Office for Nuclear Regulation

New Reactors Division – Generic Design Assessment

Step 4 Assessment of Electrical Engineering for the UK HPR1000 Reactor

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EXECUTIVE SUMMARY

This report presents the findings of my assessment of the Electrical Engineering aspects of the UK HPR1000 reactor design undertaken as part of the Office for Nuclear Regulation's (ONR) Generic Design Assessment (GDA). My assessment was carried out using a Pre-Construction Safety Report (PCSR) and supporting documentation submitted by the Requesting Party (RP).

The objective of my assessment was to make a judgement, from an electrical engineering perspective, on whether the generic UK HPR1000 design could be built and operated in Great Britain, in a way that is acceptably safe and secure (subject to site specific assessment and licensing), as an input into ONR's overall decision on whether to grant a Design Acceptance Confirmation (DAC).

The scope of my GDA assessment was to review the safety aspects of the generic UK HPR1000 design by examining the claims, arguments and supporting evidence in the safety case. My assessment during Step 4 of GDA built upon the work undertaken in Steps 2 and 3 and enabled a judgement to be made on the adequacy of the electrical engineering information contained within the PCSR and supporting documentation.

My assessment focussed on seeking confidence that the following aspects of the generic UK HPR1000 safety case were met:

- 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.
- Electrical systems remain stable to perform relevant duties in all defined operating conditions, including fault conditions.
- Nuclear power plant is capable of being connected to the UK transmission system.

The conclusions from my assessment are:

- The generic safety case comprising of the PCSR, supporting Basis of Safety Case and analyses adequately demonstrate for the purposes of GDA that the electrical systems are capable of supporting plant safety functions in design basis and design extension conditions.
- The architecture of the electrical systems is consistent with international guidance.
- The electrical system studies demonstrate the ability of the electrical systems to support structures, systems and components important to safety at the nuclear power plant.
- Using generic connection data, the RP has shown that the nuclear power plant could be capable of being connected to the UK transmission system.
- I am satisfied that the expectations of ONR's Safety Assessment Principles and Technical Assessment Guides are met in generic UK HPR1000 design.

These conclusions are based upon the following factors:

- A detailed and in-depth technical assessment, on a sampling basis, of the claims, arguments and evidence presented in the PCSR for the generic UK HPR1000 design.

- A review of the electrical system studies conducted by the RP based on the results of confirmatory studies, which have been undertaken for ONR by Technical Support Contractors (TSCs).
- Review of the electrical system architecture against relevant ONR Safety Assessment Principles and international guidance.
- Detailed technical interactions on many occasions with the RP, alongside the assessment of the responses to the substantial number of Regulatory Queries (RQs) and Regulatory Observations (ROs) raised during the GDA.

A number of matters remain, which I judge are appropriate for a licensee to consider and take forward in its site-specific safety submissions. These matters do not undermine the generic UK HPR1000 design and safety submissions but are primarily concerned with the provision of site-specific safety case evidence which will become available as the project progresses through the detailed design, construction and commissioning stages. These matters have been captured in sixteen assessment findings.

Overall, based on my assessment undertaken in accordance with ONR's procedures, the claims, arguments, and evidence laid down within the PCSR and supporting documentation submitted as part of the GDA process present an adequate safety case for the generic UK HPR1000 design. I recommend that from an electrical engineering perspective a DAC may be granted.

LIST OF ABBREVIATIONS

AC	Alternating Current
ALARP	As Low As Reasonably Practicable
AT	Auxiliary Transformer
BoSC	Basis of Safety Case
BS	British Standard
BSI	British Standards Institution
BSL	Basic Safety Level (in SAPs)
BSO	Basic Safety Objective (in SAPs)
C&I	Control and Instrumentation
CAE	Claims-Arguments-Evidence
CCF	Common Cause Failure
CGN	China General Nuclear Power Corporation
CI	Conventional Island
CRF	Circulating Water System
DAC	Design Acceptance Confirmation
DBA	Design Basis Analysis
DBC	Design Basis Condition
DC	Direct Current
DEC	Design Extension Condition
DEL	Safety Chilled Water System
DG	Diesel Generator
DMGL	Delivery Management Group Lead
DRP	Design Reference Point
DVD	Diesel Building Ventilation System
DVL	Electrical Division of Safeguard Building Ventilation System
ECC	Emergency Control Centre
EDG	Emergency Diesel Generator
EMI	Electromagnetic Interference
EMIT	Examination. Maintenance, Inspection and Testing
EN	European Standard
EPDS	Emergency Power Distribution System
EPS	Electrical Power System
FCG3	Fangchenggang Nuclear Power Plant Unit 3
FC{1,2,3}	Safety Function Category {1,2,3}
F-SC{1,2,3}	Safety Function Classification {1,2,3}
GDA	Generic Design Assessment

GNI	General Nuclear International Ltd.
GNSL	General Nuclear System Ltd.
GIC	Geomagnetic Induced Current
HF	Human Factors
HOW2	(ONR) Business Management System
HSE	Health and Safety Executive
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
iDAC	Interim Design Acceptance Confirmation
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
JPO	(Regulators') Joint Programme Office
KDS [DAS]	Diverse Actuation System
LAA	Nuclear Island 220V DC Power Supply and Distribution System (2 hour) Division A
LAP	Nuclear Island 220V DC Power Supply and Distribution System (24 hour) Division A
LGA	Conventional Island 10kV Switchboard Division A
LGB	Conventional Island 10kV Switchboard Division A
LHA	Nuclear Island 10kV Switchboard Division A
LHP	Nuclear Island Emergency Diesel Generator Division A
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
LJP	Nuclear Island Station Blackout Diesel Generator Division A
LV	Low Voltage
LVA	Nuclear Island 380V AC Uninterruptible Power System (2 hour) Division A
LVP	Nuclear Island 380V AC Uninterruptible Power System (24 hour) Division A
MCR	Main Control Room
MDG	Mobile Diesel Generator
MDSL	Master Document Submission List
MV	Medium Voltage
NI	Nuclear Island
NPDS	Normal Power Distribution System
NPP	Nuclear Power Plant
ONR	Office for Nuclear Regulation
OpEx	Operational Experience
PCER	Pre-construction Environmental Report
PCI	Pellet-Cladding Interaction
PCSR	Pre-construction Safety Report

PIE	Postulated Initiating Event
PPS	Preferred Power Supply
PSA	Probabilistic Safety Analysis
PSR	Preliminary Safety Report (includes security and environment)
PSS	Power System Stabiliser
PTI	Project Technical Inspector
PWR	Pressurised Water Reactor
QA	Quality Assurance
RCP	Reactor Coolant Pump
RGP	Relevant Good Practice
RI	Regulatory Issue
RO	Regulatory Observation
ROA	Regulatory Observation Action
RP	Requesting Party
RPS	Reactor Protection System
RSS	Remote Shutdown Station
RQ	Regulatory Query
SAA	Severe Accident Analysis
SAP(s)	Safety Assessment Principle(s)
SBO	Station Blackout
SDM	System Design Manual
SFAIRP	So Far As Is Reasonably Practicable
SFP	Spent Fuel Pool
SoDA	(Environment Agency's) Statement of Design Acceptability
SPDS	Station Blackout Power Distribution System
SSC	Structures, Systems and Components
ST	Standby Transformer
TAG	Technical Assessment Guide(s)
TLACP	Total Loss of AC Power
TSC	Technical Support Contractor
UPS	Uninterruptible Power Supply
UT	Unit Transformer
WENRA	Western European Nuclear Regulators Association

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1 INTRODUCTION

1.1 Background

1. This report presents my assessment conducted as part of the Office for Nuclear Regulation (ONR) Generic Design Assessment (GDA) for the generic UK HPR1000 design within the topic of electrical engineering.

2. The UK HPR1000 is a pressurised water reactor (PWR) design proposed for deployment in the UK. General Nuclear System Ltd (GNSL) is a UK-registered company that was established to implement the GDA on the UK HPR1000 design on behalf of three joint requesting parties (RP), i.e. China General Nuclear Power Corporation (CGN), EDF SA and General Nuclear International Ltd (GNI).

3. GDA is a process undertaken jointly by the ONR and the Environment Agency. Information on the GDA process is provided in a series of documents published on the joint regulators' website (www.onr.org.uk/new-reactors/index.htm). The outcome from the GDA process sought by the RP is a Design Acceptance Confirmation (DAC) from ONR and a Statement of Design Acceptability (SoDA) from the Environment Agency.

