New Reactors Division

Step 4 Assessment of Electrical Engineering for the UK Advanced Boiling Water Reactor

Assessment Report: ONR-NR-AR-17-018
Revision 0
December 2017

EXECUTIVE SUMMARY

Hitachi-GE Nuclear Energy Ltd (Hitachi-GE) is the designer and GDA Requesting Party for the United Kingdom Advanced Boiling Water Reactor (UK ABWR). Hitachi-GE commenced Generic Design Assessment (GDA) in 2013 and completed Step 4 in 2017.

This assessment report is my Step 4 assessment of the Hitachi-GE UK ABWR reactor design in the area of Electrical Engineering.

The scope of the Step 4 assessment is to review the safety, security and environmental aspects of the UK ABWR in greater detail, by examining the evidence, supporting the claims and arguments made in the safety documentation, building on the assessments already carried out for Step 3. In addition I have provided a judgement on the adequacy of the Electrical Engineering information contained within the Pre-Construction Safety Report (PCSR) and supporting documentation.

My assessment conclusions are:

- The generic pre-construction safety case and supporting Basis of Safety Case adequately demonstrate for GDA purposes that the electrical power system for the UK ABWR supports plant safety systems by providing robust electrical power to support these systems for design basis and beyond design basis events.
- The Hitachi-GE model of the electrical power system which analyses its capability and stability adequately demonstrates the system’s suitability to support plant safety systems.
- The architecture of the electrical power system conforms to international guidance.
- Hitachi-GE has demonstrated that generic requirements have been addressed in the UK ABWR design for connecting to the UK grid system including consideration of compliance with the UK grid code.

My judgement is based upon the following factors:

- A review of the claims, arguments and evidence presented in the electrical Basis of Safety Case.
- A review of the system studies conducted by Hitachi-GE based on the results of ONR confirmatory studies.
- Assessment of the electrical system architecture in accordance with safety assessment principles and international guidelines.

To conclude, I am satisfied with the claims, arguments and evidence laid down within the PCSR and supporting documentation for electrical engineering. I consider that from an electrical engineering view point, the Hitachi-GE UK ABWR design is suitable for construction in the UK subject to future permissions and permits beings secured.

Several assessment findings have been identified; these are for a future licensee to consider and take forward in their site-specific safety submissions. These matters do not undermine the generic safety submission and require licensee input/decision.

LIST OF ABBREVIATIONS

AC	Alternating Current
ALARP	As Low As Reasonably Practicable
ANT	Auxiliary Normal Transformer
ASD	Adjustable Speed Drive
AST	Auxiliary Standby Transformer
ATWS	Anticipated Transient Without Scram
AVR	Automatic Voltage Regulator
B/B	Backup Building
BBG	Backup Building Generator
BDBA	Beyond Design Basis Analysis
BDBE	Beyond Design Basis Event
BIL	Basic Insulation Level
BSC	Basis of Safety Case
CAE	Claims, Arguments, Evidence
CCF	Common Cause Failure
CIGRE	Council on Large Electrical Systems
CRIEPI	Central Research Institute of Electrical Power Industry
C&I	Control and Instrumentation
C/B	Control Building
DAC	Design Acceptance Confirmation
DAG	Diverse Additional Generator
DBA	Design Basis Analysis
DBE	Design Basis Event
DC	Direct Current
DG	Diesel Generator
EA	Environment Agency
EDG	Emergency Diesel Generator
EHC	Turbine Electro-Hydraulic Control
EMI	Electro-Magnetic Interference
EPA	Electrical Penetration Assemblies
EPS	Electrical Power Systems
FLSS	Flooder System of Specific Safety Facility
FRT	Fault Ride Through
FSF	Fundamental Safety Function
FSM	Frequency Sensitive Mode
GDA	Generic Design Assessment
GDS	Generator Disconnection Switch

GIC	Geomagnetically Induced Current
GLS	Generator Load Switch
GT	Generator Transformer
HF	Human Factors
HLSF	High Level Safety Function
HPCF	High Pressure Core Flooder
HVAC	Heating Ventilating and Air Conditioning
IAEA	International Atomic Energy Agency
IDMT	Inverse Definite Minimum Time
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers (USA)
IM	Island Mode
kA	Kilo Amp
kW	Kilo Watt
kV	Kilo Volt
kVA	Kilo Volt Ampere
LCO	Limits and Conditions of Operation
LFSM	Limited Frequency Sensitive Mode
LOCA	Loss of Coolant Accident
LOOP	Loss of Off-site Power
LPS	Lightning Protection System
LPT	Large Power Truck
LV	Low Voltage
MCC	Motor Control Centre
MCCB	Moulded Case Circuit Breaker
MCR	Main Control Room
MDAL	Master Data and Assumption List
MG	Motor Generator
MV	Medium Voltage
MVA	Mega Volt Ampere
NPP	Nuclear Power Plant
NRW	Natural Resources Wales
NSC	Non-Safety Class
NSEDP	Nuclear Safety and Environmental Design Principles
OPEX	Operation Experience
PCSR	Pre-Construction Safety report
PSA	Probabilistic Safety Assessment
R/B	Reactor Building
RCIC	Reactor Core Isolation Cooling

RFC	Recirculation Flow Control
RHR	Residual Heat Removal
RI	Regulatory Issue
RIP	Reactor Internal Pump
RO	Regulatory Observation
RP	Requesting Party
RPT	Recirculation Pump Trip
RPS	Reactor Protection System
RQ	Regulatory Query
RSS	Remote Shutdown System
SAA	Severe Accident Analysis
SAP	Safety Assessment Principle
SBO	Station Blackout
SC	Safety Class
SDD	System Design Description
SFAIRP	So Far As Is Reasonably Practicable
SFC	Safety Functional Claim
SoDA	Statement of Design Acceptability
SPC	Safety Property Claim
SPD	Surge Protection Device
SPT	Small Power Truck
SQEP	Suitably Qualified and Experienced Person
SR	Surveillance Requirement
SSC	Structures Systems and |Components
TBV	Turbine Bypass Valve
THD	Total Harmonic Distortion
TSC	Technical Support Contractor
TSO	Transmission System Operator
UK ABWR	United Kingdom Advanced Boiling Water Reactor
UPS	Uninterruptible Power Supply

TABLE OF CONTENTS

Annexes

1 INTRODUCTION

1. This Assessment Report details my Step 4 Generic Design Assessment (GDA) of Hitachi-GE Nuclear Energy Ltd's (Hitachi-GE) UK ABWR reactor design in the electrical engineering topic area.

1.1 GDA Background

2. Information on the GDA process is provided in a series of documents published on our website (**http://www.onr.org.uk/new-reactors/index.htm**). The outcome from the GDA process sought by Requesting Parties such as Hitachi-GE is a Design Acceptance Confirmation (DAC) for ONR and a Statement of Design Acceptability (SoDA) for the Environment Agency (EA) and Natural Resources Wales (NRW).

3. The GDA of the UK ABWR has followed a step-wise approach in a claims-arguments-evidence hierarchy which commenced in 2013. Major technical interactions started in Step 2 with an examination of the main claims made by Hitachi-GE for the UK ABWR. In Step 3, the arguments which underpin those claims were examined. The reports in individual technical areas and accompanying summary reports are also published on ONR's website.

4. The objective of the Step 4 assessment is to undertake an in-depth assessment of the safety, security and environmental evidence. Through the review of information provided to ONR, the Step 4 process should confirm that Hitachi-GE:

   - Has properly justified the higher-level claims and arguments.
   - Has progressed the resolution of issues identified during Step 3.
   - Has provided sufficient detailed analysis to allow ONR to come to a judgement whether a DAC can be issued.

5. The full range of items that might form part of the assessment is provided in ONR's 'GDA Guidance to Requesting Parties' (**http://www.onr.org.uk/new-reactors/ngn03.pdf**). These include:

   - Consideration of topics identified in Step 3.
   - Judging the design against the Safety Assessment Principles (SAPs) and whether the proposed design reduces risks to As Low as Reasonable Practicable (ALARP).
   - Reviewing details of the Hitachi-GE design controls, procurement and quality control arrangements to secure compliance with the design intent.
   - Establishing whether the system performance, safety classification, and reliability requirements are substantiated by the detailed engineering design.
   - Assessing arrangements for ensuring and assuring that safety claims and assumptions are realised in the final as-built design.
   - Resolution of identified nuclear safety and security issues, or identifying paths for resolution.

6. All of the regulatory observations (ROs) issued to Hitachi-GE as part of my assessment are also published on our website, together with the corresponding Hitachi-GE resolution plan.

1.2 Scope

7. The scope of my assessment is detailed in Assessment Plan ONR-GDA-AP-15-003 (Ref. 1).

8. The electrical engineering GDA review has followed the step-wise approach in a claims-argument-evidence hierarchy, as set out in ONR's guidance. In the earlier Steps 2 and 3, the underpinning safety claims and arguments were assessed (Refs. 2 and 3). The Step 4 assessment has built upon those earlier assessments, looking in greater detail at the evidence that supports claims and arguments made by Hitachi-GE. This has involved consideration of the following:

   - Electrical systems and equipment are adequately designed to fulfil their role of supporting nuclear safety functions.
   - Electrical systems and equipment are adequately rated for their duty in all defined operating conditions.
   - The Electrical Power System (EPS) remains stable to perform its duty in all defined operating conditions, including fault conditions.
   - The electrical systems and equipment are designed taking account of ONR's Safety Assessment Principles (SAP).

9. The evidence submitted consisted of:

   - Reports presenting electrical system studies undertaken by Hitachi-GE.
   - Reports outlining electrical protection coordination studies
   - Topic reports on specific electrical design aspects
   - Electrical System Design Descriptions (SDD)
   - Electrical System Layout drawings
   - Electrical Single Line Diagrams
   - Electrical Strategy reports
   - Electrical equipment specifications
   - Electrical Layout Plans

10. The scope of my assessment is appropriate for GDA because it focusses on the capability of the EPS design to support reactor safety systems to meet overall plant safety claims.

1.3 Method

11. My assessment complies with internal guidance on the mechanics of assessment within ONR (Ref. 2).

2 ASSESSMENT STRATEGY

2.1 Standards and criteria

12. The standards and criteria adopted within this assessment are principally the Safety Assessment Principles (SAPs) (Ref. 3), internal TAGs (Ref. 4), relevant national and international standards and relevant good practice informed from existing practices adopted on UK nuclear licensed sites.

2.1.1 Safety Assessment Principles

13. The SAPs applied within the assessment are included within annex 1. These SAPs were identified in the assessment plan at the start of GDA Step 4 and have informed the interactions with Hitachi-GE during Step 4.

14. The key SAPs related to this assessment are:

- EDR.1 – Failure to safety
- EDR.2 – Redundancy, diversity and segregation
- EDR.3 – Common cause failure
- EDR.4 – Single failure criterion
- ESS.8 – Automatic Initiation
- ESS.21 – Reliability
- EES.2 – Sources external to site
- EKP.3 – Defence in depth

2.1.2 Technical Assessment Guides

15. The TAGs that have been used as part of this assessment are set out in annex 2.

2.1.3 National and international standards and guidance

16. The international standards and guidance that have been used as part of this assessment are set out in annex 3.

2.2 Use of Technical Support Contractors (TSCs)

17. It is usual in GDA for ONR to use TSCs, for example to provide additional capacity, to enable access to independent advice and experience, analysis techniques and models, and to enable ONR‘s inspectors to focus on regulatory decision making etc.

18. To supplement ONR’s capability, a contract was placed with a TSC to undertake independent confirmatory transient studies of the electrical system. This assessment independently considered the capacity and transient stability of the electrical distribution system.

19. The study results and accompanying report identified a number of areas for Hitachi-GE to address in demonstrating the integrity of the electrical system. These were presented to Hitachi-GE to enable the GDA system study submissions to be updated to take account of the matters raised from the confirmatory studies.

2.3 Integration with other assessment topics

20. GDA requires the submission of an adequate, coherent and holistic generic safety case. Regulatory assessment cannot therefore be carried out in isolation as there are often safety issues of a multi-topic or cross-cutting nature. The following cross-cutting issues have been considered within this assessment:

- I have worked with the Fault Studies inspectors to support their assessment of Hitachi-GE responses to Regulatory Observations (RO). These covered common cause failure of electrical distribution systems, loss of offsite power events and design basis analysis of essential services and support systems. I assessed the electrical engineering aspects of the RO responses to consider consistency with the EPS design and the electrical engineering safety claims and determine the acceptability of Hitachi-GE submissions.

- I have liaised with the Severe Accident inspectors to consider the claims on the EPS in Hitachi-GE submissions concerning Severe Accident and Beyond Design Basis events. This has informed my assessment of electrical engineering submissions covering station blackout provisions and supporting arguments and evidence for claims on the EPS.

- I have cooperated with the C&I inspectors in considering the Hitachi-GE approach to the utilisation of Smart devices in the EPS. This cooperation has included joint meetings with ONR and Hitachi-GE electrical and C&I teams to understand qualification expectations developed in the C&I area and discussions on the approach to addressing risks of common cause failure due to the implementation of smart devices.

- The designs of the plant lighting and plant communications have been developed by a joint Hitachi-GE team from C&I and Human Factors. This was set up following ONR cross cutting assessment which identified the need for the design of these systems to be based on plant safety requirements.

- The assessment of the Hitachi-GE submissions on the lightning hazard and associated protection requirements for electrical and C&I systems against this hazard has been carried out jointly by electrical engineering and external hazards inspectors. Following this initial assessment Hitachi-GE has further developed its submissions to address protection against lightning hazards.

- I have assessed the electrical engineering aspects for the Internal Hazards topics of exceptions to segregation and assessment of the hazard from internal arcs in electrical equipment. This input has been used to inform the Internal Hazards topic report.

- The PSA assessment has identified a number of assumptions made in the PSA model regarding resilience of the electrical distribution system to common cause faults from incorrect coordination of electrical protection. I have assessed the Hitachi-GE electrical protection and methodology for implementing protection settings to consider the validity of these assumptions.

2.4 Sampling strategy

21. It is seldom possible, or necessary, to assess a safety case in its entirety, therefore sampling is used to limit the areas scrutinised, and to improve the overall efficiency of the assessment process. Sampling is done in a focused, targeted and structured

manner with a view to revealing any topic-specific, or generic, weaknesses in the safety case.

22. The sampling strategy was based on assessment of the structure of the EPS to meet the safety claims for equipment of each safety classification. This confirmed the Requesting Party's basic approach to EPS design by assessment of the basic principles adopted to meet each safety functional claim.

2.5 Out of scope items

23. The following have been agreed as outside the scope of the assessment:

- Detailed equipment purchase specifications for electrical equipment.
- Grid connection and coordination with grid protection system.
- Site-specific UK Grid Code compliance.
- Site-specific study of electrical fast transients, GIC and ferro-resonance.
- Commercial arrangements to provide frequency support to the UK grid.

3 REQUESTING PARTY’S SAFETY CASE

24. The Hitachi-GE safety case for electrical engineering is documented in Chapter 15 of the Pre-construction Safety Report (PCSR) (Ref. 5). The PCSR provides an overview of the design and safety requirements applicable to the electrical systems and equipment associated with the UK ABWR in providing electrical power to Structures, Systems and Components (SSC) supporting normal operation and delivery of safety functions. The PCSR provides an outline description of the Electrical Power System (EPS) architecture and identifies its major elements.

25. Chapter 15 of the PCSR is supported by the Basis of Safety Cases on Electrical System (BSC) (Ref. 6). The main role of the BSC is to set out the safety justification following a Claims, Arguments and Evidence (CAE) approach. The BSC describes the claims on the safety functions and safety properties of the EPS and its associated electrical equipment. These claims are supported by a set of arguments backed up by a presentation of evidence.

4 ONR STEP 4 ASSESSMENT

4.1 Scope of Assessment Undertaken

26. The scope of the assessment covers the electrical power distribution system which supports structures, systems and components important to safety for the UK ABWR.

4.2 AC System Architecture

27. I have assessed the compliance of the basic structure and integrity of the AC electrical system architecture of the ABWR EPS against a subset of SAPs most relevant to the architecture of the electrical power supply system. I considered the high-level design to assess whether it provides a robust system capable of supporting the high-level claims made in the Basis of Safety Cases on Electrical Systems (BSC) (Ref. 6).

28. An overview of the UK ABWR AC system is shown in Figure 1 and the high-level system description is presented in the EPS SDD (Ref. 8). I have presented my detailed assessment and findings for each part of the system such as the grid connection and Safety Class 1 (SC1) and Backup Building (B/B) Safety Class 2 (SC2) systems in the relevant sub-sections.

29. During normal operation the UK ABWR on-site EPS is supplied by the main turbine generator via two 26.5/6.9 kV Auxiliary Normal Transformers (ANT). During plant start-up and shutdown, the EPS is supplied from the external grid via the 400/26.5 kV Generator Transformer and the two ANTs.

30. There are four Safety Class 3 (SC3) 6.9 kV switchboards supplied by the ANTs and a standby supply is provided by the 400/6.9 kV Auxiliary Standby Transformer (AST). The SC3 6.9 kV switchboards feed the distribution network for SC1 and SC2 systems operating at 6.9 kV, 690 V and 420 V.

31. There are three independent SC1 divisions each fed from a 6.9 kV switchboard that is supplied directly by the SC3 6.9 kV switchboards. The SC1 6.9 kV switchboards for each division feed the distribution network for that division, consisting of switchboards operating at 6.9 kV and 420 V. All motor and other electrical loads within each division are fed from the divisional distribution network.

32. The SC1 divisions are also backed-up by three SC1 auto-start 6.9 kV Emergency Diesel Generators (EDG) with one EDG supporting one SC1 division.

33. Defence-in-depth support is provided by a single 6.9 kV manually started SC3 Diverse Additional Generator (DAG) which can be manually selected to supply any one of the three SC1 divisions.

34. An additional defence-in-depth measure is provided by a single SC3 6.9 kV Large Power Truck (LPT) and by SC3 420 V Small Power Trucks (SPT). The LPT is a mobile unit that is intended to be connected to any one of the three SC1 divisions via permanently installed connection points. The SPT is a mobile unit that can be connected to 420 V switchboards via permanently installed connection points. The trucks are manually moved into position, manually connected and manually started.

35. The diverse SC2 B/B system contains two independent divisions operating at 690 V supplied under normal operation from the SC3 6.9 kV switchboards via a power transformer. The SC2 690 V switchboards for each division feed the distribution network for that division. All electrical loads for the Division are fed from the divisional distribution network.

36. The SC2 divisions are also backed up by two SC2 auto-start 690 V Backup Building Generators (BBG) with one BBG supporting one SC2 division.

37. Hitachi-GE has undertaken a series of electrical system studies for the UK ABWR's EPS which assess its capability to support safe operation of the reactor. ONR's assessment of these studies is presented in Section 4.6 of this report.

4.2.1 Grid Connection

4.2.1.1 Assessment

38. The EPS supporting plant safety is supplied from the main turbine generator and the external grid. The main grid connection is the preferred power supply used for all operations. The design of the external connections to the incoming 6.9 kV Class 3 switchboards is described in the Electrical Power System System Design Description (SDD) (Ref. 8). Figure 1 shows the arrangement of external electrical connections from the grid switchyard to the plant.

39. During normal plant operation, power is generated by the main turbine generator and exported to the grid by the Generator Transformer (GT). Power to the plant EPS is derived via a tee off connection to the ANTs. During plant start up and shutdown, plant outages and following reactor or turbine shutdown the main generator can be disconnected by the generator load switch with the ANTs feeding the EPS from the main grid supply.

40. All electrical faults on the system feeding the EPS via the ANTs including the main generator are intended to be detected by the protection system and tripped via a 400 kV switchyard circuit breaker. This will initiate a reactor trip and EPS loads required for shutdown will be automatically transferred to the AST. The electrical protection system is described in the Hitachi-GE document electrical protection and earthing system (Ref. 9).

41. The 6.9 kV SC3 switchboards are normally fed from dual ANTs. Each ANT has a primary voltage of 26.5 kV and is provided with on-load tap changing equipment on the primary winding. The ANTs have the capacity to support normal plant operation as demonstrated in the Hitachi-GE System Study report (Ref. 10).

42. In the event of loss of supplies to the EPS from the ANTs the reactor will trip and electrical supplies will be automatically transferred to the AST. This has an independent connection to the 400 kV switchyard so will not be affected by any unavailability of the main grid connection to the EPS. The AST has a primary voltage of 400 kV and is fitted with on-load tap changing equipment on the primary winding. The AST is a single transformer of a lower rating than the ANTs as the reactor will trip upon loss of ANTs which will result in the trip of a number of systems and station electrical loading will be reduced. The AST has the capacity to support plant loads at all times when the main generator is not operating as demonstrated in the Hitachi-GE load flow studies.

4.2.1.2 Findings

43. I have assessed the design suitability of the grid connection in accordance with the requirements of the IAEA safety standard SSG-34 (Ref. 11) and consider that the requirements of this standard are met by the ABWR design.

44. The provision of a diverse means of connecting the EPS to the grid supply meets the requirements of Fukushima Stress Test Finding STF-11 from the European Council "Stress Tests" for UK nuclear power plants (Ref.12).

45. I have confirmed the suitability of the electrical protection system to adequately protect the system. I consider that the load flow studies have demonstrated the adequacy of the electrical equipment ratings for the grid connection.

46. On the basis of my assessment I am content with the generic design principles of the UK ABWR grid connection.

4.2.2 Medium Voltage 6.9 kV Safety Class 3 System

4.2.2.1 Assessment

47. The Medium Voltage (MV) SC3 system supports plant loads during normal operation. In the event of loss of supply to a MV SC3 switchboard from an ANT the supply is maintained by transfer to the AST with a momentary loss of power. The transfer is intended to be carried out automatically from a free-standing hard wired relay system when a fault is detected on the main generator circuit. The transfer is described in the electrical protection and earthing system report (Ref.9).

4.2.2.2 Findings

48. I have assessed the suitability of the MV SC3 system to support safe operation of the reactor. I consider the plans for provision of two diverse supplies derived via the grid connection supports defence-in-depth and meets the relevant good practice as defined in IAEA SSG-34, Design of Electrical Power Systems for Nuclear Power Plants (Ref. 11).

4.2.3 Medium Voltage 6.9 kV Safety Class 1 system

4.2.3.1 Assessment

49. The MV Safety Class 1 (SC1) system supports Structures, Systems and Components providing Category A Safety Functions. The MV SC1 system is intended to be divided into three redundant and independent divisions with each division normally supplied from the MV SC3 system. Each MV SC1 switchboard supplies power to the distribution network for its division via power transformers and associated switchgear.

50. Each SC1 switchboard is supported by a dedicated SC1 EDG as described in the EDG SDD (Ref.13). Each EDG is planned to be located in a separate independent building and connected to its own switchboard. Auxiliary systems supporting these EDGs are to be redundant and independent from other EDG auxiliary systems. The EDGs start automatically following the detection of low volts on the Safety Class 1 medium voltage switchboards. The EDGs also start following receipt of a signal that a Loss of Coolant Accident (LOCA) has occurred when they remain in no load operation provided that the power supplies on the Reactor Building (R/B) switchboards are not lost.

51. The starting and connection of the EDGs is controlled from a free standing hard wired relay system when low volts are detected on the MV SC1 switchboard. The transfer is described in the electrical protection and earthing system report. The EDGs are rated to support all SSCs providing Category A functions following the worst case event of Loss of Off-Site Supplies (LOOP) event associated with a LOCA .

52. The EDGs also support loads of a lower safety classification which are required for investment protection and defence in depth purposes. The UK ABWR EPS design proposes the use of higher classification switchboards to supply power to equipment of a lower classification. This design principle means that there is a risk that a fault on lower classification equipment could propagate to the higher classification system. I expect that any fault on the lower classification equipment should not prevent the performance of a higher classification safety function from fulfilling its safety related

duty. Therefore I expect appropriate measures to be taken by the licensee to mitigate this risk.

53. The Electrical Protection and Earthing Report (Ref. 9) states that where power supplies are provided from higher classification switchboards to lower classification equipment, the isolation device will be classified in accordance with the higher classification switchboard. The isolation devices will be specified, maintained, inspected and tested in line with the requirements for the higher classification switchboard and therefore provides confidence that the device will reliably isolate the lower classified equipment should a fault occur so that a fault will not propagate to the higher classification system.

54. The SC1 EDGs are required to operate at rated output for 168 hours. The capability of the EDGs to support the allocated loads is demonstrated in the System Study Report which is assessed in Section 4.6 of this report.

55. Each SC1 MV switchboard has a main and backup incoming supply from the MV SC3 system with the backup supply provided for maintenance purposes only. The incoming supplies are electrically interlocked to prevent simultaneous connection of supplies.

4.2.3.2 Findings

56. I consider that the intention to provide three redundant and independent systems backed by SC1 EDGs provides a robust architecture as one division has the ability to support the required safety functions. The EDGs are in principle protected against internal and external hazards by location in independent segregated buildings.

57. I consider that the capability for the EDGs to auto-start following a loss of normal supply meets the requirements of Safety Assessment Principle ESS 8 which covers automatic initiation.

58. I consider that the provision of independent auxiliaries for each EDG meets my expectation for compliance with Fukushima Stress Test Finding STF-10.

59. I am content with the requirement for isolation devices from higher classification to lower classification systems to be classified in accordance with the higher classification system. This meets my expectations for reducing the likelihood of a fault on the lower classification equipment impacting the capability of the higher classification equipment to perform its safety related duty.

4.2.4 Low Voltage 690 V Backup Building Safety Class 2 System

4.2.4.1 Assessment

60. Hitachi-GE has designed the Low Voltage (LV) 690 V B/B Safety Class 2 (SC2) system to support SSCs providing diverse Category A2 functions to those delivered by the SC1 system. The SC2 system is designed to be independent and diverse from the Category A1 functions as described in the Diversity Strategy Report (Ref. 14). The LV 690 V B/B system consists of two 100% systems with each system normally supplied from different MV SC3 switchboards.

61. The B/B switchboards are each backed up by a dedicated BBG with a 168 hour capability at rated load. The BBGs are described in the Backup Building Generator System System Design Description (Ref. 93). The BBGs start automatically to support the loads following a loss of main supplies to the 690 V switchboards. The BBGs also start following receipt of a signal that a Loss of Coolant Accident (LOCA) has occurred when they remain in no load operation provided that the power supplies on the B/B switchboards are not lost. The capability of the BBGs to support the

required SSCs is described in the System Study report and assessed in Section 4.6 of this report.

62. The role of the B/B SC2 system is intended to provide a diverse means of supporting diverse SSCs to bring the reactor to a safe state.

