FRCR Consultation Response Proforma

FRCR Consultation

Industry parties are invited to respond to this consultation expressing their views and supplying the rationale for those views, particularly in respect of any specific questions detailed below.

Please send your responses to box.sqss@nationalgrideso.com by **5pm** on **Friday 17th May 2024.** Please note that any responses received after the deadline or sent to a different email address may not receive due consideration.

If you have any queries on the content of this consultation, please contact box.sqss@nationalgrideso.com

Respondent details	Please enter your details
Respondent name:	Andrew Larkins
Company name:	Sygensys
Email address:	al@sygensys.com
Phone number:	07810750417

Please express your views in the right-hand side of the table below, including your rationale.

FRCR Assessment and Methodology Consultation questions		
1	Overall, do you agree that the FRCR 2024 represents appropriate development in determining the way that the ESO will balance cost and risk in maintaining security of supply while operating the system?	The GB system has an enviable record of reliability. The FRCR process contributes to that, however I have a concern that some threats to system security may be underestimated in FRCR 2024 and should be considered in future updates, as suggested in FRCR 2024 Section 8 “Future considerations”.
2	Do you agree that the FRCR 2024 has been prepared appropriately? Please elaborate.	I think that FRCR does not adequately address the risks associated with the probability and impact of coincident events leading to a cascade failure and further work will be required in future updates.
Feedback on the specific recommendation in FRCR 2024		
3	Recommendation: ***Maintain minimum inertia requirement at 120 GVA.s***	Agreed
4	Recommendation: ***Consider additional DC-Low requirement***	Agree

5	Do you agree ESO to propose lower minimum inertia requirement before FRCR 2025	Issues related to coincident (cascade) events should be addressed first.
6	Do you have any other comments?	See following information

1 Introduction

The contents of this document are proposed ideas relating to section 8 “Future considerations” in the FRCR report, it does not aim to provide input impacting the approval for the 2024 version.

The aim of this consultation response is to help contribute, in a small way, to maintaining the impressive record of GB grid reliability. Quoting the national risk register “The National Electricity Transmission System (NETS) transports electricity across Great Britain. A failure of this system has the potential to severely disrupt all other critical systems, resulting in greater consequences than typical utilities failures. Great Britain has never experienced a nationwide loss of power and the likelihood is low, however similar events have occurred internationally. In 2019 in South America, millions were left without power following a failure in the electricity system. **Great Britain has one of the most reliable energy systems in the world and maintaining a secure electricity supply is a key priority for the government.**”

The GB grid frequency event of December 22nd 2023 is used in the following analysis to highlight a number of areas that the NESO FRCR team may like to consider as part of the work toward FRCR 2025. Some of the comments apply more broadly to related areas including the Operability Transparency Forum, data access and Grid Code modifications and hopefully may contribute to future NESO plans regarding Resilience and Security.

We note that Dr Paul Golby has been appointed as the first chair of the National Energy System Operator (NESO), and he recently served as chair of the National Air Traffic Service. At a number of points within this analysis, we therefore use examples of air accident investigation methods or terminology as an analogy, sharing the approaches of an industry which applies rigorous methods to address the risks associated with low probability high impact events.

2 Event reporting by ESO

As far as we have been able to identify, ESO provided the following reports which mention the events of 22 December 2023:

ESO Operational Transparency Forum 17 January 2024 page 8 onwards (OTF Report)

ESO RIIO2 Business Plan 2 (2023-25) Q3 2023-24 Incentives Report 24 January 2024 page 34 (Incentives Report)

GC0151 and GC0105 System Incidents Report December 2023

3 Transparency

The OTF report is limited, in part due to the OTF policy of not naming impacted assets. Details of the impacted BMU assets are available publicly, for example via [Elexon,](#) as part of essential market transparency. Assets involved in the 22 Dec event were also named by ESO in both the Incentives and GC0151 reports and reported widely online, for example [IFA Interconnector fault causes 49.2Hz frequency event (current-news.co.uk)](#).

In the Current News report Shivam Malhotra, senior consultant at LCP Delta stated "In the coming days, we'll see the metering from all transmission-connected balancing mechanism assets be released, and we'll be able to see how these assets responded to this event. Technology like battery energy storage is critical in allowing us to deal with events like this both post and pre-fault." As this information is publicly available there should be no restriction of mentioning it in reports. The OTF policy of not naming assets does not support transparency.

Naming of assets would align very well with the OFGEM [Data Best Practice Guidance](#) Specifically "6. Learn and deliver to the needs of current and prospective Data Users". Where ESO has analysed data regarding a major system event from multiple sources, it would be helpful to data users if reference to all those sources were provided.

It is useful to grid users to understand that the 22 Dec event started with a trip of an interconnector on the south coast of England, but that it went on to impact resources in Northeast England and in the North of Scotland. This wide area impact on generation and HVDC links can be contrasted with [the events of 9 August 2019](#) which showed a more typical regional extent of the impact large grid asset tripping (see map below). However, it should be noted that during this event LFDD led to widespread impacts across the GB system.

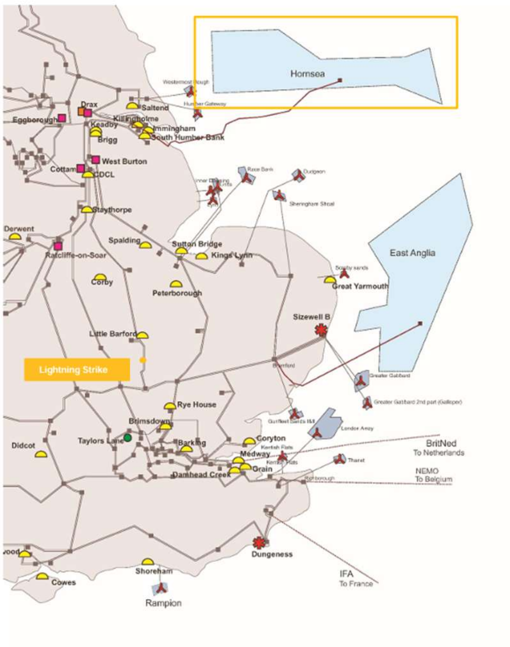


Figure 1 – Map of Hornsea, Little Barford and the Lightning Strike

Including a map of the geographic extent of the impact would be useful in future event reports.

Using the air accident report analogy, one could not imagine an aircraft accident report that did not mention aircraft type or airport (e.g. Report on the accident to Boeing 777-236ER, G-YMMM, at London Heathrow Airport on 17 January 2008 This is a good example of best practice regarding transparency.

Example data from Exelon on 22 Dec 2023 event

https://www.bmreports.com/bmrs/?q=remit/IFA202312221130G-ELXP-RMT-00000197/9/NGIFA
https://www.bmreports.com/bmrs/?q=remit/48X000000000080X-NGET-RMT-00015162/1/EECL

Message Details

Message Type	Revision Number	Message Heading
Unavailabilities of Electricity Facilities	9	New: NGIFA - Unavailability of I_IEG-FRAN1 at 2023-12-22 11:30:00

Asset Details

Asset ID	Asset Type	Affected Unit	Affected Unit EIC Code	Affected Area	Type of Fuel	Bidding Zone
I_IEG-FRAN1	Production	I_IEG-FRAN1				10YGB----------A

Event Details

Event Type	Event Start(GMT)	Event End(GMT)	Event Status	Unavailability Type	Duration Uncertainity
Transmission unavailability	2023-12-22 11:30:00Z	2023-12-23 16:00:00Z	Active	Unplanned	

Normal Capacity (MW)	Available Capacity (MW)	Unavailable Capacity (MW)	Cause
2000.000	1500.000	500.000	DC Cables - cable sealing ends

Outage Profile

Start	End	Available Capacity (MW)
2023-12-22 11:30:00	2023-12-22 13:09:00	1000
2023-12-22 13:09:00	2023-12-22 14:09:00	0
2023-12-22 14:09:00	2023-12-22 14:30:00	0

Message Details

Message Type	Revision Number	Message Heading
Unavailabilities of Electricity Facilities	1	REMIT INFORMATION

Asset Details

Asset ID	Asset Type	Affected Unit	Affected Unit EIC Code	Affected Area	Type of Fuel	Bidding Zone
T_CDCL-1	Production	CDCL-1	48W000000CDCL-1P	N	Fossil Gas	10YGB----------A

Event Details

Event Type	Event Start(GMT)	Event End(GMT)	Event Status	Unavailability Type	Duration Uncertainity
Production unavailability	2023-12-22 13:30:00Z	2023-12-22 18:00:00Z	Active	Unplanned	+- 1 day

Normal Capacity (MW)	Available Capacity (MW)	Unavailable Capacity (MW)	Cause
415.000	0.000	415.000	Under investigation

4 International event reporting and the importance of a "call to action"

The ESO approach to public disclosure of incident investigation is in significant contrast to that of NERC. They publish regular formal incident reports, including events that do not lead to LFDD. See Event Reports (nerc.com) and NERC Inverter-Based Resource Performance Subcommittee (see link on page to Webinar 2: NERC Disturbance Reports and Lessons Learned which is recommended viewing).

