National Grid ESO

Distributed Restart

DRZC FUNCTIONAL DESIGN AND TESTING SPECIFICATION

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1 EXECUTIVE SUMMARY

Global, regional and country organisational policy to address climate change over decades has driven change in the global electricity industry as we move to cleaner sources of electricity generation. One resulting impact in many countries including the UK, that is continuing at pace, is the transition of large scale transmission connected generation to increasing levels of smaller scale distribution network connected generation. This transition to distributed energy resources (DER) in Great Britain while supporting many benefits also results in many challenges that are presently being addressed.

The Distributed Restart project is exploring how DER in Great Britain can be used to restore power in the highly unlikely event of a total or partial blackout of the National Electricity Transmission System. This process known as Black Start is currently a transmission-led approach of starting large generators and energising a skeleton transmission network. The Distributed Restart project aims to resolve how to bring the organisational coordination, the commercial and regulatory frameworks, and the power engineering solutions together to achieve Black Start from DER.

This functional design report is a key element of the power engineering solution element. The power engineering solution is based on the concept of a bottom up network restoration process from distribution networks to transmission level, to provide a safe and effective Black Start service. The Distributed Restart black start process is based on distributed restart zones (DRZ). Each DRZ would be restored as an electrically isolated island network using DER within each DRZ island. The distributed Restart team has identified the need for a DRZ controller (DRZC) to assist in automating the process of restoring customer supplies in each DRZ island and then synchronising DRZ islands with each other and the transmission network to support the transmission network black start process.

Smarter Grid Solutions (SGS) has worked with the Distributed Restart team to develop a DRZC functional design that will provide the monitoring and control required throughout the DRZ island black start process, utilising a wide range of expected DER types. The functional design covers 7 key stages in the DRZ island black start process:

Stage 0: Pre-Black Start period where the DRZC will continually monitor the system viability to deliver a DRZ island black start

Stage 1: When a black out condition is declared the DRZC will support the preparation and initialisation for a DRZ island black start.

Stage 2: Ensure key DER are available and ready to support a black start.

Stage 3: Commence energising a preconfigured DRZ island skeleton network and proceed to expand customer supply restoration by switching in further distribution substations, further supporting DER and transmission circuits.

Stage 4: Maintain DRZ island stability throughout the black start process.

Stage 5: When instructed, resynchronise with other DRZ island networks and ultimately to the transmission network

Stage 6: On completion of the DRZ island black start process and once connected to the transmission network, restore various distribution network elements including modified protection settings and any primary substation supplies that could not be accommodate during the island condition.

The DRZC solution presented is based on a software platform developed by SGS for active network management (ANM) and DER management applications (ANM Strata). The software platform is very flexible and could be developed to meet any of the Distributed Restart project four extreme organisational model cases. The four organisational models are characterised by:

- The degree of automation, i.e. a largely manual process versus one that relies heavily on automation of processes;
- The lead organisation for the restoration process, which may be the single, national ESO or the local DNO.

The DRZC solution functional design developed here has been based on data and feedback provided by the Distributed Restart team. The functional design offers a high degree of automation which could be increased further to reduce control room staff requirements as focus moves from the trial phase to wide scale deployment.

The DRZC solution architecture would suit wide scale deployment. The architecture has two basic layers.

1. A central control room layer that provides control and monitoring as the DRZC progresses through 7 stages of DRZ island black start restoration.
2. A local fast response control layer that responds to protect the stability of the DRZ island from destabilising events such as a major loss of DER or demand and supports synchronised switching onto other DRZ island networks and restored transmission networks.

The functional design and physical architecture considers the interface and communication requirements with a focus on reducing the need for data miles of fast data communications through the use of a single local fast response control layer.

The SGS central control room layer (ANM Strata) could cater for hundreds of DRZ islands in parallel during network black start operations and hence one central platform per Distribution Network Operator would be feasible.

ANM Strata is being deployed in several UK DNO control rooms and has dual redundant servers and fail over features to meet stringent availability requirements. SGS has stringent organisational procedures in place to protect against cyber security issues during product development, deployment and ongoing operations and continue to work with UK DNO clients to meet developing guidance and standards in this area.

2 DOCUMENT ISSUE CONTROL

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[1] Document Update Request. SGS has an electronic document control system. When a document is being developed it is put into a process to develop, review, check, approve for issue. This is referred to a DUR process and a unique ID number is raised for each DUR process referred to as the DUR number.

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3 INTRODUCTION

3.1 Project Background

The Distributed ReStart (D-Restart) project is a partnership between National Grid Electricity System Operator (NG ESO), SP Energy Networks (SPEN) and TNEI (specialist energy consultancy) exploring how distributed energy resources (DER) can be used to restore power in the highly unlikely event of a total or partial shutdown of the National Electricity Transmission System. That is, can DER be utilised to establish distribution power islands and be expanded to energise the transmission network utilising a 'bottom up' strategy.

Given the technical and operational challenges associated with establishing, growing, maintaining and restoring a distribution power island (typically at 33 kV), and the limited human resources that may be available at the time of a Black Start (a DNO control room may have as few as two engineers on shift during the night), it is likely that some level of automation will be required for the process to be technically and operationally viable. The project has introduced the concept of a Distributed ReStart Zone Controller (DRZ Controller or DRZC) that will enable monitoring, control and coordination of a range of DER and network resources to provide Black Start services.

A key output from Stage 1 of the Distributed ReStart project will be a 'DRZ Controller Functional Design Specification'. The report(s) are to include information to a level of detail sufficient to be used in a technical requirements specification that would inform the detailed design and subsequent testing of a solution. The deliverables from Smarter Grid Solutions (SGS) will be combined, by the client team, with other information to produce a vendor neutral DRZC requirements specification that they will publish in a future project report.

3.2 Purpose of Document

This document is a Functional Design Specification (FDS), which describes how the defined functional requirements are addressed.

3.3 Document Structure

The remainder of this document is structured as follows:

The DRZC development scope and the context with regards to other systems that the DRZC system will potentially interface with are set out in section 4. Section 5 provides a summarized overview of the basic DRZC functions and associated architecture based on the detailed DRZC development information provided in sections 6 to section 10.

Based on the requirements set out in the project ITT document, reference 1, the various meetings with NG/SPEN and further information provided by NG/SPEN and gathered by SGS, Section 6 documents the development of the DRZC use cases which were then developed into a DRZC architecture documented in section 7. Further key areas of consideration are discussed in section 8. The use cases and DRZC architecture are aligned with a set of numbered functional requirements set out in section 9 with further non-functional requirements numbered and set out in section 10.

3.4 Intended Audience

This document will be used by the Distributed Restart team to validate and approve the functional design in readiness for the next stages of the project. The document will also be used by Smarter Grid

Solutions (SGS) development team to further define the design, build and testing specification for the DRZ controller if SGS are selected to play a role in the next stages of the project.

3.5 Stakeholders

Table 3-1 lists the various stakeholders involved and what their needs are.

Table 3-1: Stakeholders

Stakeholder	Needs
SGS	Supplier of function design and test specification, communications requirements and Control interfacing requirements.
National Grid ESO	Contracting entity with SGS and D-Restart team member and technical advisor.
SP Energy Networks	D-Restart team technical and delivery lead partner.
TNEI	D-Restart team specialist technical advisor, network performance modelling.

3.6 Scope

This document covers the agreed scope of supply for the Distributed Restart project Stage 1 as defined in Reference 1 with amendments agreed with the Distributed Restart team incorporated as the FDS was developed.

3.7 Exclusions

The following areas are explicitly excluded from this document and will be considered in future work.

- Detailed design work that SGS consider would be part of the next phases of the development. This includes the work that would be performed by the vendor awarded the contract to implement the solution based on the detailed requirements specification developed by the Distributed Restart team.

3.8 References

This document references the following external sources of information.

[1] National Grid document “Instructions to Tender D ReStart Controller Consultancy Tender”, December 2019.

[2] Schweitzer Engineering Laboratories “Protection and Testing Considerations for IEC 61850 Sampled Values-Based Distance and Line Current Differential Schemes” 2019

[3] Siemens “Three-cycle versus five cycle interrupting time” 2012

3.9 Terminology

This section describes the terminology used within this document.

Table 3-2: Terminology

Term	Definition
AG	Anchor Generator
ANM	Active Network Management
ANM Strata	Core Active Network Management product developed by Smarter Grid Solutions
API	Application Programming Interface
AVR	Automatic Voltage Regulator
BS DER	Black Start DER, DER contracted to provide black start island support services.
BESS	Battery energy storage system
BS	Black Start
CB	Circuit Breaker
CSV	Comma Separated Value
DER	Distributed Energy Resource
DERMS	Distributed Energy Resource Management System
DNO	Distribution Network Operator
DRZ	Distributed Restart Zone. Defined area of network that will form an isolated section of the distribution/transmission network to be re-energised after a wider network supply black out. The isolated network section will form an independent islanded section of network that will then be resynchronised to other DRZs or the transmission network.
DRZC	Distributed Restart Zone Controller. The controller that will initiate and expand an isolated island network using connected DER and resynchronise this island with other island network sections or the transmission network to effect a black start of the Transmission and distribution networks across the UK.
DSO	Distribution System Operator
EDR	End-point protection and response, relating to cyber security.
FMEA	Failure Mode Events Analysis
NGESO	Nation Grid ESO is the GB national electricity transmission network system operator.
GE	General Electric, manufacturers of the PowerOn Distribution Management System
HAZAN	Hazard Analysis
HAZID	Hazard identification
HH	Half Hour
HMI	Human Machine Interface

Term	Definition
ICCP	Inter-Control Communications Protocol, a communications protocol defined as part of IEC 60870-6 standards
ISMS	Information Security Management System
ISSG	Information Security Steering Group
LOPA	Layers of Protection Analysis
NG	National Grid
OWASP	Open Web Application Security Project (OWASP) is an online community that produces freely-available articles, methodologies, documentation, tools, and technologies in the field of web application security.
POC	Point of Connection. Point on the DNO network where DER is connected.
PowerOn	The Distribution Management System used by SPD, SPM and the majority of DNOs in Great Britain (except Electricity North West Limited) to view, manage and control the distribution network under their control
PSWG	Product Security Working Group
SDL	Security Development Lifecycle
SGS	Smarter Grid Solutions
SIEM	Security Information and Event Management
SP	Scottish Power
SPD	Scottish Power Distribution
SPEN	Scottish Power Energy Networks
SPM	Scottish Power Manweb
SQEP	Suitably Qualified and Experienced Person

4 DRZC DEVELOPMENT SCOPE AND CONTEXT

SGS has been contracted to produce a Functional Design Specification (FDS) for a DRZC with features that include:

- The DRZC must be capable of supporting the initialisation and expansion of a distribution-level power island that harnesses multiple and diverse resources to restore demand, re-energise network and resynchronise with other power islands, including a capability to re-energise transmission-level assets.
- The DRZC must have flexibility and functionality to work with the different combinations of DER which may be available in different locations within the DRZ. That must include at least one 'Anchor' generator that is capable of self-starting and subsequently provides supplies to let others restart and contribute to growing the power island.
- The DER to be utilised may include a range of different synchronous generators, wind farms, solar, batteries and other technologies connected or expected to connect to GB distribution networks. The DRZC must be configurable for the specific functionality of each DER[2] (e.g. a wind farm may be used on a constrained fixed output basis, a battery for fast frequency response for load pick up, etc.) and how each combination of DER would be coordinated.
- The DRZC must enable fast, responsive control of DER and network assets where appropriate to stabilise the power islands, taking resource availability and capability into account.
- The DRZC must have flexible control functionality to adjust response as a power island expands and more resource is connected to the islanded system.
- The DRZC must support resynchronisation functionality enabling multiple islands to be brought into synchronism across chosen boundaries.
- The DRZC must have an adequate level of cyber security, similar to other power network control systems installed[3] and recognising the critical nature of a Black Start restoration service.

Consideration is to be given to the options and necessity to utilise the existing Distribution Management System (DMS), Energy Management System (EMS), Active Network Management (ANM), DER Management Systems (DERMS) or other systems where appropriate, working in co-ordination with the DRZC, to achieve the required functionality. Consideration should also be given to the varying levels of automation/control room interaction which may be possible, along with options for the location of that control (e.g. if options exist for a primarily localised control or centralised). As far as possible the design should cater for a fall-back position of manual intervention and control[4].

The primary output from SGS for Stage 1 is three reports:

- A functional design and testing specification report for the DRZ controller
- Report on communications requirements for a DRZC

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[2] SGS' solution can be programmed to issue real and reactive power set points, or other set points such as voltage or frequency to DER, or to put into available operational modes e.g. switching BESS into a frequency control mode or a wind farm into a voltage control mode where these are available. Where constraining is utilised it is a requirement that the DER has its own constraining control system that the DRZC can issue a constraint set point to.

[3] SGS were directed by the Distributed Restart team at the project kick off meeting to base this on other power network control systems installed for SPEN

[4] Agreed with the client team at the kick off meeting on 24 Feb 2020 that control room intervention can only be taken safely at certain steps during an automated black start.

- Report on Control interfacing requirements to the different DER types

The reports must include information to a level of detail sufficient to be used in a technical requirements specification that would inform detailed design and subsequent testing of a solution.

This document details the functional and non-functional requirements for the stage 1 functional design that forms the basis for the three deliverable documents listed above.

4.1 Context diagram

Figure 4-1 illustrates the systems that will or could participate in the DRZC solution and the data interfaces that define the relationships between these systems. Where there is human operator interaction this is also represented, e.g. the DSO control room operator. In terms of a DER[5] control room, this may be manned or unmanned[6], however it is expected that the Anchor generator will have some form of manned control room. The context may alter to some degree when considering specific DRZs, i.e. there may or may not be existing ANM and DERMS systems. Interfaces are presented in a simplified manner, highlighting source and destination of information[7] exchange; note that the practical means of transfer may be through another black start compliant system[8], i.e. via the DSO DMS, by phone, text, email etc. and in general information transfer will be two way. The context diagram is not intended to show the communication routes or relate directly to the system architecture.

In terms of the DSO and ESO, during a black start there will be interactions both ways. There may be direct interfaces between the DRZC and the ESO rather than everything going via the DSO and this is reflected in the context diagram. This is a choice that NGESO and the DSOs would require to make, the context diagram reflects these potential options which would need to be pinned down at the next phase of the development process (detailed requirements specification, not part of the scope of this document).

The DRZC Data Store is representative and can be used to store historical data for long periods, e.g. ongoing monitoring of BS DER availability or it could be a shorter term storage for operational data used during the black start process, e.g. circuit load measurements retained for a short period to assist with control actions if a major event occurs. The Data Store could be linked to the DSO DMS data historian if required.

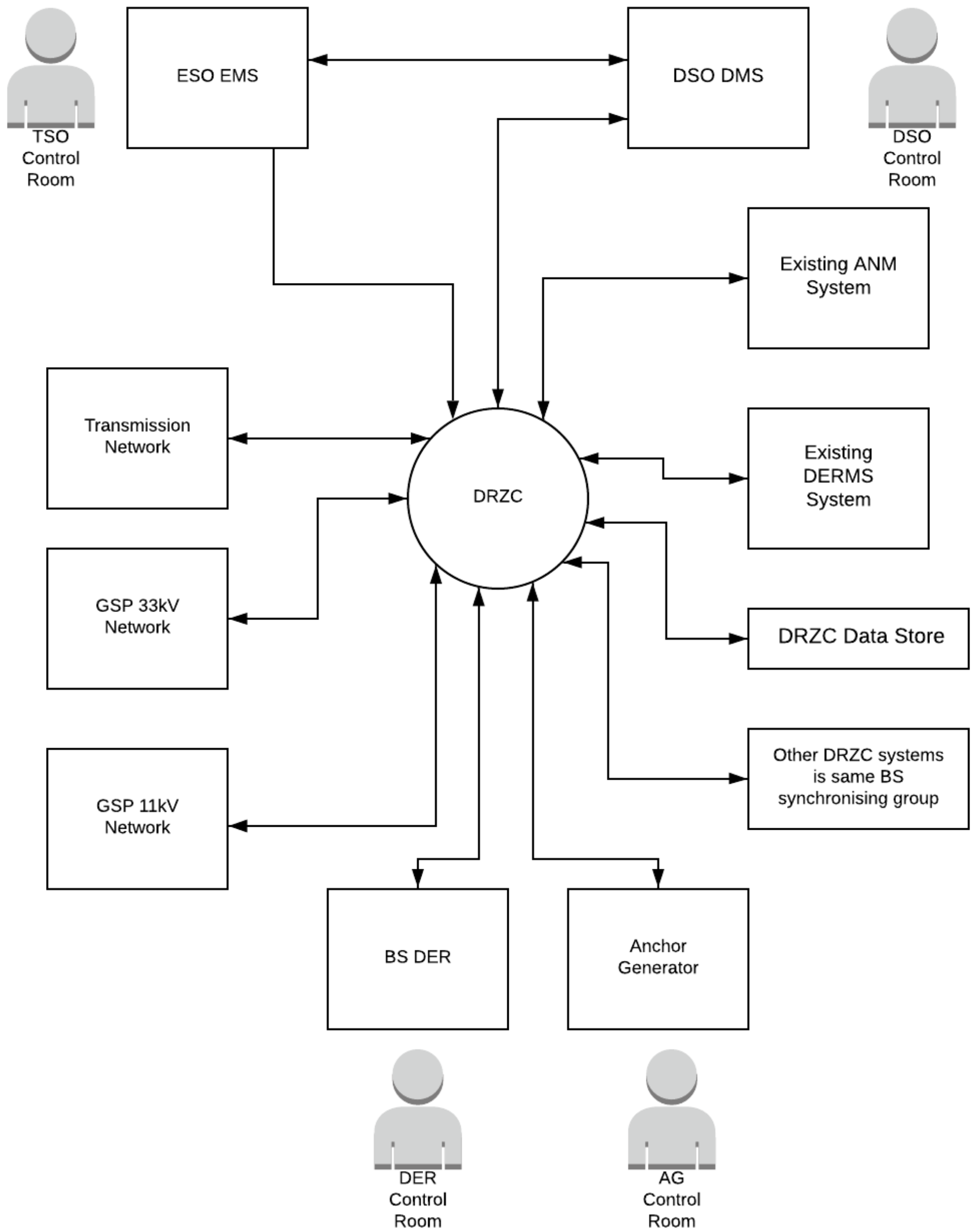
[5] DER in the context of this functional design is technology neutral and covers any distributed resource technology including all forms of electricity generation, controllable demand, energy storage and reactive power compensation.

[6] Even where DER sites such as solar, wind or BESS are unmanned, there will be a supervisory control room somewhere monitoring what is going on. These services may be part of a third party service agreement.

[7] In this context information could include various things including instructions, measurements, calculated data etc.

[8] The ESO's plan, as defined under the current BS Strategy, is to achieve an average Restoration Time across the year of 24 hours to restore 60% of national demand. The plans also identify requirements for BS Auxiliary Unit(s) to run continuously at rated output for a minimum of 3 days and that generating plant providing black start services to have fuel supplies (e.g. distillate fuel), if appropriate, to enable the power station to run for a minimum duration (ideally in the range of 3 to 7 days) following a black start instruction. The NG ITT document for this project also indicates the network will be designed to have 72 hours' independent power resilience to meet anticipated future Black Start requirements. SGS therefore assume that black start compliant systems will have resilient power sources to ensure operation for a minimum of 3 days (72 hours). This would include the ISO and DNO control room systems, associated communications systems, contracted black start service providers (DER and Anchor generators) and associated communication systems.

Figure 4-1: Context Diagram



[9]

[9] The context diagram indicates a direct interface between the ESO EMS/TSO control room and the DRZC. There is also an alternative interface via the DSO DMS/ control room. At this stage in the DRZC design process the Distributed Restart team could not confirm to SGS what the requirements would be, hence both interface routes are shown in the context diagram. The interface routes finally adopted by the Distributed Restart team would have implications on the communication requirements.

4.2 System Actors

Table 4-1: System Actors

User/Role	Example	Frequency of Use	Security/Access, Features Used	Additional Notes
DRZC	Control platform that will monitor other system readiness prior to a black start request and when instructed run through the black start sequence advising the DNO control room operator of progress and when operator action is required.	Frequent	The DRZC will be capable of communicating and controlling with all DER and network components to complete the distribution black start process ensuring protection of the Anchor generator and network stability in the process.	
NGESO Control Room Operator	The NGESO operator will issue instructions that a black out condition exists and initiate a black start.	Depends on Island configuration and level of intervention requested	Direct communications with the DRZC via the NGESO SCADA EMS would require a secure communications link that is black start compliant[10]. The alternative is communications via the DNO control room. Instructions to the DNO control room could be via various routes, phone, email, text or EMS to DMS but would need to be black start compliant.	Depending on requirements/role, this may be facilitated as an ESO-DNO (EMS-to-DMS) interface.
NGESO SCADA/EMS	Circuit breaker status data and operation	Depends on Island configuration	Data transfer with DRZC could be via ICCP protocol or similar. May also come via the DNO SCADA DMS.	
DNO Control Room Operator	The DNO operator can initiate a black start of the DNO's distribution network DRZ islands based on NGESO instructions and oversee the DRZ system restoration.	Depends on level of intervention requested	Communications with the DRZC will likely be via the SCADA DMS using an ICCP protocol or equivalent.	
DNO SCADA/DMS	Multitude of DNO network data passed	Frequent	Communications with the DRZC will likely be via the	

[10] In this context black start compliant means operationally available during the black start condition until power normal power supplies are restored. SGS interpret this to be 72 hours as a minimum.

User/Role	Example	Frequency of Use	Security/Access, Features Used	Additional Notes
	to DRZC and multitude of data passed from DRZC to the DNO SCADA DMS.		SCADA DMS using an ICCP protocol or equivalent.	
Anchor generator control engineer	Engineer responsible for ensuring the preparation to start the Anchor generator.	Occasional	Receive notifications from the DRZC or DNO Control Room operator.	
Anchor Generator control system	Automatically adjust frequency and voltage at the Anchor generator terminals, respond to set point requests from the DRZC.	Frequent	Direct communications between DRZC and Anchor generator. This may require some form of interface between the two systems.	
Other BS DER control engineers.	Engineer responsible for ensuring the preparation to start DER ready for DRZC control.	Occasional	Receive notifications from the DRZC or DNO Control Room operator.	Depending on the BS DER, there may or may not be a control engineer involved in the black start restoration process.
Other BS DER control systems	Receive and carry out DRZC instructions.	Frequent	Direct communications between DRZC and other BS DER. This may require some form of interface between the two systems.	
Other DRZC system	Control DER and Anchor generator to meet Voltage, angle and frequency targets during Island to Island resynchronising.	Occasional	If DRZC systems require to support each other's DRZ networks, this need requires to be communicated. This could be direct or via the DNO SCADA DMS.	

5 SGS DRZC SOLUTION OVERVIEW

The aim of this section is to provide a high level overview of SGS's proposed Distributed ReStart Zone Controller (DRZC) controller design. The following sub sections include a summary of the requirement, SGS's proposed solution, basic functionality of the solution, and summary details of the solution architecture.

Sections 6 to 10 of this functional design specification (FDS) provide detailed information in response to National Grids ITT that will be required to support a future detailed requirements specification for the DRZC.

5.1 Requirement

The Distributed Restart project is exploring how DER in Great Britain can be used to restore power in the highly unlikely event of a total or partial blackout of the National Electricity Transmission System. This process known as Black Start is currently a transmission-led approach of starting large generators and energising a skeleton transmission network. The Distributed Restart project aims to resolve how to bring the organisational coordination, the commercial and regulatory frameworks, and the power engineering solutions together to achieve Black Start from DER.

This functional design report is a key element of the power engineering solution element. The power engineering solution is based on the concept of a bottom up network restoration process from distribution networks to transmission level, to provide a safe and effective Black Start service. The Distributed Restart black start process is based on distributed restart zones (DRZ). Each DRZ would be restored as an electrically isolated island network using DER within each DRZ island. The distributed Restart team has identified the need for a DRZ controller (DRZC) to assist in automating the process of restoring customer supplies in each DRZ island and then synchronising DRZ islands with each other and the transmission network to support the transmission network black start process.

The Distributed Restart project has also identified four organisational models characterised by:

- The degree of automation, i.e. a largely manual process versus one that relies heavily on automation of processes;
- The lead organisation for the restoration process, which may be the single, national ESO or the local DNO.

Each DRZ island would require black start services to be contracted from local DER. Key to the restoration process is a lead DER that would provide the initial energisation of a pre-configured DRZ island skeleton network maintaining stable voltage and frequency. This lead DER is referred to as the Anchor generator. The Anchor generator also requires the ability to accept block load as distribution substations and circuits are switched into service to restore the DRZ island network and customer supplies. Hence the Anchor generator will have voltage and frequency control systems that will maintain island stability as the restoration sequence progresses.

The Anchor generator will be supported by other contracted black start supporting DER, referred to as BS DER. BS DER will cover a range of technologies including wind, solar, hydro, CHP and BESS. The DRZC will require to manage the available real and reactive power capacity of BS DER to support Anchor generator operations. This will include issuing set points to control BS DER output and also switching BS DER into alternative modes of operation where available to suit restoration operations e.g. voltage control mode when switching in transmission circuits or frequency control mode when block load switching.

While the Anchor generator will maintain stable DRZ island operations once the network has been restored as far as reasonably possible, the DRZC requires to ensure there is sufficient available real and reactive power capacity at the Anchor generator to for variations in demand and BS DER output. The DRZC also requires to respond rapidly to major events to protect the DRZ island stability e.g. major loss of block load or a sudden loss of a BS DER. Studies carried out by the Distributed Restart team show that such events will sub second removal of BS DER or block load to maintain island stability.

The DRZC requires to manage the Anchor generator, BS DER and system demand to maintain DRZ island stability until the ESO and DSO are ready to synchronise with other DRZ islands or a restored or partially restored transmission network. The DRZC will be required to facilitate and manage these synchronising operations. On completion of all synchronisation the DRZC will go through a process of handing control back to the system operators and supporting DMS and EMS systems, this may include restoring supplies to distributions substations that could not be accommodate while in island mode.

5.2 SGS Solution Basic Functionality

Smarter Grid Solutions (SGS) has worked with the Distributed Restart team to develop a DRZC functional design that will provide the monitoring and control required throughout the DRZ island black start process, utilising the expected range of DER types. SGS has used the feedback from the Distributed Restart team to confirm the systems and operators the DRZC will work with (see section 4) and to develop the DRZC functionality. This has shaped where within the four organisational models the DRZC sits (degree of automation and lead organisation). The DRZC solution presented is based on a software platform developed by SGS for active network management (ANM) and DER management applications (ANM Strata). The software platform is very flexible and the level of automation and organisational roles could be amended as the functional design progresses.

The functional design covers 7 key stages in the DRZ island black start process:

Stage 0: Pre-Black Start period where the DRZC will continually monitor the system viability to deliver a DRZ island black start.

- The DRZC will monitor the measured power export and available capacity data being sent by the Anchor generator and BS DER. This will provide an indication of Anchor generator and BS DER operational status and will also act as a communications and interface check.
- It would be a black start contract requirement for all BS DER and Anchor generators to provide real time available real and reactive power capacity and 30 minute forecasts of available capacity.
- The DRZC will also monitor the status of circuit breaker positions provide by the DNO SCADA DMS system and possibly the ESO SCADA EMS (updated on status change).
- The DRZC will also have self-monitoring functionality including heart beat signals to check communication links and system interfaces.
- The DRZC will be pre-loaded with a schedule of block load and transmission circuit switching requirements including the switching sequence. The Distributed Restart team has agreed that the schedule would be developed in an external system and then loaded into each DRZC. It should be noted that the DRZC could accept revised switching schedules at any point prior to stage3.

Stage 1: When a black out condition is declared the DRZC will support the preparation and initialisation for a DRZ island black start.

Based on feedback from the Distributed Restart team, the majority of functionality in stage 1 has been allocated to the DNO Control room operators and the SCADA DMS including:

(i) send out Black Start initiation signals to BS DER (possible DMS programming)
(ii) open/close circuit breakers to reconfigure network (DMS programming)
(iii) change protection and control settings as required (DMS programming)

The DRZC will provide confirmation of the DRZ island readiness for black start, updating this based on DMS confirmations on items (i) to (iii) and stage 0 monitoring which will continue in stage 1. It is noted that the SGS DRZC could be programmed to cover items (i) to (iii) if required.

Stage 2: Ensure key DER are available and ready to support a black start.

Based on feedback from the Distributed Restart team, the some stage 2 has been allocated to the DNO Control room operators and the SCADA DMS including:

- (i) Advise when the Anchor generator is ready to energise the DRZ island reconfigured skeleton network.
- (ii) Close the POC circuit breaker to energise the skeleton network.
- (iii) Provide permission to the DRZC to commence the DRZ island restoration.

The DRZC functions in stage 2 include:

- (i) Receiving confirmation for BS DER that they are ready to connect to the DRZ island network and provide power.
- (ii) Monitoring the Anchor generator and BS DER available power capacity.

Stage 3: Commence energising a preconfigured DRZ island skeleton network and proceed to expand customer supply restoration by switching in further distribution substations, further supporting BS DER and transmission circuits.

