Webinar: Overview of Grid Forming Interconnection Requirements	
Question	**Answer**
Various grid codes have different definitions of GFM. Will this cause problems for the future development of technical specifications (such as cross-reference)?	Yes, it is desirable to have industry-wide definition of grid forming agreed upon. The definition should only include very basic principles of grid forming and leave the individual capabilities to be defined in the specifications document.
Is the focus of the GFM only in bulk power? Is there any studies/ specifications on BTM GFM? (edited)	GFM actually is coming from microgrid application, however so far such operation was limited to one GFM resources providing reference for the rest of the microgrid. Currently there is ongoing work at National Grid ESO, EPRI and academia looking at benefits and challenges with distributed GFM resources
Are batteries fast enough for Inertia replacement? Or do we also need Supercapacitors?	GFM battery can respond nearly instantaneously, similarly to inertial contribution of a synchronous machine. For example, AEMO has previously presented charts showing response in inertial timeframe from big Tesla (Hornsdale) battery to a nearly coal generator trip. On the other hand, depending on capabilities sought from a GFM resource, Supercapacitor can be sufficient, without needing a battery.
Do you think the NERC 2023 "functional specifications" for batteries go far enough? What should NERC's next step be?	I think it's the first step in the right direction. NERC's specifications are outlined in the white paper with the goal to provide some guidance to industry already starting on this path. As we gather more experience from the GFM projects in the U.S. and internationally the next step is to produce more comprehensive Reliability Guideline probably in a year or two, depending on the pace of the development in this area.
What stability concerns drive slow interconnection and is it practical to develop GFM design standards that can replace GFL for rapid approval?	Yes, I think these two issues go hand in hand. I.e. GFL IBRs cause new or exacerbate existing stability concerns, while GFM IBRs may help mitigate existing stability concerns and reduce need for additional supplemental devices for GFL IBR support such as e.g. SynCons. With that one of the incentives can be streamlining interconnection of GFM BESS connecting into areas with existing stability constraints. This approach, for example, is adopted by Fingrid and also been suggested in ERCOT's 2018 Dynamic Assessment
Should GFM on BESS be mandated ? Or is this something we should be providing financial incentives for ?	It's a personal opinion but, I think, core capability (as e.g. AEMO defines it) should be mandated on all future BESS, but as power systems evolve, it is possible that the system operators will formulate new services and procure additional capabilities through markets. For example National Grid ESO has taken the latter path by first conducting a series of tenders for new stability service (defined as provision of inertia and short circuit current) and now designing an market for it.

Is GFM meaningful of inertia support perspective, does it have to be equipped with ESS always?	provision of initial active power response to phase jump or MW loss requires some sort of energy buffer, it can be ESS, or solar operating below maximum available production or wind turbine drawing energy from rotating mass of the turbine. Very small amount can also be drawn from the dc-circuit capacitor. How much is needed from a single resource depends on system design, capabilities of other resources and speed of frequency response that follows that initial "inertial" response. There are many options to choose from but no one definitive answer, unfortunately :)
To be viable in a Grid IBR must be reliable and continue to operate for defined set of Grid transients. What are plans to define and implement this requirement	Hopefully I understand this question correctly, but basically there are two steps that are needed 1) we need to make sure that existing and future grid following IBRs are installed with state-of-the-art capabilities. For that I firmly believe comprehensive interconnection requirements are needed and IEEE2800 is an excellent example of such requirements. 2) as power system progress towards higher shares of IBR, new capabilities will be needed from IBR themselves and this is where GFM comes into play and comprehensive specifications for GFM IBRs are needed in addition. One last but very important point to add here is that requirements alone are not sufficient, they need to come with comprehensive conformity assessment procedures and post-commissioning monitoring throughout the lifetime of the resources to make sure that the resource is designed and continuously operates in compliance with applicable requirements. This is what IEEE2800.2 is being developed for currently.
Most codes are currently non-mandatory, but GFM already exists on the system and starts to support grids and markets, will it cause problems?	As with any new resource, the issues are possible. This is a new technology, and the industry is just learning/gathering experience with it. It is important to monitor and learn from operation (an any issues) with these resources. While there are just a few of these resources, the issues shouldn't be detrimental to system reliability but will allow us to learn and fix as we go.
Are utilities open to GFM in weak grid area as an alternative to building new transmission to strengthen grid? If so, do you have any examples?	Yes 4 system operators in Germany currently have big plans for using GFM STATCOMs as transmission assets to strengthen the grid. Currently one such STATCOM (though without extra storage) is already installed in German grid and one with supercapacitor is under construction. It's more difficult with BESS since these are viewed as a resource in deregulated market and cannot be used as an alternative to transmission. However, Fingrid is allowing BESS with GFM capabilities to connect in weak grid areas (whereas the connection to GFL BESS would have been refused). They are doing this recognizing that GFM BESS will have stabilizing effect on the grid.

