Overview of High-Power Medium-Frequency DC/DC Converter Topologies for Wind Turbines Interfaced to a MVDC Collection Grid

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ABSTRACT

Remote offshore wind power plants are expected to be connected via HVDC systems to the main grids. The extension of single point-to-point HVDC systems into meshed HVDC grids is discussed actively. This leads the integration of DC technology into the collection grid of the wind farm to gain interest and relevance. Using DC technology in the collection grid demands the wind turbine systems to have a DC output, preferably in medium voltage. This paper investigates power converter topologies for DC wind turbines, especially DC/DC converter topologies comprising a Medium Frequency (MF) transformer. The MF transformer is an essential element to provide a galvanic isolation between the MVDC grid and the generator side. The topologies are compared on the basis of number of components, control, cost, redundancy and size. The topology A results as the most suitable configuration based on the evaluation.

I. INTRODUCTION

The progressive increase of the fossil fuels cost in the world market, the increased environmental concern and the need to reduce gas emissions has moved many countries to a policy encouraging electrical power production from renewable sources. An important role with the range of renewable energy sources is covered by the offshore wind power plants due to high performance and energy yields [1-2].

Some offshore wind farms are situated at a long distance from the shore. In order to minimize installation, material and transportation costs, large multi-MW wind turbine systems are being preferably employed and further developed [3]. The increase in terms of power ratings involves a consequent increase of the nominal voltage levels [2]. In this case the output voltage is increased (by means of a transformer) in order to connect the offshore system to the HVAC transmission or by using additional power electronics converters (AC/DC converter) for a HVDC transmission [4].

When the wind farm is close to shore and relatively small in size, the transmission system is made with AC. On the other hand the AC transmission for the offshore wind system involves drawbacks because the AC cable cost becomes higher as the distance grows and with increasing distances the capacitive reactive power rises [1-5]. Hence, the DC transmission is more efficient than AC if the distance between the offshore parks and the onshore system is longer than 50 to 130 km depending on the location [6]. HVDC transmission systems are increasing in popularity and advanced converter technology is today included in long distance cable systems both onshore and offshore.This approach extends the DC technology into the collection grid of the wind farm and interfaces DC wind turbines on generation side. The DC-WPP interfaces the HVDC transmission system by a DC/DC converter. The DC wind turbine (DC-WT) employs a multi-phase generator with a rated power from 10 to 15 MW. The power is split equally between the three channels of the system, see Fig.1. A three phase neutral-point clamped (NPC) 3-level converter with a DC link output of 7.5kV controls the multi-phase generator. Further system parameters are shown in the Table I.

The DC link of fed by the converter interfaces the MVDC grid by a DC/DC converter. A DC voltage of 30-50 kV is considered as nominal voltage for the MV collection grid. The medium voltage step-up DC/DC converter of the DC-WT becomes a very important component in the offshore wind energy system with MVDC grid. In order to increase the voltage and provide a galvanic isolation between the MVDC link and the generator side a MF transformer is necessary.

This paper aims to assess different topology configurations for the DC/DC converter incorporated in a high-power offshore wind turbine.

II. OVERVIEW OF POWER CONVERTERS FOR A DC WIND TURBINE

In this section, four DC/DC converter configurations for a multi-phase generator system are presented (Fig.1). The analysis is performed in terms of advantages and drawbacks of each configuration. In Fig.1 it is possible to observe that all configurations include a MF transformer. Besides the galvanic isolation, the MF transformer prevents any fault on one side to be transferred to the other. The DC/DC converters with MF transformer operate at several kHz in order to reduce its size. In Table I the used system parameters are shown in order to provide a deep analysis of the performances.