The DRZC will commence switching operations to expand the DRZ network and restore customer supplies. DRZC functions include:

- (i) Managing the available Anchor generator and supporting BS DER power capacity during execution of the pre-loaded block load and transmission circuit switching schedule (stage 0).
- (ii) Checking the block load and transmission circuit switching schedule based on DRZ island conditions prior to each switching operation and amending the schedule where appropriate to maximize the potential DRZ island restoration.
- (iii) Providing regular feedback signals to the DNO DMS that DRZ network restoration is progressing satisfactorily or raising alerts where problems occur or the restoration sequence is complete.
- (iv) Switching in additional BS DER when required.
- (v) Where available putting BS DER into voltage control mode prior to transmission circuit switching operations.
- (vi) Using load bank or BESS to preload the Anchor generator to increase permissible block load switching as required within available limits on the load bank, BESS, BS DER and Anchor generator.
    - a. Where BESS is being used for Anchor generator preloading, the DRZC will monitor and manage the BESS charge status and charging rate for preloading and move to frequency control mode when the block load is switched in to allow the BESS to remove the Anchor generator pre loading. At the first scheduled block load switching, if the BESS charge status will not accommodate the required Anchor generator pre-loading, the DRZC will move to a scheduled block load that does not require Anchor generator preloading support or one that can be accommodate within the BESS charge status. Following successful block load acceptance the DRZC will put the BESS into a discharge state to supply the power to support the newly accepted demand until such time that the BESS charge state is suitable for Anchor generator preloading support of the original sequence block loading.
    - b. Where a load bank is being used for Anchor generator pre-loading the DRZC will ensure there is available load bank capacity and switch to frequency control mode when the block load is

switched in to allow the load bank to remove the Anchor generator pre loading. Where required the DRZC will manage the block load switching schedule if the load bank has insufficient capacity for Anchor generator preloading at the first scheduled block load switching (this is only likely where the load bank is being used to provide any Anchor generator minimum loading requirement prior to sufficient demand being on the DRZ network).

(vii) Where available and where required putting BS DER into frequency control mode prior if this has been confirmed as suitable for stable operations.

Stage 4: Maintain DRZ island stability throughout the black start process.

At stage 4 the block load and transmission circuit switching schedule has been completed or completed as far as possible while ensuring DRZ island safe stable operations. The DRZC will ensure that on completion of stage 3 that suitable available capacity is retained by the Anchor generator and BS DER to maintain stable operations during stage 4.The DRZC functions in stage 4 will include:

(i) Monitor Anchor generator and BS DER real time and 30 minute forecast available capacity. Manage BS DER export to ensure the Anchor generator has sufficient available capacity to maintain voltage and frequency stability through governor and AVR action. This is aimed at catering for expected variations in demand and DER output variations.

(ii) Where Anchor generator and BS DER available safety margins are forecast to be too low, the DRZC will take action to shed some load. Note that stage 3 block loading would be controlled to leave sufficient available capacity margins to avoid the need to shed load during stage 4. However, if stage 4 extends for longer periods, the DRZC may be called on to take action to maintain DRZ island stability.

(iii) The DRZC will monitor RoCoF, aggregated demand and aggregated generation via a fast response controller which will respond to larger unexpected events that would threaten island stability and require immediate action to trip a sufficient level or block load demand or BS DER. The fast response controller will receive status data from the main DRZC indicating what operations are pending to distinguish between an unplanned event (loss of block load or BS DER) and a planned event (block load switch in).

(iv) The DRZC will provide regular status updates to the DNO DMS and alerts to serious events.

Stage 5: When instructed, resynchronise with other DRZ island networks and ultimately to the transmission network

The DRZC will be programmed to synchronise with other DRZ island networks or the transmission network across pre-programmed circuit breakers that are equipped for these operations. Where there is an alternative choice of synchronising circuit breakers, the system operator (ESO, or DNO control room operator) can select the circuit breaker from a list of options or the selection can be pre-programmed into the DRZC. The DRZC will manage the following during synchronisation:

(i) The DRZC fast response controller will receive voltage and frequency measurements from both sides of the synchronising circuit breaker and adjust the Anchor generator real and reactive power export set points to align the frequency, voltage and phase angle on both sides of the circuit breaker. Where required the BS DER real and reactive power set points will also be adjusted.

(ii) Each synchronising circuit breaker will be fitted with suitable VTs and measurement equipment including a check synch device. The check synch device will be set to close the circuit breaker when the frequency, voltage and phase angle are within an acceptable pre-programmed tolerance of each other. This ensures that measurements and circuit breaker closing decisions are take locally and independently of the DRZC central control platform.

(iii) Where available and where required BS DER can be switched by the DRZC into an alternate control mode prior to synchronising e.g. voltage control mode when synchronising with the transmission network to minimize voltage impacts.

(iv) The DRZC will observe the post-synchronisation stability. The DRZC will provide a 'successful resynchronisation' signal after a pre-configured period when the synchronized system is stable. The DRZC will continue to control the Anchor generator and BS DER to minimize the power flow across the synchronising breaker (assuming BS DER are not in a voltage control mode).

(v) Once synchronized to the transmission network the DRZC will continue to provide aggregated totals for real and reactive power availability on the DRZ network. This data will be available to the DNO DMS and can be made available to the ESO EMS directly or via the DNO DMS.

Stage 6: On completion of the DRZ island black start process and once connected to the transmission network, restore various distribution network elements including modified protection settings and any primary substation supplies that could not be accommodate during the island condition.

Having completed stage 5 and resynchronized the DRZ island with a restored or partially restored transmission network the ESO or DSO system operator will issue a 'termination of Black Start' signal to the DRZC. At this stage, the DMS DSO control room operator using the DMS will take control of the restoration of protection settings and disconnection of the 33kV earth at the Anchor generator. During this period, the DRZC will continue to report on the DRZ island available real and reactive power capacity to the ESO EMS and DNO DMS to allow control room operators to plan other restoration operations on the wider transmission network. During this period, the DRZC will also carry out the following:

(i) Restore the distribution system to a normal operating condition and restore any primaries that have not yet been connected. The ESO or DSO control room operator may apply frequency restrictions or power up ramp rates during this period which would need to be adhered to by the DRZC e.g. primary substations should only be energized if the frequency is above 49.8 Hz (or as agreed with the ESO), or other defined network areas may be assigned a maximum ramp rate for demand restoration such as 50 MW per minute. The DRZC needs to be capable of accepting data signals from the DNO DMS with these types of operational restrictions.

(ii) The DRZC will alert the DSO control room of any failures to restore the network configuration, or any primary substation that could not be energized, together with details of why the network restoration or energisation of primary substation failed.

(iii) Once the network is restored to normal conditions and all primary substations connected, the controller will advise the DSO control room that the Black Start sequence is complete, and that the controller is terminating its control over the distribution network.

5.3 Summary of System Architecture

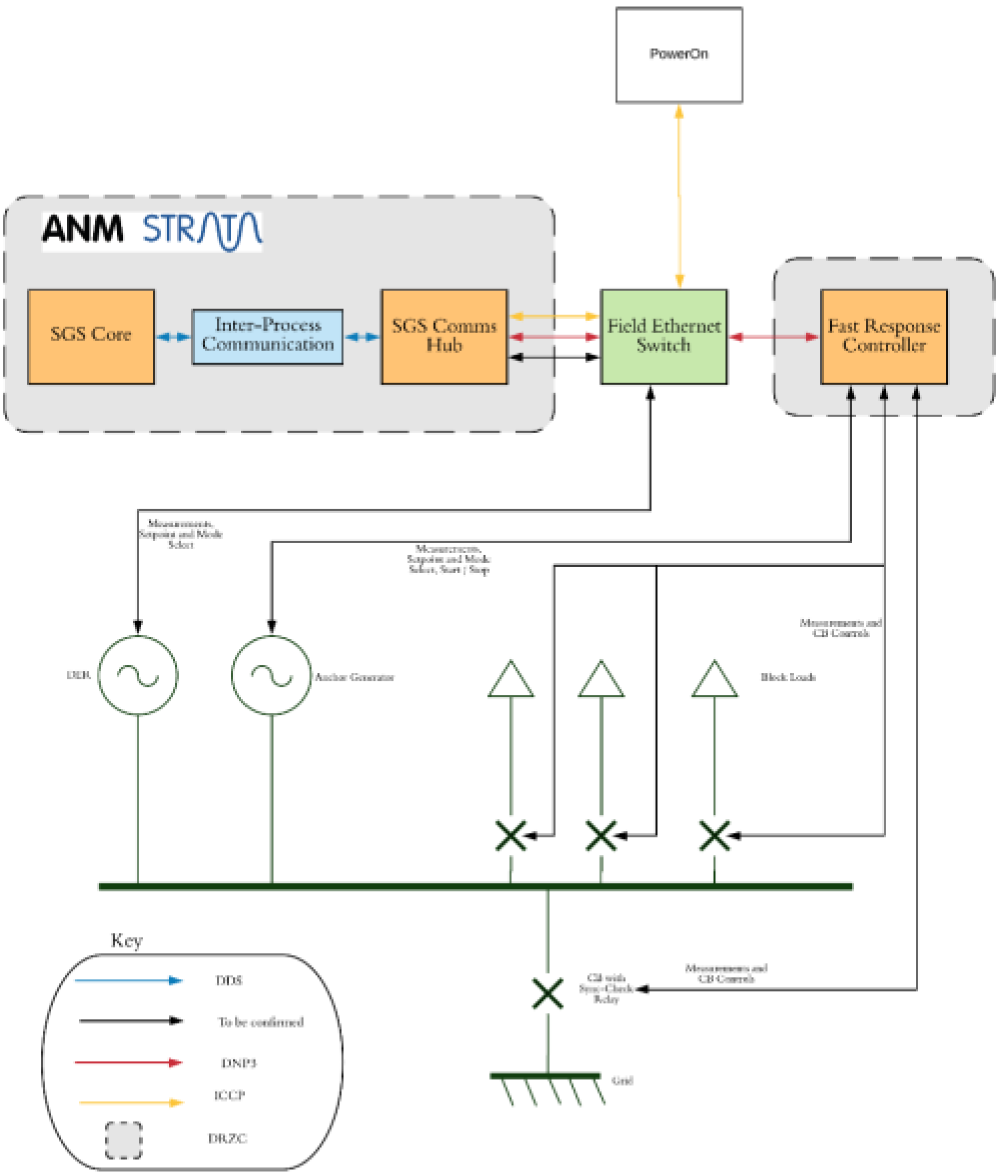
The DRZC solution architecture would suit wide scale deployment. The architecture has two basic layers.

1. A central control room layer that provides control and monitoring as the DRZC progresses through 7 stages of DRZ island black start restoration.
2. A local fast response control layer that responds to protect the stability of the DRZ island from destabilising events such as a major loss of DER or demand and supports synchronised switching onto other DRZ island networks and restored transmission networks.

The functional design and physical architecture considers the interface and communication requirements with a focus on reducing the need for data miles of fast data communications through the use of a single local fast response control layer.

The SGS central control room layer (ANM Strata) could cater for hundreds of DRZ islands in parallel during network black start operations and hence one central platform per Distribution Network Operator would be feasible. The physical architecture is illustrated in Figure 5-1.

Figure 5-1: Physical Architecture



ANM Strata is being deployed in several UK DNO control rooms and has dual redundant servers and fail over features to meet stringent availability requirements. SGS has stringent organisational procedures in place to protect against cyber security issues during product development, deployment and ongoing operations and we continue to work with UK DNO clients to meet developing guidance and standards in this area.

6 DRZC FUNCTIONAL REQUIREMENTS AND USE CASES

6.1 DER Based Black Start Restoration Stages

SGS has reviewed the Black Start restoration stages detailed in the Client ITT document and proposes a slightly modified version which now includes a Stage 0 which covers what could be a lengthy phase prior to any black start initiation requirement. The restoration stages and high level functionality are summarized as follows.

Stage 0: Pre-Black Start Initial period

This may be the only stage that a DRZC ever enters, and covers the period from commissioning to a black out situation being declared. During this period the system viability to deliver a DRZC black start requires to be monitored and continuous preparation for a black start initiation is required. The main requirements include:

- Monitoring the viability of the DRZC controlled assets to establish a Black Start Island. Anchor generator and contracted BS DER availability prior to the black start condition are useful indicators of DRZ black start viability, i.e. are the Anchor generator and BS DER exporting power.

  Historical power export or availability data analytics may point to likely availability if not exporting power prior to a black start condition. This level of DRZ network black start viability would sit on systems outside of the DRZC.

  The Anchor Generator and BS DER available real and reactive power capacity in real time along with a 30 minute forecast is required by the DRZC during the black start process and would be a requirement to be met under a black start support contract. The provision of real time available capacity to the DRZC could allow the DRZC to provide an alert of Anchor generator and BS DER concerns during stage 0 and would also act as an alert to any communication or interface issues during stage 0. Such alerts from the DRZC could be provided to the DSO DMS and/or the TSO EMS. NG/SPEN can decide if they wish this stage 0 data to be stored and where and for how long it should be stored.

  SGS recommend that the black start support contract also require the Anchor generator and BS DER issue a signal at a required interval confirming their readiness and availability. This signal could go direct to the DRZC and again would also serve as a check on the communications and interfaces between the DRZC and the Anchor generator and BS DER control systems.
- Regular updates of circuit breaker status from the DSO DMS and TSO EMS[11] system. Status can be updated by change events, e.g. the EMS and DMS can send the DRZC circuit breaker changes only when a status change occurs.
- Checking of communications and interfaces, e.g. heart beat test signal every 60 seconds. Noted that where the DRZC is receiving real time data and measurements via communication links this will act as an effective check on the communications and interfaces allowing alerts to be raised.
- DRZC platform self-monitoring event notifications (alerts) to the DNO control and the DRZC maintenance support provider.
- Logging of metrics described previously, providing regular reporting (e.g. monthly, quarterly) of DRZ asset metrics.

Stage 1: Network preparation and initialisation

[11] NGESO has indicated that the TSO EMS is currently set to timely updates for analogues and change of state for digitals. Timely updates can be set at any required time.

Main requirements include:

(i) send out Black Start initiation signals to BS DER

(ii) open/close circuit breakers to reconfigure network

(iii) change protection and control settings as required

(iv) confirm status of island for Black Start (this will be partly monitored on an ongoing basis, see Stage 0).

While actions i, ii and iii could be performed by the DRZC, based on feedback from the Distributed Restart team, actions i, ii and iii will be delivered by other systems (e.g. DMS sequential switching), but at a minimum, the DRZC must be made aware once each action process is complete.

The action processes in stage 1 can be delivered through the DNO SCADA/DMS as this will provide sufficient speed at this stage in the black start restoration process.

Stage 2: Anchor generation start up

Starting the Anchor generator and providing a stable voltage and frequency to the Anchor generator side of the 33kV point of connection (POC) will be the responsibility of the Anchor generator control room under a notice to start instruction from the DNO control room. At this stage the DNO POC breaker will be open and will be closed by the DNO control room operator when they are happy the Anchor generator has stable operation and is ready to energize a skeleton section of the DRZ island 33kV network[12].

When the DNO POC circuit breaker is closed the Anchor generation will provide the initial voltage source and frequency regulation and enable the connection of other BS DER resources. If the Anchor generator requires a minimum level of loading then this must be provided in a suitably reliable and stable manner, which may require the use of a local load bank or battery (if available). The contracted Anchor generators will be responsible for provision of their generator minimum loading requirement on site with the DNO POC circuit breaker open. However, the SGS functional design caters for Anchor generator minimum loading provided by non-local BS DER sources if required. In this case the BS DER requirements for successful Anchor generator start-up will be established by the DNO and the BS DER resources available for Anchor generator start up programmed into the DRZC where required.

Based on feedback from the Distributed Restart team the DNO control room will be responsible for reconfiguring the DRZ island network prior to any energisation through programming of the DMS system. The use of non-local BS DER for Anchor generator minimum load would require establishing a connection route between the Anchor generator POC and the source of minimum loading. This would be established as part of the DNO DMS DRZ island network configuration process.

Once the Anchor generator is started, the DNO POC circuit breaker would remain open until the DNO control room operator is ready to energize the pre-programmed skeleton 33kV network. If non-local BS DER is required for Anchor generator minimum loading then the time between starting the Anchor generator and closing the DNO POC circuit breaker to provide minimum loading to the Anchor generator will be limited by the Anchor generator requirements (time the Anchor generator can operate without sufficient loading) and will need to be accounted for by the DNO control room.

During Stage 2 the DRZC will require to monitor the Anchor generator and other BS DER performance (e.g. load banks or battery systems). The main functionality includes:

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[12] "Skeleton" network is a term used in the NG ITT documentation. SGS understand this to refer to reconfiguring the DRZ island network such that demand and embedded generation circuits are removed from service with circuit routes established linking the Anchor generator and BS DER POCs to the 33kV GSP. This would include BS DER used for non-local loading of the Anchor generator in circumstances where this is required.

- Monitor the connection status and available capacity data provided by the Anchor generator and all BS DER including BESS or load banks associated with the Anchor generator operation.
- Monitor the status of key DRZ network circuit breakers and circuits including real and reactive power flows on key circuits (BS DER circuits and block load circuits). Monitor the voltage and frequency at the Anchor generator site 33kV substation and the voltage at the 33kV GSP.

Similar to Stage 1, the DRZC could provide more automation to take work load away from the DNO control room e.g. notifying the Anchor generator to start and then closing the POC circuit breaker when the Anchor generator is ready. The DRZC could also reconfigure the DRZ island network. However, the feedback from the Distributed Restart team has steered towards the functions described in the foregoing. It is suggested that the level of automation provided by the DRZC could be further developed and tested during the trial period and continue to be developed prior to any business as usual roll out. This would be a decision for others outside of SGS.

Stage 3: Energising the network, Adding load blocks, additional BS DER, transmission circuits

The primary role of the DRZC in Stage 3 is system balancing control (frequency and voltage) as the island expands and additional load, BS DER and potentially transmission circuits are added. The DRZC will ensure that the Anchor generator has sufficient available capacity to accommodate each block load switching or transmission circuit switching. Where required the DRZC will adjust the set points of supporting BS DER to ensure the Anchor generator can accept the switching in of block loads and transmission circuits. Where required the DRZC will switch BS DER into alternate available operating modes e.g. move BS DER from a fixed power factor mode to a voltage control mode, or move a BESS system from a peak shaving mode to a frequency and voltage regulation mode. The DRZC functionality includes:

- Observe Anchor generator loading (minimum and maximum) and status of other controlled resources to ensure headroom for island control and contingencies. Monitor BS DER resource availability throughout, e.g. load bank power, BESS charge status, wind power available, Anchor generator limits, etc.
- When new demand (block load) is added (e.g. energisation of a primary substation) as part of the DRZC programmed black start restoration sequence, the DRZC will initiate control of available resources to balance the system and minimize the stress on the Anchor generator. This will ensure that the Anchor generator has sufficient available real and reactive power capacity prior to block load switching, to maintain adequate control of the island frequency and 33kV voltage post switching.
- To increase the level of DRZ island block load acceptance above the acceptance capability of the Anchor generator, the DRZC will preload the Anchor generator where required and where possible using a local load bank or alternate BS DER (BESS by controlling the charge set point). On switching in the block load, the Anchor generator preloading will be removed automatically using a frequency based control mode. To maintain frequency stability the preloading device (load bank or BESS) will require a local fast acting frequency based controller. Since this does not come as standard with a load bank, SGS's DRZC system will implement this, see section 7.1.1.8
- When switching in transmission circuits as part the black start restoration sequence, BS DER with a suitable voltage control mode available would be switched by the DRZC into this mode prior to transmission circuit switching to assist the Anchor generator and associated AVR system maintain a suitable DRZ island 33kV voltage
- DRZC block loading and transmission circuit switching will recognize the limits of the Anchor generator and supporting BS DER to accept these switched changes as the black start island grows, ensuring island frequency and voltage stability is maintained. The DRZC will be provided, pre-black start, with network block loading estimates, transmission circuit switching reactive power estimates and a sequence of

switching events. The Distributed Restart team will consider how they wish to develop a separate system for block load and transmission circuit switching power estimates and sequence data for input to the DRZC. The DRZC will check and inhibit any block loading or transmission circuit switching that is outside the estimated capability of the black start island and consider the next block load or transmission circuit in the sequence until it recognizes that no further switching can be accommodated. At this point the DRZC will alert the DNO control room operator via the SCADA/DMS that further block loading or transmission switching cannot be carried out. Any decision of further block loading or transmission circuit switching would pass back to the control room. While the block load real power estimates, transmission circuit switching reactive power estimates and initial switching sequence will be uploaded into the DRZC prior to any black start event, prior to each switching, the DRZC will check, re-evaluate and amend the sequence where required to suit the prevailing Anchor generator and BS DER limits and available power capacity. Provision of reliable real time available real and reactive power capacity and 30 minute forecast data will be a condition of the associated BS support contracts.

- After successfully picking up block load or switching in a transmission circuit, if the system remains stable for a pre-programmed period the DRZC will report a successful switching signal.
- The DRZC will monitor and control additional BS DER being added, e.g. a nearby wind farm, and control the import/export to optimize the Anchor generator loading. The DRZC will control the level of BS DER import/export to maintain a suitable safe margin of available capacity on the BS DER and the Anchor generator to accommodate variations in the island system demand, and variations in the BS DER available capacity due to variations in primary energy resources such as wind and solar irradiance and status of energy storage charge. The DRZC will track the Anchor generator and additional BS DER to ensure all resources are kept within their operational limits e.g. the Anchor generator should not go below its minimum load limit, any wind generation should maintain a DNO pre-programmed available capacity.
- Where any block load switching and subsequent Anchor generator automatic control responses and DRZC control interventions to other BS DER cannot stabilize the black start island, the DRZC will take action to remove the block load and re-establish a stable island condition. Any decision for further block loading would pass back to the control room with an alert from the DRZC that the previous block loading failed due to stability issues. A similar approach would be applied for transmission circuit switching.
- Voltage and frequency control are predominantly a function of the Anchor generator to respond to demand changes on the island network. Where available and suitable BS DER such as BESS could be switched by the DRZC into a frequency or voltage regulation mode to support the Anchor generator either continuously or at key times in the island black start restoration sequence[13]. The main function of the DRZC apart from changing operational modes on BS DER is to adjust BS DER real and reactive power set points to ensure the Anchor generator has available capacity for frequency and voltage regulation. Where required, the DRZC can recognize the power ramp down rate of the Anchor generator and ramp up other BS DER output within their limits to maintain stable island frequency during BS DER set point changes.
- The DRZC will monitor the network voltage and ensure voltage and oscillatory stability, e.g. the DRZC will track the reactive power available to control voltage.

Stage 4: Maintaining Island Stability

When the block loading and transmission switching in stage 3 to expand the DRZ island network stops, this decision by the DRZC will ensure the Anchor generator and BS DER have sufficient available real and reactive power available to accommodate expected changes in the island demand and BS DER available capacity

[13] Initially network planning studies will be required to confirm the most suitable operating mode for some BS DER. However, as knowledge is developed a more standardised approach could be adopted to avoid the need for network planning studies.

during stage 4. The DRZC will operate variable output BS DER with a programmed margin of available capacity to allow for variations in output due to primary source energy variations e.g. wind, solar irradiance. Where the available capacity margin reduces to a programmed threshold the DRZC will reduce the BS DER output set point. Adopting this approach ensures a level of reliance can be placed on variable output BS DER to support the DRZ island. The safety margins applied are assumed to be developed in systems outside of the DRZC and in theory could utilize artificial intelligence and machine learning techniques using historical output and weather data. Such techniques could be used to forecast the required safety margins over a black start sequence and update these into the DRZC for each DRZ network (outside of the present scope of work).

The DRZ island stability will require responses to expected variations in demand and BS DER available capacity (many BS DER are expected to have a variable output characteristic) and to unexpected major events such as a BS DER or a block load tripping that are outside of the Anchor generator's ability to maintain a stable island network. .

In the first case of expected frequency variations, the Anchor generator speed governor will adjust the real power export to maintain the system frequency at the set level. This requires a sufficient available capacity safety margin to be maintained to allow the generator to adjust real power export within the generator limits. The DRZC will adjust the BS DER real power export within available capacity limits to allow the Anchor generator and speed governor to maintain the system frequency. Where BS DER have a frequency supporting mode available the DRZC will enable this mode of operation at during stage 2[14]. Where the network demand increases to a point where the DRZC decides that available real power safety margins at the BS DER and Anchor generator have been sufficiently eroded the DRZC will select a block load to remove from the island as a last resort to protect the island stability.

In the case of expected voltage variations, the Anchor generator will adjust the reactive power output to maintain a target voltage. The DRZC will monitor the Anchor generator site 33kV substation and 33kV GSP voltage in real time and send signals to the Anchor generator to adjust the AVR target voltage when required. Similar to frequency control, the DRZC can control BS DER reactive power set points to support Anchor generator voltage regulation. Where BS DER has a voltage control mode the DRZC can be programmed to switch the BS DER to this mode where this may be beneficial e.g. prior to transmission switching or resynchronising with the transmission network. The Distributed Restart team should consider carrying out sufficient studies to confirm this is the best mode of operation for such operational events.

In the second case of unexpected major events such as a BS DER or a block load tripping that are outside of the Anchor generator's ability to maintain a stable island network, studies carried out by the Distributed Restart team for the proposed trial at Chapelcross GSP indicate that immediate action would be required to shed block load or BS DER depending on the event. The Anchor generator and BS DER would not be able to respond fast enough to maintain island stability. SGS has therefore proposed that the DRZC includes an additional fast response controller that would detect a major stability threatening event and take action to trip an appropriate level of block load or BS DER to maintain system stability.

The main functions of the DRZC at this stage include:

- Resource tracking as system resources approach full loading. Ensure enough headroom is maintained to stabilize the larger island. The DRZC is required to control all BS DER to keep the Anchor generator within its stability and protection limits.
- The DRZC will track the Anchor generator and other BS DER, remaining available real power and reactive power and provide the DNO/ESO control room access to this data on a continuous updated basis. This

[14] This would be subject to offline analysis and confirmation that the multiple BS DER in frequency sensitive mode can operate together in a stable and coordinated fashion.

will allow control rooms to make operational decisions during the black start process. The Anchor generator and BS DER will be required to provide real time data on real and reactive power availability along with 30 minute forecasts as part of their black start support contract.

- The operator will also be able to observe the various loadings through the DNO DMS. While the DRZC could be configured to allow the control room operator to manually make changes to the system generation and load. The Distributed Restart team would require to consider where this may be of benefit and could be carried out safely without compromising the DRZ network stability. SGS would recommend at this stage of development preventing unwanted manual interventions via the DMS or the DRZC except where specifically indicated in this report.
- The DRZC will operate controllable resources under normal expected demand and BS DER variations based on Anchor generator and BS DER available capacity, frequency and voltage measurements.
- The DRZC will also monitor RoCoF, aggregated demand and aggregated generation via the fast response controller which will respond to larger unexpected events that would threaten island stability and require immediate action to trip a sufficient level or block load demand or BS DER. The fast response controller will receive status data from the main DRZC indicating what operations are pending to distinguish between an unplanned event (loss of block load or BS DER) and a planned event (block load switch in).

Stage 5: Power island resynchronisation

The main functions of stage 5 include:

- DRZC to supervise resynchronisation, which could potentially be to:
    - Another DRZ with a similar controller, most likely at 33kV or 132kV
    - The wider system, or a larger power island, possibly synchronising on the transmission grid at 33kV, 132kV, 275kV or 400kV
- If there is a DRZC in active control on both sides of the synchronisation point, then the respective DRZCs would be programmed to have one lead controller (this could be selected by the DNO control room operator at the time of synchronisation to select the lead controller). The lead controller would adjust the Anchor generator (and BS DER if required) real and reactive power on its DRZ network to align voltage, angle and frequency across the synchronising circuit breaker to reduce the impact of resynchronisation. The second DRZC controller would attempt to keep the voltage, angle and frequency on its side of the synchronising breaker as stable as possible during this process. On completion of synchronising each DRZC would continue to control their respective networks to minimize power flows via the now closed synchronising circuit breaker. The DRZCs could be programmed to allow sharing of available Anchor generator and BS DER real and reactive power between DRZ networks if required to support overall island stability.
- Otherwise, the DRZC will adjust voltage and frequency in its power island under operator instruction/control to align voltage magnitude, phase angle and frequency to reduce the impact of resynchronisation. Suitable voltage sensors on either side of the synchronising circuit breakers are to be provided by the DNO or ESO as appropriate along with check synch protection. If there are suitable real and reactive power measurements through the synchronising circuit breaker circuits then these should also be installed to facilitate real and react power flow measurements.
- The DRZC will supervise resynchronisation and observe the post-synchronisation stability. The DRZC will provide a 'successful resynchronisation' signal after a pre-configured period when the synchronized system is stable. The DRZC will continue to control the Anchor generator and BS DER to minimize the real and reactive power flow across the synchronising breaker. The DRZC will continue to report on available real and reactive power capacity. This can be reported as aggregated totals to the ESO EMS

and DNO DMS to allow control room operators to plan other restoration operations on the wider transmission network.

