**IBRWG Meeting Minutes**

**July 2024**

**Chair: Julia Matevosyan, Vice-Chair: Miguel Cova Acosta**

**IBRWG met on July 12th (Webex, Open Meeting).**

The agenda and the presentation slides are available [here](https://www.ercot.com/calendar/07122024-IBRWG-Meeting-_-Webex)

**IBRWG Main Meeting**

**Preliminary Advanced Grid Support Inverter-Based ESR Functional Specification and Test Framework**

Andrew Isaacs (Electranix)

* + Collaborative work with ERCOT developing testing framework and functional specifications for advanced grid support from BESS. A lot of iterations back and forth with ERCOT, to capture ERCOT’s system needs.
	+ Received 4 models from commercially available grid forming (GFM) BESS from the OEMs. The models were taken through the proposed testing framework.
	+ This approach does not specify control topologies but rather specifies detailed list of tests to demonstrate advanced grid support capabilities
	+ There is a report that represents Electranix’s version of the testing specifications, probably some version of this will become public at some point
	+ Project team from Electranix and ERCOT on slide 3.
	+ First experience on this with the Hawaiian Electric Company (HECO) in 2021 then NERC’s white paper with BESS specs in 2023 and AEMO voluntary specifications and testing framework in 2023 & 2024 respectively.
	+ Need for grid forming, from NERC white paper, the idea is that GFM can provide good stabilization characteristics. Having GFM BESS allows for enhancements of stability margin at lower cost than adding transmission assets.
	+ Grid-following (GFL) definition from NERC on slide 6, the basic idea is that it tightly controlling active and reactive current while maintaining synchronization with main grid. All IBRs right now are GFL.
	+ Functional definition for GFM on slide 7, tweaked a bit from other resources. The addition from the ERCOT team is that requirements apply at the POI as for GFL IBRs (event though the capability is at the inverter terminals)
	+ Slide 8 shows the idea that GFM with a simple one-line diagram. At time t1 a generator G1 trips. GFM IBR (BESS in this case) will hold the voltage phasor constant in the transient period t1+ (on the contrary, GFL IBR will hold current constant in the transient period t1+).
	+ Slide 9 shows responses from GFM vs GFL when disconnected from the external grid and G1 trips. In GFL BESS case the plant will probably go unstable and trip but if we assume that it wasn’t unstable you can see in black what would have happened if the load was balanced. GFL tracks the angle to hold the power constant.
	+ Slide 10 shows the responses if reconnect the island and G1 trips.
	+ Slide 11 shows benefits of GFM with Maui Island example <https://www.hawaiianelectric.com/documents/clean_energy_hawaii/integrated_grid_planning/igp_meetings/20210630_electranix_report.pdf>. This has now been replicated in a number of systems/studies around the world.

There is a number of benefits with GFM BESS, such as better performance in weak grid systems, better damping at sub-synchronous frequencies and faster and more stable frequency and voltage support, black start capability (though requires additional design considerations and is not in scope for this project).

* + Ryan Quint (Elevate Energy Consulting): I heard that in Hawaii they are looking to require 1.6 pu overcurrent capability from GFM IBRs. Any thoughts about similar requirements for ERCOT? - Andrew, will come back to this question.
	+ Deepak Ramasubramanian (EPRI) asked if the units in Hawaii have FFR requirement, Andrew says that the demand for frequency response is faster than PFR or FFR, this is why there is a need for GFM. In Hawaii you are not allowed to connect GFL BESS anymore, only GFM.
	+ Slide 12, Why are we talking about BESS and not wind or solar. In the new BESS this is just a control/software change. For non-BESS resources there are technical hurdles, on his slides. High interest for ERCOT to understand what it looks like for other devices but for now we are just talking about BESS as a low hanging fruit, and these are available now in GFM configurations.

The tasks we are talking about in ERCOT, BESS can meet without adding any extra capability.