4.2.4.2 Findings

63. I consider that the provision of two independent SC2 B/B systems backed by BBGs provides a robust architecture, such that the loss of one system will not compromise the ability of the B/B EPS to support SSCs to bring the reactor to a safe state.

64. I consider that the proposal for the BBGs to auto start following a loss of normal supply meets the requirements of Safety Assessment Principle ESS 8.

65. I consider that the capability of the B/B EPS to support a set of SSCs that are diverse from the SC1 SSCs reduces the potential for common cause failure.

4.2.5 Defence-in-Depth Generators

66. The UK ABWR AC system architecture includes the provision of defence-in-depth measures in order to provide additional means of supporting electrical systems following Station Black Out (SBO) events as described in the Topic Report on SBO (Ref. 15). These defence-in-depth measures are provided by the following three systems:

- Medium Voltage 6.9 kV Safety Class 3 Diverse Additional Generator system
- Medium Voltage 6.9 kV Safety Class 3 Large Power Truck
- Low Voltage 420 V Safety Class 3 Small Power Truck

67. The MV SC3 DAG system is a defence-in-depth measure for design basis and beyond design basis SBO events.

68. In addition, as a defence-in-depth measure for design basis and beyond design basis SBO events, the EPS has provision for the connection of two mobile power trucks; a SC3 LPT that can be connected to the MV SC1 system and a SC3 SPT that can be connected to the SC1 LV distribution system.

4.2.5.1 Medium Voltage 6.9 kV Safety Class 3 Diverse Additional Generator System

4.2.5.1.1 Assessment

69. The MV SC3 DAG is described in the DAG System Design Description (Ref. 94). Hitachi-GE reference the DAG in the PCSR as providing a defence-in-depth measure for Design Basis and Beyond Design Basis SBO events although it is not subject to any formal safety claims. The DAG is classified as SC3 to support its role as a defence-in-depth provision.

70. The DAG is intended to be manually started and manually connected to any of the three SC1 switchboards. All DAG operations are carried out by the operator and I expect that operating instructions for the DAG will be developed by the licensee. The DAG is rated to support the Residual Heat Removal (RHR) system and its associated systems and is required to be able to operate for 168 hours at rated load.

71. The capability of the DAG to support the required SSCs is described in the System Study report and assessed in Section 4.6 of this report.

4.2.5.1.2 Findings

72. I am content with the proposal for the DAG to be manually started under operator control and I am content with the method of manually connecting the DAG to the SC1 6.9 kV MV switchboards. I will assess the licensee's operating instructions for the DAG as part of my assessment of the detailed design.

73. I am content that the System Study Report adequately demonstrates the capability of the DAG to support the required SSCs.

4.2.5.2 Medium Voltage 6.9 kV Safety Class 3 Large Power Truck

4.2.5.2.1 Assessment

74. The Topic Report on SBO states that the LPT is to be available but not claimed under all Design Basis and Beyond Design Basis SBO events. The LPT provides a defence-in-depth countermeasure against a subset of all postulated Design Basis and Beyond Design Basis SBO events and simultaneous failure of actuation of the DAG.

75. The LPT is mobile and is intended to be manually connected to any one of the three SC1 switchboards. Use of the LPT is under operator control and I expect the licensee to develop operating instructions for its implementation. The LPT is connected to the SC1 MV switchboard via one of three pre-installed connection points located on the outside wall of the reactor building. A connection point is provided for each of the three MV SC1 switchboards.

4.2.5.2.2 Findings

76. I am content with the proposed design of the LPT as a defence-in-depth countermeasure to support plant safety systems.

77. I am content with the proposal for the LPT to be manually started under operator control and I am content with the arrangement of using plug in points for manual connection of the LPT to the SC1 6.9 kV MV switchboards. I will assess the licensee's operating instructions for the LPT as part of my assessment of the detailed design.

4.2.5.3 Low Voltage 420 V Safety Class 3 Small Power Truck

4.2.5.3.1 Assessment

78. The Topic Report on SBO states that the SPT is available but not claimed under all Design Basis and Beyond Design Basis SBO events. The SPT is provided to support C&I and HVAC systems in the MCR following the loss of EDGs and BBGs.

79. The SPT is mobile and is intended to be manually started and connected to one of two pre-installed connection points on the outside wall of the reactor building. Each connection point corresponds to a division of the SC1 LV board and provides supplies to the C&I and HVAC systems within the MCR. The sizing calculation for the SPT is detailed in the DAG Capacity Calculation Report (Ref. 16).

4.2.5.3.2 Findings

80. I consider that the SPT provides an adequate means of supporting the C&I and HVAC loads following loss of main and standby supplies within the MCR. I have assessed the methodology described for calculating the required sizing of the SPT and am content that this demonstrates that the SPT is adequately sized to perform its safety related duty.

4.2.6 Compliance with SAPs – AC System Architecture

4.2.6.1 Assessment

81. I have assessed the design of the electrical system and electrical equipment against the requirements of specific SAPs which have particular relevance to the electrical system. The specific SAPs are considered in the paragraphs below.

82. EDR.1 covers failure to safety which is addressed in the design of the electrical protection scheme. This provides a coordinated system to ensure that failure at a single point will not impact throughout the system. Important system loads are duplicated such that loss of a single supply will not result in loss of functions. There are three independent Safety Class 1 AC divisions, each supported by an EDG in the event of the loss of the external power supply. There are four independent SC1 DC divisions each with a battery capable of supporting the required loads for 8 hours. I consider that this argument satisfies SAP EDR.1 for the EPS and my assessment of the electrical equipment

83. EDR.2 covers redundancy, diversity and segregation. The electrical structure separates the Safety Class 1 AC system into three divisions each supplied from a 6.9 kV switchboard. Each Division is backed up by an EDG which is started automatically on loss of voltage on the switchboards. The divisional segregation provides protection in the event of an internal hazard so that other divisions are not affected. There are four SC1 DC divisions each supported by a battery capable of providing 8 hour uninterruptible supplies. I consider that this argument satisfies EDR.2

84. EDR.3 covers common cause failure. The resilience to this has been demonstrated in studies undertaken to assess external sources of disturbances such as grid failures, system disturbances and lightning. The resilience to common cause failure is presented in the diversity strategy document which is assessed in Section 4.5 of this report. Resilience to CCF due to hazards is assessed in the Internal Hazards Step 4 Assessment Report (Ref. 95) and External Hazard Step 4 Assessment Report (Ref. 92). I consider that this argument satisfies the requirements of EDR.3.

85. ERL.2 covers measures to achieve reliability. Hitachi-GE has demonstrated compliance by the implementation of a combination of redundant and diverse sub-systems and equipment. The basic architecture is three Divisions of redundant equipment for AC electrical power supplies to the Safety Class 1 SSCs. The diverse B/B Safety Class 2 system supports diverse SSCs. I consider that the measures adopted are consistent with relevant good practice and satisfy the requirements of ERL.2.

86. ERL.4 covers margins of conservatism. Hitachi-GE has demonstrated comprehensive calculation methodologies to assess the capability of the system and assess margins. The provision of three independent Divisions of Safety Class 1 AC power each supported by an EDG and the provision of four independent Safety Class 1 battery powered divisions support the conservatism in the design. I consider that this argument satisfies ERL.4.

87. ESS.21 covers reliability. The requirements of this SAP have been met through the provision of a robust electrical system architecture that can withstand a very wide range of challenging single, and from the perspective of the PSA, multiple faults while still being able to perform its safety function. This is further supported by the use of nuclear qualified equipment and the avoidance of complexity in the design. I consider that this argument satisfies ESS.21.

88. EKP.3 covers defence in depth. The EPS design incorporates defence-in-depth through the provision of diverse and independent sources of electrical power. The preferred source of electrical power is from the national grid system and main turbine generator. Independent and redundant EDGs are provided as the first line of defence following the loss of the preferred source of supply. If the EDGs are unavailable, the B/B system, supplied by independent and diverse BBGs, supports a diverse set of SSCs capable of bringing the reactor to a safe state. Further defence-in-depth is provided by the DAG, LPT and SPT. I consider that these arrangements satisfy EKP.3.

4.2.6.2 Findings

89. My assessment of the above sub-set of SAPs with particular relevance to electrical systems concludes that the design of the EPS satisfies the requirements of these SAPs.

4.2.7 Conclusion

90. I consider that the basic architecture of the AC electrical system meets the requirements of relevant good practice for a new nuclear facility as presented in IAEA SSG-34, Design of Electrical Power Systems for Nuclear Power Plants.

91. The capacity of the EPS to meet load requirements, including the rating of the EDGs, is assessed in Section 4.6 of this report.

92. I note that the requirement for provision of fuel oil supplies for 168 hours of EDG operation is substantiated in the DG Fuel Oil System Design Description (Ref. 17). I expect the licensee follow a similar approach to substantiate fuel supplies for the other generators during detailed design.

93. I consider that the proposed design of EDGs and BBGs provides a robust and diverse on-site generation capability for a 168 hour period. This meets my expectation for addressing Fukushima Interim Recommendation IR-18 as described in Japanese earthquake and tsunami: Implications for the UK Nuclear Industry (Ref.96).

94. I consider the proposed high-level on-site AC system architecture supports the claims made against it for maintaining the reactor in a safe state under a wide range of operating and fault conditions.

95. In conclusion I consider that the architecture provides a robust system that is capable of supporting the claims, arguments and evidence made in the BSC.

4.3 Power Supplies to C&I Systems

4.3.1 C&I Supplies DC System Architecture

96. The DC system is described in the document DC System Design Description (Ref. 85) and the architecture of the systems is shown in Figure 2.

97. The DC power systems is to consist of four groups as follows:

- SC1 115V DC power supply system, consisting of four divisions and two standby battery chargers, all fed from SC1 420 V Motor Control Centres (MCCs).
- Control Building (C/B) SC2 115V DC power supply system, consisting of two 100% rated systems fed from the SC1 420 V MCCs.

- B/B SC2 115V DC power supply system, consisting of two divisions and one standby battery charger, all fed from SC2 690 V MCCs.
- Non Safety Class 230V DC power supply system, consisting of a single system with supplies from the SC1 420 V MCCs.

98. The SC1, C/B SC2 and non-safety class DC power supply systems are to be supplied by SC1 Motor Control Centres (MCC) during normal operation. Following a loss of AC input power, the DC power supply systems are supplied from the dedicated system batteries.

99. The B/B SC2 system is normally supplied by the B/B SC2 MCCs during normal operation. Following a loss of AC input power, the DC power supply systems are supplied from the dedicated system batteries for a period of 1 hour.

100. The adequacy of the system ratings has been presented in the System Study Report and assessed in Section 4.6 of this report.

4.3.1.1 Assessment

4.3.1.1.1 Safety Class 1 115V DC Power Supply System

101. The SC1 115 V DC system supplies is intended to supply power for 8 hours to SC1 SSCs that provide Category A functions in the event of a loss of normal supplies to the SC1 MCCs. The SC1 system design is arranged in four independent and redundant divisions with each division fully rated to support the required loads so that the loss of one division will not compromise the ability of the SC1 DC system to perform its safety related duty.

102. The 8 hour battery rating is commensurate with the Safety Functional Claim 2-1 in the BSC that states that the RCIC is supported for 8 hours during a SBO (LOOP and loss of EDGs) event. However if the EDGs are available they will auto start and supply the SC1 SSCs including the battery chargers.

103. In a Beyond Design Basis Event (BDBE), Division 1 of the SC1 115 V DC system is capable of supporting the Reactor Core Isolation Cooling (RCIC) for 24 hours following a SBO event as described in the Topic Report on SBO.

104. Each division consists of a battery charger supplied by one of the three EDG backed SC1 switchboards, a battery and DC distribution panels. There are two SC3 standby chargers and each charger can be connected to one of two divisions. Interlocks are provided to prevent the simultaneous connection of both divisions. The standby chargers are provided to provide an alternative means of charging during maintenance outages.

4.3.1.1.2 Control Building Safety Class 2 115V DC Power Supply System

105. The C/B SC2 115 V DC system is intended to supply power for ten minutes to a limited set of SC2 C&I SSCs providing Category B functions associated with the plant control system, as defined in Safety Property Claim 1.2 of the BSC.

106. The C/B SC2 system is arranged into two 100% rated groups. Each group consists of a battery charger supplied by an EDG backed SC1 MCC, a battery and DC distribution panels. An interconnector between groups is provided to maintain supplies to both distribution panels when one charger is removed for maintenance.

4.3.1.1.3 Non-Safety Class 230V DC Power Supply System

107. The Non-Safety Class (NSC) 230 V DC system supplies power to non-safety related equipment for one hour. The NSC system is comprised of a single charger and battery with two manually selected supplies available for the charger, both from SC1

EDG backed switchboards. The isolation device between the NSC charger and SC1 switchboard is designated as a SC1 device.

4.3.1.1.4 B/B Class 2 115V DC Power Supply System

108. The B/B SC2 system supplies power to SC2 equipment performing Category A functions for one hour. The system is designed to be independent and diverse from the Category A1 functions as presented in the Diversity Strategy Report. The B/B system is arranged as two independent and redundant divisions with each division fully rated to support the required loads so that the loss of a division will not compromise the ability of the SC2 system to perform its safety related duty.

109. Each SC2 division consists of a battery charger supplied by one of the two BBG backed SC2 switchboards, a battery and DC distribution panels. There is one common standby charger available to provide an alternative means of charging one battery during maintenance outages.

4.3.1.2 Findings

110. I consider that the provision of four redundant and independent SC1 divisions provides a robust architecture such that the loss of one division will not compromise the ability of the SC1 system to perform its safety related duty.

111. I consider that the provision of standby chargers for the SC1 system and an interconnector between groups for the C/B SC2 system conforms to relevant good practice by allowing batteries to remain on charge during maintenance of chargers or upstream equipment.

112. I am content with the proposal for appropriately rated isolators between the SC1 switchboard and the non-safety class 230 V DC system to provide adequate protection to prevent faults on the lower classified system compromising the ability of the SC1 system to perform its safety related duty.

113. I am content that the B/B Safety Class 2 DC system provides a diverse means of supporting SSCs that are capable of bringing the UK ABWR to a safe state. I have assessed the diversity requirements in Section 4.5 and I conclude that this arrangement provides adequate physical and spatial separation as well as diversity to reduce the potential for common cause failure.

4.3.1.3 Conclusion

114. I consider that Hitachi-GE's proposed basic configuration of the DC electrical system meets the requirements of relevant good practice for a new nuclear facility as presented in IAEA SSG-34, Design of Electrical Power Systems for Nuclear Power Plants and is robust and suitable for maintaining supplies to SSCs.

4.3.2 C&I Supplies AC System Architecture

115. The design of the AC C&I power systems are described in documents AC C&I SDD (Ref. 18) and UPS AC Power Supply SDD (Ref. 86). The system architecture is shown in Figure 2 and the Single Line Diagram of Power Supply System for Control and Instrumentation System (Ref. 19).

116. The AC C&I power systems is to provide 115V single phase or 240 V three phase AC supplies and consist of interruptible and uninterruptible supplies, as required, supporting C&I systems.

117. The uninterruptible AC Power Supply Systems consist of the following:

- SC1 115 V uninterruptible AC power supply.

- SC3 240 V uninterruptible AC power supply.

118. The uninterruptible AC power supply systems are to be directly supplied from the EDG backed SC1 MCCs. Both uninterruptible systems contain batteries in order to support loads that cannot tolerate a break in supplies.

119. The Safety Class 1 DC Battery will be sized to support the UPS for at least 1 hour under LOOP conditions as detailed in the Battery and Charger Capacity Calculation Report (Ref. 99).

120. The SC3 system battery is to be sized to support loads for one hour in order to support the safety claims made on this system.

121. The interruptible AC Power Supply Systems are to consist of the following:

- SC1 interruptible AC power supply.
- SC2 interruptible AC power supply.
- SC3 interruptible AC power supply.
- B/B SC2 Interruptible AC power supply.

122. The interruptible AC power supply systems, excluding the B/B SC2 system, are to be supplied by the EDG backed SC1 420 V MCCs via power transformers. The B/B interruptible AC power supply system is supplied by the BBG backed SC2 690 V MCCs via power transformers. Following a loss of supplies to the AC switchboards, power supplies from all interruptible AC power supply systems are to be interrupted until the relevant generator is available.

4.3.2.1 Uninterruptible AC Power Supply Systems

4.3.2.1.1 Assessment

123. The SC1 UPS is to provide 115 V AC no break supplies to the SC1 C&I power systems. The SC1 UPS system is to consist of four independent divisions containing a rectifier and a dedicated UPS with integrated bypass switch. The primary supply to each UPS is to be via a dedicated rectifier fed from the EDG supported SC1 MCCs. A secondary supply from the SC1 115 V DC system is to be provided to support the UPS loads for one hour following a loss of the normal supplies.

124. Each UPS is to be arranged so that it can be bypassed to support the required SSCs during maintenance or plant failure conditions. In this condition the SC1 SSCs are to be powered directly by an EDG supported switchboard through a dedicated standby transformer.

125. The SC3 UPS is to provide 240 V AC no break supplies to the SC3 process computers. The SC3 UPS is to be split into two systems with each system containing a rectifier, a dedicated battery and a dedicated UPS with integrated bypass switch. System A is to provide the normal supply to the computers and System B is to provide backup supplies. Both System A and System B are to be supplied with electrical power from diverse divisions.

126. The primary supply to each SC3 UPS is to be provided via the EDG backed SC1 MCCs. The dedicated UPS battery is to support the operation of the process computers for one hour following a loss of normal supplies. This meets the requirements defined in the Uninterruptible AC Power Supply System System Design Description (Ref. 86).

127. Both SC3 UPSs are to be arranged so that they can be bypassed to support the process computers during UPS maintenance or UPS fault conditions. In this

condition the 240 V three phase supply is to be provided by a reactor building MCC via a dedicated standby transformer.

4.3.2.1.2 Findings

128. I consider that the proposed architecture design of the SC1 and SC3 UPS systems complies with relevant good practice for the required safety classification of the systems supported. The SC1 UPS divisions are to be independent so that a fault on a single division does not impact the capability of the remaining divisions to perform their safety functions. The SC3 UPS is to include two systems, both capable of supporting the process computers, providing a level of redundancy suitable for SC3 systems.

129. I am content with the provision of bypass systems to allow for the continued operation of the loads when maintenance of upstream components is required.

4.3.2.2 Interruptible AC Power Supply Systems

4.3.2.2.1 Assessment

130. The interruptible AC Power Supplies Systems are to support C&I equipment SSCs that can tolerate a loss of power supply (short break) in the event of a loss of normal supplies before the start-up of on-site generators.

131. There are to be three SC1 Interruptible AC Power Supplies Systems; one for each division of SC1 AC power supply system. Each system is directly supplied from the EDG backed SC1 MCCs during normal operation. Each system is to have a secondary supply from a SC3 MCC of a different system to ensure continued supply during maintenance periods.

132. The SC2 AC Interruptible AC Power Supplies Systems is to consist of two systems; one for the reactor building and one for the turbine building. Each system is to have the capability to receive supplies from two 420 V MCC systems of different divisions by means of a manual changeover.

133. The SC3 Interruptible AC Power Supplies Systems is to be a single system normally supplied from a 420 V SC 1 MCC. The system is intended to be supplied from a Rad Waste Building 420 V MCC in case of maintenance on the SC1 power supply system.

134. The B/B SC2 AC Interruptible AC Power Supplies Systems is designed to be independent and diverse from the Category A1 functions as presented in the Diversity Strategy Report. It is to consist of two systems; one for each of the two B/B SC2 AC power systems. Each system is to be supplied by a BBG backed MCC and each system provides single phase 115 V AC power to B/B C&I systems. This architecture design allows for both systems to be supplied from a common BBG backed MCC in case of maintenance of the normal supply MCC.

4.3.2.2.2 Findings

135. I consider that the proposed architecture design of the AC Interruptible AC Power Supplies Systems meets with relevant good practice for loads that tolerate a short loss of supply. Each system's architecture is designed based on the safety classification of the SSCs the system supports and therefore provides a suitably robust system that should enable the SSC to perform its safety related duty.

136. The B/B SC2 AC system provides a diverse means of supporting SSCs that are capable of maintaining the UK ABWR in a safe state. I have assessed the diversity requirements in Section 4.5 of this report and I conclude that this arrangement can

provide adequate physical and spatial separation as well as diversity to reduce the potential for common cause failure.

137. Based on the findings above I consider that the architecture design of the AC C&I electrical system meets the requirements of relevant good practice for a new nuclear facility as presented in IAEA SSG-34, Design of Electrical Power Systems for Nuclear Power Plants. I therefore consider the system to be robust and suitable for maintaining supplies to SSCs.

4.4 Pre-Construction Safety Report (PCSR)

138. The safety case for the UK ABWR EPS is presented in Chapter 15 of the PCSR. Hitachi-GE states that Chapter 15 provides an overview of the design and safety requirements for the UK ABWR EPS and defines its role. The role of the EPS as stated in Chapter 15 is to provide electrical power to key SSCs to support normal operation of the plant and protect the plant from undesirable consequences which may arise in fault and hazard conditions.

139. Hitachi-GE states that the PCSR Chapter 15, the Basis of Safety Case (BSC) and associated topic reports form the core of the safety case for the UK ABWR EPS. These documents provide the descriptions, safety claims and arguments for the adequacy of the EPS against criteria defined by Design Basis Analysis (DBA), Beyond Design Basis Analysis (BDBA), Severe Accident Analysis, Probabilistic Safety Analysis (PSA) and international standards.

140. The PCSR focuses on the description of claims, arguments and evidence on the safety functions and safety properties of the EPS. The chapter also provides an outline description of the EPS architecture and describes its major elements.

4.4.1 PCSR Chapter 15

4.4.1.1 Assessment

141. The EPS is defined as a supporting system designed to meet the requirements of the associated SSCs which deliver safety functions. The claims associated with each SSC are defined in the PCSR.

142. The claims for the electrical system take the form of a set of Safety Functional Claims (SFC) derived from High Level Safety Functions (HLSF) and Safety Property Claims (SPC) which are derived from the Hitachi-GE Nuclear Safety and Environmental Design Principles (NSEDP) (Ref. 20). The claims arguments evidence structure is presented in the supporting electrical BSC document.

143. The safety claims are structured with a top level claim supported by five SFCs and eight SPCs.

144. The top level claim states the following:

- The UK ABWR EPS supports the SSCs providing the safety functions in the DBA, BDBA, Severe Accident Analysis (SAA) and PSA.

145. The SFCs are derived from HLSFs, each of which is derived from one of five UK ABWR Fundamental Safety Functions (FSF) as set out in Chapter 5 of the PCSR.

146. The five high-level SFCs are:

- EPS SFC 1 - The EPS supports SSCs providing HLSF associated with FSF 1: Control of Reactivity.

- EPS SFC 2 - The EPS supports SSCs providing HLSF associated with FSF 2: Fuel Cooling.
- EPS SFC 3 - The EPS supports SSCs providing HLSF associated with FSF 3: Long Term Heat Removal.
- EPS SFC 4 - The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.
- EPS SFC 5 - The EPS supports SSCs providing HLSF associated with FSF 5: Others

147. The SPCs are derived from the NSEDPs which are a set of high-level principles developed to provide guidance on relevant good practice for the design, operation and through life support of the UK ABWR SSCs.

148. The high-level SPCs are:

- EPS SPC 1 - Classification, independence, redundancy and single failure criterion requirements placed on the SSCs is applied to the design of the EPS and associated support systems including C&I, HVAC and cooling systems.
- EPS SPC 2 - The EPS will support the safety functions with the required integrity for frequent faults, infrequent faults, beyond design basis faults and severe accidents.
- EPS SPC 3 - The EPS is designed to protect against CCF.
- EPS SPC 4 - The EPS will be designed to withstand internal hazards.
- EPS SPC 5 - The EPS will be designed to withstand external hazards.
- EPS SPC 6 - The EPS will continue to meet its functional safety requirements throughout its operational life.
- EPS SPC 7 - EPS SSCs are designed to achieve adequate performance in accordance with the safety requirements including reliability, response time and ratings.
- EPS SPC 8 - The design, development and implementation of EPS SSCs complies with standards and good practice set by their classification and the EPS SSC’s role in the overall power system architecture.

149. The PCSR states that the EPS provides a supporting function and that it is classified in accordance with the importance to safety of the systems and components it supports. This is significant as each part of the EPS will only be classified in accordance with the systems being supported and classifications will not be applied to the EPS unless this is required by the supported safety function.

150. The PCSR presents considerations of common cause failure with reference to the Diversity Strategy Report. My assessment of the provisions to protect against CCF as defined in the Diversity Strategy Report is presented in Section 4.5.

151. The PCSR defines the SSCs which are required to provide support to the EPS in meeting its safety claims. These SSCs are the C&I system, HVAC system and cooling water systems and the role of each is defined in the PCSR.

152. The PCSR provides a high-level description of the electrical system architecture which identifies principal features of the EPS in supporting safety functions.

153. The PCSR contains a section on Quality Assurance and Management systems referring to the Codes and Standards used for the EPS defined in Table 5.8-6 of Chapter 5. This table refers to the use of IEC Standards but the list is limited, does not cover all equipment and refers to out of date standards. I will expect the licensee to fully define applicable standards during detailed design.

154. The PCSR defines the principles for the use of smart devices in the electrical system and references the procedures for application and qualification in PCSR Chapter 14 (Ref. 21) covering C&I systems. A very strong recommendation is made that for diversity and security reasons the B/B Class 2 EPS should contain only hard wired technology. My assessment of the Hitachi-GE approach to the use of smart devices is described more fully in Section 4.20 of this report.

155. The PCSR describes the assumptions, limits and conditions for operation of the EPS with reference to the general principles in PCSR Chapter 4 (Ref. 22) and the Generic Technical Specifications (Ref. 23). The Generic Technical Specifications define Limits and Conditions for Operation (LCO) for the EPS to operate within safety limits and corrective actions to be followed when the LCOs are not met. My assessment of the implementation of the LCOs is also considered in the Basis of Safety Case for electrical systems and Section 4.7 of this report which assesses the approach to maintaining the plant in support of safe operation.

156. The PCSR provides a high-level overview of the application of the ALARP principle to the EPS and how this topic contributes to the overall UK ABWR ALARP argument for the UK ABWR. The approach to undertaking ALARP assessment for the EPS is defined by Hitachi-GE as consisting of the following steps:

- Establishing the role of the EPS in controlling risks to safety from the EPS.
- Undertaking a gap analysis of the reference J-ABWR EPS design in International and UK relevant good practice, regulatory expectations and NSEDPs.
- Undertaking an options analysis for closing gaps.
- Selecting and implementing the optimal ALARP solution.