4. The GDA for the generic UK HPR1000 design followed a step-wise approach in a claims-argument-evidence hierarchy which commenced in 2017. Major technical interactions started in Step 2 of GDA which focussed on an examination of the main safety and security claims made by the RP for the UK HPR1000. In Step 3 of GDA, the arguments which underpin those safety and security claims were examined. The Step 2 of GDA reports for individual technical areas, and the summary reports for Steps 2 and 3 of GDA are published on the joint regulators' website. The objective of Step 4 of GDA was to complete an in-depth assessment of the evidence presented by the RP to support and form the basis of the safety and security cases.

5. The full range of items that form part of my assessment is provided in ONR's GDA Guidance to Requesting Parties (Ref. 1). These include:

   - Consideration of issues identified during the earlier Step 2 and 3 of GDA assessments.
   - Judging the design against the Safety Assessment Principles (SAPs) (Ref. 2) and whether the proposed design ensures risks are As Low As Reasonably Practicable (ALARP).
   - Reviewing details of the RP's design controls and quality control arrangements to secure compliance with the design intent.
   - Establishing whether the system performance, safety classification, and reliability requirements are substantiated by a more detailed engineering design.
   - Assessing arrangements for ensuring and assuring that safety claims and assumptions will be realised in the final as-built design.
   - Resolution of identified nuclear safety and security issues or identifying paths for resolution.

6. The purpose of this report is therefore to summarise my assessment in the electrical engineering topic which provides an input to the ONR decision on whether to grant a DAC, or otherwise. This assessment was focused on the submissions made by the RP throughout GDA, including those provided in response to the Regulatory Observations (ROs) and Regulatory Queries (RQs) I raised. Any ROs issued to the RP are published on the GDA's joint regulators' website, together with the corresponding resolution plans.

1.2 Scope of this Report

7. This report presents the findings of my assessment of the electrical engineering of the generic UK HPR1000 design undertaken as part of GDA. I carried out my assessment using the Pre-Construction Safety Report (PCSR) (Ref. 3) and supporting documentation submitted by the RP. My assessment was focussed on considering whether the generic safety case provides an adequate justification for the generic UK HPR1000 design, in line with the objectives for GDA.

1.3 Methodology

8. The methodology for my assessment follows ONR's guidance on the mechanics of assessment, NS-TAST-GD-096 (Ref. 4).

9. My assessment was undertaken in accordance with the requirements of ONR's How2 Business Management System (BMS). ONR's SAPs (Ref. 2), together with supporting Technical Assessment Guides (TAG), were used as the basis for my assessment. Further details are provided in Section 2 of this report. The outputs from my assessment are consistent with ONR's Guidance to Requesting Parties (Ref. 1).

2 ASSESSMENT STRATEGY

10. The strategy for my assessment of the electrical engineering aspects of the UK HPR1000 design and safety case is set out in this section. This identifies the scope of the assessment and the standards and criteria that have been applied.

2.1 Assessment Scope

11. A detailed description of my approach to this assessment can be found in assessment plan ONR-GDA-UKHPR1000-AP-19-010. (Ref. 5).

12. I considered all the main submissions within the remit of my assessment scope to various degrees of breadth and depth. I chose to concentrate my assessment on those aspects that I judged to have the greatest safety significance or where the hazards appeared least well controlled. My assessment was also influenced by the claims made by the RP, my previous experience of similar systems for reactors and other nuclear facilities, and any identified gaps in the original submissions made by the RP. A particular focus of my assessment has been the RO and RQs I have raised as a result of my on-going assessment.

2.2 Sampling Strategy

13. In line with ONR's guidance (Ref. 4), I chose a sample of the RP's submissions to undertake my assessment focusing on matters relating to the electrical power system (EPS) which I judged to be the most safety significant, where significant design or safety case changes may be needed, or where there was a potential for a major issue to be revealed that may prevent ONR issuing a DAC.

14. This means that in my assessment I have given particular focus to the following aspects:

- RP's safety submissions to confirm the arguments and evidence related to Electrical Engineering underpin the safety case claims for the UK HPR1000 and are complete and reasonable.
- RP's safety case confirms that the electrical power system can withstand the identified internal and external hazards.
- RP's safety case confirms that the electrical power system can support operators in fulfilling their safety roles.
- RP's safety case demonstrates an adequate approach to the application, identification and qualification of smart devices.
- UK HPR1000 electrical power system is adequately robust to meet the expectations of diverse line protection and common cause failure.
- Electrical system studies confirm that the electrical power system is robust in its design.

15. In my assessment plan (Ref. 5), I noted that I intended to assess the ability of the EPS to support the security goals of the UK HPR1000. In response to an RQ (Ref. 6) raised early in Step 4 of GDA, the RP set out that the UK HPR1000 security systems are not supported by the electrical power system which supports nuclear safety functions. The RP advised that in line with the approach taken for the HPR1000 and other nuclear plant designed and operated by the RP in China, the power system for the security systems, including diesel generator support, would be located in buildings out of scope for GDA and would be for the licensee to develop. Assessment of these aspects of the design will be considered as part of normal business with a future licensee.

2.3 Out of Scope Items

16. The following items were outside the scope of my assessment:

- Detailed design of systems which cannot be completed until the site-specific parameters and arrangements are defined.
- Electrical equipment associated with the Conventional Island to support commercial generation.

2.4 Standards and Criteria

17. The relevant standards and criteria adopted within this assessment are principally the SAPs (Ref. 2), Technical Assessment Guides (TAG), relevant national and international standards, and relevant good practice informed from existing practices adopted on nuclear licensed sites in Great Britain. The key SAPs and any relevant TAGs, national and international standards and guidance are detailed within this section. Relevant good practice (RGP), where applicable, is cited within the body of the assessment.

2.4.1 Safety Assessment Principles

18. The SAPs (Ref. 2) constitute the regulatory principles against which ONR judge the adequacy of safety cases. The SAPs applicable to electrical engineering that have been considered in this assessment are included within Annex 1 of this report. Of particular consideration to the adequacy of the design of the EPS have been the following series:

- EDR: Engineering Principles – Design for Reliability
- EES: Engineering Principles – Essential Services
- ESS: Engineering Principles – Safety Systems

2.4.2 Technical Assessment Guides

19. The following Technical Assessment Guides were used as part of this assessment:

- NS-TAST-GD-003, *Safety Systems* (Ref. 7)
- NS-TAST-GD-005, *Guidance on the Demonstration of ALARP (As Low As Reasonably Practicable)* (Ref. 8)
- NS-TAST-GD-019, *Essential Services* (Ref. 9)
- NS-TAST-GD-051, *The Purpose, Scope and Content of Nuclear Safety Cases* (Ref. 10)
- NS-TAST-GD-094, *Categorisation of Safety Functions and Classification of Structures, Systems and Components* (Ref. 11)
- NS-TAST-GD-096, *Guidance on Mechanics of Assessment* (Ref. 4)
- NS-TAST-GD-103, *Emergency Power Generation* (Ref. 12)

20. The ONR SAPs (Ref. 2) and Technical Assessment Guides have been benchmarked against the relevant WENRA Guidance (Refs 13, 14 and 15) available at the time of publication.

2.4.3 National and International Standards and Guidance

21. The following standards and guidance were used as part of this assessment:

- IAEA Specific Safety Requirements No. SSR-2/1 (Rev.1), *Safety of Nuclear Power Plants: Design* (Ref. 16)
- IAEA Specific Safety Guide SSG-34, *Design of Electrical Power Systems for Nuclear Power Plants* (Ref. 17)
- IAEA Specific Safety Guide SSG-48, *Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants* (Ref. 18)
- IAEA TECDOC-1770, *Design Provisions for Withstanding Station Backout at Nuclear Power Plants* (Ref. 19)

- IAEA Safety Guide NS-G-2.6, Maintenance, Surveillance and In-service Inspection in Nuclear Power Plants (Ref. 20)
- IAEA Draft Specific Safety Guide DS514, *Equipment Qualification for Nuclear Installations* (Ref. 21)
- IAEA Safety Report No.91, *Impact of Open Phase Conditions on Electrical Power Systems of Nuclear Power Plants* (Ref. 22)
- WENRA, *Safety Reference Levels for Existing Reactors* (Ref. 13)
- WENRA, *Safety of new NPP designs* (Ref. 14)
- WENRA, *Statement on safety objectives for new nuclear power plant* (Ref. 15)
- BS EN 62855:2016, *Nuclear power plants - Electrical power systems - Electrical power systems analysis*
- HSE Guidance HSG230, *Keeping electrical switchgear safe* (Ref. 23)
- HSE Guidance HSR25, *The Electricity at Work Regulations 1989* (Ref. 24)

2.5 Use of Technical Support Contractors

22. It is usual in GDA for ONR to use Technical Support Contractors (TSCs) to provide access to independent advice and experience, analysis techniques and models, and to enable ONR‘s inspectors to focus on regulatory decision making.

