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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: Yury Maximov

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Date: 25-05-2021**

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

1. Brief evaluation of the thesis quality and overall structure of the dissertation.

The thesis is high-quality research work. The dissertation is very well-structured and easy to follow. Addressed problems are essential for power systems operation and planning and undoubtedly have a high practical value. As a reviewer, I have only minor concerns and questions that do not affect an excellent assessment of this work.

2. The relevance of the topic of dissertation work to its actual content

The topic of the dissertation is relevant to its actual content and author's publications.

3. The relevance of the methods used in the dissertation

All methods are relevant and appropriate.

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

The results are interesting and significant and certainly advance the state-of-the-art which is proved by presentations in high-level conferences and publications in the top journals.

5. The relevance of the obtained results to applications (if applicable)

Obtained results are extremely relevant to the area of study and the thesis' topic.

6. The quality of publications

The results are published in 5 first-authored papers, one more mentioned as a work in progress. The list of publications includes three Q1 journals and two major conferences. Thereby the thesis meets Skoltech requirements on publications' quality and quantity.

7. The summary of issues to be addressed before/during the thesis defense
Despite the high-quality of the work, I have to mention of a few drawbacks of the thesis:

7.1. The state-of-the-art (SOTA) comparison
A number of relevant algorithms were proposed in the thesis; however, comparison with the SOTA is mostly missing. Having a separate chapter with a brief survey of the SOTA would benefit the thesis.

FACTS/SC/SVC placement (I have included only a few papers that have at 45+ citations):

- Sharma, Nikhlesh Kumar, Arindam Ghosh, and Rajiv Kumar Varma. "A novel placement strategy for FACTS controllers." *IEEE Transactions on Power Delivery* 18.3 (2003): 982-987.
- Bhattacharyya, Biplab, and Sanjay Kumar. "Approach for the solution of transmission congestion with multi-type FACTS devices." *IET Generation, Transmission & Distribution* 10.11 (2016): 2802-2809.Rahimzadeh, Sajad, and Mohammad Tavakoli Bina. "Looking for optimal number and placement of FACTS devices to manage the transmission congestion." *Energy conversion and management* 52.1 (2011): 437-446.
- Rahimzadeh, Sajad, and Mohammad Tavakoli Bina. "Looking for optimal number and placement of FACTS devices to manage the transmission congestion." *Energy conversion and management* 52.1 (2011): 437-446.
- Singh, J. G., S. N. Singh, and S. C. Srivastava. "Placement of FACTS controllers for enhancing power system loadability." *2006 IEEE Power India Conference*. IEEE, 2006.
- Huang, J. S., Z. H. Jiang, and Michael Negnevitsky. "Loadability of power systems and optimal SVC placement." *International Journal of Electrical Power & Energy Systems* 45.1 (2013): 167-174.

A nice review of FACTS placement techniques can be found here:

- Gaur, Dipesh, and Lini Mathew. "Optimal placement of FACTS devices using optimization techniques: A review." *IOP conference series: materials science and engineering*. Vol. 331. No. 1. IOP Publishing, 2018.

7.2. Cloud AC-OPF and Multi-Cluster AC-OPF

The idea behind both approaches is nice; however, I am not sure about the statistical guarantees that each of them has. For the scenario and for the sample approximation approaches to chance-constrained optimization we have rigorous guarantees on the number of samples required to produce the solution that meets probabilistic constraints (see papers of Campi; Luedteke and Nemirosky).

- Calafiore, Giuseppe C., and Marco C. Campi. "The scenario approach to robust control design." *IEEE Transactions on automatic control* 51.5 (2006): 742-753.
- Luedtke, James, and Shabbir Ahmed. "A sample approximation approach for optimization with probabilistic constraints." *SIAM Journal on Optimization* 19.2 (2008): 674-699.
- Nemirovski, Arkadi, and Alexander Shapiro. "Convex approximations of chance constrained programs." *SIAM Journal on Optimization* 17.4 (2007): 969-996.

Are there any rigorous guarantees behind the proposed approach? Is it possible to justify it over a simple example? What is the behavior of approximation quality when a failure probability tends to zero? Classical approximations (Markov, Chebyshev, Chernoff, scenario, etc..) tend to dramatically overestimate a failure probability. What is the behavior of your algorithms? I was also wondering why a probability of violation set to 1% (see section 6.9.1.) is reasonable in practice? How conservative are the proposed algorithms?

7.3. Scenario redundancy and uncertainty modeling (Section 6).

I suspect a number of scenarios coming from uncertainty realization are redundant, e.g., among the set of all constraints in the chance-constrained optimization problem only a few lead to a constraint violation. Is this correct?

A few alternative approaches aiming at reducing the complexity can be considered then:

- Mezghani, Ilyes, Sidhant Misra, and Deepjyoti Deka. "Stochastic AC optimal power flow: A data-driven approach." Electric Power Systems Research 189 (2020): 106567
- Barrera, Javiera, et al. "Chance-constrained problems and rare events: an importance sampling approach." Mathematical Programming 157.1 (2016): 153-189.
- Lukashevich, Aleksander, and Yury Maximov. "Power Grid Reliability Estimation via Adaptive Importance Sampling." IEEE Control Systems Letters (2021). Arxiv: 2105.08753

All these approaches are based on importance sampling, that allow disregarding useless configurations.

7.4. Algorithms' style

The thesis is well-written and I appreciate using the flowcharts to explain the algorithms; however, a concise step-by-step explanation of each of the algorithms when possible (say with the algorithm environment in LaTeX) will further improve the thesis readability.

Overall: the comments mentioned above do not chance an excellent assessment of this thesis. All changes proposed above are recommended, but not required.

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*