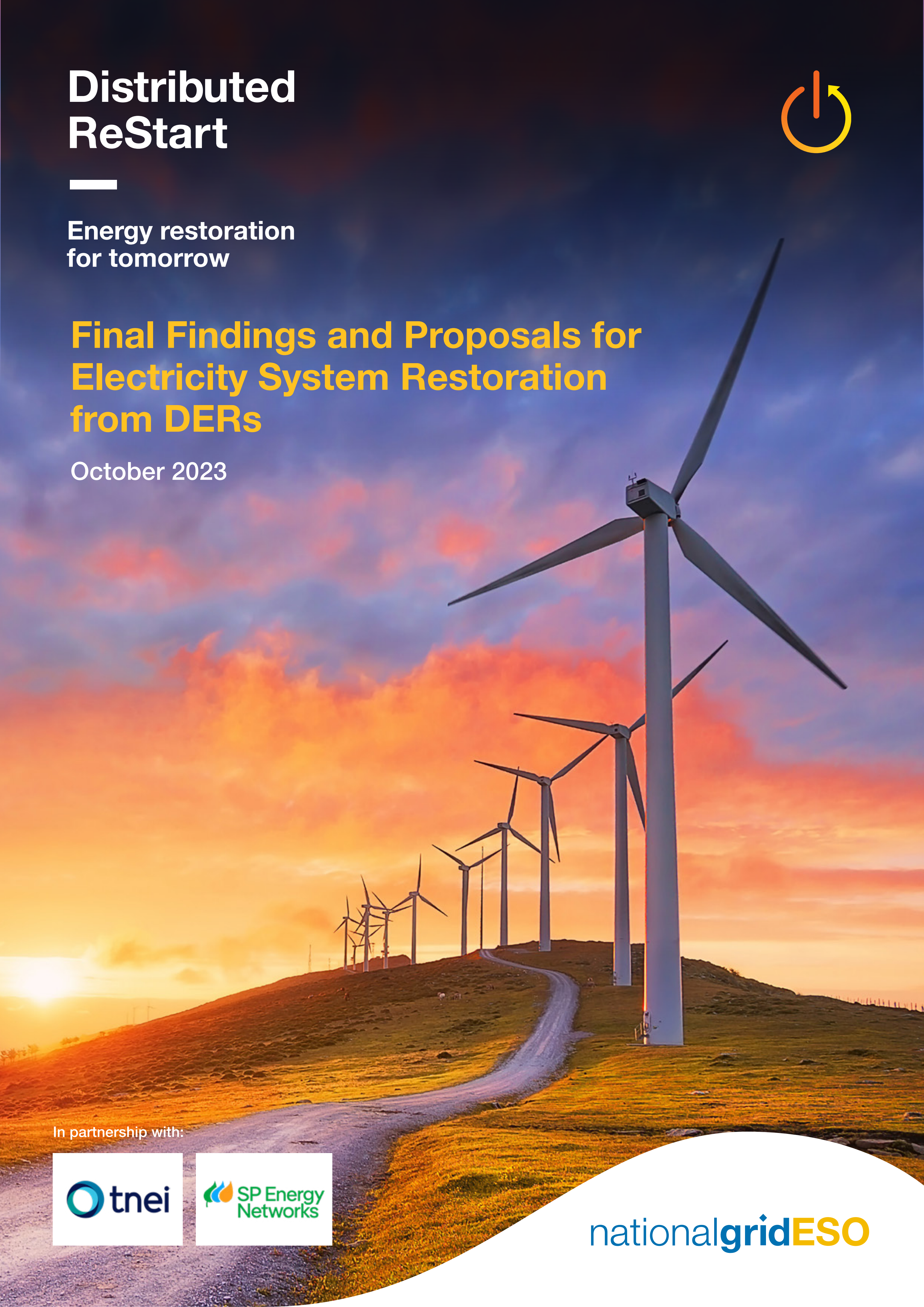

Distributed ReStart

Energy restoration for tomorrow

Final Findings and Proposals for Electricity System Restoration from DERs

October 2023

In partnership with:

tnei

SP Energy Networks

nationalgridESO

Table of Contents

List of Figures and Tables

Figures

Tables

Executive Summary

Black Start from Distributed Energy Resources (DER)

An independent review of the *Final Findings and Proposals* report has been undertaken by three members of the project's independent advisory panel, Simon Harrison, Nick Jenkins and John Scott.

This review is shown in Appendix 2 and supports and commends the work of the project, highlights the extensive engineering challenges explored and overcome, and makes a number of recommendations.

The key messages are: to secure and embed the findings and know-how of the project within the industry; to support the further work needed to transition Distributed ReStart to business-as-usual across a wide variety of use cases; to ensure policymakers and regulators are fully aware of the project's findings and their implications for decarbonisation; and to recognise the project's ground breaking innovation and international significance.

The Distributed ReStart project is a partnership between National Grid Electricity System Operator (ESO), SP Energy Networks (SPEN) and TNEI (a specialist energy consultancy). The project was awarded £10.3 million of Network Innovation Competition (NIC) funding for delivery 2019-2022.

The purpose of the project was to explore how distributed energy resources (DERs) can be used to restore power in the highly unlikely event of a total or partial shutdown of the National Electricity Transmission System (NETS). This report presents and summarises our final findings and proposals. We highlight the key learnings delivered by the project and point to the resources that provide a basis for the industry to implement these learnings.

The ESO is responsible for ensuring there is adequate provision for electricity system restoration (ESR), also known as black start. This was reinforced by the approval in 2021 of a new Electricity System Restoration Standard (ESRS) that puts new obligations on the ESO to ensure industry can deliver effective and rapid restoration.

The current restoration strategy uses large power stations and interconnectors to energise sections of the transmission system using local demand to establish a stable power island, as illustrated in the figure below. Other generators then join the growing system to progressively re-energise the whole network and restore demand across the country until full restoration is completed.

What Black Start Looked Like Before Distributed ReStart

As we transition to cleaner and more decentralised energy, new options must be developed. The enormous growth in DERs presents a big opportunity but for a wide range of reasons they have been unable to participate in ESR. Greater diversity in black start provision will improve resilience and increase competition, leading to reductions in both cost and carbon emissions. Through a combination of detailed off-line analysis, stakeholder engagement and industry consultation, desktop exercises, and real-life trials of the re-energisation process, Distributed ReStart has tackled the significant technical, organisational and commercial challenges in delivering black start from DERs.

The Organisational, Systems and Telecoms (OST) workstream considered the DER-based restoration process in terms of the different roles, responsibilities and relationships needed across the industry to implement at scale. It has developed requirements for information systems and telecommunications, recognising the need for resilience and the challenges of coordinating restoration across many parties. Proposed processes and working methods have been proposed, refined, and consulted upon with various stakeholders.

In this report, we present the proposed organisational structure and highlight the changes required across DERs, distribution network operators (DNOs), transmission owners (TOs) and the ESO. In 2021, despite the unforeseen challenges of Covid, the project ran a series of desktop exercises that proved hugely valuable in testing our proposals and allowing a wide cross-section of the industry to participate and share in project learnings. We also summarise the work done on systems and communications with links to further information on the significant work done on control system design, cyber security and specifications for resilient telecommunications.

The Power Engineering and Trials (PET) workstream was concerned with the technical requirements to establish power islands on the distribution network, following a total or partial shutdown of Great Britain's electricity network. The project has defined the concept of a distribution restoration zone (DRZ), which may incorporate multiple DERs to provide services such as restoring customer demand, energising the network to enhance substation resilience, and "bottom-up" energisation of the transmission network. As summarised in this report, we have defined the terms "anchor DER" and "top-up services" and described the capabilities required of DERs as well as identifying what DNOs may need to do to facilitate a DRZ.

The technical viability of restoration from DERs was established through extensive power system analysis of case study networks, industry engagement with DER developers and specialist consultants, development and testing of a Distribution Restoration Zone Controller (DRZC), and the planning and successful execution of several live trials. This report highlights the key learnings relating to DERs, networks and automation, and provides a point of entry to the more detailed information in our other project deliverables.

The Procurement and Compliance (P&C) workstream sought to find the best way to deliver the distribution restoration concept for customers. It explored the options and trade-offs between different competitive procurement solutions, applying a strategic process to develop fit-for-purpose commercial solutions that are open and transparent, stakeholder endorsed and designed end-to-end with customer interests in mind. Just as OST had desktop exercises and PET had live trials, the P&C workstream ran a mock tender process to test our proposals and provide an opportunity for detailed and in-depth stakeholder engagement.

This report summarises our final recommendations and service designs, including the high-level process that requires engagement with DNOs and DERs interested in providing new restoration services. We emphasise the importance of stakeholder engagement, noting the wide range of activities undertaken to ensure that our proposals offer the best solution.

Our Knowledge and Dissemination workstream ensured stakeholders were considered and communicated with through all project activities and deliverables. In this report we list and provide links to all project reports that provide full details of our learnings and recommendations.

Over the 3+ years of project delivery, there have been various industry activities and developments influencing the wider context:

- The new Electricity System Restoration Standard gives new impetus to the development of distribution restoration.
- Many aspects of distribution restoration align with other developments in the distribution system operator (DSO) transition.
- As well as project activities on live trials, there have been other successful demonstrations of new black start capability, such as the use of grid-forming wind turbines at Dersalloch.
- Other projects, like Resilience as a Service (RaaS) and Synergy, will implement new control systems that can support restoration from DERs or related functionality.
- Grid Code Modification GC0137 has established requirements for grid-forming capability, aligned with the project goal of harnessing a wider range of resources.

The project is now closed and the third and final live trial at Redhouse has been successfully completed, which focused on testing a grid-forming battery and a prototype DRZC. Distribution restoration is already transitioning to business as usual (BAU) with industry discussions on the implementation of the new ESR Standard and code modifications, like GC0148 and GC0156, to recognise the DRZ concept, terminology, roles and responsibilities having commenced a year or two before the project completed.

The ESO will continue to procure ESR services as economically and efficiently as possible. Creating a collaborative solution between the ESO and DNOs to allow DERs to participate in the ESR market is expected to bring significant benefits to consumers through increased competition, lower costs, and potentially shorter restoration times. As per the original NIC project direction from Ofgem, based on the development and demonstration of new approaches in Distributed ReStart, the ESO has included the option of services from DERs in the ESR tenders run in 2022, which aim for service commencement around 2025.

1. Organisational, Systems and Telecommunications

1.1 Introduction

This chapter consolidates the learnings from across the project into clear but non-restricting recommendations for the organisations involved. These proposals can be effectively integrated into business procedures.

Our final Organisational, Systems and Telecommunications (OST) report *Operating a Distributed Restoration Zone* was published in September 2021. It provides an analysis of the likely impacts of integration with existing black start processes, any impacts or synergies observed with the wider transition towards DER participation in markets and consideration of the ongoing development of distribution system operator (DSO) capabilities.

This report is intended as a summary of the requirements for implementation of the process for distribution restoration across the different participating organisations. These requirements cut across organisational impact assessment; processes, procedures, and training; systems, tools and data requirements, and external factors.

In Section 1.2, we give an overview of the various stages that the OST workstream went through in arriving at the final recommendations for the optimum organisational design (Central Model). We discuss the viability stage that happened early in the project and how this led to Design stages I and II, which are fully documented in our previous reports. Finally, we summarise how we tested our organisational design with desk-top exercises, that were conducted with a wide range of industry participants (including all six distribution network operators (DNOs) in Great Britain.

In Section 1.3, we illustrate this new organisational design and show how it links to and is fully supported by the proposed voice and data communications links, showing the key differences between the existing and proposed communications structure. Table 1 highlights all key project deliverables around the organisational impacts, along with links to the relevant OST reports.

In Section 1.4, Systems and Communications, we zoom in on how the automation made possible by the implementation of the Distribution Restoration Zone Controller (DRZC) becomes an essential component of the new organisational design model. It then goes on to introduce our functional designs for a cyber-secure telecommunications network that supports the end-end restoration process.

Table 2 provides onward links to the four original equipment manufacturers (OEM) suppliers who took part in our tender in autumn 2020, where readers can find detailed technical specifications that may be directly applicable to their individual circumstances.

Table 3 considers OST outputs and direct links to the relevant report sections across the DRZC, cyber security and telecommunications considerations.

Finally, Table 4 provides comprehensive links to a description of the changes required in each organisation to deliver a distribution level restoration. It is highly recommended that organisations such as TOs, DNOs and DERs review these links to familiarise themselves with the impacts to their organisations that will come with the implementation of distributed restoration.

1.2 Organisations in Restoration

In the initial stages of the project, the capabilities of existing participants in the black start restoration procedure in Great Britain were baselined through a consultation with all the network operators and owners, with the objective of creating an organisational structure that could deliver a DER based restoration process. This resulted in the identification of key issues that have been mitigated through the final design proposal.

