Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Alvaro 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 (Alternatively, Reviewer can formulate a possible conflict)	**Date: 28-09-2021**

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

Overall evaluation of the thesis

Overall, this is a strong thesis. It analyzes the timely problem of flexibility in power system operations from three different angles. Chapter 2 provides a new battery loss model, and the associated analysis reveals how important a detailed battery loss model can be if we want to leverage battery flexibility in the most effective, efficient way. Chapter 3 discusses models for heat-electric microgrids, with a focus on how exchange of heat between networks can improve cost and increase the range of feasible operation, which can be interpreted as increasing flexibility. It considers both centralized optimization and distributed optimization coordinated through heat exchange prices. Chapter 4 discusses how to allocate the cost of balancing reserves associated with renewable energy variability in a chance-constrained electricity market. As reserves can be understood as a source of flexibility, this chapter thus provide a framework for pricing and allocating cost of flexibility.

A strong point of the thesis is the range of modeling and analysis tools that are employed to obtain the results, which ranges from detailed battery modeling to distributed optimization and analysis of price formation in stochastic reserve markets. The candidate appears to have separately assessed and analyzed the needs of each problem, and then identified the methods that can effectively address the questions at hand. In particular, the chapter on battery modeling is a good example of research that does not shy away from tackling challenging, but practically important details while also keeping modeling complexity in mind. As a result, the battery model should be more readily applicable in practical applications. The results on heat exchange and reserve pricing are a little more futuristic, but does provide interesting insights for the design of markets for heat and reserves.

I will note that while the breadth of the methods and results in the thesis is impressive, it does not seem to go very deep in either of the presented topics. For example, chapter 4 utilizes deterministic line flow constraints, which seems at odds with the idea of node-to-node balancing prices. Further, in chapter 3, the consideration of electricity seems to be more of an afterthought. A deeper analysis of interactions between heat exchange and electricity operation (i.e., how they complement and improve each other) would have been a natural inclusion. I will say that this impression might be due to the presentation of the work, where each topic is organized into a separate, somewhat disconnected chapter. As an example, in chapter 3, it might be useful to first present a centralized model (with analysis and numerical results) and the create another chapter which presents a more realistic model where each area optimizes its own operation (with a separate set of analysis and results). A similar comment could be made for chapter 2 and the decision of presenting stochastic unit commitment formulation in the appendix.

The trade-off between depth and breadth in a thesis is always a challenge, and thus the above comment should not be read as a fundamental objection to the thesis. Overall, the methods and the associated analysis provides a set of interesting results that pushes the state of the art in battery modeling, modeling of heat exchange markets and pricing of reserves in chance-constrained electricity markets. The results comply with international standards, and the list of publications is impressive.

A set of more detailed chapter-by-chapter comments with suggestions for edits is appended below.

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*

DETAILED COMMENTS/SUGGESTIONS

Below, I provide a set of questions and suggestions for edits/clarifications that I believe would improve the thesis. Some of them ask for additional clarifications, while others are more editorial in nature, pointing to parts of the thesis that I found hard to read because of, e.g., the positioning of figures. The candidate does not have to incorporate all the suggested edits, but I have italicized a few that I think are particularly important.

Chapter 1

The introduction to power system flexibility is appreciated!

On page 9, I believe that the definition of FACTS (described in the section on dynamic line rating and FACTS devices) is not quite correct. In my understanding, FACTS devices is also used to control power flows.

On page 10, it might be helpful to include a reference to European imbalance netting schemes.

Chapter 2

I found the model and results in Chapter 2 to be interesting. I appreciated the model based on accurate data and it is nice to see that the proposed model leads to a considerable increase in modeling accuracy.

A few suggestions:

The model assumes the solution would automatically enforce that the battery does not charge/discharge at the same time. This is not true in all circumstances and should be discussed appropriately.

I found the notation to be somewhat confusing, is it possible to make dependence on SOC more explicit throughout? Otherwise the reader has to remember which variables are functions of the SOC.

What does it mean that the difference between the NLP model and the proposed linear model is so large in Fig 2.6? Does this mean that the linear model is not accurate?

On page 44:
- How were the sample points identified when deriving the convex envelope?
- How did you identify the Max errors in the linear model?

- *Would this improve with more sampling points?*
- *What are the trade-offs you face when choosing the number of and location of the sampling points?*

How is the MILP model on page 48? Can you include a mathematical definition and/or a more careful comparison with your proposed model?

Be careful to define all variables (x_j and y_j are not defined!)

Can you include a discussion of the results in Table 2.1?

Chapter 3

(Section 3.2.3) Can the relationship between the generated heat and power in each area always be represented as a convex region? I doubt so, so it would be helpful to explain if this is this an approximation/what assumptions it is based on?

(Page 72) The model assumes the solution would automatically enforce that an area does not export and import heat at the same time. Will this always be true? A more detailed discussion would be appreciated.

(Page 75) I realize that it is convenient for your analysis to not impose restrictions on h_ab. However, can you include a discussion of the implications of this assumption? Does it impact the results?

(Page 88) You state the that JP-ADMM algorithm is guaranteed to converge. What solution will it converge to?

Eq (3.25) Where did this update come from (i.e., why is it defined this way)?

(Section 3.5) I found it hard to understand which method was used to generate the results that are discussed. Is it using the centralized method? The distributed method?

Eq. (3.1) there seems to be a + sign missing

Comment on Figures:

In several places in the thesis, the figures are located far away from where they are first described, which makes it hard to read the thesis. I would suggest to go through the thesis and consider how to move the figures closer to where they are first mentioned.

It would also be helpful to introduce more descriptive figure captions which provide sufficient information to make the figure more or less self-explanatory, and make sure that all symbols are appropriately defined. For example, I was not able to find out what H_a^D and H_b^D represent in Fig 3.5.

Chapter 4

Can you discuss the implications and motivation for using deterministic line flow constraints in the problem formulation?

Where did the analysis for the Node-to-node (OPF-N2N-AB) come from in Table 4.1?

Is it possible to add a discussion of the violation probability observed in the solutions in Section 4.7?