Provision of Ancillary Services from Large Offshore Wind Farms

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Wind power has adopted a significant role in the rise of renewable power systems, however high wind penetration brings with it technical, economic and regulatory issues. One of the primary concerns for large scale connection of wind power is network operators' ability to maintain desired frequency and voltage for the network consumers. During faults and outages, operators must rely on spinning reserve and ancillary services from various generators to maintain frequency and prevent cascading loss of load. To enable high levels of wind penetration, it is imperative that wind farms be operated, where possible, as conventional power plants in order to provide their dynamic characteristics and network support features. This can be expensive however, and there is great need for cost effective solutions to better enable higher penetration of wind and all renewables.

1. Connection of Wind Farm using HVDC

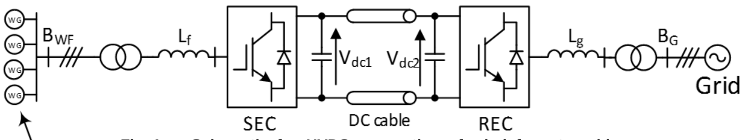

Fig 1. – Schematic for HVDC connection of wind farm to grid showing Sending-End Converter and Receiving-End Converter

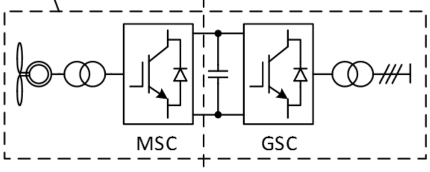

Fig 2. – Schematic for wind turbines showing back-to-back converter with decoupling capacitor

Due to the decoupling effect of capacitor in the back-to-back converter, wind turbines may be modelled as DC source connected to Grid-Side Converter in order to simplify the model.

For further simplicity, the entire offshore wind farm is represented by one equivalent unit.

2. Control of HVDC link

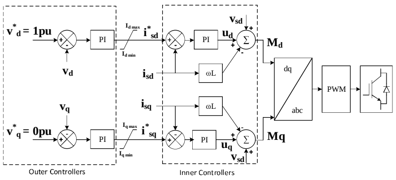

Fig 3. – Control Diagram for SEC

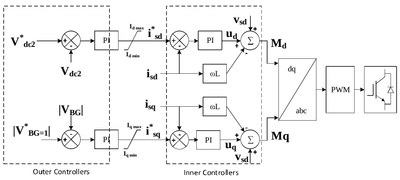

Fig 4. – Control Diagram for REC

The Sending-End Converter of the VSC-HVDC keeps a stiff ac bus at the wind farm main platform (B_{WF}). This is important to ensure stable control of wind turbine GSCs which used the voltage set by SEC as a reference.

The Receiving End Converter of the VSC-HVDC is configured to regulate the DC link voltage level at $640\ kV$ and the AC voltage at the PCC (B_G).

This control scheme allows independent control of P and Q which enables it to perform Fault Ride Through behaviour.

3. Simulation Results

Simulations were run with wind farm output initially set to $300MW\ (0.3\ pu)$, with a ramp up in power output beginning at $t = 2s$. Different magnitudes of ramp were tested as shown in Figures 5a-5f below.

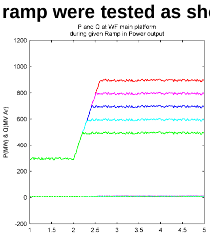

Fig 5a

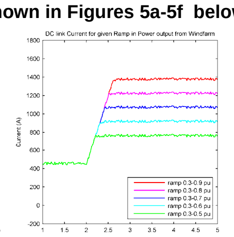

Fig 5b

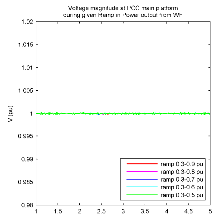

Fig 5c

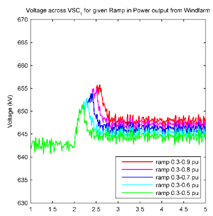

Fig 5d

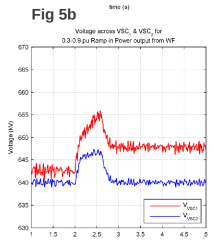

Fig 5e

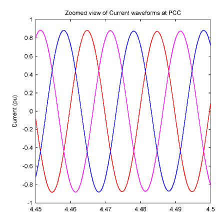

Fig 5f

To illustrate the improved ac fault ride-through behaviour of the wind farm when integrated into the mainland grid using a VSC-HVDC link, a symmetrical ac three-phase fault to ground was applied to one of the tie lines that connects bus B_G to the grid as shown in Figures 6a - 6c below.