To identify options which enable the efficient use of DERs in restoration, four organisational models were initially developed and consulted on. We considered the most appropriate businesses for leadership and the degree of automation which should be introduced, including a detailed assessment of the key risks and issues identified across each of these models. The [Organisational, systems and telecommunications viability report](#) was produced in November 2019 which detailed the considerations, risks and inputs that have been incorporated into the final proposal. The viability report also reviewed the existing telecommunications networks used in restoration and the options for a distribution level implementation.

Following on from this scoping and capability baselining, an initial process design and organisational structure was proposed for further scrutiny and review. This report, [Organisational, Systems and Telecommunications Design Stage I](#) was further built on through the publication of a telecommunications specification and cyber security assessment in a second design stage report, [Organisational Systems and Telecommunications Design Stage II](#).

These processes were further developed and tested against an end-to-end case study. The case study brought control engineers into the review process through participation in desktop exercises which emulated the operational requirements and mimicked the visibility of each organisation. The cumulation of this testing was published in our third report, [Operating a Distribution Restoration Zone](#). The report details final organisational structures and a process design to be incorporated into existing restoration processes by the businesses' responsible. Since this publication, OST's workstream efforts have been directed at supporting the ongoing change management process as the procurement for distribution restoration starts.

This *Final Findings and Proposals* report details key elements of these organisational reports to support network operators and distribution connected generation in understanding the organisational and process requirements to participate in a distribution led restoration process. This results in the following change requirements outlined in Section 1.3.

It is interesting to note that the new requirement on the DNO to manage frequency during the anchor DER stabilisation and subsequent power island growth stages represents a "letting go" of existing ESO/TO responsibilities, and this was widely discussed and commented on during the desktop exercises.

1.3 Organisational Structure

The final organisational design depicted in Figure 1 aligns with wider industry efforts around coordinating ESO and DNO procurement and control as the Distribution System Operator (DSO) model evolves with specific focus on the outcomes of the industry wide ENA Open Networks project. It represents a significant expansion of the capabilities of DNOs within restoration, building on and aligning with existing responsibilities held under conventional restoration approaches.

The proposed model leads to continued ESO responsibility for national restoration leadership, including instructing the start of distribution level restoration plans. However, it places new requirements on the DNOs which become responsible for local network energisation and management of frequency and energy resources within a restoration zone.

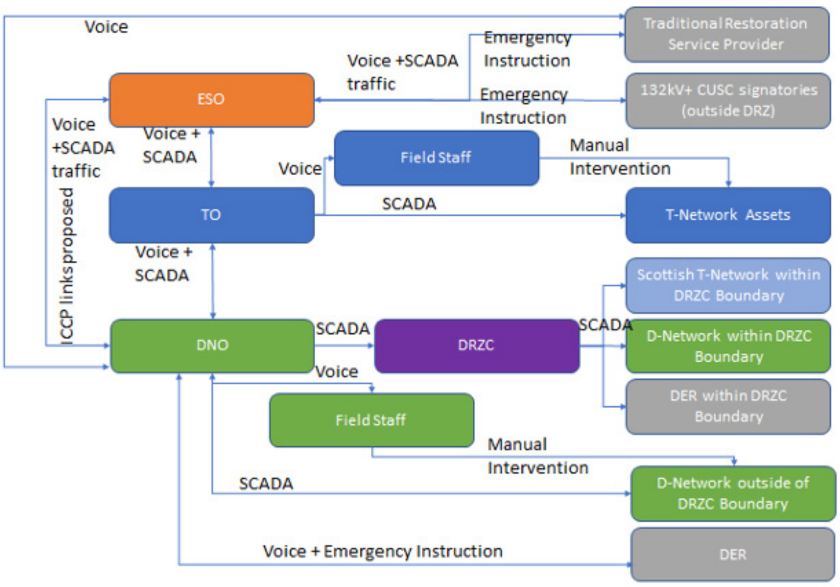

Figure 1: Communications interface including distribution level restoration

An in-depth review of the organisational and process elements of this project can be found in the report *Operating a Distribution Restoration Zone*, which details the end-to-end process for delivering a restoration with key actions and requirements for each organisation.

Table 1 below, highlights all key deliverables around the organisational impacts, along with links to the relevant OST reports.

Table 1: OST key deliverables – reports

Key Deliverable	Report
Organisational structure analysis	*Organisational, Systems and Telecommunications Design Stage I: Pages 59–60*
DNO and ESO headcount analysis with Distribution Restoration Zone Controller	*Organisational, Systems and Telecommunications Design Stage I: Pages 61–65*
Capabilities of a restoration zone	*Operating a Distribution Restoration Zone: Pages 15–18*
Desktop exercise structure and learnings	*Operating a Distribution Restoration Zone: Pages 22–28*
Control engineer interaction with a DRZC	*Operating a Distribution Restoration Zone: Page 29*
End-to-end procedure design including system, headcount, indicative duration, and headcount requirements	*Operating a Distribution Restoration Zone: Pages 31–34*
Organisational change impact assessment and requirements	*Operating a Distribution Restoration Zone: Pages 35–64*

To test the proposed organisational model and the responsibilities described, an end-to-end restoration process was developed for active testing through desktop exercises.

In this process, the DNO grew the Chapelcross distribution restoration zone (DRZ) to the point of transmission connection, following a Distribution Restoration Zone Plan. The energisation of the transmission network was then simulated including the command-and-control interfaces with the ESO, TOs and DERs involved in the process.

This exercise assumed use of a distribution restoration zone control system (DRZC) to enable outputs to be represented as steady state figures presented on a control interface similar to each operator's real view.

The outcome of these exercises was the identification of several improvement areas now incorporated into the process design but no major blockers across organisations. This represents the first restoration exercise in Great Britain to involve all responsible entities on a single platform. This structure is recommended for future cross operator training which becomes more critical given the enhanced role proposed for DNOs within this procedure.

1.4 Systems and Communications

Use of automation through the Distribution Restoration Zone Controller (DRZC) is a key component of the organisational design under most circumstances due to the potential size and number of resources likely to be included within a zone. This also leads to additional benefits including:

- an enhanced ability to protect the distribution level power island's stability
- the ability to reduce barriers to entry for smaller DERs
- enhanced timescales for restoration.

Detailed functional specifications for a DRZC have been developed and a solution has been progressed to hardware-in-the-loop testing. This is detailed further in Section 2.6 of this report. The functional design specification for a restoration zone control system is detailed in the report, *Assessment of Power Engineering – Aspects of Black Start from DER Part 2*.

Integral to the restoration process is a power resilient, cyber secure operational telephony network. A specification for this system has been developed using the requirements from the organisational design, and the requirements from the DRZC design. The technical requirements to support the telecommunications networks include interfaces, protocols, bandwidth, latency, environmental concerns, and power requirements. The technology type and network configuration also play a crucial role in determining whether the technical requirements are met and options for this are included in the detailed telecommunications design requirements. The interface diagram in Figure 1 shows the combined organisational structure and telecommunications specification.

The project approach to the DRZC was to commission several independent designs from original equipment manufacturers (OEMs), who were selected through a competitive process. These designs were reviewed to derive a generic functional specification that gives the industry full flexibility on how the DRZC functionality is delivered in future. In addition to the generic functional specification, the proposed initial designs from different OEMs can be found in Table 2.

Table 2: Initial DRZC designs from original equipment manufacturers (OEMs)

OEM	Report
GE Digital	*DRZC Design and Testing Specification*
SEL Engineering Services	*Distributed Restart Zone Controller FEED*
Smarter Grid Solutions	*DRZC Functional Design and Testing Specification*
ZIV	*A functional design and testing specification report for the DRZ controller*

In addition to these system design requirements, the end-to-end telecommunications specification is discussed in the *Organisational Systems and Telecommunications Design Stage II* report.

Table 3: Organisational, Systems and Telecommunications (OST) outputs and report links

Key Deliverable	Report
DRZC System Requirements	*Assessment of Power Engineering – Aspects of Black Start from DER Part 2: pages 7 to 21*
DRZC Functional Specification	*Assessment of Power Engineering – Aspects of Black Start from DER Part 2: pages 21–58*
Cyber Security Recommendations	*Organisational Systems and Telecommunications Design Stage 2: page 10*
Cyber Security Risk Assessment and Mitigation Strategy	*Organisational Systems and Telecommunications Design Stage 2: page 14*
Telecommunications technical functional requirements	*Organisational Systems and Telecommunications Design Stage II: pages 19–20*
Telecommunications Configuration, Environmental and other functional specification	*Organisational Systems and Telecommunications Design Stage II: pages 20–22*
Telecommunications resilience functional specification	*Organisational Systems and Telecommunications Design Stage II: page 22*
Telecommunications functional specification: Bandwidth	*Organisational Systems and Telecommunications Design Stage II: pages 23–24*
Telecommunications functional specification: Protocols	*Organisational Systems and Telecommunications Design Stage II: page 24*
Telecommunications functional specification: Cyber Security Standards	*Organisational Systems and Telecommunications Design Stage II: page 25*
Telecommunications functional specification: Voice Communications	*Organisational Systems and Telecommunications Design Stage II: Page 25–26*

DER control interface requirements	*Organisational Systems and Telecommunications Design Stage II: Pages 37–40*
DRZC Factory Acceptance Test for a prototype Distribution Restoration Zone Control (DRZC) system	*DRZC Factory Acceptance Testing 1*
The requirements for cyber security and resiliency distribution restoration system	*Distributed ReStart Lot 2 – Requirements Phase*
Design for cyber security and resiliency distribution restoration system	*Distributed ReStart Lot 2 – Design Phase*

Overall, the outputs of the final organisational proposals and telecommunications functional specification have resulted in expected change requirements against each organisation, as summarised in Table 4.

Table 4: Description of the changes required in each organisation to deliver a distribution level restoration

Organisation	Area Impacted	Changes Required
Transmission owner (TO)	**Interfaces**	No change required, although should be aware of DRZ plans in each area. For Scotland where there is a need for interface with transmission connected energy resources within a DRZ.
	Systems	No change required, except for Scotland, elements of the control system may be installed at transmission level (132 kV).
	Telecommunications requirements	There may be a requirement for transmission phasor measurement unit data to be exchanged with the DNO to enable synchronisation functionality.
	Training requirements	At least biennial training adapted for specific DRZ options.
	Staff requirements	No change required.
ESO	**Interfaces**	New interface with a DNO for each DRZ.
	Systems	New Inter-Control Centre Communications Protocol (ICCP) for situational awareness of DRZ.
	Telecommunications requirements	Existing operational telephony is suitable.
	Training requirements	Training frequency is suitable, but content needs to include distribution options. Joint training with DNO, TO and providers is recommended biennially.
	Staff requirements	No change required.
DNO/DSO	**Interfaces**	The DNO now interfaces with ESO. The DNO now interfaces with DER (via DRZC and voice communication)
	Systems	DRZC which meets the functional specification. New ICCP link with ESO. New group telecontrol sequences added to the advanced distribution management system (ADMS).
	Telecommunications requirements	Upgraded, power resilient communications network which meets the functional specification.

DNO/DSO	**Training requirements**	At least yearly training. Active participation in cross industry training at least biennially. Desktop exercises conducted with DER participants. Internal specific DNO training on use of the DRZC system. Frequency control capability for redundancy to automation.
	Staff requirements	No specific change to minimum staffing but an enhanced reliance on called in resources in the control room due to involvement earlier in the process. At least two control engineers should be involved in Distribution Restoration Zone Plan (DRZP) management. For this reason, where a DNO has multiple DRZPs and Local Joint Restoration Plan (LJRP) options, there may be a need for increased minimum resourcing or prioritisation based on staff constraints while further control engineers are called to site.
Distributed energy resources	**Interfaces**	A new interface with the DRZC and redundant voice over Internet Protocol (IP) DNO communications will be introduced.
	Systems	It is anticipated that delivery of a contracted anchor or top-up service will require the DER to install new equipment to deliver the service. This will include direct response to DRZC instructions.
	Telecommunications requirements	The telecommunications requirements must meet the functional specification.
	Training requirements	The DER must demonstrate a robust training process for restoration capability or a resilient automated response to DRZC input signals. This will form part of assurance requirements, as will participation in biennial training with the DNO and ESO.
	Staff requirements	A minimum staffing requirement should be maintained so that availability information can be provided at all times and that the contracted service can be delivered. For service delivery, any contractor, called in resource or self-starting organisational structures used, must ensure that staff are available to the specific provider in the event of restoration and that it does not compromise the overall ability of the energy resource to deliver the contracted service.

As demonstrated by Table 4, significant organisational, systems and telecommunications changes are required across multiple organisations to deliver a restoration from DERs.