* + It will be very straight forward to extend this test to require additional capability (current or energy) if there was a need from ERCOT and willingness of the market to pay for it.
	+ All IBRs are required to have some a basic set of functions on slide 13, but asking for extra characteristics from GFM is beneficial, as listed on slide 13
	+ Damping capability requirement is somewhat special to ERCOT due to presence of series capacitors in ERCOT grid and need for damping
	+ A few words about IEEE28000 and GFM. There may be areas of the standard which could possibly conflict with GFM control but there are provisions for this in the standard itself listed out on slide 14.
	+ It seems like there are likely no limitations but identified areas for further examination.
	+ Deepak asks about deadband for GFM for frequency response, are GFM resources expected to be exempt from that. Andrew will punt this question to later, but this is the area where you cannot constrain it. If you get a phase jump on the system you get the response.

Fred: from PFR requirement perspective there is no change, these resources still need to do it. Julia adds the requirement for deadband, and droop are maximum requirement, if there is capability and desire a resource is allowed to operate without the deadband.

Andrew summaries: doesn’t see any serios barriers from IEEE 2800 for deployment of GFM capabilities.

* + The limitations from IEEE 2800 for GFM should be taken into account in the next version.
	+ Andrew continues with describing testbenches on slide 16. Testbenches 1 and 3 are very similar.
	+ Testing assumptions are in addition to existing ERCOT model quality testing (MQT) requirements, the model should be usable and accurate, and should also include state of charge (SOC) requirements, as well as DC modeling, if it is determined to have impact on performance. This one has often been ignored in the past. The plant should also be able to meet GFL requirements listed on slide 17. As well as performance tests applicable to GFL.
	+ Eleven tests on slide 18, some have subtests and some a variation of the same tests so you might see a different final set. The first 3 are aligned with NERC tests and some other jurisdictions. Series compensation test was specifically introduced to serve ERCOT system needs, i.e. SSCI stability. Energy response test is a new and very interesting test, a lot of research went into this one. Frequency scan is not new per se but proposing this for GFM testing.
	+ Julia asks about test 4, it’s not in NERC paper, what was the reason for proposing this one? Andrew: it’s an interesting test and it’s passable by other resources that don’t have an energy source, such as GFM STATCOM for example.
	+ And there may be a bigger question of what is the point of all these tests? If we go back to NERC white paper, when we were drafting these first 3 tests, we really wanted to focus on bare minimum GFM core performance. Lean set of tests. More tests on top of tests, some of them you can easily pass with GFL devices, but they provide additional information about control stability, or individual functions like shape of frequency response, not necessarily the leanest set of tests. There is a column in the table on slide 18 called “Testing for” that provides additional insights about what the tests were added for.
	+ Hamzeh Davarikia, question in the chat, if the same GFM model used for all these tests? Andrew: the test benches vary for different tests as per last column on slide 18 but same IBR model is used throughout
	+ Reza Goldoost, question in the chat, for test 11 (frequency scan), what is the range of frequency scan test, and did you use publicly available PSCAD harmonic injection tool to perform the test of different tool has been used? Andrew: We’ll get to that on the slide that discusses these tests.
	+ AEMO is the most recent testing document that Electranix has been working on but working with ERCOT some additional insights were gained both based on ERCOT system specifics but also just overall evolution of the tests.