Stage 6: Power island termination

Having completed stage 5 and resynchronized the DRZ island with a restored or partially restored transmission network the ESO or DSO system operator will issue a ‘termination of Black Start’ signal to the DRZC. At this stage, the DMS DSO control room operator using the DMS will take control of the restoration of protection settings and disconnection of the 33kV earth at the Anchor generator. During this period, the DRZC will continue to report on the DRZ island available real and reactive power capacity to the ESO EMS and DNO DMS to allow control room operators to plan other restoration operations on the wider transmission network. During this period, the DRZC will also carry out the following:

- Restore the distribution system to a normal operating condition and restore any primaries that have not yet been connected. The ESO or DSO control room operator may apply frequency restrictions or power up ramp rates during this period which would need to be adhered to by the DRZC e.g. primary substations should only be energized if the frequency is above 49.8 Hz (or as agreed with the ESO), or other defined network areas may be assigned a maximum ramp rate for demand restoration such as 50 MW per minute. The DRZC needs to be capable of accepting data signals from the DNO DMS with these types of operational restrictions.
- The DRZC should advise the DSO control room of any failure to restore the network configuration, or any primary substation that could not be energized, together with details of why the network restoration or energisation of primaries failed.
- Once the network is restored to normal conditions and all primary substations connected, the controller should advise the DSO control room that the Black Start sequence is complete, and that the controller is terminating its control over the distribution network.

6.2 Black Start DRZC Restoration Sequence Requirements

On the basis that the DRZC has successfully operated through Stage 0 as described in section 6.1 the following table describes the summary steps required to complete stages 1 to 6 for a successful DRZC black start. Table 6-1 groups the sequence steps into functional use cases (UC) which can be used to either develop a DRZC software solution or configure an existing control platform. Table 6-1 is based on reference [1] with further review by SGS. Where actions are from actors other than the DRZC e.g. the DSO DMS or a control room operator this is indicated. Where steps are outside of the DRZC functionality then a use case is not indicated e.g. where the DNO control room operator carries out a particular step.

Further detailed information relating to the black start restoration sequence and use cases is included later in this report.

Table 6-1: Black Start Restoration Sequence Steps and Associated Use Cases

DRZC UC	Step	Description
Pre-Black Start Initialisation		
1	0.1	Update DRZC with information from the DSO SCADA/DMS systems on a routine basis to confirm the DRZ is viable and the DRZC is aware of the network configuration, block loads, transmission circuit switching requirements and block loading/transmission circuit switching sequence to be applied during a black start.
Black Start Initialisation (Many of the steps in the following black start initialisation sequence detailed below could be automated by the DRZC, however, feedback from the Distributed Restart team has directed the level of control room and DMS activity. This could be revised as the DRZC design is developed).		
2	1.1	DRZC receives an instruction that a Black Start situation exists. This may originate from NGESO or from the DNO Control Room via a system to system communication link e.g. ICCP link. (Black start functionality disabled until this signal received.)
	1.1a	THE DSO control room operator will advise the Anchor generator of black start and request confirmation that the station is available.
	1.1b	The DSO control room will issue a signal via the DNO DMS to the BS DER that a black out condition exists and that preparations are being made for a Black Start.
	1.2	The DSO control room operator will reconfigure the 33kV network via the DSO DMS in preparation for a Black Start and issue instructions to generators.[15] The reconfiguration will ensure that a de-energised DRZ island is formed with an initial skeleton network from the Anchor generator and BS DER to the 33kV GSP substation with all BS DER and Anchor generator DNO POC circuit breakers open. The reconfiguration will also ensure the skeleton network has the majority of demand removed ready for block load switching later in the restoration sequence.
3	1.3	The DRZC black start functionality for stages 1 to 6 is enabled by the DNO control room via the DMS.
	1.4	The DSO control room operator will advise Anchor generator to prepare for Black Start.
4	1.5	The DSO DMS having carried out the required switching on distribution network will have updated the breaker positions to the DRZC. (System to system communication link e.g. ICCP)

[15] While the DRZC could be programmed to carry out the island network reconfiguration, feedback from the Distributed Restart team has indicated a preference for the DMS to be programmed to carry this function out.

DRZC UC	Step	Description
	1.6	The DSO control room operator via the DMS will modify protection settings for low fault levels during Black Start and possibly disable auto-reclose and under-frequency load shedding.
	1.7	The DSO control room operator via the DMS will switch in the DRZ network 33kV earthing transformer, if required.
4	1.8	The DSO control room operator via the DMS will send a signal to the DRZC confirming that all network re-configuration, protection setting changes and switching in the DRZ network 33kV earth (if required) are now completed. (System to system communication link e.g. ICCP)
	1.9	The DNO control operator will await a signal from Anchor generator that it is now available to start.
5	1.10	At this stage the distribution network is correctly configured, and the Anchor generator is ready to start and this has been confirmed to the DRZC. The DRZC will request permission from the DNO control room to commence Black Start energisation of network. System to system communication link e.g. ICCP.
5	1.11	The DRZC will wait for permission from the DNO control room.
	1.12	The DNO control room instructs Anchor generator to energize to the connection point (DNO POC circuit breaker open at this stage).
	1.13	The Anchor generator control room will start the Anchor generator and increase demand (which may mean control of a load bank) to meet the minimum loading requirements of generator[16].
DRZ Network Energisation		
	2.3	When generator is loaded to a stable minimum operating point, energize pre-specified restoration route circuits (the DNO control room operator closes the DNO POC circuit breaker). This may be circuits to the Grid Supply Point (GSP) or to other BS DER.
	2.4	As part of the DNO network reconfiguration in step 1.2 circuits from the GSP to BS DER requiring auxiliary supplies to ensure they will be available when required will now be energized with the relevant POC circuit breakers closed.

[16] At this stage, starting of the AG is the responsibility of the AG site. The AG will be started and when ready the POC breaker will be closed to connect to a limited 33kV network. This could include circuits to an off AG site load bank. The DMS reconfiguration of the network prior to closing the POC breaker could accommodate this, see next step in the sequence.

DRZC UC	Step	Description
	2.4a	The DNO control room will confirm to the DRZC that it can start the DRZ island restoration sequence.
7	2.4b	The DRZC will commence the black start restoration sequence.
8	2.5	The DRZC will advise BS DER, that the circuit to their connection point has been energized. The DRZC will request confirmation when they are ready to start. This will be system to system communications either via the DNO SCADA/DMS or via more direct routes between the DRZC and BS DER control systems (assumed BS DER will be unmanned).
Block Load Pick Up and Transmission Switching		
9	3.1a	The DRZC will have been provided with block load estimates, transmission circuit switching reactive power requirement estimates[17] and the priority restoration order for transmission circuit and block load switching at stage 0 by an external DNO system.
10	3.1b	With the DRZ island skeleton network configured, energised by the Anchor generator and operating in a stable mode with other BS DER ready to connect, the sequence of block load and transmission circuit switching will commence. The sequence may commence with transmission switching or block load switching.
10	3.1c	For transmission circuit switching, the DRZC will check the estimated reactive power requirement against the available reactive power capacity on the DRZ network. Where other BS DER is connected the DRZC will switch this into voltage control mode where available. If there is sufficient capacity available, the DRZC will close the transmission circuit breaker to energise the circuit. Where other BS DER is available this can be connect if required. The Anchor generator AVR will respond to restore the system voltage.
10	3.1d	For block load switching, any load bank or BESS Anchor generator pre-loading support required to accommodate the anticipated block load within the Anchor generator block load switching capability will be energized. The DRZC will energize the primary substation (block load) and the load bank or BESS pre loading support (if any) will automatically reduce (frequency based fast control).

[17] Transmission circuits to be switched in will not be linked to demand restoration. There may be a small real power demand from associated substation auxiliary supplies. Where required when developing the transmission circuit switching sequence, offline studies may be required to confirm the DRZ island network can safely carry out the switching if there is sufficient reactive power capacity available.

DRZC UC	Step	Description
10	3.2	Prior to each switching event, the DRZC will check the estimated real or reactive power requirements (block load or transmission circuit switching respectively) and adjust the BS DER (where available) output set points where required to ensure the Anchor generator has sufficient available capacity to accept the next switching event.[18]. Post switching, the DRZC will continue checking for network demand changes for a pre-programmed time and adjust the BS DER (where available) as required prior to the next switching event in the sequence.
11	3.3	If further BS DER become available, the DRZC will connect and initially constrain to a low output to ensure the Anchor generator does not get close to any minimum load limit.
12	3.3a	The DRZC will continue transmission circuit and block loading, adjusting BS DER output and checking Anchor generator stability until the safe available capacity limit of the Anchor generator and BS DER are reached that prevents further block load or transmission circuit switching.
12	3.4	The DRZC will continue to ensure that the Anchor generator and all supporting BS DER operate within their available capacity and safe limits of operation while allowing the Anchor generator to adjust output for changes in voltage and system frequency via its AVR and speed governor systems.
12	3.5	When the DRZC determines that further transmission circuit or block load switching would compromise the pre-programmed safety margins relating to the Anchor generator real and reactive power output, it will raise an alert to the DNO control room. This includes the estimated support to the Anchor generator based on BS DER available real and reactive power and the estimated reliance on this.
Maintaining a Stable Island		
13	4.1	The DRZC will continue to ensure that the Anchor generator and all supporting BS DER operate within their available capacity and safe limits of operation while allowing the Anchor generator to adjust output for changes in voltage and system frequency.

[18] The AG will operate in frequency control mode and adjust power output to aim for a set frequency e.g. 50 Hz. The AG AVR will also control the system voltage by adjusting reactive power output. However, on a slower time scale, the DRZC will adjust the export set points of BS DER with available capacity to ensure the AG has adequate operational safety margins with its minimum and maximum real and reactive limits.

DRZC UC	Step	Description
13	4.2	The DRZC will update BS DER constrained export values on a regular basis to keep the Anchor generator within power output limits. Small differences between load and generation will be catered for using frequency control capability of the Anchor generator's governor, however larger differences will be accommodated by changing other controlled resource set-points, or switching demand or BS DER on/off depending on the speed of response required to protect the DRZ island stability.
13	4.3	Where BS DER have a frequency regulation or voltage regulation mode, the DRZC will switch to this this mode on if not already established, where suitable[19].
14	4.4	If load increases or DER output drops, the DRZC will have to prepare for possible block load disconnection to protect the island. For example, it may be acceptable that it should only disconnect load once the following conditions have been met. • BS DER at maximum output (unconstrained). • Any load bank fully switched out. • Anchor generator above a programmable percentage of rated output e.g. 95%. The exact criteria can be programmed for each DRZ network at the detailed design stage based on detailed network planning studies (not included in the scope of stage 1).
14	4.5	If a block load has been disconnected, only consider reconnecting if the following conditions have been met. • There is sufficient BS DER available power capacity plus a suitable programmable safety margin to avoid continued switch out of load. • Anchor generator below a programmable percentage of rated output, e.g. 75%, including the impact of adding the disconnected load. The exact criteria can be programmed for each DRZ network at the detailed design stage based on detailed network planning studies (not included in the scope of stage 1). Where practical, a different primary substation block load (if any remain disconnected) could be connected to minimize repeated switching of a particular primary substation.

[19] This would be subject to offline analysis and confirmation that the multiple BS DER in frequency or voltage regulation mode can operate together with the Anchor generator in a stable and coordinated fashion

DRZC UC	Step	Description
Synchronize the Island to the Transmission System or Adjacent Islands		
15	5.1	Synchronising to an adjacent island could be at 33kV, at 132kV or through a transmission circuit. Synchronising to the transmission System is taken to imply that the Black Start is nearing completion and that a stable transmission system is available to synchronize to. The decision to synchronize would have to be taken manually, by a higher-level controller supervising a much larger area of the network, or by two adjacent controllers working in a peer-to-peer manner.
16	5.2	If instructed to synchronize to the transmission system by the ESO or DNO control room operator via the SCADA EMS or DMS, the DRZC would also have to be advised of the synchronising breaker[20] to be used and would monitor the network on the other side of the synchronising breaker[21] and control generation and load (including the load bank and BS BESS) within its network to achieve conditions that would permit the synchronising breaker to be closed.
16	5.2a	The DRZC will continue to monitor the potential Anchor generator and BS DER real and reactive power capacity (MW and MVAr) available including the 30 minute availability forecasts and make this information available to the ESO and DNO control room operators. This available capacity would be paid for under the BS contracts which will require the owners/operators to provide this available capacity data[22].
16	5.3	When synchronized to the transmission system, the network should be assumed to be weak, and the DRZC should minimize the real power exchange with the transmission system, or else control the real power exchange to a value as specified by the ESO or DNO operator.
17	5.4	When synchronized to the transmission system, the DNO control room will switch out any temporary earthing transformers connected to 33kV network for the Black Start via their SCADA DMS. The DNO control room will also, consider when normal protection settings should be restored and instruct changes accordingly via their SCADA DMS.

[20] Any circuit breakers that the DNO or ESO wish to use for synchronising would need to be kitted out prior to DRZC system commissioning and pre-programmed into the controller to ensure the DRZC knows which breakers can be used. DNO/ESO operators could have the choice of circuit breakers indicated by the DRZC or the selection could be pre-programmed.

[21] For synchronising the DRZC requires visibility of the voltage, angle and frequency on both sides of the synchronising circuit breaker, closing of the circuit breaker will be actioned when these are adequately aligned on each side of the synchronising circuit breaker.

[22] The Distributed Restart team indicated at the project kick off meeting that forecasting available capacity data was not an area they wished to develop and hence the present DRZC functional design presented in this report is aligned with the Anchor generator and BS DER providing real time available capacity (real and reactive power) assumed to be a requirement of their BS support contracts. There are benefits in also requiring the Anchor generator and BS DER (particularly variable output DER such as wind, solar and storage) to provide forecast available capacity data and SGS recommend that the Distributed Restart team consider this. The present functional design has a requirement for the BS DER to provide a 30 minute forecast of available real and reactive power.

DRZC UC	Step	Description
15	5.5	If the DNO control room instructs the DRZC to synchronize with an adjacent island, the DRZC would have to be advised of the synchronising breaker to be used and the network to be synchronized with. The controller would then cooperate with the adjacent controller to achieve conditions that would allow the islands to be synchronized. The DNO control room would also instruct one DRZC to take the lead role.
15	5.6	When synchronized with an adjacent island, the controllers would maintain a balance between generation and load on their respective DRZ networks, but power transfer would be acceptable if there was excess generation in one DRZ island and excess load in the other.
15	5.7	Further merging of islands would require further consideration of how the growing island could be controlled and coordinated through the individual DRZ controllers.
Terminate Black Start Sequence		
18	6.1	When a signal is received by the DRZC from the DNO or ESO control room that the Black Start is complete, the DRZC will proceed to restore the distribution system to a normal operating condition and restore any primary substations that have not yet been connected.
18	6.2	Normal protection settings should be restored by the DNO control room via the DNO DMS.
18	6.3	When any remaining primary substations are to be connected, the ESO or DSO control room operator may apply frequency restrictions or power up ramp rates during this period which would need to be adhered to by the DRZC e.g. primary substations should only be energized if the frequency is above 49.8 Hz (or as agreed with the ESO), or other defined network areas may be assigned a maximum ramp rate for demand restoration such as 50 MW per minute. The DRZC needs to be capable of accepting data signals from the DNO DMS with these types of operational restrictions.
19	6.4	The DNO control room should be advised by the DRZC of any failure to restore the network configuration, or any primary substation that could not be energized for any reason, together with details of why the network restoration or energisation of primary substation failed.
20	6.5	Once the network is restored to normal conditions and all primaries connected, the DRZC should advise the DNO control room that the Black Start sequence is complete, and that the controller is terminating its control over the network.

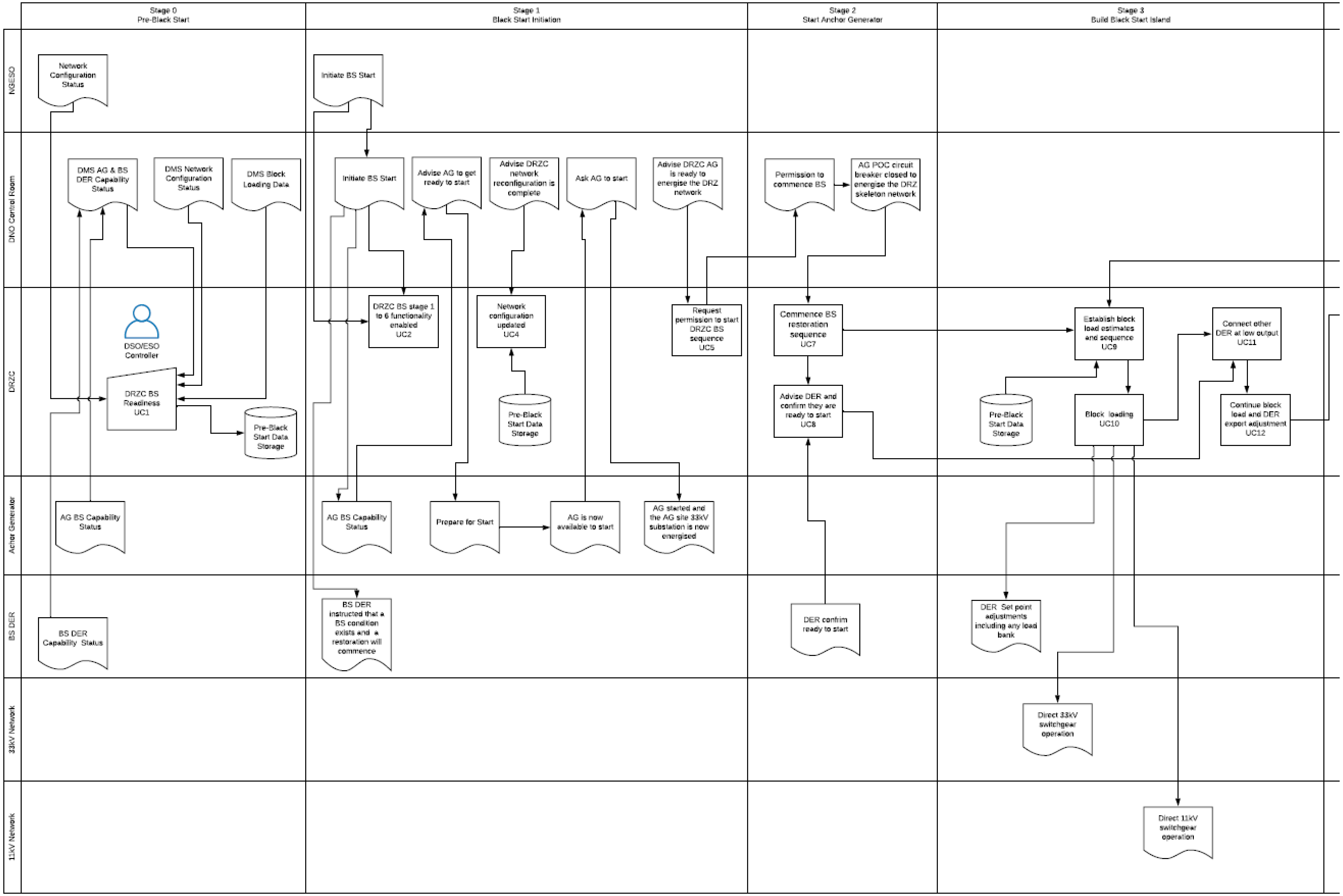
6.3 DRZC Black Start Restoration Functional Use Cases

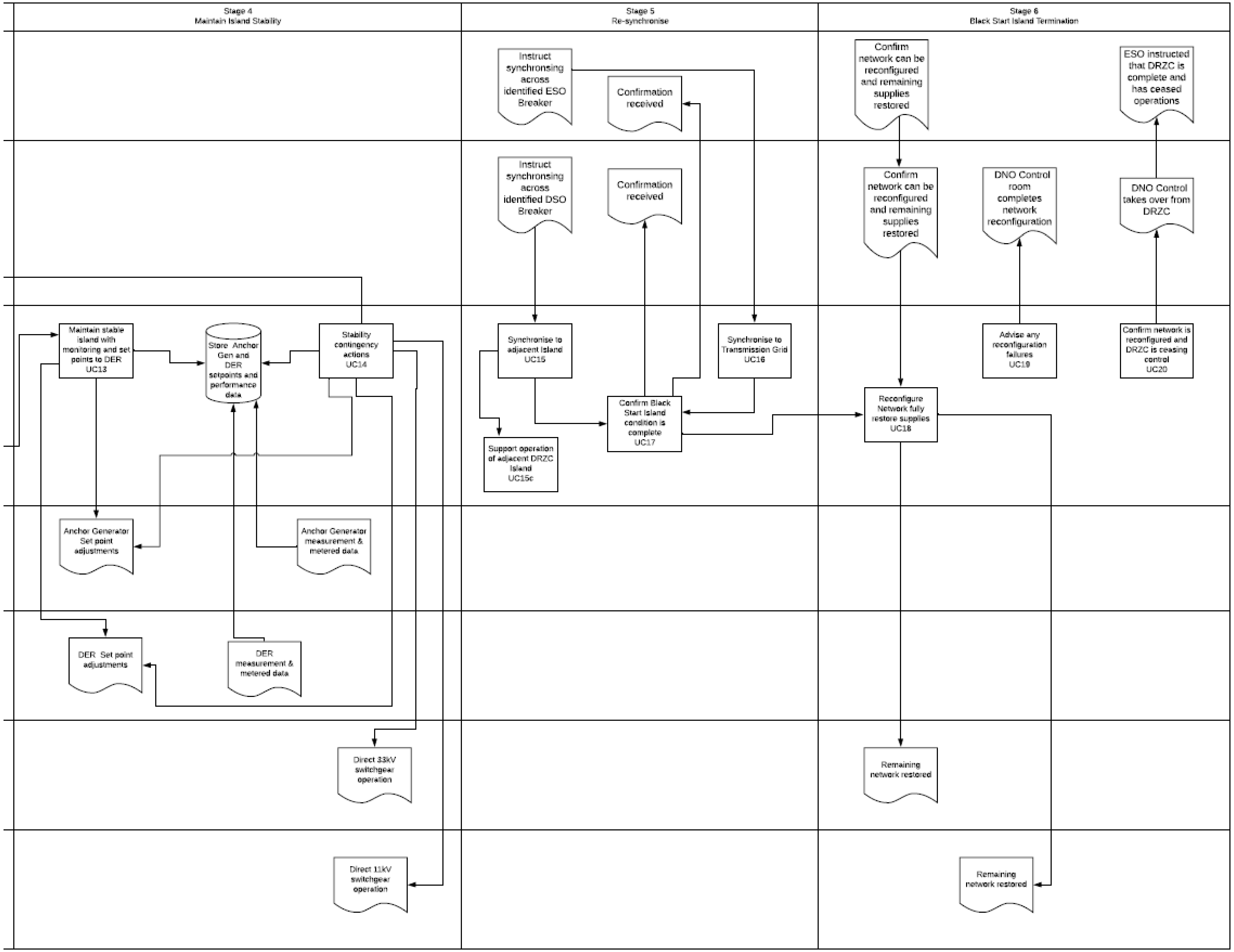
The use cases identified in this section have been developed from the black start restoration sequence steps detailed in Table 6-1. The use cases provide further detail on the DRZC functionality including the primary and secondary actors, triggers, pre-conditions, post conditions, the main success scenarios, possible use case extensions, and any open questions. During the functional design process, the use cases were also used to highlight the potential communication and measurement requirements at a high level to inform work on the

DRZC architecture design and detailed communication requirements. This high level information on communication and measurement requirements is discussed in greater detail later in this functional design report.

The following section introduces a use case flow diagram covering the full black restoration process from stage 0 to stage 6. The rows in the diagram represent the key actors and their actions relating to the various DRZC use cases. In the use case diagram the rows representing NGESO, the DNO control room, the Anchor generator and other DER include both associated control system and operational personnel actions. Each use cases in the use case diagram is documented in detail in the following sections and includes information relating to each actors actions including system and personnel actor actions.

6.3.1 Use Case Flow Diagram




Stage 4
Maintain Island Stability
Stage 5
Re-synchronise
Stage 6
Black Start Island Termination
Instruct synchronising across identified ESO Breaker
Confirmation received
Confirm network can be reconfigured and remaining supplies restored
ESO instructed that DRZC is complete and has ceased operations
Instruct synchronising across identified DSO Breaker
Confirmation received
Confirm network can be reconfigured and remaining supplies restored
DNO Control room completes network reconfiguration
DNO Control takes over from DRZC
Maintain stable island with monitoring and set points to DER UC13
Store Anchor Gen and DER setpoints and performance data
Stability contingency actions UC14
Synchronise to adjacent Island UC15
Synchronise to Transmission Grid UC16
Confirm Black Start Island condition is complete UC17
Support operation of adjacent DRZC Island UC15c
Reconfigure Network fully restore supplies UC18
Advise any reconfiguration failures UC19
Confirm network is reconfigured and DRZC is ceasing control UC20
Anchor Generator Set point adjustments
Anchor Generator measurement & metered data
DER Set point adjustments
DER measurement & metered data
Direct 33kV switchgear operation
Remaining network restored
Direct 11kV switchgear operation
Remaining network restored

6.3.2 Stage 0 Pre-Black Start

6.3.2.1 Use Case 1 DRZC Black Start Readiness

The functionality of Use Case 1 covers the period from commissioning the DRZC to a black out situation being declared. During this period the system viability to deliver a DRZC black start will be monitored on an ongoing basis with data storage. Anchor generator, BS DER and network status would be monitored by the DNO DMS and status updates provided to the DRZC. This data route ensures that the central source for DRZC black start viability will be the DNO DMS with additional DRZC system event alarms provided to the DMS by the DRZC.

The DRZC is to be capable of self-monitoring and raising alerts/events where internal issues may compromise the ability to carry out a black start sequence.

The DRZC will also monitor the communication routes and raise an alert/event where an issue is detected. This could use a heartbeat signal with a programmable period.

Based on discussions with the Distributed Restart team it is agreed that the block load real power estimates, transmission circuit reactive power estimates and switching sequence should be provided to the DRZC by an external system, as this allows maximum flexibility to develop this system. While the DRZC could be programmed with block load estimates to account for time of day, week and year or other factors at the time of block load switching during a black start sequence, it is assumed that initially the DRZC will receive a single MW value for each block load. Each block load and transmission circuit in the sequence will be associated with the switching of associated circuit breakers also provided to the DRZC as part of the initial block load and transmission switching sequence.

It should be noted that real time and historical power flow data from the DNO SCADA/DMS could be analysed in an external system to provide block load estimates at any point in the black start sequence. Such a system could consider all DRZs on a DNOs network. The key value would be the ability to improve on the default worst case block load estimates as this may assist the DRZCs restore demand customers during a black start.

UC-1	**DRZC Black Start Readiness**
Primary Actor(s)	DRZC, NGESO SCADA/EMS, DNO SCADA/DMS
Secondary Actor(s)	
Stakeholders and Interest	
Trigger	Ongoing from DRZC system commissioning (BS DER can be switched on or off depending on their BS support contract status)
Pre-conditions	The NGESO SCADA/EMS and DNO SCADA/DMS are providing the required system status and measurement data to the DZRC.
Post-conditions	The DRZC is aware of its viability to deliver a black start sequence if called upon and will alert the NGESO SCADA/EMS and DNO SCADA/DMS when it is does not have black start viability indicating the reason.
Main Success Scenario	1. Monitor the Anchor generator power export prior to the black start condition to indicate availability. DNO SCADA/DMS sends data at programmable intervals. 2. Monitor the contracted BS DER power export prior to the black start condition to indicate availability. DNO SCADA/DMS sends data at programmable intervals.

	3. Monitor any contracted BS BESS available power import, export capacity to indicate the ability to support a black start sequence if fast frequency support is required. 4. Regular updates of circuit breaker status from the DSO SCADA/DMS and TSO SCADA/EMS system to keep the DRZC advised of the network configuration prior to a black start requirement, and also the status of the Anchor generator and contracted BS DER connections. 5. DRZC issues an event warning to the DNO SCADA/DMS and TSO SCADA/EMS if an island black start appears not viable indicating the reason, e.g. Anchor generator circuit out of service, communication failure detected.
Extensions	
Priority	
Special Requirements	
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	Communications with the DNO SCADA/DMS and TSO SCADA/EMS will have sufficient speed for this use case for measurement and status data.
Measurement Requirements	Measurement data from the DNO DMS would be adequate for this use case.
Interfaces	

6.3.3 Stage 1 Black Start Initiation

6.3.3.1 Use Case 2 Black Start preparation.

Having received a signal that a black out condition now exists, the DRZC proceeds with black start preparations. Based on feedback from the Distributed Restart team, it is now taken that the DNO control room operator will deal with many of the stage 1 black start ignition sequence steps identified in Table 6-1. This could be changed at a later design stage to allow the DRZC to provide greater automation support to the DNO control room.

UC-2	Black Start preparation
Primary Actor(s)	DRZC, NGESO Control Room Operator, DNO Control Room Operator, Anchor Generator Control Engineer.
Secondary Actor(s)	NGESO SCADA/EMS, DNO SCADA/DMS
Stakeholders and Interest	
Trigger	The DZRC receives an instruction that a Black Start situation exists.
Pre-conditions	Stage 1 to 6 DRZC Black Start functionality disabled.
Post-conditions	DRZC Stage 1 to 6 DRZC Black Start functionality is enabled.
Main Success Scenario	1. DRZC receives an instruction that a Black Start situation exists. This may originate from NGESO or from the DNO Control Room. (Stage 1 to 6 Black start functionality disabled until this signal is received.)

