispatch problem and on a distribution-level scheduling problem. The performance of the battery model is compared to several benchmarks, including a detailed non-linear representation and an idealistic model with constant battery limits and efficiencies. The results illustrate the importance of using adequate battery models within power system optimization tools, in particular to avoid producing infeasible operating schedules. Moreover, the numerical findings also show that the proposed battery representation constitutes a good trade-off between accuracy and computational tractability.

Chapter 3 discusses the possibility of connecting microgrids that provide electricity and heat, and focuses particularly on the economics of heat exchange between such systems. Under somewhat simplistic assumptions about aggregate convex operating ranges for electricity and heat production within each area, optimality conditions for a centralized dispatch across integrated areas is derived. Moreover, a decentralized approach to multi-area dispatch coordination and pricing is also presented, based on the ADMM algorithm. Analytical insights are complemented by numerical results, illustrating how efficient operational exchange of heat between areas can contribute to improved flexibility provision and cost efficiency in heat and power delivery.

Chapter 4 delves into the challenge of electricity market design for systems with higher shares of VRE, and in particular improved scheduling of energy and reserves accounting for the uncertainty in these resources. The chapter proposed an improved energy and reserve dispatch algorithm based on chance-constrained programming. Novel features include asymmetric treatment of forecasting errors and different balancing responses in opposing directions of deviation. The chapter provides analytical insights as well as numerical results that demonstrate the advantages of the proposed scheme. Although the underlying assumptions are somewhat simplistic, e.g. ignoring ramp rates and unit commitment constraints, the chapter provides important insights into cost efficient system balancing and cost causation as a function of scheduling deviations imposed on the system by individual resources.

The conclusions summarizes key findings from the three main chapters and briefly outlines direction for future work.

The author demonstrates extensive skills in the analysis of complex electricity and heat markets, using tools from optimality theory as well as mathematical programming to derive insights into the rapidly changing nature of power systems and corresponding flexibility needs. The academic scholarship is excellent, as also demonstrated by the extensive list of publications that is emerging from this work in journals and conferences of high reputation. In order to make an impact on real-world industrial practice, however, the thesis would benefit from a more extensive discussion of how the proposed solutions compare to current industry practice and also from larger-scale case studies with more realistic datasets, including out-of-sample simulations to more adequately measure the benefits of stochastic formulations.

Overall, I conclude that the submitted thesis is of high international quality on par with dissertations submitted at other leading universities, including MIT.

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*