Key areas of change are focused within DNOs and depicted in Figure 1. These include:

- a requirement for an upgraded telecommunications network to meet the functional specification
- a new restoration zone control system with functionality outlined in Table 3
- requirements for real time data exchange between the ESO and DNOs for situational awareness and between TOs and DNOs for power island synchronisation.

DERs also require significant changes to enable them to participate in restoration service delivery, but these are mostly consistent with those required for new transmission level service providers. In addition to physical changes, the need for cross industry training has also been identified as a requirement to deliver a restoration service from distribution connected providers and this will impact all organisations involved.

In conclusion, the operational processes and communication requirements designed by the project are considered suitable for adoption into distribution level restoration in GB. Desktop exercises involving every network licensee and many DER representatives demonstrated the viability of the planned procedures, communication paths, restoration zone model and the proposed visibility and control requirements. The improvements identified have been incorporated into the final organisational design. However, alongside conventional training processes, continued training in distribution level restoration and use of that training to identify improvements remains critical to the success of operational procedures. Furthermore, demonstration of the proposed communications protocols has been undertaken as part of the DRZC testing showing that the expected technical aspects such as delays and bandwidth do not adversely impact operation of the zone. In addition, a full cyber security analysis and specification has been developed to enable roll-out of these systems into distribution network infrastructure without adverse impact. Overall, this leads to an end to end control specification which can be designed against by DNOs as they roll-out capability and consider specific requirements and solutions in their network areas.

1.5 Proof of Concept

Following publication of our final Organisational, Systems and Telecommunications (OST) report *Operating a Distribution Restoration Zone* in September 2021, this workstream focused on finalising our functional designs for the required organisational model. We believe these designs will best enable DNOs/DSOs and DERs interested in providing distribution restoration services to minimise the impact of the required changes such a new service will entail. This model was fully tested with a series of desktop exercises over the summer of 2021, at which all six DNOs in Great Britain participated, along with nearly 200 representatives from across the industry, including DERs.

In addition, our functional specifications (for a cyber-secure and power-resilient systems and communications infrastructure) to support the new service, have been extensively tested and refined with various techniques, including:

1. Factory acceptance testing (FAT) of a prototype system completed in April 2022 at our supplier, GE Digital's premises in Edinburgh. The resulting report, *DRZC Factory Acceptance Testing 1*, that was published on our website in May 2022, included two additional reports for communications latency and cyber penetration testing that can be carried out later.

2. Hardware-in the-loop testing (HiL) at the National HVDC Centre in Cumbernauld, using a model based on our Chapelcross live trial site, built using the real time digital simulator (RTDS) environment by colleagues at SSE and GE. This facility enabled us to conduct some additional tests not available in the FAT environment, mainly concerned with new communication protocols, such as the technical standards IEC 104 and IEC 104 encrypted required to facilitate operation of fast acting controller functionality.

Independent testing of the DRZC has been documented in the report *DRZC Independent System Testing*, which is available on the project website. These functional specifications will be of great use to participants considering providing distribution restoration services under future business as usual (BAU) contractual arrangements. They will greatly assist DNOs in specifying required testing on their networks and ensuring the wording of contractual arrangements is appropriate.

2. Power Engineering and Trials

2.1 Introduction

This section of the report summarises the learnings from the Power Engineering and Trials (PET) workstream, which is concerned with the technical evaluation of delivering an effective restoration service from distributed energy resources (DERs). It draws from previous workstream technical reports[1] and provides an overview of the DER, network and automation requirements, along with learnings from live network trials.

2.1.1 Distribution Restoration Zones (DRZs)

The PET workstream was concerned with the technical requirements to establish power islands on the distribution network, following a total or partial shutdown of Great Britain's electricity network. The project has defined this concept as establishing Distribution Restoration Zones (DRZs). These may incorporate multiple DERs to provide services such as restoring customer demand, energising the network to enhance substation resilience, and 'bottom-up' energisation of the higher voltage/transmission network. Three main components of a DRZ have been identified as DERs, the network and potentially automation.

2.1.2 DERs

Anchor Generators

Each DRZ requires an "anchor" generator, the key requirements of which include the ability to self-start and to establish an independent voltage source (grid forming capability), to initially energise a dead network. Primarily DERs connected at 33 kV are most suitable. This tends to be in the tens of MW capacity and, by default generation at the lower voltage levels, will be incorporated into the DRZ. However, DERs connected at 11 kV, transforming directly to a higher voltage, or connected at 132 kV may also be viable anchor generators. Of course, restoration can also be delivered using larger generators but their use, and the market opportunity, is already covered by existing approaches.

Additional DERs

To supplement the technical capability of the anchor generator, stabilise, or grow (connect more demand or network to) the DRZ, additional DER resources may be required. These requirements are defined in terms of top-up services and will vary for each DRZ (e.g. additional energy MW hours may be required to connect demand). In themselves the requirements are technology agnostic.

A summary of the technical considerations for DERs participating in a DRZ is given in section 2.2, along with the specific functional requirements proposed for an anchor DER and top-up services.

2.1.3 Network

In section 2.3, Network Requirements, an overview is given of the technical considerations, and changes which may be required, on the distribution and transmission networks to facilitate a DRZ. Primarily, the issue of earthing an islanded 33 kV network, and protecting the network at the voltage levels to be energised must be considered.

1 *Report on the viability of restoration from DERs, July 2019*
Assessment of power engineering aspects of Black Start from DER Part 1, July 2020
Assessment of Power Engineering Aspects of Black Start from DER – Part 2, December 2020
Demonstration of Black Start from DERs (Live Trials Report) Part 1, December 2021
Demonstration of Black Start from DERs (Live Trials Report) Part 2, October 2022
Demonstration of Black Start from DERs (Live Trials Report) Part 3, October 2023

2.1.4 Automation

To overcome the technical and human resource constraints associated with establishing and maintaining a DRZ, the project has developed automation in the form of a DRZ Controller (DRZC). Section 2.5 gives the context to the role of automation within the operation of a DRZ and lists the associated functional requirements.

2.1.5 DRZ Live Trials and Restoration

In section 2.7, a summary is given of the key achievements and learning obtained from the three project live trial sites (Galloway, Chapelcross and Redhouse) along with a high-level restoration process.

2.1.6 Conclusions

Section 2.8 summarises the key requirements to establish a DRZ.

2.2 DER Requirements

2.2.1 DER Technical Considerations

This section gives a high-level overview of the technical considerations relevant to DERs being suitable to participate in DRZs. In addition, the specific functional requirements which must be met for an anchor generator, and for the top-up services, are given. These are technology agnostic. While it is anticipated that a single DER would fulfil the role of an anchor generator, in certain cases cogeneration may be an option. A single DER may be able to provide multiple top-up services depending on its capability.

Technical considerations within this section are presented in greater detail in Chapter 3 of the *PET workstream's Report on the viability of restoration from DERs* publication.

2.2.2 Classification

For the purpose of establishing a DRZ, DERs can be split into two main categories:

1. **Grid forming** – these have the ability to establish their own independent voltage source (i.e. they do not need a live network to operate). The most common example of this would be a synchronous generator (may have prime movers such as hydro, gas, diesel or steam). This is a key characteristic required for an anchor DER.

2. **Grid following** – wind farms, solar farms and battery energy storage systems (BESS) are typically connected to the power network via a grid following converter interface (i.e. the network voltage is required as a reference before they can connect, and for stable operation). Grid forming converter technology has been developed, and proven in recent years, but is not yet commonplace on distribution network operator's (DNO) networks.

   The fastest control loop in grid following converters is known as a phase lock loop (PLL). This is used to 'track' the network voltage for the DER to synchronise and remain stable. A DRZ will have a significantly reduced fault level when supplied only by the anchor DER (compared to an intact network). Standard converter control techniques will typically fail to maintain stability when the short circuit ratio (SCR), the ratio of fault MVA to DER rating, is less than ~3.0. This will result in a limitation to the capacity of converter connected DERs which can connect in a DRZ for a given network fault level.

2.2.3 Block Load Pickup (BLPU)

A generator's ability to accept step-changes in demand is known as its block load capability. In the Grid Code this is defined as "active power step (MW) a generator can instantaneously supply without causing it to trip or go outside 47.5–52 Hz (or otherwise agreed)". The block loading capability is dependent upon three main factors:

i) The size of load applied (MW)
ii) The inertia of the generator (the lower the inertia the faster the frequency will fall when load is applied)
iii) The type of generator (the differing governor responses and associated prime movers e.g. diesel, steam, gas turbines and hydros).

For synchronous DER, the BLPU capability may vary from ~10% to ~50% of the generator rating depending on the technology and prime mover (hydro is likely to have the least inherent capability given the inertia of the water to increase the turbine speed).

For grid forming converter-based sources, the BLPU capability will depend on the converter control system as well as the physical capability of the energy source, whether that is a battery or something else. In the best cases, a fast-responding battery might be able to accept step-changes of 100% of rating.

2.2.4 Frequency Control

Fast-acting frequency control is a requirement of the anchor DER within a DRZ. Under the Grid Code, all large, embedded power stations require this capability (called frequency sensitive mode). It is unlikely it is utilised in practice as this is an ancillary service not usually requested of DERs. DERs which are not large are unlikely to have frequency control as this is not a typical requirement of distribution network operators' (DNO) connection agreements (CAs).

For DER connecting after 27 April 2019, the technical requirements are now specified in Engineering Recommendation G99. This requires all DER greater than (or equal to) 10 MW (types C & D) to have a fast-acting frequency control device.

2.2.5 Voltage Control

Voltage control is an essential capability for the anchor generator and is also likely to be required as a top-up service to supplement the anchor. This depends on the DERs being able to modify their reactive power, also described in terms of power factor, to keep all voltages on the distribution network within acceptable limits.

In Scotland, DNO CAs require that synchronous and non-synchronous (converter connected) DERs operate in constant voltage control (with a corresponding reactive power range). In England and Wales, power factor control is normally specified in the CAs (typically operation near unity power factor is required).

For DERs connecting after 27 April 2019, G99 requires that all DERs greater than (or equal to) 10 MW (types C & D) provide continuous steady state control of the voltage at the connection point with a set point and slope characteristic.

2.2.6 Resilience

The existing operational resilience of DERs, following a network blackout, varies greatly on a site-specific basis. For example, some DER sites have standby generation installed which will provide several days' resilience however others may only have battery backups for their auxiliaries which will only last for a few hours to ensure that the generation will be safely shut down.

A particular issue for wind farms is the resilience of the wind turbine generators (WTGs). The longer a WTG is without a grid connection the more likely there will be a delay, or manual intervention required, before returning to service (the grid provides the auxiliary supplies at each WTG for services such as heating). For example, bearings and gear box oil cools down when not in use and, depending on the ambient temperature, may inhibit WTG operation after approximately eight hours.

2.2.7 Self-Starting Enablement Costs

The anchor DER will require self-starting capability. Most DERs will not have this capability installed as there is no current market/requirement to justify the additional expense. The associated costs are anticipated to vary significantly based on the technology. For example, a steam generator with its power intensive auxiliaries (e.g. boiler feed pumps), will likely have much larger costs to install start up auxiliary generation than a gas or hydro station.

2.2.8 Emissions

Some DER technology types (e.g. gas or steam generators) may require a derogation from their normal emissions limits due to the change in operating practice required to provide restoration services (e.g. operating at reduced, less efficient output levels).

2.3 DER Functional Requirements

This section lists the technical functional requirements which were developed within the project and are proposed for DER to provide the service of an anchor generator, or additional top-up services, within a DRZ.

A fuller explanation of the anchor DER functional requirements is presented in Chapter 4 of the report by the PET workstream, *Assessment of Power Engineering Aspects of Black Start from DER – Part 2*.

2.3.1 Anchor Generator Functional Requirements

Table 5: Anchor generator – functional requirements

Time to connect	Requirement	**≤8h**
	Definition	• Time taken from instruction (from the relevant system operator) to start up the black start plant from shutdown, without the use of external power supplies. • Instruction to start up may be up to 72 hours after a black out. • Energise up to the DNO statutory point of connection. • Connected to DNO or transmission network at 33 kV or 11 kV (transforming directly to a higher voltage).
	Comments	Exact capability to be declared. Confirm if load bank is required to meet the proposed DER definition.
Service Availability	Requirement	**≥90%**
	Definition	• The ability to deliver the contracted black start service over 90% of each year of providing a black start service. **Note:** It is the responsibility of the provider to demonstrate its service availability.
	Comments	• A black start could happen at any time thus a high service availability is required.
Resilience of Supply, Black Start Service	Requirement	**≥72h up to 120h**
	Definition	• When instructed to black start, the minimum time the provider will deliver continuous output at 90% rated capacity.
	Comments	Exact capability to be declared.
Resilience of Supply, Black Start Auxiliary Units	Requirement	**≥72h up to 120h**
	Definition	• Run continuously for a maximum of 5 days to: → maintain the generator declared 'time to connect' availability for up to 72 hours after a blackout → maintain the generator house loads for the declared time in the "Resilience of Supply, Black Start Service" (it may be acceptable to transfer auxiliary demands to the generator supply during island mode operation).
	Comments	Provider to determine the fuel supply required.
Frequency Control	Requirement	**A fast-acting proportional frequency control capability is required**
	Definition	• Frequency control as defined in Engineering Recommendation G99 (applicable to Type C & D generators). • The ability to manage frequency level when block loading (47.5–52.0 Hz). • Fast acting frequency control capable of being operated in isochronous mode or with a set point and droop setting if required.
	Comments	During a Black Start the anchor will need to maintain frequency within limits when initially forming a DRZ. Frequency control may be supplemented by the addition of top-up service providers.

