

BETA PHASE

SIF BLADE

Black Start Demonstration from Offshore Wind (BLADE)

Stage 2 OEM Request for Input



1. Purpose of this document

1.1. Guide to this document

- Sections 1 to 3 – background information
- Section 4 specific OEM requests
- Please fill in and return the tables in the relevant sections 4.2.3, 4.3.3, 4.4.3, and 4.5.3, in particular:
 - o WTG OEMs - 4.2.3, 4.3.3, 4.4.3
 - o BESS OEMs - 4.2.3, 4.3.3, 4.4.3
 - o HVDC OEMs - 4.2.3, 4.3.3, 4.4.3
 - o E-STATCOM OEMs - 4.2.3
 - o SynCon OEMs - 4.2.3
 - o Grid Control OEMs - 4.5.3

1.2. Purpose of this document

- The BLADE project is requesting active OEM input into its final stage, in the form of models, software and engineering time.
- The reason for this request is the need for BLADE to robustly demonstrate the technical feasibility of the BLADE restoration methodology to key decision makers:
 - o international TSOs, including NESO, TenneT and RTE in the BLADE consortium
 - o international regulators, including Ofgem in the BLADE consortium
 - o offshore wind developers, including 11 leading offshore wind developers in the BLADE consortium
 - o OEMs themselves
- BLADE has engaged with several OEMs during previous stages of the project, who are members of the BLADE Advisory Panel.
- This Request for Input builds on the back of the OEM engagement – and findings of – previous stages of BLADE.

1.3. Timeline

- **31 March** – deadlines for questions – please submit any to Robert.keast@carbontrust.com and james.inkpen@carbontrust.com – we are open to verbal or written questions
- **10 April** – please respond to this request for input by completing the tables in the relevant sections 4.2.3, 4.3.3, 4.4.3, and 4.5.3 - please submit to Robert.keast@carbontrust.com and james.inkpen@carbontrust.com
- **16 April** – BLADE consortium review and selection of OEMs, including possible written or verbal discussions or interviews with OEMs
- **23 April** – conditions negotiated with OEMs (IP, confidentiality, budgets, timelines) and finalisation of Stage 2 project plan
- **30 April** – Ofgem Stage Gate assessment: Stage 2 Go-No-Go Decision
- **15 May** – Stage 2 contract negotiation and signature between BLADE consortium and OEMs
- **15 May onwards** – Stage 2 delivery in line with Stage 2 project plan

1.4. Contracting

Please note that the contracting structure for Stage 2 is not yet finalised and will depend on the IP, confidentiality and cost information supplied by OEMs in the tables in the relevant sections 4.2.3, 4.3.3, 4.4.3, and 4.5.3. It is possible for OEMs to be contracted as subcontractors, project partners or under simple NDA. We will assess and discuss with selected OEMs which of these routes is most appropriate in April (see timeline above).

Please note that other OEMs will be involved in BLADE. The BLADE project partners have experience and capability to silo OEM confidential information. We can negotiate the exact siloing mechanisms during the contract negotiations in April (see timeline above).

Please note that Stage 2 is subject to Ofgem approval. We have funding secured already, but we still must pass a "Go-No-Go" Stage Gate decision with Ofgem on 30 April. A key part of this Stage Gate will be the identification of OEM delivery partners and their roles and budgets.

2. Background on BLADE

2.1. Aims

The BLADE project aims to bring restoration capability from offshore wind into commercial deployment. Doing so will ensure that the GB system (and other high offshore wind capacity systems in the future) remains resilient to increasing offshore wind penetration, and hence will ensure that offshore wind can continue to replace gas in the electricity mix. BLADE is doing this by:

- Developing and de-risking detailed, locational-specific, practically implementable Restoration methodologies that include contributions from offshore wind;
- Understanding technology, cost and market drivers, to both inform the optimal Restoration solution and to evolve Restoration markets and regulations to ensure the optimal Restoration methodology can be implemented.

2.2. Structure

To achieve this, BLADE includes an industry-wide consortium, including:

- Transmission operators: SP Energy Networks, SSE Networks
- Offshore wind developer: EnBW, Equinor, Jera Nex BP, Ocean Winds, Ørsted, ScottishPower Renewables, Shell, SSE Renewables, RWE, TotalEnergies, Vattenfall
- System operators: NESO, RTE, TenneT
- Research and Consultancy: Carbon Trust, National HVDC Centre, Strathclyde University, TNEI

The BLADE project is funded under Ofgem's SIF programme, with co-funding from Carbon Trust's Offshore Wind Accelerator Programme.

2.3. Scope

The philosophy of BLADE is to change as little as possible to have the largest impact. Technologies like BESS, WTGs, STATCOM, synchronous condensers are being deployed throughout the networks already. The working philosophy is that, with minimal changes at the component level, we can achieve a net-zero compatible Restoration methodology. However, this requires significant development and de-risking at the system level.

2.3.1. Discovery Phase

Discovery Phase ran from March to June 2023. It showed the need and potential for offshore wind to contribute to system Restoration.

2.3.2. Alpha Phase

Alpha Phase ran from October 2023 to March 2024. It demonstrated generic technical feasibility study and cost savings for Restoration methodologies based on offshore wind.

2.3.3. Beta Phase Stage 1

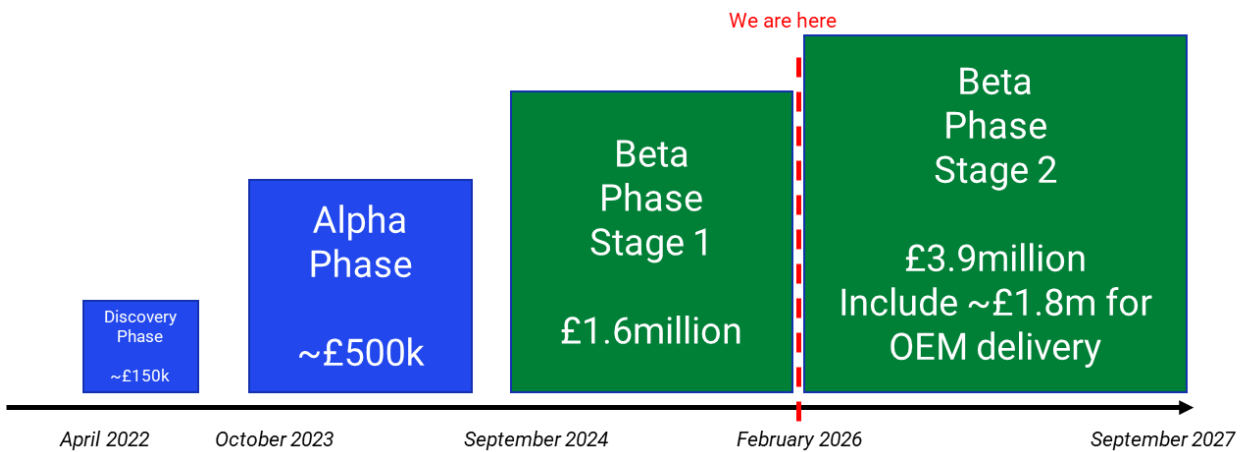
Beta Phase started in September 2024. Stage 1 was a detailed feasibility study, based on two specific network locations. This feasibility study considered both AC and DC-connected offshore wind farms, and has been informed by input from the networks, the offshore wind developers and OEMs.

