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# Study Committee B4

HVDC and Power Electronics

Paper 10111_2022

# HVDC technology advancements for the integration of an Offshore Wind Farm (Sofia Project)


K Dyke[1], M Ramet[1], J Vodden[1], L Vacirca[1], R Tieu[2], C Smith[3]

[1] General Electric [United Kingdom], [2] Sembcorp Marine [Singapore], [3] RWE Renewables [United Kingdom]



## Summary

- This paper reviews the offshore HVDC link connecting the Sofia Offshore Wind Farm, an offshore terminal located in the Dogger Bank area of the North Sea, and one onshore terminal located in the vicinity of Middlesbrough, UK. The link spans a transmission distance in the region of 220km and can deliver 1320 MW at ±320 kVdc, capable of powering over 1.2 million homes.


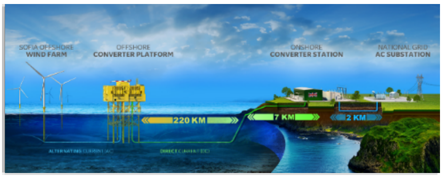


*Figure-1 HVDC scheme link for Sofia*

## Key Features

- 1320 MW, ±320 kVdc, sea water depth in Dogger Bank platform is ca. 27m and located 220km from shore.
- Higher power density achieved through novel design features of the VSC valve modules, such as higher current capability and innovative corona shielding design to reduce electrical clearances around the valve.
- Equipped with state-of-the-art control and protection systems that are the 1st in the HVDC industry to extensively implement the IEC-61850 standards.
- The new control and protection systems are an exceedingly fast computing platform, which allows for extensive use of optical instrument transformers for enhanced measurement and data sampling of voltage and current signals.
- Offshore solution includes the integration of offshore array cables rated at 66 kVac, therefore, eliminating the need of a dedicated offshore AC collector platform

## Electrical Arrangement

An overall single line diagram (SLD) is shown in Figure 2. Starting from the left:

- The offshore station, a total of 18 array cables are brought onto the platform and distributed across 4 busbars.
- Two busbars are connected to one 3-ph interface transformer (IFTX) whilst the other two busbars are connected to the other 3-ph interface transformer.
- The busbars are arranged in pairs with a bus coupling breaker between them.
- Transformer connection to 66 kV busbar is performed through gas insulated busbars.
- The IFTXs are connected to the MMC HVDC valves via 420 kV GIS busbars.
- The six valve reactors are located on the DC side of the valve to optimise the offshore platform arrangement.
- The offshore station connects to the onshore station via one HVDC circuit, two cables, one per pole.
- At the onshore station a common DC reactor is shared between the AC/DC MMC converter and the Dynamic Braking System (DBS).
- For the onshore station the valve reactors are located on the AC side of the MMC converter.
- The onshore IFTX consists of three single phase units. An additional, spare transformer is available on site. The spare transformer can be placed into service by reconfiguring the overhead busbar and secondary systems, without the need for physical relocation.

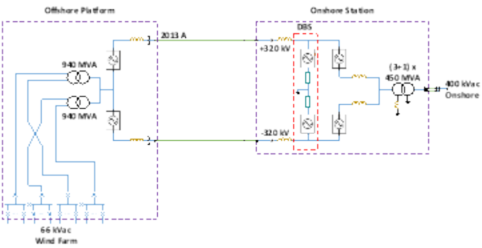


*Figure-2 Simplified electrical arrangement of the Sofia project*

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## continued

## Offshore Platform Arrangement

- Figure 3 shows the general arrangement of the main HVDC equipment on the offshore platform.
- In the figure it can be seen that the 66 kV array cables enter the platform at the mid-point of the platform on Deck 1. These cables are routed up to Deck 2 where the 66 kV GIS switchgear is located. From the 66 kV GIS switchgear the power connections are routed to the top deck (Deck 6) where the interface transformers are located.

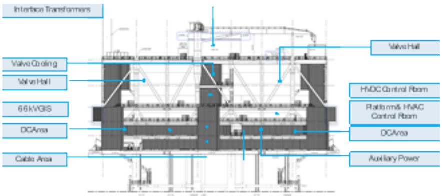


*Figure-3 Platform Arrangement*

- The design, construction and installation of the Offshore Converter Platform (OCP) comprises a 10,000 tonne topside (78 x 36 x 36, metres, L.W.H.) and a 7,000 tonne jacket foundation structure ( 54.5 x 36 x 51.5, metres, L.W.H ) piled into the seabed and will be one of the most remote OCP ever built.
- The OCP is designed to allow for sufficient export cable slack to be pulled and housed enabling for a second termination of the DC joint.
- Figure 5 illustrates how the cable is routed to ensure that both termination positions respect the required clearance and safe handing constraints, with a DC export cable design that allows for a repair termination to be made without the need of pulling extra cable.