4.4.1.2 Findings

157. I consider that Hitachi-GE has clearly defined the role of the EPS in supporting plant safety functions in the PCSR by defining the SFCs and SPCs based on the claims made for the safety functions supported by the electrical system. The PCSR defines the high-level principles and claims which are developed into more detailed sub-claims with supporting arguments and evidence in the electrical BSC. This provides a consistent reference trail to show the role of the EPS in supporting the plant safety systems. The electrical BSC provides detailed arguments and evidence to support the high-level safety case defined in the PCSR.

158. I am content with the approach adopted by Hitachi-GE in classifying the EPS in accordance with the importance to safety of the systems and components it supports as this defines a clear approach to EPS classification consistent with overall plant safety claims.

159. I am content that the PCSR describes the structure of the EPS and the main features which support plant safety. The high-level provisions which support safety are described in the PCSR with more detailed descriptions in support documents such as the diversity strategy, generic technical specifications and NSEDPs.

160. I have noted that the Codes and Standards for the electrical system in Chapter 5 Table 5.8-6 are not comprehensive and not all referenced standards are current. I will assess the licensees response to this expectation during detailed design.

161. Overall, I am content with the structure and details of the electrical Safety Case presented in the PCSR and consider that it presents a structured approach to substantiating the safety features of the EPS in supporting the plant safety functions. I expect that the safety case will be developed further during detailed design based on the GDA presentation.

4.4.2 Basis of Safety Case

4.4.2.1 Assessment

162. The electrical BSC presents the detailed safety claims on the EPS with supporting arguments and evidence. These are derived from the high-level SFCs and SPCs defined in the PCSR and are presented as part of a consistent referencing system for the safety claims of the UK ABWR.

163. Each detailed sub claim is provided with arguments to substantiate the safety claim and to justify the claims on the EPS in supporting the UK ABWR safety systems. Evidence is provided to support the arguments by referencing the design documents which substantiate the arguments supporting each claim. This evidence is provided in design documentation submitted to ONR for assessment during the GDA process.

164. I have carried out a sample assessment of the evidence provided to show compliance with plant safety claims. The evidence is derived from various document sources which have been submitted by Hitachi-GE during the GDA process. These sources include drawings, specifications, system study reports and SDDs. Documents include generic design material from the Japanese reference design and design documents developed for the GDA process.

165. In some instances evidence which is required to substantiate a safety claim is not available for GDA as it will only be developed during detailed design of the UK ABWR. The evidence to support these claims has been provided during GDA by evidence based on generic design data such as from generator or motor characteristics and from future work and assumptions which are presented in the BSC. This future work defines documentation to be developed by the licensee as part of detailed design activities which will be required to provide full evidence to support the safety claim.

4.4.2.2 Findings

166. I have conducted a sample assessment of the claims made on the EPS with the objective of verifying that the claims provide adequate substantiation of its role in supporting the plant safety systems. I find that there is a cross discipline system that establishes safety claims on the supporting EPS based on the plant claims as defined from the HLSFs and NSEDPs. I consider that the safety claims on the EPS are appropriate to demonstrate the support to the safety systems from the EPS. I will expect the licensee to develop the safety case for the detailed plant design based on these generic safety claims.

167. I am content that the evidence provided demonstrates compliance with the plant safety case claims.

168. I have conducted a sample assessment of the arguments presented to support the safety claims. I consider that there are effective arguments which provide a structured and coherent presentation of the approach to providing substantiation of the safety claims.

169. I have noted that there are some ambiguous statements in the electrical BSC where it is stated that supplies are derived from SC3 switchboards via SC1 switchboards and that the supported loads are consequently supported by the EDGs. When a system load is connected to a SC1 switchboard then it is connected to and fed from the Class 1 switchboard and not the upstream SC3 switchboard and I expect it to be classified accordingly. If the load is supporting a SSC of a lower classification then isolation should be provided to protect the SC1 system. I expect the licensee to adopt a consistent approach to describing the classification of the load based on the classification of the switchboard suppling that load.

170. Where evidence will only be available as part of detailed design then assumptions regarding future work by the licensee are presented to demonstrate the approach to developing evidence which substantiates the claims and arguments presented in the PCSR. I consider that this adequately demonstrates the approach to be taken by the licensee during detailed design to provide evidence to support the claims made by Hitachi-GE in the GDA submissions.

171. I have noted that there are discrepancies in the BSC concerning claims on the role of the DAG. The DAG is provided as a defence-in-depth measure to support the RHR and supporting systems in the event of loss of main and standby power supplies. However, there are claims in the electrical BSC that the DAG supports systems such as lighting and communications which are not derived from the overall plant safety claims. It is an important requirement for the electrical safety case to be presented based on plant safety claims so I have raised the following assessment finding:

AF-ABWR-EE-01: *ONR's GDA Step 4 assessment has identified some discrepancies and ambiguities amongst the claims made in the electrical engineering basis of safety case report on the diverse additional generator (DAG). It is therefore difficult to fully determine all the contributions it makes to nuclear safety. The licensee shall update the UK ABWR safety case so that role of the DAG is clearly established.*

4.4.3 Conclusion

172. With the exception of the important issue concerning the claims on the DAG, I am content with the presentation of the safety case for the EPS based on Chapter 15 of the PCSR and the electrical BSC which provides detailed claims arguments and evidence to support the high-level claims in the PCSR. I consider that these documents adequately present a substantiation of the electrical safety case for the UK ABWR for GDA purposes.

4.5 Diversity Strategy

173. I have assessed the provision of diversity in the design of the plant electrical systems as presented in the Hitachi-GE Diversity Strategy Report (Ref. 14). This document supports the safety case for the UK ABWR by providing evidence to support claims of diversity made in the electrical BSC. These safety claims are derived from fault schedule claims against frequent faults and potential Common Cause Failures (CCF) which require evidence to show that the power supplies to the diverse safety systems are also diverse.

4.5.1 Assessment

174. Hitachi-GE has defined the diversity strategy based on the diversity between the first line SC1 provision and second line SC2 provision. This strategy is applied to each part of the EPS and to supporting systems consisting of HVAC, C&I and generator prime movers.

175. Hitachi-GE has identified the main safety functions which require protection against frequent faults and potential CCF as:

- Emergency core cooling
- Reactor shut down
- Long term heat removal

176. For each of these systems diversity is required between the power supplies for the SC1 primary provision and the SC2 diverse provision. The diversity provisions are applied to power supplies for main functions such as pumps and also for supporting systems such as valves, HVAC and C&I power supplies.

177. Hitachi-GE has defined the fundamental principles adopted to achieve diversity as follows:

- Causes of CCF (same technology, same product etc.) should be eliminated so far as is reasonably practicable.
- Diverse technology and design shall be applied so far as is reasonably practicable. The use of different technology and design shall be given the first priority in achieving diversity.
- The consideration for diversity is not only applied to the main electrical power supply equipment such as circuit breakers and generators but also to the total electrical power supply systems including the control system and electrical protection system.

178. Hitachi-GE has described the approach to achieving diversity for each of the main safety functions taking account of the fundamental principles defined in the diversity strategy report. This is based on the fundamental principle of providing diversity between the SC1 systems and the B/B SC2 systems. The detailed proposals for each system are tabulated in the diversity strategy document. The main design features defined to achieve diversity are:

- Different voltage levels
- Different circuit breaker technologies
- Different battery technologies for DC systems
- Diversity between analogue and digital protection relays
- Different generator technologies

179. A particular diversity provision claimed is that the B/B Class 2 systems will use hard wired technology throughout with no dependence on smart devices for the continuity of power supplies. This is intended to provide diversity with the Class 1 systems in providing a diverse power source with no dependence on smart devices.

180. The diversity strategy report has considered the impact on electrical system diversity from other disciplines which potentially impact on the continuity of electrical supplies. The systems considered are Mechanical systems, C&I systems, HVAC and cooling water systems. The provisions within these disciplines to support electrical systems are fully described to provide a comprehensive demonstration of the diversity provisions for the electrical power supplies.

181. The diversity strategy report describes the diversity provisions for supporting equipment such as motors, valves, contactors and fuses. These provisions define the

basis for detail design of the UK ABWR electrical system incorporating appropriate diversity provisions to support the safety case.

4.5.2 Findings

182. The diversity strategy describes important provisions which are required to provide a diverse design for the UK ABWR EPS. These provisions are required to demonstrate resilience of the EPS to CCF. I consider that the approach described provides substantive evidence to support safety claims made in the electrical BSC and thus demonstrates the effective role of the EPS design in supporting plant safety systems. I am content that implementation of the design provisions described in the diversity strategy report will support the application of diversity in the design of the UK ABWR.

183. It is important that the provisions described are fully implemented during detail design as compliance with a number of safety claims will be achieved by detail design development in accordance with the diversity strategy. During detail design I will assess the implementation of the strategy by verification of the detail evidence which supports safety case claims of diversity in the design of the EPS.

184. A key feature of the diversity strategy is the demonstration of compliance with the provision of a B/B SC2 system with no dependence on smart devices. I consider that there are significant challenges in the implementation of this approach due to the availability of suitable equipment from suppliers and potential long-term obsolescence issues of equipment which does not include smart devices. I consider that it is important to verify the implementation of this approach at an early stage of detail design by identifying suitable equipment or determining appropriate mitigation strategies where this cannot be achieved. Therefore I have raised the following assessment finding:

AF-ABWR-EE-02: *A major claim in Hitachi-GE's GDA safety case for the UK ABWR is that its Backup Building (B/B) Safety Class 2 electrical systems contain no 'smart' devices, such that the electrical power supply system (EPS) remains effective even if the Safety Class 1 electrical systems are affected by a common cause failure (CCF). This claim could be a challenge to meet due to the availability of suitable equipment from suppliers and potential long-term obsolescence issues. Therefore, the licensee shall demonstrate that the B/B Safety Class 2 electrical equipment included in the final design do not utilise 'smart' devices or provide appropriate mitigations where it is not possible or appropriate to achieve this.*

185. In conclusion, I am content with the Hitachi-GE approach to the provision of diversity as described in the diversity strategy report subject to the resolution of the Assessment Finding regarding provision of a B/B SC2 system which does not use smart devices.

4.6 System Studies

186. Hitachi-GE has conducted a set of comprehensive studies to assess the static and transient performance of the EPS in a range of operating conditions. These studies have been conducted in accordance with International Electrotechnical Commission (IEC) Standard IEC 62855 (Ref. 24). The studies were performed using ETAP and ATP-EMTP software packages and to construct a model of the EPS.

187. The studies to be performed to analyse the EPS were identified as the following:

- Phase 1 – Off Site AC Studies
- Phase 2 – On Site AC Studies
- Phase 3 – Off site and On site transient studies

- Phase 4 – DC System Studies
- Phase 5 – Harmonic Studies
- Phase 6 – Miscellaneous Studies

188. For each of these study areas a Study Brief was prepared which defined the studies to be performed and the acceptance criteria against which the study results were to be evaluated. A Master Data and Assumption List (MDAL) (Ref. 25) was produced which defined the EPS system parameters to be used for the studies.

189. In order to verify the results from the Hitachi-GE studies for Phases 1-4 ONR utilised a Technical Support Contractor (TSC) to undertake a set of confirmatory studies. These studies were performed using DIgSILENT Power Factory 16.0 software in order to provide a diverse assessment to the Hitachi-GE studies.

190. Hitachi-GE submitted to ONR a report of the findings of each phase together with detailed study results. The results from the confirmatory studies were compared with the Hitachi-GE studies in order to highlight any discrepancies in the results. This identified a number of design and modelling issues which were resolved in discussions between ONR and Hitachi-GE. Following resolution of the issues the Hitachi-GE study reports were updated as necessary to take account of resultant design changes, changes to modelling methodology and changes to modelling input data.

4.6.1 Phase 1 Studies

4.6.1.1 Assessment

191. The Phase 1 studies cover the modelling of off-site power transients from the 400 kV grid network. As all grid connections are site specific the studies have been based on the Wylfa grid connections in order to demonstrate the methodology and the resilience of the UK ABWR EPS to grid transients.

192. The studies considered the following:

- Three Phase and Single Phase fault levels at the 400 kV grid connection points
- Critical clearing times at the 400 kV grid connection points
- The performance of the UK ABWR generator to 400 kV grid faults
- The performance of the UK ABWR generator system following Automatic Voltage Regulator (AVR) failure
- The performance of the UK ABWR generator under grid transients

193. The study results are presented in the Electrical Modelling Phase 1 Study Report (Ref. 26), which concludes that the study results generally meet the acceptance criteria defined in the Electrical Modelling Phase 1 Study Brief (Ref.27) in relation to tolerance of the EPS to grid faults. The study results state that Hitachi-GE considers that the deviations from the defined assessment criteria are not significant and ONR support this view. Hitachi-GE has identified further work to be carried out during detail design based on detailed generator parameters and actual grid connection data.

194. Critical fault clearance times have been identified. Hitachi-GE has identified the requirement for generator protection settings to be determined during detail design to ensure the main generator is adequately protected.

195. Calculated system fault levels do not present any challenges to the design of the EPS for UK ABWR.

196. The Phase 1 studies do not fully consider all operating parameters defined in the UK Grid Code particularly for fault ride through requirements. This is due to Hitachi-GE not having completed its assessment of the grid code when the Phase 1 studies were undertaken. Further studies have now been undertaken as part of the grid code compliance demonstration. ONR assessment of these studies is covered in Section 4.8 of this report.

4.6.1.2 Findings

197. ONR has conducted confirmatory studies (Ref. 87) to compare the Hitachi-GE results which conclude the following:

- The load flows and fault level studies broadly align with the claims made by Hitachi-GE with some minor outstanding issues regarding the system fault level used and the load factors implemented on the Power Centre loads on the 6.9 kV EPS switchboards.
- A number of issues were identified concerning the approach to modelling of the grid and the parameters used. These were discussed with Hitachi-GE and agreement reached on achieving a consistent modelling approach.
- Further investigation is required during detail design into the transient analyses to confirm whether the EPS is resilient and that the ABWR generator response ensures that it does not suffer undue stresses. A full assessment of this is covered in Section 4.8 (Grid Code Compliance) of this report.

198. In conclusion, I consider that the Phase 1 study results adequately demonstrate for GDA purposes the resilience of the UK ABWR EPS to grid transients. This demonstration is supplemented by the assessment of grid code compliance covered in Section 4.8 of this report.

4.6.2 Phase 2 Studies

199. The Phase 2 studies model the on-site EPS and are presented in the Electrical Modelling Phase 2 Study Report (Ref.10). The studies consist of the following:

- Load Flow studies to determine the steady state voltage, current, active power, reactive power and power factor in the EPS.
- Transient fault studies to investigate the transient and steady state voltage and frequency of the on-site switchboards after a fault.
- Transient bus transfer studies to simulate the impact upon the AC power system of changeover from the ANT to the AST and determine whether there are any impacts on the integrity of the EPS.
- Transient motor starting and reacceleration studies to verify the capability of motors under the most onerous conditions of load and power flow.
- Transient load sequencer studies to verify that loads can be connected in a pre-determined sequence with no adverse impact on voltage and frequency and no tripping of protection systems.
- Short circuit studies to determine equipment rating requirements.

- Protection coordination studies to determine adequate selectivity for all available power sources and load centres.

4.6.2.1 Load Flow Studies

4.6.2.1.1 Assessment

200. The initial load flow studies conducted by Hitachi-GE identified inadequate margins in the thermal rating of the ANT and AST. Hitachi-GE implemented a design modification to increase the ratings of these transformers and the Phase 2 studies have been updated based on the revised design with increased transformer ratings.

201. Hitachi-GE has conducted a series of studies which consider the load flows in the EPS with supplies from ANTs, AST, EDGs, BBGs, DAG and LPT. These studies assess the capability of the EPS to supply loads in steady state conditions and the capability of generators to support system loads.

202. Hitachi-GE concludes that with the exception of the two minor points discussed below the load flow studies demonstrate compliance with the acceptance criteria defined in the Electrical Modelling Phase 2 Study Brief (Ref.29). Firstly, the Generator Transformer (GT) power flow exceeds 95% of its rating which is considered acceptable as the load flow is limited by generator capacity. Secondly, under conditions of maximum voltage and frequency the ANT power flow exceeds 95% of its capacity but this condition would be of a very limited duration so is not considered by Hitachi-GE to be of concern.

4.6.2.1.2. Findings

203. ONR has conducted confirmatory studies of the Hitachi-GE load flow results. The findings of these studies were discussed with Hitachi-GE and agreement reached on reconciliation of issues. Hitachi-GE studies were updated following agreement on these issues with ONR. The following points are noted from the study results:

    - For the scenarios examined, all diesel generators remain within their rated capacity when operating in isolated supply mode. However, the EDG on SC1 D Switchboard is near its active power limit with all loads assumed to be in service. Similarly, the LPT when connected to C Switchboard is near its active power limit. Other generators have lower loadings but there is not significant spare capacity. This can be partially mitigated by ensuring that loads are balanced across divisions but I consider that it is important that the licensee verifies the EDG capacity requirements by updating the studies during detail design to ensure that the EDGs have adequate capacity to support all allocated loads.

    - The load flow results of the main generator in isolated supply mode align with Hitachi-GE findings of a flow of over 95% but this is considered acceptable as the load is limited by the capacity of the main generator.

    - Discrepancies were found between the Hitachi-GE and ONR confirmatory studies in scenarios considering high grid frequency. I agree with Hitachi-GE that this is due to the application of different modelling assumptions so I do not consider this to be a concern.

    - All EPS transformers remain within 95% of their capacity across all analysed scenarios. The ANT and AST have the capability to tap change in order to maintain normal system voltages on the EPS if the grid is experiencing abnormal voltages.

- Low switchboard voltages are calculated on some 420 V Power Centre house loads that are fed by switchboard A2 although they remain within the acceptance criteria.

204. I am content with the Hitachi-GE explanation regarding the ANT loading under maximum voltage and frequency conditions as the condition will be of a very limited duration.

205. In conclusion, I consider that the Hitachi-GE load flow studies demonstrate that all equipment within the EPS is adequately rated to support defined plant loadings but I have concerns regarding the capacity margins particularly on the EDGs. Therefore I have raised the following assessment finding:

AF-ABWR-EE-03: *Hitachi-GE has only demonstrated limited capacity margins on key electrical safety systems, notably the Class 1 emergency diesel generators, during GDA. The licensee shall demonstrate that the final design has sufficient capacity margins to ensure that all required nuclear safety functions can be provided with a high degree of confidence, or modify the design appropriately.*

4.6.2.2 Transient Fault Studies

4.6.2.2.1 Assessment

206. Hitachi-GE has conducted studies of a wide range of scenarios considering the effects of three phase and single-phase electrical faults at different points on the EPS. The studies investigated a worst-case scenario of reaccelerating the largest motor on the system following clearance of an electrical fault by the electrical protection. The motors were analysed for their speed, power output and slip response to confirm the capability to withstand the fault and reaccelerate.

207. ONR’s confirmatory studies investigated the effects of clearance of a fault downstream of the SC3 switchboards which was not considered in the initial Hitachi-GE study. Following discussion with Hitachi-GE these studies have been added to the Hitachi-GE studies to complete the comprehensive study of fault scenarios in the Phase 2 report.

208. The results show a voltage dip of 25% experienced on the switchboards. This is within the tolerance identified in the acceptance criteria defined in the study brief and the studies show that the largest motor is able to recover following fault clearance.

4.6.2.2.2. Findings

209. The results of the confirmatory studies align with the Hitachi-GE results following completion of the additional studies considering a downstream fault. I am content that this demonstrates adequate resilience of the EPS to transient faults including the capability of the largest motors to reaccelerate.

4.6.2.3. Transient Bus Transfer Studies

4.6.2.3.1. Assessment

210. Hitachi-GE has conducted studies to assess the impact of a bus transfer from ANT supply to AST supply. This assesses the capability of the largest motor to reaccelerate following completion of the bus transfer.

211. ONR requested details of how the transfer time has been determined in order to confirm that the total transfer time assumed is realistic. Hitachi-GE provided these details in the study brief.

212. Hitachi-GE has concluded that the results confirm that all acceptance criteria have been met and that all motors remain in operation following a bus transfer.

4.6.2.3.2. Findings

213. I consider the results of the ONR confirmatory studies closely align with the Hitachi-GE results in confirming that acceptance criteria are met and that motors remain operational following a bus transfer.

214. The confirmatory studies also included a sensitivity study to investigate the resilience of the electrical system to an increased dead time in the transfer sequence from the 130ms assumed in the Hitachi-GE study. Dead times of 230ms and 500ms were studied. During each of these scenarios, the motors experience a drop in speed by up to 15%. The motors then recover to a new steady state condition within 3 s of the initial fault. The frequency of the grid and EPS drops 3% from 50 Hz during the transient and, as expected, it is not seen to recover to nominal during the simulation period. However the study shows that motors are able to recover with the increased dead time which demonstrates the resilience of the system to extended dead times.

215. I am content that the Hitachi-GE studies adequately demonstrate the resilience of the EPS to continue to support loads in the event of a bus transfer.

4.6.2.4 Transient Motor Starting and Reacceleration Studies

4.6.2.4.1 Assessment

216. Hitachi-GE motor starting transient studies investigate the effects on the switchboard voltage and operation of other motors on the EPS. The largest motor is started in each scenario studied as a worst case and the transient response is studied on the second largest motor when operating at full output.

217. Hitachi-GE has studied the starting of the Residual Heat Removal (RHR) pump on C Switchboard and the High Pressure Core Flooder (HPCF) motor on D Switchboard which are the largest motors on the 6.9 kV SC1 switchboards. Scenarios feeding from the grid through the ANT/AST and feeding from the EDG and the DAG with no grid supply available have been studied. The results show that motors are able to start whilst meeting the acceptance criteria for all supply configurations.

218. Hitachi-GE has studied starting the System of Specific Safety Facility (FLSS) pump which is the largest motor on the 690 V SC2 B/B switchboard. Scenarios feeding from the grid through the ANT/AST supply have been considered together with starting from the BBG with no grid supply available. The results show that the motor is able to start whilst meeting the acceptance criteria for all supply configurations.

4.6.2.4.2. Findings

219. I consider the confirmatory study results align with the Hitachi-GE studies and confirm that the EPS has the capacity to start all the motors on the system feeding from the grid supply, EDG, BBG and DAG, as appropriate. There is one discrepancy concerning the switchboard frequency where the Hitachi-GE results show a frequency oscillation when feeding from the EDG. The EDG generator governor used in the Hitachi-GE simulations is currently an assumption based on an IEEE model so is not fully representative of the actual governor. I will require the actual governor to be modelled in the site-specific studies carried out by the licensee during detailed design. I will assess the licensee response to this requirement during my assessment of the site-specific studies.

220. I am content that the motor starting studies demonstrate the capability for all EPS power supply configurations to start all relevant motors. I agree that the frequency oscillations identified in the Hitachi-GE study are a modelling issue which should be resolved using actual governor data during detail design.

4.6.2.5 Transient Load Sequencer Studies

4.6.2.5.1 Assessment

221. Hitachi-GE has conducted load sequencer studies to consider starting of motors in sequence assuming no prior system load. These have been considered for operating scenarios of loads being sequenced from the EDG and DAG. The studies show that all relevant motors can be started in sequence from EDG and DAG following a loss of normal supply.

222. The time intervals between starting sequences will require definition so as to allow adequate time for motors to fully accelerate between starting sequences. This will need to be fully defined by the licensee during the site specific studies.

223. Similar frequency oscillations are observed to those on the motor reacceleration studies. I consider this to be a modelling issue to be resolved during detailed design.

4.6.2.5.2 Findings

224. I consider the confirmatory studies align with the results of the Hitachi-GE studies with the exception of the frequency oscillations. I am content that the studies demonstrate the capability of starting all motors from EDG and DAG in a pre-determined sequence with no adverse impact on voltage and frequency and no tripping of protection relays.

4.6.2.6 Short Circuit Studies

4.6.2.6.1 Assessment

225. Short circuit and ground fault studies have been performed to calculate maximum short circuit fault currents on system switchboards for each system configuration. The studies calculated three phase and single phase currents together with the asymmetrical DC offset currents at the instant of the fault. The studies have been conducted in accordance with IEC 60909 (Ref. 30).

226. The assessment criteria fault levels are 63 kA for the 6.9 kV system and 50 kA for the 690 V and 420 V systems. The studies have been performed based on the following configurations:

- Supply from the grid via ANT and AST
- Supply from ANT with EDG in parallel for EDG routine testing
- Supply from EDG
- Supply from DAG and LPT
- Supply from ANT with BBG in parallel for BBG routine testing
- Supply from BBG

227. Following the completion of the ONR confirmatory studies the results were compared with the Hitachi-GE results and a number of discrepancies between the results identified. These were discussed with Hitachi-GE and a number of issues were resolved concerning credible operating configurations and modelling assumptions. The results were updated following resolution of the issues and this assessment is based on the updated results. The updated short circuit fault level calculations across the EPS are tabulated in Table 1.

228. The calculated DC offset currents on the 6.9 kV system show that the time constant of the current decay is generally in line with the assumptions in switchgear standard IEC 62271 (Ref. 31) and that the levels of the offset current can be met by commercially available switchgear.

4.6.2.6.2 Findings

229. I consider the Hitachi-GE study results align with the ONR confirmatory studies.

230. The 6.9 kV study results show that the assessment criterion of 63 kA is met except for the scenario of parallel operation of the AST and EDG during routine test running of the EDG. However, this is not considered to be a credible operating configuration as the EDG would not be tested when the plant is fed from the AST. I am, therefore, content that the results demonstrate that the 6.9 kV system rating of 63 kA is appropriate.

231. I am content with the DC offset current calculated which will need to be specified in the switchgear purchase specification but do not consider that this presents a challenge to the EPS design.

232. I am content that the 690 V study results meet the assessment criterion of 50 kA.

233. The 420 V study results show a number of points on the system where the rated fault level of 50 kA is exceeded. The implications of this finding are assessed in Section 4.9 of this report.

4.6.2.7 Protection Coordination

4.6.2.7.1 Assessment

234. Hitachi-GE has produced a series of time/current graphs which show the coordination of system protection on the EPS so as to minimise the potential for loss of supplies to system loads in the event of an electrical fault occurring. The graphs are not based on actual settings as this can only be carried out during detail design when information to inform relay setting requirements is available. The graphs are provided to demonstrate the principles to be adopted to provide coordinated protection and to demonstrate the feasibility of achieving a coordinated protection system with the EPS design.

