Skoltech
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Thesis Changes Log

Name of Candidate: Vladimir Frolov

PhD Program: Engineering Systems

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

Supervisor: Professor Michael Chertkov

The thesis document includes the following changes in answer to the external review process.
The author would like to thank Jury Members for the provided feedback. It was very helpful for the improvement of the final version of thesis. Please, find the following changes made in the final thesis file: **According to the comments of Professor Göran Andersson:** 1. The list of acronyms and abbreviations is added to the Appendix 2. A small summary is added in the end of each chapter 3. Mid-term and long-term planning are defined in the Introduction (Section 1.2) and the situation is described in detail 4. A discussion of the relation to power markets operation is added to Introduction (Section 1.2) as well - A proofreading is performed **According to the comments of Professor Clement Fortin:** 1. The list of acronyms and abbreviations is added to the Appendix 2. A proofreading is performed, language errors are fixed **According to the comments of Professor Jury Dvorkin:** 1. The thesis was proofread. Typos, language errors, punctuation, references inside the text were checked and corrected 2. "Cloud" definition in the context of a set of operational conditions is introduced to the list of acronyms and abbreviations **According to the comments of Professor Federico Martin Ibanez:** 1-2. -The way of presentation and structure of the thesis were adjusted

-Introduction to the problem with examples and broader problem description were introduced. Literature review which was mentioned in the introductory part of each chapter was extended and included to the Introduction of the thesis
-Motivation of the work was additionally confirmed by examples of the USA and Europe power systems recent trends
-Aims of the research were additionally specified in Section 1.1.
3. A brief description of FACTS with industrial installation approaches is added to Appendix.
4. Chapter 2 is aimed to demonstrate algorithm operation at small number of nodes showing iterative processes at validation phase. All the examples here are situated in the incremental complexity. Chapter based on previous research corresponding to DC-modelling is removed and just referenced. Images, illustrating sequential linearization approach, are added to Section 2.3. and described step by step.
5. The thesis was proofread, and writing was improved
6. Figures sizes were adjusted. Figures were situated according to the description in the text. Fig.2.2 in the previous version was placed to give intuition about step by step adjustment of the operational point in a simple example.

According to the comments of Professor David Pozo:

- In terms of the papers from 2014. I fully understand that these papers are not output of the doctoral thesis. Chapter based on old papers was removed and just referenced. For better understanding of the approach on simpler examples (without AC and multiple scenarios), please refer to the papers.

1. Title of the thesis was reviewed, and we decided not to change it
2. The structure of the thesis was improved. Introductory part was extended and information on existing research was moved there. In terms of the chapters representing incremental growth of complexity – the decision is to keep it. The text was checked for the repetition of the provided information. Chapter 2 is specially adopted to better explain the algorithm.
3. FACTs are installed in Europe for many reasons, this is right. Additional information on FACTS installation was added in Appendix. Review of research on FACTs application is extended and put in Section 1.2. Reference to the impact of FACTs installation to LMPs and FTRs is added the description of the devices (Section 1.2)
4. In terms of the validation – we use validation against state-of-the-art IPOPT solver and Matpower toolbox, where it is applicable. In terms of comparison with other methods it is a good point. The analysis of other solutions (regarding FACTS placement) is added to the introductory part.
5. In terms of grouping operational conditions to “clouds”. It is additionally specified in the Section 1.2 that each considered operational state is individual in terms of its operational settings (basically each OPF is independent) but limited by available capacities of equipment at current time interval. It means that ramp activities are not considered. Thus, temporal correlation is not considered and not quite relevant to mid-term and long-term analysis and planning. In terms of spatial correlation – spatial effects considered for each sample by transmission system model. And grouping of samples is available for only samples from a single time interval where the grid structure/equipment capacities are virtually fixed. This information is added to Section 6.1.

6. This is a very good question. In our described approach precomputing is necessary only for the comparison with exact dispatches (not used in analytic reformulation/algorithm). It was done in about 8 hours. If precomputing in terms of OPF is not feasible, again precomputing without line capacity limits is possible (if initialization is required). Precomputed OPFs can be used for precomputation of the parametrization of the response policy, which make CC-optimization model way simpler. Now, in terms of the grid configuration. Again, inside each time interval grid is globally fixed. The way of accounting of additional installed capacity on top of the CC- formulation is already developed. Comment is added to Section 6.4.2.
7. Equations are correct. p1+p2+p3=0, there is no losses in DC-approximation. Phase of one node can be considered as 0. This chapter is removed and referenced as papers.
8. Correct. If optimal solution is to make total susceptance equal to zero for all considered scenarios, then line can be just switched off. If for some scenarios total setting is zero and for other not – then CAPEX is required. The first chapter is removed and referenced as papers. Non-wire solutions would be the ones which are fully operational. Comparison with them is a kind of separate work. They are referred to in the Section 1.1.
9. Chapter is removed from the final version
10. Here deterministic is referred to deterministic analytical modelling instead of chance-constraints. Replaced by
“A two-stage planning problem with a single set of investment variables for all available operational scenarios and an individual set of operational variables-settings for each scenario is formulated”

11. Figures are checked and corrected in terms of size. Placed properly in the text. In chapter 2 usually horizontal axis corresponds to id of the generator.
12. Typos and references in the text are checked and corrected, thank you.
13. Correct. It is avoided cost percentage in comparison with OPF solution. Information is added to the text.
14. Yes, as the algorithm always discovers an exactly feasible solution (in comparison with relaxation approaches), it could be an upper bound or infeasibility (if not solved). This information is added to Section 4.4.1.
15. It is correct (about random clustered information). The point of K-means clustering in this setting was to find “close” operational conditions and then perform analysis on a given set. Basically, one can perform K-means ones and store the assignment and then work with provided clusters in this setting. This information is added to the text.

According to the comments of Professor Yury Maximov:

7.1 additional SOTA references introduced to the thesis in the Section 1.2. Introduction is extended.
7.2 This is a good question. At a current point we have not explored a question of statistical guarantees. When failure probability tends to zero, objective function value tends to true MS-AC-OPF one, but a problem can become infeasible due to some big uncertainty margin. This question should be explored as well. 1% violation was selected experimentally as providing good approximation but demonstrating visible difference between three parametrizations of uncertainty inside the cloud. If taking too small probability violation algorithm becomes quite conservative. Additional research is required for that. Added to Section 7.3.
7.3 Scenario redundancy. Of course, many scenarios are redundant or similar in terms of their impact (low loading and medium loading). In the stochastic programming part this should be

accounted at the scenario selection stage. At the probabilistic modelling, the idea of switching to that is accounting for scenarios redundancy itself. If operational conditions are provided in the probabilistic form and parametrization of the response is known somehow, then one can work directly in terms of CC formulation and its solution.

7.4 Chapter 2 is aimed to explain algorithm operation at small number of nodes showing iterative processes at validation phase. All the examples here are situated in the incremental complexity. Chapter based on previous research corresponding to DC-modelling is removed and just referenced. Images, illustrating sequential linearization approach, are added to Section 2.3. and described step by step.