Using ELMOD to identify country-specific factors for an optimized grid performance

by
Andras Herczeg

An Abstract of a Thesis Submitted to the Graduate Faculty of Rensselaer Polytechnic Institute in Partial Fulfillment of the Requirements for the degree of MASTER OF SCIENCE
Major Subject: Engineering Science

The original of the complete thesis is on file In the Rensselaer Polytechnic Institute Library

Approved:
Professor Ernesto Gutierrez-Miravete, Thesis Adviser

Rensselaer Polytechnic Institute Troy, New York
February, 2015 (For Graduation May 2015)
ABSTRACT

In accordance with the European Union (EU) 20-20-20 targets, the share of the renewable energy generation increases rapidly in the EU Member States. While many forms of alternative generation are promoted, the majority of the green energy investments are intended into the wind or solar based power generation. As the popularity of the renewables has risen, the reliability standards for the transmission systems have received greater attention, especially regarding grid and peak power generation development. The paper reviews the recent wind developments and their effect on the transmission grid stability and reliability. After the overview of the featured optimization models, we identify the key country-specific factors that are needed to be considered to maintain an optimal grid performance.
**ACRONYMS**

The following is a list of acronyms and abbreviations that are used throughout this paper.

<table>
<thead>
<tr>
<th>ACRONYM</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELMOD</td>
<td>ELMOD is a bottom-up model of the European electricity market including both generation and the physical transmission network (DC Load Flow approach), which combines electrical engineering and economics: its objective function is welfare maximization, subject to line flow, energy balance, and generation constraints.</td>
</tr>
<tr>
<td>ENTSO-E</td>
<td>The European Network of Transmission System Operators for Electricity (ENTSO-E) is an association of Europe's transmission system operators (TSOs) for electricity. It is a successor of ETSO, the association of European transmission system operators founded in 1999 in response to the emergence of the internal electricity market within the European Union.</td>
</tr>
<tr>
<td>PCR</td>
<td>The Price Coupling of Regions (PCR) is initiative of seven European Power Exchanges, to develop a single price coupling solution to be used to calculate electricity prices across Europe, and allocate cross border capacity on a day-ahead basis. This is crucial to achieve the overall EU target of a harmonized European electricity market. PCR is based on three main principles: a single algorithm, robust operation and individual Power Exchange accountability.</td>
</tr>
<tr>
<td>TSO</td>
<td>A transmission system operator (TSO) is an entity entrusted with transporting energy (electrical power or natural gas) on a national or regional level, using fixed infrastructure.</td>
</tr>
</tbody>
</table>
1. Introduction

1.1 Background

The European Union aims to create a single, integrated European energy (including electricity) market, which became the driving force of the regional market coupling initiatives. These smaller-scale integrations ensuring the preparation for the European Price Coupling and will ultimately lead into the creation of the European Internal Energy Market by standardizing the systems and promoting cooperation between the given countries.

The first pioneers of these models are in the stage of expansion: for instance the CZ-SK-HU-RO Market Coupling was successfully launched on 19 November 2014, integrating the Czech, Slovak, Hungarian and Romanian day-ahead electricity markets and replacing CZ-SK-HU Market Coupling. The market coupling requires a close collaboration by the transmission system operators (TSOs) of each country together with power exchanges supported by national energy regulators in order to develop and implement all necessary solutions which ensure technical and procedural compatibility with the target European solution which is already implemented in other coupled European regions.

Overall, market coupling allows higher efficiency of trading and capacity allocation, which should lead to higher security of supply, higher liquidity and lower price volatility.

---


2 CZ, SK, HU, RO electricity TSOs: ČEPS, SEPS, MAVIR and Transelectrica

3 CZ, SK, HU, RO power exchanges: OTE, OKTE, HUPX and OPCOM

4 CZ, SK, HU, RO power exchanges: ERÚ, ÚRSO, MEKH and ANRE

5 Price Coupling of Regions (PCR), is the initiative of seven European Power Exchanges, to develop a single price coupling solution to be used to calculate electricity prices across Europe, and allocate cross border capacity on a day-ahead basis. For more information see: [http://www.nordpoolspot.com/How-does-it-work/European-Integration/Price-coupling-of-regions/](http://www.nordpoolspot.com/How-does-it-work/European-Integration/Price-coupling-of-regions/)
1.2 Problem description

It should be noted though that the integration also reveals several challenges:

1) The ongoing change impacts substantially both existing market players (including the large incumbents) and new entrants in the short and medium term as well. Long-term investment decisions can be challenging particularly, as the regional prices most likely are going to differ after the integration from the current ones.

2) The subsidy mechanism of the renewables (feed-in tariffs, green certificates, etc.) in a given country – such as Germany – may have a long-lasting effect on smaller markets (e.g. Central European countries). The political support of one technology (e.g. large scale wind or solar) may prompt investors to delay much needed investments into other (e.g. nuclear) capacities.