*Figure-4 Offshore Converter Platform*

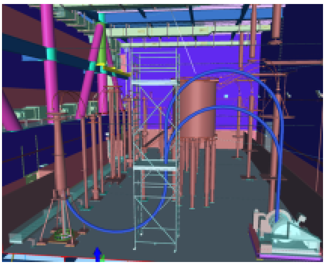

*Figure-5 Export cable slack position in reactor hall*

## Onshore Arrangement

The onshore arrangement is shown in Figure 6.

- Two parallel 400 kV AC cable connection to the Lazenby National Grid substation
- The soft-start circuit, which consists of a 400 kVac resistor in parallel with a disconnector that is used to bypass the resistor once the HVDC circuit is energized, is used to limit the inrush current into the circuit capacitance when the HVDC Link is energized from the AC Grid.
- The power circuit connects to the interface transformers before connecting to the valve reactors, located outdoors.
- The connection then enters the valve hall where the six MMC valves and the two DBS valves are located.
- The outdoor, air-cooled, DBS resistors are located next to the valve reactors. The DC reactors are located on the opposite side of the valve hall to the valve reactors alongside the HVDC cable sealing ends, opposite stands a storage building.

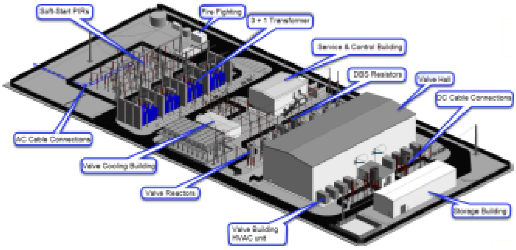


*Figure-6 Onshore Station Arrangement*

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continued

## MMC Valves

- Sofia is the first application of the second-generation Modular Multilevel Converters (MMC) valves.
- The new generation increases the power density of the valves by increasing the voltage and current capability of the valve submodules and by optimising the structural arrangement.
- The rated power level for the Sofia Wind Farm is more than 40% higher than other projects in service.
- Each valve consists of a number of series connected valve sub-modules, each containing IGBTs, diodes and DC capacitors along with the valve electronics and protection unit.
- 4 series connected sub-modules form a module; two module back-to-back form a tier; multiple tiers are stacked to form towers.
- Increased power ratings achieved by using parallel IGBTs.
- The sub-module includes a rapid discharge circuit, which effectively clamps the sub-module voltage and prevents the capacitors from over-charging in case of system faults and helps reducing the total number of sub-modules required.

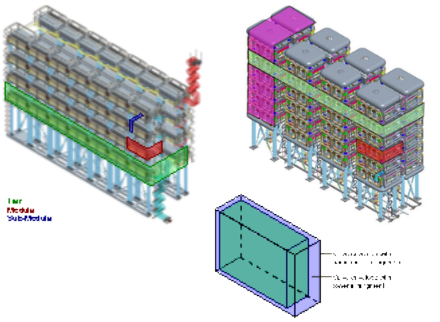

*Figure-7 Generation 1, horseshow (left) vs Generation 2, tower arrangements (right), and valve format space saving advantage (bottom)*

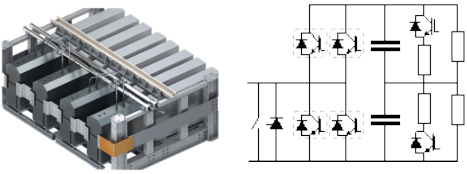

*Figure-8 Valve module illustration (left) and VSM schematics (right)*

## Integration of HVDC Control System

The windfarm connection is the first application of an advanced generation HVDC control system, which includes one of the fastest computing units in the market and enables the HVDC station to go fully digital based on broad adoption of the IEC61850 standard.

- Uses one type of real-time, physically identical, software-definable application execution units that execute all the control and protection functions.
- Designed as easy to maintain line replaceable units.
- IEC61850 networks are used to interface the HVDC control system with HMIs, AC/DC substation equipment, cooling plant, transformers and Transient Fault Recorder (TFR).
- Efficient direct data transfer among all IEC61850 devices in the network, using station and process buses.
- IEC61850-8-1 GOOSE, IEC61850-90-6 R-GOOSE, MMS are used for information exchange with plant devices.
- IEC61850-9-2 SV/IEC61869-9 are used for real-time measurements, based on a distributed architecture.

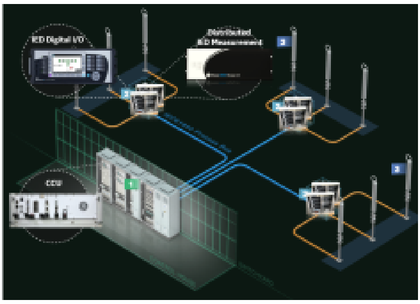

*Figure-9 HVDC digital substation using IEC61850*

## Conclusion

- The optimisation of compact HVDC design has been outlined for long-distance high-power utilisation of offshore wind.
- The Sofia solution has leveraged a new generation of valve electronics with higher power density, and fully digital control systems with increased computing power and reliability, and the smart fabrication of the platform to reduce commercial risks to cable technology.