	2. DRZC receives an instruction from the DNO DMS that enables the DRZC stage 1 to 6 functionality.
Extensions	
Priority	
Special Requirements	
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	Communications with the DNO SCADA/DMS and TSO SCADA/EMS will have sufficient speed for this use case
Measurement Requirements	
Interfaces	

6.3.3.2 Use Case 4 DRZ Network Configuration updated in the DRZC

The DRZC system will use data from the DNO DMS and ESO EMS to indicate circuit breaker status, substation voltage and power flow information prior to and after a black start condition is declared (UC1 and UC2). This information will be used by the DRZC to identify the network configuration prior to the black start and just after a black start condition is declared. Just after a black start condition is recognized, a DRZ network island will require to be correctly established in order for a black start restoration sequence to commence.

NG and SPEN have advised that reconfiguring the DRZ network to establish a viable island for a black start restoration sequence is best carried out by programming DNO DMS rather than the DRZC. If this is readily achievable for all DNOs then SGS would agree with this approach[23]. The DNO DMS will require to open the circuit breakers linking the DRZ network to the transmission network and any other DRZ network to form the required DRZ island. Specific switching sequences will vary across each DRZ, but will follow these principles:

- The DNO DMS will open all 33kV GSP substation circuit breakers on circuits that feed demand or connected generation (excluding the Anchor generator and BS DER where this is confirmed as not supporting the DRZ at this point). This is likely to be all circuit breakers except the bus-section breakers and the Anchor generator and BS DER connection circuit breaker.
- The DNO DMS network reconfiguration will ensure that the connection from the Anchor generator is in service ready for the Anchor generator to start and energize the 33kV GSP busbars. The Anchor generator DNO point of connection (POC) circuit breaker will be opened.
- The POC DNO circuit breaker at each BS DER location will be opened. This is to ensure BS DER connect and export power to the DRZ island when required to and do not automatically start to export when the network to each BS DER POC is energized.

[23] An earlier draft of the DRZC use cases included network reconfiguration as a DRZC task rather than a DNO DMS task. If the Distributed Restart team wish to revert to the DRZC carrying out the network reconfiguration than this could be implemented at the next design stage.

- The network reconfiguration will ensure there is a de-energized skeleton network from the 33kV GSP substation to the Anchor generator and other BS DER with the DNO POC circuit breakers at the BS DER and Anchor generator open.
- If the DNO DMS network status checks indicate a partially energized DRZ network island then additional circuit breaker operation will be required to ensure the DRZ island is fully de-energized prior to DRZ restoration.
- The DNO DMS or other external system will modify protection settings for low fault levels during Black Start and possibly disable any auto-reclose and under-frequency load shedding.
- The DNO DMS will switch in the 33kV system earth where required.

It is possible that the block loading sequence will require 11kV circuit breaker operation rather than 33kV circuit breaker operation to reduce the block load volume to within the Anchor generator block load acceptance limits (even with load bank or BESS pre loading support0. If this is the case, additional 11kV circuit breaker opening must be introduced to the DNO DMS switching sequence. This requirement would be defined for each DRZ based upon the Anchor generator block-loading capabilities and will be established in a non DRZC system as discussed earlier. The 11kV switching sequence and DRZC design would need to be aligned to achieve this. At this stage any proposed 11kV switching sequence has not been considered in detail but should be considered at the next design phase.

There is a balance to be struck between the volume of demand restoration that can be achieved prior to re-synchronisation with the transmission network and limiting the number of 11kV block load switching operations which adds complexity to the black start restoration sequence (particularly if fast communications from the DRZC to 11kV circuit breakers were required, e.g. where 11kV circuit breaker tripping would be required as part of the DRZC fast response to BS DER loss to protect DRZ island stability, see later use cases covering this area). Ideally a black start sequence that restores sufficient demand using 33kV block load switching only is preferred. Remaining 33kV block loads could be switched in later when the DRZ island has be synchronized and connected to the restored transmission network.

At UC 9, the initial block load sequence (including the transmission circuit switching elements) provided to the DRZC prior to a black start condition will be checked after each successful block load restoration step based on the remaining capacity availability of the Anchor generator and supporting BS DER. Where amendments to the sequence would improve demand restoration the DRZC will amend the block loading sequence and continue e.g. where the initial sequence has a 33kV block load switch in that cannot be accommodate, the DRZC could bring forward a smaller block load in the remaining sequence either at 33kV or 11kV. The DRZC will also decide when there are no options to continue the block load sequence further.

UC-4	**DRZ Network Configuration Updated in the DRZC**
Primary Actor(s)	DNO DMS, DRZC
Secondary Actor(s)	DNO Control Room operator
Stakeholders and Interest	
Trigger	DNO DMS completes the reconfiguration of the DRZ network ready for a black start sequence to commence.

Pre-conditions	• The DNO DMS has completed the DRZ network reconfiguration
Post-conditions	The DRZC has been updated with the status of the required 33kV and 11kV network circuit breakers ready for a DRZC black start sequence to commence.
Main Success Scenario	1. The DRZC representation of the DRZ network used for managing the DRZ network black start restoration sequence has the status of all components updated by the DNO DMS. 2. The DRZC receives a signal from the DNO control room operator via the DMS confirming that all network re-configuration, protection setting changes and switching in the DRZ network 33kV earth (if required) are now completed.
Extensions	
Priority	
Special Requirements	
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	Communications for network status and measurement updates would be with the DNO SCADA/DMS and TSO SCADA/EMS at this stage.
Measurement Requirements	
Interfaces	Note that the DRZC will have faster communication routes to the Anchor generator and BS DER POC circuit breakers, all block load circuit breakers and associated power flow measurements required for other use cases.

6.3.3.3 Use Case 5 Network Ready for Back Start Sequence to Commence

The DNO control room operator has confirmation that the Anchor generator is ready to start. The DNO control room operator has instructed the Anchor generator to start and energize the Anchor generator site 33kV substation (the DNO POC circuit breaker to the Anchor generator site is open at this stage and the DNO DRZ network is not energized). The DRZ distribution network is correctly configured and a request has been received from the DRZC via the DNO DMS requesting permission from the DNO control room to commence black start energisation of the distribution network.

UC-5	Network ready for black start sequence to commence
Primary Actor(s)	DRZC, DNO DMS, DNO Control Room operator,
Secondary Actor(s)	Anchor Generator Control Engineer
Stakeholders and Interest	
Trigger	DNO DMS has reconfigured the DRZ network ready for a black start (see UC4)
Pre-conditions	• The DRZC has been instructed that the DRZ network has been reconfigured (UC4)
Post-conditions	DRZC is awaiting confirmation to commence a black start sequence

Main Success Scenario	1. The DRZC sends a request to DNO Control Room operator (via the DNO SCADA/DMS) for permission to commence Black Start energisation of network. 2. The DRZC awaits confirmation that it can proceed with a black start restoration sequence.
Extensions	
Priority	
Special Requirements	
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	Communications with the DNO SCADA/DMS will have sufficient speed for this use case
Measurement Requirements	
Interfaces	

6.3.4 Stage 2 DRZ Network Energisation

6.3.4.1 Use Case 7 Commence Black Start Restoration Sequence

Following on from UC5 the DNO control room operator having received a request from the DRZC via the DNO DMS for permission to commence a black start sequence proceeds to close the Anchor generator POC breaker and energize the 33kV GSP and pre-defined restoration circuits (skeleton network). Having checked that there is stable voltage and frequency at the 33kV GSP substation, the DNO control room operator issues a signal to the DRZC giving permission to commence the remaining black start restoration sequence.

UC-7	**Commence Black Start Restoration Sequence.**
Primary Actor(s)	DRZC, DNO SCADA/DMS, DNO control room operator
Secondary Actor(s)	
Stakeholders and Interest	
Trigger	DNO control room operator issues a signal to the DRZC giving permission to commence the black start restoration sequence
Pre-conditions	Anchor generator has been operating within defined voltage and frequency limits at the POC for a pre-programmed time prior to the DNO control room issuing permission to commence the black start restoration sequence.
Post-conditions	1. Circuits to BS DER are energized to provide auxiliary supplies where required. At this stage BS DER are not producing any export power (the associated DNO POC circuit breakers are open following the pre-energisation reconfiguration of the DRZ network).
Main Success Scenario	1. DRZC receives permission from the DNO control room via the DMS to commence the remaining black start restoration sequence.

Extensions	
Priority	
Special Requirements	Monitoring of Anchor generator: P/Q, substation voltage and frequency Monitoring of network voltage at GSP busbars Monitoring of block load supporting Load Bank or BESS status DRZC monitoring of Anchor generator real and reactive power capacity availability
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	Fast acting control of the Flexible MW Resource may be required to protect the island stability, hence communications via the DNO SCADA/DMS will not suffice, and low latency direct communications will be required with the DRZC and/or local distributed control devices.
Measurement Requirements	The DRZC continues monitoring the Anchor generator real and reactive power, frequency and voltage at the site HV substation and voltage at the 33kV GSP at this stage. With the Anchor generator connected to the 33kV network, fast acting control may be required to protect the island stability and hence fast measurement updating will be required via low latency communication routes to the DRZC and/or local distributed control devices.
Interfaces	

6.3.4.2 Use Case 8 Advise BS DER and confirm they are ready to start

Having established the skeleton network which includes circuits to other BS DER, the DRZC advises the BS DER that the circuit to their connection point (POC) has been energized (DNO POC circuit breaker still open at this point so BS DER cannot export to the skeleton network). The DRZC requests and awaits confirmation that each BS DER is ready to start when called on.

UC-8	Advise BS DER and confirm they are ready to start
Primary Actor(s)	DRZC, BS DER Control Engineers/BS DER Control Systems
Secondary Actor(s)	
Stakeholders and Interest	
Trigger	DRZC has energized pre-specified circuits to BS DER POCs
Pre-conditions	Anchor generator is maintaining a stable island of pre-specified substations and circuits. BS DER and Anchor generator are advising their available real and reactive power capacity in real time and a 30 minute forecast (black start contract condition)[24]

[24] The Distributed Restart team advised at the kick off meeting to this project with SGS that they did not wish to go down the road of forecasting DER output. SGS consider that there are advantages of utilising forecast available real and reactive power capacity as part of the control system during the black start control sequence. This may reduce the need for available capacity contingency margins from many forms of DER increasing the amount of distribution demand that can be restored while in an island condition. The present functional design has a requirement for the BS DER to provide a 30 minute forecast of available real and reactive power in addition to real time data.

Post-conditions	BS DER have confirmed that they are ready to connect and support the black start sequence.
Main Success Scenario	1. DRZC advises BS DER, that the circuit to their connection point (POC) has been energized. 2. Request confirmation when they are ready to connect to the DNO network (DRZ) and provide power to support the black start sequence. 3. DRZC registers when BS DER have confirmed they are ready to start.
Extensions	• DRZC monitors BS DER available real and reactive power capacity.
Priority	
Special Requirements	
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	Fast acting control of the Flexible MW Resource may be required to protect the island stability, hence communications via the DNO SCADA/DMS will not suffice, and low latency direct communications will be required with the DRZC and/or local distributed control devices.
Measurement Requirements	The DRZC continues monitoring the Anchor generator real and reactive power, frequency and voltage at the site HV substation and voltage at the 33kV GSP at this stage. With the Anchor generator connected to the 33kV network, fast acting control may be required to protect the island stability and hence fast measurement updating will be required via low latency communication routes to the DRZC and/or local distributed control devices.
Interfaces	

6.3.5 Stage 3 Build the Black Start Island

Stage 3 includes block load switching to restore supplies to distribution demand customers and elements of transmission circuit switching to restore auxiliary supplies at some transmission substations (transmission substation related demand is not included in this element of system restoration).

The Distributed Restart team are keen to minimise the number of block load switching events as this will potentially speed up the sequence of distribution demand restoration and minimize the risk of a circuit breaker failure to operate during a GB wide black start. Hence, DRZ island restoration will focus on larger 33kV block load switching where possible rather than 11kV circuit switching. The 33kV system switching block loads will vary in size depending on many factors and estimating these has scope for large errors when switching actually occurs, hence estimates provided to the DRZC (by an independent external system[25]) will err on the cautious side (high). Each Anchor generator has a limit to the size of block load that can be switched in and keep the DRZ network within stable frequency and voltage limits.

[25] Based on feed-back from the Distributed Restart team, the concept of an external system independent of the DRZC being developed to manage estimates for block load switching has been adopted by SGS. This external system would down load the block load switching estimates and initial switching sequence to each DRZC system via the DNO SCADA/DMS. The switching sequence would also include any transmission circuit switching. This approach would allow an independent focus on developing a BAU block load estimating and switching sequence system. This system could adopt a simple approach or over time be developed into an AI based self-learning system which can update the DRZCs whenever required. The key things is that as a separate BAU system development outside of Distributed Restart it does to detract focus away from developing the DRZC key control functionality.

The Distributed Restart team has identified the potential to increase the Anchor generator block load acceptance limit by preloading the Anchor generator, and at the point of switching in the block load quickly reduce the amount of preloading to zero. The Distributed Restart team have identified that the preloading of the Anchor generator could use local load banks or BESS. In both cases, SGS see the need to have a fast frequency based controller to reduce the preloading on switching in the block load[26]. While this type of fast frequency control can be available in BESS type devices, they are not to SGS's knowledge available with standard load banks. Hence, part of the SGS DRZC design covers a fast frequency controller to turn down any load bank used for Anchor generator block load acceptance support.

The other key difference between a load bank and a BESS that the DRZC has to consider, is the ability to put load onto the Anchor generator for pre-loading. In terms of a load bank if there is free capacity this can be used immediately to preload the Anchor generator. However, for a BESS this requires the batteries to operate in a charging mode at a sufficient rate to load the Anchor generator to the desired level. While BESS could be selected to provide a sufficient charge rate (this could be as an aggregated group of BESS), the BESS charge status would have to allow for adequate charging to preload the Anchor generator for the periods block load switching support is required. Hence for the first block load switching the BESS would have to be in a suitable charge state. Since BESS used for this type of black start service are likely to operate in various electricity markets, any Black Start contract would require to compensate the BESS provider to maintain the BESS charge status for Anchor generator support. This would depend on the level of support required and the characteristics of the BESS. Where BESS does not have sufficient capacity to complete the block load switching sequence, then after the first block load switching, the BESS could discharge to support the network demand (maintaining any minimum load limit on the Anchor generator). Hence there would be a time delay while the BESS reaches a suitable charge state for the next block load switching in the sequence.

If the BESS charge is too high to support the Anchor generator preload requirement for the first block load switching in the sequence, then the DRZC could be programmed to move to a block load in the sequence that does not required pre-loading or the preloading requirement is less and within the BESS capability based on the present charge state. The DRZC would be monitoring the BESS charge status and would be programmed to manage the BESS correctly during the black start restoration process to provide block load switching support and other support during island conditions e.g. frequency and voltage regulation support.

6.3.5.1 Use Case 9 Check the block load and transmission circuit switching sequence

UC 9 checks that the block load and transmission circuit switching sequence provided prior to the black start condition (provided by an external system) is still suitable prior to each block load demand restoration or transmission circuit switching step and will amend the sequence where appropriate.

Where BESS support is required for Anchor generator preloading on the first block load switching, the DRZC will check that the BESS charge state is such that it is capable of providing the required preload support. If this is not the case, the DRZC will look for a suitable block load switching in the sequence that requires no Anchor generator preloading support or less preloading support such that it is within the BESS charge status capability. With the first block load accepted the DRZC will move the BESS to a power export mode (BESS discharging) until the charge status can accommodate the original

[26] Studies carried out by the Distributed Restart team have confirmed that the time between switching in block load and turning down the Anchor generator preloading to maintain DRZ island frequency stability is very short (sub second). Achieving this through synchronised switching of block load circuit breakers and a load bank circuit breaker that are remote from each other would be problematic to achieve. Hence the solution would be the monitor the system frequency and use this to control the load bank (or BESS).

sequenced block load switching support (rate of power discharge will be set by the DRZC to maintain minimum load requirements on the Anchor generator). The block load sequence will continue with delays if the BESS requires further periods of discharge.

Once the first block load or transmission switching is complete and a stable DRZ island condition is confirmed, the initial switching sequence will be checked and updated if required by the DRZC as a number of key factors can have changed by the time the DRZC is ready for the next block load or transmission circuit switching. In particular:

1. The block load accepted in the previous switching step may vary considerably from the pre-switching estimate provided to the DRZC. Hence the assumptions regarding available remaining available capacity from the Anchor generator and BS DER in the original sequence calculations may be impacted potentially making the remaining sequence sub optimal.
2. The supporting BS DER available capacity will have changed. Firstly under DRZC control to take up the previous block load and free up capacity on the Anchor generator (and possibly any associated load bank), noting point 1 above regarding the potential difference between block load estimates and what happens in reality. Secondly due to ongoing primary energy resource variations with time, i.e. wind, solar irradiance, BESS charge status.
3. Similar changes can impact the ability of the Anchor generator and supporting BS DER (in voltage control mode) to accept the reactive power demands of further transmission circuit switching.

UC 9 therefore continually checks and updates the block load and transmission switching sequence prior to each block load switching step and adjusts the sequence where appropriate to do so.

UC-9	**Check the block load and transmission circuit switching sequence**
Primary Actor(s)	DRZC, DNO SCADA/DMS, Anchor Generator, BS DER (including Anchor generator preloading load bank or BESS)
Secondary Actor(s)	
Stakeholders and Interest	
Trigger	The first block load or transmission circuit switching has been completed.
Pre-conditions	• DRZC has been loaded with suitable transmission circuit switching estimates, block load switching estimates and a suitable switching sequence prior to the black start condition (data from an external system) (UC1). • The DRZC has utilized available capacity in the BS DER to free up capacity on the Anchor generator for the next transmission circuit or block load switching.
Post-conditions	DRZC has checked the remaining sequence of transmission circuit and block load switching based on the available BS DER capacity and Anchor generator capacity and block load acceptance capability and amends the sequence if appropriate
Main Success Scenario	1. The DRZC confirms the available BS DER capacity on an ongoing basis. [BS DER required to provide the DZRC with real time availability of real and reactive power capacity and a 30 minute forecast[27], part of black start contract].

[27] The thinking here is to use a percentage of the available capacity updated by the BS DER in near real time, or the 30 minute forecast data.

A programmable safety margin would be used. So if we had a wind farm with a rated capacity of 30MW and it was indicating an available capacity of 20MW we would run this constrained at say no higher than 15 to 18MW to ensure a safety margin of at least 10% is maintained

	2. DRZC checks the Anchor generator available capacity and associated block load switching capability. This includes the potential to use BS DER capacity to free up Anchor generator block load acceptance capacity. This also includes the status of any available load bank or BESS that could be used to increase Anchor generator block load acceptance. 3. DRZC checks the DRZ island capacity (Anchor generator plus BS DER available reactive power capacity) to accept further transmission circuit switching. 4. The block load and transmission circuit switching sequence is checked and updated if required by the DRZC prior to each block load and transmission circuit switching. Checks and updates consider the Anchor generator and BS DER capacity availability (this includes load bank and BESS capacity status for Anchor generator preloading support). 5. The DRZC will continue to check and update the block load and transmission circuit switching sequence where required until the switching sequence is complete or until the DRZC determines that further block load and transmission circuit switching cannot be safely accommodated. At this point the DRZC will issue an alert to the DNO DMS that the block load and transmission circuit switching sequence is either complete or cannot safely continue further.
Extensions	At Step 4. In the case of Anchor generator preloading support using BESS, at the first block load switching in the sequence, if the BESS charge status is too high to provide the required support, the DRZC will move to a block load in the sequence that does not require Anchor generator preloading support or where less preloading support is required within the present charge capability of the BESS. At Step 4. Where BESS is being used for Anchor generator preloading support during block load switching, after the first block load switching, if the BESS charge status is not sufficient to support the next block load in sequence, the DRZC will manage the BESS to discharge power to support the DRZ island demand until the charge status of the BESS can accommodate the required Anchor generator preloading support for the next block load switching. This process will continue until BESS support for block load switching is no longer required.
Priority	
Special Requirements	
Open Questions	The BS DER capacity available and Anchor generator loading could be collected via direct communication routes (local RTU to DRZC) rather than via the DNO SCADA/DMS to the DRZC.
Communication Requirements (Bandwidth, latency, storage etc.)	The BS DER capacity available and Anchor generator loading under frequency control will be required to check the block loading sequence prior to each block loading operation. However, the DNO SCADA/DMS system should be sufficiently fast to collect this data. If not then direct RTU to DZRC routes would need to be established.
Measurement Requirements	BS DER capacity available and Anchor generator loading. Assumed BS DER available capacity data can be provided by the BS DER control systems and Anchor generator loading can either come from the generator control system or from metering equipment on site.
Interfaces	Interface with the other BS DER control systems for available capacity data (SPEN/NG require to provide details of how other similar system interfaces deal with security concerns).

at all times. This limit can be adjusted. Where the available capacity starts to drop below say 16.5MW (15MW +10%), the export set point would be reduced by the DRZC putting more demand onto the Anchor generator which would also operate with a safety margin. The threshold for the safety margins would be programmable to suit the DRZ network and associated BS DER. In theory the safety margins could be calculated in the DRZC or another system to set these to suit the forecast weather conditions each day etc.

The bigger the safety margin (upper export limit and lower export limit set), or the less variable the BS DER available capacity then the less the need to adjust the BS DER export set point.

	Interface with the Anchor generator control system or measurement equipment for the generator loading data.

6.3.5.2 Use Case 10 Transmission circuit switching and block loading restoration of customer supplies

UC 10 is concerned with the control of the Anchor generator and any BS DER (including any load bank or BESS) to facilitate the pre-programmed sequence of block load demand restoration. UC 10 is also concerned with the pre-programmed sequence of transmission circuit switching. DRZC checking and updating of the block load and transmission circuit switching sequence prior to each event is concerned with UC 9.

UC 10 considers cases where the Anchor generator has load bank or BESS support to accept block load demand switching or cases where this is not required. The determination of what support the Anchor generator requires to accept block load switching is based on the block load estimates provided in the pre-programmed switching sequence and the pre-programmed block load acceptance capability of the Anchor generator. Based on this the DRZC will determine the level of Anchor generator preloading support required.

The block load real power estimates, transmission circuit reactive power requirement estimate and the switching sequence are to be determined in a separate system from the DRZC and loaded into the DRZC at any point prior to black start restoration. It is the responsibility of this other system to ensure that the levels of block load and transmission circuit reactive power are realistically within the capabilities of the DRZ Anchor generator and BS DER (including load banks and BESS for Anchor generator preloading support). The facilitation of this is tasked with others and is not considered in this FDS. The DRZC only requires to manage and control the DRZ island to carry out the network restoration switching sequence provided, assuming this is realistic to be accommodated in the first place.

UC-10	**Transmission circuit switching and block loading restoration of customer supplies**
Primary Actor(s)	DRZC, Anchor Generator control system
Secondary Actor(s)	Other BS DER control systems, DNO Control room operator
Stakeholders and Interest	
Trigger	• DNO control room operator has issued a signal to the DRZC giving permission to commence the black start restoration sequence (UC7).
Pre-conditions	• The Anchor generator is operating in a stable condition supporting the DRZ network configuration at that point in time. • The block load real power estimates, transmission circuit reactive power estimates and associated switching sequence has been loaded into the DRZC prior to the black start for the first block load switching (UC1). • The updated block load switching sequence is available (UC9) prior to all block load switching and transmission circuit switching. • Where BESS is to provide the Anchor generator with pre-loading support for block load switching, the BESS has sufficient energy storage available.
Post-conditions	The DRZ has accepted the block load demand or transmission circuit and the DRZ network and Anchor generator continue stable operation.
Main Success Scenario	**Block Load Switching**

	1. Prior to the first block load switching, the Anchor generator is operating at the minimum required loading for stable operation. 2. The Anchor generator has sufficient available capacity to accept the next block load. 3. Where load bank assistance is required for frequency stability to accept block load switching: i. the load bank will be controlled to raise the Anchor generator output by a value exceeding the estimated block load less the Anchor generator block load acceptance capability (block load value from external system loaded into the DRZC prior to any black start, see UC1 and the Anchor generator block load acceptance capability programmed into the DRZC)[28] ii. The DRZC will then close the circuit breakers to switch in the block load demand and simultaneously reduce the load bank by the anticipated block load (load bank control via the DRZC frequency based fast controller). iii. The Anchor generator governor will respond to restore the system frequency and the AVR will respond to restore the system voltage. iv. Once the initial switching is complete and the system frequency stabilizes, the DRZC where required, will adjust the Anchor generator set point to return the generator to 50 Hz frequency. 4. Where other rapid response DER is supporting Anchor generator block load switching such as BESS operating in frequency support mode: i. The DRZC will close the circuit breakers to switch in the block load demand and the BESS will respond to support the system frequency. ii. Once the initial switching is complete and the system frequency stabilizes, where required (non-isochronous governor arrangements on the Anchor generator), the DRZC will adjust the Anchor generator set point to return the generator to 50 Hz frequency reducing the need for any frequency support from the BESS. 5. Where the Anchor generator is deemed capable of block load acceptance while maintaining DRZ system frequency and voltage within agreed acceptable limits for island black starting (no Anchor generator preloading support requirement): i. The DRZC will close the circuit breakers to switch in the block load demand and the Anchor generator will respond to support the system frequency. ii. Once the initial switching is complete and the system frequency stabilizes, the DRZC where required, will adjust the Anchor generator set point to return the generator to 50 Hz frequency. 6. With the Anchor generator operating stably with the accepted new demand, the DRZC will adjust the Anchor generator output set point to counteract any frequency control droop, returning the Anchor generator a nominal 50Hz. This will also reduce the need for any frequency support from any BESS being used to support system frequency. The DRZC would also be programmed to adjust other BS DER real power set points to support the system frequency where the Anchor generator has limited available real power capacity available for frequency control (i.e. BS DER export would be adjusted to free up capacity on the Anchor generator). 7. With the Anchor generator operating stably with the accepted new demand, the DRZC will adjust the Anchor generator output set point to counteract any voltage concerns at the 33kV GSP. The DRZC can also adjust BS DER reactive power set points to support voltage or ensure that BS DER are switched to their voltage control mode if available to assist support the network voltage.

[28] For example, if the block load to be switched is 15MW from UC1 and the Anchor generator has a block load acceptance capability of 10MW, then the load bank would be used to provide the Anchor generator with at least 5MW of pre loading.

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8. In preparation for the next block load to be switched in, the DRZC will send set points to any DRZ BS DER to increase output and bring the Anchor generator output down to a level suitable to accept the next block load while keeping the other BS DER within a programmable safety margin below their available capacity (UC11 covers BS DER connection).

9. With the DRZC having transferred demand to other BS DER and adjusted the Anchor generator set point to counter act any frequency droop effects, the block load switching sequence will be checked and updated as required for the next block load switching step (UC9).

10. The DRZC will restore demand following a switching sequence (UC9) until the limits (accounting for suitable capacity margins) of the Anchor generator and BS DER to accept further block load demand are reached or all demand is restored (see UC12).

Transmission Circuit Switching

11. For transmission circuit switching in the pre-programmed switching sequence, the capability of the Anchor generator and BS DER to accept the estimated reactive power change has been confirmed in UC 9 prior to switching. Where BS DER has a voltage control mode available, the DRZC will move BS DER to this mode if not already in this mode. The DRZC will then close the pre-programmed circuit breakers and the Anchor generator AVR and any other active BS DER AVR will restore the 33kV system voltage. The DRZC will adjust AVR set points to counteract any AVR droop where required.

12. In preparation for the next transmission circuit to be switched in, the DRZC will send set points to any DRZ BS DER to increase output and bring the Anchor generator output down to a level suitable to accept the transmission circuit while keeping the other BS DER within a programmable safety margin below their available reactive power capacity (UC11 covers BS DER connection).
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<tr><td>Extensions</td><td>
1. Where block loading does not result in stable operation of the Anchor generator, the block load will be disconnected to protect the system stability. The DRZC will flag up an aborted block loading event to the DNO SCADA DMS, re-order the block load sequence to select a suitable alternative block load and commence the block loading sequence again.

2. The DRZC will continue to attempt alternative block loading, flagging up failed events to the DNO SCADA DMS until all suitable options for block loading have been attempted. The DRZC will then raise an event with the DNO SCADA DMS that while there is generation capacity available, the DRZC cannot restore further demand to the DRZ. The DNO Control room operator will then decide the required course of action, which may be to move to stage 4 stable operation.

3. Where transmission circuit switching does not result in stable operation of the Anchor generator and DRZ network (adequate voltage recovery), the transmission circuit will be disconnected to protect the system stability. The DRZC will flag up an aborted block loading event to the DNO SCADA DMS, re-order the transmission sequence to select a suitable alternative transmission circuit switch and commence the switching sequence again.