Voltage Control	Requirement	**Ability to provide continuous steady state control of the voltage with a set point and slope characteristic**
	Definition	• Voltage control as defined in Engineering Recommendation G99 (applicable to Type C & D generators). • Ability to create a voltage source (independent of the DNO network) and control the voltage within acceptable limits during energisation/block loading (+/- 10%).
	Comments	During a Black Start event the anchor generator will need to maintain voltage (within limits) when creating, maintaining and expanding a DRZ.
Block Loading Size	Requirement	**To be confirmed based on specific DRZ requirements**
	Definition	• Capacity to accept instantaneous loading of demand blocks and maintain the frequency within the 47.5 Hz to 52 Hz range. • The provider should state the block load pickup/rejection (MW) of the plant.
	Comments	The minimum block load capability required for each DRZ will be determined as an output of feasibility study undertaken by the ESO and host DNO. The magnitude of discrete load blocks to be restored within each DRZ will be a key consideration to determine the block load requirement.
Reactive Power Capability	Requirement	**Minimum of 0.95 leading and 0.95 lagging power factor at the point of connection**
	Definition	• Ability to absorb Mvar (leading power factor) to energise the DNO network whilst active power is zero. • Ability to generate Mvar (lagging power factor) to supply network demand.
	Comments	Numerical (Mvar) leading and lagging capability to be declared.
Sequential Start-Ups	Requirement	**≥ 3**
	Definition	• Ability to perform at least three sequential start-ups.
	Comments	Time required between sequential start-ups to be declared.
Short Circuit Level (SCL)	Requirement	**≥ 1 x DER MVA rating**
	Definition	• Injection of reactive current during a disturbance. • SCL measured at generator terminals.
	Comments	DRZ feasibility study to determine if DER SCL is sufficient to be the anchor DER.
DRZ Specific Technical	Requirement	**To be confirmed based on specific DRZ requirements**
	Definition	• Technical requirements on an anchor DER specific to a DRZ to facilitate the restoration process.
	Comments	DRZ feasibility study to confirm.

2.3.2 Top-Up Services

Some DRZs may require additional technical capability from other DERs to help the anchor generator establish, grow and maintain the island. The necessity for additional capability will consider the characteristics of the DRZ such as the total customer load to restore, and the anticipated discrete load pickups necessary to restore that load. The additional technical capabilities required from DERs are referred to as “top-up” services, the requirements, definition, and related commentary for all top-up services are provided in Table 6.

Table 6: Top-up services – functional requirement

Fast MW Control	Requirement	**Within <200 ms provide available MW, sustained for at least 15 minutes with gradual reduction toward preferred operating position** and/or **Within <200 ms provide available MW, sustained for at least 10 seconds with gradual reduction toward preferred operating position** and/or **Active power output reduction in response to a change in system frequency above a certain value (value and required rate of reduction to be confirmed)** and/or **Active power output increase in response to a system frequency below a certain value (value and required rate of increase to be confirmed). This will only be required if output has been constrained below the maximum output power.**
	Definition	• Deliver rapid MW response triggered by a local frequency measurement or on receipt of an external control request (which will change the set point at an agreed ramp rate).
	Comment	This response will support the anchor to maintain DRZ frequency if the anchor generator alone cannot restore frequency within limits. As an example, this response could be required if a DER tripped, or if additional sub second MW support is required to energise demand.
Inertia	Requirement	**The generator should state what inertia is available**
	Definition	• The inertial response should be provided by an inherent response without any measurement delays. (For synthetic inertia refer to "Fast MW Control".)
	Comments	DRZ feasibility study to confirm what (if any) the inertia requirements will be (e.g. this may be required to increase the block load pick up capability within the DRZ).
Frequency Control	Requirement	**Provide frequency sensitive control of active power**
	Definition	• Frequency control capability as defined in Engineering Recommendation G99 (applicable to Type C & D generators). • All frequency response requirements are applicable including LFSM-O, LFSM-U and FSM.
	Comments	This response will support the anchor generator to maintain the frequency within limits during normal operational.
Voltage Control	Requirement	**Provide continuous steady state control of the voltage at point of connection**
	Definition	• Voltage control capability as defined in Engineering Recommendation G99 (applicable to Type C & D generators). • As specified in G99 the voltage control should be provided with a droop characteristic. • The voltage setpoint should be adjustable by an external control system. • If voltage control cannot be provided, it may be acceptable to provide a Mvar set point controlled by an external signal.
	Comments	The DER will help the anchor generator maintain voltage within limits during events such as energisation of the distribution/transmission network and block loading. The Mavar range available is to be declared.
Short Circuit Level (SCL)	Requirement	**≥ 1 x DER MVA rating**
	Definition	• Injection of reactive current during a disturbance. • SCL measured at DNO point of connection.
	Comments	To increase DRZ fault level if anchor generator alone doesn't provide minimum acceptable fault level.

Energy (MWh)	Requirement	**Generate or consume MW on instruction from an external control system, deliver within 10 seconds of request**
	Definition	• DER reports the maximum and minimum range of MW output which can be delivered if requested. • Intermittent output is acceptable and will be controlled by a set point (a suitable constraint value will be given).
	Comments	• The DER will support the anchor generator to deliver MWh to the DRZ and energise more demand.
Resilience	Requirement	**All top-up service providers will be required to provide the stated resilience levels** • Maintain the availability of the control and communications with the DER site for up to 72 hours after a blackout before any DNO supplies (EHV, HV or LV) are restored. • When instructed to black start, the service will be available for a minimum duration of 72 hours (exact capability to be declared). • The contracted black start service will be available a minimum of 90% of the year (exact availability to be declared).
	Definition	• Declare the time to provide availability of the top-up service after the DNO main connection has been restored (indicate if this time is dependent upon the length of time after the blackout before the DNO HV supply is restored).
	Comments	While the main connection to the DER will be restored as soon as practical, it may be up to 72 hours after a blackout before the connection is restored and the DER will have to be resilient for this time period in order to then provide the required service. The top-up services will be required to be available up to the 'resilience of supply' capability of the anchor generator.

2.4 Network Requirements

2.4.1 Network Technical Considerations

This section summarises the key technical issues which must be considered, and works that may have to be implemented, prior to a distribution network (and if applicable transmission network) forming part of a DRZ.

33 kV Network Earthing

Distribution 33 kV networks are typically resistance earthed at the grid substation, via an earthing transformer (with zigzag-star windings), connected between the grid transformer (commonly 132/33 kV), and the associated transformer 33 kV circuit breaker. This is shown in Figure 2.

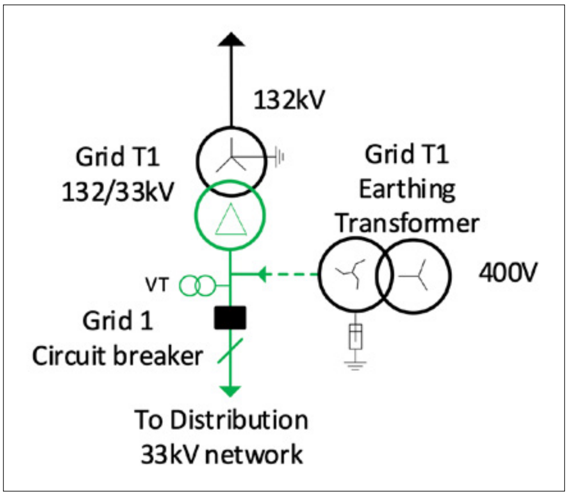

Figure 2: Network earthing

A typical DRZ will be established with a 33 kV connected anchor DER, and the grid transformer 33 kV circuit breakers opened, to establish an isolated 33 kV network to be reenergised. However, this results in an unearthed 33 kV network which is not permissible as no fault current would flow to allow faults to be detected. Moreover, the Electricity Safety, Quality Continuity Regulations (ESQCR) Regulation 8 states, "the network is connected with earth at, or as near as is reasonably practical to, the source of voltage".

In Section 3.6 of the *PET workstream's Report on the viability of restoration from DERs* this issue is described in more detail and a range of solutions discussed. Essentially, an earthing transformer will be required to be installed as close as practical to a 33 kV anchor DER. This would normally be out of service but able to be switched in service when a DRZ is to be established.

33 kV Network Protection

During the restoration process the system fault level will in most cases be significantly reduced (typically ~10% normal levels) as initially only the anchor generator will be connected. An assessment of the existing protections within a DRZ is therefore required to ascertain:

- if correct operation can still be obtained with existing protections and settings
- if correct operation can be obtained with existing protections but applying revised settings (e.g. lowering the "pick up" values of overcurrents)
- if new protections are required (e.g. voltage dependent relays, which only revert to reduced settings when a collapse in voltages associated with a fault is detected).

Where revised settings are required, in business as usual (BAU) it is envisaged these would be implemented within the "group 2" functionality of modern relays. The group 2 settings could be activated remotely via the SCADA system if there was a real black start.

Typically, as the voltage levels increase, the number of protections requiring to be modified or being inoperable increases.

In Chapter 8 of the *Assessment of power engineering aspects of Black Start from DER – Part 1*, a detailed protection assessment of a 11 kV to 400 kV case study network is given with the conclusions including a "rule of thumb" minimum fault level required at each voltage level for existing protections to be viable. Chapter 7 of the *Assessment of Power Engineering Aspects of Black Start from DER – Part 2* gives a specific protection assessment of the 11 kV and 400 V networks, and chapter 8 of the *Demonstration of Black Start from DERs (Live Trials Report) Part 1* report provides a protection assessment of the particular challenges when the anchor DER is a grid forming Battery Energy Storage System (BESS) – the converter cannot produce any fault current in excess of its full load current.

In addition to the above protection assessments, network specific assessments were carried out for the live trials which have been undertaken. It should be noted that it was found that applying definite time (DT) settings to existing protections (which typically have Inverse Definite Minimum Time [IDMT] settings), was the most practical method of grading network protections with a reduced fault level.

Switchgear Capability – Transient Recovery Voltage (TRV)

- Circuit Breaker Fault Breaking – TRV

  Breaking low fault currents associated with an islanded network (typically ~10% normal levels), can result in higher or faster TRVs across the circuit breaker (CB) contacts when opening (especially when the fault is close to the anchor generator). These may exceed the circuit breaker peak TRV rating, or the type tested Rate of Rise of Recovery Voltage (RRRV), potentially causing a disruptive failure of the switchgear. TRV switchgear limits are given as a peak value with an associated maximum RRRV. These may be found in International Standard IEC-62271-100 for high voltage switchgear.

- Circuit Breaker Network Charging Breaking – TRV

  TRV issues may also arise in an islanded network under normal opening switching duties (i.e. no network fault). For example, the anchor DER protection may operate and trip its CB which may de-energise a section of network with no load connected.

- Vacuum Circuit Breakers – Re-ignitions

  An excessive RRRV is a particular issue for vacuum circuit breakers where multiple re-ignitions may ensue. An example of this is shown in Figure 3 from a transient network simulation study where there are multiple re-ignitions across the CB contacts.