*Several OEMs provided **guidance** to the feasibility study of Beta Phase Stage 1.*

2.3.4. Beta Phase Stage 2

Stage 2 will run from April 2026 until September 2027. Stage 2 will conduct the necessary detailed de-risking demonstrations to finalise the Restoration methodology. Once the Restoration methodology is understood, Stage 2 will conclude with a final position on the necessary market and regulatory arrangements, together with NESO and Ofgem.

*In this document, we are requesting **active OEM input** into Beta Phase Stage 2. **Budget is available for these roles.***



3. Current overall status of BLADE – summary of Stage 1 conclusions and Stage 2 priorities

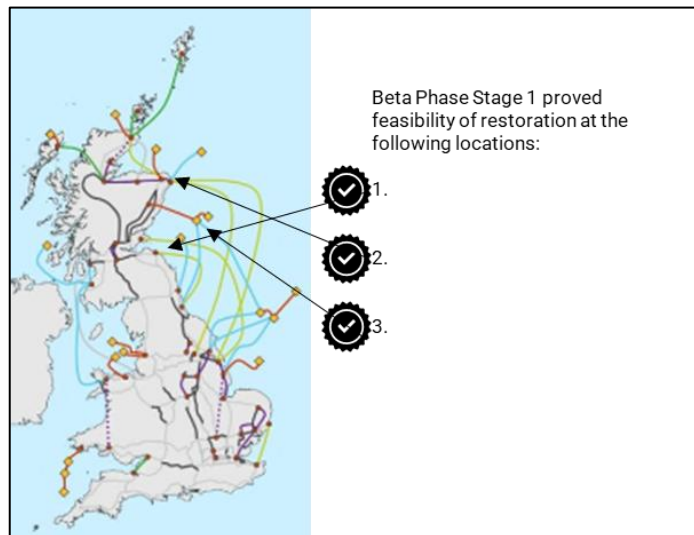
- For more details, please see the Beta Phase Stage 1 Summary Report.
- Areas flagged in **green** in this section will require **active OEM input** is flagged in green below. These are discussed in more detail in section 4.
- Areas not flagged in green will require OEM guidance only (similar to previous levels of engagement).

3.1. Technical solutions

3.1.1. Stage 1 conclusions

Stage 1 has proven that Restoration using OWF and BESS is technically feasible, even with limited wind speeds and limited energy stored in the BESS. It can be achieved a number of ways:

- GFM BESS as Primary Energisation and GFL OWF as Primary Support
- GFM BESS as Primary Energisation and GFM OWF as Primary Support
- GFM OWF as Primary Energisation and GFL BESS as Primary Support
- Hydro as Primary Energisation and GFL OWF as Primary Support
- For both AC and DC-connected wind farms



These solutions vary in TRL. However, key is that the BLADE solutions do not require novel capability at the component level. Rather, the BLADE solutions use existing (or already envisaged) components. The innovation is in the integrated system design, tuning and control.

No conclusion has yet been drawn on which of the above solutions is the most promising restoration solution. This will be work conducted in Stage 2.

3.1.2. Stage 2 priorities

Stage 2 must de-risk the above solutions sufficiently to enable their commercial adoption and provide evidence as to which is the optimal solution. Key to this will be prioritising the following:

1. **GC0156-compliant GFL OWF – short term priority – must deliver**
 - o GFM BESS as Primary Energisation and GFL OWF as Primary Support. The main priority will be focussing on a future GC0156 compliant GFL OWF, with no additional capability

beyond GC0156. However, if OWF capability is required beyond GC0156, this will be researched and defined.

- Demonstrate specific, difficult Restoration steps in real time, with OEM models, software or hardware.
 - With active OEM input, find and prove the required performance envelopes for GFL WTGs to connect to the weak network, and specify the BESS and network requirements to create a suitable network. In particular, the system strength envelope for the GFL WTGs in Restoration and whether a special Restoration mode is required; and the minimum BESS converter size, the minimum BESS energy reserve, and other network plant required.
 - Fluctuating wind speed and demand, and forecasts thereof, should be included in this de-risking. The stability performance of the GFL WTGs may vary with wind speed. A key aim will be to maintain the power island for 6-12 hours.
2. **GFM OWF – mid-term priority – should deliver**
 - GFM BESS as Primary Energisation and GFM OWF as Primary Support.
 - Similar to option 1, but using generic models informed by OEM review.
 3. **Self-Starting WTGs – long term priority – may deliver**
 - Self-Starting WTGs as Primary Energisation, with or without BESS as Primary Support.
 - Similar to option 1, but using generic models informed by OEM review.
 4. **AC and DC**
 - For 1-3, do for both AC and DC-connected wind farms.
 5. **TO control room tool**
 - For 1-4, development and demonstration of a TO control room decision making tool that supports control engineers to enact the “BLADE” LJRP. This will involve wind forecasts, generation availability data, system strength measurements, stability performance predictions of generation and storage assets, communication protocols with generators, demand forecasts, and the state (warm / cold) of thermal generation. The tool will inform control room engineers when to trigger the BLADE LJRP instead of the thermal LJRP and provide key information to conduct the BLADE LJRP as the process continues.
 6. **Technical requirements**
 - On the basis of 1-5, define and publish standard wind farm, BESS and network.

3.2. Cost savings and market definitions

3.2.1. Stage 1 conclusions

Stage 1 has shown that the cost of BLADE solutions could be comparable with the costs of existing Restoration providers, and could be much lower in the future if they enable NESO to avoid warming thermal generation restoration providers.

3.2.2. Stage 2 priorities

Stage 2 must confirm all cost assumptions as the BLADE solutions are confirmed in Stage 2 technical de-risk activities, and guide the BLADE solutions to low-cost solutions.

