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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Vladimir Frolov

PhD Program: Engineering Systems

Title of Thesis: Operational and uncertainty aware planning of power systems

Supervisor: Professor Michael Chertkov

Name of the Reviewer: David Pozo

I confirm the absence of any conflict of interest	**Date: 1-06-2021**

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

- **Brief evaluation of the thesis quality and overall structure of the dissertation.**

The doctoral dissertation titled O*perational and Uncertainty Aware Planning of Power Systems* by Mr. Vladimir Frolov, focuses on the methodological aspects for planning elements of power systems grids. The approach chosen by Mr. Folov is based on Mathematical Programming; a particular emphasis was placed on developing, first, better ways of modeling a large number of power grid operating points within planning problems; and second, iterative algorithms for solving such models.

The thesis manuscript contains eight chapters and one appendix. The doctoral thesis contents are presented in increasing degree of complexity, starting from simple power system planning models that assume deterministic future operating points and DC power grid representation to cloud-based stochastic representation of uncertainty with AC-OPF and multistage setup.

Chapters 2, 3, 4, and 5 form part I. This part is focused on sample-based stochastic programming methods. The optimal size and location of FACTSs devices in electrical grids are solutions of the proposed models in this dissertation.

Chapters 7 and 6 form part II. This part is focused on the probabilistic representation of uncertainty via chance constraints for the full support of uncertainty and for the conditionally-dependent partitions of the full support, namely in here "cloud".

Chapter 1 introduces and motivates the thesis background and problem, while chapter 8 summarizes the overall thesis proposing new avenues for further research.

- **The relevance of the topic of dissertation work to its actual content**

The actual content of the thesis is in line with the topic addressed in this dissertation. It is a relevant and challenging topic in all worldwide power systems.

- **The relevance of the methods used in the dissertation**

Mathematical Programming is used as a fundamental tool. It is the gold standard for dealing with the problems addressed in this dissertation, being it a suitable tool for the objective of this doctoral work. However, although Mathematical Programming is a well-established field, there are many open challenges when applying to power system operation, which is interdisciplinary as it involves different connections from AC-OPF, FACTs devices modeling, and non-convex optimization methods.

- **The scientific significance of the results obtained and their compliance with the international level and current state of the art**

This doctoral work and obtained results are on par with the current state of the art in the field. It is worth highlighting that it has been already recognized by the publications in highly rated journals such as IEEE Transactions on Control of Network Systems and top-notch international conferences (PowerTech and IREP). All of these confirm the interest of the power systems community in this research work.

- **The relevance of the obtained results to applications (if applicable)**

Electric power grid planning affects a wide range of stakeholders in the power systems industry, like system operators, private investors, customers, but also political decision-makers of the countries with strong opposition for new transmission lines. So, the current thesis dissertation elucidates better ways for improving the decision-making for the proper location and sizing of FACTs devices. The practical impacts of electrical grid operation are diverse: cost savings, reliability, and security, to name a few. I believe that this doctoral work from the Ph.D. candidate will attract attention beyond academia.

In terms of publications, this thesis has listed the next publications as an outcome of the research work:

- One first-author journal paper was published in the IEEE Transactions on Control of Network Systems, a highly rated Q1 journal.

- One first-author conference paper presented at a highly reputable international Scopus-indexed conference: PowerTech 2019.

- One first-author conference paper presented at a highly reputable international Non-Scopus-indexed conference: IREP 2017.

- Two first-author papers were published in 2014. But, they were published even before finishing the MSc thesis of the candidate in 2016. See ref. [42]. I am not sure if these two papers would be part of the research output of this doctoral thesis. The candidate should clarify.

- One working paper related to one of the chapters of this dissertation.

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

The next issues should be considered in the final draft.

1) Title. Please review it. Note that the standard planning models in the scientific community and in industrial practices are "operational-" and "uncertainty-" aware. It seems it is a distinction of your thesis, but it is a standard already. Also, "planning of power systems" covers a wide range of elements such as transmission lines, generation capacity, etc. Those are not covered in this thesis.

