Journal of Cleaner Production 186 (2018) 131–145

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Submarine power cable between Europe and North America: A techno-economic analysis

Arturs Purvins*, Luigi Sereno, Mircea Ardelean, Catalin-Felix Covrig, Tilemahos Efthimiadis, Philip Minnebo

European Commission, JRC — Directorate C Energy, Transport and Climate, Postbus 2, 1755, ZG Petten, The Netherlands[1]

A R T I C L E I N F O

Article history:
Available online 10 March 2018

Keywords:
Techno-economic model
Electricity system
High voltage direct current
Submarine cable
Super grid
Cost-benefit analysis

A B S T R A C T

Increasing the deployment of power generators using variable renewable power sources, such as wind and solar, brings power balancing challenges in electricity systems. One mean to achieve power balancing and to share balancing resources, is to interconnect electricity systems to geographically aggregate remotely located variable power sources. This article addresses this potential and provides insights for electricity trading through a submarine power cable between Europe and the eastern part of North America. While such ambitious power interconnection concepts appear in recent literature, this article is the first to present a techno-economic analyses.

This article concludes that, a 4000 MW cable between Europe and North America could bring an annual socio-economic benefit of 177 M€ in 2030. In addition to the differences in generation costs, mutual benefits from electricity trading between Europe and North America derive from different daily peak demand times, low correlation in generation from renewable energy sources, and in seasonal demand variations. The results of the cost-benefit analysis indicate that the benefit for society is sufficient to cover the investment costs. Thus, the proposed interconnector is welfare improving.

1. Introduction

North American (NA) and European electricity systems and markets are among the largest and most complex worldwide. They have been experiencing an increase in electricity demand and a shift towards more integration of Renewable Energy Sources (RES), especially from uncontrollable and variable sources such as wind and solar (NREL, 2012; European Wind Energy Association). Increasing the share of RES in electricity systems requires additional power balancing options (e.g. more flexible power generators and demand), or higher capacities for imports and exports (Purvins et al., 2011a; Armaroli and Balzani, 2011; Ye et al., 2016). The latter option allows higher shares of power balancing resources among interconnected electricity systems, and leads to a geographical aggregation of remotely located variable power sources. This article examines this option, and aims to identify some of the socio-economic benefits of electricity exchange between Europe and NA through a High Voltage Direct Current (HVDC)[2] submarine cable.

Similar concepts involving transcontinental power transmission were studied in previous projects, e.g. Desertec, where RES surpluses from deserts in the Middle East and the North Africa region could be delivered to the south of Africa and Europe through new HVDC power connections. Fraunhofer further analysed this approach and found large techno-economic potentials for the use of renewable energy technologies in North Africa. A similar vision for a global power grid comes from China with an emphasis on RES utilisation from remote, sparsely populated regions (State Grid Corporation of China). Furthermore, Liu (2015) also finds that transcontinental power interconnections are essential for a high utilisation of global RES.

Although a European-NA power interconnection is proposed in several studies, e.g. Liu (2015) and Chatzivasileiadis et al. (2013), no estimations are available on potential benefits.

* Corresponding author.
E-mail address: arturs.purvins@ec.europa.eu (A. Purvins).

[1] The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

[2] Currently, HVDC technology is the only option for a Europe-NA power interconnection, as AC cables cannot transfer power over such distances due to the presence of reactive power.

https://doi.org/10.1016/j.jclepro.2018.03.095

List of abbreviations

AC	Alternating Current
BCR	Benefit-to-Cost Ratio
CAPEX	CAPital EXpenditure
CCGT	Combined Cycle Gas Turbine
CF	Capacity Factor
CHP	Combined Heat and Power
CRF	Capital Recovery Factor
CS	Consumer Surplus
DC	Direct Current
EIA	Energy Information Administration
ENTSO-E	European Network of Transmission System Operators for Electricity
EPPSA	European Power Plant Suppliers Association, EWEA European Wind Energy Association
FYROM	Former Yugoslav Republic of Macedonia
HVDC	High Voltage Direct Current
JRC	Joint Research Centre (European Commission)
LCC	Line-Commutated Converter
LCoE	Levelized Cost of Electricity
MS	Merchant Surplus
NA	North America
NPV	Net Present Value
O&M	Operation and Maintenance
OCGT	Open Cycle Gas Turbine
PS	Producer Surplus
PV	Photovoltaic
RES	Renewable Energy Sources
ST	Steam Turbine
SW	Social Welfare
TYNDP	Ten-Year Network Development Plan
US	United States
VSC	Voltage-Source Converter

