# IPID4all Doctorate Research Exchange with the Technical University of Denmark

## Feedback report

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*Optimal Design of a European Power System with Very High Shares of Renewables*

## Introduction

More and more countries decide to transform their power supply systems. Conventional generation techniques based on fossil fuels shall be replaced by generators which use renewable sources – mainly wind, photovoltaics and hydro. In this context, the question about the optimal pathway along which this transformation shall take place becomes increasingly important. One way to define these pathways are so called expansion problems. Mathematically they can be defined as an optimisation problem that aims on minimising investment costs plus some operational costs. While the investment costs are determined by the investment costs of the different generator types and the total amount of power – or capacity –, which needs to be installed, operational costs strongly depend on the temporal fluctuation of (i) the generation from volatile renewable sources and (ii) the fluctuation of the demand. Since the temporal fluctuation of the generation is not only determined by meteorology, i.e. the fluctuation of the wind and the solar irradiance, but also by the installed capacity of the different generator types, minimising investment costs and minimising operational costs are coupled by this very capacity: The investment problem decides about the optimal (mostly cheapest) generation capacity setup. This setup, however, might lead to suboptimal, i.e. high operational costs and vice versa. The expansion problem needs to find the optimal trade-off between investment costs and operational costs. The fact that these two problems are coupled, however, makes its solution difficult and compuationally expensive – especially when the power system under consideration is large and when many different generator types shall be considered. Furthermore, the operational problem would ideally be solved for a very high number of scenarios, that covers the full range of variability.

To overcome the issue of high computational costs, so called scenario reduction techniques are applied. These techniques aim to minimise the number of scenarios to a number which is feasible without losing to much information about the variability. During my exchange at the electricity markets group (ELMA) at the center for electrical engineering of the danish technical university (DTU) I – together with my supervisor Prof. Pierre Pinson – tried to address the second aspect: the size of the power system.

## Research Undertaken

Power systems are commonly represented by a number of nodes. Each node is represented by time series of demand and power generation depending on its geographical position and the installed capacities of different generator types. Nodes are connected by links. In this setup, nodes can exchange energy via the links which connect them and they are, hence, able to balance potential

mismatches between generation and demand – assuming that the transmission capacities are sufficiently large. The bigger the power system, the higher the number of nodes and links and consequently the higher the number of decision variables of the investment problem.
During my exchange at DTU I – together with Pierre and other colleagues from the ELMA group – developed an approach to reduce the number of decision variables in a power system expansion problem. This involves the implementation of a program that solves this problem using the programming language R and its interface to the Gurobi solver. Furthermore, decomposition methods – in this case Benders' decomposition – had to be applied and, consequently, had to be implemented as well.
I tested the approach for a simplistic investment problem and a model of an idealised German power system I had used before consisting of more than 400 nodes and more than 1000 links. The results were promising and I am now working on a methodology to validate our approach.

## Personal Experience and Conclusions

I experienced DTU's center for electricial engineering and especially ELMA as a highly dynamic and motivating environment. The colleagues were friendly, helpful and extremely competent. I especially appreciate their time, which they spent to share and explain their ideas and to help me find my way in this new working environment. I really learned a lot and had a great time. I would like to thank everyone who made this exchange possible.

## Outlook

As mentioned above, I am recently working on the validation of the developed approach. I will continue this work. We definitely envisage a common publication. In the context of writing this publication, I am thinking about spending some additional days at DTU – maybe in connection with a conference and / or workshop.

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