Isolated Cascaded DAB DC-DC Converter to Boost Medium DC Voltage to HVDC

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Abstract

The offshore wind farms typically use ac system to collect power from each generator, with the voltage increased by means of high, heavy step-up transformers. DC collection grids have also recently been taken into consideration as a solution to simplify and minimize offshore wind farm platforms. DC collection grids offer an additional method to reduce the complexity of offshore wind farms. However, increasing the DC voltage for HVDC transmission requires the development of high-power and high-voltage converters, which presents a technical challenge. This research makes use of an isolated cascaded dual active bridge (DAB) DC-DC converter to boost medium DC voltage to HVDC. Isolated Cascaded DAB DC-DC Converters are connected in series on the output side and in parallel on the input side to obtain a high transformation ratio and high power. The bidirectional DAB DC-DC converters cab be designed with power densities in the variability of tens to hundreds of kilowatts, depending on the components used and the switching frequency at which the converters function most effectively. The input parallel output series (IPOS) topology, 225 kV HVDC can be generated from a 5 kV MVDC input by cascading DAB DC-DC up to 30 stages. This converter family is useful due to its scalability and flexibility since the power and voltage ratings can be increased while still using the same cells. MATLAB Simulink simulations are performed and verify the elementary operating characteristics of the system..

Keywords—DAB, DC-DC Converter, HVDC, MVDC, Offshore Windfarm

1 Introduction

The climate variations and a growing population, energy demand can be fulfilled by using renewable energy sources like wind, hydro, and solar power. Wind farms located offshore are becoming more dominant since this energy source has the highest potential. There has been a magnificent growth in the use of wind farms in recent years, according to energy data [1]. Even though wind energy is now a fully developed technology, its widespread adoption has been hindered by issues including limited available land and the aesthetics of proposed infrastructure. Growing the offshore wind energy market might be the key to overcoming the challenges mentioned. Additionally, offshore wind sources are ample in certain regions, and offshore places often offer better wind conditions than onshore regions, with higher average wind speeds and less turbulence. Offshore installations, however, are more expensive [2] than their on-land counterparts. For this reason, most studies focus on improving the rating and effectiveness of onshore wind farms to reduce the unit cost of energy. Therefore, the transmission of high power over a long distance is a difficult problem [3]. Offshore wind farms are typically located between 60 km and 200 km (sometimes even 250 km) from shore. This makes traditional high-voltage alternating-current (HVAC) transmission unsuitable for connecting offshore wind farms to onshore ones [4, 5]. The active current capacity of long AC cables is diminished owing to the high cable charging capacitance. High cable losses and reactive power correction are the results of HVAC transmission via AC cables [2]. Transmission at high voltages using HVDC can prevent these losses. HVDC systems eliminate the need for reactive power regulation, guarantee a high transmission capacity, and reduce losses and system

ISSN: 2523-0379 (Online), ISSN: 1605-8607 (Print)
DOI: https://doi.org/10.52584/QRJ.2101.01
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instability [5]. Transmission losses in DC cables are 30–50% lower than in a three-phase AC system[6]. With HVDC, transmission losses are drastically reduced compared to HVAC across long distances, making it possible to utilize submarine cables to transmit significant amounts of power. When compared to the magnetic fields produced by ac lines, those produced by HVDC lines are negligible [12]. Moreover, HVDC is better suited to extremely large-scale and long-distance transmission [12]. HVDC systems can either be line-commutated converters (LCC) or voltage source converters (VSC). Thyristor switches are used for line commutation in LCC, whereas IGBTs are used for self-commutation in VSCs [13]. VSCs are more flexible than LCC when used for HVDC applications and better suited to transmissions from variable and renewable power sources like wind farms. In addition to being useful for feeding HVAC networks on the mainland, VSC technology are used to construct DC grids and link clusters of wind farms or solar power systems [12].