3.3. Market definitions

3.3.1. Stage 1 conclusions

Stage 1 has found that the current market definitions (particularly high availability requirement of 80% for 10 hours, and contract duration) will prevent offshore wind participating in the Restoration market in any meaningful way. The market definitions are designed around the capability of thermal generators. Availability requirements are traditionally in Restoration market definitions to prevent unreliability of dispatchable generation, not to account for inherent variations in renewable generation. There needs to be a shift in how system operators view availability in Restoration contracts for renewable generation. Otherwise, it will prevent useful, low-cost services being provided to system operators from the renewable sector.

Wind generation is already the largest generation source in GB, and is predicted to become the dominant electricity source. Excluding wind from the Restoration market will mean GB relies on its aging and retiring thermal fleet. As the numbers of thermal generators reduce, the number of available restoration providers will reduce, shrinking the market and potentially pushing up costs. NESO, Ofgem and the UK government need to strongly consider if the current market requirements are fit for the future.

3.3.2. Stage 2 priorities

3.3.2.1. Availability

Stage 2 needs to evolve this thinking rapidly. The most likely solution is that each Restoration zone requires multiple LJRPCs. One will be based on low speed periods (relying on thermal plant, or whatever else is generating in those periods) and one will be based on high wind speeds periods (relying on offshore wind). The market definition would then be evolved to say “When we are in a **high wind period**, the Restoration provider must provide a **high** proportion of its capacity a **high** amount of the time.”

As an alternative approach, Stage 2 needs to rule out wind from participating in the market and simply focus on how GC0156 compliant OWFs can be brought on early in the Restoration process to accelerate the Restoration process and to reduce the market requirements on contracted anchor providers.

3.3.2.2. Restoration contracts for reactive power

Whilst high active power availability cannot be achieved for renewable generators, their availability for reactive power can be much higher. However, NESO’s restoration contracts are currently based around active power providers (who then also provide the necessary reactive power), and through engagement with NESO in Stage 1 it appears that this will remain the case in the future. Stage 2 needs to conclude if additional reactive power from primary, contracted restoration generators is a useful service (separate to active power primary providers) and hence whether market requirements need to evolve to consider this.

3.3.2.3. Tender timing and contract length

The market is currently tendered and offers 5-year contracts. This makes sense when most of the cost is in OPEX. However, for renewables such as offshore wind, many of the costs might be in DEVEX or

CAPEX (i.e. up front of final design and final investment decision)¹. Some of these design decisions may need to be made well in advance of any restoration service being provided, and it is not yet clear whether BLADE capability could be retrofitted into an OWF which has not been designed with it in mind. Renewable developers are in a competitive environment and seek to reduce internal costs and risks. They will not invest in CAPEX without the contract in place first. Further, if they invest in CAPEX, the assets will be built with 25+ year lifetime, not a 5-year lifetime, which will push up Restoration contract prices.

Stage 2 will also work closely with NESO on this issue to seek ways to address this structural issue in the Restoration market, which may exclude low-cost solutions being provided to NESO.

3.3.2.4. Contract boundaries

From Stage 1, it is clear that BESS and OWF need to work together and complement each other in the Restoration methodology. They are symbiotic. The capability required from one, depends on the capability provided by the other, and vice versa. Where the BESS and OWF are developed by the same company, this will not present a huge problem. However, whilst there are precedents for ancillary service provision from joint providers, where the BESS and OWF are developed by different companies, this will present a complexity that needs to be addressed.

There are open questions concerning:

- how NESO can run an open market for Primary Energisation and Primary Support (separately), when the Primary Support required depends on who wins the Primary Energisation tender; the issue here is how the tender phases allow for partnering of multiple providers (separate contractual entities) and how the tender allows for flexibility in the split of capabilities between the multiple providers, and
- how the BESS and OWF (separate contractual entities) can cooperate through the development process, commissioning and testing

These practical questions need to be addressed, and the solution developed in Stage 2 must have a workable business model for both the BESS and OWF developer to participate.

3.3.2.5. Outputs of Stage 2

On the basis of the above, Stage 2 will work closely with NESO and other system operators to seek to shift the thinking in Restoration markets to enable low-cost renewables to participate. We aim for Stage 2 to come to a firm written position on market definitions, supported by NESO and Ofgem.

As an alternative approach, BLADE should show that OWFs cannot participate in the market but can assist Restoration through GC0156 compliance alone.

¹ Conventional restoration providers can also incur CAPEX, e.g. for auxiliary generators, although this capability has, in the past, been retrofitted for existing generators.

3.4. Regulation

3.4.1. Stage 1 conclusions

Stage 1 has found that the OFTO regime could prevent offshore wind farms from providing Restoration services, should any changes be required to the OFTO assets beyond minimum viable product. Whether such changes are required, depends on the details of the specific BLADE solution, which will be finalised in Stage 2.

3.4.2. Stage 2 priorities

From a regulatory perspective, ideally the BLADE solutions that are finalised in Stage 2 will not require changes to OFTO asset designs beyond the minimum viable product. The project will continue to monitor this risk.

If changes are required, the project will work with Ofgem to understand how this can be allowable, particularly because at the time of designing and building the OFTO assets, a developer will not know if they have won a Restoration contract.

Even if changes are not required to change the minimum viable product, questions remain about how the OFTO will participate in the Restoration in practical reality, including testing.

On the basis of the above, we aim for Stage 2 to come to a firm written position on the OFTO regime for Restoration, supported by NESO and Ofgem.

4. Active OEM input requested

- *This section focuses on the active OEM input roles flagged in **green** section 3.1.2.*
- *We are open to iterations of this scope with selected OEMs: this document is the starting point.*
- *Please note that **BLADE has budget available to fund active OEM input.***
- ***We will select OEMs to work with based on the responses to this section.** So please ensure all internal approvals are signed off.*

4.1. An Overview of Expected OEM Input

4.1.1. Description of Stage 2 Plan and OEM Input

From a technical standpoint, a number of priorities are outlined in section 3.1.2 which Stage 2 should achieve. This should involve active input from OEMs to facilitate a set of Restoration studies and demonstrations which accurately reflect the C&P design, performance, and capabilities of industry equipment manufacturers. As this section outlines, there are various options for electromagnetic-transient (EMT) modelling, simulation and demonstration environments, primarily being real-time and/or offline. The choice of simulation environment shall be subject to OEM model availability, engineering resource, and study priorities.

Late-stage simulation priorities can expect to favour real-time demonstrations and consider control room operator decision-making needs, emulating longer-term forecasting, monitoring, and reactive measures in pseudo-operational timescales against factors such as wind speed or demand variation, BESS state-of-charge, or indices designed to evaluate system stability/criticality. The expected input from OEMs would be component models, including control and protection (C&P) systems and communication interfaces with the control room tool (virtual or OEM controller) to monitor and act on key indicators.

