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Question 17: 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?

Currently, the majority of grid forming inverter (GFMI) installations around the world are battery-energy storage system (BESS)-based, meaning the DC side of the inverter is fed by a battery providing a stiff DC voltage. This assists GFMIs in maintaining their DC link voltage within permissible limits when responding to various disturbances such as reference change commands, grid frequency change, voltage sags, etc.

However, the GFM control may be applied to other inverter-based resources, such as wind and solar farms, STATCOMs, and HVDC converters. Although some of the control blocks used for BESS-based GFMI (internal current control loop, point of connection voltage loop, and the primary loop for real and reactive power control) could be similarly adopted for such IBRs, there are other considerations that are needed to be taken into account to enable GFM for non-BESS IBRs. Almost for all such IBRs, the DC link voltage control when operating in the GFM mode can be a concern as no battery is assisting in maintaining the DC side voltage.

For wind farms, particularly, the situation is more challenging. The main reason is that in addition to the DC side voltage control, other parameters such as the generator speed and torque must be regulated and maintained within permissible limits when exposed to various disturbances such as operating point change, grid frequency change, grid voltage phase angle change, voltage sags, etc. Often, manufacturers have strict limits on the mechanical variables (e.g., torque and speed) of the turbine, and it is imperative that the GFM control does not violate their safe operating regions. Moreover, to ensure the optimal operationin the GFM mode, a de-loading factor should be incorporated into the GFM control for farms, which results in operating at points other than the maximum power point, leading to sacrificing some of the potentially available energy of the farm.

Compared to wind farms, GFM control of solar farms is less challenging as they do not have the strict mechanical limitations of wind farms. However, the dc link voltage control for solar farms is still challenging as the GFM controller must ensure the DC-side voltage is maintained within its permissible limits upon various disturbances. Moreover, the de-loading factor is still required in solar farms to provide the required headroom to respond to certain grid-side disturbances. It must be noted that the transferrable energy to the grid and its rate of change is limited in GFM-enabled wind and solar farms and is a function of the wind/solar farm operating point.

For STATCOMs, although GFM control may be applied, since there is not sufficient energy at the DC side of the inverter, its capabilities are limited compared to the GFM for BESSs. However, one can use oversized DC link capacitors or supercapacitors to provide a certain level of energy such that the GFM-enabled STATCOMs can respond to various disturbances

that require real power injection/absorption. However, the DC link voltage control in GFM-enabled STATCOMs still remains a significant challenge.
It must also be noted that the blackstart capability of wind and solar farms and STATCOMs equipped with GFM control is rather limited. For STATCOMs, it is almost impossible to provide such a service as the available energy at its DC side is rather limited. For wind and solar farms, with proper control, blackstart capability might be a possibility; however, particularly at low power levels, wind and solar farms face difficulties in providing blackstart capability.

To sum up, GFM capability with BESS-based inverters is the most straightforward, while wind-based GFMI is the most challenging due to its mechanical constraints. Solar-based GFMI may be a viable solution, while STATCOM-based GFMI has limited capabilities unless equipped with oversized capacitors.