IPID4all Doctorate Research Exchange

Feedback Report

Columbia University

in the City of New York

Department of Industrial Engineering and Operations Research
S.W. Mudd Building
500 West 120th Street
New York
NY 10027, USA
http://ieor.columbia.edu/

Home Supervisors:

Prof. Sebastian Sager
Otto-von-Guericke University
Magdeburg, Germany
Affiliation:
Institute for Mathematical Optimization

Dr. David Kleinhans
R&D Manager System Modeling
NEXT ENERGY – EWE Research Centre
for Energy Technology at the
University of Oldenburg

Host Supervisor:

Prof. Daniel Bienstock
Columbia University
New York, NY, USA
Affiliation:
Department of Applied Physics
and Applied Mathematics

M.Sc. Carsten Matke
EWE Research Centre for Energy Technology
at the University of Oldenburg
Carl-von-Ossietzky-Str. 15
26129 Oldenburg / Germany
Email: carsten.matke@next-energy.de

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Exchange topic: Modeling and Solving Battery Operation Problems

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Introduction

I have been working as a researcher and PhD candidate at the EWE Research Centre for Energy Technology at the University of Oldenburg (NEXT ENERGY) since October 2014. I am writing my PhD thesis in Applied Mathematics at NEXT ENERGY in the research group System Modelling and I am externally supervised by Prof. Sebastian Sager from the Mathematical Optimization Institute at the Otto-von-Guericke University (OVGU).
As part of my PhD project at NEXT ENERGY, we derived a network model of electricity transmission grid for scientific purposes, called SciGRID [1], which is based on open data provided by OpenStreetMap[1]. Using SciGRID, an open grid dataset was generated, which we used to analyze the complexity of power transmission networks by means of a graph-theoretical decomposition approach [2].

Further, I am interested in the design of networks with the ability to integrate high shares of renewable energy sources. Professor Daniel Bienstock is a renowned expert on the analysis and control of power grids, especially in studying vulnerabilities and cascading blackouts, which made him an ideal mentor. He is a Professor at the Columbia University's Industrial Engineering and Operations Research Department. As part of the research group led by Prof. Daniel Bienstock, I was involved in a new collaboration between NEXT ENERGY, OVGU and the Columbia University. This collaboration includes research on modeling and solving battery operation problems to offset uncertainty of renewable energy sources in power transmission networks.

In this short report on the exchange, I will present preliminary results from this collaboration and my personal experience of the exchange. Finally, I will give conclusions from our results and explain my further plans for collaboration with Prof. Bienstock.

Research Undertaken

During the exchange period, under the guidance of Professor Daniel Bienstock I had access to the necessary knowledge and resources to address the problem of modeling and solving battery operation problems in power transmission networks. The basic idea was to combine an optimal power flow in a multi-time period model with robust optimization techniques to handle forecast errors of renewable energy sources with an affine control for battery operations. The objective is to minimize the costs of conventional power generation. In the proposed model, the main aim is to offset uncertainty in renewable forecast output while minimizing cost.

In a first step, the multi-time period optimal power flow framework for power transmission networks was reviewed and implement. Then both a battery model with an affine control policy and a wind power generation model were developed and integrated. The wind power model represents both expected forecasts and forecast errors of wind power generation output for each time period. By means of the *Farkas Lemma, cuts* were generated. Based on these *cuts,* a *Cutting Plane Algorithm* was developed to solve the robust optimization framework. In **Figure 1,** the principles of the *Cutting Plane Algorithm* are illustrated by

[1] www.openstreetmap.org

means of a very small network with **one battery**, **two wind farms**, **three load areas**, and **three conventional power generators**. This example is taken from a presentation that we gave at at the FERC Software Conference [3].