	+ Where it says Informational in Test Type column of the table on slide 18 it may change in the future, we want the tests to be one but not necessarily to make judgement on it or change controls for it.
	+ Getting into the tests in more detail. All tests are included in the slide deck but might not go through all of them in detail in the interest of time. Test 1 is a loss of last synchronous machine when BESS are in discharging mode, same as in NERC paper, one of the oldest tests for GFM, was already there in the original HECO spec. This test held out well, it’s very difficult to game and it tells us a lot. This is not a test of islanding capability or black start, rather it’s the test to get to the core functionality of the devices. The tables for tests are similar structure as in NERC document, should be easy to follow through and carry out these tests.
	+ Some of the criteria in the tests are qualitative and some are quantitative. ERCOT was looking for more quantitative criteria, but it just wasn’t possible everywhere so tried to specify as much as possible but not overspecify and provide some guidance on the performance expectations.
	+ Slide 20 shows an example of Test 1. When the switch is open the frequency will fall and settle at some value defined by frequency droop setting of the GFM BESS. You can see the responses in the nearly instantaneous step change in active power.
	+ Skipping through to Test 6, since it is different from the other ones you’ve seen. Incremental increase in grid impedance, applying a brief fault at each step. Plant is required to perform well down to SCR=1.25. For the refence GFL resource is required to perform well for SCR=3.
	+ Skipping to Test 8, Series Compensation Step test, pass/fail. Step increase in service capacitor for up to 70% compensation. GFM is expected to remain stable through the test. The test may be extended depending on the degree of damping desired.
	+ Skipping through to Test 10, Energy Response Test (informational). Quantifies short-term (first 0.5 s) energy provided by GFM for frequency events. 0.5s stop is trying to delineate between the “inherent” response and any kind of control-based frequency response. This test provides a very easy distinction between GFM and GFL.
	+ Test 11, Frequency Scan Test, not new. A lot of research is being done in this by EPRI and NREL and others. Some of this work has been leveraged here. Two types of scans. Impedance scan to assist in confirming damping. This is a type of scan that are being done in ERCOT already for SSCI (expecting positive resistance up to 50 Hz). Q/V scan to assist in confirming core GFM functionality (expecting voltage source like characteristic over certain frequency range), a lot of research is being done by Shahil Shah, NREL and others. This is why it is an informational test only as the research work here is still being carried out.
	+ from Reza Goldoost to everyone: For test 11, what is the range of frequency scan test? and did you use the publicly available PSCAD harmonic injection tool to perform the test or a different tool has been used? Frequency range is up to 120 Hz, i.e. 60 Hz on the both sides of fundamental:
	+ from Ali Yazdanpanah: about frequency scan test. In case we get garbage results when we inject a wide band of sub-synchronous harmonics. Does Electranix have any guidance on how to do this test properly without getting garbage results? And if we can have soft requirement in case some have difficulty whit this test.? Andrew: this is a practical question about how to do it, ERCOT has a lot of guidance on that but probably not enough, need to do scans one at the time and may need to adjust the amplitude to ensure that you get strong results.
	+ Slide 15 shows impedance scan plots.
	+ Deepak: Asked if Electranix tried to tune GFM and GFL controls to achieve certain behavior in impedance scan. Andrew says no, however wants to add that by tuning GFL only a few Hz improvement can be achieved, i.e. the difference between GFM and GFL clear on frequency scans. Hamzeh Davarikia adds in the chat that the impedance scan result comparison may be improved by adjusting GFL parameters, to improve GFL results.