235. I consider that the graphs provide an adequate generic demonstration of the principles to be followed in providing coordination of protection settings on the UK ABWR. I am also content that the feasibility of providing a coordinated protection system has been demonstrated.

4.6.2.7.2 Findings

236. The demonstration of effective protection coordination is a key part of the substantiation of the design of the UK ABWR EPS. Safety claims covering resilience of the EPS to common cause failure require evidence that there is effective protection coordination so that the effects of any individual fault are minimised. I therefore consider that the submission of the time/current graphs supports the safety case in demonstrating the feasibility of the design. The graphs show effective coordination which I would expect to be replicated during detail design.

237. The protection system will require further developments during detail design based on actual equipment so as to fully substantiate safety claims. This will require the licensee to produce a full protection study to provide evidence of effective protection coordination throughout the EPS design. I therefore expect the licensee to

demonstrate effective protection coordination on the EPS by preparation of a protection coordination study based on actual relays settings.

238. I am content that the time/current graphs demonstrate the feasibility of providing an effective coordinated protection scheme to support nuclear safety.

4.6.3 Phase 3 – Off-site and On-site Transient Studies

239. The Phase 3 studies model the off-site and on-site transient studies of the EPS and are presented in the Electrical Modelling Phase 3 Study Report (Ref.32). The studies consist of:

- Transformer Inrush Studies to demonstrate that inrush current on transformer energisation will not cause loss of essential services due to impact on other equipment or electrical protection.
- Open phase fault studies to consider the impact on the EPS of loss of a phase on the 400 kV connections to the UK ABWR.
- Brown out studies to assess the impact of brown out faults on the off-site electrical system on the on-site system.

4.6.3.1 Transformer Inrush Studies

4.6.3.1.1. Assessment

240. Hitachi-GE has conducted studies to consider the inrush current to the GT, ANT, AST and all transformers with primary connections on the 6.9 kV system. For 6.9 kV system transformers the worst case scenario has been assumed of feeding the 6.9 kV system from the AST as this has lower impedance than the ANT. The studies have been performed in each case based on the most onerous duty of closing the transformer primary side circuit breaker with the secondary side circuit breaker open.

241. Hitachi-GE has defined acceptance criteria for the transformer inrush studies in the Electrical Modelling Phase 3 Study Brief (Ref. 33). These criteria are:

- The worst-case transformer inrush current shall not trigger the operation of protection.
- The short time current withstand of equipment exposed to transformer inrush currents shall not be exceeded.

242. For all transformers the study results show compliance with the acceptance criteria.

4.6.3.1.2. Findings

243. I consider that the ONR confirmatory study results for transformer inrush align with the Hitachi-GE study results. I am content with the Hitachi-GE approach to the transformer inrush studies and consider the results confirm that the acceptance criteria are met and that transformer inrush currents do not present a challenge to the integrity of the EPS.

4.6.3.2 Open Phase Fault Studies

4.6.3.2.1. Assessment

244. Hitachi-GE has conducted a series of studies of the effects on the UK ABWR of an open phase fault occurring on the 400 kV connections to the EPS. These studies considered the effects of a loss of both one phase and two phases for the following supply configurations:

- 6.9 kV system connected to AST.

- 6.9 kV system connected to ANT, main generator connected, fault on the 400 kV side of GT.
- 6.9 kV system connected to ANT, main generator disconnected, fault on the 400 kV side of GT.
- 6.9 kV system connected to ANT, main generator connected, fault on the 26.5 kV side of GT.
- 6.9 kV system connected to ANT, main generator disconnected, fault on the 26.5 kV side of GT.

245. Hitachi-GE has defined acceptance criteria for the open phase fault studies in the Phase 3 study brief document. The criteria are that each switchboard is isolated from the degraded source in the event of an open phase fault and transferred to an alternative on site power source.

246. Hitachi-GE has concluded that there are a number of scenarios studied where the assessment criteria are not met due to one or both of the following reasons:

- The fault could not be detected by the neutral earthing current relay on the 400 kV side of the GT or AST with the result that the switchboard cannot be isolated from degraded power sources.
- The fault could not be detected by the low voltage relay because the switchboard voltage does not drop to the 70% setting required to initiate a transfer to an on-site power source.

4.6.3.2.2. Findings

247. I consider that the ONR confirmatory studies show similar results to the Hitachi-GE study results and thus concur with the Hitachi-GE findings.

248. Hitachi-GE has concluded that the study results show that the protection scheme currently proposed for UK ABWR does not fully protect against open phase faults. Hitachi-GE has stated that the study results will be used to inform the development strategy to design a protection scheme to protect against open phase faults.

249. The requirement to protect against open phase faults is a recent issue on nuclear power plants arising from international Operation Experience (OPEX) and I consider that the study results are an important input to the development of a comprehensive protection scheme. I am, therefore, content with the Hitachi-GE findings.

250. As the study results have identified the potential for open phase faults to adversely affect the operation of the EPS I require that a protection scheme to protect against open phase faults is developed. Therefore I have raised the following assessment finding:

AF-ABWR-EE-04: *Hitachi-GE has performed analysis during GDA that demonstrates that the UK ABWR’s electrical protection system (EPS) could be adversely affected by open phase faults. The licensee shall develop and implement a protection scheme against open phase faults for the UK ABWR that takes account of the analysis results.*

4.6.3.3 Brown Out Fault Studies

4.6.3.3.1 Assessment

251. Hitachi-GE has conducted a series of studies to assess the impact of brown out conditions on the UK ABWR EPS in line with the requirements of IAEA guide NG-T-3.8 (Ref. 34). A brown out is defined as a condition in which the voltage on a part of the grid falls to a low level following a fault, and the voltage control arrangements are not sufficient, so the voltage continues to fall over a period of one or two minutes. These studies consist of voltage sag studies to ascertain the bounding case for faults on the off-site network that have the most severe impact on the onsite system. The results of these studies are intended to form the basis of the undervoltage protection scheme.

252. Studies have been performed considering undervoltage conditions from 0.85 pu to 0.7 pu in steps of 0.05 pu. The voltages on the 6.9 kV and 690 V systems and current on the largest motor have been monitored as worst case conditions.

253. Assessment against the acceptance criteria defined in the study brief show that not all cases are met when the main generator is not connected as the switchboard voltage does not drop sufficiently and transfer to off-site sources will not occur. Hitachi-GE has concluded that further development is required for the protection scheme in order to adequately protect against brown out conditions.

4.6.3.3.2 Findings

254. ONR has conducted confirmatory studies which align with the Hitachi-GE studies in showing that acceptance criteria are not fully met when the main generator is not connected. These confirm the requirement for further development of the protection scheme by the licensee during detail design to protect against brown out conditions.

255. Limitations on modelling capability have been identified in both the Hitachi-GE and confirmatory studies as the generator capability is shown to be exceeded. However, I agree with Hitachi-GE that the condition of exceeding generator capability is not credible. This does not impact on the study conclusions.

256. I am content with the results of the brown out studies and the resultant Hitachi-GE findings regarding development of the protection scheme during detail design.

4.6.4 Phase 4 Studies – DC Systems

257. Hitachi-GE has produced Electrical Modelling Phase 4 Study Report (Ref.35) covering the modelling studies of the on-site DC power systems on the UK ABWR. For each system the following studies have been carried out:

    - DC load flow studies to verify battery capacity, circuit and component loading and system voltages during battery charging and load voltage during all operating conditions.
    - DC short circuit studies to calculate the maximum short circuit on each system and to verify that equipment is adequately rated to withstand potential short circuit currents.
    - DC protection studies to verify the capability of protection systems to coordinate so as to disconnect equipment near to the fault and minimise disruption to the electrical system.

258. Acceptance criteria for the studies are defined in Electrical Modelling Phase 4 Study Brief (Ref. 36).

4.6.4.1 Load Flow Studies

4.6.4.1.1 Assessment

259. Hitachi-GE has carried out a load flow study of the following systems:

- SC1 115V DC System Battery A
- SC1 115V DC System Battery B
- SC1 115V DC System Battery D
- SC2 115V DC System Battery A
- Non-safety 230V DC system
- B/B SC2 115V DC system Battery A

260. These are justified in the Study Brief as bounding cases in order to rationalise studies. The SC1 Battery C has a less onerous capacity requirement than Batteries A, B and D. The SC2 Battery B has the same capacity as Battery A. The B/B Battery B has a lower rating than Battery A.

261. The acceptance criteria were met in the majority of scenarios studied. The criteria were not met in a small number of instances on the SC2 and Non-Safety systems due to low battery volts when operating from the battery with no supply from the charger. Hitachi-GE has explained in the study report that this is due to the battery data used for the modelling study compared to the generic ABWR battery calculations and conclude that the studies should be updated when the actual battery has been selected. In addition, low battery volts were calculated in other instances on downstream switchboards which Hitachi-GE explain in the study report as due to excessive volt drops resulting from the cable data used. I consider this to be an acceptable justification.

4.6.4.1.2 Findings

262. ONR’s confirmatory studies show that when the DC system is supported by the AC system the results closely align with the claims made by Hitachi-GE. The confirmatory studies indicate that all the Safety Classified DC distribution boards operate at or above the nominal 115V DC rating.

263. When the DC load system is supported by the battery system the DC load flow confirmatory studies results broadly align with the claims made by Hitachi-GE with some minor issues. The Non-Safety Class battery system experiences a 20% voltage dip (30% seen by Hitachi-GE) due to the large starting current of four pumps which are fed by the system. This is on the limit of but within the -20% of nominal voltage acceptance criteria.

264. Based on the findings of the confirmatory studies I am satisfied with the methodology used to carry out the load flow study.

265. I note that low battery volts are calculated for some scenarios which indicates that the systems have small design margins. I note the Hitachi-GE explanation that the selection of a specific battery manufacturer will be used to justify that there is adequate battery capacity but I do not consider that this can be used to provide a

robust justification of the design. The establishment of adequate battery capacity in the DC systems is important to establishing a robust electrical system to support nuclear safety and I will require demonstration by the licensee during detail design that the battery systems have adequate capacity and design margins to meet all foreseeable plant loads. Therefore I have raised the following assessment finding which also addresses issues identified in Section 4.10.2.2:

AF-ABWR-EE-05: *An adequate direct current (DC) electrical system is essential for nuclear safety. ONR's GDA Step 4 assessment has identified two issues that the licensee will need to address as part of the detailed design.*

- *Adequate battery capacity in the direct current (DC) electrical systems is essential for nuclear safety. Hitachi-GE's load flow studies have demonstrated small design margin in some fault scenarios. The licensee shall demonstrate that it understands all the requirements on the DC electrical system and can show adequate design margins, ahead of finalising the UK ABWR design and battery supplier.*

- *The provision of an isolated earth system on the DC power system provides the ability for the system to continue operating following an earth fault. An essential requirement for the implementation of this scheme is the capability to be able to effectively locate faults so as to minimise the repair time and support continuity of supplies. The licensee shall define the methods that will be employed for locating earth faults on the DC system so that earth faults can be effectively located, allowing the DC system to continue to be available to support its safety related duty.*

4.6.4.2 DC Short Circuit Studies

4.6.4.2.1 Assessment

266. Short circuit studies have been performed on the DC systems based on the following worst case scenarios which are identified as bounding cases in the study brief:

- For the SC1 system, the largest fault level contribution is assumed to arise from the largest rated battery, when the battery and charger are operating in parallel.

- For the SC2 system, the largest fault level contribution is assumed to arise from the largest rated battery, when the battery and charger are operating in parallel.

- For the Non-safety Class system, the largest fault level contribution is assumed to arise when the battery and charger are operating in parallel.

- For the B/B SC2 system, the largest fault level contribution is assumed to arise when the battery and charger are operating in parallel.

267. The acceptance criteria were established in the study brief for the fault current to be less than 95% of the rated value of 40 kA. The Hitachi-GE studies show that these criteria are met.

4.6.4.2.2 Findings

268. I consider that the confirmatory studies align with the Hitachi-GE studies in demonstrating compliance with the acceptance criteria. I am content, therefore, that the results of the DC short circuit studies demonstrate the adequacy of the DC system designs under short circuit conditions.

4.6.4.3 DC Protection Coordination

4.6.4.3.1 Assessment

269. Hitachi-GE has presented a series of time current curves which demonstrate the feasibility of coordinating the protection settings. These show that under fault conditions the immediate upstream protective device operates to isolate equipment and thus minimise disruption to the electrical system. The submitted curves cover all of the DC systems on the UK ABWR.

4.6.4.3.2 Findings

270. The results have been assessed by ONR’s TSC to establish the acceptability of the Hitachi-GE presentation. The four protection graphs in the Hitachi-GE report indicate that the different Moulded Case Circuit Breakers (MCCB) protection provision is to utilise an Inverse Definite Minimum Time (IDMT) curve characteristic to protect the downstream loads. Several of the MCCBs follow the same characteristic but rated at a lower amperage, this is then protected upstream by a larger rated MCCB. All protection curves are within the equipment short circuit rating of 40 kA.

271. I conclude that the DC protection coordination results are adequate in demonstrating the feasibility of the DC protection coordination.

4.6.5 Phase 5 – Harmonic Studies

4.6.5.1 Assessment

272. The Phase 5 studies cover the modelling of harmonic distortion on the UK ABWR electrical system to provide assurance that the propagation of non-sinusoidal currents produced by generating sources and non-linear loads is such that the electrical system switchboards remain within limits set out in Engineering Recommendation G5/4.1 (Ref. 37).

273. The studies were carried out for eight separate plant configurations and considered the following sources of harmonic distortion:

- Main generator exciter
- Battery chargers
- Uninterruptible AC power supply systems

274. Harmonic distortion from Adjustable Speed Drives (ASD) was not considered within the studies as the Motor Generator (MG) sets provide electrical separation between the EPS and ASDs. In addition, the RIP Power Supply System Equipment Design Specification (Ref. 38) states that phase-shift transformers are installed between the MG sets and the ASDs in order to reduce the harmonic distortion impact on the EPS.

275. The study results and acceptance criteria are presented in Hitachi-GE document Phase 5 Study Results (Ref. 39). Hitachi-GE concludes that there are no study cases where Total Harmonic Distortion (THD) exceeds the limits defined in the acceptance criteria.

276. The worst case THD observed was 4.36% on an AC SC1 420 V switchboard with the plant configured in standby mode (low load condition). The acceptance criteria for a 420 V switchboard is a THD not greater than 5% and Hitachi-GE consider the level of THD on this switchboard is due to the number of chargers and UPS systems connected to this system.

4.6.5.2 Findings

277. I consider that Hitachi-GE has demonstrated the adequacy of the electrical system design to comply with harmonic distortion requirements as required by Engineering Recommendation G5/4.1.

278. I consider that the use of MG sets and phase-shift transformers reduces harmonic distortion from the ASDs and therefore the ASDs can be discounted from the harmonic studies.

279. The worst case THD is close to the upper acceptance limits but I consider this is acceptable based on the systems connected to this switchboard. However I expect the licensee to update the studies based on detailed design data in order to confirm the levels of harmonic distortion are acceptable. I will assess the results of the updated harmonic studies as part of the assessment of the detailed design.

4.6.6 Phase 6 - Miscellaneous Studies

280. The scope of the Phase 6 miscellaneous studies was identified in the scoping document as follows:

    - Lightning protection studies
    - Electromagnetic Compatibility (EMC) studies
    - Geomagnetically Induced Current (GIC) Studies
    - Ferro-resonance Studies

281. The Electrical Modelling Phase 6 Study (Ref. 40) justifies not completing the EMC, GIC and Ferro-resonance studies during GDA as these can only be carried out using specific site parameters. I am content with this proposal and will assess the study results when they are submitted as part of detailed design.

4.6.6.1 Lightning Protection Studies

282. Hitachi-GE has presented a generic lightning protection study in the Electrical Modelling Phase 6 Study. The study was conducted in accordance with IEC 60071 (Ref. 41) and IEC 62305 (Ref. 42) and was performed using ATP-EMTP software which has the capability to simulate lightning strikes.

283. The purpose of the study is to present the methodology for calculating overvoltages caused by lightning strikes to demonstrate that they are below the defined design basis level and do not challenge the integrity of the EPS equipment. The acceptance criteria are stated in the Electrical Modelling Phase 6 Study Report and are derived from the Basic Insulation Level (BIL) defined in IEC 60071.

284. IEC 60071 defines the BIL for a 6.9 kV system to be 60 kV and requires the overvoltage to remain below 95% of the BIL following a lightning strike.

285. Following cross cutting work between ONRs External Hazards, C&I and Electrical inspectors, Hitachi-GE defined the Design Basis Event (DBE) lightning strike event to be 300 kA. This figure is in line with the Council on Large Electrical Systems (CIGRE) data and has been benchmarked against figures used at other UK nuclear power stations. The study takes into account the DBE lightning strike when calculating the overvoltage on the 6.9 kV switchboards. The ONR External Hazards assessment concludes that Hitachi-GE's treatment of the lightning hazard is consistent with lightning values determined by other Requesting Party's (RP) and meets relevant good practice.

4.6.6.1.1 Assessment

286. The Electrical Modelling Study Phase 6 Report provides the methodology used to conduct the lightning protection studies and determine the effects of lightning strikes on the EPS, based on generic design data and assumptions. The data required for detailed design studies is not yet available as they need to be based on site-specific design parameters.

287. The Electrical System Modelling Scoping Report (Ref.43) includes the requirement to demonstrate Surge Protection Device (SPD) coordination. Hitachi-GE has stated that detailed design information is required in order to carry out this assessment and this will be carried out during the detailed design phase.

288. The configuration of the generic off-site power system is based on the Central Research Institute of Electric Power Industry (CRIEPI) report H06 (Ref. 44). The model is based on a single circuit configuration that represents the worst case off-site connection condition.

289. The design of the generic on-site system is based on a number of assumptions regarding the system design and configuration and these are clearly defined in the Report. The study input shows the origin of the data, for example whether the data is an assumption, a typical value or based on National Grid figures. The input data are used to define an overall system model incorporating off-site and on-site systems.

290. The results of the generic study demonstrate that a DBE lightning strike does not produce overvoltages that challenge the integrity of the EPS.

4.6.6.1.2 Findings

291. I consider that The Electrical Modelling Study Phase 6 Report provides a good presentation of the methods and principles used for determining the effects of lightning strikes, based on generic design data and assumptions.

292. I consider that at this stage of the design it is acceptable that the report defines the methodology used by Hitachi-GE, rather than detailed design information. I also consider that it is appropriate for demonstration of SPD coordination to be carried out at the site specific stage, as it is not possible to demonstrate the coordination when detailed design information is not yet available.

293. I am content that the model of the off-site system provided in the Study Report provides a good basis for a generic grid system and the proposal to include only one circuit is a conservative decision that demonstrates the bounding study case.

294. I consider the generic on-site system is well documented in the report with a clear list of assumptions, a structured design showing the interface with the off-site system and a transparent list of input data. The data set provided is based on good engineering judgement and provides a reasonable demonstration of the methodology used.

295. I am content that the results of the study case show that the acceptance criteria are met based on the typical design data and assumptions used. The 6.9 kV switchboards do not exceed 25.9 kV following a DBE lightning strike which provides significant margin against the BIL of 60 kV.

296. I consider that it is necessary to demonstrate an effective lightning protection system, including a coordinated SPD system, based on detailed design data. This data will only be available when the EPS, lightning protection and earthing system designs are substantially complete. As a result, I have raised the following assessment finding:

AF-ABWR-EE-06: *An effective lightning protection system provides a significant nuclear safety function, but there are limitations to the extent Hitachi-GE could demonstrate its functionality during GDA. The licensee shall conduct lightning protection studies based on actual design data to demonstrate the resilience of the electrical power supply system (EPS) to lightning strikes and to demonstrate effective coordination of Surge Protection Devices.*

297. In conclusion, I consider that the lightning protection report demonstrates a sound set of principles, methods and assumptions to show that the EPS is robust against design basis lightning strikes. This demonstration is supplemented by the assessment of the lightning protection design specification covered in section 4.11 of this report.

4.6.7 Modelling Comparison

298. The purpose of the modelling comparison document (Ref. 28) is to compare the formula based calculations used to determine basic equipment ratings for electrical equipment in the design calculation reports with the more detailed results from the computer based studies.

299. Hitachi-GE has submitted design calculations for key electrical components of the EPS. These are based on the calculations and the design formulae from the standard Japanese ABWR. These calculations have been used as the basis of determining thermal and short circuit ratings for the main electrical plant items.

300. The load flow and short circuit studies conducted as part of the electrical system studies provide a detailed analysis of the steady state and short circuit current flows using proprietary software. Hitachi-GE has produced a modelling comparison document (Ref. 28) to validate the thermal and short circuit ratings used for the main electrical plant items by comparing the results against the system study results and justifying any discrepancies.

301. The comparison document compares the results of the design calculations and computer based study results from both AC and DC systems.

4.6.7.1 Assessment

302. There are significant discrepancies between the results of the load flow design calculations for ANT and AST although both results are within the defined equipment rating. In particular, the load flow studies show significant discrepancies on ANT Transformer 2 and AST Winding B. Hitachi-GE attributes this to the allocation of loads to the different windings in the MDAL and proposes that this can be resolved by the licensee during detailed design.

303. The load flow results for the generator transformer show good correlation between the computer based study results and the formula based calculation results.

304. Hitachi-GE shows significant variations on thermal loadings on all the 2.5 MVA SC3 power transformers with the load flow studies showing loadings above and below the calculated values. However, all the results are within the defined transformer ratings. Hitachi-GE states that this is due to the allocation of loads between divisions and also allowances made for intermittent loading and proposes that this can be resolved by the licensee during detailed design.

305. The EDG, BBG and DAG loading results from the load flow study show active power KW ratings which are higher than those obtained from the calculation results whereas the KVA ratings are lower than the calculated results. Hitachi-GE explains this as

being due to the more precise calculation in the load flow analysis from the system study.

306. The short circuit study results show a good correlation between the design calculations and the system study results.

307. The SC1 DC system study load flow results show a good correlation between the design calculations and the system study results.

308. The comparison between the system study load flow results on the SC2 and non-safety systems and the calculated values show that the acceptance criteria are not met for these systems according to the systems study. This is at variance with the results of the calculated values.

4.6.7.2 Findings

309. I agree with the findings from the ANT and AST comparisons that the allocations of loads to the different transformer windings will require determination by the licensee during detail design in order to evenly distribute the loads.

310. I agree with the findings from the Safety Class 3 power transformers that the allocation of loads and determination of load factor should be addressed by the licensee during detailed design.

311. I am concerned at the discrepancies between the system studies and design calculations for the EDG, BBG and DAG active power ratings as the capacity is limited. This topic is assessed in Section 4.6.2.1 of this report.

312. I am concerned at the discrepancies between the results of design calculations and system studies for the SC2 and non–safety batteries as the system studies identify that these batteries do not have adequate capacity. This topic is assessed in Section 4.6.4.1 of this report.

313. In conclusion I am content with the presentation of the modelling comparison as it correctly identifies issues to be resolved during detailed design when system studies will be finalised.

4.7 Electrical Maintenance Philosophy

314. The purpose of the maintenance philosophy is to maximise the availability and reliability of equipment such that the equipment performance achieves its safety function. The philosophy includes activities associated with reliability centred maintenance, preventive maintenance (periodic, predictive, and planned), surveillance and testing and equipment performance and condition monitoring.

4.7.1 Assessment

315. Assessment of the high-level maintenance philosophy for the UK ABWR reactor is based on the response provided by Hitachi-GE to RO-ABWR-0062 (Ref. 45) and is presented in the C&I Step 4 Assessment Report (Ref. 97). I have sampled a number of areas of Hitachi-GE's approach to maintenance of the plant for the purposes of this assessment.

316. Hitachi-GE has provided Generic Technical Specifications (Ref. 88) that give the Limiting Condition for Operation (LCO) and the Surveillance Requirements (SR) for each SSC. The LCOs detail minimum diverse plant availability/operability and time limits on degraded plant configurations before alternative actions must be taken and the SRs specify the surveillance intervals for each SSC.

317. The EPS is designed to allow operational capability of SSCs to be confirmed by periodic testing. However, Hitachi-GE has stated within the BSC that the detail of this requirement will be captured in processes and procedures developed during the detailed design phase. The ability to test SSCs at required intervals is important for confirming they are capable of performing their safety related duty. I expect the licensee to develop these processes and procedures during the detailed design phase based on the as-built EPS.

318. The EPS is designed with redundancy targets based on the Safety Classification of the SSC. SC1 AC SSCs are designed with an N+2 redundancy requirement so that one division can be maintained and a random single failure can occur in another division without impacting the performance of the SSC. SC1 DC SSCs are designed with an N+3 redundancy requirement so that one division can be maintained and a failure can occur in two divisions without impacting the performance of the SSC. SC2 SSCs are designed with an N+1 redundancy requirement such that one division remains available during maintenance conditions. Hitachi-GE has stated in the BSC that the evidence for the capability of the EPS to meet these redundancy requirements will be provided during the detailed design phase. I expect the licensee to demonstrate how the detailed design will achieve compliance with the redundancy requirements.

319. No more than one safety division of SC1 and SC2 equipment will be taken out of service for planned maintenance regardless of mode of reactor operation. The approach to maintenance has been assessed by ONR Fault Studies (Ref. 98). The assessment concludes that an important aspect of the UK ABWR design which allows it to tolerate maintenance on the SC1 systems, despite having fewer divisions of safety systems than existing reactor designs in the UK, is the provision of the B/B which adds two SC2 divisions that are physically separated and diverse from the SC1 divisions.

320. In response to RQ-ABWR-0537(Ref.46), Hitachi-GE has committed to incorporating appropriate condition monitoring facilities to support the capability of equipment to carry out its safety related duty over the specified design life. I expect the licensee to establish requirements and specify condition monitoring provisions in equipment specifications.

321. The EPS is designed with provisions for facilitating maintenance such as interconnectors between switchboards/systems and installed spares to provide alternative means of supporting an SSC during maintenance periods. Interlocks are provided where required to prevent paralleling of supplies or equipment.

322. The Human Factors Engineering specification (Ref. 47) is applied to the EPS to ensure the design supports the ability to access local control panels and plant equipment controls and indications, and effectively operate or maintain them.

