How are various generation technologies including the BESS, wind turbines, solar inverters, VSC HVDC and STATCOMs are compared with regard to the ease of implementation and system stability impact when equipped with grid-forming capability, and what is the impact various grid-forming controls including but not limited to the so-called virtual synchronous generator or virtual synchronous machine?

As part of the investigations of the power-frequency and voltage stability of proposed North Sea Wind Power Hub (NSWPH), grid forming capabilities of the offshore AC system with 100% renewable generation and multiple HVDC converters were evaluated. It was found that the VSM based techniques have difficulties avoiding the interactions between multiple grid forming MMC VSC converters connected together in an offshore grid. The following issues and solutions were required:

- The internal voltage was determined by a terminal voltage controller.
- The internal angle was generated by an oscillator and a frequency droop controller was used to keep the steady state power balance.
- A master controller was utilized to determine the frequency error of each converter
- The feedback through the frequency/speed was too slow to avoid instabilities during the fault recovery. A **transient angle control** mechanism was required.
- In a bipole HVDC systems, the positive and negative poles can interact with each other. This was resolved by introducing a **pole circulation current control**.
- It was observed that two HVDC bipoles can interact with each other if they are connected tightly from the AC side. There interactions were avoided using:
    - Active power oscillation damping controller
    - Reactive power oscillations damping controller

The steady state and dynamic performances were evaluated for small signal and large signal disturbances of the NSWPH AC hub configuration. The results show that the grid forming technique works well and the offshore grid voltage and frequency can be maintained well within the limits defined for onshore grids. The details of the study and the results can be found in the NSWPH consortium website [1].

[1] *https://northseawindpowerhub.eu/knowledge*