4. The DRZC will continue to attempt alternative transmission circuit switching, flagging up failed events to the DNO SCADA DMS until all suitable options for transmission circuit switching have been attempted. The DRZC will then raise an event with the DNO SCADA DMS that while there is generation reactive power capacity available, the DRZC cannot restore further transmission circuits to the DRZ. The DNO Control room operator will then decide the required course of action, which may be to move to stage 4 stable operation.
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<tr><td>Priority</td><td></td></tr>
<tr><td>Special Requirements</td><td></td></tr>
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Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	There are a number of control operations that will require fast receipt of DRZC control signals including any load banks, block load circuit breakers and other BS DER control systems to ensure system stability is maintained. Hence communications via the DNO SCADA/DMS will not suffice, and low latency direct communications will be required.
Measurement Requirements	The DRZC monitors the Anchor generator real and reactive power, frequency and voltage at the site HV substation and voltage at the 33kV GSP. Fast acting control will be required to maintain DRZ island stability. This will require fast measurement updating to the DRZC or supporting local controllers via low latency communication routes. Circuit breaker tripping may also provide a suitable indication of an event that would impact system stability e.g. BS DER circuit trip but the impact is dependent on the level of BS DER export, hence pre-event BS DER export measurements would also be required to determine what mitigating action the DRZC required to take. This is considered in other sections of the FDS report.
Interfaces	

6.3.5.3 Use Case 11 Connect other BS DER at low output

Having established a stable skeleton DRZ network energized by the Anchor generator, and received confirmation from BS DER that they are ready to connect and export power (Stage 2, UC8), UC 11 covers the connection of other BS DER onto the DRZ network ready to support block load demand restoration through Stage 3 (expansion of the DRZ island through block load restoration and transmission circuit switching).

UC 11 requires that under instruction from the DRZC other BS DER connect to the system maintaining zero power export/import until instructed to ramp up power output by the DRZC (if required and where available the DRZC can switch BS DER to a voltage control mode in which case reactive power is likely to be imported/exported). The aim is to ensure the BS DER connect to the DRZ network without resulting in any negative stability impact. [Noted that registered BS BESS with a frequency support control mode could be included to operate autonomously to provide fast frequency support.] The BS DER are required to provide the DRZC with continually updated available real and reactive power capacity. This will allow the DRZC to utilize BS DER available capacity during stage 3 while ensuring a safe margin of available capacity is maintained to ensure that demand/generation balance can be achieved as network conditions change.

During stage 3 the Anchor generator will provide the DRZ island network frequency control within the generator's capabilities. Fast frequency control can be supported by other suitable BS DER e.g. BESS or load banks, with slower frequency control supported by adjustments to BS DER power output set points issued by the DRZC. A similar approach is taken for network voltage control.

UC-11	**Connect other BS DER at low output**
Primary Actor(s)	DRZC, Other BS DER control systems
Secondary Actor(s)	Anchor generator control system
Stakeholders and Interest	
Trigger	Stage 2 is complete and the DRZC is ready to commence block load demand restoration and transmission circuit switching

Pre-conditions	• There is a stable DRZ skeleton network energized by the Anchor generator. • BS DER to be connected into the DRZ network have confirmed that they are ready (UC8).
Post-conditions	The BS DER are connected to the DRZ energized network, ready to export power when requested and maintaining net zero real and reactive power export/import.
Main Success Scenario	1. The DRZC closes the POC DNO circuit breaker at each BS DER location that has confirmed it is ready (note that this may already have been closed by the DNO control room operator where the BS DER required supplies from the grid for ancillary systems). 2. Each BS DER will maintain net zero power export/import until instructed to change by the DRZC. This includes BS DER with frequency support modes and voltage control modes of operation. 3. Each BS DER will provide the DRZC with continuously updated capacity availability figures for real and reactive power export. 4. Each BS DER will be issued with output set points by the DRZC as and when required, using the capacity availability data to maintain a suitable safety margin of available capacity (safety margin to be an available configurable data input for each DRZ). Where required, the DRZC will switch BS DER to any available frequency control or voltage control modes as required for network restoration.
Extensions	
Priority	
Special Requirements	
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	At this stage the only control is the closing of the DNO POC circuit breaker at each DER, hence DNO SCADA DMS latency would suffice.
Measurement Requirements	The DRZC will require real time measurements of the DER export/import to monitor performance and decide if actions will be required to maintain the DRZ stability. POC real time POC voltage may also be required. The DRZC will monitor and store BS DER export/import real and reactive power for checking performance against their BS support contract requirements.
Interfaces	

6.3.5.4 Use Case 12 Continue transmission circuit and block load switching and BS DER export adjustment

UC 12 covers the expansion of the DRZ network through block load and transmission circuit switching (UC10), continual checking and updating of the block load and transmission circuit switching sequence (UC9) and drawing support from other connected BS DER (UC11).

UC 12 will continue until the full DRZ network and associated demand customer supplies and transmission circuits are restored, or until the DRZC determines further system restoration is not feasible. The DRZC will issue an event alert to the DNO SCADA DMS when the DRZ network is fully restored indicating this or that further DRZ block load and transmission circuit restoration cannot proceed further.

During the stage 3 DRZ network restoration, the DRZC will issue confirmations to the DNO DMS (or the ESO EMS or both) that it is happy with progress or issue messages where the time between sequence steps are taking too long and are of concern. The definition of concerns would need to be agreed and pre-programmed into the DZRC.

UC-12	Continue transmission circuit and block load switching and BS DER export adjustment
Primary Actor(s)	DRZC,
Secondary Actor(s)	Anchor Generator control system, Other BS DER control systems, DNO SCADA DMS (possibly the ESO EMS)
Stakeholders and Interest	
Trigger	The first block load or transmission circuit switching operation is ready to commence (UC10)
Pre-conditions	• The Anchor generator is operating in a stable condition supporting the DRZ network configuration at that point in time. • The block loads, transmission circuits and associated switching sequence have been loaded into the DRZC prior to the black start DRZ network restoration switching (UC1). • The updated restoration switching sequence is available (UC9) prior to all block load and transmission circuit switching.
Post-conditions	The DRZ network is fully restored, or the network is restored as far as possible using the DZRC within the limits of the Anchor generator and supporting BS DER.
Main Success Scenario	1. The DRZC will carry out each block load and transmission circuit switching in sequence. The sequence will be checked and updated as required prior to each block load and transmission circuit switching step (see UC9). 2. The DRZC will connect and control all BS DER to maximize DRZ network restoration within safe operational margins (see UC11). 3. The DRZC will switch in each block load and transmission circuit in sequence (UC9) ensuring the DRZ network and Anchor generator are stable and Anchor generator is prepared for the next block load or transmission circuit switching (see UC10). 4. The DRZC will restore the DRZ network through block load and transmission circuit switching until the limits(accounting for suitable capacity margins)[29] of the Anchor generator and supporting BS DER to accept further restoration switching are reached or the full island network is restored. 5. During the stage 3 DRZ network restoration, the DRZC will issue confirmations that it is happy with progress or issue messages where the time between sequence steps are taking too long and are of concern. The definition of concern would need to be agreed and pre-programmed into the DZRC. 6. The DRZC will issue an event alert to the DNO SCADA DMS when the DRZ network is fully restored indicating this or that further DRZ network restoration cannot proceed further. 7. Having completed the DRZ network restoration as far as possible, the DRZC will move to a period of operating the DRZ network, maintaining stability (see Stage 4 UCs), until the resynchronisation with other DRZs or the transmission network is instructed by the DNO control room operator or ESO control room operator (see Stage 5 UCs).
Extensions	

[29] This needs to be a programmable limit in % that maintains a safety limit to allow for DER output and demand variation over a period of time. The determination of the limit to program into the DRZC needs to come from an external system. This could be a fixed % limit provided by network planners or it could be a variable limit based on an external system that forecasts demand and DER output for each DRZ network. For the present functional design it is assumed that a fixed % limited is determined by SPEN/NG network planners and programmed in by the System operator for each DRZC.

Priority	
Special Requirements	
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	There are a number of control operations that will require fast receipt of DRZC control signals including any load banks, block load circuit breakers and other BS DER control systems to ensure system stability. Hence communications via the DNO SCADA/DMS will not suffice, and low latency direct communications will be required.
Measurement Requirements	The DRZC monitors the Anchor generator real and reactive power, frequency and voltage at the site HV substation and voltage at the 33kV GSP. Fast acting control will be required to maintain DRZ island stability. This will require fast measurement updating to the DRZC or supporting local controllers via low latency communication routes.
Interfaces	

6.3.6 Stage 4 Maintain Island Stability

Stage 4 of the DRZ network restoration covers the period from restoration of the network or as much as the network as possible to the point where resynchronisation with other DRZ networks or the transmission grid commences. During this period the Anchor generator under frequency and voltage control will cater for expected changes in the DRZ network demand. The DRZC will support the Anchor generator by adjusting BS DER set points to ensure the Anchor generator remains within operational limits including any safety margin, while also ensuring supporting BS DER remain within safe limits. The stage 3 block load and transmission switching by the DRZC ensures that on completion of the network restoration switching sequence there is a safe margin of BS DER available real and reactive power capacity to cater for changes in their output and expected network demand variations. The DRZC functions required under this DRZ scenario are covered by UC13.

Where larger network demand and BS DER output variations occur that potentially exceed the BS DER capacity safety margins and Anchor generator capabilities, then the DRZC will take action to shed demand or possible BS DER to protect the Anchor generator and maintain a Stable DRZ network. Such scenarios are covered by the DRZC functions in UC14.

6.3.6.1 Use Case 13 Maintain stable island with monitoring and set points to BS DER

UC-13	Maintain stable island with monitoring and set points to BS DER
Primary Actor(s)	DRZC, Anchor generator control system, Other supporting BS DER control systems
Secondary Actor(s)	DNO Control room operator, DNO SCADA DMS
Stakeholders and Interest	
Trigger	Stage 3 Block Load DRZ network restoration complete and DRZC has issued event notice to the DNO Control Room operator via the DNO SCADA DMS (UC12)
Pre-conditions	Block load and transmission circuit switching sequence is complete (UC12).
Post-conditions	DRZ island and Anchor generator stable operation is maintained by the DRZC

Main Success Scenario	1. The DRZC is monitoring the Anchor generator real and reactive power, frequency and voltage at the site HV substation and voltage at the 33kV GSP. 2. The DRZC is being provided with the Anchor generator available real and reactive power capacity on a continuous basis. 3. The DRZC is monitoring the position of any associated load bank or BESS. 4. The DRZC is being provided with BS DER available real and reactive power capacity on a continuous basis. 5. Differences between load and generation are being catered for using the frequency control and voltage control capability of the Anchor generator's governor and AVR systems. 6. The DRZC is sending output set points to other BS DER, to keep Anchor generator close to the target power output while ensuring each BS DER will have sufficient remaining available capacity. 7. Where necessary to maintain a suitable BS DER available capacity margin, the DRZC will adjust the Anchor generator output set point while ensuring it remains within suitable output limits. 8. Where the Anchor generator and supporting BS DER including load banks and BESS can no longer be controlled by the DRZC and maintain pre-programmed available capacity margins, the DRZC will consider pre-programmed contingency actions to protect the DRZ network stability and protect the Anchor generator operation (see UC14). 9. The DRZC is to provide the DNO SCADA DMS with visibility of Anchor generator and BS DER outputs and DRZC set point requests. 10. All Anchor generator set point instructions will be stored for performance and settlement purposes.
Extensions	Where available and beneficial to do so, the DRZC could be programmed to switch BS DER to available frequency and voltage control modes of operation[30].
Priority	
Special Requirements	
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	There are a number of control operations that will require fast receipt of DRZC control signals including the Anchor generator and other BS DER control systems to ensure system stability. Hence communications via the DNO SCADA/DMS will not suffice, and low latency direct communications will be required.
Measurement Requirements	The DRZC monitors the Anchor generator real and reactive power, frequency and voltage at the site HV substation and voltage at the 33kV GSP. The DRZC also monitors the BS DER available capacity and their real and reactive power output. Fast measurement updating to the DRZC via low latency communication routes will be required from the Anchor generator, the 33kV GSP, and other BS DER.
Interfaces	

6.3.6.2 Use Case 14 Stability contingency actions

While UC13 considers DRZC control actions that are within the Anchor generator and supporting BS DER capabilities, including safety margins. UC14 considers scenarios where the stability of the DRZ network and Anchor generator could be compromised, requiring the DRZC to take alternative action such as tripping out block load or supporting BS DER to protect the DRZ black start island.

[30] Initially network planning studies will be required to confirm the most suitable operating mode for some BS DER. However, as knowledge is developed a more standardised approach could be adopted to avoid the need for network planning studies.

UC-14	Stability contingency actions
Primary Actor(s)	DRZC, Anchor Generator control system, Other BS DER control systems
Secondary Actor(s)	DNO Control Room operator, DNO SCADA DMS
Stakeholders and Interest	
Trigger	Stage 3 Block Load DRZ network restoration complete and DRZC has issued event notice to the DNO Control Room operator via the DNO SCADA DMS (UC12)
Pre-conditions	Block load and transmission circuit switching sequence is complete (UC12).
Post-conditions	DRZ island and Anchor generator stable operation is maintained by the DRZC
Main Success Scenario	1. The DRZC is monitoring the Anchor generator real and reactive power, frequency and voltage at the site HV substation and voltage at the 33kV GSP. 2. The DRZC is being provided by the Anchor generator with available real and reactive power capacity on a real time continuous basis. 3. The DRZC is monitoring the position of any associated load bank or BESS. 4. The DRZC is being provided with BS DER available real and reactive power capacity on a continuous basis. 5. The DRZC can receive status updates of all block load circuit breakers and DER POC circuit breakers through low latency communication routes (fast). Measured power flow data through each block load circuit breaker is also being monitored by the DRZC via the same low latency communication routes. 6. The DRZC is summating the measured power flows from each block load circuit breaker and retaining this information for a programmable number of seconds before over writing, (or this could be retained in the data historian until after the black start restoration for analysis purposes). 7. The DRZC detects a RoCoF outside of configurable set limits or a circuit breaker status change or an aggregated block load change, or a BS DER export flow change (limits can be set by the DSO for each DRZ network) indicating a major network change rather than a normal expected change in the island demand or generation. 8. For a rising RoCoF, sudden drop in aggregated demand, trip of block load circuit breakers: i. The DRZC will check the power flow summations retained at step 6 and estimate the step change in block load. ii. Based on the block load step drop, the DRZC will check the BS DER outputs and calculate which BS DER need to be tripped. iii. The DRZC will then trip the required BS DER POC circuit breakers. iv. The DRZC will issue the remaining BS DER with set points to return the Anchor generator to a suitable output (above the minimum load requirement) based on the BS DER available capacity. Where fast acting BS DER is required (load banks and BESS) these will be issued with new set points first (unless they are in a frequency control mode in which case they will automatically adjust their power output). v. Having stabilized the DRZ network and adjusted the Anchor generator and remaining BS DER to suitable outputs, operations will be maintained for a programmable period of time. vi. The DRZC will then request permission from the DNO control room operator via the DNO SCADA DMS to restore any tripped out block load. When the DRZC receives permission it will then revert to UC 9, 10, 11 and 12 to look to restore the missing block load and BS DER. Note, the DNO control room operator will investigate the reason for the sudden loss of demand before issuing permission to the DRZC to proceed to restore any missing block load. The DNO control room operator may decide to restore the missing BS DER and block load manually. (Note that step vi could be automated for BAU.) 9. For a dropping RoCoF, sudden loss of generation export, trip of BS DER POC breaker:

	i. The DRZC will check BS DER outputs and summate the loss of BS DER output (requires BS DER output to be retained or retained for a programmable number of seconds before refreshing). ii. Based on the BS DER step drop, the DRZC will check the present block loads and calculate which block loads need to be tripped. iii. The DRZC will then trip the required block load circuit breakers. iv. The DRZC will issue the remaining BS DER with set points to return the Anchor generator to a suitable output (above the minimum load requirement) based on the remaining BS DER available capacity. Where fast acting BS DER is required (load banks and BESS) these will be issued with new set points first (unless they are in a frequency control mode in which case they will automatically adjust their power output). v. Having stabilized the DRZ network and adjusted the Anchor generator and remaining BS DER to suitable outputs, operations will be maintained for a programmable period of time. vi. The DRZC will then request permission from the DNO control room operator via the DNO SCADA DMS to restore any tripped out BS DER. When the DRZC receives permission it will request confirmation from the missing BS DER that it is ready to reconnect and provide BS support. On receiving BS DER confirmation, the DRZC will then revert to UC 9, 10, 11 and 12 to look to restore the missing BS DER and restore the block load where possible. Note, the DNO control room operator will investigate the reason for the sudden loss of BS DER before issuing permission to the DRZC to proceed to restore any missing BS DER and block load. The DNO control room operator may decide to restore the missing BS DER and block load manually. (Note that step vi could be automated for BAU.) vii. If the DNO control room operator or missing BS DER control engineer advise the DRZC that the missing BS DER will not be available for the remainder of the BS sequence, then UC9 may indicate that the block load cannot be restored and UC12 will indicate that block loading is complete as far as possible. 10. Having restored the DRZ network to stable operation, the DRZC reverts to UC13 functionality. 11. The DRZC will provide the DNO SCADA DMS with visibility of Anchor generator and BS DER outputs and DRZC set point requests. 12. All Anchor generator set point instructions will be stored for performance and settlement purposes.
Extensions	
Priority	
Special Requirements	Note that reference to DRZC in this use case may include local programmed controllers that will detect a sudden system change that could compromise stability and take decisions and execute the required trips. This is described further in other sections of this FDS report, see section 7.
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	There are a number of control operations that will require fast receipt of DRZC control signals including any load banks, block load circuit breakers and other supporting DER control systems and POC circuit breakers to ensure system stability. Hence communications via the DNO SCADA/DMS will not suffice, and low latency direct communications will be required.
Measurement Requirements	The DRZC monitors the Anchor generator real and reactive power, frequency and voltage at the site HV substation and voltage at the 33kV GSP. The DRZC also monitors the supporting BS DER available capacity and their real and reactive power output. The DRZC is also monitoring the block load circuit breaker power flows. Fast measurement updating to the DRZC via low latency communication routes will be required from the Anchor generator, the 33kV GSP, and other supporting BS DER.
Interfaces	

6.3.7 Stage 5 Re-synchronising

The DRZC will maintain a stable operating DRZ network with as much of the network and as many of the demand customers restored as possible, see Stage 4 UCs 13 and 14. This will continue until the DNO and NGESO is ready to either synchronize the DRZ island network with other DRZ networks or is ready to synchronize the DRZ network to the transmission network. Decisions on resynchronising will be taken by the ESO, and or DNO operators based on other higher level black start support systems.

6.3.7.1 Use Case 15 Synchronize to adjacent Island

UC15 covers synchronising adjacent DRZ network islands to establish a larger island network. In establishing the DRZ networks, the DNO will have identified the circuit breakers that synchronising will take place across and fitted suitable VTs with voltage, voltage phase angle and frequency measurement equipment on both sides of each synchronising breaker. Measurement devices may be separate or may take the form of a check synch device that will prevent breaker operation outside of programmed limits to protect against out of synchronism switching. Where measurement devises are separate it is recommended that a check synch device is also fitted to protect against out of synchronism switching and for automatic closing of the circuit breaker when synchronising conditions are met.

In carrying out any synchronising operation between two DRZ networks the DRZC controlling each DRZ network will require to control the Anchor generator and possibly the BS DER[31] real and reactive power set points to achieve alignment of voltage magnitudes, voltage phase angles and system frequencies within the difference settings of the check synch protection device. Since each DRZ network will have varying demand and generation capacity, where DRZCs need to synchronize their DRZ network, one is programmed to be the lead controller and the other is the subordinate controller. This could be left as a potential option for the DNO control room operator to select when instructing a synchronising of two DRZ islands.

The subordinate DRZC (DRZC2) would aim to maintain the present voltage, angle and frequency at the DRZC2 side of the synchronising breaker. The DRZC2 should have the option for the DNO control room operator to set a target voltage and frequency for the DRZC2 system if necessary. The lead DRZC (DRZC1) will adjust the Anchor generator and possibly the BS DER real and reactive power set points to adjust the voltage, angle and frequency on the DRZC1 side of the synchronising breaker until it meets the check synch device requirements to close the circuit breaker. At this point the check synch device will issue the close signal to the breaker and the two systems will be connected.

UC-15	**Synchronize to adjacent Island**
Primary Actor(s)	DRZC1, DRZC2, DNO control room operator, DNO SCADA DMS
Secondary Actor(s)	Other BS DER control systems, Anchor Generator control systems
Stakeholders and Interest	

[31] The Anchor generator frequency and voltage output would be controlled by the DRZC adjusting the P and Q set points. The BS DER P and Q set points would only be adjusted to ensure the Anchor generator has sufficient margin to adjust its P and Q set points. Since the DRZ networks will be operated with suitable P and Q safety margin at the Anchor generator, adjusting BS DER P and Q set points may not be required during synchronising.

Trigger	Signal from the DNO control room operator via the DNO SCADA DMS to synchronize DRZC1 and DRZC2 via the identified synchronising circuit breaker.
Pre-conditions	DRZC1 and DRZC2 have completed stage 4 and are operating independent of each other in a stable condition.
Post-conditions	DRZC1 and DRZC2 synchronized together and are operating connected together in a stable condition.
Main Success Scenario	1. The DNO control room operator issues instructions via the DNO SCADA DMS to DRZC1 and DRZC2 to synchronize across a specific circuit breaker instructed by the DNO control room operator. The DRZCs have a pre-programmed list of potential synchronising circuit breakers. The DNO control room operator will designate which system is DRZC1 (lead) and which is DRZC2 (subordinate). 2. DRZC2 will aim to maintain the present voltage, angle and frequency at the DRZC2 side of the synchronising breaker. Option for the DNO control room operator to set a target voltage and frequency for the DRZC2 system if necessary. 3. DRZC1 will adjust the Anchor generator and possibly the BS DER real and reactive power set points to adjust the voltage, angle and frequency on the DRZC1 side of the synchronising breaker until it meets the check synch device requirements to close the circuit breaker. 4. When the check synch devise breaker close settings are reached, the check synch device will automatically issue the close signal to the breaker and the two systems will be connected. DRZC1 will see the synchronising circuit breaker status change to closed and issue an event notice to the DNO SCADA DMS that the two DRZ systems are connected. 5. DRZC1 and 2 will monitor the real and reactive power flow across the synchronising circuit breaker and continue to control their respective Anchor generators and BS DER to balance demand and generation on their respective network areas, minimising the real and reactive power flow across the synchronising breaker and any further circuits connected to link the DRZ networks (see UC13 and UC14). 6. If the power flows across the synchronising breaker (and any further circuits connected to link the DRZ networks) exceed pre-programmed thresholds DRZC1 will trip the synchronising breaker (and any further circuits connected to link the DRZ networks) and issue an alert to the DNO control room operator via the DNO SCADA DMS. The DNO control room operator can play back the DRZC1 and 2 control set points, BS DER and Anchor generator real and reactive power flows and the synchronising circuit breaker (and any further circuits connected to link the DRZ networks) real and reactive power flows before deciding on a course of action prior to initiating another synchronising command. 7. The DRZCs will provide the DNO SCADA DMS with visibility of Anchor generator and BS DER outputs, available capacity and DRZC set point requests. 8. All Anchor generator set point instructions will be stored for performance and settlement purposes.
Extensions	• The DRZCs will provide event information to the DNO SCADA DMS where their respective DRZ network is operating with available BS DER and Anchor generator capacity below a pre-programmed safety margin indicating the amount of deviation and similarly for operation above a pre-programmed safety margin. • Where one DRZ network has less available capacity margin than required and one has more, the DNO Control room operator can manually adjust BS DER set points. • Alternatively the DRZCs will be programmed to transfer excess available capacity to the DRZ network with limited available capacity by adjusting the BS DER output set points in its DRZ network, see UC15c. This would be initiated and monitored by the DNO control room operator.
Priority	
Special Requirements	
Open Questions	

Communication Requirements (Bandwidth, latency, storage etc.)	Low latency direct communications will be required between the DRZC1 and the synchronising breaker, Anchor generator control system and DER control systems on the DRZC1 side. Low latency direct communications will be required between the DRZC2 and the synchronising breaker, Anchor generator control system and DER control systems on the DRZC2 side.
Measurement Requirements	DRZC1 and DRZC2 require rapid updating of the voltage, voltage angle and frequency on their respective sides of the synchronising circuit breaker. DRZC1 also requires rapid updating of the voltage, voltage angle and frequency on the DRZC2 side of the synchronising circuit breaker in order to adjust the Anchor generator and BS DER real and reactive power set points on the DRZC1 side to get alignment of the voltage, angle and frequency on both sides of the synchronising breaker. Low latency direct communications will be required.
Interfaces	

6.3.7.2 Use Case 15c Support Operation of adjacent DRZC Island when synchronized

Once the two DRZ islands are connected (UC15), DRZC1 and DRZC2 will manage their respective Anchor generators, BS DER and block load breakers as required to keep their respective DRZ networks in demand/generation balance. The power flow measurements through the synchronising circuit breaker and other circuit breakers switched into service to link the two DRZ networks are available to both DRZC1 and DRZC2. Each DRZC will monitor the power flows between the two DRZ networks to ensure they are balancing their own network generation and demand (power flow between DRZ networks should be minimal under this condition). Where, one island has limited available generation capacity and another has more available generation capacity than required as a safe operating margin, it should be possible for the two DRZCs to modify their BS DER set points to redress this situation and send some supporting power via the circuits linking the two DRZ networks. The DRZCs would need to do this within network circuit thermal limits and network voltage limits. It is likely that the DNO control room operator would be required to provide the DRZCs permission to carry out this type of operation and monitor progress. This level of control is considered to be an extension to the basic control functionality to synchronize to DRZ networks in UC15.

UC-15c	**Synchronize to adjacent Island**
Primary Actor(s)	DRZC1, DRZC2, DNO control room operator, DNO SCADA DMS
Secondary Actor(s)	Other BS DER control systems, Anchor generator control systems
Stakeholders and Interest	
Trigger	Signal from the DNO control room to move power from one DRZ network to another once synchronized.
Pre-conditions	DRZC1 and DRZC2 are synchronized together (UC15 complete) and each is operating to balance their own network and keep the power flow on the circuits between them to a minimum.
Post-conditions	DRZC1 or DRZC2 is supporting the other by transferring power across the DRZ island interconnecting circuits keeping stable operating conditions with safe margins of available BS DER and Anchor generator capacity in each DRZ network.
Main Success Scenario	1. The DNO control room operator issues instructions via the DNO SCADA DMS to DRZC1 and DRZC2 to share available generation capacity between them up to a pre-programmed safe limit.

	2. The DRZCs will permit this where one is below pre-programmed safe margins of available generation capacity and the other DRZC is reporting available generation capacity above pre-programmed safe margins. 3. The DRZC with excess available capacity will adjust its BS DER and Anchor generator output set points to transfer power to the other DRZ network. This will be limited by maintaining the safe margins of available capacity on the sending DRZ network and by any other pre-programmed safety limit covering network thermal and voltage issues. 4. DRZC1 and 2 will communicate their respective available capacity margins to each other and each will monitor the power flows across the connecting circuits between them. 5. While sharing available capacity margins between each DRZ network, each DRZC will follow UC13 for small variations in demand and generation while maintaining a stable power flow across the DRZ island interconnecting circuits. Adjustments to the available capacity margin sharing will be carried out in a time frame to maintain system stability. 6. Where there is a sudden change in system frequency, or demand or generation capacity each DRZC will follow UC14 to carry out mitigating actions to protect system stability and protect their respective Anchor generators. Note that in UC14 each DRZC is monitoring the outputs from their respective block load circuits and DER/Anchor generators and will know what has caused the sudden frequency change and therefore mitigating action will be taken by the correct DRZC. Once the mitigating action is taken and stability restored, UC15c will resume any power sharing requirements. If the mitigating actions do not restore stability e.g. an Anchor generator has tripped then the DRZC that sees the issue will open the breakers on the circuits connecting the two islands. 7. The DRZCs will provide the DNO SCADA DMS with visibility of Anchor generator and BS DER outputs, available capacity and DRZC set point requests. 8. All Anchor generator set point instructions will be stored for performance and settlement purposes.
Extensions	
Priority	
Special Requirements	
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	Low latency direct communications will be required between the DRZC1 and the synchronising breaker, Anchor generator control system and DER control systems on the DRZC1 side. Low latency direct communications will be required between the DRZC2 and the synchronising breaker, Anchor generator control system and DER control systems on the DRZC2 side.
Measurement Requirements	DRZC1 and DRZC2 require rapid updating of the voltage, voltage angle and frequency on their respective sides of the synchronising circuit breaker. DRZC1 also requires rapid updating of the voltage, voltage angle and frequency on the DRZC2 side of the synchronising circuit breaker in order to adjust the Anchor generator and BS DER real and reactive power set points on the DRZC1 side to get alignment of the voltage, angle and frequency on both sides of the synchronising breaker. Low latency direct communications will be required.
Interfaces	

6.3.7.3 Use Case 16 Synchronize to Transmission Grid

UC16 covers synchronising the DRZ network with the local transmission network. In establishing the DRZ networks, the DNO/ESO will have identified the circuit breakers that synchronising will take place across and fitted suitable VTs with voltage, voltage phase angle and frequency measurement equipment on both sides of each synchronising breaker. Measurement devices may be separate or may take the form of a check synch device that will prevent breaker operation outside of programmed limits to protect against out of synchronism switching. Where measurement devises are separate it is recommended that a check synch device is also fitted to protect against out of synchronism switching and for automatic closing of the circuit breaker when synchronising conditions are met.