The NERC reports, like air accident investigation reports, aim to communicate publicly information that helps reduce future risk with specific "calls to action". See the NERC section "Key Findings and Recommendations".

By contrast, the OTF report hides the detail of any recommendations from public view via the statement "We continue to follow up with relevant parties to further understand the learnings from this event, and to ensure we implement any additional improvements for continued secure system operation."

There was no specific call to action for participants at the OTF, no emphasis on the importance of all grid Users helping reduce the risk of cascade events and no planned follow-up to share key findings with all grid users, not just the parties impacted by this specific event.

Greater transparency regarding major events will enable both industry and academic researchers to contribute to activities to help maintain system security in this period of rapid evolution towards NetZero generation and increasing load associated with the decarbonisation of heat, transport and other energy consumption.

5 Terminology: Cascade

The event on 22 Dec was particularly concerning as it was a cascade event impacting at least 5 asset types in rapid succession. It is almost certain that there was a causal link between these events, rather than them occurring due to random coincidence.

1. IFA1 Interconnector 1000MW (importing)
2. Cottam Development Centre - Gas 440MW
3. Caithness – Moray HVDC link 200MW (no direct impact on generation capacity)
4. Distributed generation at least 260MW

ESO reported total cumulative infeed loss at this time was around 1700MW

5. To that we can add the unplanned 116 MW under-delivery of frequency response services (see OTF report), which will have contributed to the low frequency nadir.

Note the data above is from the OTF report. For item 2 there are some discrepancies with other sources. The GC0105 report gives a value of 383.3 MW for CDCL-1 and related REMIT message states “Unavailable capacity 415 MW (100%)”.

Note I have chosen to use the term **cascade**, in contrast to the FRCR terminology of simultaneous events. I believe the term cascade more accurately reflects the causal link between the multiple assets impacted. The FRCR terminology of “simultaneous” is confusing, because the events are separated in time typically by seconds or more. As far as I am aware ESO provide no clarification of their meaning of “simultaneous”; this would be helpful for the industry.

Using the term “cascade” would help catch the attention of readers of the report as it is well known that “Cascading failures are the cause of most large-scale network outages.” Dynamically induced cascading failures in power grids | Nature Communications

Note for any non-ESO readers of this document who may not be familiar with the importance of cascades, the National Risk Register 2023 states “A nationwide loss of power would result in secondary impacts across critical utilities networks (including mobile and internet telecommunications, water, sewage, fuel and gas). This would cause significant and widespread disruption to public services provisions, businesses and households, ***as well as loss of life****.” The likelihood of this occurring is rated as 1 to 5%. For context during the 2021 Texas power crisis “At least 246 people were killed directly or indirectly, with some estimates as high as 702 killed as a result of the crisis.”*

Knowledge from the 22 December 2023 GB event that two of the assets in this cascade event were HVDC links is particularly important given plans for more interconnectors and the Beyond 2030 plans for multiple new HVDC links.

6 Monitoring trends over time

It is good to see that the Future Considerations section of FRCR contains the commitment “Simultaneous events: Review and better quantify the probability of faults forming simultaneous events.” Related to this, analysis of fault statistics was raised within the FRCR 2024 Q&A, see fields A18 and B18 in the spread sheet FRCR2024 Webinar Question and Answers.xlsx (live.com)

Question “Have you analysed events & trips reported under GC0105 to test your assumptions of trips, performance of the responses and probabilities of events?

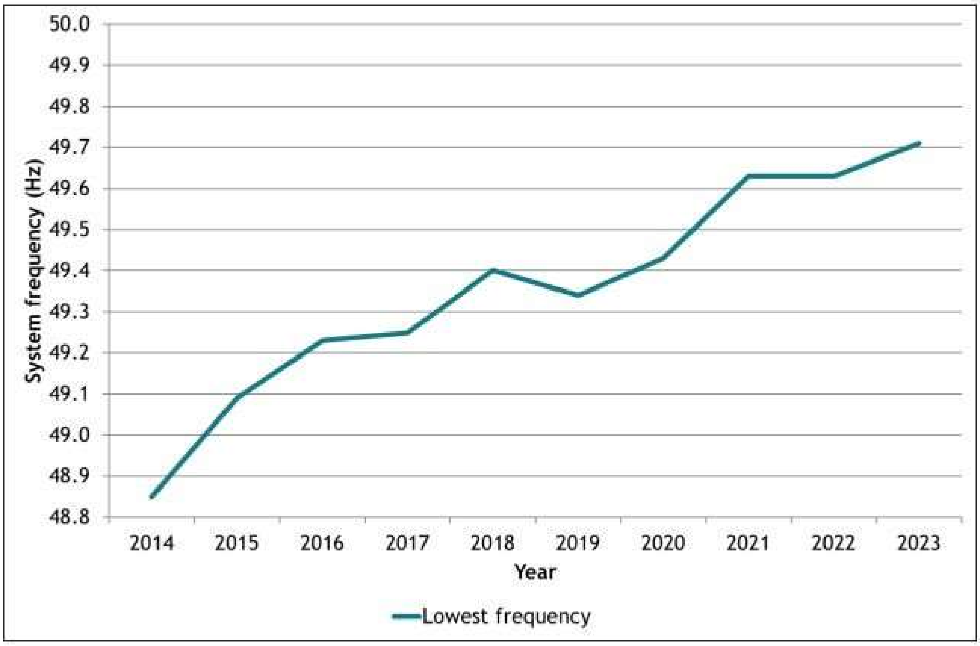
Answer "Event risk statistics are derived from two aspects: Generator trips that caused more than 250 MW power loss - fault statistics can be found in eGAMA for any fault/unplanned outages."

The brief answer suggests that fault statistics can be found in eGAMA but, having requested access via the Modelling & Insight team, I was told this data is not available publicly; using [REMIT | Insights Solution (elexon.co.uk)] was suggested as an alternative. However, this does not distinguish sudden trips from controlled shutdowns for unplanned outage, and it does not provide exact timing of events to allow firm identification of sequence of events and cascades.

It would be useful if ESO could share information on fault statistics and the occurrence of trips and cascade (coincident) trips. For example, could NESO consider producing an annual summary report for GB cascade events as part of FRCR? This could be based on setting a threshold where two or more BMUs have an unplanned disconnection within 1 minute of each other and total losses exceeds 750MW.

- The 750MW power threshold, about half the typical largest secured loss, is aimed to provide regular information on "near miss" (see later explanation of this air accident term) cascade events.
- The time threshold of 1 minute relates to the combination of typical decision making and dispatch response time for fast responding assets. It also matches the 60 second limit for frequencies 49.5 to 49.2Hz mentioned in FRCR 2024 as the L1 range.

Another form of reporting of trends could be that used in Ireland showing lowest (and potentially highest) frequency seen on the system each year.

