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Assessing the impact of sampling and clustering techniques on offshore grid expansion planning

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Abstract

Due to the ongoing large-scale connection of non-dispatchable renewable energy sources to the power systems, short- to long-term planning models are challenged by an increasing level of variability and uncertainty. A key contribution of this article is to explore and assess the implications of different dimension reduction approaches for long-term Transmission Expansion Planning (TEP) models. For the purpose of this study, a selection of sampling and clustering techniques are introduced to compare the resulting sample errors with a variety of sampling sizes and two different scaling options of the original data set. Based on the generated samples, a range of TEP model runs are carried out to investigate their impacts on investment strategies and market operation in a case study reflecting offshore grid expansion in the North Sea region for a 2030 scenario. The evaluations show that dimension reduction techniques performing well in the sampling and clustering process do not necessarily produce reliable results in the large-scale TEP model. Future work should include ways of incorporating inter-temporal constraints to better capture medium-term dynamics and the operational flexibility in power system models.

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Keywords:
Transmission Expansion Planning, Sampling, Clustering, Dimension Reduction, Offshore grids

1. Introduction

1.1. Increasing variability and uncertainty in TEP models

Most power systems around the world experience an increasing share of variable and non-dispatchable generation in their energy mix. At the same time, adequate models for both short-term and long-term planning become more complex. In comparison to traditional power systems which were primarily subject to power demand variations and fault occurrences, introducing high shares of renewable sources yields a significant rise of the power systems' underlying variability and uncertainty [1].

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Determining investments in new transmission lines or reinforcements of the existing transmission network is a crucial task in power system planning. These investment decisions are lumpy and capital intensive, which can have a long-lasting effect on expected market prices and power system operations. For this reason, the task of making sensible Transmission Expansion Planning (TEP) decisions is a widely studied problem [2].

The TEP is particularly relevant in the European context, where the European Union is pursuing a fully integrated internal energy market in which energy can flow freely across its regions. Robust transmission and distribution infrastructure, as well as a well-interconnected European network are seen as key constituents for a successful integration of renewable energy [3]. To be more specific, spatial levelling effects of fluctuating renewable energy resources, such as on- and offshore wind as well as solar, make grid reinforcements attractive [4]. With that in mind, recent developments, such as the aforementioned rise in variability and uncertainty, make efficient solutions of long-term TEP problems even more relevant, but at the same time increase their complexity.

1.2. Model complexity and computational challenges

In order to keep long-term TEP models tractable for a large geographical scope and a high level of spatial and temporal detail, a common approach is to use load duration curves or other generic scenario reduction approaches, such as sampling and clustering methods on the model's input data [5], [6], and [7]. For instance, a reduction approach focused on the model's output data rather than the input data is shown in [8]. Computationally, condensing the input data yields a smaller number of variables and constraints in the resulting optimization problems and leads to more acceptable solution times.

Dimension reduction can be crucial when dealing with large-scale planning models, as they often cover a multi-regional and multi-national scope. Given the broad geographical extent, location-specific climate- and weather-dependent characteristics cannot be omitted, as temperature, wind speeds and solar irradiation exhibit significant variations within the considered scope. Hence, it is of great importance to sustain the characteristic correlations when approximating full year time series with reduced-size, sampled time series. This is particularly valid for TEP, as the incentives for grid investments are triggered by spatial differentials, e.g. a high non-dispatchable production in one area with low demand could use a transmission line to transmit power to another area with high demand and low non-dispatchable generation.

1.3. Literature review

Regarding different dimension reduction approaches, a comprehensive and consistent comparison including a variety of sampling as well as clustering techniques is still not available from the literature. In [9], a number of partitioning and hierarchical clustering approaches are compared for probabilistic load modelling. Recently, a comparison of different approaches for selecting representative days in generation expansion planning problems as well as a new optimization-based approach is presented in [10]. Other works such as [11] present a comparison of different clustering techniques in the context of power system reliability assessments.

What is not yet clear is the impact of different dimension reduction methods on the results of TEP problems, such as the model for offshore grid expansion shown in this study. Metrics describing the quality of a raw data sample might significantly deviate from the effect it eventually has on the TEP model's quality of results which needs to be addressed. Therefore, it is the key objective of this study to assess the impact of different sampling and clustering techniques reducing the number of hourly time steps being considered by a long-term TEP model on its performance and the quality of its results.

In the remaining part of this article, Section 2 discusses the methodology used to carry out the comparative analysis of dimension reduction techniques and their consequences for a long-term TEP model. Section 3 provides an overview of the employed dimension reduction techniques in this study, i.e. sampling and clustering methods, and elaborates on the two scaling options applied in this article. Introducing the second phase of the study, Section 4 highlights the mathematical formulation of the long-term TEP model and the analysed case study reflecting an offshore grid expansion in the North Sea area. The first part of Section 5 presents the sampling results, and the second part exhibits the long-term TEP model results capturing the model-dependent effects of the dimension reduction techniques. In Section 6, the obtained comparison and evaluation results are discussed, and Section 7 concludes the study.