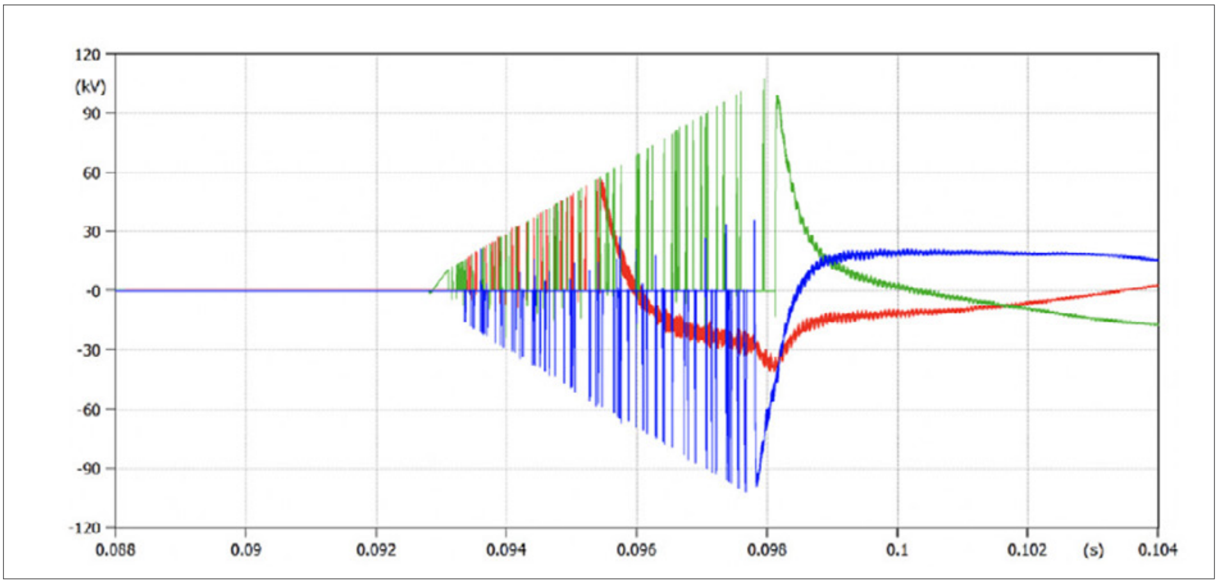

Figure 3: Peak phase voltages measured across CB when contacts opened in response to a three-phase fault

  Vacuum CBs are known for their excellent interruption capability and dielectric recovery characteristics. Re-ignitions are prone to happen when the contacts open near the power frequency current zero (thus the phenomenon is dependent upon the Point on Wave on which the CB opens). If the high RRRV exceeds the dielectric strength of the vacuum gap, then re-ignitions will occur, and high frequency currents will flow depending on the characteristics of the circuit. The repeated interruption of these high frequency currents can result in multiple re-ignitions and voltage escalations which may lead to overvoltages exceeding the basic insulation level (BIL) of the electrical system components. These high frequency currents may also excite the internal resonance of nearby transformer and generator windings creating voltages several times greater than the original transients leading to insulation breakdown and damage to internal windings.

In Chapters 2,5,7 and Appendix 1 of the *Demonstration of Black Start from DERs (Live Trials Report) Part 1* report, further detail is given regarding potential CB TRV issues within a DRZ.

Resilience

Before a black start, it is necessary to ensure all substations are safe to energise. This means that essential elements such as protection, monitoring and control are available. These systems are powered by batteries, with a low voltage (LV) supply for charging which may also provide motive power for equipment such as tap transformer change motors, and circuit breaker spring charging where required. The ability of these services to be maintained following a network blackout is what is referred to as the resilience of the substation.

The existing resilience of distribution and transmission substations may vary greatly across Great Britain, and on a site-by-site basis, depending on factors such as the age and capacity of the batteries installed, the extent of implementation of asset modernisation programmes and the policies of the asset owner. For DRZ implementation, it is proposed that a minimum of 72 hour resilience is in place for all network equipment being the maximum time after a blackout initiation of a DRZ is anticipated (the substation LV supplies would then be restored from the re-energised network).

Further discussion of the key substation systems where resilience needs to be ensured is given in Chapter 3.8 of the PET workstream's *Report on the viability of restoration from DERs.*

2.4.2 Network Technical Requirements

To facilitate the development and operation of a DRZ, the following network modifications are proposed:

Earthing (33 kV)

- A "switchable" earth will be required on the 33 kV network as close as practical to the anchor DER.
  - → A 33kV earthing transformer can be connected at the DNO substation at the anchor DER site or
  - → the anchor DER may have an alternative means of 33 kV earthing that can be utilised (e.g. switchable earthed star point of 33 kV transformer winding).
- Fault level studies should be undertaken to ensure the proposed 33 kV earthing (and relevant impedance) gives adequate earth fault current flow to be detected.

Network Protection

- A fault level study should be undertaken of the proposed DRZ network when supplied only by the anchor DER to identify the minimum fault level at all relevant network nodes.
- A protection assessment should be undertaken with the minimum fault levels to identify:
  - → if existing protections will still operate
  - → alternative settings or protections required to ensure the network is protected (it may be acceptable to relax standard protection discrimination requirements to simplify modifications required. e.g. a primary transformer 11 kV CB may protect the complete 11 kV network).
- The required protection modifications should be implemented with the ability to be switched in remotely in the event of a black out.
  - → Protection settings changes required should be programmed into an alternative settings group of the protection relay with remote control (some relays may need upgraded to modern versions which have this functionality).

Switchgear Capability – Transient Recovery Voltage

- A TRV study should be undertaken to assess the opening capability of the relevant CBs within the DRZ network under fault opening and load switching conditions to identify if the peak TRV and RRRV values are within switchgear limits (and if so, if an existing issue or caused by the islanded network).
- If vacuum CBs are installed, then a CB model should be included in the modelling to identify if re-ignitions occur.
- An assessment will be required as to whether mitigation works are required. These would involve:
  - → surge arrestors being installed at strategic locations to limit the peak TRV values (these can be installed in CB cable boxes if there are spare "lugs")
  - → RC Snubbers being installed to reduce the RRRV (required to prevent re-ignitions in vacuum CBs).
- The maximum "charging current" that a circuit breaker may break under normal switching (to de-energise a section of islanded network), should be assessed against the capacitor bank switching tests of the CB to ensure this is within its capability.

Resilience

- For each power island, a survey will be required to ensure the required resilience at the key substations. This may be provided by additional battery capacity, battery demand disconnection schemes, and/or standby generation.
- DNO resilience and asset management policies may need to be amended to reflect the requirements of black start from DERs in the future.

2.5 Automation Requirements

This section presents context to the role of automation within the operation of a DRZ and lists the associated functional requirements.

2.5.1 Background

Given the technical and operational challenges associated with establishing, growing and maintaining a DRZ, and the limited human resources which may be available at the time of a black start, it is anticipated that some level of automation will be required. The application of automation to the DRZ restoration process is further discussed in Chapter 3.4 of the PET workstream's *Report on the viability of restoration from DERs*, and Chapter 11 of the report, *Demonstration of Black Start from DERs (Live Trials Report) Part 1*.

The wide area control system that has been developed within the Distributed ReStart project (up to the prototype stage) is referred to as a Distribution Restoration Zone Control (DRZC) system.

DRZ Controller Requirement

Primarily a DRZC will be required if:

1. **The Block Load Pick Up (BLPU) capability of the anchor DER is insufficient to make demand restoration viable.**

   For example, the BLPU capacity may be less than typical 11 kV feeder loadings, or not sufficient for restoring a primary substation on its own (if desired for faster, less laborious switching restoration).

   A truly innovative function of the proposed DRZC is that it will provide sub-second control of additional DERs (e.g. a BESS or load bank) to maintain the frequency within limits when block loads are applied causing a sudden frequency disturbance. This function of the DRZC is called "fast balancing".

2. **Additional DER (e.g. wind farms) are required to restore demand (MWh) in excess of the anchor DER's capability.**

   The DRZC will monitor the loading of all DERs and initiates rebalancing such that the output of all DERs is optimised (e.g. the maximum use made of wind resource when available), and the generation/load balance is always maintained such that the frequency can be kept within acceptable limits. This function of the DRZC is called "slow balancing".

2.6 DRZC Generic Functional Requirements

2.6.1 Introduction

The Distributed ReStart project contracted several technology companies to propose the functional design of a DRZC system. These were reviewed to identify the functionality essential for a viable DRZC solution which are expected to be applicable in the wide range of conditions found across Great Britain. The requirements define the required functional capability of a DRZC but are technology/vendor agnostic and therefore do not dictate or recommend any aspect of how a DRZC should be implemented. These are summarised in Section 2.6.2.

The detailed functional requirements of the DRZC system necessary for a business as usual (BAU) deployment (e.g. visualisation, communications monitoring/failsafe and system configuration/maintenance) are detailed in Chapters 2 and 3 of the *Assessment of Power Engineering – Aspects of Black Start from DER, Part 2* report. That same report also presents the designs proposed by the technology companies associated with the key functional requirements listed below (e.g. designs associated with "fast balancing" and "slow balancing").

2.6.2 DRZC Functional Requirements

Fast Balancing

The DRZC must be capable of taking an active role to co-ordinate the anchor generator and other DER resources to ensure that there is sufficient fast balancing response (both pickup and drop-off) available to maintain the generation/load balance of the island when subject to credible disturbances (e.g. load pickup).

Slow Balancing

The DRZC System should be capable of pre-positioning different DERs to indirectly move the anchor operating position up or down to create more headroom/foot room.

Block Loading

The DRZC System should be capable of calculating the block load capability (pickup/acceptance and drop-off/rejection capability) of the DRZ.

The system must use DER resources to complement the block load capability of the anchor generator and therefore increase the effective block load pickup and drop-off capability of the island.

Distribution Network Energisation

Once the anchor generator has started up (against its own load if required) the DRZC must determine when the start-up has been completed successfully (using measurements and any other relevant signals from the anchor generator) and the network is stable to begin energising the wider network.

Energy/Distribution Management System Requirements

The DRZC design outputs vary in the proposed role of Energy Management and Distribution Management systems (EMS and DMS respectively) within the restoration process. The requirements listed below are recommendations which represent the majority opinion from the DRZC companies' design outputs.

- The EMS/DMS system is required to dispatch alternative protection settings to DSO/ESO protection relays as required and appropriate for each stage of restoration.
- The EMS/DMS system is required to perform a network switching schedule to energise the skeleton network of the DRZ. The execution of the energisation should be co-ordinated with the DRZC.
- The EMS/DMS system should confirm that the network configuration is suitable to begin black start before informing the DRZC.
- The EMS/DMS system is required to provide the DRZC with live network measurements associated with each block load.

Wider Network Synchronisation

Before, during and after the process of synchronising to the wider network, the DRZC is required to maintain stability of the island as per normal operation. Once frequency and voltage are aligned, a synchro check relay operating on the interface will close the associated circuit breaker.

The following requirements are relevant to the DRZC during synchronisation:

- The DRZC is required to dispatch pre-determined set-points (e.g. voltage or frequency setpoints) or control modes (e.g. request enter voltage control mode if not already) to DERs to prepare the DRZ for synchronisation with the wider network.
- Once synchronised to the wider network, the DRZC is required to report dispatchable real and reactive power to the supervising control room, i.e. operate the island as a "virtual power plant".

2.7 DRZ Live Trials and Restoration

This section provides a summary of the live testing carried out as part of the Distributed ReStart project, the key learnings obtained, and an outline of a DRZ restoration process.

2.7.1 Live Trials

Background

As part of the Distributed ReStart project, the PET workstream has undertaken live network testing of the DRZ restoration process at three sites within the SP Energy Networks (SPEN) license area (Galloway, Chapelcross and Redhouse).

At the Galloway trial site, a total of five days live testing was completed culminating in a 11 kV (13 MVA) hydro generator (the anchor DER) successfully:

- energising the local transmission network (including two grid transformers and 60 km of 132 kV overhead tower line simultaneously), and two 240 MVA 275/132 kV super grid transformers simultaneously
- energising distribution primary (33/11 kV, 24 MVA) transformers
- energising two wind farm 33 kV cable arrays (and associated turbine transformers), and connecting several turbines at each to form a stable DRZ with multiple DERs.

At the Chapelcross site, a 60 MVA 11 kV biomass DER was used as the anchor and was proven to:

- operate in island mode and energise its own 11/33 kV 60 MVA transformer
- energise the local distribution 33 kV network including a 24 MVA primary (33/11 kV) transformer
- synchronise to the main system at 33 kV
- energise the transmission network up to 400 kV (via a 400/132 kV 240 MVA super grid transformer).

At the Redhouse site, an 11 MVA BESS was used as the anchor (in conjunction with a prototype DRZC) and the following deliverables were achieved:

- BLPU capability of the BESS was successfully tested.
- Stable island operation both in frequency and voltage droop control modes was proved.
- Energisation of two primary transformers (separately and simultaneously) was proved.
- Energisation of Middle Balbeggie Solar Farm and stable island operation was proved.
- Energisation of a 90 MVA grid transformer and a 10 km 132 kV overhead line was proved.
- Successfully demonstrated different functionalities of the DRZC including fast and slow balancing, state of charge management and virtual power plant operation.
- Successfully demonstrated resynchronisation with the intact system via the DRZC.