3) The location of capacities (especially the renewable ones) requires additional grid development projects, which causes congestion in the present. Under current network management methods this factor can be challenging to properly taken into account, and we expect that the problem will exist at least until the internal energy market is not completed with a more developed capacity planning process.

The paper examines scenarios in the light of the current German investment plans (focusing on the renewables, especially wind development) and their impact on the prices and grid stability in the Central European countries.
2. Theory and Methodology

2.1 Theoretical background

Ventosa et al. (2005) provide a detailed overview of market modeling tendencies. They point out three trends: optimization models, equilibrium models and simulation models.

Economic modeling of electricity markets not possible without accounting for technical constraints (Huppmann and Kunz, 2011). Researchers of the electricity market restructuring heavily rely on a model-based research, since it allows implementing a complex approach of operations research, applied economics and engineering (Leuthold, 2010). The economic-engineering model-based approach is especially popular in the US (Hogan, Hobbs, UC Berkeley, etc.); on the other hand, the available research for Germany and Europe limited. The most known model for the European electricity markets is the ELMOD.

2.2 ELMOD Analysis

ELMOD is a bottom-up model of the European electricity market including both generation and the physical transmission network, which combines electrical engineering and economics: to maximize welfare, subject to line flow, energy balance, and generation constraints. The scope of the (physical) model is the ENTSO-E countries, in particular Portugal, Spain, France, Netherlands, Belgium, Luxembourg, Denmark, Germany, Switzerland, Austria, Italy, Poland, Hungary, Czech Republic, Slovenia and Slovakia.

---

6 Optimization models can either apply a profit maximization of a single firm or a welfare maximization approach under perfect competition.
8 The model was developed at the Chair of Energy Economics and Public Sector Management (EE2) at Dresden University of Technology in order to analyze various questions on market design, congestion management, and investment decisions, with a focus on Germany and Continental Europe (Leuthold, 2008).
9 41 TSOs from 34 countries are members of ENTSO-E. Source: <https://www.entsoe.eu/about-entso-e/inside-entso-e/member-companies/Pages/default.aspx>
The model provides simulations on an hourly basis, taking into account variable demand, wind input, unit commitment, start-up costs, pump storage, and other details (Leuthold, 2010).

ELMOD is a DC-Load Flow model of the European integrated transmission grid. Generation and demand are localized at the nodal level to allow for a detailed representation of different grid situations. Load at each node is modelled using the gross value added of services and industries as well as the number of inhabitants and typical load profiles. In different scenarios characteristic winter and summer workdays are implemented on an hourly basis. Generation plants are represented with marginal costs based on plant individual efficiency values and fuel and CO2-certificate-prices. The model is implemented in GAMS. ELMOD is capable of different congestion management (Kunz, 2013).
3. Approach

Electricity is a special commodity due to several features: (a) non storable, (b) grid-bound, (c) high fix cost ratio, (d) economies of scale in generation and transmission, (e) daily and seasonal demand patterns, (f) power flows according to physical laws (Kirchhoff). Power generation and the wholesale activities are unregulated in the EU; however transmission and distribution remains a natural monopoly due to its characteristics, similarly to other network industries (electronic communications, energy and transport sectors).

The paper uses several assumptions when analyzing the different scenarios such as:

- Perfect competition (no strategic players)
- Perfect market bidding (marginal cost bids, no market power)
- etc.

First we analyze the variation of ramping-costs and the variation of probabilities/wind power generation of scenarios. Also, analyzing the impact of stochasticity on market results (deterministic vs. stochastic model setup) can be assessed. Based on the initial results the analysis can be expanded on the effect of the wind generation capacity expansion or carry out an investment analysis (policy evaluation) regarding installing new power lines or endogenous pumped-hydro storage dispatch.
4. Expected results and outcomes

We expect that the results show the importance of:

- maintaining the existing peak capacities to balance demand
- integrating the Central European grid network and constructing the required cross border capacities

The final document will detail the various scenarios with the experienced issues. Because of the public nature of all inputs and documents, the final report will be non-proprietary and will be able to be readily distributed.
5. Milestones and resources

The schedule with key milestones has been made for execution of the project. Status reports will be provided to the advisor.

Project development deadlines are the following:

1) Abstract (100 word writeup) – Feb 5, 2015
2) Tentative Project Proposal Draft extended (5-pages) abstract – Feb 9, 2015
3) Project Proposal – Feb 13, 2015
4) Collection of Industry Reference and Analysis – Feb 20, 2015
5) First Progress Report – Feb 27, 2015
7) Final Draft – Apr 3, 2015
8) Preliminary Final Report – Apr 17, 2015
9) Final Report – Apr 24, 2015

A number of industry resources are available for potential public event sourcing:

1. GAMS and ELMOD codes and documentations
2. ENTSO-E reports and database
3. EUROSTAT database
4. US EIA database, documents for counter check
6. References


References for Electricity Data


References for Wind Power Generation


7. Appendices

This appendix provides a print out of example GAMS codes presented in the paper related to the ELMOD.