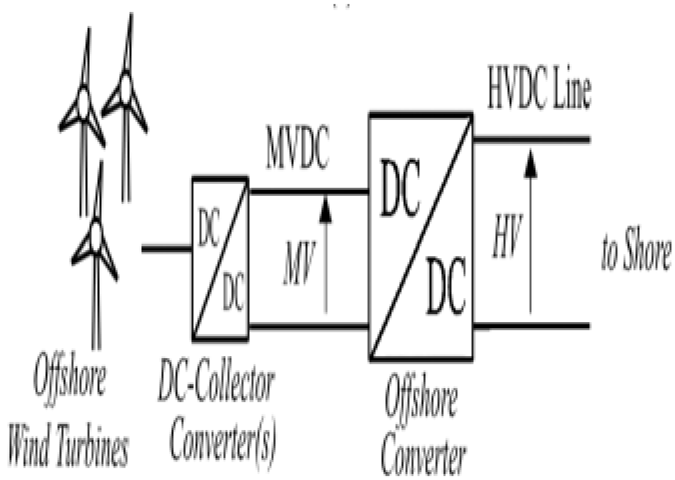

Fig. 1: Overview of HVDC Transmission

2 II.Isolated DAB DC-DC Converter

Dedicated DAB DC-DC converters for HVDC grids can do more than merely step voltages up and down [14,15]. They can also regulate power flows, regulate DC grid voltages, isolate faults, interface with various DC transmission topologies as (monopolar and bipolar), and connect to both LCCs and VSCs [6]. Although various established methods for low and medium-voltage DC-DC conversion exist [16,17], it is not easy to adapt these approaches to high-voltage applications. The need for many low-voltage elements, just like semiconductor switches [18] and low-voltage converters [19], HVDC converters cannot make use of conventional conversion techniques directly. For the sake of stability and safety, galvanic isolation may be required [18]. Isolation is helpful as it prevents high voltage from apparition on low voltage terminals, which is particularly crucial to keep in mind in high-transformation ratio applications [18]. When it comes to grounding, the structures allow for two DC grids with different grounding methods to be linked. There are other ways to accomplish these goals as well, but implementing isolated converters complicates the design and makes safety evaluation procedures easier. Inherent DC-fault blocking capabilities and voltage adaptation through transformer ratio are benefits of using these isolated converters. Blocking both of the converter's ac-dc conversion stages in the case of a DC fault eliminates the fault current [20].

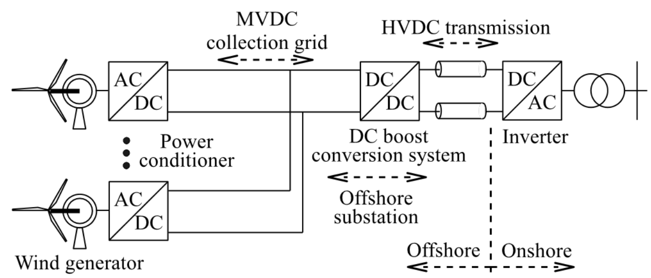

Fig. 2: DC Boost Conversion System

Power density, power quality, efficiency, and reliability can be significantly improved by getting rid of low-frequency transformers, reducing platform size, and simplifying the integration of different energy storage facilities, and variable loads [22]. The cheap cost, easy maintenance, scalability in voltage and power rating, and voltage balancing among semiconductor devices make a modular design preferable for MVDC applications [21]. DAB topology is generally used in medium voltage applications having high power density, bidirectional, and soft-switching operations. Because of many advantages, such as bidirectional power control, zero voltage switching, high-power density, and the convenience of paralleling and cascading. A DAB DC-DC converter is a type of switching converter that is used to efficiently convert a DC voltage from one level to another level. The converter uses PWM to control the output voltage by adjusting the duty cycle of the input voltage. The basic working principle of a DAB DC-DC converter consists of two main stages - one is the input stage, and the other is the output stage. The switching stage consists of a pair of switches that operate alternatively and are controlled through the duty cycle. During the turn-on of the switches, one pair of the switches turns on first while the other remains off. This allows energy to continue to flow to the output capacitor, which maintains the output voltage. The DAB DC-DC converter is a highly efficient type of converter due to the use of switching techniques. By controlling the duty cycle of the switches, the output voltage can be regulated with high efficiency. The converter's operation can be further improved by using advanced control techniques, such as pulse frequency modulation or pulse skipping modulation to reduce the power loss.