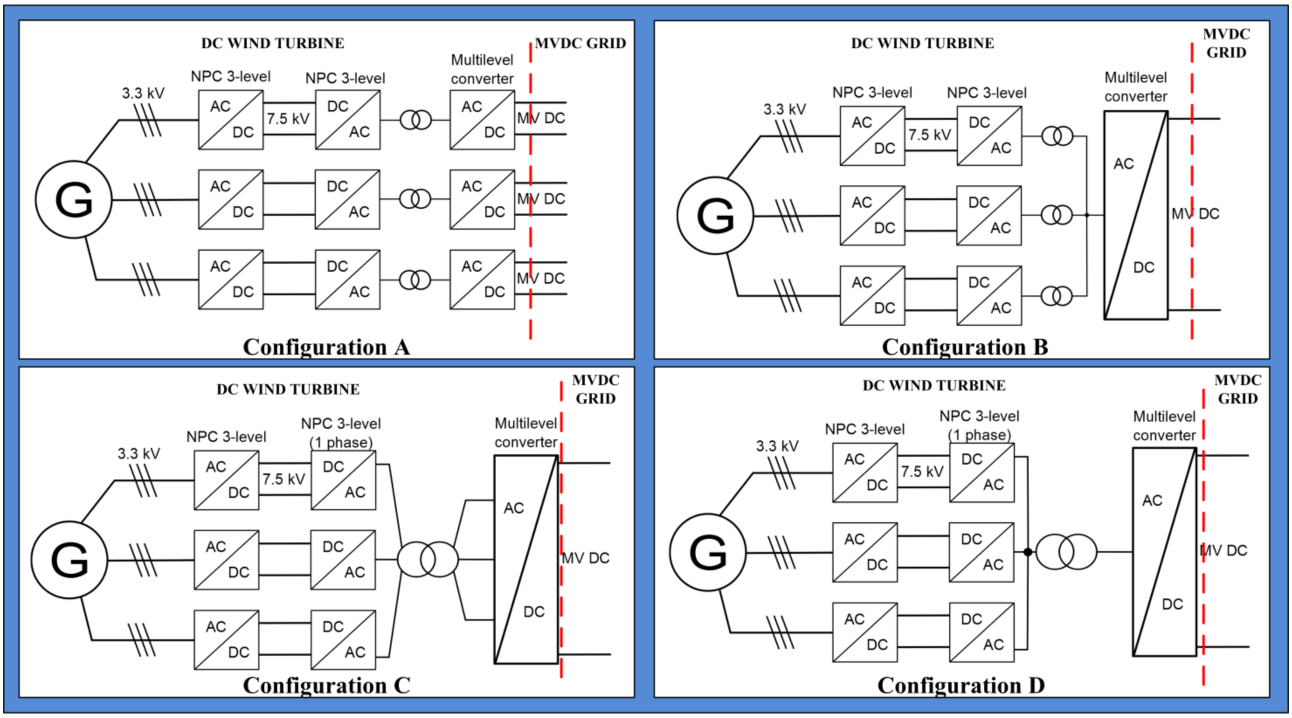

Figure 1: DC/DC converter configurations for a multi-phase generator system.

Tab. I: System Parameters.

GENERATOR SIDE			
Rated Power [MW]	10 - 15		
Voltage rms [kV]	3.3		
Back to Back NPC Converter			
DC Voltage [kV]	7.5		
MF Transformer			
Primary Voltage [kV]	Secondary Voltage [kV]	Turns Ratio	MVDC Voltage [kV]
3.3	21	1 / 7	30
	33	1 / 10	50

In the configurations A and B each phase has a DC/DC converter connected to the 7.5 kV DC link with a NPC single phase three level converter and to the MVDC side with a single phase multilevel converter. In the configuration A the output of each MF transformer is connected to a single AC/DC multilevel converter for each phase, while in the configuration B the outputs of each MF transformer are connected in parallel to a single multilevel converter. The configuration A provides a redundant system in the case of a fault because this architecture has all three branches connected in parallel. On the other hand the main drawback of this configuration is the space available inside the tower of the wind turbine and its cost. Regarding the configuration B the use of a single multilevel converter involves a small AC/DC converter in terms of volume/size. The main drawback is that no redundancy exists, compared to the other solutions (the transformers are redundant and the multilevel converter provides redundancy if extra cells are included, another drawback is the control complexity because phase synchronization is important).

Compared to the previous case, in the configurations C and D the DC/AC converters of each phase are connected to a three phase or single phase MF transformer, respectively. In the configuration C the output of each MF transformer is connected to a three phase AC/DC multilevel converter, while in the configuration D the inputs of each MF transformer are connected in parallel. The most relevant advantages of configuration C are the same as option B with the difference that in this case there is only one MF transformer. The main drawback is that there is no redundancy at the output of the multilevel AC/DC converter and there is no redundancy at the transformer although it has a low failure rate. Furthermore, B is a safer option than D because the outputs of the converters in D are connected directly to each other and the commutation of one converter can affect the other, while in the case of B the transformer provides some decoupling. On the other hand configuration D has the same characteristics of the architecture C.

The case of C is more reliable than D (although in terms of redundancy are equal) but the lack of converter synchronization will lead to a lower efficiency because there will appear a homopolar current in the neutral point of the transformer (due to unbalanced voltages) which counts as power losses.

It is worth noting that architecture A is the most similar to the actual converter and maintains completely the redundancy. In Table II the comparison of the four architectures with respect to advantages and drawbacks is shown.

Table 2: Qualitative comparison of the 4 architectures.

	ADVANTAGES	DRAWBACKS
A	• Low current rating; • Full redundancy; • Simpler control system.	• Converters are underused (low power); • MMC converter has high reliability, making less necessary redundancy; • More space and investment required.
B	• Redundancy at transformer level; • Reliable concept; • Small multilevel converter since single-phase system is considered.	• The use of more transformers (3) implies higher cost (about 15%) in comparison with only one with 3 times the rated power.
C	• Three-phase transformer is smaller than a single-phase;	• No redundancy on transformer stage; • MMC bigger (three branches).
D	• Similar to B; • Cost reduction due to the use of only one single-phase transformer.	• No redundancy at transformer level.

Fig. 2 shows the described results of the comparative evolution of the different DC/DC converter topologies. Architecture A is considered as base topology for the technical and economic analysis. It considers the size/volume, costs, control complexity, number of components and the redundancy. It is visible that the configuration A is the best solutions because it offers the best compromise between the costs and the redundancy. In this analysis the redundancy is the most important factor in order to ensure the continuity of service in case of failure of a single element of the converter.

Figure 2: Comparison of configurations.

III. CONCLUSIONS

The aim of this paper is to analyze different solutions for DC/DC converters for a DC-WT. Different approaches have been compared highlighting their performance and limitations. The result of the qualitative comparison claims that configuration A is the most interesting to precede the investigations. In according to Fig.2 the configuration A offers a high redundancy, a competitive cost, a lower size and a simpler control compared to the other configurations. For these reasons the configuration A is the most interesting for the high-power DC wind turbine application.

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