The DRZC will adjust the Anchor generator and possibly the BS DER real and reactive power set points to adjust the voltage, angle and frequency on the DRZC side of the synchronising breaker until it meets the check synch device requirements to close the circuit breaker. At this point the check synch device will issue the close signal to the breaker and the two systems will be connected. The Anchor generator frequency and voltage output would be controlled by the DRZC adjusting the P and Q set points. The BS DER P and Q set points would only be adjusted to ensure the Anchor generator has sufficient margin to adjust its P and Q set points. Since the DRZ networks will be operated with suitable P and Q safety margin at the Anchor generator, adjusting BS DER P and Q set points may not be required during synchronising.

Where synchronising involves a distribution island formed of multiple DRZ networks (UC15), one DRZC will carry out the synchronising with the transmission grid utilising its Anchor generator, BS DER and associated synchronising circuit breakers, communications and measurement equipment and check synch relays. The synchronising breaker utilized and hence the DRZC used would be selected by the ESO or DNO control room operators appropriate.

During the process of connecting the DRZ island with the restored transmission grid it is likely there will be a transfer of reactive power via the synchronising circuit breaker on closure. Prior to synchronising with the transmission network and where possible any BS DER operating in a fixed reactive power or power factor control mode would be switched to a voltage control mode to help stabilize the network voltage.

Once the DRZ island is connected to the transmission network, the DRZC will manage the Anchor generator, BS DER and block load breakers as required to keep the real and reactive power flow to near zero until instructed otherwise by the NGESO control room engineer via the NGESO SCADA EMS. The DRZC will continue to receive available real and reactive power capacity data from the Anchor generator and BS DER and make this data available to the DNO SCADA DMS and NGESO SCADA EMS systems. Where synchronising involves a distribution island formed of multiple DRZ networks, each DRZC will provide their respective available real and reactive power capacity data to the DNO SCADA DMS and NGESO SCADA EMS systems. Where the NGESO requires aggregation of available real and reactive power this can be carried out by the EMS. Alternatively each DRZC can aggregate available real and reactive power for their respective DRZ network.

It is noted that signals and data indicated as to or from the ESO SCADA EMS may be direct or routed via the DNO SCADA DMS system. This is a decision for the Distributed Restart team.

UC-16	**Synchronize to Transmission Grid**
Primary Actor(s)	DRZC, NGESO Control room operator, NGESO SCADA EMS
Secondary Actor(s)	Other BS DER control systems, Anchor generator control systems, DNO Control room operator, DNO SCADA DMS, other DRZCs involved in the island network.
Stakeholders and Interest	
Trigger	Signal from the NGESO control room operator via the NGESO SCADA EMS to synchronize the DRZ with the transmission network via the identified synchronising circuit breaker.

Pre-conditions	DRZ network has completed stage 4 and is operating in a stable condition.
Post-conditions	DRZ network and local transmission network are synchronized together and are operating connected together in a stable condition.
Main Success Scenario	1. The NGESO control room operator issues instructions via the NGESO SCADA EMS to the DRZC to synchronize across a specific circuit breaker instructed by the NGESO control room operator. The DRZC has a pre-programmed list of potential synchronising circuit breakers. 2. Where BS DER has a voltage control mode, the DRZC will ensure the associated BS DER are switched to this mode prior to synchronising, to help stabilize the network voltage on closing the synchronising circuit breaker. 3. In the first instance the DRZC will adjust the Anchor generator real and reactive power set points to adjust the voltage, angle and frequency on the DRZC side of the synchronising breaker until it meets the check synch device requirements to close the circuit breaker. Where necessary to support this process the DRZC will issue set points to the BS DER to ensure the Anchor generator has sufficient control margin available. 4. When the check synch device breaker close settings are reached, the check synch device will automatically issue the close signal to the breaker and the two systems will be connected. The controlling DRZC will see the synchronising circuit breaker status change to closed and issue an event notice to the NGESO SCADA EMS and DNO SCADA DMS that the DRZ system and transmission network are connected. 5. The DRZC will continue to receive available real and reactive power capacity data from the Anchor generator and BS DER and make this data available to the DNO SCADA DMS and NGESO SCADA EMS systems. 6. The DRZC will monitor the real and reactive power flow across the synchronising circuit breaker and continue to control the Anchor generator and BS DER (see UC13 and UC14) to keep the real power flow to near zero. The Anchor generator AVR and any BS DER switched to a voltage control mode will result is reactive power flow across the synchronising circuit breaker as conditions on the transmission network and DRZ network change post synchronising.[32] This will continue until the DRZC receives instructions to adjust the Anchor generator and or BS DER real and reactive power output set points. Instructions may come from the DNO SCADA DMS or the NGESO SCADA EMS. Note that there is an option here for the DNO or NGESO control room operator to take manual control and by pass the DRZC. 7. The DRZC will provide the NGESO SCADA EMS and DNO SCADA DMS with visibility of Anchor generator and BS DER outputs, available capacity and DRZC set point requests. 8. All Anchor generator set point instructions will be stored for performance and settlement purposes.
Extensions	
Priority	
Special Requirements	
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	Low latency direct communications will be required between the DRZC and the synchronising breaker, Anchor generator control system and DER control systems on the DRZC side.

[32] The DRZC can be programmed to target a voltage at the Anchor generator or GSP by adjusting the Anchor generator AVR set point and BS DER voltage control set point or reactive power output set point. This will be limited by the control action to maintain a level of available reactive power at the Anchor generator and each BS DER. The ESO or DNO could command changes to the target voltage set point at the GSP which the DRZC would attempt to achieve within the limitations of the available reactive power limits set.

Measurement Requirements	The DRZC will require rapid updating of the voltage, voltage angle and frequency on both sides of the synchronising circuit breaker in order to adjust the Anchor generator and DER real and reactive power set points on the DRZC side to get alignment of the voltage, angle and frequency on both sides of the synchronising breaker. Low latency direct communications will be required.

6.3.7.4 Use Case 17 Confirm Black Start Island condition is complete

Once two DRZ networks have been synchronized UC15, or the a DRZ network has been synchronized to the transmission network UC16, after a pre-programmed period of stable operation, the respective control rooms will be notified by the DRZC of a successful resynchronising operation.

UC-17	Confirm Black Start Island condition is complete
Primary Actor(s)	DRZC, NGESO Control room operator, DNO Control room operator
Secondary Actor(s)	NGESO SCADA EMS, DNO SCADA/DMS
Stakeholders and Interest	
Trigger	Synchronising process is complete and stable operation has been maintained for a pre-programmed time (see UC15 and UC16)
Pre-conditions	DNO Control room operator has instructed a DRZ to DRZ network synchronisation UC15 or the NGESO Control room operator has instructed DRZ network synchronising operation with the local transmission network UC16.
Post-conditions	DRZC has provided confirmation that the synchronising operation has been successfully completed.
Main Success Scenario	1. UC15, the DRZC will send an event notification to the DNO Control room operator via the DNO SCADA/DMS that the DRZ to DRZ network synchronising has been completed successfully. See UC15 for failure to complete. 2. UC16, once successfully synchronized with the local transmission network the DRZC will switch out any BS island 33kV earth at the Anchor generator site. 3. UC16, the DRZC will send an event notification to the NGESO Control room operator via the NGESO SCADA/EMS that the DRZ to local transmission network synchronising has been completed successfully. See UC16 for failure to complete. 4. UC16, the DRZC will request permission from the NGESO Control room operator via the NGESO SCADA EMS to restore the normal operational protection settings. Once the DRZC receives permission via the NGESO SCADA/EMS it will restore the protection settings via the DNO SCADA/DMS raising an event notification to advise the DNO Control room that this is occurring. 5. UC16, the DRZC will report on the block load circuits that could not be restored during the DRZC restoration sequence and the associated block load estimates for each circuit (UC9). Report sent to the NGESO SCADA EMS and the DNO SCADA DMS. 6. UC16 the DRZC will request permission from the NGESO Control room operator via the NGESO SCADA EMS to reconfigure the DRZ network and fully restore supplies. An event will be raised indicating this request to the DNO Control room operator via the DNO SCADA DMS.
Extensions	
Priority	
Special Requirements	
Open Questions	

Communication Requirements (Bandwidth, latency, storage etc.)	All communications for UC17 can be at SCADA EMS or SCADA/DMS speeds. Note that the DRZC is still controlling the DER and Anchor generator so other control operations to maintain system stability will require Low latency direct communications.
Measurement Requirements	All measurements for UC17 can be at SCADA EMS or SCADA/DMS speeds. Note that the DRZC is still controlling the DER and Anchor generator so measurements to maintain system stability control will require Low latency direct communications.
Interfaces	

6.3.8 Stage 6 Black Start Island Termination

On completion of Stage 5 the DRZ network (or combined DRZ networks) will be synchronized with the local transmission network. The DRZC will also have disconnected any DRZ Island 33kV earth at the Anchor generator and restored any protection settings altered for island mode conditions.

The DRZ network then requires to be fully restored to the pre-black out network configuration before confirming that the DRZC black start sequence is complete and it is ceasing operational control.

6.3.8.1 Use Case 18 Reconfigure network and fully restore supplies

Once permission is received from the NGESO Control room operator via the NGESO SCADA EMS, the DRZC will go through a phase of restoring any DRZ block load circuits that could not be connected to the DRZ network during island conditions. The DRZC will then restore the network to the network configuration prior to the blackout conditions.

UC-18	Reconfigure network and fully restore supplies
Primary Actor(s)	DRZC, NGESO Control room operator, DNO Control room operator
Secondary Actor(s)	NGESO SCADA EMS, DNO SCADA/DMS
Stakeholders and Interest	
Trigger	Permission received from the NGESO Control room operator via the NGESO SCADA EMS to reconfigure the DRZ network and fully restore supplies.
Pre-conditions	Stage 5 is complete and the DRZ network(s) is synchronized with the local transmission network and has been operating in a stable condition for a pre-programmed period. The DNO control room via the DMS will disconnect any temporary 33kV earth at the Anchor generator and restore protection settings to pre-blackout conditions. UC17, the DRZC has reported on the block load circuits that could not be restored during the DRZC restoration sequence and the associated block load estimates for each circuit (UC9). Report sent to the NGESO SCADA EMS and the DNO SCADA DMS.
Post-conditions	The DRZ network configuration and customer supplies have been restored to pre-blackout conditions.
Main Success Scenario	1. On providing permissions for the DRZC to start the process of restoring any missing block load circuits, the NGESO Control room operator should submit any frequency conditions that require to be met prior to each block load switching. The DRZC will commence block load switching once frequency measurement at the 33kV GSP exceed any minimum frequency level submitted by the NGESO Control room operator via the NGESO SCADA EMS.

	2. The DRZC will switch each missing block load from the largest to the smallest, checking the frequency conditions are met prior to initiating each switching operation. This will continue until all circuits are energized and the DRZ network supplies are restored. 3. The DRZC will check that all circuit breakers have been restored to their pre-black start operational status. Where this is the case an event notice will be sent to the DNO SCADA DMS indicating all circuit breakers are now restored to their pre-black start status.
Extensions	
Priority	
Special Requirements	Pre-black start circuit breaker status only applies to those circuit breakers operated by the DRZC when reconfiguring the network for black start operations (UC4).
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	All communications for UC18 can be at SCADA EMS or SCADA/DMS speeds. Note that the DRZC is still controlling the DER and Anchor generator so other control operations to maintain system stability may require Low latency direct communications if the transmission network condition is such that it would still require DRZC support if a block load or DER trips or load back/Anchor generator support during block load switching.
Measurement Requirements	All measurements for UC18 could possibly be at SCADA EMS or SCADA/DMS speeds. Note that the DRZC is still controlling the DER and Anchor generator so measurements to maintain system stability control may require Low latency direct communications.
Interfaces	

6.3.8.2 Use Case 19 Advise any reconfiguration failures

If the DRZC fails to connect any remaining block load circuits or restore the network to the pre-blackout network configuration it will notify the DNO Control room operator via the DNO SCADA/DMS of any such issues. The DNO Control room operator can then investigate and take the appropriate action.

UC-19	Advise any reconfiguration failures
Primary Actor(s)	DRZC, DNO Control room operator
Secondary Actor(s)	DNO SCADA/DMS
Stakeholders and Interest	
Trigger	UC18, the DRZC has identified circuit breakers that cannot be returned to the pre-black start status.
Pre-conditions	The DRZC has checked that all circuit breakers have been restored to their pre-black start operational status and found this not to be the case (UC18)
Post-conditions	All circuit breakers that have not been restored to their pre-black start operational status and reported to the DNO Control room operator to investigate and manually change circuit breaker status where appropriate.
Main Success Scenario	1. The DRZC will check that all circuit breakers have been restored to their pre-black start operational status, flagging up any circuit breakers not restored to the DNO Control room operator via the DNO SCADA DMS. 2. The DNO Control room operator can then investigate and manually change circuit breaker status where appropriate.

	3. The DRZC will report to the DNO control room operator via the DNO SCADA DMS that any circuit breakers not returned to their pre-black start status have been reported for investigation and DNO Control room operator action and the DRZC has now completed the black start sequence.
Extensions	
Priority	
Special Requirements	Pre-black start circuit breaker status only applies to those circuit breakers operated by the DRZC when reconfiguring the network for black start operations (UC4).
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	All communications for UC19 can be at SCADA EMS or SCADA/DMS speeds. Note that the DRZC is still controlling the DER and Anchor generator so other control operations to maintain system stability may require Low latency direct communications if the transmission network condition is such that it would still require DRZC support if a block load or DER trips or load back/Anchor generator support during block load switching.
Measurement Requirements	All measurements for UC19 could possibly be at SCADA EMS or SCADA/DMS speeds. Note that the DRZC is still controlling the DER and Anchor generator so measurements to maintain system stability control may require Low latency direct communications.
Interfaces	

6.3.8.3 Use Case 20 Confirm network is reconfigured and DRZC is ceasing control

Having restored the DRZ network to the pre-blackout configuration or advised the DDN Control room where this could not be completed, the DRZC will confirm that the DRZC black start sequence is complete and it is ceasing operational control.

UC-20	**Confirm network is reconfigured and DRZC is ceasing control**
Primary Actor(s)	DRZC, DNO Control room operator
Secondary Actor(s)	DNO SCADA/DMS
Stakeholders and Interest	
Trigger	UC18, the DRZC has identified circuit breakers that cannot be returned to the pre-black start status.
Pre-conditions	UC18 has reported that all DRZ network circuit breakers switched at Stage 1 have been restored to pre-black start status. Where required, UC19 has reported any circuit breakers not restored to pre-black start status to the DNO Control room operator via the DNO SCADA DMS
Post-conditions	
Main Success Scenario	1. If all missing block load circuits have now been restored and any other circuit breaker status conditions returned to pre-black start conditions (UC18), the DRZC will report to the DNO SCADA DMS that the DRZC back start sequence is now complete and the DRZC is ceasing operational control. 2. If the DRZC has reported to the DNO control room operator via the DNO SCADA DMS any circuit breakers not returned to their pre-black start status for investigation and DNO

	Control room operator action, the DRZC will report to the DNO SCADA DMS that the DRZC back start sequence is now complete and the DRZC is ceasing operational control. 3. The DRZC will return to Stage 0 operational conditions.
Extensions	
Priority	
Special Requirements	Pre-black start circuit breaker status only applies to those circuit breakers operated by the DRZC when reconfiguring the network for black start operations (UC4).
Open Questions	
Communication Requirements (Bandwidth, latency, storage etc.)	All communications for UC20 can be at SCADA EMS or SCADA/DMS speeds. Note that the DRZC is has ceased control.
Measurement Requirements	All measurements for UC20 could possibly be at SCADA EMS or SCADA/DMS speeds. Note that the DRZC is has ceased control.
Interfaces	

7 ARCHITECTURE

The DRZC solution physical architecture will depend on many factors including:

- The vendor solution selected.
- The location of the DRZC, e.g. at the local GSP, the DNO control room, deployed in the cloud or distributed across the network.
- If deployed in a dedicated hardware platform or in a virtual environment.
- The need for local control versus central control to reduce data miles, increase speed, increase reliability, improve security, etc.

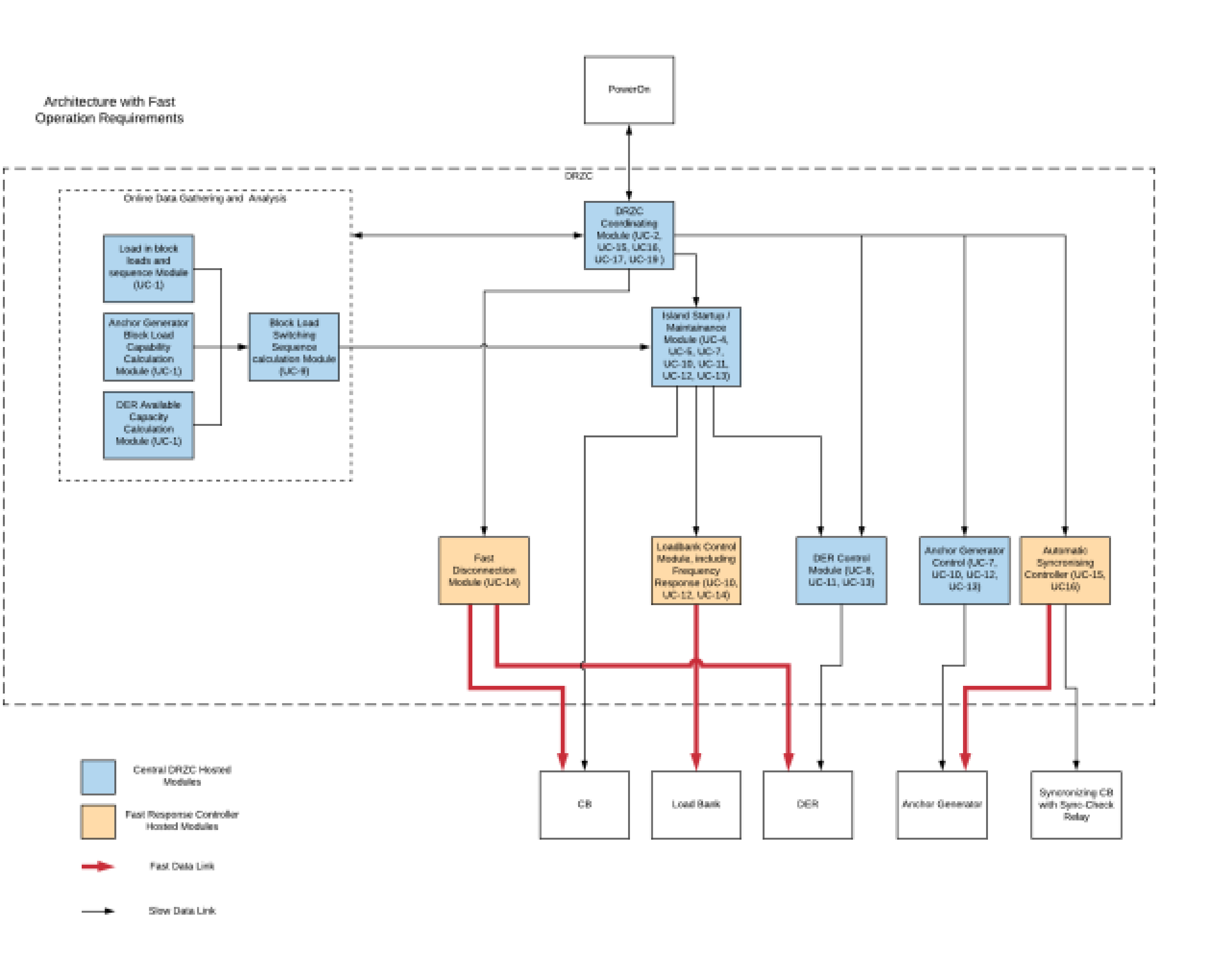
To assist the D-Restart team, the following sections illustrate a potential DRZC architecture for Chapelcross. This architecture provides adaptable centralised functionality for normal operations with local functionality where fast actions are required to maintain DRZ island stability during the black start restoration process. SGS believe this type of architecture strikes a cost effective balance between functional requirements and the cost of the communication requirements and would be suitable for the general DRZC case.

7.1 Potential Architecture using SGS Solution

7.1.1 Logical Architecture

The Use Cases described in section 6 detail the steps required to deliver the functionality of the DRZC. The logical architecture describes the logical components of the system and their interaction with each other required to deliver the functionality described in the use cases. The diagram shown in Figure 7-1 shows the logical components in two categories, ANM Strata Components and fast acting components. ANM Strata is typically able to achieve round trip processing time for measurements and control actions of around 1 second. Elements of the DRZC require faster round trip processing times and are therefore specified to have fast acting communication links and logic processors to meet this requirement.

Figure 7-1: Logical Architecture



7.1.1.1 Load in Block Load Real Power Estimate, Transmission Circuit Reactive Power Requirement Estimate and Switching Sequence Module

The Distributed Restart team has indicated a preference for an external system to calculate the block load, cold load pick up estimates, transmission circuit switching reactive power requirement estimates and the initial sequence of switching. The inputs to this module from this external system could be loaded into the DRZC during stage 0 prior to the occurrence of a black start and updated when required, or data could be loaded during the black start initiation process, stage 1 or 2 prior to the commencement of system restoration in stage 3. It is suggested that the block load estimates using this external system approach could be based on either a fixed, seasonal or daily estimate, or on recent measurements.

Host	Central DRZC
Inputs	Fixed, seasonal or daily estimate, block load, cold pick up values for each block load and associated circuit breaker switching sequence (provided by external system to DRZC.
Outputs	Estimated cold Load Pickup value (MW) for each block load.

Physical Communication Link Requirements	Link to external system providing data. Assumed via SCADA/DMS ICCP link.

7.1.1.2 Anchor Generator Block Load Capability Calculation Module

This module estimates the capability of the Anchor generator to accept a block load at a given time. The Anchor generator can pick up a block load up to its block load pickup rating. In addition there are other considerations that may limit the ability of the Anchor generator to pick up block loads such as, loading of the Anchor generator, BS DER connected and their available capacity, loading of the DRZ network etc. There are also considerations that can increase the ability of the Anchor generator to accept block loads through pre-loading and pre-load removal on switching the block load.

Having pre-programmed the DRZC with the block load acceptance capability of the Anchor generator (data to be provided by Anchor generators through their black start contract[33]), the DRZC can assess the Anchor generators available capacity to accept a block load switching event. This will include the available BS DER capacity that could be used to free up Anchor generator capacity by revising BS DER export set points. This would also include assessing the potential available load bank or BESS capacity to pre-load the Anchor generator as part of the block load switching sequence to increase the potential block load switching capacity possible.

Host	Central DRZC
Inputs	Anchor Generator Capability Parameters Measured Anchor Generator Load BS DER Connectivity BS DER available capacity Anchor Generator available pre-loading (load bank or BESS)
Outputs	Estimated Anchor Generator Block Load Capability
Physical Communication Link Requirements	None – data collected by other modules

7.1.1.3 BS DER Available Capacity Calculation Module

This module calculates available capacity each BS DER for the next 30min time period. The goal of this module is to estimate the minimum power that the BS DER is capable of providing in the time period. This is calculated based upon a capacity forecast provided by the BS DER. The appropriate scaling is applied to this forecast in order to account for short duration drops in capacity that may be expected depending on the BS DER type.

Host	Central DRZC
Inputs	Forecasted capability from BS DER Scale Factor for each BS DER
Outputs	Estimated BS DER Capability (MW) for the next 30 mins

[33] The Distributed Restart team should consider how this can be checked, confirmed or certified as part of the black start contract.

Physical Communication Link Requirements	None – data collected by other modules

7.1.1.4 Block Load and Transmission Circuit Switching Sequence Calculation Module

This module takes inputs from the:

- Block Load Real Power Estimate, Transmission Circuit Reactive Power Requirement Estimate and Switching Sequence Calculation Module (see section 7.1.1.1),
- the Anchor Generator Block Load Capability Calculation Module (see section 7.1.1.2)
- and the BS DER Available Capacity Calculation Module (see section 7.1.1.3).

It uses the information provided, along with an understanding of DRZ characteristics to check the preloaded switching sequence is acceptable and amends where required based on available Anchor generator, BS DER (including BESS for Anchor generator preloading), and load bank capacity.

Host	Central DRZC
Inputs	Block Load real power estimate. Transmission circuit required reactive power estimate Block load and transmission circuit switching sequence Anchor Generator Block Load Capability BS DER Capability
Outputs	Update Block Load and Transmission Circuit Connection Sequence
Physical Communication Link Requirements	None – data collected by other modules

7.1.1.5 DRZC Coordinating Module

This module controls the mode of the DRZC and instructs other modules to execute their functionality. The DRZC Coordinating Module interacts with PowerOn to exchange control and status information. In addition, it checks initial configuration of the DRZ CB's for Island operation, DRZ start-up and shutdown, coordinates instructions to synchronisation modules. Based on feedback from the Distributed Restart team, the DNO DMS will reconfigure the required skeleton network prior to the black start restoration commencing and the DNO control room will coordinate with the Anchor generator site to initiate starting of the Anchor generator and will close the POC circuit breaker to energise the initial skeleton 33kV network to the GSP substation and other BS DER.

Host	Central DRZC
Inputs	PowerOn Commands Anchor Generator Status BS DER Mode Status BS DER Capability On-Line Data Analysis Results Island Status Fast Frequency Response Status

	Load bank Status Sync Status
Outputs	Anchor Generator Mode Commands BS DER Mode Commands Auto Synchronising Controller Commands Island Commands
Physical Communication Link Requirements	Automatic Synchronising Module (Slow Communication Link) BS DER Control Module (Slow Communication Link)

7.1.1.6 Island Start-up and Maintenance Module

The island start-up and maintenance module controls the expansion and contraction of the DRZ. It uses ANM Strata control algorithms to gradually build the DRZ whilst maintaining the Anchor generator and BS DER within their capability limits, whilst maximising the load connected. If Load increases, or BS DER capacity reduces, this module disconnects load to maintain the Anchor generator within its capability limits.

Host	Central DRZC
Inputs	DRZ Frequency DRZ Voltage Anchor Generator Status Load bank Status CB Status Block Load Status BS DER Status Block Load Connection Sequence Block Load Disconnection Sequence
Outputs	BS DER P and Q Set points Load bank Mode Command Load bank P Set point Load bank Frequency Set point CB Commands
Physical Communication Link Requirements	Bulk Load CB Control (Slow Communication Link) Load bank Control Module (Slow Communication Link) BS DER Control Module (Slow Communication Link)

7.1.1.7 Fast Disconnection Module

This module is used to allow the DRZ maintain operation during disruptive events such as unplanned loss of load or BS DER. It monitors the frequency of the network and compares against frequency thresholds and rate of change limits. It also monitors circuit breaker status and BS DER and Anchor generator real P and Q export. It makes the decision to disconnect load in the event of low or reducing frequency or sudden large changes in BS DER export. It makes the decision to disconnect BS DER in the event of high or increasing frequency, or block load circuit breaker status or large changes in DRZ network demand. The order in which load or BS DER are disconnected is based on outputs from the DRZC Coordinating Module.

Host	Fast Response Controller
Inputs	ROCOF Setting Lower Frequency Threshold Lower Frequency Time Delay Upper Frequency Threshold Upper Frequency Time Delay Disconnection Sequence Frequency Measurement Block load measurements BS DER export measurements Block load and BS DER circuit breaker status.
Outputs	CB Trip Commands
Physical Communication Link Requirements	ANM Strata (Slow Communication Link) Block Load CB (Fast Communication Link) BS DER CB (Fast Communication Link) Frequency Measurement (Fast Communication Link)

7.1.1.8 Load bank Control Module, Including Frequency Response

This module is used to control the load bank in a number of discrete operating modes.

- Set point Control Mode – In this mode, set points are passed directly from the DRZC to the load bank.
- Frequency Response Mode – in this mode, frequency response is achieved by adjusting the load bank set point based on DRZ frequency measurements, i.e. increasing load when frequency is high, or decreasing load when frequency is low.

Using a combination of Set point Control Mode and Frequency Response mode, the load bank usage for frequency response may be maximised for planned events, i.e. the connection of load or BS DER. For example, the load bank may be gradually ramped up to maximum load and then placed in Frequency Response Mode prior to the connection of a block load. The Load bank then has its full capacity available to support the drop in frequency expected upon connection of the block load.

Host	Fast Response Controller
Inputs	Load bank Mode Section Load bank Set point Droop Curve Frequency Measurement Load bank Status
Outputs	Load bank Set point
Physical Communication Link Requirements	ANM Strata (Slow Communication Link) Frequency Measurement (Fast Communication Link) Load bank (Fast Communication Link)

7.1.1.9 BS DER Control Module

The DRZ network frequency and voltage under normal operations will be controlled by the Anchor generator frequency governor and automatic voltage regulator (AVR). The DRZC will be capable of issuing target set points for frequency and voltage to the Anchor generator control systems. However, where BS DER have control modes to support frequency or voltage, where these are required during a restoration sequence, the DRZC will be able to switch to such control modes.