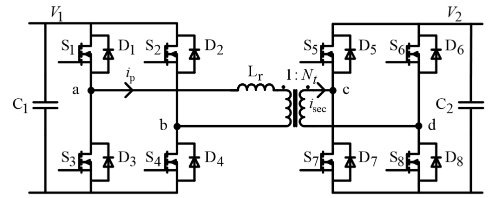

Fig. 3: DAB Converter

A high-frequency transformer connecting the bridges uses leakage inductance, which is often utilized as energy storage. The major control method for DAB is phase-shift control, which transmits power via the phase difference between the AC voltage of the primary and secondary sides. Particularly, for single-phase-shift control, vab and vcd are square waves with 50% duty cycles and the transferred power can be expressed as

$$P = \frac{V_1 V_2 \delta(\pi - \delta)}{2\pi^2 N_t f_s L_t} \tag{1}$$

V1 and V2 are the input and output voltages, is the phase-shift angle, and Lt is the leakage inductance. Single-phase-shift control is very simple to set up. Single-phase-shift changes to dual-phase-shift control or triple-phase-shift control if the duty cycle of vab and vcd is not 50 percent. Taking dual-phase-shift control as an example, the transferred power is

$$P = \frac{V_1 V_2 \delta(\pi - \delta)}{2\pi^2 N_t f_s L_t} + \frac{1}{2}\delta_1(2\delta\ - \delta_1 - \pi) \tag{2}$$

Where $0 \leq \delta_1 \leq \delta \leq \pi$, δ_1 is inner phase-shift angle and δ is the outer phase-shift angle. Related to single-phase-shift, the dynamics response, flexibility control and the degrees of freedom of double and triple-phase-shift increases.

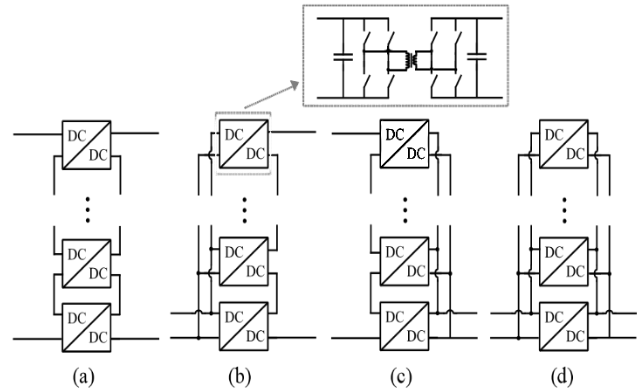

Fig. 4: Cascaded DAB DC Converter (a) Input-series Output-series (ISOS), (b) Input-parallel Output-series (IPOS), (c) Input-series Output-parallel (ISOP), (d) Input-parallel Output-parallel (IPOP)

3 III.Methodology

Cascaded DABs can operate at high frequencies and high-power density and low cell ratings that cause low voltage stress [25]. Therefore, the devices' current ratings decrease since each cell is responsible for a lesser proportion of the overall power [25]. Both a series and parallel connection can be used to link cells at the input and output side. IPOS, Input parallel output parallel (IPOP), input series output series (ISOS), and input series output parallel (ISOP), are the four possible configurations. IPOS systems are suitable for application that requires high output voltage and high power [21]. The converter cells can be connected in a variety of manners [27,28]. When the cell modules are connected in parallel, the DC line current flows through all of them, whereas in series, the DC line voltage does follow the same pattern. When large DC currents are needed, converters are connected in parallel, whereas when high voltages are required then converters are connected in series. It is possible to combine the two methods to fulfill the needs of various HVDC applications [29,30]. Each module is regulated as a typical DAB for the converter's operation, with the added requirement of a balanced distribution of module current and voltage [27,30]. With medium frequency operation, the passive components and transformer can be made smaller and lighter. It operates in soft-switching mode, which minimizes losses. High transformation ratios at high power are possible due to the many associated configurations. The DC boost conversion system includes high-frequency transformers for isolating the MVDC collection grid from the HVDC transmission line. As a result, bulky low-frequency transformers are unnecessary. Multiple separate DC-DC converter modules make up the boost conversion system. They have a parallel input connection and a series output connection. The modules' capacity and voltages are determined by the components used and the desired capacity. Optimal high voltage for HVDC transmission is achieved by maximizing the number of modules, N. Assuming Vdc as the module's output voltage, NVdc is the system's output voltage. For instance, if Vdc = 5 kV and N = 30, the resulting HVDC line voltage would be 225 kV. Using interleaving, we can equally operate the many modules in equal phase shift. Using this method, voltage ripples on both the input and output are decreased [23]. DC-DC converters having high power [24] come in a variety of configurations, and the system is selected based on the input voltage, output power, and operating frequency. With snubber capacitors, switching devices can turn off and on zero voltage switching. Since their switching loss has been drastically reduced, they can now achieve switching frequencies of several kHz. Thus, using high frequencies the size of the transformer decreases. IV.Simulation Results The system layout of the DAB dc-dc converter is symmetrical, and the two VSCs can be used at both ends of the high-frequency transformer. Reduced switching stress on IGBTs and reduced ripple voltage or current stress on DC capacitors are advantages of using the DC-DC converter. DC-DC converters use capacitors for zero-voltage switching. Hence, the bidirectional isolated dc-dc converters can be designed with high power densities. Despite the high-power density, the tiny size of the filter components and the low ratings of the cells allow for operation at high frequencies in cascaded DABs. The high output voltage and high-power requirements of certain applications can be achieved through the topology of IPOS systems. The cascaded DAB DC-DC Converter is simulated in MATLAB Simulink as shown in Figure 5 and Figure 6. The simulation parameters are given in Table 1. The isolated DAB dc-dc converters are cascaded in IPOS topology to obtain high voltage density and power rating.