2) Structure. For me, the dissertation is a bit long and repetitive. The author could decide if he would prefer to restructure it or keep it as it is. Many figures are repeated (e.g., 7.1. and 5.1), many passages are identical or almost identical to others (e.g., 7.2.3.), and practically all chapter introductions (from ch. 2 to ch. 7) repeat the same motivation and background for planning under uncertainty. I guess that structural-wise could be a better way of presenting the research work developed. In the end, the planning model from chapter 7 generalizes the previous chapters' models under certain assumptions.

3) The authors mentioned the case of Europe as an example of where the "transmission network is severely limited by social and environmental constraints." Many of the FACTs devices have been installed for many other different reasons that the one motivating this thesis. So, economic efficiency is not the driver in this case. In addition, there could be other issues such as LMPs and

FTRs impact when adding new FACTs devices. The student should consider providing an additional discussion of these issues.

4) The overall work has been very focused on *scalability* issues of planning models by providing "cloud"-based representation and *accuracy on the grid model* used (DC vs. AC). However, I am missing comparisons with the standard solutions from state-of-the-art that validate and better position the methodology proposed in this thesis, such as scenario reduction techniques, operational clustering points, out-of-sample analysis.

5) Something that I have not yet fully understand is the idea of clustering/grouping operational points by "clouds" without considering temporal correlation or spatial correlation. This issue leads to missing the ability to capture flexibility needs such as ramps or any time-linking constraints (batteries, hydro reservoirs) when not using temporal correlation. But also, it leads to missing the ability to capture renewable location complementarity when producing when not using spatial correlation. Both are key for understanding and quantifying the benefits of new grid updates. Please, could you further elaborate on this issue?

6) Following up on the rationality of clustering/grouping operational points/conditions based on the system states, x:

- Firstly, the system states should be precomputed ex-ante. It is not well documented in this thesis. For instance, what is the pre-computing simulation time? Was it always guaranteed optimality?

-Secondly, the system states depend on the final grid configuration. So, it cannot be known as ex-ante. Please, elaborate on this issue. I am missing something that is not clear in the manuscript.

7) Example 2.5.1 and 2.5.2. Eq. 2.5.1. Why does power p12 not depend on p3? By superposition principle, it should. What is missing here?

8) One of the observations from the experiments is that the algorithm choses susceptance corrections that set a line's total susceptance to zero. This solution requires CAPEX to install a FACT device while the same output can be achieved by transmission switching (TS) with no CAPEX and no new installations. I understand that TS is not included, but you can see that easily can be found a better alternative. In addition, there are no discussion on the non-wire solutions. It would be great to refer to (not to model) them in this thesis dissertation.

9) Title "2.8.2 Robust optimal placement and sizing." Please review the term "robust optimization" because it does not follow the concept of that the OR community has on robust optimization.

10) In the abstract, it is mentioned:

"The first is stochastic programming, when variability and uncertainty are represented by a set of deterministic scenarios. A two-stage planning problem with a single set of investment variables for all sampled operational scenarios." Here deterministic and sampled operational scenarios are contradictory.

11) Please add units to figures. Many of them are without units.

12) Review the overall text; there are several typos. For instance, on page 57, it is mentioned "it was discussed in Section 9.6 real power systems", but it is chapter 3; on page 92, you refer to equations from the previous chapter while it is not what do you intend to; on page 128 review "more optimal".

13) Page 66. What do you mean by "economy percentage"? is this "avoided cost percentage"?

14) Page 94. "Our main algorithm gives upper bounds solutions of the objective function with the gap less than 0.1%." Can you prove that the algorithm proposed always provides an upper bound?

15) Section 7.2.1. It is proposed to cluster operational conditions using K-means. The standard K-means algorithm is random, depends on the seed. Thus, the cluster itself will be random, and therefore the output of any model that uses K-means-based clustered information will be random. Please, elaborate on the impact of it.

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*