Question	Answer
How difficult would it be to retrofit to grid-forming inverters? Would that make systems more "robust"?	Retrofitting is definitely more difficult and costly as compared to building GFM into new BESS facilities. Concerns with inverter sizing, DC bus coordination, SCADA integration, downtime/lost revenue, new system studies, etc., all play a role in these complexities.
Which is the biggest challenge in GFM modelling? Is it to mingle into RMS?	GFM controls need to be modeled in different domains, from different perspectives. The dynamic response of a GFM can affect stability as well as short-circuit. So getting accurate models in EMT domain, positive sequence domain, and short-circuit domain are important. EMT domain is more straightforward since OEM-supplied models can be acquired. Positive sequence standard library models may not adequately represent the OEM-specific controls, which could raise challenges with interconnection requirements.
How was OEM's GFM and GFL designated for these studies? Was it purely based on pass/fail regarding the NERC functional spec?	Yes, models that adequately met basic model quality checks were used in the microcosm testing and real system testing. All applicable models provided by the OEMs as "GFM" passed the NERC tests while all the "GFL" failed. So that differentiation held up in terms of defining which model was which.
Did the team look into the performance of GFM-BESS compared to the synchronous machine for UFLS assessment under NERC PRC 006 performance requirements?	No, UFLS studies were not within the scope of this study. However, GFM BESS could be a useful resource to help arrest rapidly declining system frequency and help stabilize an islanded portion of the BPS during a system separation event. This could be future study work conducted.
Which software package/platform was used for the modelling and testing?	PSCAD.
How do NERC requirements relate to the GFM requirements in Europe ?	There are no NERC requirements for GFM. NERC has published a recommendation that all future BESS by GFM and published the functional specification and simulation test procedures. However, they are not enforceable. Some TSOs in Europe have required GFM or are incentivizing GFM. This is similar to how some entities in the US are moving to require GFM as well.
Are we really going to be able to keep 60+% RE isolated systems (such as is aimed for in Australia) stable without more detailed models from the OEMs	Unless a significant standard library model initiative is undertake by NERC/FERC, it is unlikely that the standard library models will be adequately accurate to reflect the evolving IBR controls. For exaple, some GFM standard library models have been released, but there is not unilateral "approval" from all OEMs that the models can be parameterized to match their equipment. Thus, more reliance on user-defined modeling may be needed due to these circumstances. Additionally, real system post-event GFM model validation efforts have been performed in Hawaii and Australia which show that the detailed user-defined models closely match reality.

What is the impact to the protection system with the incorporation of GFM?	This was outside the scope of this study. However, it is expected that GFM controls would be a net positive from a protective relaying perspective.
How does the synchronization occur between GFMs when multiple of those are in the grid ?	Similar to synchronous generators, the GFMs rely on common power and voltage control sharing practices such as active power-frequency droop and reactive power-voltage droop that enable these resources to stably control a common bus.
Can these models be accurately added to a power world base case? Say a WECC case to look at the effect of GFM on large interconnections. Thank You!	Positive sequence simulation is outside the scope of this study. However, some standard library models for GFM have been developed and incorporated into the simulation platforms. Thus, it is expected that GFM standard library models can be used in PowerWorld either today or in the future. The accuracy of those models for each specific OEM may vary.
For the simulated systems, please shed light on power loop-flows (if any) among BESS systems connected to same bus while operating in different control modes.	All BESS had adequate droop or compensation controls such that power sharing between units within a plant or across plants was accomplished stably and reliably. No abnormal looped power flows were observed within the multi-OEM plants. Loop-flow was briefly observed plant-to-plant in some of the Scenario 2 cases, however the plant outputs quickly synchronized within a few cycles. In the dynamics realm, some resources responded with different reactive power responses; however, this is to be expected based on system topology and voltage needs.
On slide 26, it looks like GFM is not hitting a limit while GFL response is hitting a limit. Is is expected that GFM will be overbuilt with wider limits?	In the simulation results on Slide 26, these are small disturbance steps so operating limits are not expected to be reached. There are no discontinuities or nonlinearities in the active or reactive power flows from either GFM or GFL in these results.
Is it possible that GFL BESS follows the GFM BESS intervention after a fault, thus "supporting" the GFM intervention? Do we see any similar behaviour?	The GFM resources tend to respond faster during the sub-transient timeframe and immediately following fault clearing. Thus, the team would actually test to flip the questions and say the GFM is "supporting the GFL" by providing that additional grid-stabilizing response in this timeframe which the GFL tends to generally lack in response.
How do you model GFM in network system planning studies? (IEC 60909 Method)	Short circuit modeling is outside the scope of this study work. These studies were conducted in PSCAD. However, similar methods to GFL IBRs can be used to represent GFM IBRs by accurately parameterizing the different models. DLL-based user-defined modeling methods could also be used to provide more accurate results, as these practices evolve.
Is the study for phase angle jumps for the purpose of ride through? if so, what angle value is the vector shift relay set to in the models?	Yes, the purpose of the test was to check ride-through for phase angle jumps. However, we did not make any changes to the models themselves. The models were provided by the OEMs and whatever relays necessary are already included.
Some of the differences between GFM and GFL is within milliseconds. Does this mean EMT studies should be part of long term planning?	It is likely that increasing levels of IBRs across the bulk power system will drive the need for more EMT studies as part of interconnection studies and long-term planning studies.