Restoration Technical Considerations – Key Learnings

Along with system studies, the live testing has highlighted key issues, and potential mitigations, relevant to the restoration process. These can be summarised as:

- **Islanded networks** – Energising a network from a weak source (low fault level) is likely to result in significant harmonic and resonant frequency voltages and currents that are higher in magnitude and longer in duration than would occur on the same network when the fault level is much higher.
- **Transformer energisation** – The transformer inrush currents, which can be of high magnitude and rich in harmonics, can excite the resonance of the circuit connecting to the anchor generator, resulting in temporary overvoltages (TOV) that can last for several seconds. The TOV may operate the overvoltage protection at the generator terminals (typically set at ~1.1 pu to ~1.3 pu with a few seconds' delay or instantaneous operation) resulting in the generator circuit breaker tripping on transformer energisation. A harmonic impedance study of

the network to be energised can be undertaken to identify if there are resonances around typical inrush current frequencies, and therefore the potential for TOV.

To avoid generator tripping on overvoltage protection, several strategies were identified and tested:

- → Generator terminal voltage reduction – reducing the generator terminal voltage prior to energisation (on synchronous generators by adjusting the Automatic Voltage Regulator), increases the headroom so that the TOV produced by transformer inrush currents will be less likely to exceed the generator overvoltage limit.
- → Point of Wave (PoW) – In some network/transformer energisation scenarios, reducing the generator terminal voltage is insufficient to stop the overvoltage protection operating. In these cases, a PoW relay can be installed to control the closing time of the energising circuit breaker to reduce transformer inrush currents, and the corresponding overvoltages (a reduction to ~10% of worst-case inrush currents was observed in the live trials).
- → Resistive damping – The live network trials showed that by introducing resistive damping onto an islanded network (using a temporary load bank), TOV which had previously tripped the anchor generator was eliminated. (On an intact network damping is normally inherently provided by customer load.)
- → Soft energisation – A "skeleton" network may be connected to the anchor DER and the generator voltage ramped up from zero (over a matter of seconds) to full voltage. This will eliminate any transformer inrush currents, although the network will be unprotected until the voltage is at a sufficient magnitude for protection operation (this was not tested in the live trials as the previous options were successful).

- **Network Reactive Loading** – When distribution or transmission circuits are energised, they will generate Mvar depending on their capacitance. Care must be taken such that the total Mvar generated by the network, for intact and fault outage scenarios, does not exceed the reactive power absorption capacity of the anchor generator (or additional DER connected).

- **Switchgear Capability**
  - → Reactive loading – The relevant switchgear must be capable of breaking the maximum possible network reactive current when opened for non-network fault scenarios (e.g. by generator protection or planned switching). The circuit breaker capacitor bank switching rating may normally be assumed as the capability for this duty.
  - → TRV – Circuit breakers may be required to carry out duties which are outside their designed capability. TRV studies may be required to ascertain this.
- **System Modelling** – Simulations are carried out using an electro-magnetic transient (EMT) software program. There is often a lack of equipment data for an EMT type of study, particularly data required to model transformer core saturation, so assumptions have to be made. This may result in poor correlation between simulation and test results. In addition, it is not always possible to predict protection relay operation based on simulated waveforms.

- **Live Testing** – While extensive system modelling must be used to gain better understanding of the effects of network model sensitivities, without an actual demonstration via live testing there is a risk that restoration efforts in practice will be subject to unknown factors which will emerge to be overcome during an emergency, potentially blocking the restoration progress. As such, as much testing as practical of unconventional network energisation sequences should be carried out to increase the confidence that they will proceed as expected should the need arise to be used in practice.

Further details of the live trials and the key learnings, can be found in the PET workstream report, *Demonstration of Black Start from DERs (Live Trials Report) Part 1*.

DRZ Restoration Process

As a high-level guide to the DRZ restoration process, the proposed key stages are given below. The detail of how these stages will be implemented in practice will depend on factors such as the functionality of a DRZC (if included), and the level of automation/human intervention desired.

Stage 1: Network preparation and initialisation

- Send black start initiation signals to DER.
- Open/close circuit breakers to reconfigure the network.
- Change protection and control settings as required.

Stage 2: Anchor generator start up and initial network energisation

- Provide "generator start" signal to anchor DER.
- Supervise the configuration and stabilisation of the anchor generator in island mode operation (controlling the voltage and frequency) and connection of a 33 kV earthing transformer if required.
- Distribution Management System (DMS) switching as required to energise a "skeleton" network (this will likely include other DER networks as a priority e.g. wind farms).

Stage 3: Power island expansion

- Step-by-step energisation of more of the network to restore demand at primary substations. Also to restore auxiliary supplies to substations or other DER if required.

Stage 4: Maintaining a stable power island

- With the distribution power island energised as far as possible given the available DER, maintain stable operation for as long as is necessary before the next stage of the restoration process.
- Control resources to keep all within operational limits and maintain island voltages and frequency while responding to events, volatility in demand or generation, or operator actions as necessary.

Stage 5: Transmission network energisation (where in scope for the DRZ)

- On operator instruction, prepare for and manage controlled resources during step-by-step energisation of transmission network assets responding to the transient disturbances and enduring change in conditions caused by energising transmission network transformers and circuits.

Stage 6: Power island resynchronisation

- On operator instruction, prepare for and supervise resynchronisation, which could be with another DRZ or with the wider system, possibly synchronising on the transmission grid.
- Adjust voltage and frequency in the power island under operator instruction/control to align angle and frequency to enable resynchronisation.
- Maintain post-synchronisation stability of all resources within the DRZ area of control.

Stage 7: DRZ termination

- On receipt of a "termination of black start" signal, restore settings and transition to normal operating conditions.

2.8 Conclusions

The PET workstream has established the technical viability of restoration from DER by learnings gained through extensive power system analysis of several DRZ case study networks, industry engagement with DER developers and specialised consultants (including universities and national electrical testing centres), development of an automation scheme (with several external suppliers), and the planning and successful execution of several live trials, all of which have contributed to the requirements presented in this report.

2.8.1 Conclusions – DRZ Requirements

In the transition to BAU, it will be necessary for all DRZ participants to tackle the technical challenges identified in our project analysis and live trials. This will be driven by the process of the ESO tendering for new restoration services and working with the DNOs and DERs to assess viability and define workable DRZs.

DER owners will need to determine what service they are able to provide:

- **Anchor DER** – Each DRZ requires an “anchor” DER, a key requisite is having grid-forming capability.
- **Top-up services** – To supplement the technical capability of the anchor generator, stabilise or grow (connect more demand or network to) the DRZ, additional DER resources may be required. The requirements are defined in terms of “top-up services” (such as fast MW control, short circuit level) and in themselves are technology agnostic.

The key technical issues to be considered by DNOs, which may require investment on the network to allow it to form part of a DRZ, include:

- 33 kV network earthing
- network protection
- switchgear capability
  - → TRVs (for fault and switching operations)
  - → load switching – capacitive breaking capacity
  - → reignitions (applicable only to vacuum interrupter circuit breakers).

To overcome the technical and human resource constraints associated with establishing and maintaining a DRZ, the DNO may have to implement automation in the form of a DRZ controller (DRZC). This will primarily be required if either of the following “top-up services’ are required:

- Fast MW control – This enables the block load pickup (BLPU) capability of the anchor DER to be enhanced (its ability to pick up instantaneous blocks of demand) to make a viable restoration strategy (e.g. pick up primary [33/11 kV] substations in a single step). The DRZC is truly innovative in requiring sub-second control of DER to achieve this (to maintain acceptable frequency levels). This DRZC function is called fast balancing.
- Energy MWhs are required to enhance the capacity of the anchor DER to restore demand. The DRZC will control the additional DER to ensure the generation/load balance is such that the frequency is kept within limits. This DRZC function is called slow balancing.

The live trials have provided learning that will inform the transition to BAU, highlighting key issues like:

- the level of transient voltages and currents in an islanded network
- transformer energisation and techniques to mitigate associated generator tripping
- switchgear and network reactive loading capability
- the accuracy of system modelling
- the benefits of live assurance testing.

3. Procurement and Commercial

3.1 Introduction

The Procurement and Compliance (P&C) workstream aimed to address the best way to deliver the concept for customers. It explored the options and tradeoffs between competitive procurement solutions and mandated elements. It used a strategic process to develop fit-for-purpose commercial solutions that are open and transparent, stakeholder endorsed and designed end-to-end with the commercial objectives of the project and workstream in mind. The proposals will feed directly into business as-usual activities to make changes as necessary in codes and regulations.

The strategy development process was iterated using inputs from the Power Engineering and Trials (PET) and Organisational, Systems and Telecommunications (OST) workstreams, along with industry feedback.

A set of commercial objectives for the service were agreed:

- Accelerated restoration times
  - → functional route to market for new service.
- Financial value to the end consumer
  - → increased transparency
  - → increased competition
  - → reduced barriers to entry.

These were used to inform the designs of proposed procurement approaches. Three procurement approaches were developed with one selected to move forward for further development, following stakeholder feedback.

The recommended approach enables contracting for each of the required services for a distribution restoration zone (DRZ) individually, as necessary, with the parties who provide the best value proposition. It provides the most flexibility for the procuring entity on the specific design of the service, and it also offers the lowest barriers to entry for potential providers.

3.2 Final Developments

In 2021, the focus was on the development of the proposed end-to-end procurement process which indicates at a high level the roles for Ofgem, National Grid Electricity System Operator (ESO), distribution network operators (DNOs), the lead procurement agent and distributed energy resources (DERs) service providers – both as anchor generator (AG) and top-up service (TUS) providers. As part of this work, the Procurement and Compliance (P&C) workstream has engaged with various stakeholders to review options and come out with recommendations for:

- the lead procurement agent
- contracting
- settlement and funding.

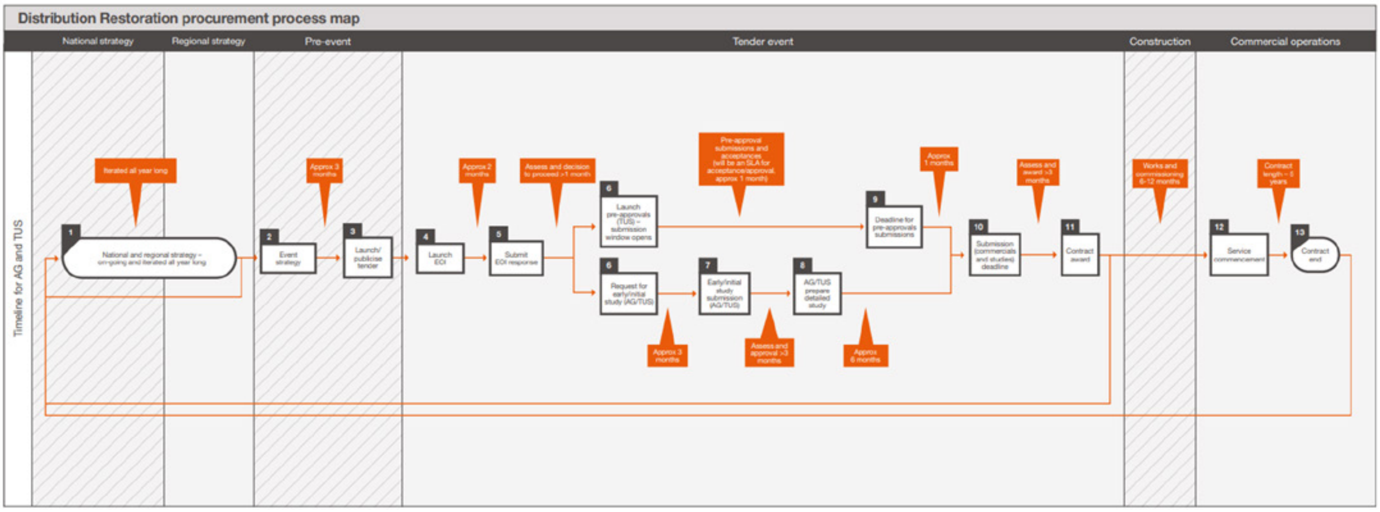

Figure 4: Procurement process timeline

Working closely with the other workstreams, the functional requirements for a distribution restoration service, and the "rules of play" to help govern the development of distribution restoration zones (DRZs), were also set up. To incorporate this distribution restoration service, the P&C workstream have coordinated the drafting of potential codes changes through a project code working group of code specialists across ESO, SP Energy Networks (SPEN), TNEI, the Energy Networks Association (ENA) and Cornwall Insight.

The Procurement and Compliance workstream considered the different high-level phases of procurement processes, such as those mature processes used by National Grid ESO and the newer flexibility service processes used by DNOs. The high-level phases which have been developed for the distribution restoration service are national strategy, regional strategy, pre-event, procurement event, construction and commercial operations.

The national and regional strategy phases will set out the needs for running a procurement event. The pre-event phase involves strategising and planning for the procurement event as well as any engagement required.

The procurement event phase involves all the elements required to end in contract award, including testing/ feasibility studies, submissions and assessment.

The construction phase will be where any required enabling works for assets happen. Finally, the commercial operation phase is the management of the contract across the duration of the contract length.

