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A review of the North Seas offshore grid modeling: Current and future research

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ABSTRACT

The North Seas offshore grid serves to connect offshore wind power to onshore systems, and to interconnect power systems in Northern Europe. Its development is a priority for the European climate and energy policy, which has led to a number of studies on the subject. Nonetheless, research questions, assumptions and typologies can vary considerably among them, and thus to guide future research this paper reviews the published works that use bottom–up energy models. This review develops a simple and effective methodology that can be applied to other reviews of energy systems models. It jointly considers the studies of interest, the system characteristics, a categorization framework and relevant indicators. The analysis indicates most studies focus on investment and operation of the grid using optimization models, with rare use of other research questions or other model approaches. Moreover, results vary significantly, and their comparability is limited due to differences in assumptions, methodology and detail of results publication. Nonetheless, integrated typologies frequently present economic, operational and environmental benefits, although the reviewed studies do not unambiguously warrant immediate and full cooperation on grid governance. Lastly, future research should be attentive to the presentation and resolution of data, assumptions and results, as well as consider grid characteristics relevant to the research questions.

Contents

Abbreviations: CCGT, combined cycle gas turbine; CSC, current source converter; HVDC, high-voltage direct-current; HVAC, high-voltage alternated-current; NSB, net social benefits; NSOG, North Seas offshore grid; TEP, transmission expansion planning; TYNDP, ten-year network development plan; OWP, offshore wind power; RES, renewable energy sources; VSC, voltage source converter

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1. Introduction

Saying that the power sector is complicated is an understatement. It comprises multiple technologies, actors and institutions interacting among themselves and with other systems, which certainly does not make the life of the energy analyst easy - nor uninteresting. Furthermore, many power systems have gone through technical and institutional change in the last decades, and face further ones due to the energy transition. An interesting case is Europe, where the North Seas offshore grid (NSOG) will play a leading role in the transition of its power system. The NSOG is an offshore high-voltage transmission system connecting offshore wind power (OWP) and onshore power systems in the North Seas. It is composed of transmission assets (interconnectors and generation connectors), without a predefined transmission technology or topology of the grid, that is, on the connection pattern of the assets. Although some of these transmission assets already exist, it is expected future development will significantly alter the typology of the grid (the combination of a topology and technologies). In this future typology the offshore grid can be one of the world's first supergrids, large and long-distance transmission networks which enable transitions in energy systems. Besides these technical components, the NSOG also comprises a social sub-system with many actors, their networks and the institutions influencing their behavior.

This review addresses the recently published (from 2010 on) studies on the offshore grid, limiting itself to bottom–up approaches. These more adequately address the features of the NSOG and are thus commonly employed in its modeling. It reviews studies results, compares their differences and presents indicators, and relates the studies to the characteristics of the offshore grid. Furthermore, this review contributes a simple but effective methodology for analyzing energy systems models according to the characteristics of the system in question. Finally, the framework of offshore grid characteristics developed is useful for researching this grid as a system.

The North Seas offshore grid is a priority corridor for the European Commission (EC) and will contribute to the 2030 Climate and Energy Policy framework goals, to the completion of the Internal Energy Market and to technological and industrial policy goals [1]. The 2020 climate and energy package established a binding target for renewable energy in each Member State final energy consumption. Complementarily, a secondary goal of the 2030 Climate and Energy Policy Framework is to take renewable energy to 27% of energy consumption, and to achieve EU pledges the power sector must reach almost complete decarbonization by 2050 [2]. With the promotion of competition and security of supply, these are the pillars of European energy policy driving offshore wind, and broadly renewable power. However, the lack of 2030 binding targets at a national or sectorial level and the necessity of specific support schemes for renewable energy are still a subject of debate, the latter being summarized by EEG [3].

Despite these drivers having a European aspect, offshore wind development has occurred so far at a national level, as the offshore wind trends presented by Rodrigues et al. [4] indicate. Over 8 GW of capacity was installed in Europe by 2014, and was forecasted to reach 10.9 GW by the end of 2016 [5]. De Decker and Woyte [6] list technical progress and development of OWP and interconnectors as the main drivers affecting the NSOG, which will concur to give OWP development an increasingly European perspective. It is relevant to note that the North Seas are considered to be the Irish, North and Baltic seas, the English Channel and Kattegat and Skagerrak.

Independently of its typology, the NSOG serves two functions: connecting offshore generation to onshore power systems (the connection function), and interconnecting different power systems (the interconnection function). Through those, it can develop offshore power generation, interconnect power markets, increase reliability, reduce CO_2 emissions, and promote technological and industrial policy goals. While the NSOG can in the future connect other renewable energy sources (RES) of electricity such as tidal or wave, wind will be the main one for the offshore grid. Spro et al. [7] also indicate supplying power to offshore facilities and connecting deep-water energy storage as benefits. Nonetheless, these are unlikely to be the as relevant as the main functions of the grid, even in the long term.

Several research projects in the last years studied the NSOG, such as OffshoreGrid, North Sea Transnational Grid or the collaboration between E3G and Imperial College [8–10]. Despite these, there is still uncertainty on the NSOG pathway and the most adequate policies and market designs for it. The offshore grid requires the use of different methodologies to address different research questions, and a large number of studies have been published due to its importance to European goals. Thus, these studies use diverse approaches, which make their comparison and validation challenging. As a consequence, to review the models is to address a relevant but complicated area of energy systems modeling. In this way, readers interested in modeling theory, transmission expansion or energy policy will find contributions to those in this review.

Energy systems models are usually classified by approach (top–down or bottom–up) and method (optimization, equilibrium or simulation), although other classifications are possible [11–13]. On the one hand, top–down models address whole economic sectors and their interaction using aggregated high-level indicators. On the other, the bottom–up approach models sectors in detail, considering specific features such as technologies and costs. Thus, top–down models account for feedback between different sectors but are unable to represent any given sector in detail, whereas bottom–up models capture those details at the cost of ignoring feedbacks in a broader system. Hence, it is not surprising that to the authors' best knowledge all models currently developed for the NSOG are bottom–up models, which are thus the focus of this review. The disadvantages of the bottom–up and top–down approaches did lead to the advocacy of hybrid models. These models combine top–down approaches with detailed representation of some sectors to capture both feedbacks and system features of interest, at the cost of increased model complexity. However, this review did not find studies using hybrid models that study the NSOG specifically.

The rest of this paper is organized as follows. Recent developments concerning the grid and a summary are presented next in this section, while the second section presents the methodology of the review. Then, the third section reviews the bottom–up modeling studies according to the categorization framework, the relevant indicators and the characteristics of the offshore grid. Finally, the conclusion summarizes the main findings of the review and presents recommendations for future work on the offshore grid.