4.7.2 Findings

323. I consider that the implementation of a periodic testing regime, the ability to be able to remove plant for maintenance without impacting the redundancy requirements and the provision of condition monitoring facilities are all key elements of the maintenance philosophy that the licensee will need to demonstrate. Therefore I have raised the following assessment finding:

AF-ABWR-EE-07: *A vital consideration in the design of the electrical power supply system (EPS) is the ability to perform necessary maintenance and testing activities without compromising the ability of structures, systems and components (SSCs) supported by the EPS to perform the safety functions claimed in the safety case. However this has not been demonstrated during GDA as the focus has been on* *defining the redundancy targets. The licensee shall develop an electrical maintenance and testing philosophy document in accordance with the high-level plant maintenance philosophy document. This shall demonstrate that safety significant electrical SSCs can be maintained and tested without challenging the redundancy requirements that are derived from the safety case claims and classification of the SSC.*

324. In conclusion, I consider that the maintenance philosophy presented by Hitachi-GE is sufficient for the purposes of GDA. It is clear that achieving the maintenance requirements whilst meeting safety constraints has been factored into the design through the provision of redundant system architecture. Consideration of Human Factors requirements in plant design optimises operator actions for carrying out plant isolations, maintenance, energisations, return to service and condition monitoring.

4.8 Grid Code Compliance

325. It is necessary for a Connection Agreement to be in place for the UK ABWR to be connected to the UK Grid. A requirement before this is put in place is for the grid technical requirements to be met. These technical requirements are defined in the UK Grid Code (Ref. 48).

326. The Connection Agreement for each reactor will be site specific and this will be based on agreement of technical parameters for each site based on the specific grid connection arrangements. Assessment of the site-specific arrangements for the grid connection is outside the scope of GDA.

327. There are various requirements within the UK Grid Code for generating plant to remain connected at times of grid disturbances in order to support National Grid, the Transmission System Operator (TSO) in maintaining continuity of grid supply. However, this requires the main turbine generator and the EPS for the reactor to remain operational up to defined disturbance limits. It is the purpose of this assessment to consider the functioning of the EPS and its connected equipment at the maximum tolerances defined in the UK Grid Code in order to determine that there is no impact upon nuclear safety.

4.8.1 Assessment

328. Hitachi-GE initially identified a number of potential non-compliances of UK ABWR EPS with the UK Grid Code for which derogation applications were under consideration. In response, ONR expressed its expectation of full compliance and raised RO-ABWR-0063 (Ref. 49). This required Hitachi-GE to conduct an ALARP review of options to address all areas of potential non-compliance of the UK ABWR design with the UK Grid Code. The RO required the options under consideration for achieving full compliance to be considered taking account of nuclear safety, complexity of implementation of changes, cost to implement and potential programme effects. The review was also required to confirm full compliance with all other UK Grid Code requirements.

329. Hitachi-GE addressed Grid Code compliance in two stages. Stage 1 identified potential non-compliances and identified options to address the non-compliances. In Stage 2 Hitachi-GE conducted a detailed analysis and ALARP review to confirm the preferred option to address each potential area of non-compliance.

330. Hitachi-GE identified four potential non-compliances and confirmed compliance with all other clauses. The non-compliances were identified as follows:

- Clause CC 6.3.15 Fault Ride Through (FRT)

- Clause CC 6.3.7c Control of frequency of a grid island (IM)
- Clause CC 6.3.7 Frequency Sensitive Mode (FSM)
- Clause CC 6.3.3 Limited Frequency Sensitive Mode (LFSM)

331. The options for further assessment during Stage 2 are presented by Hitachi-GE in the following documents:

    - Response to RO-ABWR-0063 Stage#1 regarding Grid Code Non-Compliance – Preferred options for Islanding Mode (IM) performance (Ref. 50)
    - Response to RO-ABWR-0063 Stage#1 regarding Grid Code Non-Compliance – Preferred options to achieve FSM compliance (Ref. 51)
    - Response to RO-ABWR-0063 Stage#1 regarding Grid Code Non-Compliance – Preferred options to achieve LFSM compliance (Ref. 52)
    - Response to RO-ABWR-0063 Stage#1 regarding Grid Code Non-Compliance – Preferred options to achieve FRT compliance (Ref. 53)

332. The Stage 2 response with detailed analysis and ALARP review is documented in the following:

    - Response to RO-ABWR-0063 Stage#2 regarding Grid Code Non-Compliance (Ref. 54)

333. Hitachi-GE's preferred option for complying with LFSM mode is a minor change to the droop and bias settings of the Turbine Electro Hydraulic Control (EHC) system which will provide full compliance.

334. Hitachi-GE's preferred solution for FSM is to use the Turbine Bypass Valve (TBV) with continuous bypass. Additional work is required by the licensee in order to verify this solution.

335. For Island Mode compliance with the UK Grid Code would require 100% TBV capability which requires significant changes to the plant design. The ALARP review has identified the requirement for significant design changes which are unproven, have significant cost implications and significant programme implications and has concluded that compliance would be grossly disproportionate to the benefit. An option of providing 55% TBV capability was considered but the review concluded that this does not comply with the Grid Code and introduces project and programme risks so does not provide any benefit. Hitachi-GE has, therefore, concluded that maintaining the existing design and applying for a lifetime derogation is the appropriate option.

336. For FRT Hitachi-GE has proposed a design modification increasing the MG sets on the Reactor Internal Pump (RIP) from two to four. This will support full compliance with the requirement to remain connected and recover active power following a grid fault. Hitachi-GE has produced the document Fault Ride Through Assessment Report (Ref. 55) to document the work in progress to remain transiently stable. Although there is further study work required Hitachi-GE has expressed a high level of confidence that full compliance can be demonstrated.

337. The identified changes required to achieve UK Grid Code compliance in the UK ABWR design have not been formally adopted. The licensee plan to apply the formal design modification process once the detail design requirements have been finalised.

4.8.2 Findings

338. I consider that Hitachi-GE has conducted a thorough and comprehensive set of studies to determine the status of UK Grid Code compliance for the UK ABWR design. Where design modifications are required to achieve compliance these have been assessed and no potential impact on nuclear safety has been identified. The process for assessment and adoption of design solutions is well documented and the justifications for design decisions are fully recorded.

339. For Island Mode the ALARP review has determined that to achieve full compliance is disproportionate in terms of cost, programme, complexity and nuclear safety risk in adopting an unproven design change. I agree with the proposal to apply for lifetime derogation as the ALARP conclusion.

340. Further work is required to complete the process of confirming Grid Code compliance and the requirements for this are well defined. I conclude that the work carried out is sufficient to provide confidence that the requirements are fully understood and that with the exception of IM operation full compliance will be achieved whilst not impacting nuclear safety.

341. There is further work to be carried out by the licensee to demonstrate full compliance and it is important that this is carried out in a comprehensive and timely manner. The required design changes will then have to be formally adopted by the licensee in to the UK ABWR design. I have, therefore, raised the following assessment finding:

AF-ABWR-EE-08: *There were limitations in the extent to which Hitachi-GE has considered the requirements of the UK Grid Code in GDA, and those studies which have been performed have identified the need for design changes to be implemented. The licensee shall finalise the work to demonstrate that the UK ABWR complies with the UK Grid Code and implement any necessary design changes.*

4.9 Switchgear Design

342. The UK ABWR AC switchroom design is based upon the use of 420 V and 6.9 kV switchgear manufactured by Hitachi Ltd. Space requirements in the plant have been determined based on the dimensions of this equipment. ONR has expressed expectations that switchgear is compliant with IEC standards and Hitachi-GE has accepted this expectation.

343. The electrical system studies undertaken for the UK ABWR design have calculated system fault levels which exceed currently tested levels for the Hitachi-GE switchgear. These prospective fault levels are in some instances at the limits for commercially available 6.9 kV switchgear. ONR has expressed concern at the potential programme risks and has assessed Hitachi-GE responses which consider the feasibility of accommodating appropriately rated equipment within the defined equipment footprints.

4.9.1 Assessment

4.9.1.1 Low Voltage Switchgear

344. The Hitachi-GE Low Voltage (LV) switchgear has been type tested to Japanese standards to a symmetrical fault rating of 50 kA. ONR expectation is that LV switchgear for the UK ABWR should be type tested to demonstrate compliance with IEC standards at the maximum calculated fault level arising from the system studies including appropriate margins.

345. The Phase 2 system studies show that the fault levels on the LV system exceeds 50 kA in some instances and in response to this ONR requested confirmation that Hitachi-GE will use switchgear which can meet the calculated fault level. Hitachi-GE responded by advising that the switchgear will either be appropriately rated or that the impedance of the power centre transformers will be increased to reduce the fault level so that the standard Hitachi-GE switchgear can be used.

4.9.1.2 6.9 kV Switchgear

346. Hitachi-GE identified a requirement to undertake a programme of development and type testing in accordance with IEC Standards for 6.9 kV switchgear including capability to withstand internal faults. ONR has expressed concern that the type testing programme extends beyond the period of GDA assessment and requires Hitachi-GE to demonstrate its plans to manage the potential design risks associated with this ongoing work.

347. I raised RO-ABWR-0074(Ref. 56) requiring Hitachi-GE to demonstrate the robustness of the 6.9 kV switchgear proposals for the UK ABWR by submitting documents which cover the following:

- Completion of system studies to establish thermal and short circuit ratings for the 6.9 kV switchgear.
- Definition of system design parameters for the 6.9 kV switchgear
- Provision of layout drawings showing switchboard and cable layouts
- Indicative development and test programme
- Design and development plan which identifies risks and provides appropriate mitigation strategies.

348. In response Hitachi-GE has submitted the following documents:

- Electrical Modelling Phase 2 Study Report
- Topic Report For Switchgear Design (Ref. 57)
- Electrical Equipment and Raceway Separation Plan (Ref. 58)
- Electrical Panel Layout Plan (Ref 59)
- 6.9 kV Switchgear Development and Test Programme (Ref. 60)
- 6.9 kV Switchgear Development Strategies (Ref. 61)

349. The electrical modelling Phase 2 study report describes the results of the electrical system studies for the UK ABWR electrical power distribution system. The thermal and short circuit currents are calculated for all operating configurations of the EPS which enables the 6.9 kV equipment ratings to be determined.

350. The topic report for switchgear design describes the principles of the proposed design of the 6.9 kV switchgear to meet IEC type testing requirements. The proposed type tests are described in principle. Details in the topic report regarding the applicable standards and test waveforms have been clarified in response to RQ – ABWR-1383 (Ref. 62).

351. The adequacy of the space available for switchboards and cable routes is demonstrated in the electrical panel layout plan and equipment and raceway separation guide.

352. The switchgear development and test programme (Ref.60) describes in detail the tests to be performed and their objectives.

353. The switchgear development strategies document (Ref.61) describes the draft programme for full type testing with an indicative date for completion of full third party testing of May 2019. The development risk and design hold points are described together with the options at each stage of the programme to resolve potential design issues.

354. The switchgear development strategies document provides assessment of development risk contingencies considering the following scenarios:

- Design footprint cannot be maintained
- Arc containment testing failure
- Design ratings cannot be achieved during testing.

355. For scenarios where the footprint cannot be maintained Hitachi-GE has identified options for creating additional switchroom space as a contingency plan to accommodate compliant equipment with a larger footprint. This would impact the design of the reactor building, turbine building and heat exchanger building.

356. Arc containment testing failure options are considered which involve switchgear redesign. This could involve programme risk which, if significant, could be mitigated by the options considered to adopt a larger footprint in order to accommodate alternative type tested switchgear from alternative manufacturers.

357. For failure to achieve ratings options are considered for reducing fault levels on the system so that type testing at a lower fault level would be acceptable. This would have a significant impact on the system studies which would have to be rerun due to the need to increase system impedances. The new studies would have to consider the effects of the revised impedances on the motor starting and system stability capabilities in order to confirm there are no detrimental impacts on the stability of the electrical system.

4.9.2 Findings

358. I consider that the options considered for LV switchgear fault levels are both technically acceptable. However, reducing fault levels by increasing impedances would impact upon system studies and I would require the licensee to demonstrate the validity of findings from existing studies and to confirm that there is no impact on system capability. As the provision of adequately rated LV switchgear is an essential requirement for providing an adequate EPS design I consider that resolution of the LV equipment short circuit rating to be essential. Therefore I have raised the following assessment finding:

AF-ABWR-EE-09: *Consistent with the principle of reducing risks to be as low as is reasonably practicable (ALARP), Hitachi-GE has identified credible options to be considered outside of GDA to further reduce faults in the low voltage (LV) switchgear. However, some of these options could invalidate the electrical system studies which underpin the GDA safety case. Therefore, the licensee shall demonstrate the on-going validity of the GDA system studies once the final design of the LV switchgear is* *established or provide an alternative solution which ensures the LV equipment short circuit rating is appropriate.*

359. For 6.9 kV switchgear I consider that Hitachi-GE has conducted a realistic assessment of risks and has identified appropriate strategies to mitigate these risks. However, there are potentially significant impacts on building sizes if switchgear sizes need to be increased to meet rating requirements. There are also potential impacts from decreasing fault levels by changing transformer impedances as this could impact on the demonstration of system stability in the system study results.

360. However, I consider that the work carried out by Hitachi-GE on the response to RO-ABWR-0074 has de-risked GDA by presenting clear options to address issues which arise during the switchgear development and test programme. As a result GDA conclusions are not dependent on progress with the switchgear testing programme.

361. The progress with Hitachi-GE's development and testing programme will require close monitoring by the licensee during detail design work. This will require assessment of potential design impacts as testing progresses and taking appropriate actions to mitigate potential programme impacts. Therefore I have raised the following assessment finding:

AF-ABWR-EE-10: *The UK ABWR GDA safety case establishes a requirement for 6.9 kV switchgear with a high fault rating. However, the proposed equipment is still at an early testing and development stage. If it becomes necessary to change the approach by utilising similar equipment currently available from alternative manufactures, there could be significant impacts on site layout or the UK ABWR electrical system design. The licensee shall establish a process for managing and tracking the future development and testing of the proposed switchgear equipment. The implications of failing to achieve the desired design intent and needing to switch to an alternative strategy shall be kept under review.*

4.10 Electrical System Protection

362. Hitachi-GE has defined the principles of the design of electrical protection for the UK ABWR in the electrical protection and earthing system report (Ref. 9). The development and configuration of an effective electrical protection system is an important feature of the EPS in providing the following:

- Detection and clearing of faults to limit damage to the electrical system.
- Minimisation of the section isolated to the section closest to the fault in order to provide continuity of power supplies in support of safety functions.
- Protection of plant equipment under fault conditions.
- Isolation of the plant electrical system following grid faults and disturbances.
- Protection of plant operators.
- Supporting system stability in the event of system disturbances.

363. I have assessed the effectiveness of the principles described in the electrical protection and earthing system report in meeting the above objectives.

4.10.1 AC Systems

4.10.1.1 Assessment

364. The electrical protection and earthing system report states that the design and operation of the protection system conforms to the following fundamentals of protection practice:

- The disconnection of electrical faults as quickly as possible to minimise risk to personnel, damage to plant and the risk of power system disturbances.
- Simplicity through the use of conventional protective relaying practices for the isolation of faults.
- Preserving plant functions and limiting loss of healthy equipment function under fault conditions through effective discrimination.
- System stability is supported by choosing protection equipment to match the plant electrical operating characteristics and minimise plant electrical transients.

365. Hitachi-GE describes the electrical protection proposed for the generator main protection system between the main grid connection, main generator and ANT. The main turbine generator is connected via a load break switch so the protection is applied to the zone which includes the main generator, ANT secondary 6.9 kV circuit breakers and 400 kV grid circuit breaker. The scheme for detection of a fault on the main generator circuit is described including initiation of a transfer from ANT to AST via a hard-wired logic system in the event of a fault on the generator circuit.

366. Hitachi-GE describes the protection on the SC1 6.9 kV system which is a co-ordinated scheme of instantaneous and inverse time overcurrent relays. The earthing on the 6.9 kV system is a high impedance system through a neutral earthing transformer. In the event of an earth fault occurring this is detected by earth fault relay in the earthing transformer and by directional earth fault relays fitted in feeder circuits to identify fault location. These relays will initiate an alarm in the main control room to inform the operator but do not initiate a trip. The circuit will remain in operation to enable the operator to configure alternative supplies before tripping the affected circuit manually in order to carry out repairs.

367. The earth fault protection scheme for the SC1 420 V LV system is similar to that on the 6.9 kV system with earthing through a neutral earthing transformer. Indications are provided in the control room and tripping of the faulted circuit is carried out manually.

368. The report states that where supplies are taken from higher classification switchboards to lower classification equipment the circuit breaker of the higher classification switchboard will be an isolation device. This protects against a fault in lower classification equipment propagating to the higher classification system.

369. The provisions for detecting undervoltage on the 6.9 kV SC1 switchboards consist of undervoltage relay protection on each switchboard. In the event of undervoltage being detected by the undervoltage relay hard wired signals are sent to trip the incoming circuit and to initiate the starting of the EDG connected to the individual switchboard.

370. The B/B protection scheme follows similar principles of co-ordinated protection to that adopted on the SC1 systems. This includes detection of undervoltage on the back up building 690 V switchboards and the starting of the BBGs via a hard-wired logic

system. There is an additional provision on the B/B generator protection for the generator reverse power relays to be disabled during reactor low water level conditions in order to maintain the continuity of supply to operating loads under these conditions.

371. Hitachi-GE states that in order to support diversity between the BBG and the EDG the protection relays will be of different types.

372. The use of smart devices in electrical protection relays is not addressed in the protection and earthing system report as this report is limited to defining the electrical protection scheme functionality. The application of smart devices is covered the document List of Smart Devices in the Electrical System (Ref. 63) and the diversity considerations are assessed in the Diversity Strategy Report. I expect that qualification of smart devices will be addressed in accordance with the process assessed in the C&I Step 4 Assessment Report.

373. The protection and earthing system report refers to the requirement for the licensee to develop a protection scheme for open phase protection during detailed design of the plant. This was identified as a vulnerability of the EPS in the Phase 3 modelling study which was assessed in Section 4.6.3 of this report.

4.10.1.2 Findings

374. I have assessed whether the electrical protection scheme described by Hitachi-GE meets the fundamental objectives for a protection scheme as defined in Section 4.10 and conclude that the scheme defined by Hitachi-GE forms a sound basis for meeting these objectives. This is achieved by providing effective protection of the plant in the event of an electrical fault and by providing the basis for a coordinated protection scheme to effectively isolate electrical faults, support system stability and minimise the loss of supplies following a fault. The protection settings which will require to be determined as part of detail design form an important part of the protection system. Correct protection settings are required to support the safety case and in order to substantiate these the effectiveness of the coordinated protection settings will be assessed by ONR during detail plant design.

375. I have considered the provision of the high impedance earthing system on the 6.9 kV and 420 V systems and have no comments on the design noting the advantages of the capability to maintain supplies following an earth fault. I consider that an essential requirement for the implementation of this scheme is the capability to be able to effectively locate faults so as to minimise the repair time. The protection scheme includes directional earth fault relays on each circuit to enable fault location and I will be assessing the detail design from the licensee to implement this during detail design to determine the effectiveness of the fault location provisions.

376. I note the statement regarding the provision of an isolation device on feeders to lower classification equipment to prevent propagation to the higher classification system and confirm that this meets my expectations.

377. I am content with the provision of the independent hard-wired logic schemes described for ANT to AST changeover, EDG start up and connection to assigned loads and BBG start up and connection to assigned loads. I consider that these individual changeover schemes reduce the risk of common cause failure.

378. I am content with the approach described regarding the use of protection relays of different types and the approach to the use of smart devices in protection relays. I expect the selection of protection relays by the licensee to take account of the principles outlined in the diversity strategy and the qualification of smart devices in

accordance with the List of Smart Devices in the Electrical System (Ref. 63). I will assess the implementation of this with the licensee during detailed design.

379. I am content with the commitment to develop a protection scheme for open phase protection.

380. In conclusion, I am content that the protection principles defined in the report provide a sound basis for development of the detailed protection system by the licensee.

4.10.2 Supplies to C&I Equipment

4.10.2.1 Assessment

381. The protection and earthing system report describes the protection on UPS systems and DC and AC systems supplying C&I systems. The systems are to be provided with cascaded protection system to provide multiple levels of protection and provide backup should the main protection fail to operate.

382. The DC power systems are to have an isolated earthing system with a protection relay to detect earth faults and initiate an alarm in the event of an earth fault. Hitachi-GE has stated that an optioneering study will be conducted during detail design to identify options for earth fault location equipment to improve the repair time for faults.

383. Power supplies from higher classification switchboards to those of a lower specification are to be fitted with isolation devices to protect against a fault on the lower classified system propagating to the system of higher classification.

384. Inverter outputs are to be fitted with current detectors to protect the inverter in the event of an overcurrent. The supply is intended to be switched to the standby supply on detection of an overload and an alarm activated.

385. The B/B is described as having the same protection principles as the main system.

4.10.2.2 Findings

386. I consider that the system protection system described for supplies to C&I systems provides an effective system in line with ONR expectations. I am satisfied with the isolation provisions for preventing equipment of a lower classification impacting on that of higher classification.

387. Hitachi-GE has identified a requirement for an optioneering study to consider the location of earth faults on the isolated DC system. I consider an effective earth fault detection system to be an important provision in supporting maximum system availability for the DC system and I expect the licensee to develop this requirement further during detailed design as part of their response to **AF-ABWR-EE-05** as raised in Section 4.6.4.1.2 of this assessment report.

388. In conclusion, I am content with the protection principles described on the electrical systems which supply the C&I systems.

4.11 Lightning Protection

389. Lightning strikes, both direct and indirect, can affect personnel, SSCs and services. To address the risk of common cause failure initiated by a lightning strike, an effective Lightning Protection System (LPS) is required to support nuclear safety.

390. Hitachi-GE's initial submissions did not present a coordinated approach to lightning protection. Hitachi-GE responded to RQ-ABWR-0835 (Ref. 64) with a commitment to:

- Develop an overall approach to protection against lightning strikes for the UK ABWR, working with External Hazards and Civil Engineering teams.
- Consider the potential hazards arising from lightning strikes in line with IEC 62305-1.
- Consider the risk assessment approach set out in IEC 62305-2.
- Use the risk assessment to inform the selection of Lightning Protection Levels applicable to the EPS.
- Describe the principles of a coordinated surge protection system to demonstrate compliance with the requirements of IEC 62305-3 and IEC 62305-4.
- Include the requirements for testing of the LPS to verify its integrity.

391. Hitachi-GE presented an overall approach to protection against lightning in the Topic Report on Lightning Protection Strategy (Ref. 65) which defines discipline roles and identifies interfaces between the disciplines and documents. The topic report identifies the following document structure relating to lightning protection:

- The Topic Report on External Hazards (Ref. 66) describes the process for identifying external hazards and the general protection policy for each identified GDA external hazard. The Topic Report identifies lightning as an external hazard that should be considered as part of GDA.
- The Topic Report on Fault Assessment (Ref. 67) considers the external hazards (in this case, lightning strike) identified in the Topic Report on External Hazards and identifies what kind of systems need to be protected from that hazard.
- The Support Document on EMI for Generic Site Envelope (Ref. 69) provides the immunity countermeasures for C&I equipment.
- The Lightning Protection Specification (Ref. 89) details the lightning strike protection measures required for the EPS SSCs and is based on the requirements of IEC 62305.

392. The electrical aspects of the approach to lightning protection are detailed in the lightning protection specification.

4.11.1 Assessment

393. I have focussed on the adequacy of the lightning protection principles to protect the EPS against lightning strikes, as set out in the lightning protection specification. I have assessed the lightning protection strategy for the UK ABWR as a cross cutting issue involving External Hazards, Civil, C&I and Electrical Engineering disciplines.

394. The lightning protection specification details generic principles for the design of the lightning protection system in order to provide protection for personnel and SSCs from lightning strikes. The principles conform to the requirements of IEC 62305 and include:

- The LPS should provide protection to personnel, SSCs and services.

- The requirements for lightning protection for each SSC will be evaluated by SQEP personnel.
- Detailed quantitative risk assessments will be performed in accordance with IEC 62305-2.
- The design of the LPS will be in accordance with the LPS design flow diagram in IEC 62305-3.
- Equipotential bonding will be provided between external LPS components and other electrically conducting components internal to the structure.
- Surge protection devices capable of withstanding transient overvoltages will be provided in line with the requirements of IEC 62305-4, including the definition of lightning protection zones.
- The detailed design of the LPS will be supported by calculations.

395. The specification describes the measures to be adopted in the design of the LPS to protect the UK ABWR from the impacts of direct and indirect lightning strikes supporting nuclear safety.

4.11.2 Findings

396. The lightning protection specification provides a good presentation of the design principles required for an effective LPS. I consider the specification demonstrates how the generic principles will be achieved and that this provides the basis for the design of an effective lightning protection system.

397. I support the Hitachi-GE recommendation to use SQEP personnel to evaluate the requirements for the LPS as lightning protection is a specialist field that requires an in-depth understanding of the requirements of IEC 62305. I expect the licensee to demonstrate the implementation of this approach and I will assess this during detail design.

398. For the protection of SSCs, I consider that it is appropriate for the specification to require the lightning protection level for each SSC to be informed by a quantitative risk assessment based on the requirements of IEC 62305-2. The requirement will ensure each SSC is adequately protected based on its safety related duty.

399. I consider that the specification provides a clear set of requirements for defining surge protection and lightning protection zones, in compliance with IEC 62305-4. Hitachi-GE has specified the requirement for coordination between lightning arrestors, surge protection components, withstand voltage of equipment and the earthing system. I consider this provides a coordinated system that will suppress on-site and off-site surges in order to support nuclear safety. Hitachi-GE has also specified the requirement for three protection zones, given examples of how the zoning will be applied to structures and provided examples of the general arrangements for the protection required within each zone. I expect that this approach will be supported by studies which demonstrate effective coordination.

400. I am satisfied that the specification adequately describes the requirement for the interface between the LPS and the earthing system. I consider this arrangement provides an integrated network that protects electrical and electronic systems from lightning electromagnetic pulses and I consider the specification is in accordance with appropriate international standards. I have assessed the earthing system design in Section 4.19 of this report.

401. I note that Hitachi-GE has not provided detailed design calculations for the LPS for GDA purposes. I consider that this is reasonable as detailed design information is required which is not available at this stage. However Hitachi-GE has presented a generic methodology for lightning protection studies which I have assessed in Section 4.6 of this report.

402. In conclusion, I am content that the lightning protection specification provides a good basis for the design of a LPS to protect the UK ABWR from the risks from direct and indirect lightning strikes.

4.12 Reactor Internal Pump Supplies

403. The reactor coolant is circulated by ten Reactor Internal Pumps (RIP) each of which is fed via an individual Adjustable Speed Drive (ASD).

