**Coastal Consumption of Off-Shore Wind Energy:
Simulation and Optimization**

Masterarbeit

zur Erlangung des akademischen Grades „Master of Science (M.Sc.)“ im Studiengang Wirtschaftsingenieur der Fakultät für Elektrotechnik und Informatik, Fakultät für Maschinenbau und der Wirtschaftswissenschaftlichen Fakultät der Leibniz Universität Hannover

vorgelegt von

Name: Schneider Vorname: Konrad

[redacted] [redacted]

Prüfer: Prof. Dr. Breitner

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Introduction

Renewable Energies are in a rising uptrend. "In the EU, Renewables accounted for almost 70 % of new electric generation capacity in 2012"[1], while Germany's renewable share was 23.3 % of the gross electricity consumption[2]. The energy production mix of each country is determined by the interaction of political agendas, environmental conditions and economical necessities.

The political agenda regarding energy production may contain the substitution of nuclear power with other technologies. Reasons for this are mostly the same; External effects caused by nuclear power plants such as uncertainty of final storage and the fear of nuclear accidents shape the public opinion and therefore the political agenda. Because nuclear power – neglecting external effects – is known to be the lowest priced power production technology, this subject is mostly addressed by highly developed countries capable of allocating the necessary funds for the additional investments.

Environmental conditions globally shape the general framework for energy production. Global warming leads to the need of decreasing C02 emissions, of which the biggest polluter are coal power plants. Thus coal energy production is not an alternative to nuclear power with regard to environmental effects.

These mechanisms lead to an increase of Renewable Energy production that comes with a challenge: The permanent availability of electricity, which is achieved by operating power networks to balance supply and demand. The integration of renewable energies hinders this process due to volatility of production. Instancing Germany's energy market, the feed-in priority of renewable energies forces conventional power plants to reduce or shut down production in times of high supply by renewables. When the renewable energies' supply is at a low, the conventional plants' ramp-up behavior is used to secure power distribution.

Technical restrictions to balance volatility of offshore wind power causes an absurd mechanism; If the the power grid cannot compensate for peaks, a wind farm's excess power supply will be deposed, while compensation money will be paid to the wind farm's operator. In 2011, this excess supply tripled to a total amount of 1 % of the offshore wind production.[3]

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[1] McGinn et al. (2013), p.3
[2] Cf. Rohrig (2012), p. 7
[3] Cf. ibd., p.7

With the objective of creating a higher demand within the power grid and therefore avoiding disposal of excess energy, d. c. transmission cables will be used to connect the Northern Sea with Southern Germany, where most of the energy demand occurs. For this purpose, the Bundestag even enacted a law to secure the transmission cables' roll-out.[4]

This network expansion is expensive as well as it controversial due to possible external effects on the residents along the transmission cables. An alternative to this network expansion could be costal consumption of offshore wind energy. For this matter, balancing the supply with energy storing technologies is vital to the process of further roll-out of offshore wind farms.

This thesis deals with balancing the volatility of a wind farm's power supply by adjusting domestic heat demand. In a first step, a wind farm is modeled to determine offshore energy supply over a year. Secondly, a building model to evaluate domestic energy demand for heating with a temporal resolution of one hour is developed on the basis of the IWU's calculations for aggregated heat demand over the year.[5] The aggregated demand of a building's entirety is then adjusted by internal temperature adjustment as well as thermal heat storage in order to balance volatility of the wind farm's supply. Since domestic energy accounts for a fraction of 25.1 % of the overall demand in Germany[6], adjusting it to volatility of renewables could make a contribution to the power networks' needed storage capacity.

State of the art

A building's heat demand is evaluated for new constructions and energy-efficient renovations. The calculation procedure is based on monthly or seasonal averaged values such as external temperatures and solar radiation. The IWU provides a calculation basis with a seasonal approach for building typologies in Germany.[7] This method, however, cannot be used to balance volatility of renewable energies, because it lacks the necessary temporal resolution. An accurate representation of a building's heat demand and temperature distribution requires the use of digital systems for measurement and control.[8] With such an approach, it is possible to predict a building's heat demand on an hourly basis. The model presented in this thesis is set in between; it is based on the approach of the IWU and expands the calculation model by a temporal resolution of one hour.

Nabe et al. evaluate the " heat pump's potential of load management and grid integration of renewable energies"[9] by considering a "linked simulation of building systems and energy supply systems"[10]. A dynamic building model is implemented in order to represent the buildings' continuous heat demand over a year. The heat demand is then used to determine

[4] The law is „NABEG", cf. Bundesnetzagentur (2013), p. 5
[5] Cf. Loga et al. (2013)
[6] Cf. umweltbundesamt.de
[7] Cf. Loga et al. (2013)
[8] Bianchi, for example, describes a predictive regulation for small heat pumps. cf. Bianchi (2006)
[9] Nabe et al (2011), p.11
[10] Ibd., p.11

heat storages capacity of 1,000 liters is underdesigned for building type C, while it provides acceptable values for building types A and B.

The wind farm's excess energy supply basically occurs in summer. Its aggregated supply over a theoretical heating period from first of october until 31^{st} of march sums up to an amount of 572.29 GWh, representing a fraction 59.39 % of the aggregated supply over the year. Compared to this value, the aggregated heat demand and heat storages basically balance all the supply during winter, as can be seen in the figures of the analysis.

Conclusion

The building model developed in this thesis evaluates a building's continuous heat demand and is based on a seasonal approach for determination of aggregated heat demands over a year. It is modified on that basis to provide calculations with a temporal resolution of one hour, with which three building types are evaluated for analysis. The aggregated heat demands of these three represent fractions of 86.7 %, 81.4 % and 98.9 % of the values determined by the seasonal approach.

For analyzing the potential of balancing a wind farm's volatility by domestic energy demand, a buildings' entirety is evaluated in four scenarios: with a buildings' fixed set-point temperature, internal temperature adjustment and heat storages with a capacity of 10,000 and 1,000 liters, in which the excess energy is calculated by discounting demand from the wind farm's supply over the year. In scenario 1, the balanced energy varies from 50.3 % to 54.9 % of the original supply, depending on the used building type. In scenario 2 with temperature adjustment, it sums up to amounts from 52.0 % to 55.42 %, resulting in an additional balanced amount on the scale of 1 %. The use of heat storages with a capacity of 10,000 liters in scenario 3 results in an amount of balanced energy of 64.7 % up to 70.0 %, which is an additional amount of 14.4 % up to 15.1 % compared to scenario 1. In scenario 4, the balanced energy varies from 58.2 % to 64.98 % of the wind farm's original supply, resulting in an additional amount of 7.9 % to 10.0 % compared to scenario 1. The analysis of scenarios 3 and 4 show that heat storages with a capacity of 1,000 liters are underdesigned for building type C with a heated area of 275 m², while building types A and B, each with a heated area of 196 m², provide values within an acceptable range.

Using heat storages with a capacity of 10,000 liters rather than 1,000 results in an additional amount of balanced energy of 5.0 % up to 6.5 %, which is relatively small compared to the tenfold increase of capacity. This is due to the heat demand's seasonal fluctuation; The wind farm's excess supply can be balanced to nearly 100 % during winter, but the low demand during summer limits the possibility of balancing supply by domestic energy demand.

While temperature adjustment has a relatively small impact on the overall domestic energy demand, heat storages provide a sufficient amount of storage capacity for balancing a wind farm’s supply during the heating period.

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