What makes WEM GFM so much harder than PV GFM?	in WEM energy needed to respond in subtransient/transient timeframe comes from rotating mass of the drive train, this introduces additional stress on mechanical parts and requires additional design considerations. While tests on existing wind plant in Scottland have proven that GFM operation of a wind plant is possible, there is no good understanding currently about long term impacts of such operation on a wind turbine. In PV plant there are no rotating parts, GFM operation will require continuous operation below maximum available production. While this results in loss of revenue, technically GFM controls and impacts on hardware in PV are the same as in BESS application
Is the cost of over sizing an GFM practical to provide phase jump active power, or is it better to obtain service through other mechanism?	My personal opinion if the need of the system is such that it requires oversizing of the equipment, it has to be compensated through a market mechanism.
Can you speak to what is going on in Canada, given different jurisdictions?	As far as I know there are no existing GFM IBRs in Canada. To my knowledge somewhat different interconnection requirements currently apply to grid following IBRs. Two years ago GE Energy Consulting has carried out comprehensive comparison of those requirements as well as provided comparison of existing requirements for IBRs that apply internationally. The report is posted here https://weican.ca/docs/Canadian%20Provincial%20Grid%20Code%20Study%20-%20Final%20Public%20R2.pdf
To support my fast enough comment re batteries. How fast is Synchronous Inertia actually delivered? Microseconds?	The start of synchronous inertial response is immediate but since it has to do with drawing kinetic energy from the mass takes hundreds of millisecond to several seconds to deliver full response. In fact, theoretical meaning of inertia constant is how much time it will take for a synchronous generator initially operated at nominal speed generating at rated power (drawing only from kinetic energy stored in it's rotating mass) to come to a complete stop.
In one of the slide you said GFM should supply short-circuit current. How this can be done with Power Electronics converters?	At a minimum it can supply 1 pu current, but normally 1.1-1.2 pu is possible over subtransient/transient timeframe. If more capability is needed this will require oversizing the converter in relating to the primary source (wind turbine, solar array, BESS) and should be incentivized as it will result in significant hardware costs. Prior to requiring/procuring oversizing careful analysis is needed as to how much short circuit current is required and for what purpose (e.g. proper operation of protections, dynamic voltage support, black start or restoration)
Beyond the inverter/interconnection point, is there other infrastructure that is needed to enable GFM?	Not in a BESS or Solar PV but for wind additional considerations are required in drive train and tower design. If capability above rating is required than there's additional hardware required.

Are the percentages on slide 2 based on installed capacity or energy penetration?	Percentages are based on penetration but are illustrative, as they may be dependent on system characteristics in addition to IBR capabilities.
Are there different considerations being given to grid-edge or new infrastructure applications for GFI's versus integration with established grids?	Yes GFM technology is actually coming from microgrids and island applications first, if that what you meant by grid-edge. In Australia there are about 4-6 GFM BESS supporting mining sites. Florida Power and Light is currently considering GFM BESS on the end of long 110 kV feeder that already has a number of GFL IBRs connected. The aim with GFM BESS is to improve system strength and stability in the area. There's HVDC back-to-back converter that is grid forming on one side installed between Upper and Lower peninsula on lake Michigan (in Mackinac straight), the GFM converter can provide grid strength, support islanded operation and even do black start of the Up, if is using the Lower peninsula grid as an energy buffer for this.
How do you determine the response time for 5msec? is there any reference?	Nope unfortunately no reference, I think the point with saying "in less than 5 ms" is just to say "nearly instantaneous".
For a utility that is procuring black start resources today, what standards do you think should be in the RFP so that they can consider IBRs and CTs?	I think consideration should be given to inrush current needs (or soft-start should be used in GFM IBR to limit inrush currents) and duration of storage needed. I think to develop requirements for GFM IBRs to provide blackstart a system operator needs to do a study to understand the system needs and then translate these needs into black start resource specifications. Note that the needs with regard to above two parameters will also depend on other resources available to support restoration after initial black start. Similarly to how National Grid ESO does it for GFM IBRs overall, rather than requiring certain amount of overcurrent capability and energy storage duration from a black start resource, a better approach is to base remuneration on the capability a black start capable resources has.
What specific value (degrees) phase jump withstand capability should a "GFM" resource have as a technical minimum? IEEE 2800-2022 specifies 25deg for pos. seq.	National Grid ESO states 60 degrees phase jump withstand capability, but I understand that discussions in the grid code development group have been to reduce this number and the according update of the code language will follow soon.