404. The RIP power supply system for the Japanese ABWR includes two Motor Generator (MG) sets fitted with flywheels which supply three ASDs each. The inclusion of the MG sets provides system inertia to limit the impact of electrical transients and Loss of Offsite Power (LOOP) on the RIPs. The remaining four ASDs were directly supplied by the 6.9 kV SC3 EPS. In order to address Grid Code compliance requirements for the reactor to have fault ride through capability the system has been modified for UK ABWR to supply all the ASDs from MG sets with no RIPs directly supplied.

4.12.1 Assessment

405. Hitachi-GE has submitted the RIP Power Supply Specification (Ref. 90) which defines the design of the RIP power supplies. My assessment has focussed on the adequacy of the RIP power supply system to support the RIP system during all required operating modes.

406. The RIP power supply system specification describes:

- System architecture.
- Operation of the RIP power supply system in all operating modes.
- Design specification for the system components and design calculations for demonstrating the adequacy of the ratings specified.

407. The RIP systems are supplied by the Safety Class 3 EPS. There are ten RIP motors, each fed by a dedicated Adjustable Speed Drive (ASD). The ASDs receive power from four Motor-Generator (MG) sets via an input transformer; two MG sets supplying three ASDs each and two MG sets supplying two ASDs each. Figure 3 shows an overview of the RIP power supply system.

408. The RIP system is initiated via a hardwired control system in the MCR. Upon reaching a lower frequency set point the RIP system is deemed to be operational. Once operational, the speed of the RIP motors is determined by the Recirculation Flow Control (RFC) System. The RFC system provides the set point to the ASD, and the ASD derives a specific voltage and frequency as determined by the RFC to the RIP, thereby controlling the speed of the RIP.

409. The specification details two trip systems which trip the RIPs through circuit breakers which are situated between the MG sets and the ASDs. The Recirculation Pump Trip (RPT) trip operates into the Safety Class 3 circuit breakers as defined by plant operating procedures. The Anticipated Transient Without Scram (ATWS) trip operates into SC2 circuit breakers to trip all RIPs.

410. The MG sets provide limited inertia based ride though to limit the impact of electrical transients, including loss of offsite power, in order to provide predictable changes to coolant flow. The MG sets constantly supply electrical power to their ASD drives under normal operation conditions and for a limited time on interruption or loss of power supply to the input of the MG set

411. In response to RQ-ABWR-1188 (Ref. 70) Hitachi-GE has identified the possibility of the RIP power supply system containing SMART devices in supporting protection and automatic control functions. The consequence of CCF of any SMART devices is analysed and results in the initiation of a reactor trip in all cases.

412. The RIP power supply specification provides electrical calculations for determining the rating of the ASD, input transformer and MG set based on the RIP pump data.

4.12.1.2 Findings

413. The RIP Power Supply Specification provides a good presentation of the structure and the operational requirements of the system in all modes. I consider that the document clearly defines the required specification for each of the key components and I consider that this will result in an effective RIP power supply system.

414. I am satisfied that the design change in order to satisfy the Grid Code requirement for fault ride through has increased the overall robustness of the system. The requirement for all RIP pumps to be supplied via MG sets has increased tolerance to both short (<500 ms) and longer (>500 ms) electrical transients. The use of MG sets also reduces the impact of harmonic distortion as the MG set is mechanically coupled but electrically isolated from the supply source.

415. I consider that the trip functions for RPT and ATWS are appropriately classified as they align with their associated system classification. This ensures the breakers operated by the trip function are classified in accordance with the nuclear safety function they perform.

416. I am content that Hitachi-GE has presented an appropriate understanding of the impact of the use of SMART devices in the RIP power supply system. Hitachi-GE has identified the possible location of SMART devices in the RIP power supply system and any devices will be captured in List of Smart Devices in Electrical System to enable qualification requirements to be defined. I consider that the failure modes described are based on sound principles and will support reactor SCRAM before fuel temperatures exceed design basis levels.

417. I consider that the electrical calculations for determining the size of the ASDs, input transformers and MG sets are based on appropriate data and contain conservative margins at each stage of the calculations. I am therefore content that the RIP power supply system specification defines adequate ratings to support performance of its safety related duty.

418. In conclusion, I am content that the RIP power supply system specification adequately defines the requirements for the RIP power supply system to support the RIP system in all operating modes.

4.13 Installation Practice

419. Hitachi-GE has presented a set of design principles covering installation practice for the UK ABWR in the following documents:

- Topic Report on Electrical Installation (Ref. 71).
- Electrical Panel Layout Plan.

- Electrical Penetration Specification (Ref. 72).
- Electrical Equipment and Raceway Separation Plan.

420. I have taken into account the resolution of RO-ABWR-0078(Ref.73): Exceptions to Segregation, which was raised in the Internal Hazards topic area. The RO required Hitachi-GE to provide a design philosophy and a set of rules to apply for segregation of C&I, electrical and mechanical SSCs.

421. The Topic Report on Electrical Installation also references specifications for the following topics which I have assessed under the relevant topics in this report:

- Earthing System
- Lighting System
- Communication System

4.13.1 Electrical Equipment and Raceway Separation Plan

4.13.1.1 Assessment

422. The Electrical Equipment and Raceway Separation Plan defines four methods of providing separation for electrical equipment, electrical panels and electrical raceways that are applied in the UK ABWR design. These are:

- Separation of equipment, panels and raceways based on segregation by civil structures.
- Separation of equipment, panels and raceways based on separation by barrier or distance.
- Separation of electrical circuits between different divisions by isolators.
- Separation according to voltage or signal level of the circuits (e.g. power circuits, C&I circuits).

423. The plan defines how these methods are applied to different circuit types including Reactor Protection System (RPS) circuits, Engineered Safety Features and circuits contained within electrical panels. Where methods of separation cannot be maintained, for example within electrical panels, Hitachi-GE has defined additional countermeasures such as the use of flame retardant barriers within panels.

424. The plan presents various separation scenarios between cable raceways of different Safety Classes with descriptions of how the separation will be provided for each scenario:

- Separation of SC1 division raceways.
- Separation of SC1 and SC 3/non-classified raceways.
- Separation of SC1 division raceways in MCR and RCCV.
- Separation of SC2 raceways from SC1 or SC3 / non classified raceways.

425. Where divisional segregation could be compromised by fire, the use of 3-hour fire rated cable wrapping is proposed. Hitachi-GE confirmed that the impact of fire wrapping on cable heat loading will be taken into account when specifying cable sizes.

4.13.1.2 Findings

426. I am content that the design principles described for the UK ABWR electrical system are appropriate for maintaining adequate separation between electrical equipment, panels and raceways to prevent faults in one division impacting on other divisions.

427. The four methods of achieving separation are based on sound principles and relevant good practice and I consider that the application of the principles will result in an electrical system that is robust against fault propagation between divisions.

428. Hitachi-GE has confirmed the use of fire wrapping will be by exception and has demonstrated an understanding of the potential impact on the cable design. On this basis I consider the use of wrapping to be acceptable.

429. I consider that the design principles described for the UK ABWR design are appropriate to provide isolation between circuits of different safety classes and types.

4.13.2 Electrical Panel Layout Plan

4.13.2.1 Assessment

430. The electrical panel layout plan describes the same four methods for providing separation as described in the electrical equipment and raceway separation plan.

431. The plan describes how civil structures and barriers will be used to provide panel separation. It also presents specific separation principles for various panel types. This includes the principle of locating safety classified panels in safety classified rooms and to separate panels by division.

432. Hitachi-GE has presented panel layout designs taking into consideration panel size, surrounding space requirements and installation space requirements. This forms the basis of the concept plant layout drawings contained within the plan.

4.13.2.2 Findings

433. I consider that Hitachi-GE has presented an electrical panel layout design based on sound principles that are appropriate for the purpose of GDA.

434. There is a risk that the electrical panel layout design may be impacted by the switchgear design, as assessed in Section 4.9 of this report. However Hitachi-GE has identified options for creating additional switchroom space to accommodate switchgear with a larger footprint and I consider for the purposes of GDA that this provides adequate risk mitigation.

4.13.3 Electrical Penetrations

4.13.3.1 Assessment

435. The Electrical Penetrations Specification describes outline designs for the Electrical Penetration Assemblies (EPA) for RCCV penetrations. These include environmental conditions for normal and abnormal operations as defined in the Hitachi-GE document Equipment Design Environment Specification (Ref. 74). The specification defines a minimum lifetime of 60 years for each EPA assembly after taking into account the abnormal environmental conditions.

436. In order to minimise EMI, separate EPAs are used for cables of different voltage levels. Spare EPAs are also installed to accommodate potential future requirements.

437. SC1 cables of each division are contained in separate EPAs to maintain segregation. In order to minimise penetrations through the PCV, the design principles state that SC2, SC3 or non-classified cables can be routed through the same EPAs as the SC1 cables from a different division.

438. The test and inspection principles for the EPAs are defined in IEEE Standard 317, Standard for Electric Penetration Assemblies in Containment Structures for Nuclear Power Generating Stations (Ref.75).

4.13.3.2 Findings

439. I am content that the design principles for electrical penetration assemblies are appropriate for the UK ABWR design. Hitachi-GE has defined the expected environmental conditions consistent with the overarching environmental design specification.

440. I consider the lifetime expectancy of 60 years to be appropriate given the expected lifetime of the UK ABWR and due consideration for ongoing maintenance has been included in the specification.

441. I am satisfied that the approach to segregating cables is adequate. I consider segregation by voltage level to be in line with design principles for reducing EMI and I have assessed the approach to EMI protection further in Section 4.16 of this report. I consider that minimising the number of penetrations complies with relevant good practice and will reduce the maintenance burden placed on operators. Segregation of SC1 cables of different divisions is required in order to maintain segregation and so prevent faults on one division impacting on the operation of other divisions.

442. I consider that routing SC1 cables from one division through an EPA containing SC2, SC3 or non-classified cables from another division to be acceptable in principle. However I would expect the licensee to demonstrate that there is no additional risk of CCF between divisions.

443. I note that the design of the EPAs is based on IEEE standards; which is acceptable for GDA. However, I will expect the licensee to apply appropriate IEC standards or to carry out a gap analysis to show that the use of IEEE standards is equivalent. I will assess the licensee response to this during detailed design.

4.13.4 Overall Conclusions

444. In conclusion, I am content that the document submissions provide an adequate basis for the installation practices to be adopted for the UK ABWR. I will expect that these documents will provide the basis for the installation practices followed during detailed design.

4.14 Lighting and Service Power

445. The UK ABWR EPS supplies the lighting system that provides illumination to support operator actions to be carried out during operation, maintenance, testing and emergency response conditions.

446. My initial assessment identified that the Hitachi-GE design principles for the lighting system should be based on supporting plant operations and this was not evident from the initial design specifications. In response Hitachi-GE set up a joint working group involving Electrical, C&I and Human Factors (HF) disciplines to update the specification for the lighting system based on operational requirements.

447. I have assessed the design with input from C&I and HF assessors to ensure that operational requirements were suitably identified.

4.14.1 Assessment

448. I have assessed the adequacy of the UK ABWR lighting system based on the following Hitachi-GE documents:

- Lighting and Service Power Specification (Ref. 76)
- Topic Report on Electrical Installation
- Response to RQ-ABWR-1519 (Ref. 77)

449. The ABWR lighting system is classified in accordance with Human Based Safety Claims report (Ref. 78) and is comprised of three systems:

- The SC3 lighting system provides lighting in emergency response areas. These are areas where operators are required to work to support nuclear safety such as the Main Control Room (MCR) and Remote Shutdown System (RSS) room.
- The non-safety class lighting system provides lighting in normal operations areas such as the Turbine Building.
- The escape route lighting system provides a safe egress route from buildings for site personnel in case of loss of AC power. The escape route lighting system is classified as SC3 in emergency response areas and non-classified in normal operation areas.

450. During normal operation, the SC3 lighting system is supplied via the SC1 boards. During a LOOP event, 100% of the luminaires are supplied by the Safety Class 1 power supply system. Each of the three SC1 power supply divisions is capable of supplying 50 % of the luminaires; therefore two manually selected divisions are required in service to support 100% of the luminaires. In addition, the SC3 lighting system within the MCR is backed by a dedicated UPS. Illumination levels are maintained as per Table 3 and are in accordance with the requirements defined in Human Factors Engineering Specification (Ref. 47).

451. For the non-safety class lighting system, during normal operation 90 to 95% of luminaries are supplied via the SC3 power supply system. The remaining 5 to 10% of the luminaires are supplied by the SC1 power supply system. During a LOOP event, only the luminaires supported by the Safety Class 1 system remain supplied. Illumination levels are maintained as per Table 2 and are in accordance with the requirements defined in Human Factors Engineering Specification (Ref. 47).

452. Hitachi-GE has confirmed in the RQ response that appropriate isolation will be provided to prevent the propagation of a fault from the SC3 lighting system to the SC1 supply system.

453. The escape route lighting system is supported by batteries rated to supply the luminaires for a minimum of 60 minutes in compliance with BS 5266-8, Emergency Escape Lighting Systems (Ref. 79). This allows the required site personnel time to perform a safe egress of buildings, if required.

454. The service power system supplies general service tools and equipment such as the hoist crane, airlock doors and welding machines. The service power system is supplied from the SC3 power supply system and is not subject to any safety claims.

4.14.2 Findings

455. I consider that the Lighting and Service Power System Specification adequately presents the high-level design principles for the lighting system. I am content that the principles defined provide appropriate support to operators in carrying out their required actions during operation, maintenance, testing and emergency response in order to support nuclear safety.

456. I am satisfied that there is an adequate level of defence-in-depth in the provision of electrical supplies for the lighting system. The dedicated battery backed UPS for MCR lighting will support operator actions following a LOOP and prior to EDG availability. This is a key time period that is appropriately addressed by the provision of the UPS.

457. I consider that the classification of supplies to each system is appropriate and underpinned by the requirements of the Human Based Safety Claims report (Ref.78). I also consider that Hitachi-GE has provided appropriate isolation to prevent fault propagation from a lower to a higher safety class system as the isolation device is specified to the higher of the two safety classes.

458. I am satisfied with the illumination levels described are as defined by the Human Factors Engineering Specification (Ref 47). The lighting levels specified are appropriate to support operators in carrying out the required tasks in support of nuclear safety.

459. I consider that the requirement to have two SC1 divisions in service to supply 100% of luminaires is acceptable. Based on the Human Factors requirements, one SC1 division, supplying 50% of luminaires provides more than the minimum levels of lighting required for operators to carry out work in the MCR.

460. I consider the Emergency Escape Lighting system is designed to appropriate standards and supports the safe egress of operators from buildings, if required.

461. I have assessed the service power system and conclude that the system provides an effective supply for non-safety related equipment and the system has no impact on nuclear safety.

462. In conclusion, I am content that the lighting and service power specification provides an adequate basis for the design of a lighting system that delivers the specified illumination levels to support all operating conditions.

4.15 Communications

463. The communication system supports plant operators in carrying out tasks involving safety classified equipment and thus the provision of an effective communications system supports is required to support nuclear safety.

464. ONR’s initial assessment identified that the Hitachi-GE design principles for the communication system were required to be based on supporting plant operations. In response Hitachi-GE set up a joint working group involving Electrical and Human Factors (HF) disciplines to update the specification for the communication system based on operational requirements.

465. Hitachi-GE has presented the communication system requirements in the Communication System Specification (Ref. 80). This includes requirements for operation and maintenance of communication systems and has been assessed in conjunction with HF assessors.

4.15.1 Assessment

466. The communications system consists of SC3 and non-classified devices. The communications system is classified in accordance with the Human Based Safety Claims report. The SC3 devices are provided in emergency response areas (including MCR, reactor building, B/B) for use during both normal and emergency operation. The non-classified devices are provided in areas where routine activities take place (including the turbine hall) and are for use during normal operation only. Both are supplied by a dedicated communication DC power unit that consists of an 8 hour rated battery, main charger and spare charger.

467. The communication DC power unit is supplied by the three 6.9 kV Safety Class 1 switchboards two switchboards supply the main charger unit and one switchboard supplies the spare charger. The spare charger has a second supply from the B/B power supply system. Only one supply can be selected at any time via a manual selector switch. Appropriate isolation is specified to prevent the propagation of a fault from the SC3 communications system to the SC1 and SC2 power supply systems.

468. Hitachi-GE has defined principles for the provision of diverse communications systems using portable radios and satellite communication devices. These would be based on commercially available equipment and requirements developed on a site-specific basis.

4.15.2 Findings

469. I consider that the communications specification provides an adequate presentation of the high-level design principles required for the communication system. I am content that the principles defined provide appropriate support to operators in carrying out their required actions during operation, maintenance, testing and emergency response in order to support safe plant operation.

470. I consider that the proposed power supply to the communications system is robust and consists of diverse means of supplying power to the communication DC power unit so that the communications system remains available following design basis events.

471. I am satisfied that there is an adequate level of defence-in-depth in the provision of electrical supplies for the communication system. The communication DC power unit will support operator actions following a LOOP and prior to EDG availability. This is a key time period that is appropriately addressed by the provision of the communication DC power unit. The communication DC power unit is also capable of supporting the communication system over a longer period; the 8 hour battery rating providing operators with communication systems in the event of a longer term loss of all AC power.

472. The classification of supplies to each system is consistent and underpinned by the requirements of the Human Based Safety Claims report (Ref.78). I consider that Hitachi-GE has provided appropriate isolation to prevent fault propagation from a lower to a higher safety class system as the isolation device is specified to the higher Safety Class.

473. I am content with the Hitachi-GE proposal to provide a diverse communication system based on portable radios and satellite communication devices. I consider that this is an important diverse provision which needs to be fully developed during detail design activities. These systems provide diverse means of maintaining off-site communications which meets my expectations for addressing Fukushima Interim Recommendation IR-23.

474. In conclusion, I consider that the communications specification provides a thorough set of requirements for the design of a communication system that provides appropriate means of communication in all operating conditions.

4.16 Electromagnetic Interference

4.16.1 Assessment

475. I have assessed the basic principles adopted for the UK ABWR EPS design to provide protection against the hazard caused by EMI as presented in the Topic Report on Electrical Installation (Ref.71).

476. Internal Hazards and C&I inspectors have assessed the EMI hazard in their Step 4 assessment reports. This assessment includes sources and magnitude of EMI and is based on information presented in the Topic Report on EMI (Ref 81).

477. The fundamental design principle of the EPS in relation to EMI is that it is designed, installed and operated to provide immunity and/or protection against EMI. The EPS is designed in accordance with IEC 61000: Electromagnetic Compatibility (Ref. 91) and adopts a number of design principles in order to reduce EMI risks:

- Electrical circuits are separated by voltage level and signal level to prevent EMI interference on lower voltage/signal level circuits.
- Electrical equipment is designed and qualified to prevent EMI emissions.
- Instrumentation circuits use electrostatic and electromagnetic shielded cables.
- Instrumentation cables are separated from electromagnetic noise sources.
- Twisted pair cables and shield cables are used for instrumentation cables.
- Systems sensitive to EMI have cables installed in trunking or in conduits.
- Cable ladders are fitted with equipotential bonding to protect electrical equipment and avoid EMI emissions.

4.16.2 Findings

478. I expect the licensee to consider EMI protection when designing the coordinated surge protection system as assessed in Section 4.11 of this report as this plays an important role in protection against sources of off-site EMI.

479. I expect the licensee to develop a set of requirements and levels for EMI testing in line with IEC 61000. However, I consider that for the purposes of GDA it is acceptable that this has not yet been completed.

480. In conclusion I consider that the design principles are adequate for ensuring the EPS is protected and immune to EMI. I consider that the document Topic Report on Electrical Installation provides sound a set of sound design principles for the EPS for providing immunity and protection against EMI. Measures to restrict EMI by system layout and design are clearly described.

4.17 Geomagnetically Induced Currents

4.17.1 Assessment

481. I expect the design of the EPS for the UK ABWR to take account of the risks from Geomagnetically Induced Currents (GIC) as, unless adequate protective measures are provided, GIC can pose a threat to the integrity of the EPS. Hitachi-GE has stated in the Phase 6 System Study document that it is not possible or practical, as part of GDA, to undertake modelling studies due to the level of design detail required. Hitachi-GE proposes as part of detailed design to provide a substantiated engineering assessment to demonstrate that the UK ABWR design is ALARP.

482. An overview of the GIC hazard has been provided in the External Hazards document on EMI for the Generic Site Envelope (Ref 69). Hitachi-GE has confirmed that no design basis envelope value of GIC is considered in the design of the EPS and compliance is substantiated by engineering judgement. The External Hazards Step 4 Report (Ref. 92) has raised **AF-ABWR-EH-02** that requires the licensee to consider the magnitude, frequency and potential effects of GIC along with reasonably practicable resilience enhancements to protect against these hazards to reduce risks SFAIRP and concludes that the current position does not undermine the generic safety submission.

4.17.2 Findings

483. I am content with the Hitachi-GE position to undertake GIC studies as part of the detailed design when the design information is available. However it is important that a design basis GIC value is determined before major plant equipment is specified as modifying equipment to take account of GIC presents significant difficulties. Therefore I have raised the following assessment finding in addition to the External Hazards Assessment Finding:

AF-ABWR-EE-11: *Due to the fact that the design basis Geomagnetically Induced Current (GIC) value has not been determined and the GIC studies have not been carried out, the licensee shall substantiate the protection measures needed to protect against the threat of GIC to the EPS and incorporate these requirements in purchase specifications for electrical equipment as modifying equipment to take account of GIC presents significant difficulties.*

4.18 Station Blackout Provisions

484. Hitachi-GE has defined Station Blackout (SBO) as a Loss of Off-site Power (LOOP) coincident with a CCF of either the EDGs or CCF of the SC1 6.9 kV switchboards.

485. Hitachi-GE has considered the requirements for the EPS following an SBO event in the Topic Report on Station Black Out. The requirements for EPS performance in the event of an SBO are defined in the Topic Report on Fault Assessment and Topic Report on SBO analysis (Ref. 82).

4.18.1 Assessment

486. The requirements for the following SSCs are considered in the topic report:

- Emergency Diesel Generators (EDG)
- Backup Building Generators (BBG)
- Diverse Additional Generator (DAG)

- Large Power Truck (LPT)
- Small Power Truck (SPT)
- SC1 DC system
- B/B SC2 DC system

487. The topic report on SBO analysis defines a series of Design Basis and Beyond Design Basis SBO events for consideration.

488. The Design Basis SBO Events considered are:

- Short Term LOOP with the CCF of the three EDGs
- Medium Term LOOP with the CCF of the three EDGs
- Short Term LOOP with the CCF of the SC1 Switchboards
- Medium Term LOOP with the CCF of the SC1 Switchboards

489. The Beyond Design Basis SBO events considered are:

- Long Term LOOP with the CCF of the three EDGs
- Long Term LOOP with the CCF of the SC1 Switchboards
- Long Term LOOP with the CCF of three EDGs and two BBGs
- Long Term LOOP with the CCF of the SC1 switchboards and two BBGs

490. It is made clear in the topic report on SBO analysis that safety claims are made on the EDGs, BBGs, SC1 DC system and SC2 DC systems only. The availability of the DAG, LPT and SPT are considered as defence-in-depth provisions but there are no safety claims on these items.

491. The SC1 EPS supported by the EDGs and SC1 DC power supply are defined as the first line of protection for Category A Safety Functions against frequent and infrequent LOOP events.

492. The SC2 B/B is defined as providing the second line of protection against frequent and infrequent LOOP events by providing a diverse source of power to support SSCs providing diverse Category A functions.

493. The DAG is stated to provide a defence-in-depth countermeasure against a subset of all postulated Design Basis and Beyond Design Basis SBO events caused by LOOP and the CCF of the EDGs. The DAG has the capacity to support the RHR and associated systems to bring the reactor to a sustainable safe state.

494. The LPT is stated to also provide a defence-in-depth countermeasure against a subset of all postulated Design Basis and Beyond Design Basis SBO events together with simultaneous actuation failure of the DAG. The LPT is designed to support the same loads as the DAG. I note that the deployment time for the LPT has not been defined and I will expect to see this defined by the licensee as part of detailed design.

495. Hitachi-GE state the SPT supplies power to one division of the SC1 420 V switchboard during SBO as the backup of the failure of the FLSS.

496. Additional requirements are identified in the Station Black-out topic report for the SC1 DC system to support SSCs providing safety functions during SBO events. These requirements are included in the DC Power system SDD and are:

- The SC1 DC batteries are required to supply power to the RCIC for 24 hours without charging.
- The SC1 DC batteries are required to supply power to the SC1 SRVs of Division 1 for 24 hours without charging.
- The SC1 DC batteries are required to supply power to the SC1 SRVs for 8 hours without charging.

497. An additional requirement has been identified for the B/B SC2 DC system as follows:

- The B/B SC2 DC batteries are required to supply power for a period of one hour without charging before the BBGs are initiated.

498. Details are provided of responses from the EPS to each of the defined Design Basis and Beyond Design Basis events. These responses consider the capability of the EPS to maintain supplies to SSCs supporting safety functions in each of these scenarios and describe the responses from the electrical system to support the safety systems.

4.18.2 Findings

499. I consider that the topic report on Station Black-out provides a comprehensive consideration of the required responses from the EPS to defined SBO events. These events are established from fault assessment and there are clear definitions between safety claims and defence-in-depth provisions. The function of the DAG, LPT and SPT are defined to establish their role of providing defence-in-depth support to the operation of the UK ABWR.

500. I consider that the requirements from the SC1 and SC2 battery systems to have the capability to support safety systems during SBO events are defined and substantiated.

501. In conclusion, I am content with the provisions described for responses to SBO events as defined in the SBO topic report.

4.19 Earthing

4.19.1 Assessment

502. I have assessed the UK ABWR earthing provisions based on Hitachi-GE Earthing Specification (Ref. 83) and Electrical Protection and Earthing System Report. As part of the assessment I have considered the role of the earthing system in providing an effective conducting path for support to the lightning protection system which is assessed in Section 4.11 of this report.

503. Table 4 provides a summary of the earthing methods to be utilised on the UK ABWR.

504. The 6.9 kV and 420 V systems are to be high impedance earthed by grounding potential transformers that provides an IT earthing system. This form of earthing enables loads to operate continuously when subjected to a single earth fault. Effective location and removal of earth faults is an important requirement for these systems and I have assessed these provisions in Section 4.10 of this report.

505. The AC C&I power systems are to employ a centre tapped solidly earthed design. This form of earthing results in a high fault level current and I will expect the licensee to provide an effective protection scheme for the system.