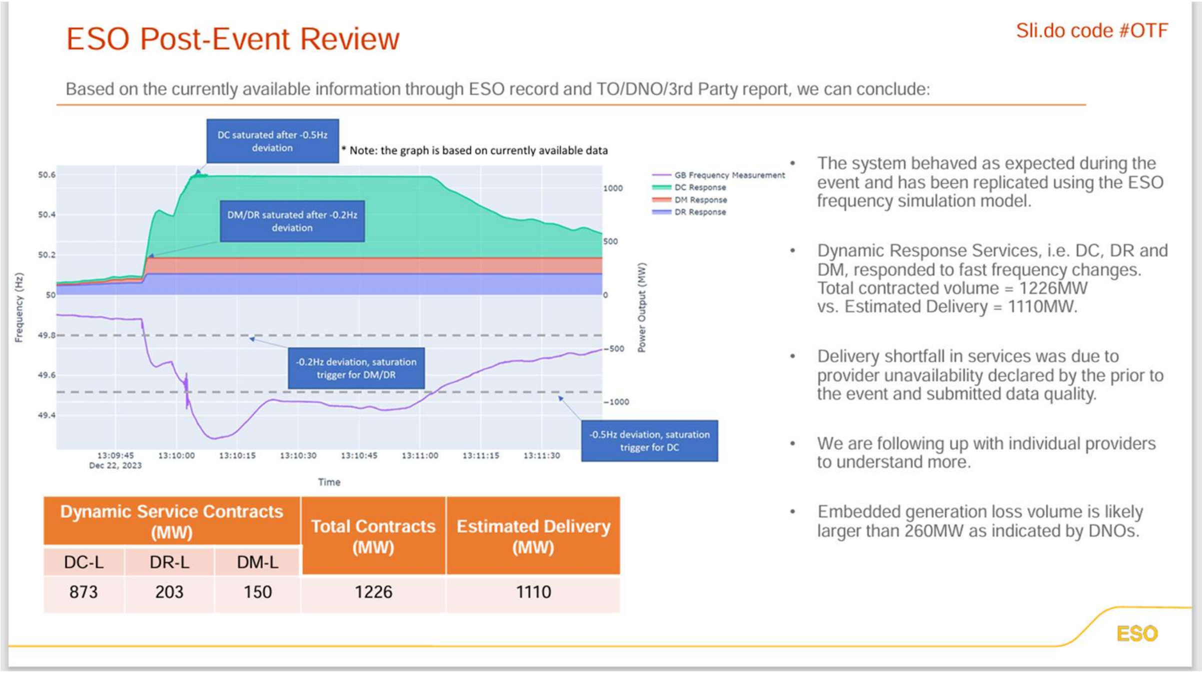


All-Island-Transmission-System-Performance-Report-2023.pdf (eirgrid.ie)

This shows a continuing improvement in frequency control; however, it does not highlight the associated costs. The value of such a graph would be enhanced if it was annotated with any significant changes in frequency management policy (e.g. changes in minimum inertia or largest secured loss).

7 Downplaying of the seriousness of the 22 December 2023 event

An OTF report extract is shown below.



From the top right of the slide “**The system behaved as expected during the event** and has been replicated using the ESO frequency simulation model.”

This statement is potentially misleading and significantly downplays the seriousness of the event. Tripping of IFA1 should not have caused any other assets to trip, let alone the multiple stage cascade event that was seen on this occasion. The system therefore did not behave as expected.

I believe the statement could be revised to provide greater clarity: “The cascade series of events was not expected. However, given post-event knowledge of these trips and the related loss of infeed, the system frequency behaved as expected during the event and has been replicated using the ESO frequency simulation model.”

Using air accident terminology, this event was the equivalent of a **“near miss”** or “airprox”. There was no LFDD, but it came close. The Air Incident Investigation Branch dedicate significant resource to investigating and publicly reporting in detail on near misses where there was no injury or damage. This aims to help prevent more serious incidents.

Could NESO consider the same approach for significant frequency events in future, similar to NERC, and not leave formal reporting to incidents when a million or more consumers were impacted such as Technical Report on the events of 9 August 2019 ?

To identify the seriousness of the 22 December event, it is important to note from the OTF slide above that within 11 seconds of the start of the event, the frequency response services DM, DR and DC were all saturated. In other words, all of the fastest frequency reserves were fully used. The system was potentially at a cliff edge where frequency could have fallen very rapidly had the losses been a little larger.

Note the slower static FFR remained as an automatic frequency response service, but is has up to 30 sec for full delivery. The size of any sFFR contribution is not shown on the OTF graph.

Many attending the OTF report/webinar could have been left with the impression that this event was not particularly serious and "The system behaved as expected during the event".

8 Under delivery of response

FRCR suggest that even down to 49.2Hz there is "reasonable certainty over plant performance." See L1 below. It would be easy to dispute this statement given the cascade of events on 22 Dec 2023.

3.4 Levels of impact

This report uses the four levels of impact set out below when assessing the balance between the key objectives. These levels allow for comparison with historic performance:

#	Deviation	Duration	Relevance
H1	50.5 Hz < f	Any	• Above current frequency standards. • Plant performance prescribed in detail by Grid Code, but not tested often in real-life conditions.
L1	49.2 Hz ≤ f < 49.5 Hz	60 seconds	• Current SQSS and System Operation Guideline (SOGL) frequency standards. • Infrequent occurrence, but reasonable certainty over plant performance.
L2	48.8 Hz < f < 49.2 Hz	Any	• Beyond current frequency standards and SOGL, but without triggering Low Frequency Demand Disconnection (LFDD). • Plant performance prescribed in detail by Grid Code, but not tested often in real-life conditions.
L3	47.75 Hz < f ≤ 48.8 Hz	Any	• First stage of LFDD.

Does FRCR methodology allow for the risks associated with under delivery from frequency response and inertia providers?

Alongside the tripping of a ~400MW gas turbine plant, during the 22 Dec event the OTF report also shows there was under delivery of 1226-1110 = 116 MW or about 10% from frequency response services.

Dynamic Service Contracts (MW)			Total Contracts (MW)	Estimated Delivery (MW)
DC-L	DR-L	DM-L		
873	203	150	1226	1110

Is this typical and allowed for in FRCR?

Are the reasons for this under delivery known? Are there any conditions where the mechanism(s) responsible could escalate this under delivery? Are actions in place to address this?

9 Risk of major events

The headline figure from FRCR is that there is a “1-in-30 years risk of a 48.8 Hz event.” That frequency corresponds to the first stage of LFDD tripping.

No mention is made of more serious events where the frequency falls to lower levels, with further LFDD tripping, or leads to a complete system collapse requiring system restoration (black start). Is there any reason this is not considered in FRCR?

Could future versions of FRCR include reference to EU NCER: System Defence Plan making it clear that FRCR scope either does or does not review the effectiveness of the system defence plan?

Note the approach taken by AEMO “The first Power System Frequency Risk Review (PSFRR) was undertaken in 2017 (SA) and 2018 (NEM) in response to a rule change following the 2016 South Australia black system event. The biennial PSFRR has **expanded to include events and conditions that could lead to cascading failures or supply disruptions**, with the first annual GPSRR published in 2023.” From G-PST/ESIG Webinar Series: Evaluating Major Contingencies and Conditions with the Potential to Cause Power System Disruptions - ESIG

The related presentation “other risks” section highlights topics including:

- Communication infrastructure diversity for generators
- Cyber attacks
- Ramping limitation
- Aggregated fast frequency response from multiple BESS

All of these emerging or rapidly evolving risks were highlighted in the NIA Project Resilient Electric Vehicle Charging (REV) , which Sygensys undertook for ESO. The findings of that project can be applied across a wide range of flexibility services including domestic Energy Smart Appliances and other forms of within day flexibility. See Operability Strategy Report 2023 Page 85.

Future versions of the FRCR or System Defence Plan could consider the potential impact of a successful cyber-attack on distributed energy resources or flexibility services, and what additional lines of defence could be incorporated. This should be complementary to the DESNZ/BEIS activity Delivering a smart and secure electricity system: the interoperability and cyber security of energy smart appliances and remote load control - GOV.UK (www.gov.uk)

10 Limited Frequency Sensitive Mode (LFSM)

It is good to see LFSM mentioned in the future considerations section of FRCR. It has the potential to have a major impact on increasing system security, adding another line of defence ahead of LFDD.

Going below 49.5Hz is unusual for the GB grid. Given the exceptional event on 22 Dec 2023, have ESO undertaken evaluation to see if plants which were expected to provide LFSM-U actually did so?

Future consideration within FRCR should include assessment of the potential impact of LFDD on embedded generation and especially the interactions with LFSM-U.

We have also proposed in a number of forums that a frequency sensitive mode, operating outside the region 49.5-50.5Hz, applied to some flexible loads could provide a major contribution to system security, acting as another line of defence against frequency collapse, for example during a successful cyber-attack on demand side response systems.

There does however have to be market fairness consideration of the trade-off between frequency response services provided by the market and non-remunerated mechanisms such as LFSM.

11 Fault Ride-Through (FRT)

The 22 December 2023 event goes beyond the faults guaranteed to be secured within FRCR 2023 policy, because of the nature of the cascade (simultaneous events). This included significant embedded generation (DER) loss.

No analysis is presented as to the reason for the DER losses. The OTF report suggests that the losses may be under-reported. “Embedded generation loss volume is likely larger than 260MW as indicated by DNOs.”