Prior to late-stage demonstrations, a set of stability studies shall be conducted using both the time-domain and frequency-domain (in parallel), to inform an impedance shaping exercise of the active converter devices (WTGs, BESS, HVDC, etc.) such that they comply with frequency-dependent impedance envelopes (to be specified in Stage 2).

Table 1 - OEM Model Options

Electromagnetic Transient Simulation	
RSCAD (Real-Time)	PSCAD (Offline)
GTSOC Black Box (Software-in-Loop)	Black Box (Compiled)
White Box (OEM-Benchmarked)	White Box (OEM-Benchmarked)
Generic (OEM-Informed)	Generic (OEM-Informed)

As the stability studies are expected to require iterations and controller development, it is important for us to understand the level of EMT model detail and engineering support the OEMs can provide. The nature of the study groups may mean that it is more practical to consider different levels of EMT model detail and/or simulation environments between the stability studies and the Restoration demonstrations. In the following sections we give recommendations on preferred models subject to the study group, though ultimately, we are seeking OEMs to tell us the full range of models and environments they can offer.

The expected level of detail of OEM models and their respective simulation environments are outlined in Table 1, while an indicative technical study framework is illustrated in Figure 1.

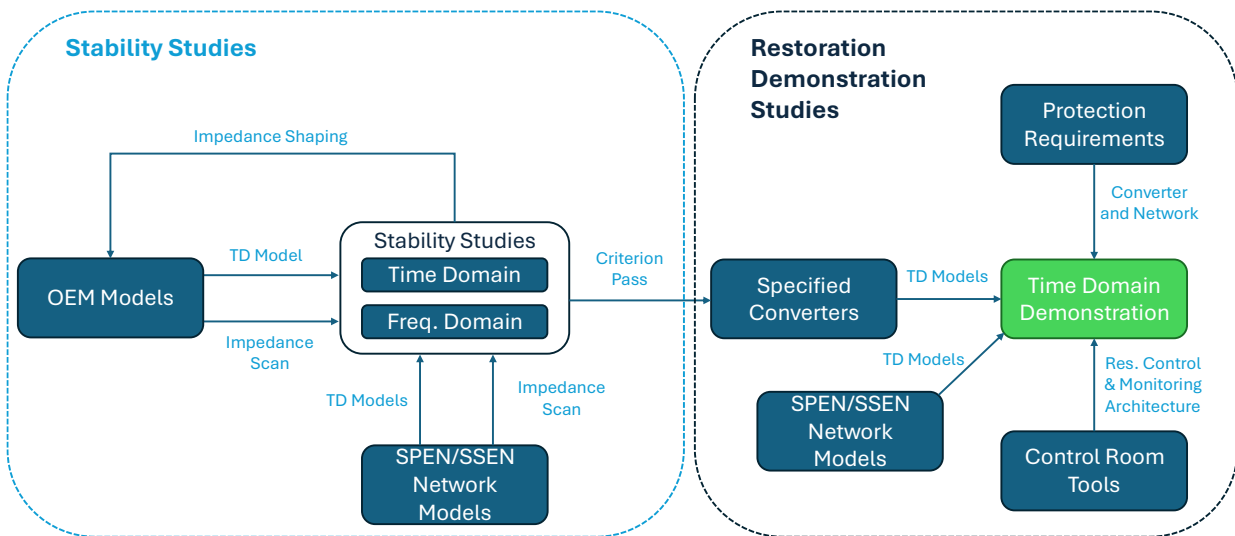


Figure 1 - Indicative Stage 2 Study Framework

4.1.2. Options for Modelling and Simulation

Option 1: Real-Time Stability Studies and Real-Time Demonstration

This is the BLADE project’s preferred option. In this option, OEM models would be provided for simulation in RTDS/RSCAD, at a level of detail consistent with the one of the options in the left-hand column of Table 1. Black box models offer the potential for a level of C&P closest to the real-world systems. However, the stability studies will likely require iterative control tuning based on the stability envelope requirements. It may be more practical in this sense to undertake the stability studies based on white box (OEM-benchmarked) or generic (OEM-informed) RSCAD models, both still relying on OEM input. A decision can then be made whether to proceed to the real-time demonstration with the white box or generic models developed to comply with the envelope specifications. Or alternatively, using the output envelopes to inform a single specification iteration of a black box OEM model (SiL GTSOC solution) for the real-time Restoration demonstration studies.

Option 2: Offline Stability Studies and Real-Time Demonstration

This option would be triggered if the best available EMT models that an OEM can provide is in the offline (PSCAD) environment, at a level of detail consistent with the one of the options in the right-hand column of Table 1. Compiled black box models offer the potential for a level of C&P closest to the real-world systems. However, the stability studies will likely require iterative control tuning based on the stability envelope requirements. It may be more practical in this sense to undertake the stability studies based

on white box (OEM-benchmarked) or generic (OEM-informed) PSCAD models, both still relying on OEM input. If a real-time simulation environment remains preferable for the Restoration demonstration studies, then the PSCAD models used to develop the stability envelopes cannot be carried forward. At this stage, the OEM would therefore need to consider leading or supporting the development of a black box (GTSOC) or white box (OEM-benchmarked/informed) RSCAD model, respectively, which complies with the stability envelopes as an input to the real-time demonstration studies.

Option 3: Offline Stability Studies and Offline Demonstration

This option would be triggered if the best available EMT models that an OEM can provide is an the offline (PSCAD) environment, at a level of detail consistent with the one of the options in the right-hand column of Table 1. Compiled black box models offer the potential for a level of C&P closest to the real-world systems. However, the stability studies will likely require iterative control tuning based on the stability envelope requirements. It may be more practical in this sense to undertake the stability studies based on white box (OEM-benchmarked) or generic (OEM-informed) PSCAD models, both still relying on OEM input. It may be decided that the Restoration demonstration studies can be conducted to a sufficient level of detail and adequately representative in terms of informing control room tools in an offline (PSCAD) environment. Under such circumstances, white box or generic models, or alternative black box (compiled) models, can be specified against the stability envelopes and input into the offline demonstration studies.

4.1.3. Practical Preference for OEM Models

As there are various levels of studies and potential OEM model inputs, this section attempts to summarise the preferred model options as per the Stage 2 studies. Further description of the study methodologies and how the OEM models shall feed into them are described in greater detail through section 4.2 to 1.1.

