Skoltech
Skolkovo Institute of Science and Technology

Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Oleg Khamisov

PhD Program: Engineering systems

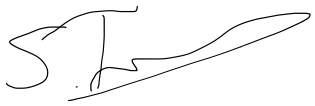
Title of Thesis: Optimization of Frequency Control in Power Systems

Supervisor: Assistant prof. Anatoly Dymarsky

Co-advisor: Prof. Janusz Bialek

Date of Thesis Defense: 02 April 2020

Name of the Reviewer: Dr. Simon H. Tindemans

I confirm the absence of any conflict of interest	**Signature:**  **Date: 09-03-2020**

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

I have read Mr. Khamisov's thesis with great interest. It addresses a classical problem in power system engineering – frequency control – that has regained prominence and has grown in complexity due to the reduction in system inertia and increasingly distributed nature of control. The approach proposed in this thesis, using a set of integral algebraic equations that are implemented in a decentralized manner, is very appealing, as it is sufficiently powerful to achieve a wide range of objectives, yet simple enough to analyze analytically – as demonstrated in this thesis. In particular, it is refreshing to see that sufficient attention is given to the problem of missing measurements and data, and the robustness of the algorithm to the use of imputed values, e.g. by smoothing measurements for the disturbance vector approximation (chapter 11). The results presented in this thesis are significant and of a high standard; in my opinion, they are internationally competitive.

In my opinion, the thesis is generally well-structured and gradually builds up the complex subject matter. It starts by carefully explaining the problem and introduces relevant notation and models in chapters 5-9. The general solution approach in chapters 10-11 is very helpful, even more so on second reading, as it helps putting the results in context. The use of 7 problems of increasing complexity was useful to separately analyze each partial solution, before tackling the full problem in Section 13.4 – Chapter 14. The comparison with existing literature in chapter 3 was useful and very thorough.

Key results from this thesis have appeared in a number of publications, which appear to be of good quality. They are mostly conference publications, which is not a problem, but I do think a wider audience could be reached for this interesting research by a publication in a journal paper. It would have been useful, but not essential, to have a clear overview of which results (e.g. Problems 1-7 and their solutions) have been covered in each of the publications. Looking through the references, I do wonder how the work in [99], also briefly referenced on p160, relates to this work.

Upon close reading of the derivations, proofs and text I did come across a couple of relatively minor issues that ought to be corrected or (re-)considered prior to the defense. They are the following:

1. I came across a number of typos. Especially those in mathematical expressions risk confusing readers – but they do not seem consequential for the results. I have attached a marked-up copy of the thesis that highlights what I believe to be typos.
2. The proof of Theorem 9.4 (p82) appears to be slightly incomplete. First, going from (9.22) to (9.23), relies on the false identity $\sum_i \omega_i d_i = (\sum_i \omega_i)(\sum_i d_i)$. Moreover, it does not immediately follow from (9.25a) that $\omega_i = \omega_j$. The missing step (perhaps implied by the candidate), appears to be that $\ker(C^\top) = (1, \dots, 1)^\top$, so that (9.25a) *does* imply $\omega_i = \omega_j$. That result can then be used to derive (9.26) from (9.22), skipping (9.23).
3. In the example in Section 13.5, it is not entirely clear to me that the controller does indeed preserve inter-area flows – or if it does, compared to which reference state. Figure 13.7 shows that the generators in the upper area have adjusted their settings by (-100MW (forced), -31MW, +36MW), for a total of -95MW. And indeed, generation in the lower area increases by 95MW. I am not sure how to reconcile this with the convergence to 0MW shown in Figure 13.10. More generally, this raises a question about the performance of the control algorithm if no feasible solution can be found (in this case, both G10 and G8 are very constrained), a question that is also raised by the candidate in the Suggestions for Future Work. I would like the candidate to check and possibly explain this result, and am interested in discussing the more general case at the defense.
4. In Figures 14.2 and 14.3, it is not clear which curves are overlapping with the control limits (solid black curves). Perhaps dotted lines can be used for control limits, so that underlying curves are not hidden from view.
5. The use of the 'disturbance' vector r occasionally confused me. First, the name suggests it is typically small (i.e. having 'no' disturbance during normal operations), but it consists of "load and unknown disturbance" (p73). Second, r_i is first introduced on p64 as being the consumption on bus i, presumably with a positive sign, but it changes sign later (p73 onwards). A clear statement of the sign convention would be useful.

I look forward to discussing the thesis, results, and general problem setting, with the candidate during the formal thesis defense.

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*