Following the detailed review of the industry codes, the codes work has progressed to developing legal text draft changes and solutions to enable Distribution Restoration.

Draft legal text has been developed for the Grid Code, Distribution Code and the System Operator Transmission Owner Code (STC). The proposed legal text changes for the Grid Code and Distribution Code have been progressed via the code modification GC0156: Facilitating the Implementation of the Electricity System Restoration Standard. The STC legal text changes have been progressed via a code modification for Distribution Restoration, which was raised in early 2023.

A more detailed review of the commercial codes has also been undertaken and solutions proposed to enable Distribution Restoration. The key codes considered are the Connection and Use of System Code (CUSC), Balancing and Settlement Code (BSC) and the Distribution Connection and Use of System Agreement (DCUSA). These changes are being progressed via code modifications and issue groups, for implementation by the end of 2023.

A summary list of the key discussions that have been held during 2021 to agree the required changes to the codes are as below:

- How to deal with non-CUSC parties participating in restoration services.
- How to capture Distribution Restoration service providers and their obligations in the Grid Code and Distribution Code via the definitions and legal text drafting.
- How to deal with DER providers and fuel compensation payments within the BSC.
- The impacts on the DCUSA with potential increased DNO spending due to a new Distribution Restoration service.

3.3 Stakeholder Engagement

Throughout the development of these specifications, the P&C workstream have actively engaged with various stakeholders including DER providers, aggregators, the Department for Business, Energy and Industrial Strategy (BEIS), Ofgem and the DNOs via the Open Networks project (ENA), to examine the options and agree the best solution to take forward.

This has been done through:

- P&C progress updates through the Distributed ReStart 'The Live Trials Stage' podcast event
- stakeholder webinars – one for updating DER providers on progress, and two more as part of the P&C Test Procurement Event
- a Test Procurement Event over the summer 2021
- presenting at various industry forums including: ESO's incentives meeting with Ofgem, Energy Networks Association's (ENA) Commercial Operations Group, ENA's Flexibility Services workstream 1A and ESO's Whole Electricity System Joint Forum
- regular monthly meetings with Ofgem and BEIS through ESO's Restoration team's tripartite sessions
- bi-lateral meetings with DER providers and DNOs
- regular checkpoint meetings with other teams developing similar DER-based services such as the Regional Development Programmes (RDPs), Power Potential, Resilience as a Service (RaaS)
- conferring on legal matters with contract experts in Shakespeare Martineau and ESO's Legal team, liaising with the ESO's Distribution System Operator (DSO) team
- seeking advice on regulatory matters from RIIO price control leads within SPEN, ESO and Ofgem through various meetings.

3.4 Final Proposals

Following extensive stakeholder engagement, the P&C workstream has produced a set of final recommendations and service designs, which were approved by the Distributed ReStart Project's Steering Committee. The final proposals are:

1. The end-to-end procurement process is the primary deliverable, and following stakeholder input, the AG and TUS processes have been aligned as part of the service designs. To view this process, download *Distribution Restoration Procurement Process Map*.
2. As part of the discussions on the proposed procurement process, the lead procurement agent has been agreed to be ESO until a suitable point in time when a review of the process should be held for instance around December 2026, when the new Electricity System Restoration Standard, which has a stronger focus on regional restoration, is planned for rollout. At this stage, depending on the outcomes of other industry-wide

initiatives and following direction from Ofgem, the process can be evolved accordingly. For more background on this, see section 3.3 in the P&C final report, *Distribution Restoration future commercial structure and industry codes recommendations*.

3. For the settlement and funding aspect of the process, ESO will cover DER contract costs, reclaiming costs through its price control, and the DNOs should recuperate their network upgrade and automation system costs through their own price control. Ofgem have clarified that provisions in ESO RIIO-2 and DNO ED2 plans can be made as required, especially for any initiatives supporting net zero ambitions. For more breakdown of considerations made, see section 9 in the P&C final report.

4. To supplement the changes in codes and to capture roles and obligations effectively, a tripartite contract is recommended which will use the *Flexibility Services Standard Agreement* produced by the Open Network's WS1A as the boiler plate detail that underpins the contract. More on this is available in section 10 in the P&C final report and the draft contract terms are in *Appendix 2 Draft Distribution Restoration Contracts*.

5. A detailed review of industry codes was undertaken, highlighting that the key codes requiring change were the Grid Code, Distribution Code and the System Operator Transmission Owner Code (STC). This progressed to legal text draft changes. These changes will be progressed via code modifications and issue groups with a target of implementation in 2022/23. Section 12 in the P&C final report explains this detail and the track changes are captured in *Appendix 3 – Codes Legal Text Drafts*.

4. Knowledge and Dissemination

4.1 Reports and Documents List

All the workstreams, Project Direction, Organisational, Systems and Telecommunications (OST), Power Engineering and Trials (PET) and Procurement and Compliance (P&C), have delivered reports that fully satisfy the Project Direction from Ofgem. These have been published on the *"documents library"* webpage of the Distributed ReStart website. Links to these documents can be found in Table 7.

Table 7: List of project reports with links

Workstream	Document Weblink	Date Published
Project Direction	*Project Progress Report*	December 2021
Project Direction	*Project Progress Report*	June 2021
Project Direction	*Project Progress Report*	December 2020
Project Direction	*Project Progress Report*	June 2020
Project Direction	*Project Brief*	March 2020
Project Direction	*Project Progress Report*	December 2019
Project Direction	*Project Progress Report (Bi-annual)*	January–June 2019
Project Direction	*Bid document to Ofgem (NIC submission)*	March 2019
OST/PET	*DRZC Factory Acceptance Testing 1 Report*	May 2022
OST	*Distributed ReStart Lot 2 – Design Phase Final Report*	December 2021
OST	*Operating a Distribution Restoration Zone*	September 2021
OST	*Distributed ReStart Lot 2 – Requirements Phase Final Report*	September 2021
OST	*Organisational, Systems and Telecommunications Design Stage II*	December 2020
OST	*Organisational, Systems and Telecommunications Design Stage I*	October 2020
OST	*Organisational Systems and Telecommunications Viability Report*	November 2019
PET	*Demonstration of Black Start from DERs (Live Trials Report) Part 1*	December 2021
PET	*Demonstration of Black Start from DERs (Live Trials Report) Part 2*	October 2022
PET	*Demonstration of Black Start from DERs (Live Trials Report) Part 3*	October 2023
PET	*Assessment of Power Engineering – Aspects of Black Start from DER Part 2*	December 2020
PET	*Assessment of Power Engineering– Aspects of Black Start from DER Part 1*	July 2020
PET	*Report on the viability of restoration from DERs*	July 2019
P&C	*Distribution Restoration future commercial structure and industry codes recommendations*	December 2021
P&C	*Appendix 1 Stakeholder Engagement*	December 2021
P&C	*Appendix 2 Draft Distribution Restoration Contracts*	December 2021
P&C	*Appendix 3 Codes Legal Text Drafts*	December 2021
P&C	*Appendix 4 Distribution Restoration procurement process map*	December 2021
P&C	*A high level outline of commercial and regulatory arrangements*	October 2020
P&C	*Functional Requirements for Procurement and Compliance*	November 2019

A series of webinars and podcasts have also taken place throughout the project. For further details, please visit Distributed ReStart's *"stakeholder engagement"* webpage.

5. Next Steps – The Transition to Business as Usual (BAU)

5.1 Commercial Considerations

The outcomes and designs of the Procurement and Compliance (P&C) workstream will support the next round of Electricity System Restoration (ESR) tenders; the first of which is in the South East (SE) region and commenced in June 2022 with contract delivery from 2025 onwards.

The Northern Region Tender was launched in October 2022 with service delivery anticipated for Autumn 2025.

It is intended that the two processes – the traditional process and the new distribution restoration process – will be combined to run in tandem. The process designs, draft contract and the test procurement documents that were developed in this project, will require further consultation by National Grid ESO's BAU Restoration team to align with their tender plans. For both regional tenders, DNO collaboration will be a key requirement to the successful tender of DER providers to this market.

Following the initial trial in the SE Tender, the ESO will continue to evolve the ESR procurement process using provider and DNO feedback to ensure that it is fit for purpose for industry needs for distribution restoration.

5.2 Technical Considerations

Please refer to section 2.8.1 where this was fully covered and discussed.

5.3 Organisational Considerations

From a people perspective, the resourcing requirements on distribution network operators (DNOs) are mitigated by the introduction of automation. It is expected that one DNO control engineer will be capable of managing a single distribution restoration zone (DRZ) inclusive of loading the anchor to a stable operating position.

However, with familiarity and increased levels of training and confidence in automation, a DNO control engineer may manage multiple islands in parallel, allowing stable operation to be maintained by the DRZC. This is not recommended for initial rollout but mitigates against an exponential engineering requirement.

From a DER perspective, the anchor DER is required to have sufficient engineering resource to deliver against this requirement within eight hours of instruction (from the lead DNO) to the point of energisation. This also applies to any top-up service providers from the point of DRZ instruction.

As Distributed ReStart will be the first process to require this capability within DNOs under an emergency condition, it is essential that training focuses on this specific capability despite the support received through automation.

6. Closing Statement

In closing, some of the key findings from the Distributed ReStart project are:

This concept can harness the growth of distributed energy resources (DERs) to provide bottom-up restoration requirements – Over the past three years, Distributed ReStart has proven this capability with thorough testing, live trials and stakeholder engagement of the commercial, technical and organisational designs.

DERs can contribute towards Electricity System Restoration Standard (ESRS) compliance – The new standard requires 60% restoration of demand in all parts of the country within 24 hours and 100% in five days. We see our proposals as supplementing traditional restoration services and helping to achieve this.

Distribution restoration is technically complicated – There is no "one size fits all" solution as all Distribution Restoration Zones (DRZs) will be different. The costs for implementation are likely to vary widely across DRZs.

Enhanced role and requirements from distribution network operators (DNOs) and DERs in the whole process – From regional strategy development through to the organisation and coordination of a Distribution Restoration Zone Plan (DRZP).

Use of the automated Distribution Restoration Zone Control (DRZC) system – A pure "manual" DER-based restoration will be slow and difficult to manage. Our DRZC designs support automation and acceleration of the process, which could help meet the ESRS regional restoration targets.

Doing the right thing for all participants – The proposed procurement process provides a more open and transparent route to market for DER providers, through a technology agnostic competitive tender route.

The importance of being stakeholder-led – Co-creation with DER stakeholders, DNOs and other industry expertise through numerous webinars, bi-laterals, exercises, live trials and networking with various key industry forums.

Further industry engagement is still required before this can fully transition into business as usual (BAU) – There are many learning points to consider, however the timeline for restoration service tenders means there is urgency to get this mobilised.

Future participation in distribution restoration might be summarised as shown in Table 8.

Table 8: Future participation in distribution restoration

WHO	• DERs • DNOs • Transmission Owners (TOs) • National Grid Electricity System Operator (ESO) • Ofgem • Equipment and service providers.
WHY	• All industry parties have a role in restoration, however it is delivered. • All parts of the industry will need to work together to satisfy the challenging new ESRS. • Consumers, government, Ofgem and others expect DERs to be utilised if effective. • Development of new restoration services and capabilities aligns with other smart network and flexibility goals. • Restoration is a critical capability and an essential service to ensure social and economic well-being of the nation.
HOW	• Engage with ESO/DNOs on strategic review of requirements and opportunities in each zone. • Develop organisational capacity to support a distribution restoration process. • Implement equipment modifications and enhanced communications and control as required.
WHERE	• Across all of Great Britain on a zonal basis, focusing on specific areas of opportunity.
WHEN	• As per the national strategy for ESRS and the timing of existing contracts and the South East and Northern tenders.