Stability Studies (Standard OWF Testing for Short Term Priority)

- Black box GFL OWF models (AC and DC-connected)

Stability Studies (Impedance Shaping for Short/Mid/Long Term Priorities)

- White box GFL/GFM/Self-Starting OWF (AC and DC-connected) (OEM-Benchmarked)
- White box GFM BESS models (OEM-Benchmarked)

(Real-Time) Restoration Demonstration Studies

- (GTSOC) black box models (WTGs, HVDC, BESS) that meet impedance envelope criterion
- Restoration control and monitoring control room tool (virtual, SiL, or HiL)

4.1.4. General Overview of Stage 2 Input and Responsibilities

Study Inputs and Responsibilities

Model Inputs – Converter/Power Systems:

- BESS, WTG, HVDC C&P system models (**OEM** as per section 4.1)
- SynCons, E-STATCOMs (optional) (**OEM**)

- OEM model management (NHVDCC)

Model Inputs – Restoration Controller:

- Wide area monitoring system (Restoration control room aid) (**OEM**)
- OEM model management (NHVDCC)

Engineering Inputs:

- Model development (**OEM**)
- Advising white box or generic C&P development (**OEM**)

Additional Inputs:

- Network modelling (SPEN, SSEN, NHVDCC)
- OWF plant description (SSER, Orsted, JNBP/EnBW)

Stability Studies:

- Time domain impedance scanning (NHVDCC)
- Stability criterion definition, mathematical modelling, and envelope specification (Strathclyde, NHVDCC)
 - Define number of scenarios; network conditions and operating points (Strathclyde, NHVDCC)
 - Perform frequency domain stability studies (Strathclyde, NHVDCC)
- Impedance shaping exercise (**OEM** if black box, Strathclyde/NHVDCC if white box or generic with **OEM** support)
- Time-domain stability verification (NHVDCC, Strathclyde)
 - Follow above scenarios; network conditions and operating points (NHVDCC, Strathclyde)
 - Perform time domain stability studies (NHVDCC, Strathclyde)

Time-Domain Restoration Demonstrations:

- Definition of Restoration solutions, pathways, and operational considerations (SPEN and SSEN)
- RSCAD/PSCAD converter model inputs (**OEM**, Strathclyde, NHVDCC)
- RSCAD/PSCAD time-domain modelling, validations, simulation, and analysis (NHVDCC, **OEM**, SPEN, SSEN)
- Protection study conceptualisation and protection logic development (**OEM**, SPEN, SSEN, NHVDCC)
- Definition of control and monitoring parameters within control room tools (Delivery Team)
- OEM or virtual Restoration control room tool within RSCAD (**OEM**, SPEN, SSEN, NHVDCC)

Outputs:

- Robust methodology for ensuring active component stability and interoperability
- C&P requirements, specification, and validation for BESS' and OWFs (AC and DC)
- Demonstration and recommendation for control room tools and operational interfaces
- Demonstration of Restoration in the time-domain (real-time preference)

4.2. GC0156-compliant GFL OWF and GFM BESS – short term priority – must deliver

4.2.1. Key outcomes – what does BLADE need to prove?

1. Prove how a GC0156-compliant GFL OWF (i.e. a “standard future OWF”) can connect to a weak grid formed by an onshore GFM BESS and can provide active and reactive power to restore the system with the BESS.
2. Define need, feasibility and requirements for a GFL WTG “black start” control setting (a “GC0156 plus” option that – unlike GC0156-compliant wind farm – may require a separate paid restoration contract from NESO).
3. System strength and stability: the performance limits of the GFL WTGs to connect to a weak grid and the limits of the GFM BESS to form a sufficiently strong grid. Where these limits are not mutually met, define what the network needs to install (e.g. SynCons or E-STATCOMs or other).
4. Active power: the performance limits of the GFL WTGs and the limits of the GFM BESS, and the implications of this on TO control room decision making.
5. Reactive power: the performance limits of the GFL WTGs and the limits of the GFM BESS, and the implications of this on TO control room decision making.
6. Energy: the performance limits of the GFL WTGs and the limits of the GFM BESS, and the implications of this on TO control room decision making.

4.2.2. Key tasks – how does BLADE prove the above?

Study Methodology – Short term priority

1. For a standard GC0156-compliant OWF, it can be assumed that rigorous tuning has not yet been undertaken to prove the capability of the WTGs to operate in a very weak grid with a strength less than that specified by in NESO in their bilateral connection agreement. The tuning of the WTG (or onshore HVDC converter) GFL controllers can therefore be assumed as fixed at parameters sufficient to operate in a grid with a strength consistent with today’s minimum short circuit levels. The stability studies under this scenario would therefore look to shape the frequency-dependent impedance of the GFM BESS as the Primary Energisation provider, in order to stabilise the interconnected island system. The impedance condition which satisfies system stability, with a sufficient margin, across the necessary range of operating points, would form the basis of its stability envelopes. This study can therefore be considered a test of the GFM BESS plants ability to stabilise a supporting OWF(s) without any real development on the OWF part (i.e. standard WTG or HVDC systems of today). This would then be validated in the time domain, based on the required onshore network composition to facilitate a TO-specified restoration pathway, and consider various exchanges of active and reactive power to confirm the frequency-domain predictions.

(Connection Topology) OEM Model Inputs:

- (AC) GFL WTG models – a black box model is preferred to most accurately reflect the C&P behaviour of existent market-ready and operational GFL turbines, as this study will not attempt to shape the WTG controllers
 - (DC) GFL HVDC system models – a black box model is preferred to most accurately reflect the C&P behaviour of market-ready, operational GFL HVDC systems for offshore wind connections, as this study will not attempt to shape the WTG controllers
 - GFM BESS models – as the burden of iterative tuning is on the GFM BESS, a white box model (preferably OEM benchmarked), would offer the greatest flexibility in assessing how parameter or control algorithm changes impact the stability margins through frequency domain analysis.
2. Taking point 1 a step further, point 2 considers the potential of designing the GFL OWF for enhanced operation in very weak grids, beyond the minimum short circuit levels typical of today (i.e. closer to black start conditions). Should the studies against point 1 find the stability margins for a standard GC0156-compliant OWF too problematic, the impedance shaping exercise can be extended to the OWF itself (WTGs for an AC connection or HVDC system for a DC connection). This would lead to stability envelope specifications for both the OWF and GFM BESS in order to satisfy interconnected system stability with a greater margin. As point 2 is considering impedance shaping on both the GFL OWF and GFM BESS, iterative tuning requirements makes the black box option preferred for the OWF in point 1 less practical in this study.