This module coordinates control of the BS DER devices. BS DER are modelled in 3 discrete states: Grid Connected and operating outside of DRZC Control, Under DRZC Control but offline, Under DRZC Control and Online. The mode selection is received from the DRZC Coordinating Module.

Whilst in Under DRZC Control and Online, P and Q set point signals are received from the Island Start-up and Maintenance Module.

While operating in "Grid Connected and operating outside of DRZC Control", the BS DER can operate under its own control systems for P and Q export. The DRZC will issue signals to the BS DER to switch to available control modes e.g. frequency support, voltage control mode where these are available.

Switching BS DER to voltage control model would help support synchronising with the transmission grid or with the switching in of any transmission circuits linked to the GSP substation where required in the network restoration sequence.

Host	Central DRZC
Inputs	BS DER Status Mode Selection DER Set point
Outputs	BS DER Set point BS DER Mode Selection
Physical Communication Link Requirements	BS DER (Slow Communication Link)

7.1.1.10 Anchor Generator Control Module

This module coordinates the control of the Anchor generator. The Anchor generator is modelled in 3 discrete states: Started, Not Grid Connected and operating outside of DRZC Control, Grid Connected and operating outside of DRZC Control, Under DRZC Control and Online, and Synchronising. The mode selection is received from the DRZC Coordinating Module.

Whilst under DRZC Control and Online the Anchor generator provides voltage support and frequency response based on pre-defined settings. The DRZC manages the DRZ to maintain the Anchor generator within its capability parameters.

Whilst in synchronising state, control of the Anchor generator is extended to include the alteration of voltage and frequency set points as described in Section 7.1.1.11.

7.1.1.11 Automatic Synchronising Controller

This module is responsible for getting the DRZ into a position where it can be synchronised with an adjacent grid or DRZ. The Automatic Synchronising Controller controls the Anchor generator to ensure the frequency and voltage at the synchronising CB are matched on both sides on the synchronising circuit breaker. Prior to conditions being met, a close request is sent to a sync check relay at the synchronising circuit breaker, which, when the appropriate frequency, voltage and phase angle conditions are met, closes the synchronising circuit breaker.

Host	Fast Response Controller
Inputs	Frequency and Voltage measurements at each side of each synchronising CB. Anchor Generator Status Synchronising CB Status
Outputs	Anchor Generator Frequency Set point Anchor Generator Voltage Set point
Physical Communication Link Requirements	Anchor Generator (Fast Communication link) Synchronising CB (Fast Communication link)

7.1.2 Physical Architecture

The physical architecture is delivered with the following design goals, based on feedback from the Distributed Restart team:

- Allow a centralised solution, able to coordinate a large number of DRZs.
- Minimise the number of hardware components required to provide the system.
- Minimise the number of communication links required to provide data exchange between system components.

As described in the logical architecture, the system has two main components, the Central DRZC and the Fast Response Controller.

7.1.2.1 ANM Strata

The Central DRZC is based on SGS' ANM Strata platform and provides the DRZ island control based on the modules identified in the logical architecture in Section 7.1.1. ANM Strata can be deployed on commodity server hardware, substation hardened computers or in a virtualised environment. The platform can be specified with dual redundant or Site to Site Failover capabilities in order to achieve the required high levels of availability required for the DRZC. ANM Strata may be deployed in a centralised location, where it can provide Central DRZC capabilities for multiple DRZ locations.

7.1.2.2 Fast Response Controller

The Fast Response Controller, is based on an upgraded version of the SGS ANM Element platform, incorporating the capability for fast measurement and control to meet the requirement to provide DRZ island fast control for some use-cases (e.g. reduction of load bank Anchor generator pre-loading during the supported block load switching sequence; switching out BS DER or Block Load due to a major DRZ island stability threatening event where a BS DER or Block load trips out unexpectedly). The Fast Response Controller is deployed on SEL-2240 Axion hardware[34] with the appropriate interface modules selected for I/O requirements based on the interfaces required.

[34] Details of the SEL-2240 Axion hardware can be found using the following link to the manufacturer's web site. https://selinc.com/products/2240/

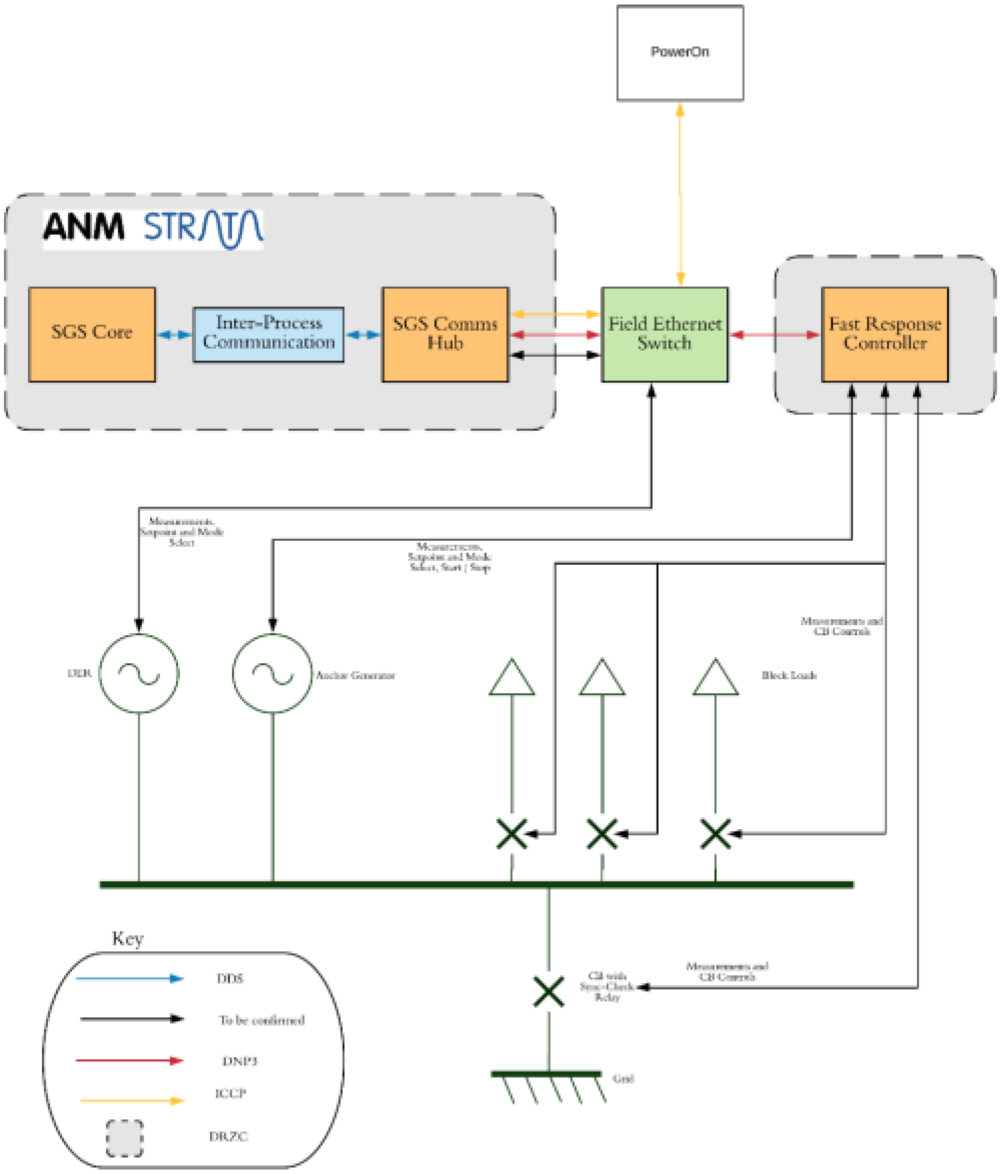
The Fast Response Controller is located physically within the DRZ to allow direct connection to VTs within the DRZ for fast frequency measurements. Communication links from the fast response controller to the Synchronising CB, BS DER CBs and Block Loads and Load bank allow control actions to be executed quickly to preserve DRZ stability.

7.1.2.3 Additional Hardware

In addition to the hardware which make up the DRZC, additional hardware may be required depending on the interfaces and protocols selected. This may include:

- Tele-protection Terminal – for terminating C37.90 lines or similar.
- Remote I/O terminal – for converting protocols or transmission media.
- Synchro-check relay – for controlling the timing of the circuit breaker close during synchronising.

Figure 7-2: Physical Architecture



7.2 Measurements and Data Requirements

This section details an example of the expected status and control data requirements for the DRZC when interfacing to external devices or systems. This is a minimum set of information to be exchanged and it is expected that this will be expanded and modified during the detailed design process.

7.2.1 Anchor Generator

Description	**Input / Output w.r.t DRZC**	**Analogue / Digital**	**Update Frequency Required**	**Comments**
Anchor Generator Operating Mode	Input	Analogue (Enum[35])	1 update per second	
Anchor Generator Measured Voltage	Input	Analogue	1 update per second	
Anchor Generator Measured Frequency	Input	Analogue	25 updates per second	
Anchor Generator Voltage Set point	Output	Analogue	1 update per second	
Anchor Generator Frequency Set point	Output	Analogue	1 update per second	Expected to require low latency during synchronising process
Anchor Generator Mode Request	Output	Analogue (Enum)	1 update per second	
Energise to POC Command	Output	Digital	1 update per second	
Energised to POC	Input	Digital	1 update per second	

7.2.2 BESS

Description	**Input / Output w.r.t DRZC**	**Analogue / Digital**	**Update Frequency Required**	**Comments**
BESS Real Power Measurement	Input	Analogue	5 updates per second	Based on BESS being able to adjust output 5 times per second.
BESS Operating Mode	Input	Analogue (Enum)	1 update per second	

[35] An Enum type is a special data type that enables a variable to be a set of predefined constants. The variable must be equal to one of the values that have been predefined for it. Common examples include compass directions (values of NORTH, SOUTH, EAST, and WEST) and the days of the week and in this case a set of operating modes.

BESS Energise Command	Output	Digital	1 update per second	
BESS Energised Status	Input	Digital	1 update per second	
BESS Real Power Set point	Output	Analogue	5 updates per second	Based on BESS being able to adjust output 5 times per second.
BESS Mode Request	Output	Analogue (Enum)	1 update per second	
BESS State of Charge	Input	Analog	1 update per second	
BESS maximum instantaneous real power import	Input	Analog	1 update per second	
BESS maximum instantaneous real power export	Input	Analog	1 update per second	

7.2.3 Load Bank

Description	Input / Output w.r.t DRZC	Analogue / Digital	Update Frequency Required	Comments
Load bank Real Power Measurement	Input	Analogue	5 updates per second	Based on load bank being able to adjust output 5 times per second.
Load bank Operating Mode	Input	Analogue (Enum)	1 update per second	
Load Bank Energise Command	Output		1 update per second	
Load Bank Energised Status	Input		1 update per second	
Load bank Real Power Set point	Output	Analogue	5 updates per second	Based on load bank being able to adjust output 5 times per second.
Load bank Mode Request	Output	Analogue (Enum)	1 update per second	

7.2.4 Block Load (for each Block Load)

Description	Input / Output w.r.t DRZC	Analogue / Digital	Update Frequency Required	Comments
Block Load Real Power Measurement	Input	Analogue	1 update per second	
Block Load Reactive Power Measurement	Input	Analogue	1 update per second	
Block Load CB Status	Input	Digital	1 update per second	
Block Load CB Control	Output	Digital	25 updates per second	Low Latency required for CB Control

7.2.5 BS DER

Description	Input / Output w.r.t DRZC	Analogue / Digital	Update Frequency Required	Comments
BS DER Real Power Measurement	Input	Analogue	1 update per second	
BS DER Reactive Power Measurement	Input	Analogue	1 update per second	
BS DER Available Capacity	Input	Analogue	1 update per second	
BS DER Operating Mode	Input	Analogue (Enum)	1 update per second	
BS DER Real Power Set Point	Output	Analogue	1 update per second	
BS DER Enter Black Start Response Mode	Output	Digital	1 update per second	
BS DER CB Control	Output	Digital	1 update per second	Low Latency required for CB Control
BS DER CB Status	Input	Digital	1 update per second	

7.2.6 Synchronising CB

Description	Input / Output w.r.t DRZC	Analogue / Digital	Update Frequency Required	Comments
Grid Side Frequency Measurement	Input	Analogue	5 updates per second	Low latency required for use during synchronising process.
Grid Side Voltage Measurement	Input	Analogue	5 updates per second	Low latency required for use during synchronising process.
DRZ Side Frequency Measurement	Input	Analogue	5 updates per second	Low latency required for use during synchronising process.
DRZ Side Voltage Measurement	Input	Analogue	5 updates per second	Low latency required for use during synchronising process.
CB Position	Input	Digital	5 updates per second	Low latency required for use during synchronising process.
Sync-Check Close Request Active	Input	Digital	5 updates per second	Low latency required for use during synchronising process.
Sync-Check Close Request Timeout	Input	Digital	5 updates per second	Low latency required for use during synchronising process.
Sync-Check CB close Request	Output	Digital	5 updates per second	Low latency required for use during synchronising process.

7.2.7 PowerOn

Description	Input / Output w.r.t DRZC	Analogue / Digital	Update Frequency Required
Island Boundary in place	Input	Digital	1 update per second
Block Loads Configured for DRZC Control	Input	Digital	1 update per second
Black Start Active – Initiate Stage 1	Input	Digital	1 update per second
Anchor Generator Started Command (stage 2)	Input	Digital	1 update per second
DRZ island network Energised (stage 3)	Input	Digital	1 update per second
DRZC Mode	Output	Analogue (Enum)	1 update per second
Synchronise to Grid Command	Input	Digital	1 update per second
Grid Synchronising Status	Output	Analogue(Enum) Synchronised, Not Synchronised, Synchronising)	1 update per second
Anchor Generator Frequency Set point	Output	Analogue	1 update per second
DRZ Frequency	Output	Analogue	1 update per second
Anchor Generator Measured Real Power	Output	Analogue	1 update per second
Anchor Generator Measured Reactive Power	Output	Analogue	1 update per second
Anchor Generator Measured Voltage	Output	Analogue	1 update per second
BS DER Connection Status	Output	Digital	1 update per second
BS DER Operating Mode	Output	Analogue (Enum)	1 update per second
BS DER Measured Real Power	Output	Analogue	1 update per second

BS DER Measured Reactive Power	Output	Analogue	1 update per second
Load Bank Connection Status	Output	Digital	1 update per second
Load Bank Operating Mode	Output	Analogue (Enum)	1 update per second
Load Bank Real Power Measurement	Output	Analogue	1 update per second
Load Bank Real Power Set point	Output	Analogue	1 update per second
Load Bank Reactive Power Measurement	Output	Analogue	1 update per second
Block Load Connection Status	Output	Digital	1 update per second
Block Load Real Power Measurement	Output	Analogue	1 update per second
Block Load Reactive Power Measurement	Output	Analogue	1 update per second

7.3 Data Storage

The DRZC stores data in a number of locations across the various components that make up the system. Data may exist in two discrete forms, Real-time data (including real time 30 minute forecast data) and historical data.

Real-time data is data which represents the current state of the system, for example, this includes the latest measurement data, set point data, available capacity data etc. and is used by the system control algorithms to make control decisions in real-time. Real-time data exists in the 'in-memory' databases on ANM Strata and the Fast Response Controller and is exchanged between systems using interfaces described in Section 7.6.

Historical data is data which represents the state of the system at a previous point in time and is stored centrally on redundant SQL databases hosted on SGS Comms Hub. Historical data is linked to real-time data by a shared data structure and is configured to record to the historical database using a store-on-change approach. Historical data includes measurement data, set point data etc. as well as event and alarm data.

7.4 Key Assumptions and Pre-requisites

This FDS has been developed in the absence of documented and verified BS DER and network dynamic performance information from the D-Restart team partners, e.g. expected RoCoF during block loading, BS DER loss, or block load loss.

7.4.1 General capability assumptions and pre-requisites

- Network substations, BS DER sites, and essential telecoms infrastructure are provided with resilient power supplies which cover the period of DRZ operation.
- BS DER, the Anchor generator and embedded generators have protection systems configured in line with G99 or G98 as applicable.
- Any existing under frequency load shedding schemes at the GSP are disabled prior to DRZC operation (taken as part of stage 1 DNO Control room function via the DMS).

7.4.2 Anchor Generator

- Anchor generator is assumed to be a synchronous machine with a frequency control and voltage control operational mode[36].
- Anchor generator must be capable of independently starting and maintaining a stable voltage and frequency output.
- Anchor generator block load acceptance capability is pre-defined.
- Anchor generator power ramp up and ramp down rate limits are pre-defined.
- Anchor generator protection limits are predefined for under/over Frequency, Rate of Change of Frequency, and Under/Over Voltage.
- Anchor generator Rate of Change of Frequency protection trip can be blocked by the DRZC.
- Anchor generator can accept a voltage and frequency set point using an agreed, secure interface.
- Anchor generator can initiate start-up and shut-down processes on instruction from the DRZC using an agreed, secure interface.
- Anchor generator can alter control mode for black start running on instruction from the DRZC using an agreed, secure interface.

7.4.3 BS DER

- BS DER power export ramp up and ramp down rate limits are pre-defined.
- BS DER protection limits are predefined for under/over Frequency, Rate of Change of Frequency, and Under/Over Voltage.
- BS DER Rate of Change of Frequency protection trip can be blocked by the DRZC.
- BS DER can initiate start-up and shut-down processes on instruction from the DRZC using an agreed, secure interface.
- BS DER can provide a forecasted value for the minimum and maximum available capacity over the following 30min period.
- BS DER can follow a real power set point inside of the minimum and maximum available capacities.
- BS DER can be disconnected via a CB trip initiated by the DRZC.

[36] A synchronous generator is presently viewed by SGS as the most likely and suitable candidate technology for an Anchor generator providing a source of inertia as well as voltage and frequency control. Where the Distributed Restart team wish to consider other forms of generation with converter based control systems and synthetic inertia for BAU roll out then the availability of such suitable alternative Anchor generators should be established by the Distributed Restart team.

7.4.4 Block Loads

- Block Load connectivity to the DRZ can be controlled via a single CB operation initiated by the DRZ.
- Block Loads may be disconnected from the DRZ in response to frequency events as required by the DRZ.
- Block Loads can be measured individually.

7.4.5 Load Bank

- Load bank is capable of configuring for load pickup when incoming supply is de-energised.
- Load bank is capable of applying updated load set point within 50 milliseconds of received set point signal.
- Load bank is not limited in the number of set point changes it can accommodate.

7.4.6 BESS

- BESS is capable of configuring for load pickup when incoming supply is de-energised.
- BESS is capable of applying updated load set point within 50 milliseconds of received set point signal.
- BESS is not limited in the number of set point changes it can accommodate.

7.5 Communications

Communication links in the DRZ context can be split into 3 possible categories. Fast Communication Link, Slow Communication Link and SCADA communication link.

7.5.1 Fast Communication Links

These links are used by the DRZC for the purpose of fast DRZ island network control. These communication links are required to facilitate measurement or control commands within short time limits, in order to maintain the DRZ island network during periods of potential instability.

7.5.1.1 Bandwidth Requirement

Bandwidth requirement varies depending on the interface selected and the usage of the link. For IEC 61850-9-2LE up to 5.760 Mbps per analogue measurement may be expected 0.

7.5.1.2 Latency Requirement

Latency of the link is crucial to the operation of the DRZC. The stability of the DRZ island network relies on the DRZC being able to quickly action responses in reaction to frequency excursion events on the grid and the speed of the response is influenced directly on the latency of the Fast Communication link.

Round-Trip latency requirement < 10ms

This value is based on a requirement that the BS DER or block load be tripped within 100ms of a load or BS DER loss event. Assuming a CB interrupting time of 50ms [3] and a DRZC control loop time of 40ms, 10ms may be afforded for communication link latency, including any latency introduced by networking or multiplexing equipment.

7.5.1.3 Usage

- Block Load CB Status and Operation – Used by the fast disconnection module to quickly disconnect block loads during under frequency events.

- Load bank control – Used to communicate set points to the load bank to permit the use of the load bank to alter its output to assist in the response to frequency excursion events.
- Synchronising Measurements – Used to communicate voltage and frequency measurements from remote synchronising CBs to the Fast Response Controller during synchronising.
- Anchor generator Control – Used to communicate voltage and frequency set points to the Anchor generator.

7.5.2 Slow Communication Links

These links are used by the DRZC for the purpose of slower DRZ island network control. These communication links are required to facilitate measurement, control and configuration activities within medium time limits in order to establish and maintain the DRZ island network.

7.5.2.1 Bandwidth Requirement

Slow communication link bandwidth is expected to be low due to the relatively slow polling rate of the protocols used (expected to be 1-2 seconds) and the low overhead nature of the chosen protocol (DNP3).

Bandwidth requirement – 20 Kbit/s

This value is based on SGS experience using DNP3.0 for data transfer between ANM Strata and field devices.

7.5.2.2 Latency Requirement

Latency is not crucial to the performance of the slow communication link and a relatively long round trip latency communication link may be used with little impact on system performance.

Round-Trip latency requirement – 500ms

This value is based on SGS experience using DNP3.0 for data transfer between ANM Strata and field devices.

7.5.2.3 Usage

- BS DER Measurement and control – used to communicate set point limits and retrieve measurements from each BS DER.
- Central Controller to Fast Controller – used to exchange measurement information, mode and control signals between the central controller and the fast controller.
- Anchor Generator Configuration – used to exchange configuration and mode settings to the Anchor generator.

7.5.3 SCADA/DMS Communication Link

This link is used by the DRZC for exchanging control and status information with the DNO via the SCADA/DMS. This communication link is used in the coordination and monitoring of the DRZ.

7.5.3.1 Bandwidth Requirement

Calculation to be made in detailed design stage of project based on the Distributed Restart team's recommended ICCP configuration.

7.5.3.2 Latency Requirement

Latency is not crucial to the performance of the slow communication link and a relatively long round trip latency communication link may be used with little impact on system performance.

Round-Trip latency requirement – 500ms

7.5.3.3 Usage

- Central Controller to PowerON – used to exchange control and Status information on the DRZC with PowerOn.

7.6 Interfaces

Interfaces can be split into 4 categories:

- Digital Only – Fast Communications
- Analogue and Digital – Fast Communications
- Analogue and Digital – Slow Communications
- SCADA

7.6.1 Digital Only – Fast Communication

This interface requires fast operation across a wide area. Protocol options include:

- IEC 61850 Routable GOOSE [37]Messaging
- Tele-protection messaging using dedicated hardware over an IEEE C37.94 Interface or similar.
- SEL Mirrored Bits.
- SCADA Protocols (Modbus / DNP 3.0 or IEC60870-5-104) configured for high speed operation)

7.6.2 Analogue and Digital – Fast Communication

This interface requires fast operation across a wide area. Protocol options include:

- IEC 61850-9-2LE (Sampled Values) using Routable GOOSE Messaging
- SEL Mirrored Bits.
- SCADA Protocols (Modbus / DNP 3.0 or IEC60870-5-104) configured for high speed operation)

7.6.3 Analogue and Digital – Slow Communication

This interface requires slower operation across a wide area. Protocol options include:

- IEC 61850 MMS
- DNP3.0
- IEC60870-5-104
- Modbus

The protocol selected is likely to be on a link-by-link basis, taking into account capabilities of remote devices and security considerations.

7.6.4 SCADA Interface

This interface to the SPEN SCADA System (GE PowerOn) is specified as using the IEC 60870-6/TASE.2 (ICCP) protocol. This decision is based on discussions with SPEN and the use of the same protocol on a

[37] SGS note that the Distributed Restart team has advised that Routable Goose is not considered a secure communication protocol outside of substation internal communications, i.e. substation to substation, DER site to DNO substation/control room communications.

number of ANM Systems being supplied by SGS to SPEN. The ICCP link associated with other DNO SCADA systems would require to be considered by the Distributed Restart team for the other GB DNOs for national roll out. At this stage in the DRZC functional design it is assumed that any communications with the ESO SCADA EMS would be routed via the DNO SCADA DMS system.

8 ADDITIONAL KEY AREAS OF CONSIDERATION

8.1 Co-Location of DRZC and Distribution Active Network Management system for thermal constraints.

The DRZC functionality described in this document assumes that the DRZC is able to utilize the Anchor generator, BS DER, BESS and Load bank devices as required to maintain network stability and maximize the number of customers connected. Operating a DRZ in a constrained distribution network presents additional challenges specifically around:

- Ensuring that constraints within the distribution network are not overloaded during DRZ operation
- Ensuring that the systems do not provide conflicting controls to managed devices.
- Ensuring handover of control between systems is managed.

It is expected that, for a number of reasons, the likelihood of distribution constraints being breached during DRZ operation is low. These include:

- All Generation must be consumed in the DRZ, i.e. no export from the local area and therefore potentially a smaller amount of generation available.
- All ANM managed DER may not participate in the DRZ. All ANM managed DER not managed by the DRZC would be disabled during a black start condition.

In the event that distribution constraints exist during possible DRZ running conditions, it would be necessary to place fixed export limits upon specific BS DER to limit export in order to prevent constraint overloads whilst the DRZ is in operation. This may in turn, reduce the number of customers that can be restored by the DRZ due to reduced BS DER availability.

In addition, if studies and the specific DRZ design process identified that the DRZ control sequence and DER operation might result in distribution network constraint breaches, then coordination and/or arbitration of ANM operation would be required. Advanced ANM systems are capable of addressing multiple constraints, executing parallel control logic and for control arbitration and coordination. This includes enabling and blocking of different ANM functionality at different stages of the DRZ control sequences.

8.2 Cyber security

For the purposes of commercial confidentiality, this section has been redacted.

8.3 Organisational Models

The DRZC solution presented by SGS is based on a software platform developed by SGS for ANM and DER management applications (ANM Strata). The software platform is very flexible and would allow SGS to deliver a solution that could be developed to meets any of the four extreme organisational model cases depending on what the Distributed Restart team wish to specify. The four organisational models are characterised by:

- The degree of automation, i.e. a largely manual process versus one that relies heavily on automation of processes;

- The lead organisation for the restoration process, which may be the single, national ESO or the local DNO.

Based on the information in the NG ITT document at Appendices 2 and 3 and gathered through the various meetings with the Distributed Restart team, the solution use cases developed offer a high degree of automation having key interfaces predominately with the DNO Control Room but also with the ESO Control Room. Feedback from the Distributed Restart team during the functional design development, directed SGS to move some of the early restoration sequence (stage 1 and stage 2) functions from DRZC control to the DNO Control Room operator and DNO SCADA/DMS system. This indicates the potential flexibility of our solution. The later stages that consider block load restoration of the system, stable operation and synchronising are largely automated as this will improve the speed of system restoration and reduce the need for control room staff in the system restoration sequence. However, involvement of the ESO Control Room and the DNO Control Room is still included at key decision points where potentially useful, e.g. the decision on when to synchronise back to the transmission network or with other DRZ island networks.

SGS understand that at the DRZC trial phase, the Distributed Restart team will wish to take a more cautious approach to the automation of the restoration sequences as they work towards a business as usual solution. However, if the system is rolled out and a black start is required where hundreds of DRZ networks require to be controlled, the automation functionality proposed at this stage can be modified or developed to reduce the requirement for ESO and DNO control room operator staff e.g. the DRZC can be programmed to text or email BS DER and Anchor generator named staff warning of a black start requirement and asking them to prepare, rather than this being a control room task.

8.4 Standards

The DRZC functional design and potential outline architecture has considered a number of industry standards, guides and codes including:

- Engineering Recommendation G99 Issue 1 Amendment 6 (applicable from 6 March 2020).
- THE GRID CODE, ISSUE 5, REVISION 40, 05 March 2020, National Grid

At the detailed design stage SPEN/NG has requested that the following standards are also met:

- Hardware equipment intended for substations should be compliant to the IEC 61850-3 Class 2.
- Communications infrastructure is compliant with cyber security standard IEC 62351.
- The DRZC solution is also required to be compliant with IEC62351 (Components) and IEC62443 (Processes and Functions) as appropriate and necessary.
- FMEA (aligned to ISO 60812) used to support Functional Safety Assessment by identification of failure modes and effects of the DRZC design.

8.5 Safety Assessment

SGS can provide key individuals with suitable experience and expertise as required to support the Distributed Restart team carry out any LOPA, HAZID, HAZAN or other safety assessment. In supporting these assessments SGS would identify the need to perform:

FMEA (aligned to ISO 60812) used to support Functional Safety Assessment by identification of failure modes and effects of the DRZC design.

We will use an in-project, best practice process separating out safety related documentation from the rest of the project documentation. This Provides focus and allows a Suitably Qualified and Experienced Person (SQEP) (SGS, SPEN or third party) to review the safety specific information.

8.6 Training

SGS offers training on the operation and integration of our solution to client staff. We can also offer training on the maintenance of our solution software and hardware, although we also offer extensive support services to maintain and remedy software issues as discussed in section 8.8.

8.7 Testing

A staged approach to testing should be used to ensure that the system meets the requirements. A test strategy should be developed to set out the stages, checks and assurances necessary to demonstrate the capability of the deployed solution.

As described below, SGS recommend a phased approach where various test harnesses and simulation environments are utilised to build a comprehensive understanding of the system performance prior to commissioning of the production system.