23. Table 1 below sets out the areas in which I used TSCs to support my assessment. I required this support to undertake independent confirmatory system studies of the electrical distribution system to gain confidence in the ability of the electrical power system to be adequately rated and in the RP's ability in undertaking such studies.

Table 1: Work Packages Undertaken by the TSC

Number	Description
1	Electrical System Studies to independently assess the: • adequacy of the sizing and rating of the key safety electrical distribution equipment; and • ability of the system to respond to system transients

24. Whilst the TSC undertook detailed technical activities, this was done under my direction and close supervision. The regulatory judgment on the adequacy, or otherwise, of the generic UK HPR1000 safety case in this report has been made exclusively by ONR.

2.6 Integration with Other Assessment Topics

25. GDA requires the submission of an adequate, coherent and holistic generic safety case. Regulatory assessment cannot be carried out in isolation as there are often issues that span multiple disciplines. I have therefore worked closely with a number of other ONR inspectors to inform my assessment. The key interactions were:

- I have worked with the ONR Fault Studies inspectors to support their assessment of the RP's response to Regulatory Observations on Examination, Maintenance, Inspection and Testing and Diverse Line of Protection. I assessed the electrical engineering aspects of the RO responses in the application to the electrical power system safety claims and design.
- I have worked with the ONR External and Internal Hazards inspectors to gain confidence that the design of the EPS is appropriately resilient to relevant hazards.

- I have worked with the ONR Human Factors inspector in considering the approach to the design of the lighting and communication systems to gain confidence that the design of these systems appropriately considers the human actions.
- I have co-operated with the ONR Severe Accident inspector to ensure the design of the UK HPR1000 has adequate provision of electrical supplies in support of Design Extension Conditions.
- I have liaised with the ONR C&I inspector in considering the utilisation of smart devices in the electrical power system. The RP C&I team has led the development of the UK HPR1000 smart device approach to substantiation and the ONR C&I inspector has co-ordinated ONR's assessment.
- I have supported a multi-discipline team led by the ONR Mechanical Engineering inspector in assessing the RP's design of the heating, ventilation and air conditioning systems. I have assessed the ability of the proposed system to manage temperatures in electrical equipment rooms.
- I have been supported by the ONR Fuel & Core and Structural Integrity inspectors in gaining confidence that the design of the UK HPR1000 could be connected to the UK electricity transmission system.

3 REQUESTING PARTY'S SAFETY CASE

3.1 Introduction to the Generic UK HPR1000 Design

26. The generic UK HPR1000 design is described in detail in Chapter 2 of the Pre-Construction Safety Report (PCSR) (Ref. 25). It is a three-loop PWR designed by CGN using the Chinese Hualong technology. The generic UK HPR1000 design has evolved from reactors which have been constructed and operated in China since the late 1980's, including the M310 design used at Daya Bay and Ling'ao (Units 1 and 2), the CPR1000, the CPR1000$^+$ and the more recent ACPR1000. The first two units of CGN's HPR1000, Fangchenggang Nuclear Power Plant (NPP) Units 3 and 4, are under construction in China and Unit 3 is the reference plant for the generic UK HPR1000 design. The generic UK HPR1000 design is claimed to have a lifetime of at least 60 years and has a nominal electric output of 1,180 MW.

27. The reactor core contains zirconium clad uranium dioxide (UO_2) fuel assemblies and reactivity is controlled by a combination of control rods, soluble boron in the coolant and burnable poisons within the fuel. The core is contained within a steel Reactor Pressure Vessel (RPV) which is connected to the key primary circuit components, including the Reactor Coolant Pumps (RCP), Steam Generators (SG), pressuriser and associated piping, in the three-loop configuration. The design also includes a number of auxiliary systems that allow normal operation of the plant, as well as active and passive safety systems to provide protection in the case of faults, all contained within a number of dedicated buildings.

28. The reactor building houses the reactor and primary circuit and is based on a double-walled containment with a large free volume. Three separate safeguard buildings surround the reactor building and house key safety systems and the main control room. The fuel building is also adjacent to the reactor and contains the fuel handling and short-term storage facilities. Finally, the nuclear auxiliary building contains a number of systems that support operation of the reactor. In combination with the diesel, personnel access and equipment access buildings, these constitute the nuclear island for the generic UK HPR1000 design.

3.2 The generic UK HPR1000 Safety Case

29. The UK HPR1000 safety case for electrical engineering is documented in Chapter 9 of the PCSR (Ref. 3), which presents an overview of the design and the safety requirements relevant to the electrical systems and equipment of the generic UK HPR1000 design in their role of providing electrical power to the structures, systems, and components (SSC) that support both normal operation and safety functions. To aid traceability of the safety case, Reference 3 sets out a claims, arguments and evidence (CAE) approach to set out the safety requirements and how the design achieves these.

30. Ref. 3 sets out that the electrical power system (EPS) that supplies power to systems important to safety is essential to the safety of the nuclear power plant. The EPS includes both on-site and off-site systems, which work together to provide necessary power in all plant conditions so that the plant can be maintained in a safe state. Although the external power grid is not controlled by the nuclear power plant, the RP identifies it plays a significant role in providing defence in depth to faults and is important to the safety of the nuclear power plant.

31. The RP has set out in Ref. 3 the intended electrical power system approach to defence in depth for the UK HPR1000 as follows:

- Normal operation: The off-site grid or the main generator provides power supply to the normal power distribution system. They also supply the emergency and station blackout (SBO) power distribution systems, keep the DC batteries charged and provide power to the loads which are powered from the emergency or SBO power distribution system during normal operation. Electrical protection systems, a standby grid connection and the ability to transfer to house load are provided to limit the effect of plant equipment failures.

- Design basis faults: The systems delivering the first line of protection are powered from the emergency power distribution systems, with power supply from the grid (if available), from the main generator (if available) or from the emergency diesel generators (EDG). For frequent faults where a diverse line of protection is required, the systems delivering the diverse line are powered from the SBO power distribution systems, with power supply from the grid (if available), from the main generator (if available), from the EDG (if available) or from the SBO Diesel Generators. For DC and alternating current (AC) uninterruptible power supply (UPS) systems, the Nuclear Island (NI) 2 hour DC and AC UPS system provides power supply to the first line of protection equipment. The NI 24 hour [*]DC and AC UPS system provides power supply to the diverse line of protection equipment.
- Design extension faults, including severe accidents: Where systems are provided to mitigate design extension conditions, these may be powered from either the emergency or SBO power distribution systems depending on the nature of the fault. Connections are also provided for mobile diesel generator power supply to mitigate an event which causes the prolonged loss of grid and all on-site generation sources. Systems provided to mitigate severe accidents are powered by the 24h DC and AC UPS systems.

32. Ref. 3 is supported by a Basis of Safety Case (BoSC) on Electrical Power System (EPS) (Ref. 26). The objective of the BoSC is to provide a clear trail of the safety case expanding the claims in PCSR Chapter 9 through a series of arguments and a full set of supporting evidence.

[*] *As discussed in Section 4.3, the initial design of the UK HPR1000 included NI 12 hour DC and AC UPS systems. Following further analysis during GDA, the RP modified these to an autonomy time of 24 hours.*

4 ONR ASSESSMENT

4.1 Structure of Assessment Undertaken

33. My assessment covers the electrical power distribution system which supports structures, systems and components important to safety for the UK HPR1000. It does this by building on my earlier assessments during Steps 2 and 3 of GDA (Refs 27 and 28), where the development of the claims and arguments of the safety case were assessed. This assessment during Step 4 of GDA has considered the findings in those earlier assessments, focusing on the evidence which substantiates those claims and arguments. It is based on the submissions that support PCSR Chapter 9 (Ref. 3) and is consistent with the RP's Design Reference 3.0 (Ref. 29). My assessment 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.
- Electrical systems remain stable to perform relevant duties in all defined operating conditions, including fault conditions.
- Nuclear power plant is capable of being connected to the UK transmission system.
- The safety case and design for electrical systems and equipment are consistent with the expectations of ONR's Safety Assessment Principles and relevant good practice.