	+ Jonathan is asking if there is a specific reason why GFM appeared better? Andrew: This is by the nature of the voltage source characteristic vs the current source.
	+ On Q/V scans still working on it, a bit harder to distinguish GFM and GFL.
	+ Slides 26 shows a summary of OEMs’ GFM BESS performance. Details are on the slide.
	+ Some other tests and responses are included in the slide deck but didn’t go through it in the interest of time. Also, some technical rationale behind the Pass/Fail criteria that were selected. Encouraged folks to go through and send questions to Fred or him.
	+ Deepak has a question, question on slide 26, are the GFL models that have been tested here passing all of the ERCOT’s performance requirements? Andrew answers yes, the ones that are tested in MQT.
	+ Yenpo: If more than one GFM how theta would be formed on them? Andrew: each device has its individual controller and each one of them is doing some kind of forming of the grid transiently after an event. In a longer timeframe they’ll all synch and settle, based on their available headroom. Studies need to be done to ensure that there are no adverse interactions. Yenpo also asked if the parameters of controls are constant or changing in time. Andrew said not changing.
	+ Hamzeh: Could changing models/parameters in GFL lead to improved results? Andrew: Yes, and Deepak already alluded to that. There is definitely a potential to improve grid following control, you can actually change GFL controls to pass all these tests and in this case these IBRs will be considered GFM. This is exactly the purpose of the tests, not to prescribe controls but to test GFM performance.
	+ Julia: Asking if behavior at the current limits is tested in any of these tests and what happens with GFM behavior at the limit. Andrew: it’s a good high interest question. Some of the tests are already done with MQT, there are faults that are being tested there that will definitely drive up GFM IBR to the limits. But additionally Tests 1-3, 7.1 & 7.2 (angle step change), depending on dispatch may show at the limit behavior. Some criteria there with regards to the behavior are also provided in the tests.
	+ Julia also asks if there is a need for something beyond a single-machine-infinite-bus (SMIB) type of test set up and if multiple GFL, GFM combinations are needed in the tests? Andrew: this question comes up a lot. One of the key benefits of GFM devices is that they are expected to stabilize the system with GFL devices. We are worried about interactions with GFL devices already today, and GFM is actually expected to make things more stable. The problem with MMIB test is what devices to put in there and how to translate the performance to what will happen in the field. OEMs will tune the controls specifically for this set up, which is a bit dangerous and can make the controls actually less robust. Best to just carry out the series of connection studies as we do today and see how GFM devices interact with others planned on the grid. Similar question from Jian Sun in the chat.
	+ Farhad Yahyaie (Elevate Energy Consulting): question regarding inertia, why cannot the same test as we use for synchronous machines to determine inertia be used here, through the swing equation, using RoCoF over 0.2 s? Andrew: 0.5 s is needed to measure RoCoF more accurately and give time to these characteristics (especially from different types of GFM to kick in), you don’t want to do it for longer because then other controls responses may kick in too. Suggest Farhad tries to test the shorter time and compare the results. Can also make comparison between GFL and GFM response in those tests and see at what timeframe the difference is visible between the two. – and refer to slide 45 for additional rationale.
	+ Julia suggested that Fred and the team bring any questions that are being asked offline to the upcoming meetings. Fred agrees and also suggests that the questions can be discussed at future IBRWG meetings.