(Connection Topology) OEM Model Inputs:

- (AC) GFL WTG models – white box (OEM-benchmarked) likely most practical for iterative tuning
 - (DC) GFL HVDC system models – white box (OEM-benchmarked) likely most practical for iterative tuning
 - GFM BESS models – white box (OEM-benchmarked) likely most practical for iterative tuning
3. The stability studies are expected to determine frequency-dependent impedance envelopes for the active devices, which if satisfied, would ensure system stability. However, should the tuning required to deliver this impedance profile be too difficult (such as passivity in frequency ranges not possible), then the incorporation of additional assets may have to be considered to provide additional strength or stability. This may mean additional GFM BESS devices, or other assets such as SynCons and E-STATCOMs.

OEM Model Inputs:

- GFM BESS – reuse or engage with multiple OEMs for several independent white box models
 - E-STATCOM – consider OEM availability of E-STATCOM models
 - SynCons – white box or generic (OEM-informed)
- 4-6. Whilst the stability envelopes shall specify the frequency-domain requirements for the WTG, BESS, and HVDC systems across the expected range of operating points for sufficient stability margins, factors such as a progression toward to the lower end of these margins, power balancing challenges, converter current limits, or BESS energy constraints should be monitored

and managed. A communication system which facilitates control room operators with visibility of such metrics against variables during the Restoration process, such as wind output and demand changes, provides operators with the best possible opportunity of securing the system.

OEM Model Inputs:

- For real-time Demonstration studies, a black box (GTSOC) model that complies with the stability study envelopes is preferred
- Measurement and control interfaces between black box outer controls and Restoration controller (can assume if white box, assumed such parameters will already be accessible)

4.2.3. OEM input and roles – what are you able to provide and under what conditions?

Please complete the following table.

Input requested	Intended use	Can this be provided?	Under what conditions?	Estimated Engineering Time	Cost	Timeline
Software models of core plant, conversion systems, and its control & protection logic. . It can be assumed that the core plant extends up to and including the terminal control point.	Delivered to partner(s) The National HVDC Centre and Strathclyde University to conduct Stage 2 tests (Figure 1).	GFL WTG - Yes / no GFM BESS – Yes / no GFL HVDC – Yes / no E-STATCOM – Yes / no SynCon – Yes / no	Please describe confidentiality and IP conditions (high level) Please be aware that there may be necessarily other OEMs involved in the demonstration (e.g. WTG, BESS, STATCOM, HVDC). We have the capability and experience to silo the IP securely. However, please flag any specific requests in this regard.	Please estimate the engineering time you can provide against the development or support of each model option (If none please state so) A range +/- 25% is fine at this stage	A range +/- 25% is fine at this stage	A range +/- 25% is fine at this stage
RSCAD black box model (GTSOC)	Stability and Restoration demonstration.	GFL WTG - Yes / no GFM BESS – Yes / no GFL HVDC – Yes / no E-STATCOM – Yes / no SynCon – Yes / no				
RSCAD white box model (OEM-benchmarked)	Impedance shaping (stability studies).	GFL WTG - Yes / no GFM BESS – Yes / no GFL HVDC – Yes / no E-STATCOM – Yes / no SynCon – Yes / no				
RSCAD generic model development support	Impedance shaping (stability studies).	GFL WTG - Yes / no GFM BESS – Yes / no				

Input requested	Intended use	Can this be provided?	Under what conditions?	Estimated Engineering Time	Cost	Timeline
		GFL HVDC – Yes / no E-STATCOM – Yes / no SynCon – Yes / no				
PSCAD black box model	Stability and Restoration demonstration.	GFL WTG - Yes / no GFM BESS – Yes / no GFL HVDC – Yes / no E-STATCOM – Yes / no SynCon – Yes / no				
PSCAD white box model (OEM-benchmarked)	Impedance shaping (stability studies).	GFL WTG - Yes / no GFM BESS – Yes / no GFL HVDC – Yes / no E-STATCOM – Yes / no SynCon – Yes / no				
PSCAD generic model development support	Impedance shaping (stability studies).	GFL WTG - Yes / no GFM BESS – Yes / no GFL HVDC – Yes / no E-STATCOM – Yes / no SynCon – Yes / no				
Other	Please specify if you would recommend alternatives					

4.3. GFM OWF and GFM BESS – mid term priority – should deliver

4.3.1. Key outcomes – what does BLADE need to prove?

1. Prove how a GFM OWF can connect to a weak grid formed by an onshore GFM BESS and can provide active and reactive power to restore the system with the BESS. In particular see how this reduces the requirements on the GFM BESS and the network (which may be key to unlocking the business case).
2. System strength and stability: the performance limits of the GFM WTGs to connect to a weak grid and the limits of the GFM BESS to form a sufficiently strong grid. Where these limits are not mutually met, define what the network needs to install (e.g. SynCons or E-STATCOMs or other).
3. Active power: the performance limits of the GFM WTGs and the limits of the GFM BESS, and the implications of this on TO control room decision making
4. Reactive power: the performance limits of the GFM WTGs and the limits of the GFM BESS, and the implications of this on TO control room decision making.
5. Energy: the performance limits of the GFM WTGs and the limits of the GFM BESS, and the implications of this on TO control room decision making.

4.3.2. Key tasks – how does BLADE prove the above?

The OEM input for the mid term priorities is expected to remain broadly the same as for the short-term priorities in section 4.2.

Study Methodology – Mid term priority

- 1-2. Study methodology will follow a very similar approach as to the short-term GC0156-compliant scenario. The difference in the assessment should explore the impact of the GFM OWF (WTGs or onshore HVDC converter) impedance profile on the iterative impedance shaping requirements for both the GFM BESS and GFM OWF to achieve a sufficiently stable condition. In other words, this study shall determine if and how the frequency-dependent behaviour of the GFM OWF makes it easier for both the OWF and BESS to fit within the specified envelopes. Furthermore, it shall explore the potential for GFM turbines to support the onshore system through the delivery of stability services such as voltage support and inertia.

(Connection Topology) OEM Model Inputs:

- (AC) GFM WTG models – white box (OEM-benchmarked) likely most practical for iterative tuning
- (DC) GFM HVDC system models – white box (OEM-benchmarked) likely most practical for iterative tuning. For DC-connected topologies, only the onshore HVDC converter is required to possess GFM capability – the turbines may be either GFL or GFM.
- GFM BESS models – white box (OEM-benchmarked) likely most practical for iterative tuning

3-5. These points will follow the same methodology outlined for the short term priorities.

OEM Model Inputs:

- For real-time Demonstration studies, a black box (GTSOC) model that complies with the stability study envelopes is preferred
- Measurement and control interfaces between black box outer controls and Restoration controller (can assume if white box, assumed such parameters will already be accessible)

4.3.3. OEM input and roles – what are you able to provide and under what conditions?

Please complete the following table.