34. At the end of Step 2 of GDA, following an assessment of the reference HPR1000 design to the UK legal and regulatory expectations, the RP developed a Production Strategy for Electrical Engineering (Ref. 30) which set out the RP plans for further submissions. I have sampled these submissions in line with my assessment strategy that is set out in my Assessment Plan (Ref. 5). I have structured the reporting in the remainder of this section in line with the systems or topics, below, that I have targeted in meeting the objectives of my plan:

- Safety Case Structure
- Electrical System Architecture
- CCF and Diversity Strategy
- Electrical System Protection
- Electrical System Studies
- Grid Code Compliance
- Cabling
- Lightning Protection
- Earthing
- Lighting Systems
- Communication Systems
- Heating, Ventilation and Cooling
- Geomagnetic Induced Currents
- Smart Devices
- Electrical Maintenance Philosophy
- Ageing Management
- Equipment Qualification
- Demonstration that Relevant Risks Have Been Reduced to ALARP
- Consolidated Safety Case
- Comparison with Standards, Guidance and Relevant Good Practice

35. I have sought clarity through regulatory queries (RQ) (Ref. 6). I raised one regulatory observation (RO) (Ref. 31) where I considered a potential regulatory shortfall existed.

Throughout the remaining GDA period, the RP regularly updated its production strategy document (Ref. 30) to identify the development of new supporting evidence to the safety case or to recognise the need to provide clarity in extant submissions in response to RQs.

36. In this report, I have referenced my assessment against the final revision of each submission unless my actions through the RO or an RQ provided significant impact on the approach of the RP in demonstrating a safety case claim. In these cases, my assessment refers to specific revisions of submissions and how the RO or RQ has influenced the safety case.

4.2 Safety Case Structure

4.2.1 Assessment

37. The electrical engineering aspects of the safety case for the UK HPR1000 is set out in Chapter 9 of the PCSR. The RP states that Chapter 9 provides the design information of the electrical power system and its components to demonstrate that the system design meets the performance requirements.

38. Within this chapter, the RP states that the role and requirements for the electrical system have been derived from a safety analysis and is designed as a supporting system to provide power to SSCs which deliver safety functions.

39. In my assessment, I have considered if the structure and depth of the RP's safety case is consistent with the expectations of ONR Safety Case SAP SC.4 (Ref. 2) and Technical Assessment Guide TAG-051 (Ref. 10)

40. In early engagement with the RP (Ref. 32), I set out my expectations for a safety case, in line with the ONR SAP SC.4, in that:

- the safety case should provide the arguments and evidence necessary to demonstrate that the EPS meets the requirements of its safety role;
- the EPS should be demonstrated capable of providing electrical power to support the required safety functions for all identified operational and fault conditions;
- the claims on the EPS should be related to the overall safety claims of the plant and should have been established in conjunction with fault studies and incorporation of the outcome of probabilistic safety assessment of the electrical system design; and
- the electrical safety assessment should demonstrate the capability of the electrical distribution system in supporting the safety claims.

41. I noted in my Assessment Report for Step 2 of GDA (Ref. 27) that "Whilst the claims presented in the Chapter 9 of the Preliminary Safety Report for Electrical Engineering are at a high level at this stage, I consider this is sufficient. As the depth of my assessment increases in subsequent GDA steps, I would expect more specific claims and arguments to be presented, each ultimately supported by evidence demonstrating compliance with the argument. In my discussions, the RP has recognised this and advised it intends to develop a specific claims, arguments and evidence structure for the PCSR."

42. At the start of Step 3 of GDA, the RP introduced in Revision 000 of PCSR Chapter 9 (Ref. 33) a claims, arguments and evidence (CAE) structure for the electrical engineering aspects featuring a single high-level claim supported by five sub-claims. I considered this structure and the associated Revision B of the Basis of Safety Case on Electrical Power System (Ref. 34) partially addressed the expectations of the Safety

Case SAPs and my concerns highlighted above. However, I was concerned it was not clear how the design of the EPS had been derived from the fault analysis. In effect, it was not possible for anyone without implicit knowledge of the RPs design process to identify how the requirements for the electrical system design had been derived from the safety analysis; something often referred to as the 'golden thread' of a safety case.

43. ONR's expectation as set out in the SAPs (Ref. 2) is that arguments should provide sufficient detail to justify how the evidence demonstrates a claim or sub claim. Furthermore, it is expected that where organisation processes are used to establish the links from analysis to design, that documentation should be referenced. I raised a regulatory query, RQ-UKHPR1000-0206 (Ref. 6), for the RP to demonstrate the 'golden thread' in the safety case for a specific safety claim, thereby demonstrating it had an underpinning structure to its design process. Since the ONR C&I inspector had identified similar concerns with the C&I safety case, I supported the RQ with a joint presentation to the RP to set out our concerns and expectations at a workshop, early in Step 3 of GDA (Ref. 35).

44. In its response to RQ-UKHPR1000-0206 (Ref. 6), the RP demonstrated the structure of the safety case claim with greater clarity, identifying how it used the safety analysis, definition of safety functions, categorisation and classification and mechanical design to show the process it had employed in developing the design.

45. The RP subsequently adopted this detailed structure in presenting its safety case in future revisions to the PCSR Chapter 9 and BoSC. In the remainder of this section, my assessment considers the final GDA revisions of both documents, namely Revision H of PCSR Chapter 9 (Ref. 3) and Revision F of the BoSC (Ref. 26), which also reflect any design changes associated with Design Reference 3.0 (Ref. 29) that are referred to in later sections of this report.

46. PCSR Chapter 4: General Safety and Design Principles (Ref. 36) sets out the fundamental safety objective that "The Generic UK HPR1000 could be constructed, operated, and decommissioned in the UK on a site bounded by the generic site envelope in a way that is safe, secure and that protects people and the environment."

47. In PCSR Chapter 4 (Ref. 36), this fundamental objective is underpinned by five high level 'Level 1' claims which each focus on different aspects:

- Level 1 Claim 1: Site characteristics
- Level 1 Claim 2: Design development and organisational arrangements
- Level 1 Claim 3: Nuclear safety
- Level 1 Claim 4: Environmental protection, security and conventional safety
- Level 1 Claim 5: Decommissioning

48. The claims in each PCSR Chapter are then linked as appropriate to one or more of these claims. In the case of PCSR Chapter 9 (Ref. 3), it is set out that the safety case for the electrical systems are linked back to the Level 1 Claim 3:

> Claim 3: The design and intended construction and operation of the UK HPR1000 will protect the workers and the public by providing multiple levels of defence to fulfil the fundamental safety functions, reducing the nuclear safety risks to a level that is as low as reasonably practicable.

through an engineering system Level 2 sub-claim 3.3:

> Claim 3.3: The design of the processes and systems has been substantiated and the safety aspects of operation and management have been identified.

49. A single Level 3 sub-claim to this focuses on how the electrical system meets the expectations of Claim 3.3:

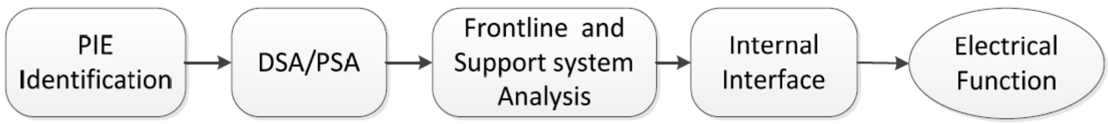
> Claim 3.3.5: The design of the electrical power systems has been substantiated

50. The RP has developed a sub-claim structure below this to demonstrate how the electrical system design ultimately support this level 3 claim. PCSR Chapter 9 (Ref. 3) describes the role, design and underlying design principles of the electrical engineering aspects; setting out the full sub-claim structure of Claim 3.3.5. In so doing, sub-chapters of Ref. 3 set out how the electrical engineering aspects:

- link to relevant aspects of the safety case through a route-map to other PCSR Chapters;
- apply and select appropriate electrical codes, standards and guidance for the UK context;
- are reflected in a description of the electrical systems, setting out their safety requirements, design basis, system description and operation and substantiation;
- contribute and are consistent with the overall UK HPR1000 ALARP assessment; and
- consider how the design enables commissioning, EMIT and ageing management activities to demonstrate and assure the design through its lifetime.

51. The RP provides in the BoSC (Ref. 26) a clear presentation of the full claims, arguments and evidence (CAE) structure of Claim 3.3.5. Within this submission, examples are given to assist in understanding how the various safety analyses and engineering schedules are used to link the safety analysis to safety functions, mechanical and C&I SSCs and ultimately electrical systems; in effect demonstrating the ‘golden thread’.