How can we define and calculate the value of virtual inertia? How can we know what quantity is enough to replace traditional SG to achieve same inertia in grid	Theoretically in a last synchronous machine loss test that I had on one of the slides, frequency control can be disabled and only inertial response of the GFM BESS captured. The area active power injection in the timeframe before frequency nadir should correspond to "inertial energy", using MVA_base of the resource this can be converted to the equivalent of inertia constant. With regard to your second question, I don't thing trying to replace inertia for synchronous machine 1:1 is the right approach. Synchronous machines were providing certain level of inertia because of their design not because system needed this inertia specifically. In an IBR-dominated grid a study is needed to understand how much of virtual inertia is needed. The result will depend on the size of the largest MW loss, UFLS trigger (assuming that this is what we are trying to protect against), any high RoCoF limitations that may exist and other hand what frequency response capabilities that are there (are IBRs providing fast frequency response? how fast and what's the deadband? are loads providing fast frequency response? How fast and what's the deadband? Are there any synchronously connected motor load on the system (they too have inertia contribution). Sorry long list of things to consider but there is no one definitive answer to this.
For GFM with inner current loop control, what is the differente in the bandwidth (response time) of this inner loop control and the one from GFL? (edited)	I had to ask Deepak Ramasubramanian (EPRI) to help me with this question: Bandwidth of inner current loop in GFM is often of very similar order as the bandwidth of inner loop in non-GFM controls. The presence of an inner current control loop doesn't necessarily imply instability by default as actual instability is related to how the outer loops interact with this inner loop.
In the generator-trip test, how is the load modelled? Constant power, constant impedance, or something	Constant impedance model is used in this test
Will any of ERCOT's 17.5 GW of committed batteries be able to be installed with GFM specs? Or does it have to be in their original interconnection applications?	ERCOT still doesn't have GFM specs. These 17.5 GW of storage are in various stages of development. I am just theorizing but I think for the ones where equipment has already been procured and interconnection studies completed it will be as hard as a retrofit to get GFM capability. Even through theoretically GFM control on a BESS requires just a software change, the retrofit is still not easy because the OEM of the equipment might not have GFM controls developed. Even if conversion is possible it will require IBR model updates and restudy. So in conclusion ERCOT needs to develop GFM specs soon and have implementation timeline to go with it to deploy it on as many BESS (out of 17.5 GW) as possible but considering limitations of the projects that already too far in the process.