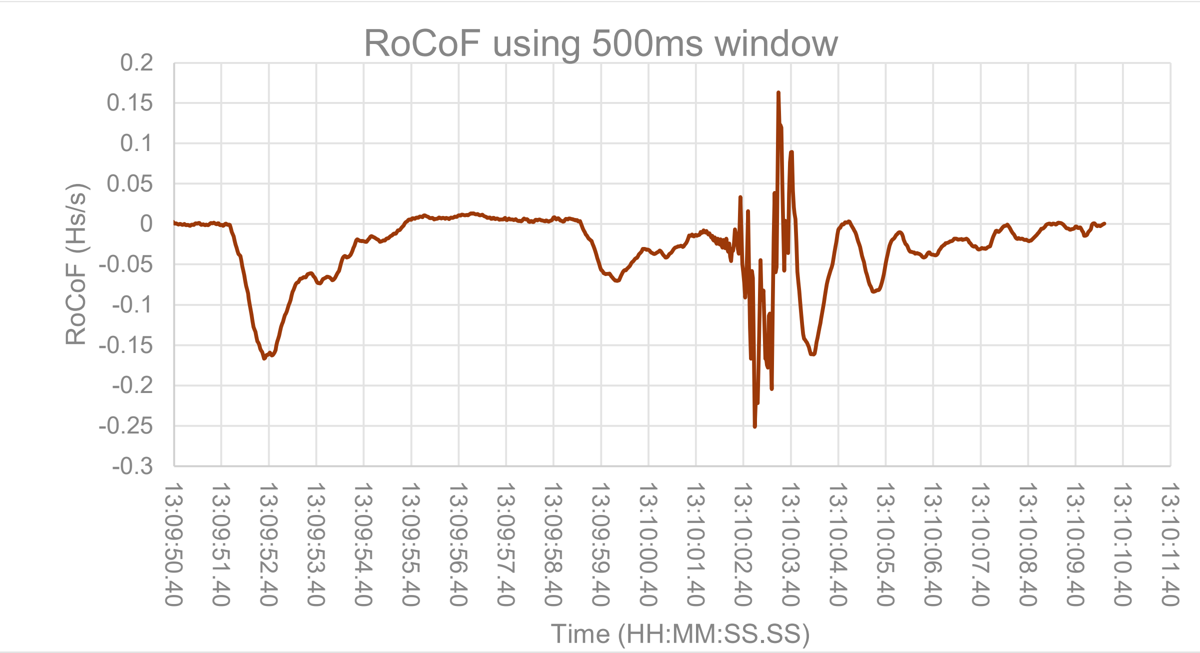
It should be noted for a reporting standpoint however that this figure is not given in the related GC0151 and GC0105 System Incidents Report December 2023. See cell highlighted below.

			Date and time of the incident	System frequency trace (1-second interval) for the incident	System frequency immediately before the incident	System frequency immediately after the incident	Maximum/Minimum rate of change of frequency (RoCoF) of the incident	System inertia at the time of the incident	Where known, MW trip/loss of all generation/ interconnection related to the incident		Where known, MW trip/loss of all Embedded Generation(EG) related to the incident	Wh of a the
Reference	Name	Notes	Date Time	System Frequency (Refer	Pre-Event Frequency (Hz)	Post-Event Frequency (Hz)	RoCoF (Hz/s)	System Inertia (GVAs)	Generation/Interconnection (MW)		EG (MW)	Den
20231202-1	Trip of CARR-1		02/12/2023 05:17:09	20231202-1	50.00	49.87	-0.003	267	CARR-1	425.40		
20231204-1	Trip of DAMC-1		04/12/2023 08:03:50	20231204-1	50.01	49.85	-0.025	294	DAMC-1	257.84		
20231206-1	Trip of DRAXX-4		06/12/2023 11:35:32	20231206-1	50.06	49.83	-0.052	333	DRAXX-4	621.86		
20231207-1	Trip of KEAD-2		07/12/2023 10:22:38	20231207-1	49.93	49.69	-0.058	291	KEAD-2	833.36		
20231212-1	Trip of DIDCB6		12/12/2023 19:46:28	20231212-1	49.80	49.70	-0.023	313	DIDCB6	661.64		
20231213-1	Trip of SVRP-10		13/12/2023 11:27:32	20231213-1	49.93	49.86	-0.023	306	SVRP-10	263.75		
20231219-1	Trip of PEMB-51		19/12/2023 06:18:56	20231219-1	50.03	49.95	-0.009	163	PEMB-51	378.85		
20231220-1	High frequency deviation - Interconnector swing		20/12/2023 06:01:00	20231220-1	49.84	50.32		156				
20231221-1	Loss of Supply at Western Isles and Dunvegan 33 kV substation		21/12/2023 01:57:00	20231221-1				319				West
20231222-1	Trip of IFA bipole 1, CDCL-1		22/12/2023 13:09:51	20231222-1	49.88	49.27	-0.152 -0.062	155	IFA bipole 1 CDCL-1	1000.00 383.30		
20231227-1	Low frequency deviation		27/12/2023 23:05:00	20231227-1	49.85	49.68		156				

It should be noted that, even at 260 MW, **this loss of distributed generation is larger than DR or DC services procured by ESO at the time of the event.** This could be used to justify putting significant effort into better understanding potential losses of infeed from DER during major events.

From the GC0151 report above, the RoCoF is stated as between -0.152 (max) and -0.062Hz/s (min). This may have triggered RoCoF anti-islanding protection if any generators remain with settings at 0.125 Hz/s. The Accelerated Loss of Mains Change Program should have dramatically reduced the number of plants impacted, so it is unlikely to account for all the observed embedded generation losses.

A concern regarding the reporting of RoCoF is that over the 500ms time window now used for RoCoF protection setting, RoCoF is not uniform across the system. For example, a PMU we gained access to recorded a peak RoCoF of -0.25 Hz/s based on a 500ms average during the event.



The limited time resolution of existing public historic system frequency data from ESO (1 sample per second) prevents meaningful RoCoF analysis, and this includes the related GC0151 and GC0105 System Incidents Reports.

For major events, could NESO consider publishing frequency (and voltage - see later) data at a 50Hz rate (cycle by cycle) to allow accurate assessment of RoCoF across varying time windows? Ideally this should be from multiple PMUs across the system to allow for regional RoCoF assessment.

In relation to RoCoF phenomena, it could be useful to consider the RoCoF ride-through limits proposed in the upcoming EU "Requirements for Generators" 2.0 and how that may impact future system design:

> "Staying connected to the network and operating at:
> • ±4,0 Hz/s over a period of 0,25 s,
> • ±2,0 Hz/s over a period of 0,5 s,
> • ±1,5 Hz/s over a period of 1 s, and
> • ±1,25 Hz/s over a period of 2 s"
> From Workshop_10_May_final_v2.pdf (europa.eu)

See Authority decision to approve the 2023 Frequency Risk and Control Report | Ofgem "We note that a respondent noted concern over the lack of clarity of the Grid Code Fault Ride Through definition, and its impact on likelihood of loss of infeed. We note that Fault Ride Through issues are resolved in real time via the measures put in place under GC0151, and the lack of clarity in the Grid Code Fault Ride Through definition is being addressed via the ongoing GC0155 . Through discussion with the ESO, we understand that **Fault Ride Through compliance is assumed within the FRCR assessments**."

OTF report Q&A section:

"Q: Can the update of the frequency event next week highlight activity in grid code modification GC0155 and the importance of fault ride through?

A: Thanks for your question. Investigation is on-going. We are working with individual parties to understand their deload / trip mechanism. We are not able to comment at this stage."

This question was the only mention of fault ride through in the OTF reporting process. We consider it was a missed golden opportunity to reemphasize the importance of FRT to grid users, which is a known persistent issue in the GB and other grids around the world. It would have been desirable to at least suggest plant operators look at their logs and fault recorders for the specific time of the incident to see how their equipment operated during this GB system-wide disturbance.

The FRCR assumption of fault ride-through compliance is misplaced, as (probably) demonstrated by the events of 22 Dec 2023. (This assumption is obviously subject to the confirmation via the detailed private technical investigation undertaken by ESO with impacted parties, a summary of which has not been published to date. I note that the 3-month timeline for FRT investigation allowed within Grid has now passed, so ESO should have the information to confirm.)

This is especially the case as Grid Code modification GC0155: Clarification of Fault Ride Through Technical Requirements is still ongoing. Ahead of full implementation, there clearly remains some risk of multiple events occurring rapidly as a cascade.

