10 THINGS YOU SHOULD KNOW ABOUT GRID-FORMING INVERTERS

There is growing accord that grid-forming (GFM) technology for inverter-based resources (IBRs) like wind, solar PV and battery energy storage, will be part of the future deeply decarbonized power system. GFM inverters are expected to replace and improve on some important functions provided today by synchronous generation. Here are 10 things you ought to know about GFM inverters.

1. **GFM inverters are not new.** *Basic GFM functionality, especially for battery energy storage, has been around for decades. Successful operation of small power systems with only GFM IBRs is well established.*

2. **Commercially available, utility-scale wind and PV today do not have GFM capability.** *Only some battery systems have GFM functionality.*

3. **Most GFM concepts are variations on "virtual synchronous machines".** *A primary motivation for GFM technology is to "replace" synchronous generation. There is not a single design or performance that defines GFM. There is some consensus that just mimicking synchronous machines will not give the best outcomes. Research on control concepts is vigorous and ongoing.*

4. **GFM is not a "silver bullet":** *grid limitations still exist and must be respected. Failure modes are altered. Institutional understanding of how large power systems with mainly or only GFM IBRs behave is incomplete. The amount or fraction of resources that must have GFM capability for successful operation is not clear yet. Protection and relaying are an area of concern.*

5. **Hitting current and power limits will strongly impact grid-formation.** *Devices that are at their maximum power output available or at their maximum current behave differently, and in general their grid-forming capability is compromised. Equipment designs and system planning must include consideration of these limits for efficacy and reliability.*

6. **Stored extra energy can help accommodate grid-forming.** *In addition to power from wind and solar, power to enable successful grid-formation can come from various stored energy sources, including electro-chemical (batteries), electric-field (capacitors), and mechanical (inertia). Extra energy can help mitigate power limit concerns.*

7. **GFM is more than just software changes to present grid-following inverters.** *Physical changes are needed. Retrofit of existing inverters for GFM is usually not possible.*

8. **GFM will affect capital costs.** *Manufacturers stress that there are design tradeoffs. Higher current ratings add costs to inverters. GFM inverters introduce mechanical stresses on rotating equipment, notably wind-turbines, that are not presently fully understood or evaluated by manufacturers. Manufacturers are making progress on commercializing GFM offerings. Commercial issues remain.*

9. **The need for GFM is being felt today in several systems that are leading decarbonization trends.** *Systems that are far from reaching deep annual decarbonization goals experience periods of extremely high IBR penetration which must be securely handled. Initially, the need for GFM technology tends to be locational, with portions of large systems becoming dominated by IBRs.*

10. **GFM technologies present an opportunity to improve power system performance** *beyond that possible with today's synchronous generator dominant systems. Present focus on doing as well as synchronous generation will give way to new control concepts that do better.*

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