Do these specifications of grid forming presented apply for HVDC system?	From all specs I have presented I believe only FNN/VDE (German) requirements apply to HVDC converters on HVDC links. Note that e.g. offshore wind connecting through HVDC would be considered a part of GFM Resource for the purpose of requirements (e.g. in National Grid ESO specs)
Where can I find the NERC grid forming functional specifications in their final version mentioned at the beginig of the presentation? I only found the draft.	The draft had been approved by NERC RSTC 3 hours prior to my presentation. The technical content with that is approved and set but NERC publishing is working on editorial changes. The final document will be posted shortly.
when can we expect IBR provide black start capability on a transmission system? and when would you target codes/regs to support this? thank you	I wish I had a crystal ball :). I think first it will be GFM specs for connected operation and black start will follow in system that are facing extra high shares of IBR where existing black start units are retiring. I believe National Grid ESO has already started working in that direction in their Distributed Restart program and I would expect HECO to start thinking about it very soon as well.
Hi Julia, there is also CENELEC TC8/WG03 that is working at 50549-20, what is your suggestion for a real standardization? (edited)	I am not sure what "real standardization" mean in this question. I think we need a standard definition of GFM behavior at it's core, past that, I believe, GFM requirements should be plant-level performance requirements similar to how IEEE2800 applies to IBRs today, with that we need to work on performance scandalization rather than equipment standard. But that's just my opinion.
NERC requirements did a poor job to capturing the capabilities GFL inverters and updates are underway. Do we need to consider requirements now for GFM?	I don't understand if the question means to say it's to early to think about GFM until we have GFL issues fixed? In that case, I think, these efforts can continue in parallel. If the question is how not to consider lessons learned from GLF IBR requirements when developing ones for GFM, then the answer is yes absolutely. Additionally, GFM requirements are on top what already applies to (GFL) IBRs, so all improvements to GFL IBR requirements will apply to GFM IBRs as well.

what method is proposed to measure the stability of a system with synchronous generators, Grid forming inverters and Grid following inverters	Excellent question! Ideally stability should be determined from comprehensive studies subjecting the system or a part thereof to realistic stress-tests. Stability then is determined by ability of the system to reach new acceptable steady state after a disturbance (small or large signal). This approach applies independent of resource types that exist on the system. These studies need to be carried for variety initial system conditions. In reality it is difficult and time consuming, especially if studies are carried out in EMT. Therefore there is a need in industry to use screening methods that allow to quickly and effectively select study cases that require more detailed study. Historically short circuit ratio was used as one of such screening metrics. This metric uses short circuit current as the measure of proximity to strong voltage source. This works well in a synchronous-machine dominated grids however it fails to capture e.g. voltage source behavior of GFM IBRs that do not provide short circuit current beyond 1-1.2 p.u. In reality what we are trying to understand with this metric is voltage sensitivity at a POI to current injection (not the amount of short circuit current that will be injected during a fault). In my opinion new metrics are needed to screen for stability concerns in high IBR grids. This is active area of research. E.g. some of these metrics/screening methods were presented at ESIG Spring Workshop in 2023.
Could you please provide the link for NERC IRPS white paper?	The draft version that was published for industry comments in June is avaialble here https://www.nerc.com/comm/RSTC_Reliability_Guidelines/White_Paper_GFM_Spec_BESS.pdf. The final version after industry comments were addessed was approved by NERC RSTC 3 hours before the webinar and is currently undergoing internal editorial review at NERC. I believe it will be posted shortly
the accurate measurement of the ROCOF rate following a phase jump is very important. How will this be implemented as most existing systems give false data	Why is RoCoF measurement very important during phase jump? The idea is that grid forming resource is responding to phase jump inherently because it's trying to hold internal voltage angle constant in subtransient/transient timeframe, which will result in change in current injection from grid forming resource in response. There is no underlying RoCoF measurement. If I misunderstood your question please follow up with me by email julia@esig.energy, I am interested to understand the motivation behind it.
Has NERC or its Regional Entities proposed anything to bring standards for GF Batteries?	NERC IRPS white paper that I talked about during the webinar is the first step in that direction. Otherwise ERCOT currently planning to work on development of GFM BESS interconnection requirements, this is at a very early stage yet
What other smart grid operations does the GFM will initiate ?	I don't quite understand this question. In the webinar that slide with blue bubbles covers everything that system operators think GFM resource should do so far.

A standard is needed for the allowed Phase Jump Angles in an AC grid is needed so that IBRs can be type tested. What value is proposed for typical systems	Yes this is a great comment! National Grid ESO so far proposed 60 degrees, but I believe there is ongoing discussion to reduce it (don't think they have agreed on a specific value yet). IEEE2800 has 25 degrees requirement. I agree with you that there is a need for minimum that IBR can expect to see and should be designed for and if the system start deteriorating below this minimum one option could be for the network owner/operator to always maintain that minimum still. Same concept can be applied to system strength for example and currently is implemented in Australia. However, in this case, I don't thing SCR is the right metric to use going forward (especially as we start getting more GFM resources), see my response to questions 34.