506. The DC and UPS systems are to have isolated earths with the insulation integrity continuously monitored. The risks of using an unearthed DC system are that the location of an earth fault can be difficult to detect and while the earth fault is present on one pole the voltage to earth of the other pole will be at the full rated pole-to-pole value. Hitachi-GE has specified the provision of DC earth leakage detectors to support fault location following an earth fault.

507. The earthing system design principles provide a bonding network and earth termination system that allows internal equipment to be integrated into the earthing system. Key design principles include the use of a buried earth mesh connected via trunk lines to earthing networks within the building concrete. Earthing meshes under individual buildings are connected together to form a single earth reference point.

508. The earthing system is to be designed in accordance with BS 7430:2011 Code of practice for protective earthing of electrical installations. The design principles also comply with other relevant standards, as stated in the specification, that give detail on the prevention of personal injury from electric shock, earthing system component sizing and EMI prevention.

509. The principles of inspection and maintenance define the procedures to be followed during plant construction and plant operation to verify the provision of an effective earthing system. Inspection chambers are defined to allow for regular testing and inspection of the earthing connections during plant operation.

510. The earthing system design follows a design process based on BS 50522, Earthing of power installations exceeding 1 kV AC. This iterative process ensures that touch and step voltages are below the necessary voltage levels to ensure operator safety.

511. The earthing system is to be classified in accordance with the classification of the earthing system which the earthing system protective conductors support.

4.19.2 Findings

512. I consider that the principles for design and construction of the earthing system defined in the earthing specification are an appropriate basis for the provision of an effective earthing system. I expect the licensee to adopt the principles in the detailed design of the system.

513. I am content with the codes and standards defined for the design of the earthing system.

514. I consider that the approach to classification of the earthing system is appropriate for the earthing system in performing its safety related duty.

515. I am content that the earthing system design supports the provision of an effective lightning protection system.

516. In conclusion, I am content with the earthing system design submissions and consider that they define an effective approach to design and installation of the earthing system.

4.20 Smart Devices

4.20.1 Assessment

517. Smart Devices are extensively used within the EPS for equipment such as protection relays, battery chargers, UPS systems and voltage regulators. The implementation of these devices needs to be managed by the licensee in the design of the NPP to address the potential for CCF due to the common use of smart devices in equipment items procured from different manufacturers. It is therefore necessary to identify all smart devices utilised on the EPS to ensure that verification and validation is undertaken for each device and implementation is managed to address potential CCF issues.

518. Where smart devices are utilised, a major consideration is to ensure that adequate justification procedures are followed to verify the software used in Smart Devices. The justification procedures have been assessed in the C&I Step 4 Assessment Report and **AF-UKABWR-CI-007** has been raised by ONR C&I requiring further development of the approach.

519. Hitachi-GE has presented its proposals to manage the use of smart devices on electrical systems in the document List of Smart Devices in the Electrical System (Ref.63). This document identifies the potential implementation of smart devices in classified electrical equipment. The document confirms that there will be a common approach to justification across all disciplines in accordance with the Topic Report on Smart Devices (Ref. 84) in the C&I area.

4.20.2 Findings

520. I am content with the approach to justification defined in the List of Smart Devices in the Electrical System as it ensures that a cross discipline approach to justification is adopted.

521. The List of Smart Devices in the Electrical System identifies potential smart device applications as the actual applications can only be finalised based on manufacturer's actual equipment. This will require determination by the licensee as part of detailed design. I am content with this initial identification of potential applications for GDA purposes.

522. An important requirement during detailed design of the UK ABWR will be to manage the application of smart devices on the EPS. This will require the list of smart devices to be updated so that justifications can be conducted in a timely manner and potential for CCF due to the utilisation of the same devices in different systems can be addressed. Therefore I have raised the following assessment finding:

AF-ABWR-EE-12: *It is important to manage the risk of common cause failure from the application of smart devices on the UK ABWR electrical power supply system. Because of the potential for common cause failure due to the utilisation of the same devices in different systems, I require the licensee to develop a process for identifying and managing the implementation of smart devices on the electrical system as part of the equipment procurement process.*

4.21 Safety Assessment Principles

4.21.1 Assessment

523. I have assessed the compliance of the EPS design with the subset of electrical SAPs in Annex 1. The table presents my consideration of the capability of the generic design to comply with each SAP.

524. The subset of SAPs cover redundancy, diversity, defence-in-depth etc. and I consider that the system structure complies with the requirements of the SAPs. The design principles described in the Hitachi-GE documentation are in accordance with the SAPs.

525. I have challenged Hitachi-GE in a number of design areas regarding demonstration of how the design meets the design requirements. This has resulted in changes to the design details in order to achieve compliance.

4.21.2 Findings

526. I conclude from my assessment of the generic electrical design submission that the UK ABWR design is in accordance with the requirements of the SAPs. However I will require further assessment of the detailed design. As part of this assessment I will require the licensee to develop designs in accordance with the Assessment Findings or to justify a suitable equivalent.

527. I have identified a key subset of SAPs in Section 2.1.1 of this report that have particular relevance to my electrical engineering assessment. I am content with the generic UK ABWR EPS design from my assessment against these SAPs.

4.22 Regulatory Observations

528. Regulatory Observations (ROs) are raised when ONR identifies a potential regulatory shortfall which requires action and new work by the RP for it to be resolved. Each RO can have several associated actions.

529. I have raised the following ROs during my assessment of the UK ABWR design:

- RO-ABWR-0038: Additional electrical power source
- RO-ABWR-0063: Compliance with the grid code
- RO-ABWR-0074: Switchgear design for the UK ABWR.

530. I am content that all of the above ROs have been satisfactorily closed.

4.23 Assessment findings

531. During my assessment, 12 residual matters were identified for a future licensee to take forward in their site-specific safety submissions. Details of these are contained within the main sections of this report and they are listed in Annex 4.

532. These matters do not undermine the generic safety submission and are primarily concerned with the provision of site-specific safety case evidence, which will usually become available as the project progresses through the detailed design, construction and commissioning stages. These items are captured as assessment findings.

533. I have recorded residual matters as assessment findings if one or more of the following apply:

- Site specific information is required to resolve this matter;
- resolving this matter depends on licensee design choices;
- the matter raised is related to operator specific features / aspects / choices;

- the resolution of this matter requires licensee choices on organisational matters;
- to resolve this matter the plant needs to be at some stage of construction / commissioning.

534. Assessment Findings are residual matters that must be addressed by the Licensee and the progress of this will be monitored by the regulator.

5 CONCLUSIONS

535. This report presents the findings of my Step 4 electrical engineering assessment of the Hitachi-GE UK ABWR.

536. My assessment conclusions are:

- The generic PCSR and supporting BSC adequately demonstrate for GDA purposes that the EPS for the UK ABWR supports plant safety systems by providing reliable electrical power supplies to support these systems for design basis and beyond design basis events.
- The Hitachi-GE model of the EPS which analyses its capability and stability adequately demonstrates the system’s suitability to support structures, systems and components important to safety at the plant.
- The architecture of the EPS conforms to international guidance.
- Hitachi-GE has demonstrated that generic requirements have been generally addressed in the UK ABWR design for connecting to the UK grid system including consideration of compliance with the UK grid code.

537. To conclude, I am satisfied with the claims, arguments and evidence laid down within the PCSR and supporting documentation for electrical engineering. I consider that from an electrical engineering view point, the Hitachi-GE UK ABWR design is suitable for construction in the UK subject to future permissions and permits beings secured.

538. Several Assessment Findings (Annex 4) have been identified; these are for future licensee to consider and take forward in their site-specific safety submissions. These matters do not undermine the generic safety submission and require licensee input/decision.

6 REFERENCES

1	Generic Design Assessment of Hitachi-GE's UK Advanced Boiling Water Reactor (UK ABWR) - Step 4 Assessment Plan for Electrical Engineering, ONR-GDA-AP-15-003, Revision 0, November 2015, TRIM 2015/404297
2	ONR Guidance on Mechanics of Assessment, TRIM 2013/204124
3	Safety Assessment Principles for Nuclear Facilities. 2014 Edition Revision 0, ONR, November 2014, www.onr.org.uk/saps/saps2014.pdf
4	ONR Technical Assessment Guides, http://www.onr.org.uk/operational/tech_asst_guides/index.htm
5	Generic PCSR Chapter 15 Electrical Power Supplies, GA91-9101-0101-15000, Revision C, August 2017, TRIM 2017/335042
6	Basis of Safety Cases on Electrical Systems, GA91-9201-0002-00033, Revision 5, August 2017, TRIM 2017/333633
7	Not used
8	Electrical Power Distribution System System Design Description, GR10-1001-0001-00001, Revision 5, April 2017, TRIM 2017/163845
9	Electrical Protection and Earthing System Report, GA33-1001-0007-00001, Revision 4, April 2017, TRIM 2017/163796
10	Electrical Modelling Phase 2 Study Report, GA91-9920-0010-00001, Revision 1, February 2017, TRIM 2017/61252
11	Design of Electrical Power Systems for Nuclear Power Plants, Specific Safety Guide No. SSG-34, IAEA, Vienna, 2016, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1673web-53477409.pdf
12	European Council "Stress Tests" for UK nuclear power plants, National Final Report, December 2011, TRIM 2014/137800
13	Emergency Diesel Generator System Design Description, GR43-1001-0002-00001, Revision 3, December 2016, TRIM 2016/490939
14	Diversity Strategy Report, GA33-9920-0001-00001, Revision 5, July 2017, TRIM 2017/290448
15	Topic Report on Station Black Out, GA91-9201-0001-00191, Revision 3, July 2017, TRIM 2017/293893
16	Diverse Additional Generator Capacity Calculation Report, GR45-3807-0001-00001, Revision 0, January 2017, TRIM 2017/39605
17	DG Fuel Oil System Design Description, GR43-1001-0001-00001, Revision 2, June 2017, TRIM 2017/254794
18	Instrument and Control Power Supply System System Design Description, GR47-1001-0001-00001, Revision 3, December 2016, TRIM 2016/496577
19	Single Line Diagram (AC Instrument and Control), GA33-2201-0005-00001, Revision 1, June 2017, TRIM 2017/212866
20	UK ABWR Nuclear Safety and Environmental Design Principles, GA10-0511-0011-00001, Revision 1, July 2017, TRIM 2017/416047
21	Generic PCSR Chapter 14 Control and Instrumentation, GA91-9101-0101-14000, Revision C, August 2017, TRIM 2017/335110
22	Generic PCSR Chapter 4 Safety Management throughout Plant Lifecycle, GA10-9101-0100-04000, Revision C, August 2017, TRIM 2017/334963

23	Generic Technical Specifications, GA80-1502-0002-00001, Revision 3, August 2017, TRIM 2017/337634
24	Nuclear power plants - Electrical power systems - Electrical power systems analysis, IEC 62855:2016
25	MDAL (Master Data and Assumption List), GA91-9920-0004-00001, Revision 6, March 2017, TRIM 2017/104850
26	Electrical Modelling Phase 1 Study Report, GA91-9920-0011-00001, Revision 0, March 2016, TRIM 2016/92766
27	Electrical Modelling Phase 1 Study Brief, GA91-9920-0005-00001, Revision 0, January 2016, TRIM 2016/45876
28	Electrical Power System Modelling Comparison Document, GA91-9920-0015-00001, Revision 0, April 2017, TRIM 2017/153760
29	Electrical Modelling Phase 2 Study Brief, GA91-9920-0006-00001, Revision 1, December 2016, TRIM 2016/504931
30	Short-circuit currents in three-phase a.c. systems, IEC 60909:2016
31	High-voltage switchgear and control gear, IEC 62271:2017
32	Electrical Modelling Phase 3 Study Report, GA91-9920-0012-00001, Revision 1, April 2017, TRIM 2017/163764
33	Electrical Modelling Phase 3 Study Brief, GA91-9920-0013-00001, Revision 0, December 2016, TRIM 2016/498843
34	Electric Grid Reliability and Interface with Nuclear Power Plants, IAEA Guide NG-T 3.8, 2012, http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1542_web.pdf
35	Electrical Modelling Phase 4 Study Report, GA91-9920-0007-00001, Revision 1, April 2017, TRIM 2017/163756
36	Electrical Modelling Phase 4 Study Brief, GA91-9920-0014-00001, Revision 0, January 2017, TRIM 2017/25201
37	Planning Levels for Harmonic Voltage Distortion and the Connection of Non-Linear Equipment to Transmission Systems and Distribution Networks in the United Kingdom, ER G5/4.1, October 2005.
38	RIP Power Supply System Equipment Design Specification, GA33-1001-0014-00001, Revision 1, April 2017, TRIM 2017/173357
39	Electrical Modelling Phase 5 Study Report, GA91-9920-0008-00001, Revision 0, March 2017, TRIM 2017/115348
40	Electrical Modelling Phase 6 Study, GA91-9920-0018-00001, Revision 1, May 2017, TRIM 2017/203109
41	Insulation coordination, IEC 60071:2006.
42	Protection against lightning, IEC 62305:2013
43	Electrical System Modelling Scoping Report, GA33-9920-0004-00001, Revision 2, February 2016, TRIM 2016/61283
44	Guide to Lightning Protection Design of Power Stations, Substations and Underground Transmission Lines, CRIEPI report H06, 2016.
45	Testing and Maintenance of Safety Systems, RO-ABWR-0062, July 2015, TRIM 2015/260354
46	Basis of Electrical Safety Case, RQ-ABWR-0537, May 2015, TRIM 2015/190746
47	Human Factors Engineering Specification, GA91-9201-0001-00037, Revision D,

	January 2017, TRIM 2017/23078
48	The Grid Code, Issue 5, Revision 21, March 2017
49	ABWR compliance with UK Grid Code, RO-ABWR-0063, August 2015, TRIM 2015/311365
50	Response to RO-ABWR-0063 Stage#1 regarding Grid Code Non-Compliance – Preferred options for Island Mode (IM) performance, GA91-9201-0003-00997, Revision 0, October 2015, TRIM 2015/405056
51	Response to RO-ABWR-0063 Stage#1 regarding Grid Code Non-Compliance – Preferred options to achieve FSM compliance, GA91-9201-0003-00998, Revision 0, October 2015, TRIM 2015/405073
52	Response to RO-ABWR-0063 Stage#1 regarding Grid Code Non-Compliance – Preferred options to achieve LFSM compliance, GA91-9201-0003-00999, Revision 0, October 2015, TRIM 2015/405088
53	Response to RO-ABWR-0063 Stage#1 regarding Grid Code Non-Compliance – Preferred options to achieve FRT compliance, GA91-9201-0003-01524, Revision 1, November 2016, TRIM 2016/431682
54	Response to RO-ABWR-0063 Stage#2 regarding Grid Code Non-Compliance, GA91-9201-0003-01733, Revision 2, April 2017, TRIM 2017/167769
55	Fault Ride Through Assessment Report, GA91-9920-0019-00001, Revision 0, April 2017, TRIM 2017/168077
56	6.9 kV Switchgear Design for UK ABWR, RO-ABWR-0074, November 2016, TRIM 2016/429768
57	Topic Report for Switchgear Design, GA91-9201-0001-00169, Revision 3, April 2017, TRIM 2017/163794
58	Electrical Equipment and Raceway Separation Plan, GA33-1001-0001-00001, Revision 3, April 2017, TRIM 2017/163810
59	Electrical Panel Layout Plan, GA33-1001-0005-00001, Revision 3, April 2017, TRIM 2017/158692
60	6.9 kV Switchgear Development and Test Programme, GA91-9201-0003-01950, Revision 0, February 2017, TRIM 2017/82201
61	6.9 kV Switchgear Development Strategies, GA91-9201-0003-01949, Revision 0, March 2017, TRIM 2017/87555
62	Document Submissions for RO-74 Closure (Response to RQ-ABWR-1383), GA91-9201-0003-02074, Revision 0, April 2017, TRIM 2017/167403
63	List of Smart Devices in the Electrical System, GA91-9201-0003-01415, Revision 2, April 2017, TRIM 2017/167608
64	Lightning Protection Specification, RQ-ABWR-0835, April 2016, TRIM 2016/143614
65	Topic Report on Lightning Protection Strategy, GA91-9201-0001-00257, Revision 0, April 2017, TRIM 2017/151766
66	Topic Report on Combined External Hazards, GA91-9201-0001-00118, Revision 3, June 2017, TRIM 2017/256288
67	Topic Report on Fault Assessment, GA91-9201-0001-00022, Revision 6, July 2017, TRIM 2017/287331
68	Not Used
69	Support Document on EMI for Generic Site Envelope, GA91-9201-0003-00585, Revision 4, June 2017, TRIM 2017/247270

70	Queries relating to RIP Power Supply System Equipment Design Specification, RQ-ABWR-1188, December 2016, TRIM 2016/462712
71	Topic Report On Electrical Installation, GA91-9201-0001-00126, Revision 2, April 2017, TRIM 2017/173390
72	Electrical Penetration Specification, GR35-G001-3011-01-01, Revision 2, April 2017, TRIM 2017/153856
73	Exceptions to Segregation, RO-ABWR-0078, January 2017, TRIM 2017/9447
74	Equipment Design Environment Specification, GA11-1001-0004-00001, Revision 0, December 2016, TRIM 2016/504221
75	Standard for Electrical Penetration Assemblies in Containment Structures for Nuclear Power Generating Stations, IEEE 317-2013.
76	Lighting and Service Power Specification, GA33-1001-0006-00001, Revision 2, April 2017, TRIM 2017/165675
77	Queries Relating to Safety Class 3 Lighting System, RQ-ABWR-1519, July 2017, TRIM 2017/279636
78	Human-Based Safety Claims Report, GA91-9201-0001-00043, Revision E, September 2017, TRIM 2017/349973
79	Emergency Escape Lighting Systems, BS5266-8:2004
80	Communication System Specification, GA33-3001-0001-00001, Revision 2, April 2017, TRIM 2017/164052
81	Topic Report of Electro-Magnetic Interference, GA91-9201-0001-00083, Revision 4, June 2017, TRIM 2017/254860
82	Topic Report on SBO Analysis, GA91-9201-0001-00114, Revision 7, June 2017, TRIM 2017/234326
83	Earthing Specification, GR34-1003-0001-00001, Revision 2, February 2017, TRIM 2017/72694
84	Topic Report on SMART Devices, GA91-9201-0001-00046, Revision 3, April 2017, TRIM 2017/137065
85	DC Power Supply System System Design Description, GR42-1001-0001-00001, Revision 3, December 2016, TRIM 2016/501403
86	Uninterruptible AC Power Supply System System Design Description, GR46-1001-0001-00001, Revision 2, October 2016, TRIM 2016/430076
87	Confirmatory Studies for the UK ABWR EPS, Frazer Nash Consultancy, TRIM 2017/275407
88	Not Used
89	Lightning Protection Specification, GA33-1001-0002-00001, Revision 3, April 2017, TRIM 2017/173341
90	Not Used
91	Electromagnetic Compatibility, IEC 61000:2016
92	External Hazards Step 4 Assessment Report, TRIM 2017/98329
93	Backup Building Generator System System Design Description, GR44-1001-0002-00001, Revision 2, December 2016, TRIM 2017/5690
94	Diverse Additional Generator System Design Description, GR45-1001-0001-00001, Revision 1, April 2017, TRIM 2017/166006

95	Internal Hazards Step 4 Assessment Report, TRIM 2017/98141
96	Japanese earthquake and tsunami: Implications for the UK Nuclear Industry, Interim Report, ONR, May 2011, http://www.onr.org.uk/fukushima/interim-report.pdf
97	Control & Instrumentation Step 4 Assessment Report, TRIM 2017/98182
98	Fault Studies Step 4 Assessment Report, TRIM 2017/98169
99	Battery and Charger Capacity Calculation Report, GA33-3807-0001-00001, Revision 1, December 2016, TRIM 2017/21091