We are delighted that over-voltage ride-through is being addressed in GC0155, but have concerns that vector shift (or phase jump) ride-through requirements are not being clearly defined to clarify requirements for grid users.

FRCR2024 Webinar Question and Answers.xlsx (live.com)

"Q VS protection is no longer permitted, but why is there no requirement for VS ride through? This has been excluded from GC0155.

A: The current Grid Code requirements for fault ride-through state that plant is required to remain connected and stable for a fault / voltage disturbance at the connection point or a fault on the transmission system. A plant connected to the system via a healthy circuit should not trip for any reason unless the specific reasons identified through GC0155. VS is not included in the list of exceptions."

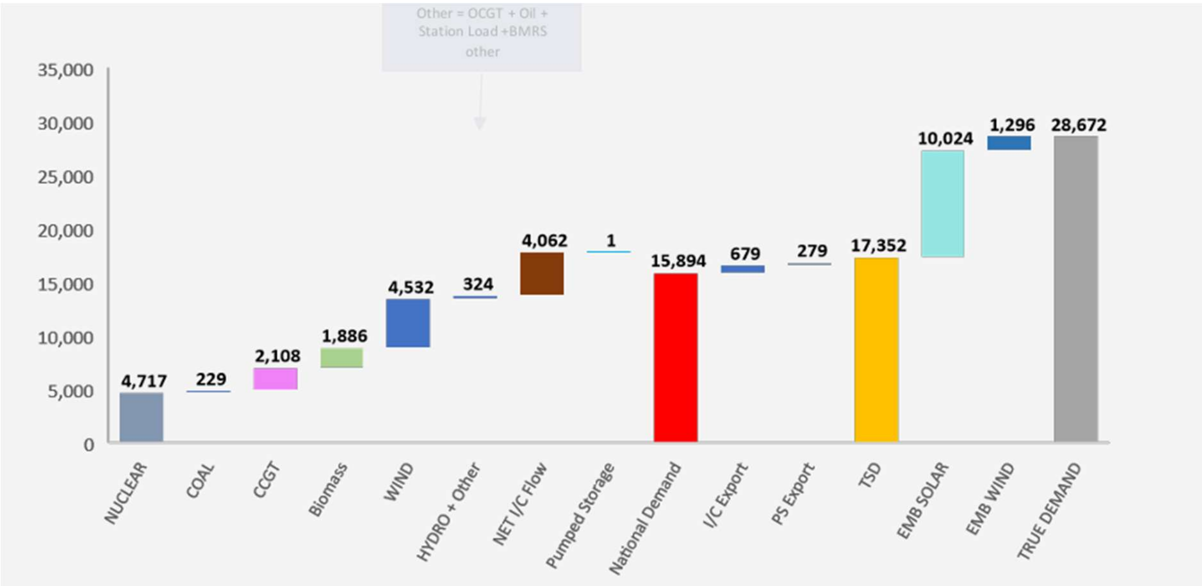
How is a developer expected to know what phase jump their plant may see? Especially those for smaller facilities where no simulation studies are performed.

The impact of phase jumps (or vector shift) remains a concern. This topic was raised at GCDF February 2024 in relation to a presentation which recommends EMT simulation of phase angle jumps.

See appendix where for reference we include input to GC0155 working group that has been provide by Sygensys in January 2023. It is included here as these documents are not in any of the workgroup meeting papers and this should make the content accessible to a wider audience.

12 Embedded generation (EMB) / Distributed Energy Resources (DER)

The OTF presentation 15 May 24 shows that on Saturday 11 May – Minimum Demand almost 40% generation at this time was embedded. The performance of these resources during grid disturbances will have a major impact on system security.



One of the great challenges here is that the smaller distribution-connected generation does not employ real-time operational metering, so the performance of individual plants during disturbances is almost invisible to the ESO and DSOs.

Loss of DER during a disturbance will add to the size of the contingency. There is likely to be some loss for major events. Given existing FRT requirements for DER, for example as defined in ENA EREC G99, some coincident tripping should be expected even from fully compliant plant. This could occur, for example, during over-voltage conditions.

It is good to see that ESO are concerned by operational visibility of DER. However, we are not aware of the current actions that are in place to better assess this challenge. It is reassuring that this topic is mentioned in the “future considerations” section of FRCR 2024.

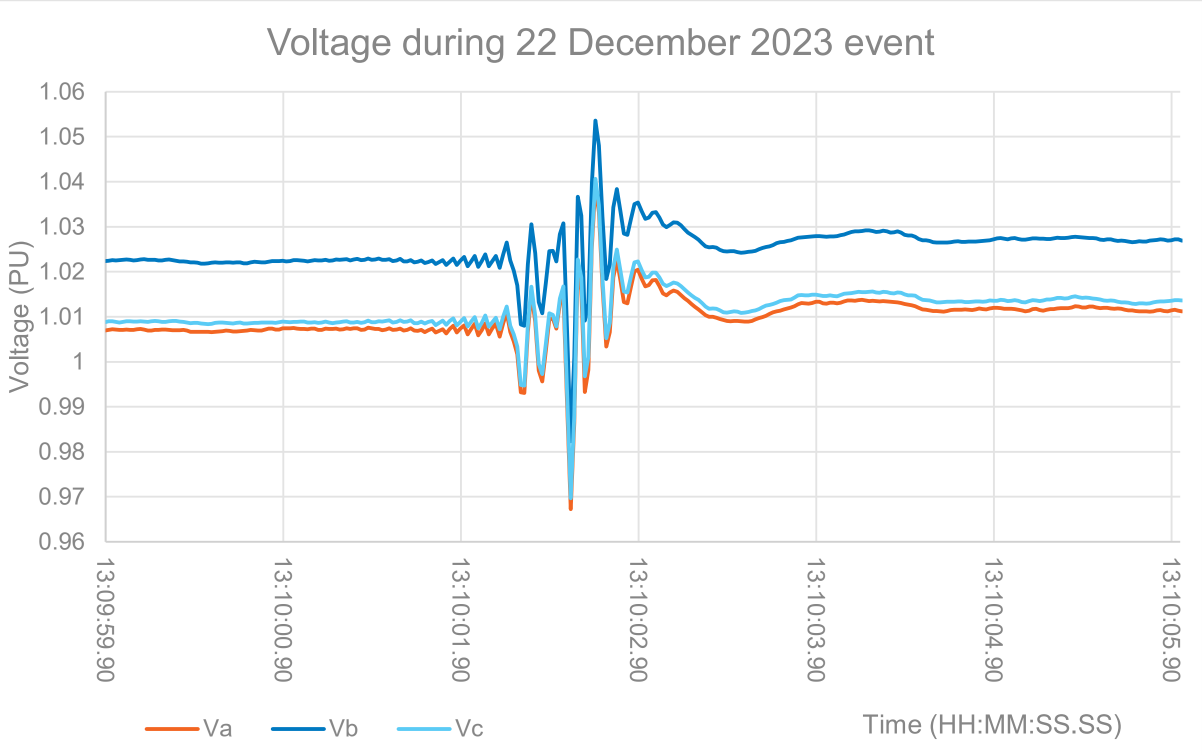
I would suggest that ESO could consider looking at AEMO work on this issue. They use the concept of DER “shake-off” and analyse the impact of major events on both generation and load. For example, see Operating a power system on 100% Distributed Resources and the links this document contains.

Combined frequency and voltage events

It is important to recognise that major frequency events often have a significant impact on voltage, causing short term disturbances that could trigger fault ride-through issues.

This appears to receive little attention in ESO regular reporting. For example, the OTF report on the event of 22 Dec 2023 did not make any mention of voltage in relation to the event. Similarly, looking at the GC0151 and GC0105 System Incidents Report December 2023, frequency graphs are provided for all events, but there are no examples of voltage graphs.

For reference, below is a PMU recording of the voltage at an LV location in the Central belt of Scotland during the 22 December 2023 event, expanded around the time of wide voltage deviations. This shows a moderate disturbance, remaining well within 0.9 to 1.1 PU, but it should be noted that this measurement was a significant distance from the assets which tripped.



Greater awareness of voltage disturbances during events will help in the analysis of FRT risks and may shed light on events such as the 22 December 2023 Caithness HVDC trip.

We are aware that ESO are investigating options to obtain access to fault recorder data where these are mandated on larger generations. Alongside this, it would be good to consider how to get similar data for DER, even if this is only on the basis of a selective sample of the million or so DER that are connected to the GB grid. Automation of the associated process for data collection and analysis would reduce the associated workload.

