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Low Frequency AC transmission for offshore wind power: A review

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ABSTRACT

Offshore wind farm integration is providing substantial technical and economic challenges in the medium term and the trend for farther shore development in the future is focusing research and industry attention on cost effective transmission alternatives to existing technologies. In 2014, offshore wind capacity in Europe consisted of 8045 MW, with the majority of this connected to onshore grid via High Voltage AC (HVAC) transmission. Wind farms commissioned further offshore (> 80 km) utilise High Voltage DC (HVDC) transmission for grid interconnection. The deployment and operation of Voltage Sourced Converter (VSC) HVDC substations in harsh offshore environments is still a major challenge for the offshore wind industry. Recently, research studies to reduce the complexity of the offshore network have been undertaken both in industry and in academia, with the primary motivation of reducing cost and increasing reliability.

This paper provides a review of Low Frequency AC (LFAC) transmission, which is of significant interest for offshore wind farm integration at a range of 80–180 km. LFAC is an adaptation of HVAC transmission, operated at lower frequency, typically 16.7 Hz. The key advantage of LFAC compared to HVDC is the elimination of the requirement for an offshore converter station, thereby reducing offshore complexity and potentially increasing the operational life of the offshore wind farm. Design challenges are introduced surrounding the design of the 16.7 Hz transmission transformer and associated offshore platform for this potential transmission technology. A comprehensive review of existing research conducted on LFAC and a discussion centreing on the design considerations for offshore LFAC transmission components is presented. The frequency changing converter onshore, offshore LFAC substation and the wind turbine considerations are evaluated in detail. LFAC multi-terminal offshore grids are also considered, as this alternative to HVDC multi-terminal grids may reduce the requirement for multiple offshore converter stations.

Contents

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1. Introduction

Offshore wind is a key enabler to achieving the ambitious European renewable energy targets [1], which are driven by concerns over climate change from fossil fuel based power generation. Challenges on the availability of land and public opposition to large onshore wind turbines are driving wind power plants offshore. In addition consistently stronger wind conditions offshore create higher capacity factors, making the move offshore more appealing. Fig. 1 shows onshore and offshore wind installations in Europe from 2001 to 2014, from which it can be seen that the proportion of offshore wind to onshore wind has been steadily increasing from 2006. Offshore wind farms enable the use of larger wind turbines to increase power capture. Opposition to unsightly near shore wind farms reduces their attractiveness and therefore offshore wind farms are being planned further offshore. With the move further offshore the feasibility is very dependent on reliability and cost, so current research in the area tends to focus on reducing the overall cost of offshore wind and increasing the reliability to reduce offshore wind plant down time.

Numerous topologies and configurations have been suggested for efficient power transfer from the offshore wind site to the onshore grid. For near shore wind farms (less than 50 km approx.), High Voltage AC (HVAC) transmission at 50 or 60 Hz is sufficient [2], and most of the existing wind farms are built with HVAC transmission [3]. For further offshore installations, current trends in research and practice point towards the use of High Voltage Direct Current (HVDC) transmission with Voltage Source Converter (VSC) based HVDC transmission being the preferred approach as it displays distinct control and design advantages over traditional Line Commutated Converter (LCC) technology [4]. In such installations the wind farm collector network typically operates at 50 or 60 Hz, which is then converted to HVDC by an offshore converter station for transmission to an onshore converter station. VSC-HVDC is currently considered the market leader for offshore wind integration at distances greater than 100 km largely due to its established use in onshore point to point bulk power transfer [5]. The offshore converter station however becomes a concern when the reliability and the cost of the system are considered. Large power electronic converter stations far offshore are costly and difficult to reach if a failure occurs, therefore potentially increasing down time and interruption of supply.

A CIGRE general meeting 2014 contribution by Bell et al. [6] indicates that efforts to decrease the amount of complexity offshore could be advantageous to the overall feasibility of an offshore transmission system, stating that due to the high cost of offshore HVDC transmission systems "*the balance between cost and reliability for an offshore HVDC network will be shifted significantly towards minimisation of the number and size of physical assets and, arguably, away from high continuity of supply*". Transmission solutions seeking to minimise the complexity of the offshore network have been proposed in the recent past, both as competitors, and complimentary systems to VSC-HVDC. Low Frequency AC (LFAC) transmission, typically at a frequency of 16.7 Hz has been proposed as an alternative to conventional 50 Hz AC or VSC-HVDC [7–9]. LFAC is an interesting alternative transmission option for offshore wind, primarily due to the extension of AC power transmission distance at lower frequency and the elimination of the need for an offshore converter station when compared to VSC-HVDC transmission. The elimination of the offshore converter station is based on the assumption that the wind turbines have the ability to produce AC at a lower frequency [7], which is possible with full converter type 4 wind turbines. The LFAC transmission line transmits power at low frequency to the shore where a frequency changing converter converts from low frequency to the grid frequency. This technology reduces the complexity offshore and therefore may reduce the capital investment costs, and increase reliability, with the impact of decreasing the overall cost of offshore wind. It should also be noted that other alternative technologies have been presented which aim to reduce offshore infrastructure complexity, reduce the number of conversion steps and increase reliability. These include DC wind turbines connected to a HVDC station [10], DC wind turbines connected to a LFAC

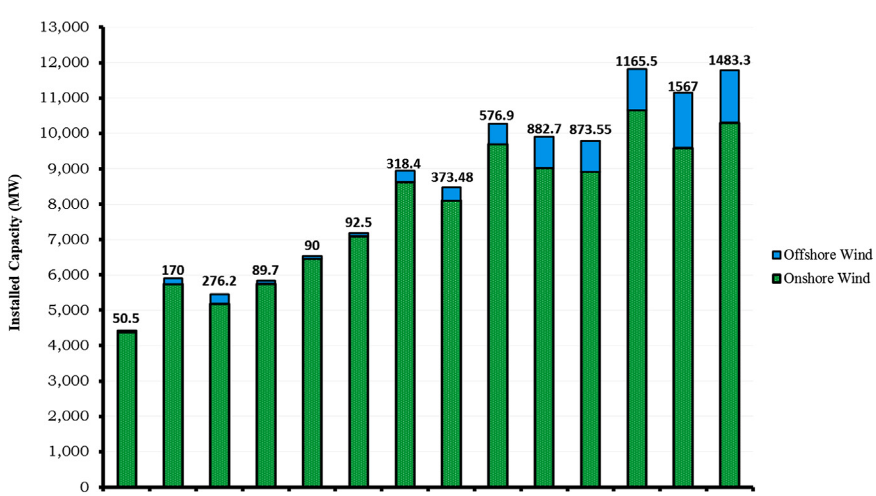

Fig. 1. Annual onshore and offshore wind installations in Europe 2001–2014 [12].