4 IV.Simulation Results

The system layout of the DAB dc-dc converter is symmetrical, and the two VSCs can be used at both ends of the high-frequency transformer. Reduced switching stress on IGBTs and reduced ripple voltage or current stress on DC capacitors are advantages of using the DC-DC converter. DC-DC converters use capacitors for zero-voltage switching. Hence, the bidirectional isolated dc-dc converters can be designed with high power densities. Despite the high-power density, the tiny size of the filter components and the low ratings of the cells allow for operation at high frequencies in cascaded DABs. The high output voltage and high-power requirements of certain applications can be achieved through the topology of IPOS systems. The cascaded DAB DC-DC Converter is simulated in MATLAB Simulink as shown in Figure 5 and Figure 6. The simulation parameters are given in Table 1. The isolated DAB dc-dc converters are cascaded in IPOS topology to obtain high voltage density and power rating.

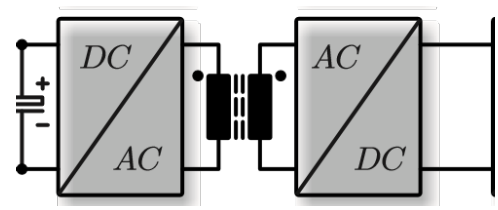

Fig. 5: Single Stage DAB DC Converter

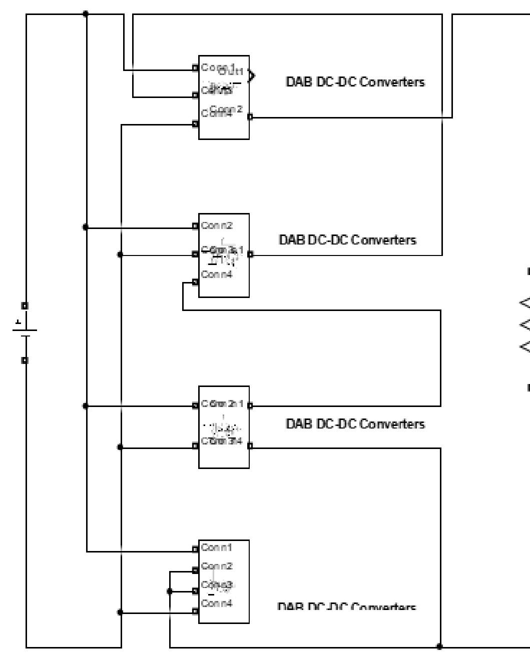

Fig. 6: Isolated Cascaded DAB DC-DC Converter

TABLE 1: DAB DC Converter Operating Parameters

Parameters	Values
Input Voltage	5 kv
Output Voltage	225 kv
Output Current	22 A
Output Power	5 MW
Transformation ratio	1:5
Switching Frequency	5 Khz
Cascaded numbers	30