**ERCOT Advanced Grid Support Inverter-Based ESR Assessment and Adoption Discussion**

Fred Huang (ERCOT)

* + Electranix’s job was to cover performance of GFM from the resource perspective, this presentation will cover system perspective.
	+ ERCOT plans to propose standards for advanced grid support from IBRs: voluntary first and mandatory for new resources in the near future date.
	+ Going to propose it for ESR first as it’s commercially available and only requires software/control modifications.
	+ ERCOT’s preliminary assessment identified benefits for system stability and benefits for GTCs.
	+ On slide 3, some background with the point that ERCOT is one of the largest power grids with significant IBR penetration. The IBRs need to meet the state-of-the-art interconnection requirements, such as IEEE 2800 and provide advanced grid support (grid forming), to support grid security and reliability.
	+ ERCOT may reach 100 GW of IBRs in 2025 based on the current trends (as of June 2024 GIS report).
	+ Slide 5 shows evolution of the ERCOT Grid Support capability requirements, while slide 6 identifies issues with declining number of synchronous generation and increasing number of GFL IBRs.
	+ Slide 7 highlights areas where advance grid support would be needed, including positive damping for SSR with series capacitors, and how it can be provided by GFM IBRs.
	+ Slide 8 summarizes mitigation options for notable grid challenges with high IBRs, including advanced grid support from IBRs and dynamic support devices. If ERCOT relies only on certain technology, such as e.g. synchronous condensers, the benefits to reliability can quickly diminish over time and new mitigations will be needed again.
	+ On slide 9, there’s a slew of existing connection requirements for GFM, from ESIG website <https://www.esig.energy/working-users-groups/reliability/grid-forming/gfm-landscape/specifications-and-requirements/>
	+ ERCOT contracted Electranix to help recommend required IBR advance grid support capability and testing framework. ERCOT also reached out to major OEMs to understand the existing and potential grid support capability (like GFM). Based on OEM feedback, and industrial experience from other countries like Australia, UK, Hawaii, Finland, Germany, ERCOT currently focuses on the advance grid support provided by inverter-based ESRs.
	+ Table on slide 11, shows a comparison for tests between ERCOT, NERC, AEMO, Fingrid and NG ESO, demonstrating some similarities.
	+ Slide 12 summarizes 2023 preliminary assessment of the impact of advanced grid support of inverter-based ESRs to ERCOT grid. Additionally, to 2023 studies it was found that GFM ESR may potentially increase WESTEX, McCamey and Panhandle GTC limits approximately 5-10% based on tested cases. For several other GTCs the constraints can also be potentially mitigated.
	+ Major OEMs have commercially available ESRs with advanced support capabilities. These have minimal impact on project design and commercial operation compared to existing GFL ESR technology. The resources will still need to meet all existing ERCOT requirements for IBRs, as well as coordinate control settings, modeling accuracy and performance monitoring with ERCOT, all connection studies will also still be required.
	+ ERCOT’s adoption proposal is that all existing inverter-based ESRs are not required but highly recommended to provide advanced grid support. New inverter-based ESR will be required to provide advanced grid support. ERCOT and TSPs should also start considering advanced grid support devices like STATCOM.
	+ Next steps: submit revision request by the end of 2024 to adopt the advanced grid support form inverter-based ESR. ERCOT plans to continue assessing the application of advanced support by wind and solar as well, and assess application of IBRs for black start. Stakeholders are encouraged to provide comments and suggestion to Shun-Hsien.Huang@ercot.com
	+ Julia commented: MISO also coming out with similar requirements for inverter-based ESR and Megan Pamperin (MISO) placed the link to the latest draft in the chat [https://cdn.misoenergy.org/20240723%20IPWG%20Item%2004b%20DRAFT%20GFM%20BESS%20Performance%20Requirements%20Whitepaper%20(PAC-2024-2)\_REDLINE639677.pdf](https://cdn.misoenergy.org/20240723%20IPWG%20Item%2004b%20DRAFT%20GFM%20BESS%20Performance%20Requirements%20Whitepaper%20%28PAC-2024-2%29_REDLINE639677.pdf)
	+ Ryan Wu: Any considerations about the increased risk of islanding with GFM adoption? Fred: ERCOT had internal discussion about that, in general ERCOT is not designed to split into islands and is expected to operate as a single grid.
	+ Julia: Are you planning to bring NPRR / NOGR drafts to this group for review. Fred: yes, that’s the plan to discuss the draft with this group. Electranix’s recommendation will be the primary reference for developing these. Some additional adjustments based on today’s discussion may be done to what has been presented today.

**DWG and IBRWG Collaboration**

**DWG Procedure Manual Updates for NOGRR-245**

Johnathan Rose (ERCOT)

* + The DWG Procedure Manual draft was pasted on this event page and the current version of the manual can be found on ERCOT webpage.
	+ This is continuation of the work to propose some model testing for NOGRR245, because a lot of the requirements will be evaluated through MQT.
	+ Preferred ride-through curves, there was a recent modification there

There are things that cannot be modeled, and the plant designer will need to take care of. But most of the things, specifically those that may result in the tripping behavior are expected to be included in the model and for ERCOT to be able to evaluate.