Appendices

Appendix 1: Abbreviations and Acronyms

Abbreviation	Definition
ADMS	advanced distribution management system
AG	anchor generator
BAU	business as usual
BEIS	Department for Business, Energy & Industrial Strategy
BESS	battery energy storage systems
BIL	basic insulation level
BLPU	block load pickup
CA	connection agreements
CB	circuit breaker
DER	distributed energy resources
DMS	distribution management system
DNO	distribution network operator
DRZ	distribution restoration zones
DRZC	Distribution Restoration Zone Controller
DRZP	Distribution Restoration Zone Plan
DSO	distribution system operator
DT	definite time
EMS	energy management system
EMT	electro-magnetic transient
ENA	Energy Networks Association
ESO	electricity system operator
ESQCR	Electricity Safety, Quality Continuity Regulations
ESR	electricity system restoration
ESRS	Electricity System Restoration Standard
FAT	factory acceptance testing
HiL	hardware-in the-loop testing
ICCP	Inter-Control Centre Communications Protocol
IDMT	inverse definite minimum time
IP	Internet Protocol
LJRP	Local Joint Restoration Plan
LV	low voltage
NETS	national electricity transmission system

OEM	original equipment manufacturer
OPTEL	operational telephony network
OST	Organisational, Systems and Telecommunications workstream
P&C	Procurement and Compliance workstream
PET	Power Engineering and Trials workstream
PLL	phase lock loop
POW	point of wave
RaaS	Resilience as a Service
RDP	Regional Development Programme
RRRV	rate of rise of recovery voltage
RTDS	real time digital simulator
SCADA	supervisory control and data acquisition
SCR	short circuit ratio
SE	South East
SPEN	SP Energy Networks
STC	System Operator Transmission Owner Code
TO	transmission owner
TOV	temporary overvoltages
TRV	transient recovery voltage
TUS	top-up service
WTG	wind turbine generators

Appendix 2: Independent Commentary

Independent Commentary on the Final Findings and Proposals Report of the Distributed ReStart Project

02/11/2022

Prepared by Simon Harrison, Nick Jenkins, and John Scott

We are electrical power engineers, each recognised for our contributions to thought leadership in how the GB electricity system needs to change to address the challenges of decarbonisation. We have been members of the advisory panel to the Distributed ReStart Project and have thus seen its evolution from beginning to end, whilst being one step removed from the activity itself. None of us have been remunerated for our involvement, meaning we have been and are able to act independently of National Grid ESO, SP Energy Networks and TNEI.

The Distributed ReStart Project (the Project) set out to address a major gap in knowledge and practice on the journey to decarbonisation. With the increasing decentralisation of generation, the closures of conventional large synchronous generators and the rise of convertor-connected generation and energy storage at all scales, it had become apparent that black start options beyond the traditional centralised approach were needed for the GB power system. There is no international precedent for this, although some other work overseas has been underway at the same time as the Project.

Making progress in this area was known to be and has proven complex, involving not only ground-breaking work in electrical engineering, but also telecommunications, codes and standards, procurement, and in the development of organisational and human capabilities (supported by automation). Distribution network operators will increasingly play a vital role in an area of competence largely new to them. Much new internationally important knowledge has been gained and documented and, importantly a body of expertise of practice built up amongst a wide group of industry professionals. The project has paid particular attention to disseminating its findings – both positive and negative, and has been innovative in how this has been achieved, especially during the pandemic. It has also been a model for good collaboration, not just between the consortium members but a much wider group of network operators, industry specialists, test facilities, and commercial parties such as small generators.

During the course of the work the context for the project has shifted from an exploration of commercial alternatives to conventional black start service, to the development of a vital building block for GB's energy decarbonisation. The importance of this work should not be under-estimated and there is national strategic value in both the findings and for their significance to be understood by industry and amongst policymakers and regulators.

The project has taken industry knowledge and maturity to the point that:

- The industry has a good measure of understanding of what it takes to deliver a Distributed ReStart under a number of particular use cases.
- Technology and methodologies have been developed that give confidence that these use cases and wider applications can be implemented.
- Unexpected engineering challenges and phenomena have been discovered and obstacles overcome, using solutions that can be expected to have wide application.
- The industry has gained confidence in understanding how Distributed ReStart services might be procured from the landscape of contributors within a restart zone.
- The industry has an appreciation of the organisational issues involved in a Distributed ReStart, and how to support the complexity involved with automation.
- Live trials have been conducted to, as far as possible, prove that Distributed ReStart works in practice, although it should be noted that these trials (understandably) did not go as far as taking real customers off supply and reconnecting them using the Distributed ReStart arrangements.

- There has been widespread dissemination and comprehensive documentation of findings.
- It is reasonable that the project is brought to a "soft close" at the current stage, due to constraints on power system access that are delaying the final stage of work. We note that the project team is conscious of the importance of the outstanding trials (Redhouse BESS site) that are planned for mid-2023, and the steps needed to assess and report on these later in the year as an integrated part of the Distributed ReStart project's website and records.

The Final Findings and Proposals report has many merits but it is our view that the engineering and technical learning from the project warrant a higher profile, notwithstanding that this is described in the detailed supplementary reports. We observed these learnings include: block load pick-up; vacuum circuit breaker TRV and RRRV challenges; DRZ automation; grid-forming power convertors; PLL performance and stability; and protection operation under low-SCL energisation from battery energy storage. To this should be added engineering management challenges associated with running live trials, such as: equipment owned by third parties; insurance; safety; measurement systems and evidence gathering. The knowledge gained in working through these challenges is of immense importance if Distributed ReStart capability is to be migrated to Business as Usual across a range of network contexts.

We note that operational requirements have resulted in the report being written prior to undertaking the live trials at Redhouse substation. These trials are of particular importance because they involve a battery anchor generator operating in conjunction with a grid-forming convertor, and testing of the DRZ Controller automation. These are firsts for the GB system and will be of international interest. Notably, the Redhouse trials will be the closest demonstration to "Business as Usual" operation of all the tests to date.

The Redhouse tests involve a convertor-connected battery energising a power island that contains other DER sites, so has the potential to provide learning about how Distributed Re-Start interacts under changing electrical system characteristics including low short circuit level and inertia levels, which are now being experienced nationally as synchronous generation is supplanted by generators connected to the system through power convertors.

Importantly, it will also be the first time a DRZ controller, an automation device developed as part of the Project, is tested in a live trial environment so will also allow the integration of the component elements of the Project to be tested and demonstrated.

We note in the context of this discussion about the Redhouse trials, that highly unusual and potentially concerning events occurred in August 2021 where oscillations arose twice on the Scottish network, resulting in voltage swings of some 14kV. These events are still being investigated and the root cause has not yet been established. It is possible that convertor-connected generation and PLL instability is involved and these are matters of considerable relevance to the secure operation of the national system at large.

In view of the foregoing, it is of particular importance that findings from the Redhouse trials are captured and disseminated in the same thorough way as in the rest of the Project. We would encourage the Redhouse team to consider how maximum learning can be drawn from the trials, including the understanding of stability margins and any opportunities to validate the modelling, which for this topic can be problematic.

We understand that the proposed next step is for Distributed ReStart capabilities to participate in tenders for initial deployment, competing with traditional providers of black start service. The value of this being deployed in a "fully commercial setting" is high, as it will galvanise and focus attention on resolving outstanding details. This is one way of embedding the knowledge and practice discovered during the Project within the industry. However we believe this to be an unusual way to build on the findings to date of what essentially was a research, development and demonstration project. As regards Distributed ReStart deployment, the tender process could have successful or unsuccessful outcomes, and we comment below on each.

If the Distributed Restart tender succeeds

A successful tender will place remaining activity to develop Distributed ReStart within a commercial operating environment, effectively creating a live pilot. This will provide a focus to drive implementation forward, but may dilute the emphasis on learning and optimising what should be viewed as a development activity going through scale-up. Currently we would assess Distributed ReStart to be at TRL (Technology Readiness Level) = 7, while commercial operation would normally commence at TRL = 8 or 9. We acknowledge that assessment of TRL level is not precise, but in view of the learning yet to come from the Redhouse trials we believe a current TRL of 7 expresses that a number of unknowns remain outstanding.

Regarding a successful Distributed Restart tender, areas that occur to us of potential concern might be:

- The degree to which the host DNO commits, bearing in mind this could be unfunded activity.
- How anchor and other generators commit to ensure adequate 24/7 availability and staffing.
- How abnormal network and generation configurations in normal service are responded to.
- How network and generation developments and changes are analysed and dealt with to ensure ongoing viability of ReStart plans.
- How operational processes and staff training are handled, and experience gained of the best balance between manual and automated actions.
- How capabilities are exercised and kept fresh.
- How learning from all the above is captured and shared.

If the Distributed Restart tender fails

A failed tender, meaning that no Distributed ReStart capabilities form part of the tendered regional restoration services, will require an alternative course of action and investment such that experience that has been built progressively, with hard-won know-how gained, does not dissipate.

Failure in the tendering process could create a requirement for further development to take place under more controlled conditions and in a manner more consistent with planning a rollout at scale in the future.

Issues such as DNO commitment to this additional work, how to handle network developments and changes, organisational processes, and staff capabilities could be developed further, and appropriate actions taken. In our view this would require a further, funded project such that this is undertaken purposefully and until such time as a successful tender could be made.

Acknowledging that Distributed ReStart is new, it is optimistic to expect it to compete with established restoration providers on price, as price will fall with application experience and learning. We would urge consideration of an approach that financially supports early applications to remove this barrier and help drive cost reduction, in the same way, for example, that cost reduction in offshore wind has been enabled through support. Financial support could be structured to ensure learning from initial implementations of Distributed ReStart are widely disseminated across stakeholders. Conversely, allowing experience and know-how to be lost would amount to wasting the customer and company money that has been invested in the project. This would delay GB establishing effective restoration plans for the future power system, and cast doubt on the ability of the sector and its regulatory framework to innovate at scale and with commercial service providers.

Going forward there is a risk that withdrawal of conventional restart facilities from the market might occur at a faster pace than learning for Distributed ReStart enables it to be deployed at more complex locations. This could result in shortage of restoration capability in parts of the country. One way to manage this risk would be to support targeted further work into different, more complex, use cases, that probed the limits of application.

We are of the view that the above duality concerning tender outcomes should be recognised in the report, with actions recommended for each outcome.

Overall, we believe that:

- The Project has more than met the objectives agreed with Ofgem.
- The Project has produced six-monthly progress reports and has engaged well with ourselves and the wider energy industry as the project progressed, which included the challenges of the pandemic.
- The Project has created new knowledge and know-how of high value to the industry and to customers (in that it moves forward substantially the sector's ability to deliver an affordable decarbonised electricity system). Technical findings are summarised and collated within the final findings report, functional and design specifications, which we believe will support generators, network operators and others with implementation in their contexts.
- The conduct and dissemination of findings has been of good quality, and adapted well and innovatively to the constraints of the pandemic.
- The project has interacted constructively with its advisory panel, providing helpful information and responding to advice offered.

Our recommendations, as the Project concludes but the important journey towards Distributed Restart continues, are as follows:

1. **Explicit steps are taken to maintain momentum** in the journey to deployment, whether through a successful tender process or otherwise, to avoid loss of embedded know-how amongst all parties.
2. **A continuing level of rigour is applied** to knowledge capture and dissemination going forward as was applied during the Project, until such time as Distributed Restart is considered 'Business as Usual' across diverse system contexts.
3. **Measures are taken to safeguard the documentation** into the indefinite future, such that access is not impeded
by broken internet links and such like. Continuing access is vital to value realisation.
4. **The Redhouse live trial continues beyond this final report and needs to be documented.** Findings should be captured and integrated within the Project catalogue, and a supplemental Final Findings report issued if appropriate.
5. **The names and roles of leading individuals and organisations involved should be recorded**, and held along with the documentation, to maximise engineering networking and promote access to detailed know-how. This would be fully consistent with practices in other engineering sectors and in academia.
6. **DNOs should be incentivised** by regulatory frameworks to champion Distributed Restart and invest in it, as they form a key element of the process and are not currently engaged as a matter of routine to this level of participation in system restoration.
7. **If the regional tender is not successful**, further consideration is given to financial support to allow Distributed Restart to move through the deployment learning curve such that costs reduce to become competitive.
8. **Evolution of Distributed ReStart** is strategically important for the national decarbonisation agenda and further consideration should be given to the risk that for complex applications it does not evolve through market processes in a timely fashion. Further investment in research and development in this area would build on the success of the project to date.
9. **The extent and technologies of converter connected distributed generation** continue to evolve rapidly and its role and capabilities in Distributed ReStart require further research and investigation. The proposed Redhouse trial and demonstration of a DRZ Controller are particularly important next steps.
10. **The reducing short circuit and inertia levels of the system and other emerging changes in system dynamics** may have impacts on Distributed ReStart that the Project has not assessed. We recommend further analysis in this area.
11. **Engagement with policymakers and regulators.** There would be considerable benefit in the leadership of the Project's partners engaging with policymakers and regulators to explain not just its findings but why these findings matter in the context of energy decarbonisation, highlighting the contexts where further work is needed for BAU application. Noting current the TRL maturity level, caution is recommended regarding the desirability and mechanisms of leaving the next steps solely to market solutions. Next steps are not only in the national interest strategically, but key to ensuring value to customers for the project investments to date.
12. **Recognising the achievements to date**, the team of people from National Grid ESO, SP Energy Networks and TNEI should be congratulated. We believe this project to be a deserving candidate for industry innovation awards, which would also increase its profile and help to disseminate its findings further. We believe the findings from this project are of international interest and channels such as CIRED and CIGRE should also be explored for dissemination.

National Grid Electricity System Operator
Faraday House
Warwick Technology Park
Gallows Hill
Warwick
CV34 6DA
United Kingdom

Registered in England and Wales
No. 11014226