Figure 1: AC System Single Line Diagram

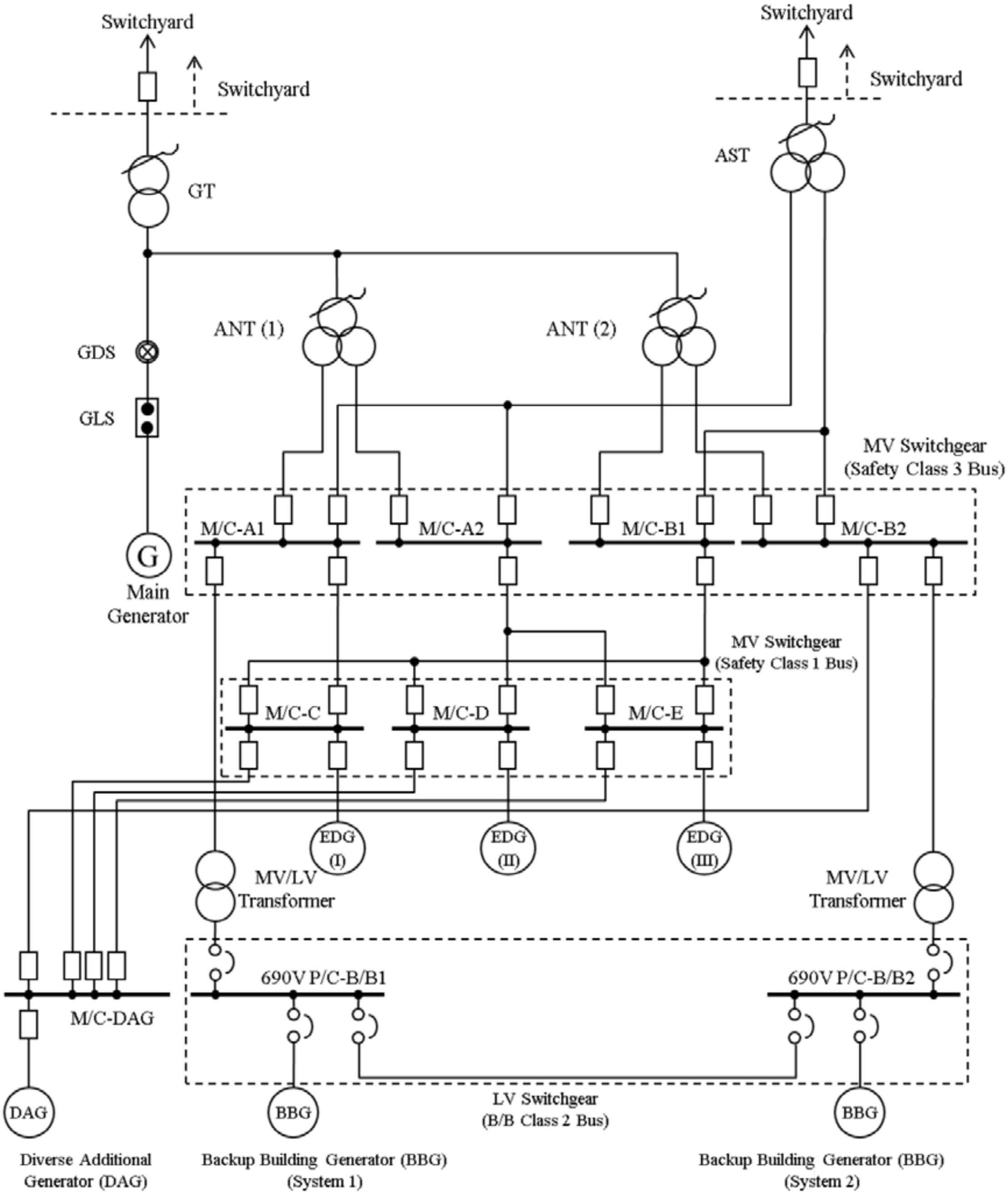

Figure 2: AC and DC C&I Power Supplies Single Line Diagram

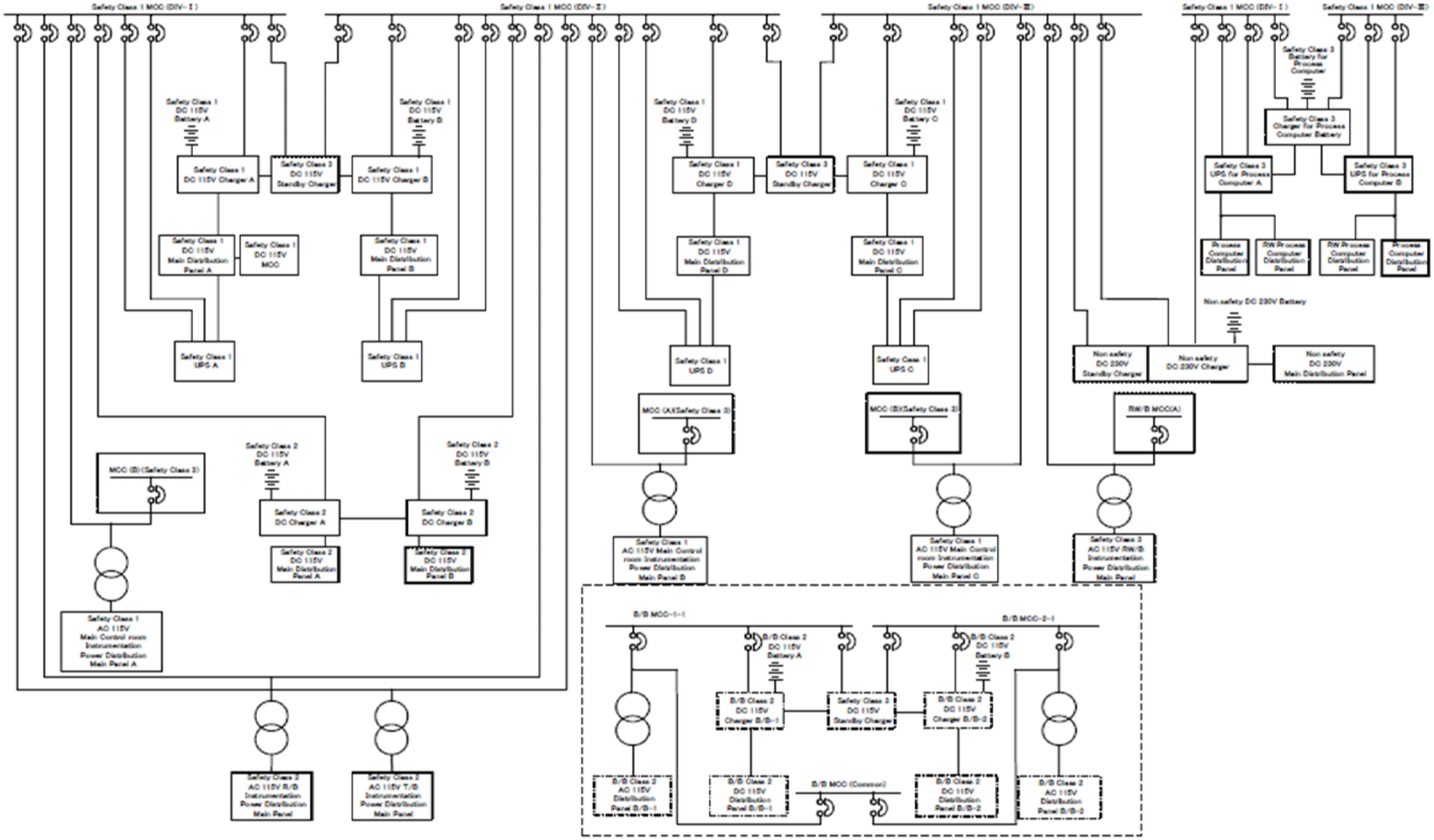

Figure 3: Reactor Internal Pumps Power Supply System Single Line Diagram

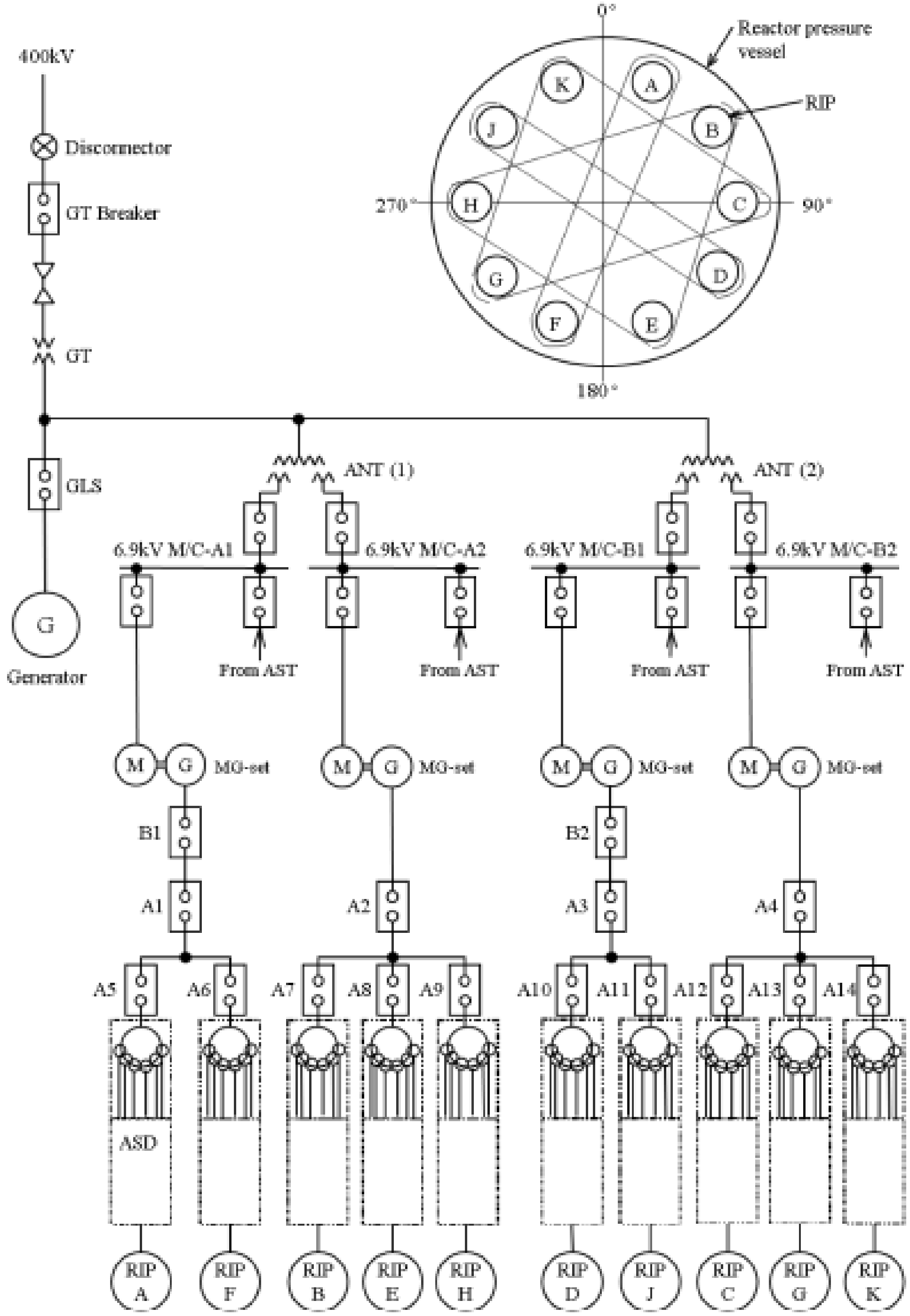

Table 1: Results of Short Circuit Studies – RMS Symmetrical fault Current (kA)

ID	Nominal kV	Rating kA	A3-1	A3-3	A3-5	A3-7	A3-9	A3-11	A3-13	A3-15		A3-17	A3-19	A3-21	A3-23		A3-25	A3-27	A3-29	A3-31		A3-33	A3-35	A3-37	A3-39		A3-41			A3-43		A3-45			A3-47	
										1 *	2 **				1	2				1	2				1	2	C	D	E	1	2	C	D	E	C	D
DAG_Bus	6.9	63	40.65	40.60	49.49	37.51			40.60	34.52	37.63			40.70	34.63	41.88			40.65	34.52	37.63			40.65	34.51	37.57	7.61	7.53	7.33	38.67	41.72					
LPT_Bus	6.9	63																														7.37	7.29	7.10		
M/C_1A1_Bus	6.9	63	56.74	51.80	61.16	52.27			57.59	48.94	58.29			56.74	43.08	52.56			56.81	43.19	58.26			57.33	43.65	53.03				43.08	52.52					
M/C_1A2_Bus	6.9	63	55.47	55.41	61.16	52.27			55.48	45.72	58.28			55.48	45.60	52.56			51.29	51.44	58.29			55.48	45.60	53.03				45.60	52.53					
M/C_1B1_Bus	6.9	63	54.75	49.80	60.26	43.25			49.81	39.90	43.41			60.59	45.77	49.20			54.75	39.90	43.41			54.75	39.89	43.33				40.01	47.43					
M/C_1B2_Bus	6.9	63	47.52	47.44	60.27	43.25			47.45	39.29	43.41			47.58	39.43	49.18			47.52	39.29	43.41			47.52	39.28	43.33				43.39	47.44					
M/C_1C_Bus	6.9	63	51.40	47.36	54.92	47.55	9.94	5.94	53.26	45.95	53.74			51.40	39.99	47.88			51.45	40.08	52.54			51.86	40.46	48.25	7.59			39.99	47.85	7.37				
M/C_1D_Bus	6.9	63	50.24	46.08	54.76	40.27			46.09	37.38	40.41	10.43	5.96	56.16	43.31	46.27			50.24	37.38	40.41			50.24	37.37	40.34		7.52		37.47	43.86		7.29			
M/C_1E_Bus	6.9	63	49.79	49.73	54.26	45.96			49.79	41.54	51.75			49.79	41.54	47.19	10.00	5.95	55.69	47.45	53.00			49.79	41.54	47.55			7.31	41.54	47.17			7.10		
PC-A1-1Bus	0.42	50	51.75	51.55	51.90	47.96			51.78	47.81	48.19			51.75	47.49	47.97			51.75	47.50	48.19			51.77	47.53	47.99				47.49	47.97					
PC-A1-2Bus	0.42	50	45.51	45.32	45.66	44.05			45.55	43.91	44.28			45.51	43.59	44.06			45.52	43.60	44.28			45.54	43.62	44.08				43.59	44.06					
PC-A2_Bus	0.42	50	50.08	50.07	50.27	46.71			50.08	49.63	50.18			50.08	49.62	49.96			50.28	49.91	50.18			50.08	49.62	49.98				49.62	49.96					
PC-AdB_A_Bus	0.42	50	37.15	37.15	37.29	37.06			37.15	36.85	37.22			37.15	36.84	37.07			37.29	37.05	37.22			37.15	36.84	37.08				36.84	37.07					
PC-AdB_B_Bus	0.42	50	36.98	36.98	37.33	36.82			36.98	36.64	36.83			36.98	36.65	37.04			36.98	36.64	36.83			36.98	36.64	36.82				36.83	36.98					
PC-B/B1_Bus	0.69	50	41.62	41.41	41.78	41.44			41.55	41.28	41.68			41.62	40.95	41.45			41.62	40.95	41.68	26.14	13.22	50.90	50.23	50.73				40.95	41.45					
PC-B/B2_Bus	0.69	50	41.32	41.31	41.86	37.35			41.31	37.08	37.36			41.32	37.09	37.68			41.32	37.08	37.36			41.32	37.08	37.36				37.36	37.59					
PC-B1-1Bus	0.42	50	44.08	43.87	44.27	43.53			43.87	43.31	43.54			44.28	43.67	43.85			44.08	43.31	43.54			44.08	43.31	43.53				43.32	43.76					
PC-B1-2Bus	0.42	50	42.88	42.67	43.07	42.33			42.57	42.12	42.34			43.08	42.48	42.65			42.88	42.12	42.34			42.88	42.12	42.34				42.13	42.56					
PC-B2_Bus	0.42	50	47.71	47.70	48.22	47.47			47.70	47.21	47.48			47.71	47.22	47.79			47.71	47.21	47.48			47.71	47.21	47.48				47.48	47.70					
PC-C1-1_Bus	0.42	50	52.94	52.76	53.09	50.21	45.05		53.02	50.12	50.48			52.94	49.76	50.22			52.95	49.77	50.43			52.96	49.79	50.24	35.11			49.75	50.22	34.84				
PC-C1-2_Bus	0.42	50	44.06	43.87	44.20	41.90	41.40		44.13	41.82	42.17			44.06	41.46	41.91			44.06	41.47	42.12			44.08	41.49	41.93	39.04			41.45	41.91	38.76			12.86	
PC-C2_Bus	0.42	50	41.77	41.59	41.90	42.73	35.34		41.84	42.65	42.98			41.77	41.18	41.61			41.77	41.19	41.81			41.79	41.21	41.63	29.97			41.18	41.61	29.72				
PC-D1-1_Bus	0.42	50	50.47	50.27	50.66	48.63			50.27	48.42	48.64	43.09		50.71	48.82	48.99			50.47	48.42	48.64			50.47	48.42	48.63		33.93		48.42	48.86		33.65			
PC-D1-2_Bus	0.42	50	43.69	43.49	43.88	41.20			43.49	40.99	41.21	41.46		43.93	41.39	41.55			43.69	40.99	41.21			43.69	40.99	41.20		38.64		41.00	41.42		38.35			12.55
PC-D2_Bus	0.42	50	41.35	41.16	41.53	40.83			41.16	40.63	40.84	35.05		41.58	41.02	41.17			41.35	40.63	40.84			41.35	40.63	40.83		29.96		40.64	41.04		29.71			
PC-DAG_Bus	0.42	50	43.29	43.28	43.75	43.07			43.28	42.84	43.08			43.29	42.85	43.37			43.29	42.84	43.08			43.29	42.84	43.08	34.35	34.27	34.04	43.17	43.36					
PC-E1_Bus	0.42	50	45.61	45.61	45.79	45.48			45.61	45.20	45.69			45.61	45.19	45.49	41.73		45.84	45.51	45.74			45.61	45.19	45.51			39.01	45.19	45.49			38.73		
PC-E2_Bus	0.42	50	39.90	39.90	40.08	39.76			39.90	39.47	39.98			39.90	39.46	39.78	33.29		40.14	39.79	40.03			39.90	39.46	39.79			30.12	39.46	39.78			29.87		
PC-IB_A_Bus	0.42	50	48.57	48.57	48.76	46.42			48.57	46.12	46.64			48.57	46.11	46.43			48.77	46.39	46.64			48.57	46.11	46.45				46.11	46.43					
PC-IB_B_Bus	0.42	50	48.32	48.31	48.82	46.06			48.31	45.81	46.07			48.32	45.82	46.37			48.32	45.81	46.07			48.32	45.81	46.07				46.07	46.29					
PC-RWB_A_Bus	0.42	50	44.29	44.29	44.45	44.18			44.29	43.93	44.38			44.29	43.92	44.19			44.46	44.16	44.38			44.29	43.92	44.21				43.92	44.19					
PC-RWB_B_Bus	0.42	50	42.02	42.01	42.43	41.82			42.01	41.61	41.83			42.02	41.62	42.09			42.02	41.61	41.83			42.02	41.61	41.83				41.83	42.02					
PC-SB_A_Bus	0.42	50	43.13	43.13	43.32	41.85			43.13	42.70	43.23			43.13	42.69	43.02			43.32	42.97	43.23			43.13	42.69	43.03				42.69	43.01					
PC-SB_B_Bus	0.42	50	42.71	42.71	43.21	41.33			42.71	42.23	42.49			42.71	42.24	42.79			42.71	42.23	42.49			42.71	42.23	42.49				42.49	42.71					
SPT_Bus	0.42	50																																	12.86	12.55

Table 2: Emergency Response Area Illumination Levels

No.	Lighting Area	Illumination Level	
		Normal Operation (lx)	Emergency Operation (lx)
1	Main control room	500	500
2	RSS panel room	500	500
3	Back-up building panel room	500	500
4	Access routes to Emergency Response Area	100	100

Table 3: Normal Operations Area Illumination Levels

No.	Lighting Area	Illumination Level	
		Normal Operation (lx)	Emergency Operation (lx)
1	Local control panel	300	15-30
2	Computer room	300	15-30
3	R/B operating floor	500	25-50
4	T/B operating floor	200	10-20
5	Emergency D/G rooms and control panel rooms	200	10-20
6	Emergency power supply rooms	200	10-20
7	General machine room area	200	10-20
8	Emergency battery rooms	100	5-10
9	Access route to Class 3 rooms	100	5-10
10	Stairs	100	5-10
11	Inside RCCV	100	0
12	Pipe space, etc.	10	0

Table 4: Summary of UK ABWR Earthing Methods

System	Voltage	Method of Earthing
Main turbo-alternator	26.5 kV AC three-phase	High Impedance earthing via a neutral grounding transformer.
ANT and AST secondary sides	6.9 kV AC three-phase	Impedance earthing via a neutral grounding transformer.
EDG, DAG	6.9 kV AC three phase	High Impedance earthing via a neutral grounding transformer (IT earthing).
BBG	690 V AC three phase	High Impedance earthing via a neutral grounding transformer (IT earthing).
6.9 kV System	6.9 kV AC three-phase	High Impedance earthing via a grounding potential transformer (IT earthing).
420 V System	420 V AC three-phase	High Impedance earthing via a grounding potential transformer (IT earthing).
AC C&I power supply systems	Various	Centre tapped solidly earthed
DC and UPS systems	Various	Isolated earth (IT earthing)

Annex 1

Safety Assessment Principles

SAP No	SAP Title	Description
EQU.1	Qualification Procedures	Qualification procedures should be in place to confirm that structures, systems and components that are important to safety will perform their required safety function(s) throughout their operational lives.
EDR.1	Failure to Safety	Due account should be taken of the need for structures, systems and components important to safety to be designed to be inherently safe or to fail in a safe manner and potential failure modes should be identified, using a formal analysis where appropriate.
EDR.2	Redundancy, diversity and segregation	Redundancy, diversity and segregation should be incorporated as appropriate within the designs of structures, systems and components important to safety
EDR.3	Common cause failure	Common cause failure (CCF) should be explicitly addressed where a structure, system or component important to safety employs redundant or diverse components, measurements or actions to provide high reliability.
EDR.4	Single Failure Criterion	During any normally permissible state of plant availability no single random failure, assumed to occur anywhere within the systems provided to secure a safety function, should prevent the performance of that safety function.
ERL.2	Measures to achieve reliability	The measures whereby the claimed reliability of systems and components will be achieved in practice should be stated.
ERL.4	Margins of Conservatism	Where multiple safety-related systems and/or other means are claimed to reduce the frequency of a fault sequence, the reduction in frequency should have a margin of conservatism with allowance for uncertainties.
EMT.1	Identification of requirements	Safety requirements for in-service testing, inspection and other maintenance procedures and frequencies should be identified in the safety case.
EMT.3	Type Testing	Structures, systems and components important to safety should be type tested before they are installed to conditions equal to, at least, the most severe expected in all modes of normal operational service.
EMT.6	Reliability Claims	Provision should be made for testing, maintaining, monitoring and inspecting structures, systems and components important to safety in service or at intervals throughout plant life commensurate with the

		reliability required of each item.
EMT.7	Functional Testing	In-service functional testing of systems, structures and components important to safety should prove the complete system and the safety-related function of each component.
ELO.1	Access	The design and layout should facilitate access for necessary activities and minimise adverse interactions during such activities.
EHA.10	Electromagnetic Interference	The design of facility should include protective measures against the effects of electromagnetic interference.
ESS.1	Requirement for safety systems	All nuclear facilities should be provided with safety systems that reduce the frequency or limit the consequences of fault sequences, and that achieve and maintain a defined safe state.
ESS.2	Determination of safety system requirements	The extent of safety system provisions, their functions, levels of protection necessary to achieve defence in depth and required reliabilities should be determined.
ESS.3	Monitoring of plant safety	Adequate provisions should be made to enable the monitoring of the plant state in relation to safety and to enable the taking of any necessary safety actions.
ESS.7	Diversity in the detection of fault sequences	The protection system should employ diversity in the detection of fault sequences, preferably by the use of different variables, and in the initiation of the safety system action to terminate the sequences.
ESS.8	Automatic Initiation	A safety system should be automatically initiated and normally no human intervention should be necessary following the start of a requirement for protective action.
ESS.9	Time for human intervention	Where human intervention is necessary following the start of a requirement for protective action, then the time before such intervention is required should be demonstrated to be sufficient.
ESS.10	Definition of capability	The capability of a safety system, and of each of its constituent sub-systems and components, should be defined.
ESS.11	Demonstration of adequacy	The adequacy of the system design as the means of achieving the specified function and reliability should be demonstrated for each system.
ESS.12	Prevention of service infringement	Adequate provisions should be made to prevent the infringement of any service requirement of a safety system, its sub-systems and components.
ESS.15	Alteration of configuration, operational logic or associated data	No means should be provided, or be readily available, by which the configuration of a safety system, its operational logic or the associated data (trip levels etc) may be altered, other than by specifically engineered and adequately secured maintenance/testing provisions used under strict administrative control.

ESS.16	No dependency on external sources of energy	Where practicable, following a safety system action, maintaining a safe facility state should not depend on an external source of energy.
ESS.19	Dedication to a single task	A safety system should be dedicated to the single task of performing its safety function.
ESS.20	Avoidance of connections to other systems	Connections between any part of a safety system (other than the safety system support features) and a system external to the plant should be avoided
ESS.21	Reliability	The design of a safety system should avoid complexity, apply a fail-safe approach and incorporate the means of revealing internal faults from the time of their occurrence.
ESS.23	Allowance for unavailability of equipment	In determining the safety system provisions, allowance should be made for the unavailability of equipment
ESS.24	Minimum operational requirements	The minimum amount of operational safety system equipment for which any specified facility operation will be permitted should be defined and shown to meet the single failure criterion.
EES.1	Provision	Essential services should be provided to ensure the maintenance of a safe plant state in normal operation and fault conditions.
EES.2	Sources external to site	Where a service is obtained from a source external to the nuclear site, that service should also be obtainable from a back-up source on the site.
EES.3	Capacity , duration, availability and reliability	Each back-up source should have the capacity, duration, availability and reliability to meet the maximum requirements of its dependent systems.
EES.4	Sharing with other plants	Where essential services are shared with other plants on a multi-facility site, the effect of the sharing should be taken into account in assessing the adequacy of the supply
EES.5	Cross connection to other services	The capacity of the essential services to meet the demands of the supported safety functional requirement(s) should not be undermined by making cross-connections to services provided for non-safety functions.
EES.6	Alternative sources	Alternative sources of essential services should be designed so that their reliability would not be prejudiced by adverse conditions in the services to which they provide a back-up.
EES.7	Protection devices	Protection devices provided for essential service components or systems should be limited to those that are necessary and that are consistent with facility requirements.
EES.8	Sources external to the site	Where a source external to the nuclear site is employed as the only source of the essential services needed to provide adequate protection, the specification and in particular the availability and reliability should be the same as for an on-site source.

EES.9	Loss of service	Essential services should be designed so that the simultaneous loss of both normal and back-up services will not lead to unacceptable consequences.
EKP.3	Defence in depth	A nuclear facility should be so designed and operated that defence in depth against potentially significant faults or failures is achieved by the provision of several levels of protection
EKP.5	Safety measures	Safety measures should be identified to deliver the required safety function(s).

Annex 2

Technical Assessment Guide

TAG Ref	TAG Title
NS-TAST-GD-019 Rev. 3	Essential Services

Annex 3

National and International Standards and Guidance

National and International Standards and Guidance
Design of Electrical Power Systems for Nuclear Power Plants SSG-34. March 2016 www.iaea.org.

Annex 4

Assessment Findings

Assessment Finding Number	Assessment Finding	Report Section Reference
AF-ABWR-EE-01	ONR’s GDA Step 4 assessment has identified some discrepancies and ambiguities amongst the claims made in the electrical engineering basis of safety case report on the diverse additional generator (DAG). It is therefore difficult to fully determine all the contributions it makes to nuclear safety. The licensee shall update the UK ABWR safety case so that role of the DAG is clearly established.	4.4.2.2
AF-ABWR-EE-02	A major claim in Hitachi-GE’s GDA safety case for the UK ABWR is that its Backup Building (B/B) Safety Class 2 electrical systems contain no ‘smart’ devices, such that the electrical power supply system (EPS) remains effective even if the Safety Class 1 electrical systems are affected by a common cause failure (CCF). This claim could be a challenge to meet due to the availability of suitable equipment from suppliers and potential long-term obsolescence issues. Therefore, the licensee shall demonstrate that the B/B Safety Class 2 electrical equipment included in the final design do not utilise ‘smart’ devices or provide appropriate mitigations where it is not possible or appropriate to achieve this.	4.5.2
AF-ABWR-EE-03	Hitachi-GE has only demonstrated limited capacity margins on key electrical safety systems, notably the Class 1 emergency diesel generators, during GDA. The licensee shall demonstrate that the final design has sufficient capacity margins to ensure that all required nuclear safety functions can be provided with a high degree of confidence, or modify the design appropriately.	4.6.2.1.2
AF-ABWR-EE-04	Hitachi-GE has performed analysis during GDA that demonstrates that the UK ABWR’s electrical protection system (EPS) could be adversely affected by open phase faults. The licensee shall develop and implement a protection scheme against open phase faults for the UK ABWR that takes account of the analysis results.	4.6.3.2.2

AF-ABWR-EE-05	An adequate direct current (DC) electrical system is essential for nuclear safety. ONR's GDA Step 4 assessment has identified two issues that the licensee will need to address as part of the detailed design. • Adequate battery capacity in the direct current (DC) electrical systems is essential for nuclear safety. Hitachi-GE's load flow studies have demonstrated small design margin in some fault scenarios. The licensee shall demonstrate that it understands all the requirements on the DC electrical system and can show adequate design margins, ahead of finalising the UK ABWR design and battery supplier. • The provision of an isolated earth system on the DC power system provides the ability for the system to continue operating following an earth fault. An essential requirement for the implementation of this scheme is the capability to be able to effectively locate faults so as to minimise the repair time and support continuity of supplies. The licensee shall define the methods that will be employed for locating earth faults on the DC system so that earth faults can be effectively located, allowing the DC system to continue to be available to support its safety related duty.	4.6.4.1.2 and 4.10.2.2
AF-ABWR-EE-06	An effective lightning protection system provides a significant nuclear safety function, but there are limitations to the extent Hitachi-GE could demonstrate its functionality during GDA. The licensee shall conduct lightning protection studies based on actual design data to demonstrate the resilience of the electrical power supply system (EPS) to lightning strikes and to demonstrate effective coordination of Surge Protection Devices.	4.6.6.1.2
AF-ABWR-EE-07	A vital consideration in the design of the electrical power supply system (EPS) is the ability to perform necessary maintenance and testing activities without compromising the ability of structures, systems and components (SSCs) supported by the EPS to perform the safety functions claimed in the safety case. However this has not been demonstrated during GDA as the focus has been on defining the redundancy targets. The licensee shall develop an	4.7.2

	electrical maintenance and testing philosophy document in accordance with the high-level plant maintenance philosophy document. This shall demonstrate that safety significant electrical SSCs can be maintained and tested without challenging the redundancy requirements that are derived from the safety case claims and classification of the SSC.	
AF-ABWR-EE-08	There were limitations in the extent to which Hitachi-GE has considered the requirements of the UK Grid Code in GDA, and those studies which have been performed have identified the need for design changes to be implemented. The licensee shall finalise the work to demonstrate that the UK ABWR complies with the UK Grid Code and implement any necessary design changes.	4.8.2
AF-ABWR-EE-09	Consistent with the principle of reducing risks to be as low as is reasonably practicable (ALARP), Hitachi-GE has identified credible options to be considered outside of GDA to further reduce faults in the low voltage (LV) switchgear. However, some of these options could invalidate the electrical system studies which underpin the GDA safety case. Therefore, the licensee shall demonstrate the on-going validity of the GDA system studies once the final design of the LV switchgear is established or provide an alternative solution which ensures the LV equipment short circuit rating is appropriate.	4.9.2
AF-ABWR-EE-10	The UK ABWR GDA safety case establishes a requirement for 6.9 kV switchgear with a high fault rating. However, the proposed equipment is still at an early testing and development stage. If it becomes necessary to change the approach by utilising similar equipment currently available from alternative manufactures, there could be significant impacts on site layout or the UK ABWR electrical system design. The licensee shall establish a process for managing and tracking the future development and testing of the proposed switchgear equipment. The implications of the failing to achieve the desired design intent and needing to switch to an alternative strategy shall be kept under review.	4.9.2
AF-ABWR-EE-11	Due to the fact that the design basis Geomagnetically Induced Current (GIC) value has not been determined and the GIC studies have not been carried out, the licensee shall	4.17.2

	substantiate the protection measures needed to protect against the threat of GIC to the EPS and incorporate these requirements in purchase specifications for electrical equipment as modifying equipment to take account of GIC presents significant difficulties.	
AF-ABWR-EE-12	It is important to manage the risk of common cause failure from the application of smart devices on the UK ABWR electrical power supply system. Because of the potential for common cause failure due to the utilisation of the same devices in different systems, I require the licensee to develop a process for identifying and managing the implementation of smart devices on the electrical system as part of the equipment procurement process.	4.20.2