This article also addresses one of the key energy trends in Europe, that is, ambitious electricity interconnection targets of the European Union (European Commission, 2014). Currently, the average interconnection level among European countries is about 8% of the installed electricity generation capacity. Taking into account the importance of interconnectors for strengthening security of supply and the need to facilitate cross-border trade, the European Commission proposes to extend the current 10% interconnection target to 15% by 2030 while taking into account the cost aspects and the potential of commercial exchanges in the relevant regions. Power exchanges between Europe and NA would be challenging also due to incomplete information in competitive bilateral trading. Some studies have been addressing such challenges proposing new trading strategies (Huang et al., 2011; Bompard et al., 2011).

Current installations of submarine HVDC power cables can transfer up to 2000 MW power (CIGRE, 2009a), reach 1600 m depth (Rendina et al., 2012), and stretch for more than 500 km (ABB). However, the submarine power interconnections planned for the next decade are expected to greatly exceed the characteristics of the current installations (Ardelean and Minnebo, 2015). For example, the EuroAsia submarine HVDC cable (Greece-Cyprus-Israel) is planned for a 2000 MW power capacity, reaching 2700 m depth, with a length of 1520 km (EuroAsia Interconnector). This project will break the length and depth records, and enrich the knowledge on building challenging submarine power interconnections. Similarly, the IceLink project HVDC submarine cable between Iceland and Great Britain (National Grid; Landsvirkjun) would be another pioneering project exceeding length of current installations, i.e. 1200 MW capacity and 1000 km length.

The concept of the transcontinental power exchange of this article is illustrated in Fig. 1. The submarine HVDC cable would connect Europe (via Great Britain) with NA (via Canada). These connection points form the shortest path through Iceland and Greenland, which would be 3300 km long and reach a maximum depth of 3000 m. The main challenges would be the manufacturing time due to the long length of the cable, and, as in the EuroAsia project, the laying methods and tools in the profound depths.

The potential cost-benefits of a European-NA power submarine cable connection are estimated through a techno-economic load-flow analysis. For this purpose, a power (generation) dispatch model is developed which is comprised of the European and eastern NA electricity systems. Two 2030 scenarios are considered: without and with a European-NA power interconnection.

The modelling results show that such an interconnection would have a capacity factor of 0.78 and would increase social welfare by 177 M€ annually. The performed financial analysis indicates that the annual benefit can entirely justify the investment and operation costs of the interconnector.

The following section (2) outlines the European-NA power dispatch model for 2030. Section 3 presents and discusses technical modelling results. A cost-benefit analysis on social welfare results is provided in Section 4. Section 5 concludes.

2. The power dispatch model

A techno-economic analysis is performed using a power (generation) dispatch model developed by the authors in the PLEXOS power market simulation software[3]. The model covers the year 2030 and comprises of (i) 33 European countries[4] modelled as one node (one price) per country, (ii) the cross-border transmission connections among these European countries, (iii) an HVDC cable connecting Europe with NA through Iceland and Greenland, and (iv) NA modelled as one node. The modelled countries and their cross-border connections are shown in Fig. 1. Each node in Fig. 1 has its unique hourly demand pattern, hourly generation profiles from solar irradiance and wind, monthly water inflow profile for hydro power plants, and mix of aggregated generation capacities divided by technology.

The model can forecast and manage generation dispatch and power flows, and provide an asset performance valuation in terms of electricity prices and social welfare, for the considered European-NA power interconnection.

The techno-economic analysis is performed for a one year period (2030), at an hourly time-step, applying optimal dispatch of power generators following the objective function (PLEXOS):

[3] https://energyexemplar.com/.

[4] Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, former Yugoslav Republic of Macedonia (FYROM), Germany, Great Britain, Greece, Hungary, Ireland (and North Ireland as separated region), Italy, Latvia, Lithuania, Luxembourg, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden and Switzerland.