52. As part of my assessment of the safety case structure, I considered how the RP allocated loads to the electrical system and ensured that these were consistent with their availability in relevant degraded power conditions, such as LOOP, SBO or TLACP. In Ref. 26, the RP set out the logical sequence for the derivation of the electrical function from a plant initiating event as follows:



53. I have sampled this linkage between safety analysis and the requirements of the electrical system as part of an assessment of load allocation scenario bounding case determination in support of the electrical system studies (see Section 4.6) and the CCF and Diversity analysis (see Section 4.4). I am satisfied that the safety case demonstrates that the SSCs are supplied from switchboards with the necessary resilience and to the appropriate classification (see Section 4.3).

54. I have sampled a number of the remaining legs of the CAE structure as part of my detailed assessment of the electrical power system for GDA, as reported in the

remaining sections of this report, and consider the structure to be well laid out, targeted and supported by evidence. I consider that the structure adopted has addressed the concerns I raised in RQ-UKHPR1000-0206 (Ref. 6) to develop a robust, comprehensive and demonstrable CAE structure. I further consider that the approach taken in the structure of PCSR Chapter 9 (Ref. 3) and the supporting Basis of Safety Case (Ref. 26) is consistent with the project level principles set out in PCSR Chapter 4 (Ref. 36).

55. I also consider that through using a CAE structure, updates and changes to the safety case can be easily made. This can be important during the detailed design of the complete nuclear power plant as site specific safety requirements need to be incorporated. This flexibility was demonstrated when the RP needed to revise the safety case claims made in respect to equipment earthing (see Section 4.10).

56. An expectation of a safety case is to demonstrate that the risks are managed to reduce them so far as is reasonably practicable. For technical disciplines, this can often be demonstrated through compliance with relevant good practice, international guidance and the use of the appropriate and relevant codes and standards. The CAE structure in PCSR Chapter 9 (Ref. 3) presents specific sub-claims to show that the selection of codes, standards and guidance for the UK HPR1000 and the design is consistent with ALARP principles. I have considered the RP's application of codes and standards throughout my assessment and consider its approach to ALARP in Section 4.19 of this report, which concludes that the RP has developed and followed a robust process in ensuring the electrical engineering risks are reduced so far as is reasonably practicable.

57. In so doing, I consider that the safety case provides a structure with appropriate arguments and evidence to demonstrate that the electrical system meets the requirements of its safety role and thereby is consistent with the expectations of ONR SAP SC.4 (Ref. 2).

58. During Step 2 of GDA, in response to the concerns of a number of ONR inspectors about the apparent reactive development of the safety case, ONR raised cross-cutting RO-UKHPR1000-0004 (Ref. 31) for the RP to set out its safety case development strategy, delivery programme, organisation and process for capturing assumptions, requirements and commitments. I consider the work undertaken by the RP in the electrical discipline in developing the CAE structure to have met the technical expectations of the RO actions.

59. In the Requirements Management Summary Report (Ref. 37) produced as part of its resolution plan to address RO-UKHPR1000-0004 (Ref. 31), the RP identified that it would develop specific engineering schedules to support demonstration of the linkage in the overall design management process. In respect of electrical engineering, it identified that an electrical engineering schedule would be developed to capture the electrical engineering requirements for electrical SSCs and link this accordingly to the mechanical SSCs.

60. The Requirements Management Summary Report (Ref. 37) provided a template of the electrical engineering schedule and examples to show how the safety case requirements for the mechanical SSCs are linked to the relevant electrical system. These are also reflected in the latest revision of the Basis of Safety Case (Ref. 26) and the RP has made a formal commitment (Ref. 38) to develop this schedule post-GDA. I consider the linkage demonstrated in the examples to be consistent with my sampling of the safety case and that the proposed schedule should further improve visibility of the case. The ONR 'Step 4 Assessment of Cross-cutting Topics for the UK HPR1000 Reactor' (Ref. 39) has considered the wider response of the RP to Regulatory

Observation RO-UKHPR1000-0004 (Ref. 31) and has raised an assessment finding AF-UKHPR1000-0107 for a future licensee to fully develop the safety case schedules.

4.2.2 Strengths

61. I have identified the following areas of strength in the safety case:

- The RP has taken into consideration the advice on expectation of a safety case provided during the early steps of GDA and developed a robust safety case structure for the electrical power system which links the postulated initiating events to the required functions.
- The RP has adopted a CAE approach that is well structured and flexible, which should facilitate changes and updates to be easily incorporated into the safety case as it develops.
- The RP has committed to provide an electrical engineering schedule which should further improve the clarity between the mechanical safety functions and the EPS that supports them.

4.2.3 Outcomes

62. From my assessment, I am content that the RP has developed a well laid out structure to the safety case of the electrical engineering aspects of the UK HPR1000. I consider that the use of a CAE structure is well defined and supported by evidence. During the GDA process that the RP has demonstrated that it can easily modify its safety case through additional claims, arguments and evidence to satisfy ONR technical and regulatory expectations in an electrical engineering context.

63. To address an ONR project level concern raised through Regulatory Observation RO-UKHPR1000-0004 about the traceability of the UK HPR1000 safety case, the RP demonstrated how it could develop engineering schedules to improve this visibility. I consider these will improve visibility and support assessment finding, AF-UKHPR1000-0107, which has been raised in the ONR cross-cutting assessment report for a future licensee to complete this work.

4.2.4 Conclusion

64. Based on the outcome of my assessment of the safety case structure for the electrical power system, I have concluded that the RP's proposed approach including the claims, arguments and evidence structure appears robust but flexible to any future changes to the safety case. I consider that it meets the expectations of the relevant technical SC series of ONR SAPs. The RP has developed a template and provided examples on how it could improve the visibility of the safety case linkage through the development of engineering schedules. I support a cross-cutting assessment finding, AF-UKHPR1000-0107, for a future licensee to complete the development of these schedules.

4.3 Electrical System Architecture

4.3.1 Assessment

65. I have assessed the architecture of the electrical system of the UK HPR1000 to gain confidence that it provides a robust electrical supply and distribution system which can support the claims made in the PCSR and BoSC.

66. The reference plant design on which the initial safety case presented in the UK HPR1000 Preliminary Safety Report (Ref. 40) was based included:

- Emergency Diesel Generators (EDG) and Station Blackout Diesel Generators (SBO DG) both rated at 10kV

- 12 hour Nuclear Island (NI) Uninterruptible Power Supply (UPS) systems to support Design Extension Condition - B (DEC-B) events
- SBO DGs and 12 hour NI UPS systems designated as Class F-SC3.

67. Following challenge during the Step 2 of GDA (Ref. 27), whilst the first version of PCSR Chapter 9 (Ref. 33) still included these aspects in the design, the RP identified the need to review them as part of an EPS common cause failure and diversity analysis. The RP commenced this review at the start of Step 3 of GDA, concluding it during Step 4. This work ultimately led to the following modifications to each of these systems and is the design reflected in the latest issue of PCSR Chapter 9 (Ref. 3):

- Introduction of a 690Vac voltage level for the SBO DG and its associated switchboard
- Increase in the autonomy time of the 12 hour NI UPS to 24 hours
- Reclassification of SBO DG and 24 hour battery to reflect their role in supporting diverse lines of protection to Category FC1 safety functions.

68. The outcome of my assessment of this analysis and modifications is considered in Section 4.4 of this report.

69. The description, below, and my assessment of the system architecture is based on the latest GDA system architecture, as included in revision H of PCSR Chapter 9 (Ref. 3) and the associated BoSC (Ref. 26).

70. An overview of the UK HPR1000 electrical power system (EPS) is shown in Figure 1 and a high-level description of the sub-systems and their roles is set out in the PCSR and Basis of Safety Case. The EPS consists of the following sub-systems:

- Normal Power Distribution System
- Emergency Power Distribution System
- Station Blackout Power Distribution System
- DC and AC UPS Systems
- Mobile Diesel Generators

71. I have set out my assessment and findings of each aspect of the electrical system in the following sub-sections.

72. In normal operation, the UK HPR1000 on-site electrical system is supplied by the main turbine-generator through two 24/10.5kV Auxiliary Transformers (AT). During plant start-up and shutdown, the two ATs can be supplied from the offsite transmission system through a Unit Transformer (UT). Should any of these be out of service, the shutdown plant can be supplied by a Standby Transformer (ST)[†].

73. The following paragraphs describe the architecture of Division A; the relational and architectural differences for Divisions B and C described later.

74. AC loads required to support power generation are supplied by the 10kV Normal Power Distribution System (NPDS) (RP System Code: LGA) switchboard. Since operation of these loads are not claimed as part of the safety case, for the purposes of GDA the RP has considered design information for Fangchenggang Nuclear Power Plant Unit 3 (FCG3) (Ref. 41) and I have not considered the adequacy of their design.