13 Sub-Synchronous Oscillation (SSO)

The "future considerations" section of FRCR2024 states "Events associated with lower system inertia and short circuit level: The change in the likelihood of existing events or new events created due to the increasing penetration of renewable generation connected to the whole system."

We would like to highlight that future updates to FRCR could consider SSO, which is not explicitly mentioned within FRCR2024. SSO represents a risk to frequency control as highlighted in SSO OTF 8 Nov 2023

"During June and July 2023, 8Hz Sub-synchronous Oscillation (SSO) occurred on five separate days, all centred in the Scottish network. The SSO events caused disturbances on the power system which included the **tripping of assets** – no demand was lost at any time."

The related recommendation below shared at the OTF included increasing frequency response and reserve holding:

Manage the impact of SSO:

- To secure against the absolute worst-case loss of generation the ESO determined that it was necessary to increase the response and reserve holding
- Between 3rd July and 14th August, the ESO updated the response policy with increased DC-L requirement and procurement to cover a largest loss up to 1800MW. If the SSO loss risk was greater than 1800MW, actions could be taken in control timescales to procure additional Mandatory Frequency Response (MFR), curtail wind or reposition the Moyle interconnector.
- The ESO also reviewed reserve policy and agreed to hold additional reserve during SSO investigation. The increased reserve requirement would be covered by procuring additional short term operating reserve (STOR).

From Operability Strategy Report 2023 “During June and July 2023, 8Hz Sub-Synchronous Oscillations (SSO) occurred on five separate days, centred in the Scottish network. The SSO events caused disturbances on the power system which included the tripping of generation, an interconnector, a HVDC link, and a transmission circuit.”

The Appendices to the Technical Report on the events of 9 August 2019 also mentions SSO.

“The de-load was caused by an unexpected wind farm control system response, due to an insufficiently damped electrical resonance in the sub-synchronous frequency range, which was triggered by the initial event.”

Key to analysing this risk is ESO activity on EMT modelling “The recent Grid Code Modification GC0141 obligates the Users to provide the EMT models of their plant and apparatus to the ESO.”

“RMS models based analysis might not identify potential system risks such as oscillations at sub synchronous frequencies. EMT models would be needed, for the system security, to identify the potential risk with high penetration of IBR such as system oscillations. “

14 Summary

The aim of this consultation feedback is to provide ideas into future OTF and FRCR reports with the objective of helping assist NESO maintain their enviable system reliability record.

In summary, our recommendations are:

OTF reports (and associated actions):

Section 3: Include naming of assets and a geographical map for the incident.

Section 4: Make public all report recommendations, as a "Call to action" for the industry.

Section 5: Describe incidents as "cascade events" where this is the case and update the 22 December 2023 report accordingly.

Define the term "simultaneous" where this is used to associate separate events with a single incident.

Section 7: Introduce aviation-style "Near Miss" reports.

Section 10: Review delivery of LFSM (including the 22 December 2023 incident).

Consider proposal for frequency-sensitive mode for flexible loads.

Section 11: Include analysis of reasons for DER tripping where this occurs.

GC0105 and GC0151 reports to include 50 samples per second data on frequency and voltage, from a selection of sites across the system.

Request plant operators to check FRT performance after significant events.

Publish results of FRT investigation from 22 December 2023 event.

Include Vector Shift FRT requirements in scope of GC0155 or future Grid Code modification.

Section 12: Publish actions relating to "Operational Visibility of DER".

Include voltage graphs in GC0105 and GC0151 reports (as above).

Investigate development of automated collection and analysis of event data from a sample of DERs across the system.

FRCR to include:

Section 6: Annual reports of cascade events (>1BMU, >750MW, <1minute)

Annual trend in lowest and highest system frequency.

Section 8: Investigation of under-delivery of response and any risks arising.

Section 9: Consideration of new risk types, such as cyber-attack to demand response.

Consideration of risks that might be more severe than a 48.8Hz event.

Statement on any review of the System Defence Plan.

Section 13: Include SSO-related risks.

15 Appendix Sygeneys Input to GC0155

1

High voltage ride through as part of GC0155 fault ride through clarification

Andrew Larkins
January 2023

Introduction

- Sygensys is not a party to the grid code
  - Presence of the working group is only as an Observer contributing to the discussion
  - We can not propose a modification, WACOM, or vote.
- Sygensys involvement in GC0155 came from undertaking an NIA project for NGESO
  - Project REV: The impact of Electric Vehicle charging on grid short term frequency and voltage stability, and cascade fault prevention and recovery.
- NGESO Operability Strategy Report 2023
  - Summary states "We also need to continue to ensure standards for capabilities like loss of mains protection and fault ride through remain fit for purpose as the system changes"
  - The only other mention of fault ride through in that report is with reference to Project REV.
- Project REV FRT concern include voltage, frequency and phase jumps (vector shift)
  - Vehicle to Grid FRT requirement are the same as small generators
  - EV charging fault ride-through is also a concern (Historically FRT for loads has not been considered a significant issue)
  - A project REV WP2 report covers high and low voltage ride though issues in pages 28 - 40
  - https://www.sygensys.com/wp-content/uploads/2022/09/Project-REV-WP2-Report.pdf

3

GC0155: Clarification of Fault Ride Through Technical Requirements

The term **Fault Ride Through** [1] is defined in the grid code as

"The capability of Power Generating Modules (including DC Connected Power Park Modules) and HVDC Systems to be able to remain connected to the System and operate through periods of low voltage at the Grid Entry Point or User System Entry Point caused by secured faults."

Taken from Complete Grid Code ISSUE 6, REVISION 16, 5 January 2023

https://www.nationalgrideso.com/electricity-transmission/document/162271/download

The phrase "low voltage" used in the definition does not mean the term **Low Voltage** which has an explicit definition in the gird code.

In interpreting the definition of **Fault Ride Through** and considering changes to include high voltage ride through requirements this document uses the following terms.

Low Voltage: Less that 100%, or 1.0 PU of the nominal voltage

High Voltage: Greater than 100% or 1.0 PU of the nominal voltage

[1] Note is this document text in **Bold** is used with reference to a terms which are explicitly defined within the grid code.

4

High Voltage Fault Ride Through

It is clear from the current definition of **Fault Ride Through** in the grid code that none of the limits in CC.6.3.15 could reasonably be interpreted requiring high voltage ride though as **Fault Ride Through** as the term currently only refers to low voltage.

If GC0155 seeks to include high voltage fault ride though requirements the term **Fault Ride Through** will need to be redefined.

As an aside please note that the term **Fault Ride Through** is defined twice on consecutive pages within the latest version of the grid code. This could be rectified as part of the GC0155 modification.

Strawman proposed modification to the definition of the term **Fault Ride Through**

"The capability of Power Generating Modules (including DC Connected Power Park Modules) and HVDC Systems to be able to remain connected to the System and operate through periods of ~~low voltage~~ where voltage is significantly above of below 1 PU at the Grid Entry Point or User System Entry Point caused by secured faults."

Note in this document underlined text is used to indicate proposed change to grid code legal text.

Requirements for high voltage operation

The grid code does not define requirements for **Fault Ride Through** above 1.0 PU, however it does provide details on the expected operating voltage range. A potential high voltage ride through requirement could be produced based on this parameters.

Steady state voltages are defined in CC.6.1.4

When considering potential requirement for high voltage ride through one need to also consider the impact of Voltage Fluctuations defined in grid code CC.6.1.7.

From CC 6.1.4

National Electricity Transmission System Nominal Voltage	Normal Operating Range
400kV	400kV ±5%
275kV	275kV ±10%
132kV	132kV ±10%

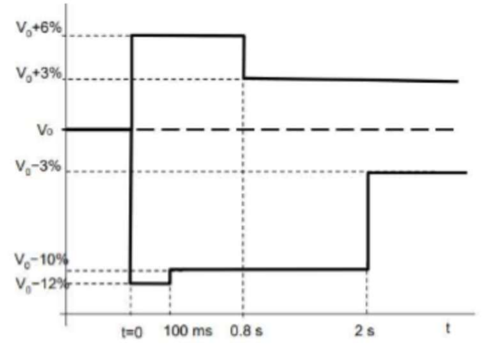


Figure CC.6.1.7 (3) — Voltage characteristic for very infrequent events

6

Potential source to derive requirements for high voltage ride through

Worst case steady state CC.6.1.4 and voltage fluctuations CC6.1.7 combined could to some extent be considered as an exiting definition of high voltage ride through.

