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Assessment of collection systems for HVDC connected offshore wind farms

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ABSTRACT

A technical and economic comparison is made between DC and AC collection systems of offshore wind farms. DC collection systems have the advantages of reduced weight and size of the DC cables and DC cables are free from reactive power compensation. The heavy 50/60 Hz transformers in the offshore transmission platform of AC collection systems can be replaced with smaller size medium frequency transformers in DC collection systems. However, the need for a high power DC–DC converter with high voltage transformation ratios and DC protection methods will remain a challenge for the DC collection systems. Also, DC collection systems do not necessarily reduce the power conversion stages compared to the AC collection systems even if HVDC (High Voltage DC) transmission is used to transfer the offshore wind power from the collection systems to the onshore grids. A cost assessment study verifies that the cost reductions achieved by the reduced size of the DC cables and offshore platform are outweighed by the cost of DC protective devices and DC–DC converters. This is because the length of the DC collection cables is relatively short compared to the long distance HVDC cables. The technical comparison supported by the simulation results shows that the total losses in the DC collection systems are higher than in AC collection systems. The effect of collection bus voltages on the losses is analysed for the DC collection systems.

1. Introduction

The technical and economic performance of a wind farm depends on the configuration of the collection and transmission systems. AC collection system options for offshore wind farms were discussed in [1]. The 50/60 Hz transformers used on the offshore transmission platform of AC collection systems are heavy and require a large support structure leading to a high transport and installation cost. The reactive power compensating devices and the power quality filters also consume space on the offshore platform [2].

With the aim of reducing the footprint and size of the offshore platforms, the idea of DC collection systems with DC–DC conversion is being studied. The control structure and different possible configurations of the DC collection systems were discussed in [3]. Several topologies of isolated DC–DC converters including the full bridge DC–DC converter, single active bridge converter, and resonant converters were studied and their energy efficiencies were compared in [4]. In [5,6], DC collection systems using resonant DC–DC converters were analysed. Research on finding a suitable DC–DC converter topology for DC collection systems is still ongoing and several novel topologies of high power DC–DC converters have been proposed in [7,8].

Comparative studies of different collection configurations have been performed to identify the technical and economic benefits of alternative collection topologies. The DC series connection of wind turbines was compared with AC radial transmission in [9]. The cost and losses of the offshore wind farms based on centralized power electronic converters [10] were compared for AC and DC configurations. In the AC and DC collection comparative study [11], DC series and DC series-parallel collection systems were identified as cost effective.

DC collection systems have a number of advantages. The medium frequency transformers used in isolated DC–DC converters reduce the size of the converters. The elimination 50/60 Hz transformer with DC–DC converters can save space on the offshore platform and yield associated savings in cost. The weight and size of DC collection cables are smaller than those of AC cables. DC collection cables will not require reactive power compensation. DC transmission and collection systems will essentially decouple a wind farm from the onshore grid and enhance the fault withstand capability of wind turbines.

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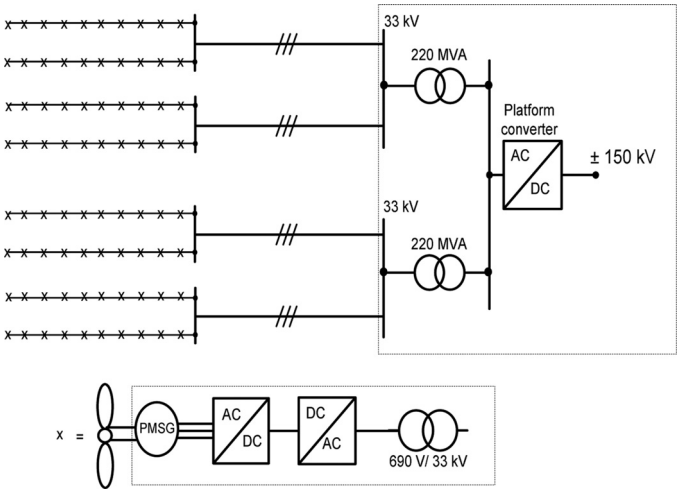

Fig. 1. AC collection systems.

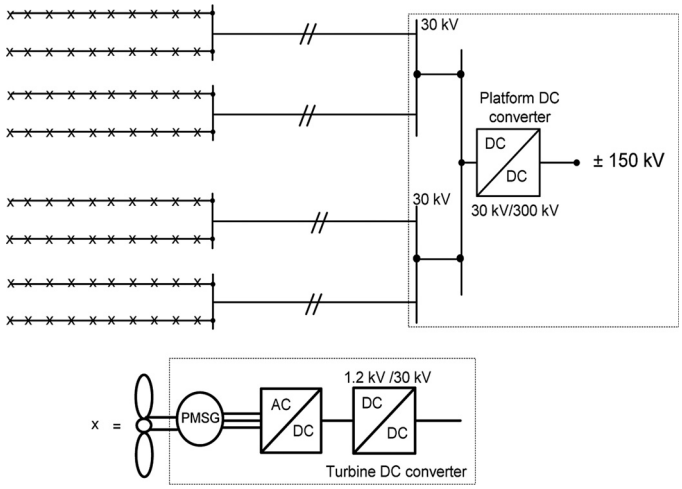

Fig. 2. DC1 collection systems.