75. AC loads that require power during unit shutdown are supplied through the 10kV NPDS (RP System Code: LGB) switchboard. During normal operation, start-up and

[†] *The voltages of the offsite transmission system for the UK HPR1000 are based on a generic site transmission connection. The RP recognises in the safety case that these voltages for a future UK plant will be defined during site-specific design based on the transmission system connection.*

shutdown these switchboards are supplied from ATs through interconnection to the LGA switchboard. When this supply is unavailable, the switchboard is directly supplied by the ST. To minimise disruption, when a loss of supplies from the AT transformer is detected, there is an automatic transfer of the power supply from the AT to the ST. This transfer can also be triggered manually by the operator. The return from the ST to AT can only be triggered manually by the operator. The transfer from AT to ST does not occur if following a transmission system fault, the trip to house load operation is successful.

76. In the event of Loss of Offsite Power, power is lost to the LGB switchboard, which results in a loss of supply to any AC switchboards fed from it. A 10kV Emergency Diesel Generator (EDG) (RP System Code: LHP) will start and connect to the NI 10kV Emergency Power Distribution System (EPDS) (RP System Code: LHA) switchboard automatically. To prevent stalling of the diesel engine, the electrical loads are shed and reloaded by the Reactor Protection System which controls the load shedding and reloading sequence. The reloading sequence depends on the plant condition that has been detected. Electrical loads are connected to switchboards supplied by this system at 10kV and 380V.

77. In the event of Station Blackout, the EDGs and the 10kV NI EPDS switchboards are not available. A Station Blackout Diesel Generator (SBO DG) (RP System Code: LJP), is manually started and connected by the plant operator to the NI 690V SBO Power Distribution System (SPDS) (RP System Code: LJA) switchboard. Electrical loads are connected to switchboards supplied by this system at 690V and 380V. When available the CI NPDS or 10kV NI EPDS can supply power to the SPDS.

78. Electrical loads which support safety functions which require either a no-break supply or to operate in the period before a DG can be started are supported by a NI 2 hour DC and AC UPS system (RP System Codes: LAA/LVA). This system is kept in a state of continuous charge by a battery charger supplied from the SPDS.

79. A NI 24 hour DC and AC UPS System (RP System Codes: LAP/LVP) supplies electrical power to safety functions which require power in the following situations:

- Operation in a Station Blackout event and requiring a no-break supply, supporting equipment that acts as a diverse line of protection.
- Operation in a Loss of Offsite Power (LOOP) event combined with a Loss of all EDG and SBO DG, referred to as a Total Loss of AC Power (TLACP) situation.

80. This NI 24 hour DC and AC UPS System is kept in a state of continuous charge by a battery charger supplied from the SPDS.

81. In the event of an extended TLACP situation, 690V and 380V Mobile Diesel Generators (MDG) can be transported from a secure on site location and connected to the LJA switchboard and the NI 24 hour DC and AC UPS system battery charger, respectively, to provide ongoing supplies to equipment.

82. Three redundant safety divisions are provided. The electrical power distribution systems in Divisions A and B are identical. Division C is supported by an EDG identical to those in Divisions A and B but does not include a 690V SPDS, SBO DG or NI 24 hour DC and AC UPS system. Division C also supports an additional NI 2 hour DC and AC UPS system to provide a fourth independent channel for the Reactor Protection System (RPS).

83. The RP principles for the design of the EPS including configuration, classification and load allocation are set out in the General Principles of Electrical Power Distribution (Ref. 42). I have assessed this document and consider it establishes a sound basis for

the design of an NPP electrical system and am satisfied that its approach and requirements are in line with the guidance set out in IAEA guidance (Refs 17 and 19). I have sampled various safety loads of different safety classifications connected to the various electrical systems. From my sampling, I consider the process set out in Ref. 42 has been followed and the load allocation is consistent with their safety role. Further consideration of the application of load allocation in the context of main and diverse line of protection is assessed in Section 4.4 as part of the RP review of CCF and Diversity.

84. The RP has undertaken a set of electrical system studies to demonstrate the capability and resilience of the UK HPR1000 electrical power distribution system to support safe operation of the reactor. My assessment of these studies is summarised in Section 4.6 of this report.

85. In each of the sub-sections below, I have considered whether the proposed architecture of each of the various sub-distribution systems are consistent with the principles set out in the General Principles of Electrical Power Distribution (Ref. 42) and the expectations of the IAEA guidance (Refs 17 and 19).

86. The following sections detail the assessment of the various sub-sections of the electrical supply and distribution system. In the following sections I have considered, as relevant, whether the proposed design is consistent with the following ONR SAPs (Ref. 2):

- ECS.2 Safety Classification
- ECS.3 Codes and Standards
- ESS.8 Automatic Initiation
- ESS.10 Definition of Capability
- ESS.16 Dependence on external sources of energy
- ESS.21 Reliability
- EES.3 Capacity, Duration, Availability, Resilience and Reliability
- EES.5 Cross-connections to other services
- EES.7 Protection Devices
- EES.8 Automatic Initiation
- EDR.2 Redundancy, Diversity and Segregation
- EDR.3 Common Cause Failure
- EDR.4 Single Failure Criterion

87. In so doing, I have considered if the proposed design is consistent with the following guidance:

- IAEA Specific Safety Guide SSG-34: Design of Electrical Power Systems for Nuclear Power Plants (Ref. 17)
- IAEA Technical Document 1770: Design Provisions for Withstanding Station Blackout at Nuclear Power Plants (Ref. 19)
- IAEA Safety Report No.91: Impact of Open Phase Conditions on Electrical Power Systems of Nuclear Power Plants (Ref. 22)

4.3.1.1 Preferred Power System

88. As per the definition in the IAEA guidance (Ref. 17), I consider the Preferred Power Supply (PPS) to be the power plant electrical system from the transmission system up to the safety classified electrical power system. It includes connections to the transmission system switchyard, the main generator and the on-site power distribution system up to the safety classified electrical power system. In the UK HPR1000, the PPS includes the equipment from the transmission system up to and including the Normal Power Distribution System.

89. In my assessment, I have considered the following submissions:

- Preferred Power Supply Design Scheme (Ref. 43)
- Categorisation and Classification of Electrical Power System (Ref. 44)
- LG* 10kV Normal Power Distribution System Design Manual Chapter 3 (Ref. 45)
- Technical Specification of the NI MV AC Switchboard (Ref. 46)

90. The proposed arrangement of the UK HPR1000 is to connect to the external transmission system through a main connection and a standby connection. The two off-site power supplies are to be designed to be physically independent and their equipment located such that the likelihood of their simultaneous failure is minimised.

91. For the purposes of GDA, the RP has assumed that the Unit Transformer shall be of a 420/24kV design for connection to the transmission system at 400kV and the Standby Transformer of a 275kV/10.5kV design for connection to the transmission system at 275kV. I consider this assumption reasonable and whilst a future licensee will need to ensure appropriate transformer ratios are considered during detailed design once a site is selected, ensuring that any system studies remain valid, I do not consider any changes are likely to materially affect the safety case made during GDA. The RP has recognised this requirement as a matter to be addressed in detailed design in its Post-GDA Commitment Log (Ref. 38).

92. During normal operation, the electrical power generated by the plant is transmitted to the external grid through the main connection. The main connection also provides reliable power from the grid to the plant auxiliaries through two ATs during normal operation as well as in the start-up and shutdown phases.

93. The standby connection can provide a reliable source of power to the plant auxiliaries through a Standby Transformer (ST) during the shutdown phase when the main connection is unavailable.

94. The RP states that all PPS transformers will be equipped with on-load tap changers on their primary windings to stabilise the voltage to the on-site electrical system to changes on the transmission system.

95. Should the main connection to the transmission system be lost, the reactor is designed to reduce output and support the on-site loads through a ‘house load’ operating mode.

96. When the main connection is unavailable due to a fault and the transfer to house load operation is not successful, automatic switchover between the main and standby connection is intended to be triggered to ensure the continuous power supply to the unit to support safe shut down of the plant.

97. The transfer of supplies from AT to ST is considered in the RP’s safety analysis to be a defence-in-depth action for the “control of abnormal operation and detection of failures” (IAEA DBC-2). The RP has recognised this as a category FC3 safety function and the equipment associated with its detection and operation as Class F-SC3. I consider this is consistent with the RP’s strategy for Categorisation and Classification of Electrical Power Systems (Ref. 44) which I assessed during Step 3 of GDA (Ref. 28). From a review of the relevant System Design Manual (Ref. 45), I am satisfied that the classification requirements for the system are reflected in the system requirements.