Input requested	Intended use	Can this be provided?	Under what conditions?	Estimated Engineering Time	Cost	Timeline
Software models of core plant, conversion systems, and its control & protection logic. It can be assumed that the core plant extends up to and including the terminal control point.	Delivered to partner(s) The National HVDC Centre and Strathclyde University to conduct Stage 2 tests (Figure 1).	GFM WTG - Yes / no GFM onshore HVDC – Yes / no (for other components please answer in section 4.2.3)	Please describe confidentiality and IP conditions (high level) Please be aware that there may be necessarily other OEMs involved in the demonstration (e.g. WTG, BESS, STATCOM, HVDC). We have the capability and experience to silo the IP securely. However, please flag any specific requests in this regard.	Please estimate the engineering time you can provide against the development or support of each model option (if none please state so) A range +/- 25% is fine at this stage	A range +/- 25% is fine at this stage	A range +/- 25% is fine at this stage
RSCAD black box model (GTSOC)	Stability and Restoration demonstration.	GFM WTG - Yes / no GFM onshore HVDC – Yes / no (for other components please answer in section 4.2.3)				
RSCAD white box model (OEM-benchmarked)	Impedance shaping (stability studies).	GFM WTG - Yes / no GFM onshore HVDC – Yes / no (for other components please answer in section 4.2.3)				
RSCAD generic model development support	Impedance shaping (stability studies).	GFM WTG - Yes / no GFM onshore HVDC – Yes / no				

Input requested	Intended use	Can this be provided?	Under what conditions?	Estimated Engineering Time	Cost	Timeline
		<i>(for other components please answer in section 4.2.3)</i>				
PSCAD black box model	Stability and Restoration demonstration.	GFM WTG - Yes / no GFM onshore HVDC - Yes / no <i>(for other components please answer in section 4.2.3)</i>				
PSCAD white box model (OEM-benchmarked)	Impedance shaping (stability studies).	GFM WTG - Yes / no GFM onshore HVDC - Yes / no <i>(for other components please answer in section 4.2.3)</i>				
PSCAD generic model development support	Impedance shaping (stability studies).	GFM WTG - Yes / no GFM onshore HVDC - Yes / no <i>(for other components please answer in section 4.2.3)</i>				
Other	Please specify if you would recommend alternatives					

4.4. Self-Starting OWF – long term priority – may deliver

4.4.1. Key outcomes – what does BLADE need to prove?

1. Prove how a Self-Starting OWF can restart itself and the onshore system, with or without the support of a GFM BESS.
2. System strength and stability: the performance limits of the Self-Starting WTGs to energise the onshore system. Where these limits are not mutually met, define what the network needs to install (e.g. BESS, SynCons or E-STATCOMs or other).
3. Active power: the performance limits of the Self-Starting WTGs, and the implications of this on TO control room decision making.
4. Reactive power: the performance limits of the Self-Starting WTGs, and the implications of this on TO control room decision making.
5. Energy: the performance limits of the Self-Starting WTGs, and the implications of this on TO control room decision making.

4.4.2. Key tasks – how does BLADE prove the above?

The long term priority studies should consider the possibility of initial Restoration coming from self-starting WTGs as opposed to a GFM BESS. This is expected to require development in terms of modelling to best represent the requirements, interfaces, and components necessary beyond typical GFM turbines to deliver self-start capability.

Study Methodology – Long term priority

- 1-2. Study methodology will follow a similar approach as to the short and mid term GC0156-compliant scenario. The difference in the assessment should explore the offshore requirements, auxiliaries, and interfaces to deliver a self-start. As the studies shall initially seek to explore the capability of the OWF to self-start its own plant and provide onshore Restoration independent of a GFM BESS, the iterative impedance shaping process will be performed against the passive network and any other Primary Support assets incorporated along the way.

(Connection Topology) OEM Model Inputs:

- (AC or DC) Self-Starting WTG models – white box (OEM-benchmarked) likely most practical for iterative tuning.
- (DC) HVDC system with onshore GFM and offshore DC voltage control – white box (OEM-benchmarked) likely most practical for iterative tuning. This recommendation is indicative based on primary control objectives onshore and offshore to deliver the self-start, though HVDC manufacturers may propose a different philosophy.
- GFM BESS models – white box (OEM-benchmarked) likely most practical for iterative tuning. **Should only be used to support stability or Restoration should the self-starting OWF performance be found insufficient for independent Restoration demonstration.**

3-5. These points will follow the same methodology outlined for the short and mid term priorities.

OEM Model Inputs:

- For real-time Demonstration studies, a black box (GTSOC) model that complies with the stability study envelopes is preferred
- Measurement and control interfaces between black box outer controls and Restoration controller (can assume if white box, assumed such parameters will already be accessible)

4.4.3. OEM input and roles – what are you able to provide and under what conditions?

Please complete the following table.

Input requested	Intended use	Can this be provided?	Under what conditions?	Estimated Engineering Time	Cost	Timeline
Software models of core plant, conversion systems, and its control & protection logic. It can be assumed that the core plant extends up to and including the terminal control point.	Delivered to partner(s) The National HVDC Centre and Strathclyde University to conduct Stage 2 tests (Figure 1).	Self-starting WTG - Yes / no GFM onshore HVDC with offshore DC voltage control (for offshore to onshore restoration pathway) – Yes / no (for other components please answer in section 4.2.3)	Please describe confidentiality and IP conditions (high level) Please be aware that there may be necessarily other OEMs involved in the demonstration (e.g. WTG, BESS, STATCOM, HVDC). We have the capability and experience to silo the IP securely. However, please flag any specific requests in this regard.	Please estimate the engineering time you can provide against the development or support of each model option (If none please state so) A range +/- 25% is fine at this stage	A range +/- 25% is fine at this stage	A range +/- 25% is fine at this stage
RSCAD black box model (GTSOC)	Stability and Restoration demonstration.	Self-starting WTG - Yes / no GFM onshore HVDC with offshore DC voltage control (for offshore to onshore restoration pathway) – Yes / no (for other components please answer in section 4.2.3)				
RSCAD white box model (OEM-benchmarked)	Impedance shaping (stability studies).	Self-starting WTG - Yes / no GFM onshore HVDC with offshore DC voltage control (for offshore to onshore restoration pathway) – Yes / no				