However this is not the case a CC.6.1.7 NOTE 7 states: “These are examples only. Customers may opt to conform to the limits of another category providing the frequency of occurrence is not expected to exceed the ‘Maximum number of occurrence’ for the chosen category” The latter is defined as “1 event in 3 calendar months” This means customers do not have to comply with this threshold as HVRT events are rare.

We should also note CC.6.1.7 “very infrequent events” only includes “commissioning, maintenance & *post* fault switching”. It does not include voltages which may occur during the fault, so there could potentially be a need for a higher limit that CC.6.1.4 and CC.6.1.7 combined.

A higher limit may be necessary to cover high voltages during the fault.

7

Existing requirements for high voltage operation - continued

A number of documents has been discussed with the working group that cover high voltage operation.

TGN288 https://www.nationalgrid.com/sites/default/files/documents/TGN%28E%29_288_0.pdf

TS1 https://www.nationalgrid.com/sites/default/files/documents/TS_1_RES_0.pdf

SPEN Specific EPS-03-033 https://www.spenergynetworks.co.uk/userfiles/file/EPS-03-033.pdf

Note TGN288 issue 1 is date May 2016 and TS1 Issue 1 is dated May 2018. It is not immediately clear that these documents would apply retrospectively to plant installed before those dates.

Note these documents are withstand requirements. The document do not define the term withstand. There is reference CIGRE GC 30.10, which dates from the 1990. It does not define withstand and does not mention power converters.

https://e-cigre.org/publication/ELT_179_3-temporary-overvoltage-withstand-characteristics-of-extra-high-voltage-equipment

For a generating plant the term withstand could be interpreted as meaning survive the over voltage without damage or continue to operate normally delivering power. These documents were not written with generators in mind and in such a way that they clearly defined the requirements for active and reactive power delivery during over voltage conditions.

8

ENA G99

https://www.energynetworks.org/assets/images/Files/ENA_EREC_G99_Issue_1_Amendment_9_(2022).pdf

The G99 section 10.3 on fault ride through requirements are based on the grid code so only apply to low voltage.

However the protection settings and realted tests do effectively define an over voltage ride through requirement.

10.6.7 defines over voltage trip thresholds.

ENA Engineering Recommendation G99
Issue 1 Amendment 9 2022
Page 108

10.6.7 Protection Settings

10.6.7.1

Table 10.1 Settings for Long-Term Parallel Operation

Protection Function	Type A, Type B and Type C Power Generating Modules				Type D Power Generating Modules and Power Generating Facilities with a Registered Capacity > 50 MW	
	LV Protection(1)		HV Protection(1)			
	Trip Setting	Time Delay Setting	Trip Setting	Time Delay Setting	Trip Setting	Time Delay Setting
U/V	Vφ-n† -20%	2.5 s*	Vφ-φ‡ -20%	2.5 s*	Vφ-φ‡- 20%	2.5 s*
O/V st 1	Vφ-n† + 14%	1.0 s	Vφ-φ‡ + 10%	1.0 s	Vφ-φ‡ + 10%	1.0 s
O/V st 2	Vφ-n†+ 19%$	0.5 s	Vφ-φ‡ + 13%	0.5 s		
U/F st 1	47.5 Hz	20 s	47.5 Hz	20 s	47.5 Hz	20 s
U/F st 2	47.0 Hz	0.5 s	47.0 Hz	0.5 s	47.0 Hz	0.5 s
O/F	52.0 Hz	0.5 s	52.0 Hz	0.5 s	52.0 Hz	0.5 s
LoM (RoCoF)#	1 Hzs^{-1} time delay 0.5 s		1 Hzs^{-1} time delay 0.5 s		Intertripping expected	

9

G99

For example for type D plant >50 MW overvoltage threshold is +10% (1.1 PU) for 1 second.

To meet this requirement the plant should

- Must not trip and be able to continue operating indefinitely at 1.1 PU minus trip tolerance
- Must trip for 1.1 PU plus trip tolerance sustained for 1 second or more

(In other sections of G99 the trip threshold tolerance allowed is +/- 1%)

There is no explicit definition for what happens if the voltage is above 1.1 PU for less that 1 second. This is potentially a may trip region.

For some voltage of less than 1 second duration above 1.1PU it is essential that the plant trips to provide protection from damage.

Currently there appears no specific rule that would prevent tripping at for example 1.15PU for 1 cycle.

This may help explain why one of the work group members suggested some plant may trip for any voltage above 1.1 PU.

Potential next steps

In addition to the existing WG actions

- Work group review the information provided in this document and check for accuracy
- NGESO (as modification proposer) or another work group Member propose a strawman for a high voltage ride through curve.
- Ideally this should be based on

    the voltage limits defined in the grid code CC 6.1.4 and CC 6.1.7,

    if necessary evidence that higher limits are required to ensure system security
- Work group review the proposed curve, including review against international standards/grid codes
- Then consult generator operators and OEMs
- What is their current high voltage ride through curve for existing plans and typical new equipment
- Could their plant comply with the propose new curve without massive expense
    - If so at what cost
    - If not what is the best HVRT that could reasonably economically be achieved

1

Vector Shift ride through as part of GC0155 fault ride through clarification

Andrew Larkins

January 2023

2

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- Project REV FRT concern include voltage, frequency and phase jumps (vector shift)
  - Vehicle to Grid FRT requirement are the same as small generators
  - EV charging fault ride-through is also a concern (Historically FRT for loads has not been considered a significant issue)
  - A project REV WP2 report covers **vector shift** issues in pages 17-27
  - https://www.sygensys.com/wp-content/uploads/2022/09/Project-REV-WP2-Report.pdf

3

Why do we need to define vector shift ride through requirements?

- Coincident tripping due to vector shift has been known to be a problem on the GB system for over ten years.
- Tripping due to vector shift Loss of Mains protection is well known and contributed to the August 2019 incident
- The Accelerated Loss of Mains Change Program is addressing the removal of vector shift protection as a form of anti-islanding detection.

- However, the related changed to rules and regulations failed to define a required ride-through performance for vector shift.
- Vector shift ride through, to beyond the old protection limit of 6 degrees, is essential for system security.
- **Currently there is no clearly defined requirement for generators to ride through a vector shift.**
- The lack of a clear ride through requirement is a unmanaged risk to system security.

4

Inverter based resources are not like synchronous machines

- Software controlled inverter-based generation are not like synchronous machines which depend on underlying physics of the rotating machine.
- You can not rely on a basic intrinsic level of vector shift ride through as it is software algorithm dependent.
- **International experience has shown vector shift events can cause tripping of inverter based resources due to multiple causes, anti islanding projection, PLL unlock (loss of sync), AC over current, + more**
- With no defined vector shift ride through specification requirement generator may achieve ride through of steps of only 6 degrees or other may ride through 60 degrees or more.

5

Vector shift ride through is an internationally recognized issue

IEEE P1547 requires that multi-phase DER ride through the following in the sub-cycle-to-cycle time frame: (1) positive-sequence phase angle changes of less than or equal to 20 degrees, and (2) individual phase angle changes less than 60 degrees.

https://www.nrel.gov/grid/ieee-standard-1547/assets/pdfs/smart-inverters-applications-in-power-systems.pdf

AS/NZS 4777.2:2020 states that "the inverter shall remain in continuous operation for a single phase voltage angle shift within a voltage cycle of at least 60 electrical degrees".

https://arena.gov.au/assets/2022/05/realising-electric-vehicle-to-grid-services-lessons-learnt-2.pdf

EN 50549-10 Requirements for generating plants to be connected in parallel with distribution networks - Part 10: Tests for conformity assessment of generating units. Should be published formally in early 2023 and will include a test for vector shift immunity.