98. In my assessment for Step 3 of GDA (Ref. 28), I reported that I was satisfied that the RP’s use of category FC1-3 was consistent with ONR’s Category A-C functions and F-SC1-3 classification consistent with ONR’s Classes 1-3, as defined in the ONR SAPs (Ref. 2) and ONR Technical Assessment Guide (Ref. 11).

99. The RP has undertaken electrical system studies to confirm the ratings of the AT and ST transformers and switchgear. It has also undertaken studies to demonstrate satisfactory operation for relevant operational states when the power plant is connected to the transmission system through either the AT or ST supply. I have assessed these studies in Section 4.6 of this report. I am satisfied that the results adequately demonstrate the capability of the system and where further work will be required during detail design once the transmission system parameters for a site are known, credible options have been provided during Step 4 of GDA which could be implemented.

100. As part of those system studies, the RP has demonstrated how the electrical power system provides adequate protection to a loss of phase condition, considering the experience and reflecting the good practices identified in the IAEA Safety Report. (Ref. 22).

101. Since the RCPs are not used in shutdown situations, these are connected to the 10kV NPDS. Although non-classified in operation, in certain fault scenarios, it is important following a reactor trip that the pump motors are tripped to prevent over-cooling of the reactor core. From a review of the relevant System Design Manual (Ref. 45) and Technical Specification (Ref. 46), the RP has identified the tripping of these motors to be Category FC1 safety function and therefore the design and trip function of these breakers are classified Class F-SC1. I consider this is consistent with the expectations of ONR SAP ECS.2.

4.3.1.2 Emergency Power Distribution System

102. My assessment of the role, design and justification of this system is based on the following submissions:

- General Principles of Electrical Power Distribution (Ref. 42)
- EPDS System Design Manuals (Refs 47, 48, 49 and 50)
- Plant Auxiliary Electrical System Wiring Diagram (Ref. 51)
- Electrical Relaying Protection Scheme (Ref. 52)
- Technical Specifications (Refs 46, 53, 54 and 55)
- Application of Mechanical Interlocks in Electrical Power System (Ref. 56)

103. The EPDS consists of switchboards rated at 10kV and 380V. Equipment important to safety is connected to the appropriate voltage level dependent upon the electrical power requirement of the load whilst ensuring diversity in supply can be assured for main and diverse lines of protection. This is in accordance with a requirement set out in the General Principles of Electrical Power Distribution (Ref. 42).

104. In its submissions, the RP designates the Emergency Power Distribution System (EPDS) a Class F-SC1 system since it supports SSCs that perform FC1 and FC2 safety functions. The EDGs that support the EPDS during a LOOP situation are also designated Class F-SC1.

105. The RP has identified in PCSR Chapter 9 (Ref. 3) that the principal design requirements for single failure criterion, redundancy, independence, and qualification are derived from its Class F-SC1 classification. I have reviewed its design approach and consider its requirements to be consistent with ONR's expectations for a Class F-SC1 system. I have reviewed the relevant System Design Manuals (Refs 47, 48, 49 and 50) and Technical Specifications (Refs 46, 53 and 54) and consider that the requirements are adequately reflected and therefore the design is consistent with ONR SAPs EDR.2 and EDR.4 (Ref. 2).

106. The design incorporates limited interconnections between switchboards in different divisions. Through a review of the General Principles of Electrical Power Distribution (Ref. 42) and Application of Mechanical Interlocks in Electrical Power System (Ref. 56) submissions, it is stated that their use is limited to the following roles:

- To support ongoing maintenance activities during refuelling outage periods when the core is completely discharged, ensuring only one electrical division is unavailable when they are used
- To support critical safety functions (such as containment isolation valves) where the availability of manually selected alternative supplies of critical functions can further improve safety

107. Ref. 56 states that simple mechanical interlock schemes are employed to be used to control operation of such systems.

108. I am content that the RP is limiting the use of interconnections to essential functions. Furthermore, through the set of design principles for the use of electrical system interlocks (Ref. 56) I am content that appropriate technical controls are proposed. I consider this approach is consistent with the ONR SAP EDR.2 (Ref. 2). I would expect a future licensee to ensure it establishes appropriate operational controls to ensure these are effectively managed but consider the development of this part of detailed design.

109. In its submissions, the RP has identified how the EPDS of each division is located in the respective segregated safeguard building, which has been designed to mitigate common cause failures. The three EDGs are located in two buildings on the site which are physically separated. In addition, the building containing two EDGs is designed to ensure that a design basis event cannot result in the loss of both EDGs. I am satisfied that the principles are consistent with ONR expectations for redundancy and segregation. The resilience of these structures to design basis events has been considered by the ONR External and Internal Hazards inspectors in their assessments (Ref. 57 and 58).

110. The RP states that each EDG is designed to operate continuously without operator support at full rated power for at least 168 hours. I consider this duration is appropriate and consistent with previous GDA designs. It is aligned with good practice identified in IAEA guidance (Refs 17 and 19) and has appropriately considered the lessons identified in the ONR report into Fukushima (Ref. 59) relating to difficulties in obtaining offsite support immediately after a significant event. I would expect a future licensee to demonstrate that its fuel and oil resupply arrangements are appropriately resilient to support 168 hours of operation but consider the development of this part of detailed design.

111. The RP identifies in Refs 3 and 48 that dedicated auxiliary systems are provided for each EDG to enable each to operate independently.

112. The RP states that the EDGs start automatically following the detection of a low voltage on the 10kV associated NPDS or EPDS switchboard, before connecting to the isolated NI EPDS. The electrical loads are then applied in sequence. In addition, all EDGs are started automatically following receipt of a Loss of Coolant Accident (LOCA) signal. When started due to a LOCA signal, all EDGs will be started but remain disconnected from the 10kV NI EPDS unless offsite electrical supplies are subsequently lost or the plant operator manually reconfigures the system. Each EDG can also be started manually from the control room or locally from the diesel house. This approach is consistent with the good practice identified in Refs 17 and 19.

113. In Ref. 52, the starting, connection and load sequencing of the EDGs by the F-SC1 Reactor Protection System (RPS) is described. I am satisfied that the use of this system is consistent with the RPS System Requirements Specification (Ref. 60), appropriate to the control of the EDGs and consistent with the classification of the EDGs and meets the expectations of ONR SAP ECS.2 (Ref. 2). The architecture and adequacy of the RPS design has been considered in the ONR C&I Assessment Report (Ref. 61).

114. The RP has set out requirements that the loads applied to the EDGs are kept to those essential to the safe shutdown and cooling of the power plant. In its submissions, it has shown it has minimised any non-classified loads to those which provide significant asset value protection. I consider this approach reasonable. The system studies undertaken by the RP, and that I have assessed in Section 4.6, include these loads and have shown that the rating or operation of the EDGs are not challenged as a result. The studies have also shown that a significant margin exists against the design rating of the EDGs which provides confidence that reasonable load increases could be accommodated with the current design.

115. I consider that the RP has set out design principles in Reference 42 which are reflected in the EPDS design (Refs 47, 48, 49 and 50) to ensure that where a lower classified load is connected to higher classified distribution system, the isolation device will be classified consistent with the higher classified switchboard. I consider this approach provides confidence that the device should reliably isolate the lower classified equipment so that a fault will not propagate to the higher classified system. This approach demonstrates consistency both with ONR SAP ECS.2 and EES.5 (Ref. 2).

116. I consider the design principles adopted for the EDGs are consistent with IAEA guidance (Ref. 17), the expectations of ONR SAP EDR.4 (Ref. 2). and meets the expectations for automatic action identified in ONR SAP ESS.8.

117. The RP has undertaken a number of system studies to confirm the rating and load application of the equipment. I have assessed these studies in Section 4.6 of this report. I am satisfied that the results from these studies are consistent with the equipment parameters in the relevant System Design Manuals (SDM) (Refs 47 and 48) and Technical Specification (Refs 46 and 54).

118. I have considered how the RP has specified relevant electrical engineering equipment for the EPDS. In its submission on the Justification of Codes and Standards on Electrical Engineering (Ref. 62), the RP has analysed and identified the appropriate codes and standards for the UK HPR1000 in accordance with the project level principles for identification and selection (Ref. 63). Ref. 62 sets out the potential sources of standards and sets the following principles for selection:

- The latest version of the codes and standards that is in use should be applied. If there is more than one version in use, the chosen version should be justified as reasonable.
- The IEC standards have the highest priority.
- If there is a corresponding BSI standard to the IEC standard, the difference between the BSI standard and the IEC standard should be reviewed.
- The IEEE standards can be applied where there is no IEC standard in certain areas.
- The AFCEN RCC-E code will be applied for the qualification and separation principles.