Are you testing GFM in GFM mode, or just its GFM capability while initially in following mode with auto transition to forming?	All models were provided directly by the OEMs as "GFM"; thus, there was nothing unique in terms of transitioning from GFL to GFM beyond what OEMs have configured their product to do.
Is it possible to optimize a grid's resilience by strategically combining GFM and GFL inverters?	The study results show that as more GFM is added to the system, additional stability benefits can be achieved such as better performance in weak grids, increased stability margins, larger IBR hosting capacity, etc.
What do you do with the PSSE buses that are not "kept" in the PSCAD model? Some sort of equivalent?	Yes, network equivalents were determined at the PSCAD boundaries based on the PSSE model information. These equivalents are established beyond the study region to ensure they do not have a significant impact on the study results.
What was found to be an issues with the vendors with GFM models that were giving problems, I.e OEM D	OEM "D" GFL models were not initializing properly. OEM "E" GFM and GFL model was not dispatchable.
In the case of ATC, is the utility using only PSCAD model instead of co-simulation ie PSCAD-PSSE?	PSCAD simulations.
On slide 26, active power plots for different OEMs: Is the PPC active power command identical to each GFM and GFL inverter?	Yes.
3 phase bolted faults or normally cleared with reclosure?	The studies included normally cleared three-phase faults and single line to ground faults; no reclosing was studied.
On slide 26, Why does the GFM inverter show more oscillations than the GFL?	This is based on the inherent dynamic response of GFM controls.
What's the benefit of having GFM on STATCOM instead of GFL?	GFM STATCOMs were not in scope of this study effort.
What was the mix of VSM vs. droop vs. ??? approaches to GFM for the OEM GFM models?	The study team did not explore the GFM controls per each manufacturer in extensive detail. Rather the team ensured a mix of different controls from various OEMs. The goal was not to explore GFM control topologies; the goal was to ensure the system would remain stable using OEM-supplied GFM BESS resources, which it did.
Was there any modeling done on a radial system? Specifically a weak radially Transmission line?	During N-1-1 outage contingencies studied, a significant amount of IBRs (GFM and GFL) were connected radially through a series of circuits to the stronger bulk system. Stability results showed improved performance under these conditions with increased GFM adoption.
Other studies suggest that multiple GFM close together on strong networks might cause problems..maybe network structure needs more focus	This concern was studied and the results showed that the OEM-supplied models did not exhibit these issues. Any model can be tuned (for better or worse) and thus a poorly tuned GFM could result in issues in specific networks. The goal of this study was to use the OEM-supplied models on a real strong network and no issues were identified.

How would BESS GFM compare to synch condenser in terms of inertia support ?	Synchronous condensers provide true rotational inertia from a spinning mass, instantaneously resisting frequency deviations with no control delay based on physics. GFM BESS provide a similar response but based on power electronic controls, which can therefore be tuned.
How does the placement of GFM BESS within the network impact local stability in a weak transmission area?	Placement of GFM may play a role in improving local stability of a network. However, this study explored whether more significant growth of GFM would cause any issues and it did not. Thus, if you are only implementing one GFM you may want to be thoughtful around location; however, it it becomes a requirement or more widespread, it is expected that these benefits would propagate.
For the cases comparing GFL vs GFM operation (ex. slide 35) why are the final steady state conditions different post fault?	The GFM case has 125 MW more solar PV (GFL) included in the local network, demonstrating that increased IBR hosting capacity was obtained before hitting a stability limit. Thus, the cases are slightly different in this regard.
Comparing the GFM and GFL plots, have the PPC or inverter PLL parameters been tuned or the same parameters used for both GFM and GFL under low SCR condition?	No special tuning from what the OEMs provided with off-the-shelf models was done. This applies to both the strong and weak grid conditions.
How did you determine that GFLs were unstable, as compared to GFM?	In the microcosm system, the IBRs would go unstable and trip from protections or result in operating conditions that were unacceptable (e.g., very low voltage). In the real system, the system experienced unacceptably damped oscillatory behavior or voltage/angular instability issues.
Any matrix used to quantify the system strength with GFM addition?	Conventional SCR and WSCR values were used for calculating system strength.
Did you consider unbalanced fault conditions?	Single line to ground faults in the system studies.
Did your findings reveal that the increased ratio of GFM helps to improve the grid strength?	Yes, it helps overall system stability. Classical SCR-based "system strength" calculations may not be changed by the move to more GFM; however, the system was more stable overall.
Where can we find the slides?	The slides will be shared via email through ESIG and also posted to the ESIG webpage.
Your studies showed that BESS with GFM performed much better than BESS with GFL. How would GFM performance compare to the performance of a spinning generator?	This was not explored in this study. However, this depends on the size and location of the synchronous generator as well as the specific stability limitation.
What time step was using in the PSAD simulation, what computing spec was used and how long did it take per second of the simulation?	PSCAD cases were ran at a timestep of 10 to 20 uS (parallel PSCAD cases were ran at various time-steps as some models required specific timesteps). A 32 core AMD Ryzen Threadripper was the processor used to run the cases. The run durations were on the order of 3 minutes per simulation second.