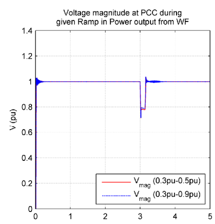

Fig 6a

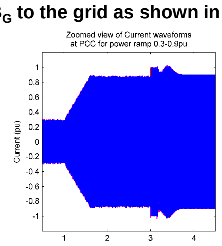

Fig 6b

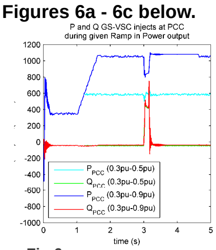

Fig 6c

4. Preliminary Study on Hybrid Converter for SEC

The SEC VSC can be reduced to 1/3 of original rating and connected with two equally rated 12-Pulse Diode Rectifiers in a hybrid topology as shown in Figure 7. This reduces the number of IGBTs used, replacing them with Diodes resulting in a lower cost converter with lower losses.

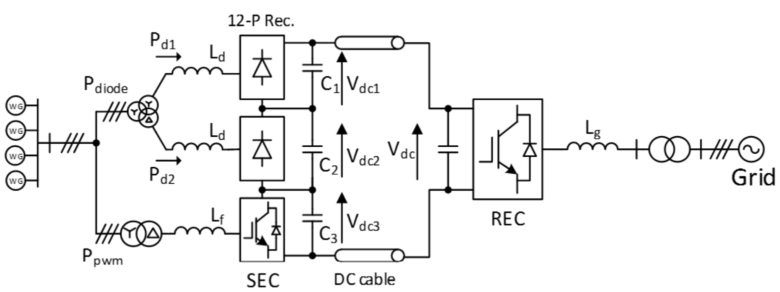

Fig 7. – Schematic for HVDC link with Hybrid Sending End Converter

Simulation was run with ramp up in power output from wind farm of $0.5\ pu\ to\ 0.9\ pu$, starting at $t = 2s$.

For this brief preliminary investigation into the described hybrid converter design, control of the SEC VSC was as before.

It can be seen from Figure 8 that Voltages across capacitors in the SEC of the DC link do not remain balanced with different magnitudes of power flow from the wind farm and additional control is required to achieve this.

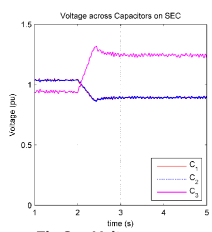

Fig 8. – Voltage across capacitors C_1, C_2 & C_3

5. Conclusion from Results

Figures 6a – 6c illustrate current HVDC technologies ability provide Low Voltage Ride Through (LVRT) support to the network while other ancillary services, such as frequency support, may also be demonstrated.

Since the REC converter, which governs HVDC link voltage, and its controller design remained the same for hybrid design, the DC link dynamics are similar to those seen in Figure 5b.

Therefore it should demonstrate LVRT capabilities but this is yet to be tested through simulations.

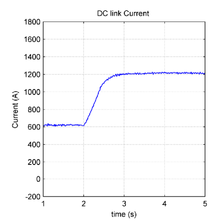

Fig 9. – Current through HVDC link

It is of high importance that the hybrid design for SEC be able to keep a stiff bus for the offshore AC network while also balancing the capacitor voltages in the SEC.

This will require additional control of power injected though the VSC into the DC link, thus controlling the balance of power injected by 12-P rectifiers and VSC allowing balancing of the capacitor voltages on the DC link.

With robust control over this, followed by demonstration of the models LVRT capabilities, investigations into frequency restoration services from the low cost hybrid converter may begin.

Future Work

- **Improve SEC control loop for voltage regulation both for offshore AC network and balancing C_1, C_2, C_3.**
- **Demonstrate LVRT for HVDC link with hybrid converter and investigate capability for participating in frequency restoration services.**
- **Investigate optimised solution for low cost, high support capability HVDC link for large offshore wind farms.**

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