However, the challenges of the DC collection systems also need to be considered. The isolated DC–DC converters of offshore wind farms require medium frequency transformers with high voltage transformation ratios. Complexities in the construction of such high power medium frequency transformers increase the cost of DC–DC converters. DC collection systems do not necessarily reduce the power conversion stages compared to the AC collection systems. A reduced power conversion stage is possible only with turbines of higher ratings and high output voltage. Developing cost effective protection methods is also a challenge for DC collection systems.

2. Collection topologies considered

The wind farm considered in this study is rated at 400 MW. This wind farm has 80 turbines each rated at 5 MW. Each wind turbine uses a Permanent Magnet Synchronous Generator (PMSG) rated at 690 V. The voltage of the HVDC link is ±150 kV.

2.1. AC collection systems

The AC collection topology considered for comparison is shown in Fig. 1. AC–DC and DC–AC converters in the wind turbines use two-level VSC converters. The switching frequency of these converters is 1260 Hz. A wind turbine transformer steps up the voltage from 690 V to 33 kV. The AC collection systems use a 33 kV collection bus voltage. A cable length of 5 km between the wind turbine strings and the medium voltage collection bus is assumed. The offshore transmission platform has two transformers each rated at 220 MVA (33 kV/155 kV) and a platform converter. This two-level VSC platform converter is rated at 400 MW.

2.2. DC collection systems

A DC collection topology-1, (referred as DC1) similar to the AC collection and another DC collection topology-2 (referred as DC2) using centralized DC–DC converters are considered for DC collection systems.

The structure of DC1 collection systems is shown in Fig. 2. Each turbine is connected to a medium voltage DC–DC converter (referred as turbine DC converter). The turbine DC converter is rated at 5 MW. A cable length of 5 km between the wind turbine strings and the collection bus is assumed and the collection bus voltage is rated at 30 kV. Another DC–DC converter on the offshore platform (referred as platform DC converter) is used. The platform DC converter is rated at 400 MW.

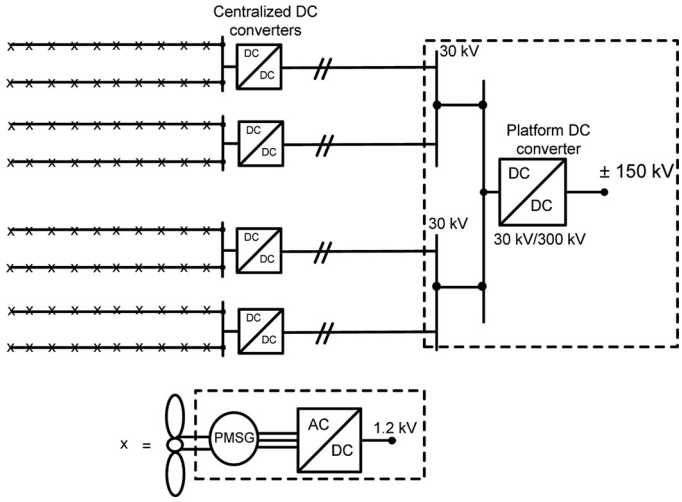

Fig. 3. DC2 collection systems.

The structure of the DC2 collection systems is shown in Fig. 3. In this configuration, a group of wind turbines with DC output in strings is connected to centralized DC–DC converters (referred as centralized DC converters). The centralized DC converters are placed on a converter platform closer to the turbines. A cable length of 5 km between the centralized converter platform and the collection bus is assumed. The collection bus voltage is rated at 30 kV. The advantage of this configuration is that the DC–DC converters located at each wind turbines are removed. This helps to reduce the number of power electronic converters in the wind turbines. Another platform DC converter is used on the transmission platform. This DC2 collection configuration considered is different from the centralized converter concept described in [20]. The centralized converter configuration in [20] eliminates a single stage of power conversion by considering a medium output voltage turbines and a high voltage transformation ratio DC–DC converters.

A hard switched full bridge DC–DC converter employing duty cycle control is used for the turbine DC converter, centralized DC converters and platform DC converter. The circuit of a full-bridge DC–DC converter is shown in Fig. 4a and the duty cycle control structure in Fig. 4b. In DC1 collection systems, the turbine DC converter maintains the internal DC link voltage of each turbine constant. In DC2 collection systems, the centralized DC converters maintain the internal DC link voltage of the turbines constant.