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Transmission expansion planning in Northern Europe in 2030—Methodology and analyses

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HIGHLIGHTS

- Two-step investment algorithm with a detailed operation optimisation model is shown.
- A 2030 scenario for the power system of Northern Europe is analysed.
- Increase of wind power production is expected around the North Sea.
- Significant requirements for transmission expansion.

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ABSTRACT

The expected increase of intermittent electricity production imposed by renewable energy sources in Northern Europe poses rising challenges to the operation of the power system. The Nordic hydro based power system, particularly the Norwegian, is in a favourable position to provide necessary production flexibility to the Continental European power system. For this provision sufficient transfer capacity is required.

In order to assess the provision of power production flexibility, a detailed operation optimisation model is necessary. Moreover, investments in the power system have to be set in relation to the economic outcome of the system operation. As a simultaneous system optimisation is not possible due to the size of the operation optimisation model, a two-step investment algorithm containing an iteration loop is proposed in this paper.

The proposed investment algorithm identifies profitable investments based on the results of the operation optimisation model, where the effect of the investments on the power market outcome is taken into account through the iterative process.

The presented investment algorithm is used for a transmission expansion analysis for a 2030 scenario of the Northern European power system. The results for the simulation of the scenario and the transmission expansion analysis are presented as well.

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1. Introduction

Ambitious targets have been set by the European Directive 2009/28/EC, which establishes an overall quota of 20% renewables in gross consumption of energy by 2020 (European Commission, 2009b). Furthermore, in its “Energy Roadmap 2050” the European Commission explores the challenges, which the Energy Sector will face when reducing greenhouse gas emissions to 80–95% below 1990 levels up to 2050 (European Commission, 2012). At the same time the European Commission is enforcing the process of liberalisation and integration of national power markets, explicitly addressing cross-border issues (European Commission, 2009a). There is significant progress in the integration of day-ahead spot markets (Meeus and Belmans, 2008), with a common Nordic market – Nordpool[1] – and a day-ahead spot market-coupling, which covers central-west Europe and Scandinavia – CWE-ITVC.[2]

Abbreviations: EMPS, EFI's Multi-area Power-market Simulator; ENSTO-E, European Network of Transmission System Operators for Electricity; NTC, Net transfer capacity; RES, Renewable energy source; TSO, Transmission System Operator; SPP, Solar power production; WPP, Wind power production.

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[1] http://www.nordpoolspot.com/.
[2] http://www.marketcoupling.com/.

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Nomenclature

water value calculation

α	expected operation cost in the rest of the planning period (water value)
x	state vector (reservoir content)
k	stage index, $k \in [1, K]$
K	total number of stages in the planning period
u	decision vector (hydro production)
L	immediate cost associated with u
S	value of stored energy at the end of the planning period

Investment algorithm

Sets

J	climatic years
T	time steps within a year
A_G	investment alternatives for thermal generators
A_W	investment alternatives for wind generators
A_T	investment alternatives for transmission corridors

Constants

N	number of climatic years
ϵ	annuity
β	threshold for the investment significance
d_τ	duration of the time step τ
c_a	marginal production cost
I_a	marginal investment cost for alternative a
I_a^ϵ	annualised marginal investment cost for alternative a
l_a	linear transmission losses on corridor a

Variables

$p_{j,\tau,m}$	simulated area price from EMPS for area m
$u_{j,\tau,m}$	relative wind power production in area m
π_a	marginal operational profit of alternative a

Indexes

τ	time step
j	climatic year
a	investment alternative
$m_f{}^a$	connected from area of transmission corridor a
$m_t{}^a$	connected to area of transmission corridor a

These renewable targets as well as the progressing market integration will have a profound impact on the transmission expansion planning and the future power system operation.

Among the renewable energy sources wind energy is expected to prospectively contribute a large share throughout Northern Europe (European Wind Energy Association, 2009b). The main areas for the commissioning of wind power production facilities are located in and around the North Sea as well as the Baltic Sea. Due to the intermittency of wind power production (Aigner and Gjengedal, 2011) increased production flexibility and additional back-up capacity (Eurelectric, 2011) will be required for the reliable operation of the future power system. The Nordic, especially Norwegian, hydro-dominated power system has ideal characteristics to provide these necessary resources to the Continental European power system. In order to effectively exploit the resources, sufficient transfer capacity must be available between the Nordic region and Continental Europe.

This paper assesses transfer capacity requirements related to the wind power production intermittency in Northern Europe. To assess the contribution of production flexibility from the Nordic hydro power system in order to balance power production from renewable energy sources a rather detailed operation optimisation model for the power system is necessary. However, the integration of such an operation optimisation model with the simultaneous optimisation of investments is not yet possible. Thus, in this paper an investment analysis methodology is suggested, which uses results of a detailed operation optimisation model to identify profitable investments. Furthermore, there is an iteration between the power system simulation and the investment decision, to take into account the effects of the investments on the power market outcome. Finally, a transmission expansion analysis for a future scenario of the Northern European power system is carried out with this proposed investment algorithm.

The paper consists of two main parts. Firstly, the proposed methodology for the optimisation of generation and transmission investments in the power system is presented. Secondly, this methodology is applied to a case study of transmission expansion planning for the Northern European power system in a 2030 scenario.

2. Related research studies

According to the European Commission (2009a, 2009b, 2012) the main drivers for the development of the future power system are:

(i) The development of the Internal Electricity Market in Europe.
(ii) An increase in the Security of Supply in Europe.
(iii) The promotion of energy efficiency and the utilisation of renewable forms of energy sources towards the development of a more Sustainable European power system.
(iv) The promotion for the interconnection of various energy networks.

Presently, all of these topics receive much attention. Technical as well as economic assessments for a reliable and sustainable integration of renewable energy sources (RES) in the power system are numerous.

The European Network of Transmission System Operators for Electricity (ENSTO-E, 2011a) published its Ten Years Network Development Plan (TYNDP). As one part of the TYNDP, the Regional Investment Plan North Sea identified future developments requiring expansions of the European transmission system between 2012–2020 and beyond. Significant changes in the generation mix up to 2020 are expected to increase the cross-border flows between Ireland and Great Britain, between Norway and Denmark as well as from Western Denmark and Northern Germany to Southern Germany. Furthermore, the increase in the variable generation from RES, especially wind power production (WPP) in Ireland and Great Britain is expected to increase the volatility of these power flows.

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