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Grid-forming technologies have opened additional options and functionality for existing inverter-based devices, such as battery energy storage systems (BESS), wind turbines, solar inverters, VSC HVDC and STATCOMs. This presentation outlines the experience of connecting a grid-forming inverter (GFMI) virtual synchronous machine (VSM) BESS to a weak grid and the key challenges that were encountered. The connection was extremely remote with a short circuit ratio (SCR) of approximately 2.0 and was very close to two other grid-following inverter-based resources (IBRs). Grid-forming devices, especially those with virtual synchronous machine functionality, have additional challenges with control coordination at the inverter and plant wide levels. Furthermore, the inherent physics of a power system still prove difficult to manage when connecting grid-forming technologies in weak grid locations.

Plant level control is important for normal system operation and stability. This typically is managed by a Power Plant Controller (PPC) which is responsible for translating plant level setpoints to individual inverters. In a traditional grid-following inverter context, PPCs provide an active power and reactive power command to the inverters as grid-following inverters control their output power. In contrast, grid-forming inverters typically control voltage magnitude and phase angle, letting power system physics dictate their power output. This connection experience utilised a standard PPC structure where an active power and reactive power command were provided to the inverters. The specific inverter utilised required an internal voltage magnitude and speed reference. For the inverters to operate correctly, they convert the power commands from the PPC into the corresponding voltage magnitude and speed references. The voltage magnitude reference is determined through a proportional-integral (PI) controller, while the speed reference is yielded as an output of a VSM control loop, also referred to as a virtual inertia control loop. The tuning of these two control loops introduces additional transients and delays in the plant response and the inverters are less likely to directly follow the PPC commands. This is further exacerbated in weak grid conditions. To facilitate stable control, it was found that PPC tuning needs to be slow while inverter tuning is sufficiently fast enough to follow PPC commands without introducing oscillations, poor damping, or any other instabilities.

A secondary control coordination aspect, specific to devices with virtual synchronous machine control loops, is management of the virtual inertia response and sustained frequency control. Virtual inertia responds to rate of change in frequency, and plant response can be adjusted through tuning of the inertia constant (H) and damping constant (D) parameters of the control loop. However, once frequency settles to a constant value, the plant's inertia response will cease. The Australian National Electricity Market (NEM) has several frequency markets and primary frequency response rules, requiring devices to maintain an active power injection or absorption for a longer duration than the typical 1-2s virtual inertia response timeframe. Hence, in this experience, additional sustained frequency control through the PPC was required. Sustained frequency control through the inverter was ruled out as an option due to the PPC utilised not possessing a frequency ride through functionality, or sufficient ability to coordinate response with the inverters to prevent integrator wind-up. As such, PPC level sustained frequency control is currently viewed as simpler to implement and coordinate with VSM control loops.

This experience of a weak grid grid-forming BESS connection encountered a key challenge in voltage collapse driven by large changes in power output when experiencing a frequency disturbance. Under weak grid conditions, a network is very sensitive to voltage changes, but voltage is also significantly more impacted by power flow changes. When the plant experienced a change in active power output from 0pu to 1pu, for some operating conditions it was sufficient to drive the voltage up or down enough to trigger fault ride through (FRT). This was more likely to occur if the plant's voltage control response was slow or poorly tuned, and especially likely to occur if insufficient reactive power capability was available. A frequency disturbance results in an active power injection or absorption due to the plant's virtual inertia response and sustained frequency response, and, if set too aggressive, led to voltage collapse. This was observed as FRT re-striking, as when the plant entered FRT the active power output would reduce, and voltage would recover. Once voltage recovered, FRT would clear and the plant would respond to the frequency change again, repeating the cycle. As such, in weak grid conditions frequency control must be factored into plant operation to ensure voltage stability is maintained.

Grid-forming technologies have opened an increased number of options for managing supporting power system stability. Despite this, they are still prone to some specific and more global challenges when connecting and being used to manage power system responses. This experience of a weak grid connection VSM GFMI BESS highlighted this. Plant level and inverter level control coordination is key to achieving the true potential of grid-forming technologies. While weak grid conditions still prove to be challenging to connect in due to network physics, and power flow limitations. However grid-forming devices and virtual synchronous machine capabilities are still very beneficial when used in suitable settings and tuned appropriately.