* + The presentation has been shown before and there have been only a couple of updates since the last meeting.
	+ Slide 2 lists out previous presentations on the topic.
	+ Targets August ROS for the language approval and then effective once NOGRR245 language is approved. ERCOT doesn’t expect ongoing discussions of NOGRR245 to further affect the language in the procedure manual, as the topics under discussion there are not related to it. But if needed ERCOT will update the DWG Procedure manual as well
	+ ERCOT asked for comments within a week, by 7/19 to expedite the process.
	+ Summary of the DWG Manual Edits provided on slide 3.
	+ Slide 5 shows the proposed language and the test for LVRT set up. Both are included in DWG procedure manual.
	+ Slide 6 is showing LVRT Path/Fail Criteria, no changes for “legacy curves” but for new “preferred curves” there is some new language in the procedure manual, this has been presented before. No significant difference to the previous criteria. ERCOT provided a bit more guidance on the expected active power injection to avoid unnecessary reduction of active power during shallow voltage dips (as were observed during Odessa events).
	+ Slide 7-8 on HVRT set up and criteria respectively. No real change to the criteria.
	+ Requirement in NOGRR245 to maximize your performance. This is to acknowledge that people shouldn’t be setting their equipment to trip right on VRT curve settings. To help people to make sure they are doing this, we are going to request people to provide tables that show that they are maximizing their performance at the POI. And these tables you’ll be asked to fill out whenever you are submitting the models. This is an exercise to get people to think about equipment capabilities and if these are being fully utilized. The dynamic models should of course reflect this too, if ERCOT was to test this, but most likely ERCOT will be just testing VRT curves, but the table allows ERCOT to check that you’ve gone through this exercise and provides a reference point for future model updates, allows ERCOT to notice and ask questions if anything changed.
	+ Slide 10 changes on modeling switched shunts and transformer taps controllers. ERCOT observed a fair number of plants have difficulty passing commissioning tests AVR, PFR. Once reason it may be occurring is due to shunts and taps. Many IBRs have switch shunts to compensate for collector system losses, these need to be coordinated with dynamic reactive devices. Mayu be some plants have not fully thought about this coordination and this is being discovered during commissioning. Additionally, ERCOT has issues reproducing commissioning test results in the models and shunts/taps may be to blame. To help avoid these situations, and pass the testing, ERCOT is going to start modeling switch shunt controllers and tap controllers, these devices should also initialize correctly. Adding language to the procedure manual, though technically already has the authority to be asking for it. ERCOT realizes that there may be timing issues and invites stakeholders to seek extension with ERCOT, if needed.
	+ Table added to the procedure manual, it doesn’t have any new requirements just summarizes what applies where, slide 11
	+ Slide 12, next steps. Comments requested by 7/19, email addresses on the slide. ERCOT will request DWG to consider moving forward with the changes at August ROS.
	+ Question from Deepak: Transformer tap controllers are much slower and they would operate with longer time constant (30 seconds to minute), have you seen cases where transformer tap is much faster control (a few seconds). Jonathan – yes we had seen tap operation within 10 s (sometimes 5 s), OEMs don’t seem to be worried about these wearing out. If the transformers are taking longer (outside of AVR timeframe) to tap, this change is not relevant to provide dynamic model for them as it’s not going to show up in the dynamic studies but knowing the limits on the tap settings still useful for model initialization.
	+ Katie Rich (ROS chair) comments: Requesting a little more time for review to avoid potential tabling at ROS. Jonathan, we would still like to target ROS in August if possible. Sun Wook Kang (ERCOT): the reason for this target date is because of the effective date of NOGRR 245 in the middle of August for that time ERCOT has to have DWG Manual in place. May be can give stakeholders one more week and target September ROS.
	+ Katies says that with the addition of one week still possible to target August ROS. Sun Wook agreed that ERCOT can go with 7/24 deadline.
	+ Question in the chat from VS: So, the modeling of the capacitor and transformer tap switches are done regardless of the time delay? Also, will ERCOT provide acceptable curves for leading and lagging cases in the DWG? Jonathan: The initialization of the transformer taps should be provided somehow to us regardless of the model, otherwise we might not have them in the right position. This can be provided as outside of the model parameters (for plants that have taps outside of the AVR timeframe).
	+ Ling Chen question in the chat: When the new ride-through curves will become effective? There are a lot of undergoing MQT studies, do the consultants need to include tests using the new profiles? For the OEM does OEM need to redo the IBR unit model validation/MQT test including the test with new curves? Johnathan: As soon as the procedure manual becomes approved and for the resources for which requirements apply. The requirement for model testing will apply going forward and as existing models are being updated. Johnathan adds that the curves are already included in ERCOT MQT tools so if you are using those, the curves are already there.

**Other Business**

* + Julia brings up that there is an item on auto-reclosing close to IBRs. SPWG is meeting on 7/17 and this item is on their agenda. We’ll discuss it at IBRWG in August.
	+ Market notice about ERCOT’s plan to send an RFI in the beginning of August to support the transition to a single resource ESR model, may be an update at the next IBRWG meeting on that could be useful.