8.7.1 Test Phases

The Test Strategy involves a number of test phases, designed to successively test the system in increasingly accurate test environments prior to and including site commissioning.

8.7.1.1 Factory Acceptance Test (FAT)

FAT is carried out in the SGS Test Environment. Test harnesses are developed and deployed to permit simulation of 3rd party systems, i.e. GE PowerOn, DER, Load Bank, Anchor generator, Block Load. This test environment is utilised to test unit, link and system functionality as described in Section 8.7.2 prior to the delivery of the system.

8.7.1.2 Pre-Production Testing (PPT)

PPT is carried out in the client Test Environment. In this Test environment, it is possible to more accurately represent some 3rd party systems and processes. For example, a Test Instance of the DNO DMS may be available, or the IT environment, including cybersecurity measures, patching and backup process closely mimic those expected in production.

8.7.1.3 Hardware-In-the-Loop Testing (HIL)

The HIL may be used to increase confidence in the deployed design's response to the dynamic conditions expected on a DRZ island network. This test phase would be carried out at a suitable test laboratory and would involve the creation of a real-time dynamic model of the DRZ, DER, Anchor generator, load bank and Block Loads. This would allow realistic micro-grid scenarios to be simulated and the system tested to ensure the dynamic performance of the system.

8.7.1.4 Site Acceptance Testing (SAT)

SAT involves the integration and testing of the DRZC and 3rd Party system on the production system. Whilst it is not expected that a full test of the micro-grid is possible at SAT, it is possible to test individual components and subsystems to the extent that confidence can be gained in the capability of the system to perform in black start conditions.

8.7.1.5 In Service Testing (IST)

IST involves the testing of areas of the DRZC whilst the system is in service and the power network is not experiencing a black start condition. The purpose of this testing is to ensure that the system responds as expected during a black start condition. Examples of IST include:

- BS DERs can transition successfully to Black Start mode and can respond to DRZC Controls.
- Ensure that the Anchor generator can respond to DRZC Controls.

8.7.2 Test Categories

Tests are split into multiple categories depending on the scope and purpose of the test.

- Unit Tests – Tests used to ensure that an individual component operates as required.
- Link Tests – Tests used to ensure that multiple components of a solution link together as required.
- System Tests – Tests used to ensure that the system as a whole operates as required, including functional and non-functional testing.
- Integration Test Phase – System Tests used to ensure that the system as a whole operates as required in conjunction with 3rd party systems, e.g. GE PowerOn, Anchor generator, DER, system measurements etc.
- Non-Functional Test Phase – Tests used to ensure that the system performance is acceptable, and that the system can be maintained and operated.

8.8 Ownership and Support

SGS provide our software based on a license fee. Design and specific software development, integration services and support services are charged for at agreed costs or rates.

Our support service cover can include[38]:

- 24/7, 365 days per annum
- Dedicated Managed Services team, staffed by qualified SGS engineers
- Contact options including telephone, email or web portal

[38] SGS's support service could be partially available during a black out condition, but not fully available. While all data is on black start secured servers and support engineers have access to charge facilities for mobile phones and lap tops and could attend site, there will be some impact on our support via email and web portals etc.

- Zendesk ticketing and reporting systems[39]
- Every reported incident assigned a unique reference number to track the incident through to resolution
- Three levels of support:
    - Level 1: we gather information about the incident and provide basic assistance;
    - Level 2: we investigate the incident and provide a solution or mitigating action, where possible;
    - Level 3: this involves more detailed technical investigation and a resolution to the incident.
- Additional proactive monitoring of the operation of the DRZC and, where we identify an incident, we record that in the same support system and inform the client of the incident
- Monthly service report that includes the relevant service information as agreed with the client
- Our support service level agreement includes the following response times:

Severity Level	Resolution Time
Severe	4 Hours
Major	48 Hours
Minor	1 Week
Cosmetic	1 Month

- During a fault investigation, we provide regular updates to the client's nominated contact until the incident is resolved.
- In the event of a fault being resolved, we provide a report detailing the Root Cause, the resolution, mitigating actions to avoid a repeat occurrence and details on how the fault impacted the DRZC and the affected DER.

Our support service maintenance can include:

- Development, testing, installation and deployment of product releases to resolve support incidents

[39] Zendesk is a software company that provides customer service, ticketing systems or support ticket solutions that takes incoming customer requests for support and automatically generates a customer service ticket. A ticketing system allows customers to contact a company via their preferred channel but also ensures support agents are set up for success with a consistent view of the customers. This includes contextual data and previous support requests all within software that tracks all of this relevant data over time, allowing support teams to learn and improve the support they provide.

- Development, testing, installation and deployment of annual product release

Our support service reporting can include:

- Quarterly report on service level achievement, incidents, resolutions and any version / releases made during the reporting period or planned in the future
- Quarterly Operational Data Review (ODR) reports that provide the high level performance of the ANM system over a 3-month period
- Quarterly service review meeting between the client and SGS to review the operation of the ANMS and following completion and submission of the quarterly report
- Annual meeting between the client Senior Management Team and SGS Senior Management, including an annual Performance Review
- Additional meeting, as requested by the client.

8.9 Technology Road Map

For the purposes of commercial confidentiality, this section has been redacted.

8.10 Cost Estimate

For the purposes of commercial confidentiality, this section has been redacted.

9 FUNCTIONAL REQUIREMENTS

This section identifies the functional requirements for the general black start island DRZC case and any additional or amended functional requirements specific to the Chapelcross case study.

9.1 Network Observation Requirements General Case

The system should be able to use equipment status indications and measurements from the DNO DMS and ESO EMS to determine the network topology prior to and after any black start condition.

Req. 1 **Monitor the service status of Anchor generator pre-black start**. The system will use data from the DNO DMS to indicate Anchor generator export power to determine the likely service status of the Anchor generator for a black start request. Data is to be sent from the DNO DMS on an ongoing basis and used to continuously monitor the Anchor generator black start readiness.

Req. 2 **Determine the service status of other black start DER assets pre-black start.** The system will use data from the DNO DMS to indicate the likely service status of other contracted black start DER e.g. battery storage, load banks, wind farms etc. This may require a range of data from power export to available charge status for battery systems. Data is to be sent from the DNO DMS on an ongoing basis and used to continuously monitor the BS DER black start readiness. Where any data is not available from the DNO DMS, this will be accessed through other routes where feasible.

Req. 3 **Determine the service status of the DRZ electricity network.** The system will use data from the DNO DMS and ESO EMS to indicate circuit breaker status, substation voltage and power flow information prior to and after a black start condition is declared. This information will be used by the DRZC to identify the network configuration prior to the black start and just after a black start condition is declared. The data will also be used by the DRZC to confirm that the DRZ network has been reconfigured by the DNO DMS ready for commencing the black start restoration sequence.

Req. 4 **Upload block load and transmission circuit switching schedule.** The DRZC system will be loaded with a schedule of block load, cold start power estimates, transmission switching reactive power requirement estimates and a switching sequence by an external system prior to a switching sequence commencing.

Req. 5 **System frequency, RoCoF and voltage measurements.** The DRZC system will be able to observe the system frequency, RoCoF and voltage with sufficient speed and accuracy to take control actions to prevent frequency and voltage instability under black start restoration conditions.

While system frequency and RoCoF is likely to be monitored at the Anchor generator site substation, voltage measurements will be required at the 33kV GSP and Anchor generator site substation and possibly other locations such as the BS DER HV substations.

To allow DRZC control response that will prevent DRZ instability under all likely conditions, measurement will not be taken from the DNO DMS and ESO EMS. Faster data transfer routes will be required. The DRZC will consider the most suitable architecture which may include local observation, decision making and control actions where fast actions are required to protect the DRZ island stability.

Req. 6 **Block load circuit and BS DER circuit monitoring.** To assist the DRZC mitigate against severe unplanned events that may cause frequency stability issues that would lead to a collapse of the DRZ island network, the breaker status and power flows at all BS DER site DNO connection circuit breakers and all 33kV and key 11kV block load switching circuit breakers would be monitored. This will allow the DRZC to quickly identify any major loss of generation or demand that would threaten collapse of the DRZ island if mitigation action were not taken by the DRZC. To allow DRZC control response that will prevent DRZ instability under all likely conditions, measurements will not be taken from the DNO DMS and ESO EMS. Faster data transfer routes will be required.

Req. 7 **System frequency, voltage magnitude and phase angle for synchronising.** At the synchronising circuit breaker locations, the DRZC system will be able to observe the system frequency, voltage magnitude and phase angle on both sides of the synchronising circuit breaker with sufficient speed and accuracy to facilitate DRZC control actions that will allow system synchronising. Again measurement will not be taken from the DNO DMS and ESO EMS with faster data transfer routes required. The DRZC will consider the most suitable architecture which may include local observation, decision making and control actions to facilitate synchronising.

Req. 8 **DRZ Island to DRZ Island circuit monitoring.** Where two or more DRZ islands are synchronised together but remain disconnected from a sufficiently restored transmission network, the DRZCs on each DRZ network will require to monitor the power flows (real and reactive) on the circuits connecting them. This will initially be the circuit at the synchronising circuit breaker and then any other circuit switched into service between them. This will assist the DRZC controllers share available BS DER capacity between each DRZ island to support the Anchor generators. To allow DRZC control response that will prevent DRZ instability under all likely conditions, measurements will not be taken from the DNO DMS and ESO EMS. Faster data transfer routes will be required.

Req. 9 **Anchor Generator & BS DER available power capacity.** The Anchor generator and all black start BS DER will be required to provide the DRZC with ongoing real time updates of available real and reactive power capacity. Forecasted values for the minimum and maximum available real and reactive capacity over the following 30min period that the controller can draw upon will also be required. This will be the case through stages 0 to 6 inclusive. It is assumed that this requirement will be part of the black start contract. Data transfer to the DRZC will require sufficiently fast data transfer routes, the DNO/DMS data route will not be suitable for the real time data.

9.2 Controls Requirements General Case

The general case DRZC control requirements cover stages 1 to 6 outlined in section 6.1.

Req. 10 **DRZ initial network configuration.** Having established the DRZ network status, (see Req. 3), the DNO DMS will require to open the circuit breakers linking the DRZ to the transmission network and any other DRZ to form the required DRZ island. The DNO DMS will also require to open all 33kV GSP substation circuit breakers on circuits that feed demand or connect generation (likely to be all circuit breakers except the bus-section breakers). If block loading requires 11kV circuit breaker operation rather than 33kV circuit breaker operation to reduce the block load volume within the Anchor generator block load acceptance limits, then additional 11kV circuit breaker opening will be required.

If the DNO DMS network status checks indicate a partially energised DRZ network island (see Req. 3 then additional circuit breaker operation will be required to ensure the DRZ island is fully de-energised.

Once switching operations to establish the DRZ initial skeleton network configuration are complete, the DNO DMS is required to confirm this to the DRZC. At this point the DRZC will have updated the control status of all key circuit breakers from the DNO DMS included in the controller and checked these are as expected.

Req. 11 **Anchor generator starting.** Having confirmed the status of the Anchor generator (Req. 1), and notified the Anchor generator site to prepare for a black start, and reconfigured the DRZ island (see Req. 10), the DNO DMS will switch in the DRZ island 33kV earth and the DNO control room operator will request the Anchor generator to start and load up to any required minimum loading for the generator (using a local load bank where required[40]). The DNO DMS is to return a signal to the DRZC when the generator is ready to connect to the DRZ island network. The DNO Control room operator will then close the required circuit breakers to energise the 33kV GSP substation and skeleton network and send a signal to via the DNO DMS to the DRZC confirming this.

Req. 12 **BS DER notification and connection to the DRZ.** Having confirmed the status of participating BS DER (Req. 2) and notified participating BS DER to prepare for black start service, the DRZC will close the required circuit breakers to energise the circuits to the DER site DNO substations. Ideally the network reconfiguration (Req. 10) will ensure that there is no or limited block load switching during this process. If this is not possible then this requirement may also involve Req. 13 which covers block load switching. Note that connecting additional BS DER with zero power export to the DRZ network at this stage may provide frequency stability benefits (a stiffer grid) depending on the type of DER. Note also that where BS DER require auxiliary supplies from the DNO network, the BS DER POC circuit breaker will remain closed during the network reconfiguration (Req. 10) to provide these supplies when the skeleton network is energised (Req. 11), keeping the associated BS DER with zero power export to the DRZ network.

Req. 13 **Block load switching.** Having energised the 33kV GSP using the Anchor generator (Req. 11) and potentially connected BS DER (Req. 12), block load switching will commence to expand the energised DRZ island and restore customer supplies. Depending on the Anchor generator ability to accept prospective block loads, other BS DER may be required to assist in this process e.g. a suitable BESS or load bank.

[40] BESS may be considered as an alternative to a load bank to provide the minimum Anchor generator pre-loading until sufficient demand is switched onto the DRZ network. However, any BESS would require to be suitably rated and in a charged condition that would allow the BESS to go into a suitable rate of charging for a sufficient time to allow maintain the Anchor generator minimum loading for a sufficient period of time.

Req. 14 **Transmission circuit switching.** Having energised the 33kV GSP using the Anchor generator (Req. 11) and potentially connected BS DER (Req. 12), transmission circuit switching will commence. BS DER may require to be switched into a voltage control mode where available by the DRZC prior to transmission circuit switching. Transmission circuit switching reactive power requirements and the sequence of switching will be included as part of the block load and transmission circuit switching schedule, see Req. 4

Req. 15 **Anchor generator control post start-up**. Anchor generator control covers the period after Anchor generator start up (Req. 11) when the DRZ network is being expanded through block load switching (Req. 13) and adding additional BS DER support (Req. 16). While the Anchor generator will be operating in frequency control and AVR control mode, the DRZC may require to send set points to the Anchor generator to adjust the network frequency and voltage. This may require a lower latency communication route from the DRZC than provided by a control route via the DNO DMS.

Req. 16 **Control of individual BS DER.** Having checked the status of BS DER, and advised the BS DER sites that a black start condition exists, and the network has been energised to the BS DER site DNO substations, the BS DER site will be requested to connect to the DRZ network initially controlling their output to minimise their impact on the DRZ island i.e. near zero power export at unity power factor. Once connected to the network, during block load switching the DRZC will send BS DER set point commands to ramp up the BS DER site export. The power ramp up rate will be aligned with the ability of the Anchor generator to ramp down power under frequency control. The DRZC will monitor system frequency and voltage measurements and adjust BS DER and Anchor generator set points to maintain sufficient available capacity on the Anchor generator to allow it to control frequency and voltage and maintain the DRZ network stability.

Outside of block load switching, the DRZC may require to send BS DER set points to help maintain the system voltage and frequency where the Anchor generator requires additional support.

Where BS has available modes for automatic control to meet target voltages or target frequency support, the DRZC will switch BS DER to these modes when required e.g. voltage control mode when synchronising to the grid or switching in transmission circuit elements.
BS DER control will require lower latency communication routes than offered via the DNO DMS to ensure RoCoF impacts due to sudden large impacts (BS DER loss or block load loss etc.) can be mitigated against.

Req. 17 **Network synchronising.** Having expanded the DRZ island as far as possible within the Anchor generator and BS DER limits, allowing for suitable capacity safety margins, and ensuring the island has maintained stable operation for a suitable period (period to be determined by the DNO/TSO operator), the DNO/TSO operator will issue commands to resynchronise the DRZ island to either the transmission network or another DRZ island. The DNO/TSO command will identify the synchronising circuit breaker to be used. The DRZC will use the appropriate voltage, frequency and phase angle measurements (see Req. 7) to send set points to the

Anchor generator and other BS DER (where required to free up capacity for control of the Anchor generator) to align the DRZ island parameters with the other system and close the synchronising breaker when this is achieved to safely synchronise the two systems. Where a check synch device is installed at the synchronising circuit breaker, the circuit breaker closure can be controlled by this device when parameters are aligned across the circuit breaker by the DRZC.

Anchor generator set point control, BS DER set point control and potentially the synchronising breaker closing (no local check synch device) will require lower latency communications than provided by routing measurements and control via the DSO DMS or ESO EMS.

Where two DRZ island networks are to be synchronised, the DRZC is to be capable of being programmed to take or not take the lead role in the synchronising process. The DRZC will also be cable of accepting a DNO DMS operator or ESO EMS operator instruction regarding the lead role in the synchronising process.

Req. 18 **Combined DRZ island operation.** Where two or more DRZ islands are synchronised together but remain disconnected from a sufficiently restored transmission network, the DRZCs on each DRZ network may require to share available BS DER capacity between each DRZ island to support the Anchor generators.

Each DRZC will monitor the power flows between the two DRZ networks (Req. 8) to ensure they are balancing their own network generation and demand (power flow between DRZ networks should be minimal under this condition). Each DRZC will be updated in real time with available power capacity and 30 minute forecast capacity at each BS DER site as well as at the Anchor generator (Req. 9). Where, one DRZ island network has limited available capacity and another has more available capacity than required as a safe operating margin, the two DRZCs will modify their BS DER set points to redress this situation and send some supporting power via the circuits linking the two DRZ networks. The DRZCs would need to do this within network circuit thermal limits and network voltage limits. The DRZCs will be monitoring the real and reactive power flows on the circuits connecting the two islands (Req. 8) and the voltages at the respective 33kV GSPs and Anchor generator and BS DER substations (Req. 5). It is likely that the DNO Control room operator would be required to provide the DRZCs permission to carry out this type of operation and monitor progress. This operation would require BS DER available capacity data.

To allow DRZC control response that will prevent DRZ instability under all likely conditions, measurements will not be taken from the DNO DMS and ESO EMS. Faster data transfer routes will be required.

9.3 Protection of Island Network Requirements General Case

The following requirements are aimed at unplanned events or failures that could threaten the black start island network recovery. The aim of these requirements is to ensure continued stable operation of the black start island through stages 1 to 6 or prevent unsafe operation where this is not possible.

Req. 19 **Unplanned trip of block demand.** The DRZC is monitoring in real time the BS DER power export to the DRZ island and the block load circuit power flows and associated circuit breaker status (Req. 6). The DRZC detects a rising RoCoF (Req. 5) and a sudden major change in the system demand and an unexpected change in block load circuit breaker status outside of configurable set limits (limits can be set by the DSO for each DRZ network) indicating a major network change and possible block load loss. The DRZC will check the retained power flow summations of the block load circuit measurements and estimate the step change in block load. Based on the block load step drop, the DRZC will check the BS DER power outputs and calculate which BS DER need to be tripped. The DRZC will then trip the required BS DER POC circuit breakers. The DRZC will issue the remaining BS DER with set points to return the Anchor generator to a suitable output (above the Anchor generator minimum load requirement) based on the BS DER available capacity measurements (Req. 9). Where fast acting BS DER is required (load banks and BESS) these will be issued with new set points first (where such BS DER are in frequency control mode and have capacity availability they may not require a set point instruction from the DRZC).

Fast acting mitigation will be required before BS DER and the Anchor generator G99 protection operates resulting in collapse of the DRZ island operations. Distributed intelligent control devices as opposed to centralised control may be required to provide protection of network stability to such severe unplanned events. Such devices would require the ability to select which BS DER to trip out, however, resetting of the remaining BS DER output to support the Anchor generator would likely be carried out by a centralised DRZC control element as the time scales for this are less critical than the initial event mitigating action. It is expected that in many DRZ networks the RoCoF rates will exceed the G99 protection settings and require faster mitigation than the over frequency protection. In this case blocking of a RoCoF trip should be considered[41].

Req. 20 **Unplanned trip of BS DER.** The DRZC is monitoring in real time the BS DER power export to the DRZ island, the associated BS DER connection circuit breakers and the block load circuit power flows (Req. 6). The DRZC detects a dropping RoCoF (Req. 5) and a sudden change in a BS DER export power and perhaps an associated circuit breaker status change (but not necessarily the case) outside of configurable set limits (limits can be set by the DSO for each DRZ network) indicating a major network change and possible BS DER loss. The DRZC will check the retained BS DER export flow summations and estimate the step change in BS DER power provision to the DRZ network. Based on the BS DER power export drop, the DRZC will check the block load measurements and calculate which block loads need to be tripped. The DRZC will then trip the required BS DER block load circuit breakers. The DRZC will issue the remaining BS DER with set points to return the Anchor generator to a suitable output (above the generator minimum load requirement) based on the BS DER available capacity measurements (Req. 9). Where fast acting BS DER is required (load banks and BESS) these will be issued with new set points first(where such BS DER are in frequency control mode and have capacity availability they may not require a set point instruction from the DRZC).

Fast acting mitigation will be required before BS DER and the Anchor generator G99 protection operates resulting in collapse of the DRZ island operations. Distributed intelligent

[41] G99 RoCoF protection is a loss of mains protection designed to prevent independent island operation from the grid. The concept for black start operations here is to ensure island operation is sustained and the RoCoF protection is a potential barrier to this and should be prevented from operating where feasible.

control devices as opposed to centralised control may be required to provide protection of network stability to such severe unplanned events. Such devices would require the ability to select which block loads to trip out, however, resetting of the remaining BS DER output to support the Anchor generator would likely be carried out by a centralised DRZC control element as the time scales for this are less critical than the initial event mitigating action. It is expected that in many DRZ networks the RoCoF rates will exceed the G99 protection settings and require faster mitigation than the under frequency protection. In this case blocking of a RoCoF trip should be considered.

Req. 21 **Communications failures**. The DRZC solution will be designed and implemented to fail to a safe operating state when communication failures are experienced.

Req. 21.1 **Communication failure between the DRZC central controller and the Anchor generator.** The DRZC will allow the Anchor generator to continue to control the DRZ frequency and voltage automatically. Where the Anchor generator and BS DER available capacity margins are limited the DNO Control room operator will have the option to trip block load or BS DER as necessary via the DNO DMS. In addition, synchronising functionality is disabled during this time**.**

Req. 21.2 **Communications failure between BS DERs and the DRZC central controller**. **The DRZC will provide a failure notice to the DNO control room via the DNO DMS.** BS DER may still be visible to the DNO control room via DNO DMS. The DER controller will maintain the DER at its current output if possible. The DNO control room operator will be able to take an action to mitigate such alarms via the DNO DMS system.

Req. 21.3 **Communications failure between the DRZC central controller and the DNO DMS**. The DRZC will hold at the operational stage and control the system in a stable operating condition. The DNO control room operator will have visibility of the DRZ network, Anchor generator and BS DER via the DNO DMS. The DNO control room operator will decide what action to take, which could be to manually continue the black start restoration via the DNO DMS, hold and continue to let the DRZC control things as is under control room supervision or to shut down the DRZ island etc.

Req. 21.4 **Communications failure between the DRZC central controller and the synchronising circuit breaker**. In this condition the DRZC will not receive data on the voltage, frequency and phase angle on both sides of the synchronising circuit breaker. If this occurs automatic synchronisation via the DRZC is disabled.

9.4 Interface Requirements General Case

Req. 22 **SCADA System Link**. The DRZC system will interface with the NGESO or DNO SCADA (EMS or DMS) system using DNP3 or ICCP protocols to provide visibility and control of DRZC functions; provide the DRZC with network status and measurement information; allow the DRZC to carry out network switching to reconfigure the DRZ distribution network and initiate the changes to protection settings on the DRZ distribution network.

Req. 23 **BS DER and Anchor Generator System Link.** At each local DER site providing black start support to the DRZC system, a local control interface with the DER control system will be required. This will provide the control and measurement interface of the DRZC with each BS DER. BS DER would include the Anchor generator, any load banks, battery storage, distributed generation or other controllable demand. At the Anchor generator site, the status of (and possibly control of) a black start island 33kV earth may also be required (note that this expected to be a DNO DMS requirement).

Req. 24 **DRZC solution HMI for control operator use**. The DRZC solution has an HMI for configuration, control and monitoring.

Req. 24.1 **Central HMI (DMS and EMS Control Rooms)**. A central HMI will allow protected operator control, configuration and monitoring over the full DRZC system.

Req. 24.2 **Local HMI (DRZC is located at each BS GSP substation)**. A local HMI at each DER will allow protected local operator control, configuration and monitoring.

Req. 24.3 **Local HMI (BS DER locations)**. A local HMI at each BS DER will allow protected local operator control, configuration and monitoring. This would depend on the DER control interface used and may or may not me a requirement.

9.5 Communication Requirements General Case

Req. 25 **DRZC to DNO DMS and ESO EMS.** See section 7.5.

Req. 26 **DRZC to Anchor Generator including local load bank and 33kV earth switch.** See section 7.5.

Req. 27 **DRZC to Black Start DER.** See section 7.5.

Req. 28 **DRZC to Synchronising circuit breakers and associated measurements.** See section 7.5.

9.6 HMI User Requirements General Case

Req. 29 **HMI user accounts**. The HMI can be configured with multiple user accounts with different access rights. The solution will have three types of user accounts, Read Only, Operator and Administrator. Read Only accounts will have access to DRZC displays but are unable to execute any control actions. Operator accounts will have access to the full HMI functionality. Administrator accounts will have access to full HMI functionality and will also be able to maintain user accounts.

Req. 29.1 **DER Customer HMI accounts.** User accounts should be configurable to provide each black start DER service provider including the Anchor generator with visibility of the DRZC service status and measurements that are relevant to that individual DER.

Req. 30 **All system measurements, status indicators and control actions shall be logged and fully auditable.**

Req. 31 **HMI control functionality**. User accounts are able to view the following information:

Req. 31.1 DRZC service status;

Req. 31.2 Measurement Point service status;

Req. 31.3 DER service status;

Req. 31.4 DRZ island status

Req. 31.5 Measurement Point state, measurement value (power, voltage, frequency, voltage phase angle, thresholds and communication status;

Req. 31.6 DER state, power output, capacity availability, circuit breaker status and communication status.

Req. 31.7 Anchor generator state, power output, capacity availability, circuit breaker status and communication status.

Req. 31.8 DRZ network status, circuit breaker status, voltage, power flows, 33kV earth status,

Req. 31.9 Protection setting status normal or island condition.

Req. 31.10 Administrator accounts have all User account capabilities with the following additional features:

Req. 31.11 Control of Measurement Point service status;

Req. 31.12 Control of DER service status;

Req. 31.13 Control of DRZC service status; and

Req. 31.14 Manual override functionality to allow DRZC controls to be overridden;

Req. 31.15 User account administration.

10 NON-FUNCTIONAL REQUIREMENTS AND DESIGN CONSTRAINTS

The following section sets out non-functional requirements.

10.1 Platform

10.1.1 General Requirements

Req. 32 **Deterministic real-time performance**. The DRZC system will be designed and implemented to achieve deterministic real-time performance.

Req. 33 **Configurability and Extensibility**. The Platform should be capable of being reconfigured and extended to allow for a range of DRZ network/DER arrangements and operational changes.

10.1.2 Hardware Requirements

Req. 34 **Hardware requirements**. See section 7.1.2.

10.1.3 Support and Maintenance

Req. 35 **Maintain and support the system.** An appointed provider is to provide operational support and maintenance of the DRZC system throughout the trial stage.

10.1.4 Third Party Software

Req. 36 **Third party software register**. The appointed DRZC vendor is to supply details of third party software used in the DRZC solution.

Req. 37 **Vendor supported third party software**. Third party software is to be vendor supported.

Req. 38 **Support lifetime**. Third party software should be of an appropriate version for the DRZC solution and have an extended support for lifetime of the system.

10.1.5 Operating Systems

Req. 39 **Operating system specification**. The DRZC vendor is to provide a specification of the operating systems used for all relevant hardware.

10.1.6 Communications

Req. 40 **Communication physical interface specification**. The DRZC vendor is to provide a suitable interface specification appropriate for the operation of the DRZC solution.

Req. 41 **Communication data exchange**. The DRZC vendor is to provide a detailed list of all data points exchanged between the DRZC solution and external systems.

10.2 Security

10.2.1 General Security Requirements

Req. 42 **Security measures**. The DRZC supplier is to provide details of all security measures in the DRZC solution design.

Req. 43 **Security patching**. The DRZC supplier is to provide details of how the solution will be update and maintained for security purposes.

Req. 44 **Support arrangements**. The DRZC supplier is to provide relevant details of its internal IT security policy and support practices.

10.2.2 Deployment specific cyber-security requirements

Req. 45 **Specific cyber-security requirements**. Communications infrastructure is compliant with cyber security standard IEC 62351.

10.3 Performance

Req. 46 **Server availability**. The server architecture of the DRZC solution will be such that the failure of a single server does not cause the DRZC to be unavailable. In the event of a double server failure during a black start restoration sequence, all DRZC connected BS DERs will be disconnected and the network returned to a black out condition.

10.4 Monitoring

Req. 47 **Hardware/software health monitoring and logging**. The solution provided will have a mechanism for the monitoring and logging of the health of both the software and hardware that make up the DRZC solution.

10.5 Design Constraints

The following design constraints are to be considered during system design:

Req. 48 **Protocol support**. The DRZC design is to support at least one of the protocols used by the DNO and ESO for communication between their SCADA Master systems/Front End Processors and Remote Terminal Units.

10.6 Other

Commercial framework, principles of access, solution scalability and training requirements are outside the scope of this document.

Req. 49 **Quality assurance**. The DRZC solution is to be delivered in compliance with an ISO 9001 certified Quality Management System (QMS).