The studies were performed with BESS at Pmax, is higher initial loading the most dynamically challenging operating point (separate from obvious headroom reqmt)?	Studies were performed with BESS at Pmax as this would result in high power transfers through the system. Some sensitivities were performed at different dispatch levels, however there was no notable difference in study outcomes. Detailed assessment of which dispatch is most challenging for the BESS was not performed, and will likely change case to case.
Are GFM inverters a better option than E-STATCOM from a cost perspective for resolving voltage stability issues?	If GFM can be integrated into an upcoming BESS and solve a voltage stability problem, then this cost would be far less than adding a STATCOM (or E-STATCOM). The study team is unable to answer costs of products side-by-side.
Would the GFM in a PV or Wind plant have similar behaviour with GFM BESS?	It depends on the design and dynamics of the resources. It is expected that different resource types may have different dynamics (e.g., GFM BESS versus GFM wind). This will require further exploration once GFM technology in other resource types becomes more widely available. Hence, this study focused on GFM BESS specifically.
Did the study evaluate interactions between GFL and GFM in weak grids?	Yes, results showed not significant adverse impacts or interactions between GFM and GFL resources in weak grids.
Were the GFM OEMs able to present model validation reports to show that the models used match the real hardware?	This was not within the scope of the studies conducted. The studies used the latest product models for GFM.
Are there CCT or stability limit impacts if a GFM is lost as a part of system protection in an area of high penetration of GFL resources?	This was outside the scope of this study.
Several recommendations seemed very generalized and could be accomplished through any BESS solution. How do you quantify/validate that they need to be BESS GFM?	The studies used deployment of GFL BESS and GFM BESS in the same scenarios and found positive benefits of deploying GFM versus GFL. The findings presented are focused specifically on GFM benefits. The recommendations focus more on advice to industry to advance GFM adoption.
The modelled gfm behaviour looks great. How confident are you that the OEM models reflect the actual behaviour?	These are the verified models supplied directly from the OEMs as reflective of their latest products, which are being deployed in various part of the world. No reason to not trust the OEMs or the models provided.
Do you see much potential impact on protection design due to the lower IBR short circuit currents compared to synchronous machines?	This was not within the scope of the studies conducted.
In N-1-1 results (fault on line 5-6, prior outage of line 8-9) is the GFL vs GFM difference in curtailment from bus 6,7,8 due to differences in mode (fixed pf?)	No significant plant-level control changes were made between GFM versus GFL such as fixed pf versus voltage control. The difference is based on the stability performance of the GFM versus GFL inverters in those conditions.

Thank you for the presentation. Did you test the system only using PDT models? How far were the results for the GFM model? Any expectations about the results?	The studies were conducted using EMT simulations only.
Do you know if the four GFM models used in this study have been validated to perform very closely to the physical inverters they represent?	These GFM products are used in various parts of the world, with rather rigorous modeling and performance requirements.
Is there an optimized ratio of GFM:GFL batteries that provides for the most stable system? And does the location/distribution of them matter?	Results showed that increasing levels of GFM as compared with GFL resulted in more stable conditions. Optimization was not a focus for this study as the intent was to explore the benefits or challenges of growing adoption. No challenges were identified and results showed benefits as GFM BESS penetration increases.
Were these examples where it proves interoperability of GFM BESS from different OEMs operating having different modes of operation or unified mode of operation?	The GFM BESS had different modes of operation (i.e., different GFM controls) across OEMs and thus were interoperable in the study.
Under weak grid conditions there are some "cheaper" control adjustments that can improve the performance of GFL IBRs in general. Example adopting a slower active power ramp-up following fault clearing, or capping the recovery power to 90% of its pre-disturbance level for a short period. It would be interesting to understand when the latter strategies are no longer sufficient, thereby justifying the adoption of grid-forming technology.	Results showed that no tuning was needed from GFM BESS across weak and strong grids to achieve more stable response. Hence, the study team believes this concept of "special tuning" of GFL IBRs to achieve stability is a distraction from a superior stability solution overall. Adoption of GFM is well-justified.
How can these ideas be applied in the energy transition from the point of view of power electronics converters?	As the grid goes to higher levels of IBRs, adding GFM (BESS) to the system can increase stability, improve reliability, increase hosting capacity, reduce curtailment, and result in a more optimized and stable grid overall.
Where harmonics studied as part of this study?	No.
Any plans to bench mark these on a HIL and restudy if assessments are holding same ?	There are no current plans under the current project to study hardware-in-the-loop.
Is there any incentives or policies exist to encourage the deployment of GFM inverters for grid stabilization?	Some regions around the world have provided incentives, others have included GFM in their RFPs, and others are establishing requirements. There is a mix of approaches; however, this was outside the scope of this study.