Input requested	Intended use	Can this be provided?	Under what conditions?	Estimated Engineering Time	Cost	Timeline
		<i>(for other components please answer in section 4.2.3)</i>				
RSCAD generic model development support	Impedance shaping (stability studies).	Self-starting WTG - Yes / no GFM onshore HVDC with offshore DC voltage control (for offshore to onshore restoration pathway) – Yes / no <i>(for other components please answer in section 4.2.3)</i>				
PSCAD black box model	Stability and Restoration demonstration.	Self-starting WTG - Yes / no GFM onshore HVDC with offshore DC voltage control (for offshore to onshore restoration pathway) – Yes / no <i>(for other components please answer in section 4.2.3)</i>				
PSCAD white box model (OEM-benchmarked)	Impedance shaping (stability studies).	Self-starting WTG - Yes / no GFM onshore HVDC with offshore DC voltage control (for offshore to onshore restoration pathway) – Yes / no <i>(for other components please answer in section 4.2.3)</i>				
PSCAD generic model development support	Impedance shaping (stability studies).	Self-starting WTG - Yes / no				

Input requested	Intended use	Can this be provided?	Under what conditions?	Estimated Engineering Time	Cost	Timeline
		<p><i>GFM onshore HVDC with offshore DC voltage control (for offshore to onshore restoration pathway) – Yes / no</i></p> <p><i>(for other components please answer in section 4.2.3)</i></p>				
Other	Please specify if you would recommend alternatives					

4.5. TO control room decision making tool

4.5.1. Key outcomes – what does BLADE need to prove?

1. TO control room is capable of conducting an LJRP using methodologies of sections 4.2 to 4.4.
2. The additional capability required by TO control rooms vs today's capability.
3. A TO control room decision making tool is required and is feasible.
4. Development of high-level specifications by TOs in order to engage a partner that can develop the tool.
5. The development of such a TO control room decision making tool.

4.5.2. Key tasks – how does BLADE prove the above?

As indicated in section 3.1.2 and Figure 1, a control room tool to provide operators with improved visibility and management of the variability involved in BLADE LJRPs has been identified as a key enabler of Restoration execution. We are seeking OEM input on the ability to deliver or support the development of a wide area Restoration monitoring and control system, in RSCAD or PSCAD, to aid control room operators in enacting the LJRPs.

1-5.

- i. TOs to develop BLADE LJRPs for their respective areas.
- ii. OEM to develop a tool (virtual, or hardware with compatibility in RTDS/RSCAD) that can provide the additional information required by the TO control engineers to help them respond appropriately during Restoration. The TO control room should have access to wind forecast information, generation availability, demand forecasts, generation and storage predictions, visibility of thermal generation state (situational awareness), communication protocols with generators and possibly system strength measurements.
- iii. The tool should only work as a guide to help the Control Engineer make relevant decisions in a Restoration. It is not required to control anything on the network.

4.5.3. OEM input and roles – what are you able to provide and under what conditions?

Please complete the following table.

Input requested	Intended use	Can this be provided?	Under what conditions?	Estimated Engineering Time	Cost	Timeline
Control Software of wide area monitoring and control system for control room to enact Restoration and BLADE LJRPs.	Delivered to partner(s) The National HVDC Centre to conduct Restoration demonstration tests, with SPEN and SSEN emulating decision making.	Yes / no	<p>Please describe confidentiality and IP conditions (high level)</p> <p>Please be aware that there may be necessarily other OEMs involved in the demonstration (e.g. WTG, BESS, STATCOM, HVDC). We have the capability and experience to silo the IP securely. However, please flag any specific requests in this regard.</p>	<p>Please estimate the engineering time you can provide against the development or support of each model option (If none please state so)</p> <p>A range +/- 25% is fine at this stage</p>	A range +/- 25% is fine at this stage	A range +/- 25% is fine at this stage
Controller hardware for hardware-in-loop studies within RTDS/RSCAD	Restoration demonstration.	Yes / no				
RSCAD GTSOC black box model controller	Restoration demonstration.	Yes / no				
RSCAD white box model (OEM-benchmarked)	Restoration demonstration.	Yes / no				
RSCAD generic controller development support	Restoration demonstration.	Yes / no				
PSCAD black box model	Restoration demonstration.	Yes / no				
PSCAD white box model (OEM-benchmarked)	Restoration demonstration.	Yes / no				

Input requested	Intended use	Can this be provided?	Under what conditions?	Estimated Engineering Time	Cost	Timeline
PSCAD generic controller development support	Restoration demonstration.	Yes / no				
Other	Please specify if you would recommend alternatives					

Appendix 1: Definitions

No.	Key Terms	Definition
1	Grid following	Grid following converter control can actively regulate its output active and reactive power by synchronising to an established voltage at the connection point
2	Grid following WTG	A wind turbine which uses a grid following converter control defined in 1.
3	Grid forming	Grid forming converter control can actively balance its output active and reactive power controlling the voltage magnitude and frequency without a dedicated synchronising loop
4	Grid forming WTG	A wind turbine which uses a grid forming converter control defined in 3.
5	Primary Energisation	Energy resources which can self-start to supply power and energise part of the system without any external power supply. It is the voltage source that forms the grid, providing stability and control. The Primary Energisation provider may or may not have finite energy reserves. A Primary Energisation source may require to be complimented by a Primary Support source in order to offer a practically useful Restoration service. The Primary Energisation provider would receive a Restoration contract. Primary Support role similar to NESO's "Anchor"; however, the capability and requirements may differ compared to NESO's definitions, so we do not want to use the same terminology to avoid conflict.
6	Primary Support	Energy resources which are required to compliment a Primary Energisation source in order to – in combination – provide a practically useful Restoration service. The Primary Support may for example provide active and/or reactive power once a (weak) skeleton network is established by the Primary Energisation provider. In some situations, the Primary Support provider can be the same asset and legal entity as the Primary Energisation provider. In some situations, it may be different assets and / or different legal entity. The Primary Support provider would receive a Restoration contract. Primary Support role similar to NESO's "top-up"; however, the capability and requirements may differ compared to NESO's definitions, so we do not want to use the same terminology to avoid conflict.
7	Restoration	Formerly known as Black Start, it is defined as the process used to restore power in the event of a total or partial shutdown of the national electricity transmission system
8	Self-starting Wind Turbine Generators	A self-starting WTG is a wind turbine with internal energy source and capable of starting to generate electricity without the need of an energised point of connection.
9	Standard Generation Capability	A GC156 compliant offshore wind farm. Please note that this is not a top-up capability, as used in the Alpha Phase reports. Please note that this is not a Primary Support provider and would not receive a Restoration contract. It is not controlled in the same way as a Primary Support offshore wind farm during the Restoration and is not tuned to connect to the initially energised very weak grid.