Odessa Disturbance Texas 2021

Table 1.1: Causes of Reduction

Cause of Reduction	Reduction [MW]
PLL Loss of Synchronism	389
Inverter AC Overvoltage	269
Momentary Cessation	153
Feeder AC Overvoltage	147
Unknown	51
Inverter Underfrequency	48
Not Analyzed	34
Feeder Underfrequency	21

* See explanation below.

https://www.nerc.com/pa/rrm/ea/Documents/Odessa_Disturbance_Report.pdf

IEEE 2800 - 7.3.2.4 Voltage phase angle changes ride-through

- **The *IBR plant* shall ride through positive-sequence phase angle changes within a sub-cycle-to-cycle time frame of the *applicable voltage* of less than or equal to 25 electrical degrees.**
- In addition, the *IBR plant* shall **remain in operation for any change in the phase angle of individual phases** caused by occurrence and clearance of unbalanced faults, provided that the positive-sequence angle change does not exceed the forestated criterion.
- Active and reactive current **oscillations** in the *post-disturbance period* that are **positively damped** shall be acceptable in response to phase angle changes.
- ***Current blocking*** in the *post-disturbance period* **shall not be permitted**.

https://www.ercot.com/files/docs/2022/05/24/EPRI_ERCOT_IBRTF_Meeting_Apr_8-2022.pdf

GC0137 GB Grid Forming requirement 60 degrees, ECP.A.9.1.9.6

6

ENA discussion re G98 & G99

Sygensys interest was related to EVs and V2G so we first discussed the issue with ENA

ENA G99 requirement 10.4.11

- *The voltage vector shift technique is not an acceptable loss of mains protection.*

Appendix includes

- *A Loss of Mains Protection, Vector Shift Stability test: +/- 50 degree*
- *Pass is confirm no trip of Interface Protection*

This is not a ride through test for the full Power Generating Module.

It does not consider the possibility of no trip interface protection but a reduction in output power.

ENA advice:

The Grid Code should define the requirements for system security, these would then be reflected within G98 & G99.

7

NGESO discussions

The **NGESO** GC0155 team have actively discouraged Sygensys suggestion to include a vector shift ride though requirements into the mod initially saying it was out of scope. However, the modification proposal form clearly states

This modification therefore proposes minor changes and improvements to the existing Grid Code Fault Ride Through (FRT) requirements as a minimum but not limited to the following:

- *To clarify instances where User plant is permitted to trip where required in order to clear the fault from the transmission system.*
- *To amend requirements for generating maximum reactive current during faults which may be unachievable for many Generators.*
- *To amend post fault active power requirements to reflect that low load Generators may have greater oscillations than the requirements currently allow for.*
- *To provide requirements for overvoltage events following a fault.*

8

NGESO discussion (continued)

In an initial email from NGESO appeared to prefer the current ambiguity.

“If we were to specify a VS resilience requirement then the operation of the system in the future dictates that larger VS events happen, the requirements will need to be updated and will need to apply retrospectively as the costs associated with managing such generation losses when compounded with other generation losses are prohibitive and the impact on the security of supply is detrimental.”

This does not align with GC0155 which aim is to provide clarity of ride through requirements.

In follow up discussion the following points were made

NGESO: Connection studies will pick up problems for large generators.

Sygensys: This would only be true if the study look for the issue and there is a detailed and accurate EMT models. RMS modelling will not accurately identify vector shift ride through issues.

Sygensys: This does not address the growing capacity of distribution connected generation that does not require detailed connection study.

NGESO: We are not seeing lots of problems currently

Sygensys: We should learn from international experience and not wait until the issue becomes a problem needing an expensive retrospective fix.

9

Strawman

Phase Jump Withstand - All generators

For positive or negative phase jump of 50 degree the plant must remain connected and within 0.5 seconds the Active Power output shall be restored to at least 90% of the level being delivered immediately before the fault.

Once Active Power output has been restored to the required level, Active Power oscillations shall be acceptable provided that:

(a) The total active energy delivered during the period of the oscillations is at least that which would have been delivered if the Active Power was constant.

(b) The oscillations are adequately damped.

(c) In the event of power oscillations, Power Generating Modules shall retain steady state stability when operating at any point on the Generator Performance Chart.

Proposal are based on parameters which are already in G99 https://www.energynetworks.org/industry-hub/resource-library/erec-g99-requirements-for-connection-of-generation-equipment.pdf and CC.6.3.15.1 a ii

10

Notes on strawman

The 0.5 sec time delay matches other requirements on recovery time for active power already in another section of the grid code.

From and OEM/operators standpoint this would for example allow an inverter PLL time to relock after the phase jump if necessary.

The allowance for oscillation in power accommodates synchronous machines which would have a natural tendency for power oscillation after a phase jump.

Going beyond phase shift a modification could include:-

Vector Shift Withstand - Type B,C and D

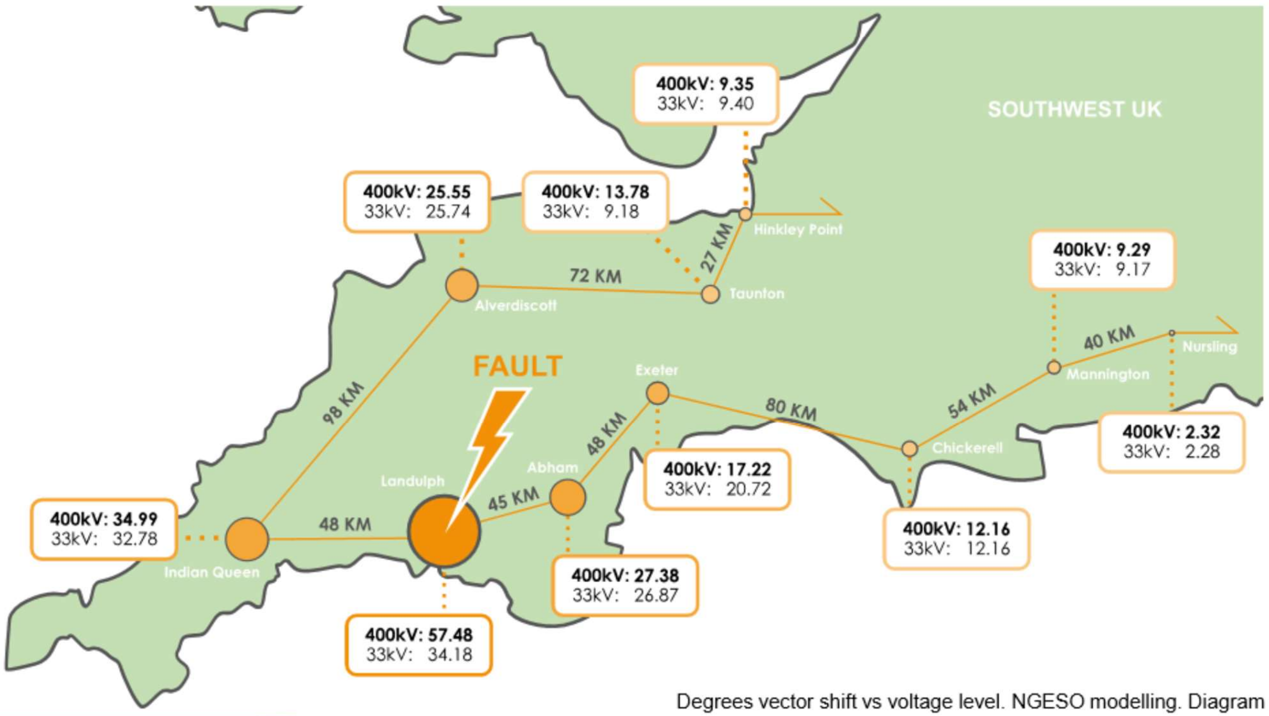
For positive or negative phase jump of 25 degrees and voltage in the range 0.5 to 1.1 PU the plant must remain connected and the Fast Fault Current Injection, as defined in ECC.6.3.16, shall be at least 90% of the level required when there is no phase jump.

11

Appendix

12

Example of vector shift in degrees across a region around a fault



Degrees vector shift vs voltage level. NGESO modelling. Diagram from

https://www.sygensys.com/wp-content/uploads/2022/09/Project-REV-WP2-Report.pdf

13

Grid and Distribution Code modification history
GC0035, GC0079, DC0079, GC0137, GC0155

"That vector shift protection technique should not be used as Loss of Mains protection for type tested generators and that **the generation must not trip for vector shifts of up to 50°."**

http://www.dcode.org.uk/assets/uploads/DC0079_Report_To_The_Authority_Type_Tested_Plant_Phase_2_Final_version_280318v1.pdf

"On further discussion with these manufacturers, it became clear that the need to undertake repeat type testing, particularly the proposed level of vector shift immunity of 50°, may require further investigation and specification before it is prescribed as a requirement."

http://www.dcode.org.uk/assets/uploads/Report_To_the_Authorityv3_1.pdf

LV PV inverter testing – key findings "All inverters remained connected during G83 recommended 50 deg VS type testing."

https://www.dcode.org.uk/assets/uploads/Workshop_slides_June_18_1.pdf