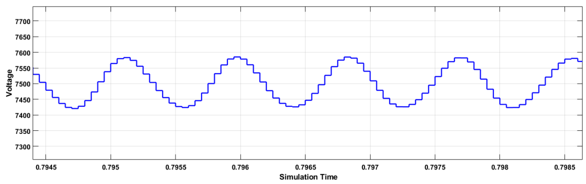

Fig. 7: First stage output voltage of DAB DC-DC converter which is 7.5 kV

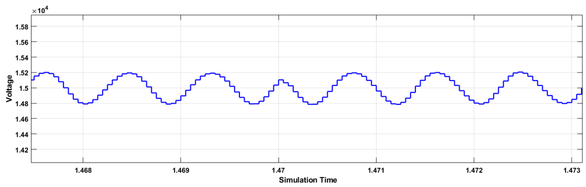

Fig. 8: DAB Converter have connected in IPOS topology so the output of the first stage is added up with second stage and equals to 15 kV

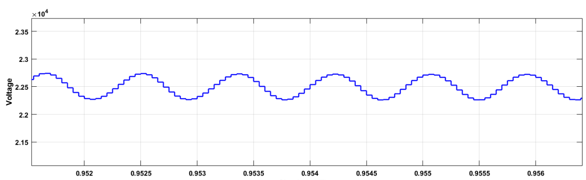

Fig. 9: The output of the first stage, and second stage is added up with the third stage and equals to 22.5 kV

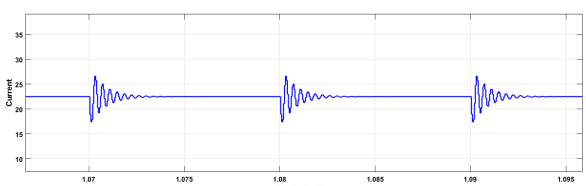

Fig. 10: Output current of Cascaded DAB Converter, output current is 22 A

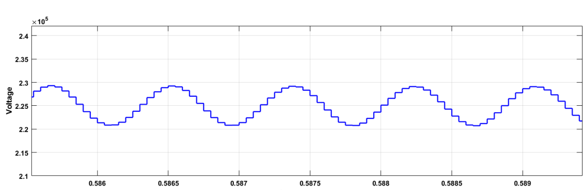

Fig. 11: Output Voltage of Cascaded DAB Converter in IPOS configuration up to 30 stages to achieve 225 kV

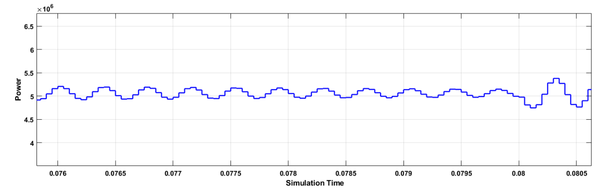

Fig. 12: Output power of 5 MW with Cascaded DAB Converter

In Table 1, the current mentioned as 22 A is an output load current. The transformer in the DAB DC-DC converter is used to provide voltage isolation and to adjust the output voltage level. The turns ratio determines the transformation ratio of the DAB DC-DC converter and can be used to set the appropriate output voltage level. By changing the number of turns in the transformer, the voltage transformation ratio can be adjusted to match the desired output voltage level.

5 V.Conclusion

Wind energy is a promising renewable energy and lately, the trend is towards offshore wind farms. Offshore wind sources are abundant and the wind speed at this location is high and consistent. HVDC system is used for the transmission from offshore wind farms grid to the onshore. HVDC system has many advantages over HVAC system i.e., HVDC has a good control system and is economical as compared to HVAC. HVDC link can isolate the two grids and hence can block the fault in voltage and frequency. MVDC is used for this application as it offers modular design, convenient maintenance, and reduces cost as it can operate at high frequencies. The isolated Cascaded DAB DC-DC converter is used to boost the MVDC to the HVDC level. DAB DC-DC converter offers many benefits that make them an attractive solution for offshore wind farms' HVDC systems. The Cascaded DABs use an IPOS configuration to obtain 225 kV HVDC voltage from 5 kV MVDC with reduced cost and increased efficiency.

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