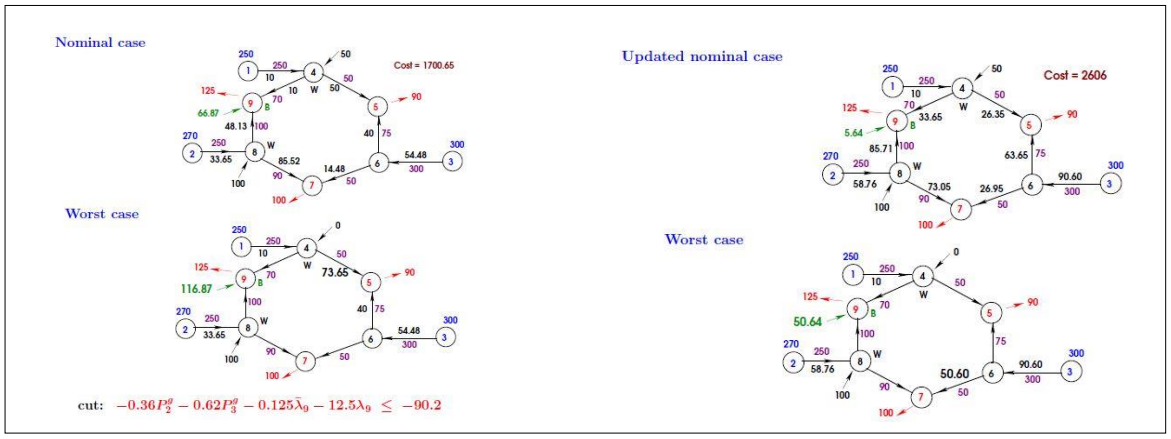

Figure 1: All four networks represent cost-optimal power flows. **TOP LEFT:** Nominal case without consideration of forecast errors. **BOTTOM LEFT:** Worst case of forecast errors for wind power output results in a violation of the flow limit of line 4-5. From this violation a cut is generated to prevent this violation. **TOP RIGHT:** Nominal case without consideration of forecast errors but with consideration of the cut. Note that the costs increased. **BOTTOM RIGHT:** Worst case of forecast errors for wind power outputs with consideration of the cut results in a prevention of the line 4-5 from exceeding the flow limit.

Personal Experience

Most of the people I met at the Columbia University were international students from all over the world. The three PhD Students working in the Group of Prof. Daniel Bienstock came from Singapore, Canada, and Chile. Furthermore, there was a very informal and pleasant atmosphere in the research institute.

In the first month, Prof. Daniel Bienstock explained how to analyze and control power grids in general. In particular, we investigated the AC & DC power flow equations, the use of the *Farkas Lemma*, and the possibilities for affine control of batteries. Further, he elaborated robust optimization methods that can be used for power transmission networks with high share of renewable energy sources.

In the second month, we had many meetings on modeling battery operation problems to balance power supply and load. As a consecutive step, we started implementing and testing our model based on open grid data from MATPOWER[2]. Herby, we made in particular use of my knowledge in software development from the SciGRID project at NEXT ENERGY.

In the last month, we further extended and improved our model for large grids with thousands of busses and branches and presented our first results at the FERC Software Conference [3]. At this conference, I had the opportunity to talk with Prof. Ray Zimmermann who is responsible for the development of MATPOWER. We talked about the development of case files and he agreed that the open grid dataset derived with SciGRID could be part of MATPOWER in a future release.

[2] http://www.pserc.cornell.edu/matpower/

Overall, it has been rewarding to be working with an interesting group of international researchers in the Columbia University's Industrial Engineering and Operations Research Department located in Manhattan of New York City. Through this exchange I extended my knowledge in mathematical programming and vulnerability analysis of power networks with high share of renewable energy sources. I gained experience, important skills, and methodological input which is crucial for my success in my PhD.

Conclusions

I had a very successful exchange period in the Columbia University's Industrial Engineering and Operations Research Department. The undertaken research provides important methodological contributions to the research of transmission networks with high share of renewable energy sources by establishing a method that can be used for validating power transmission networks. In particular, the model for investigating battery operation problems in a multi-time period robust optimization framework enables further research on the storage placement problem and for analyzing the vulnerability of power transmission networks. The approach and results of this project provide a significant progress for my PhD. Furthermore, the results are considered to be subject of joint scientific publications.

Outlook

In addition to our joint presentation at the FERC Software Conference [3], our further research plan is to use the established battery operations model and investigate the above mentioned storage placement problem and analyze the vulnerability of power transmission networks. This implies that I will keep close contact with the researchers at Columbia University. This research is intended to lead to joint scientific publications as a Journal Paper and contributions to upcoming conferences.

This exchange established a new collaboration between NEXT ENERGY and Columbia University and could be the first of several exchanges of students in both directions.

Acknowledgement

I would like to express my personal gratitude to Daniel Bienstock, Gonzalo Munoz, Chen Chen, and Shuoguang Yang from the research group at the Columbia University's Industrial Engineering and Operations Research Department, for hosting me and conduction research together. I had the great opportunity to be part of this research group that influenced and strengthened my passion for research in many ways.

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References

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[3] D. Bienstock, G. Munoz, S. Yang, C. Matke, *Presentation*: Modeling and Solving Battery Operations. *Technical Conference to Increasing Real-Time and Day-Ahead Market Efficiency Through Improved Software at the Federal Energy Regulatory Commission, Washington D.C., USA,* June 2016.