119. I consider the principles are generally reasonable. It is noted that where a BSI implementation of a corresponding IEC standard exists, the RP only claims to review the differences. In addition, it makes no claimed intent to use a relevant BSI standard

where no IEC equivalent exists. There is a potential that this may result in the RP not being consistent with UK good practice which may be set out in either a dedicated BSI standard or a BSI implementation of an IEC standard. However, from a review of a selection of electrical technical standards referenced in the UK HPR1000 safety case, I am satisfied that the RP is in fact utilising BSI implementations of IEC standards where they exist and BSI standards where they are most relevant. For this reason, I consider that the safety case is generally consistent with the expectations of ONR SAP ECS.3 (Ref. 2) but as a future licensee develops the detailed design and develops equipment procurement specifications, it should consider reinforcing the approach adopted in Ref. 62 to ensure the design continues to meet the expectations of ONR SAP ECS.3. I consider this matter to be a minor shortfall.

120. From my review of the SDMs and Technical Specifications, I consider that the RP is applying the relevant analysis, design or test standard to the principal equipment, such as the application of IEC 62271-100 (Ref. 64) for high voltage switchgear. However, it is not always explicit in how it will assure the design of sub-components. For example, many SDM and TSs refer to a requirement to use of “low-smoke halogen-free flame retardant cable” without reference to a recognised international standard on what this is expected to conform to. I, therefore, raise the following assessment finding:

AF-UKHPR1000-0012 – The licensee shall when developing the equipment purchase specifications ensure that any safety case requirements for sub-components identify appropriate codes and standards.

4.3.1.3 Station Blackout AC Power Distribution System

121. As discussed in Section 4.3, above, the reference design, as presented in the initial Preliminary Safety Report (PSR) (Ref. 40) included a Station Blackout (SBO) AC Power Distribution System (SPDS) consisting of switchboards at 10kV and 380V. The system was supplied by a 10kV SBO DG. The RP identified that since the safety function of the systems that were supported by the SPDS when supplied by the SBO DG were Category FC3, the classification of the SBO DG was Class F-SC3. Since some of the systems may support higher category functions when supplied by the EDGs, the SPDS was classified Class S-FC1.

122. During Step 2 of GDA, as reported in my Step 2 Assessment Report (Ref. 27), I was concerned that the SBO DG may be expected to provide power to systems providing a diverse line of protection to a Category FC1 safety function. In addition, I was concerned that given the defence in depth role of the SBO DG and the SPDS to the EDG and EPDS, I would expect the RP to demonstrate that the systems met the expectations for diversity and common cause failure, as set out in the EDR series of ONR SAPs (Ref. 2). Therefore, in Ref. 27 I stated “However, in its own gap analysis for UK HPR1000, the RP has identified that it needs to complete a CCF analysis considering both individual component and system architecture, including design, operation and maintenance aspects across the whole electrical system. I will review the outcome of this analysis during Step 3, including how any application of equipment diversity is used to address any shortfalls.”

123. The RP has since undertaken a review of the approach to classification of the electrical system and a detailed common cause failure (CCF) and diversity analysis review. I reported in my Assessment Note of Step 3 of GDA (Ref. 28) that I was content with the approach to classification adopted for the UK HPR1000 and in respect of the SPDS this has led to reclassification of the SBO DG as Class F-SC2 (Ref. 65). The CCF and diversity analysis has resulted in a modification of the 10kV SPDS switchboards to 690V. My assessment of the analysis undertaken by the RP to support this modification is reported in Section 4.4 of this report. My assessment of the SPDS

architecture considers this modified configuration as presented in the final revision of the PCSR (Ref. 36) and the associated submissions.

124. The role, design and justification for the system is described in the following documents which have formed the basis of my assessment:

- General Principles of Electrical Power Distribution (Ref. 42)
- SPDS System Design Manuals (Refs 49, 66 and 67)
- Plant Auxiliary Electrical System Wiring Diagram (Ref. 51)
- Technical Specifications (Refs 53, 68 and 69)

125. Each 690V NI SPDS switchboard supports dedicated 380V switchboards which supply power to equipment important to safety which have lower power demands. The system is designed to power the necessary safety functions in a LOOP scenario combined with a common cause failure of the EPDS or EDGs. Under a LOOP only scenario, the system can be supported by the EDGs. As discussed in Section 4.2, above, the RP assigns the load allocation to the appropriate electrical system through a systematic process set out in Ref. 42.

126. Since the SPDS provides power to diverse line of protection equipment up to Class FSC2 and equipment in response to Design Extension Conditions at Class F-SC3, the RP identifies that the system does not need to meet the single failure criterion at a functional level. As a result, two fully redundant and segregated SPDS including SBO DGs are designed aligned with Divisions A and B. The SPDS switchboards and transformers are located in their respective safeguards building, which have been designed to mitigate common cause failure. The SBO DGs are located in separate buildings on opposite sides of the nuclear island, co-located with the respective division EDGs. The RP has implemented design measures to the structures to ensure that a design basis event cannot result in the loss of both SBO DGs or the EDG and SBO DG of a single division. The resilience of these structures to design basis events has been considered by the ONR External and Internal Hazards inspectors in their assessments (Refs 57 and 58).

127. In its design submissions, the RP states that each SBO DG is designed to operate continuously without operator support at full power for at least 72 hours. I consider this duration appropriate and is consistent with good practice set out in IAEA guidance (Ref. 19). I would expect a future licensee to demonstrate that its fuel and oil resupply arrangements are appropriately resilient as it develops the site layout but consider the development of this part of detailed design.

128. Dedicated auxiliary systems are provided for each SBO DG to enable them to operate independently. Furthermore, the RP states in the relevant SDMs and Technical Specifications (Refs 67 and 68) the SBO DG systems are to be diverse from those of the EDG.

129. The SBO DGs are started manually by the control room operator, or alternatively locally from the diesel house. The RP assumes that operators will not initiate this until 30 minutes after the event. I consider this approach is reasonable since it alleviates the need to develop and qualify a Class F-SC2 automated starting and load sequencing system, that would need to be diverse from that for the EDGs. I consider this satisfies the expectation of ONR SAP ESS.9 (Ref. 2) in respect of human response. The ONR Fault Studies inspector has considered the analysis supporting an SBO condition in their assessment (Ref. 70).

130. The SBO DG is controlled through a Class F-SC2 I&C system, independent of that used to control the EDGs. This control system is powered by the NI 24 hour AC and DC UPS system, which is independent and diverse to the 2 hour system that supports

the EDG. Detailed consideration of the independence and diversity of the I&C systems is considered by the ONR C&I inspector (Ref. 61). However, I consider the use of an independent and diverse power supply for the control systems to the EDG and SBO DG to be consistent with ONR's expectations as set out in ONR SAPs EDR.2 and ESR.6.

131. The RP has shown in its submissions that the loads applied to the SBO DGs are kept to those essential to providing diverse lines of protection to frequent faults and to support loads in response to SBO events. Furthermore, the design principles set out in the Refs 42 and 52 ensure that where a lower classified load is connected to higher classified distribution system, the isolation device will be classified consistent with the higher classified switchboard. I consider this approach provides confidence that the device should isolate the lower classified equipment if a fault were to occur so that the fault will not propagate to the higher classified system and is therefore consistent with ONR SAP ECS.2.

132. I consider the application of the two diverse systems, EPDS and SPDS, classified F-SC1 and F-SC2, when taking into account the reliabilities considered in the PSA analysis, should ensure the required system target reliability is met. However, the RP has not specifically defined the required system reliabilities in the system design manuals or technical specifications. As a result, I do not consider the RP has demonstrated what the selection of a specific system classification means in terms of the expected equipment reliability and, therefore, it does not meet the expectations for linking safety class with system target reliability set out in the ONR guidance for Safety Systems (Ref. 7). Whilst this aspect is specifically raised in this section of the report, I consider that it applies to the definition of all electrical equipment requirements. As a result, I raise the following assessment finding:

AF-UKHPR1000-0013 – The licensee shall ensure that the target reliability for all electrical systems important to safety are defined in the system requirements, reflecting the target reliability of the safety functions they support.

133. The RP has undertaken electrical system studies to confirm the rating and load application of the equipment. I have assessed these studies in Section 4.6, of this report. I am satisfied that the results from these studies are consistent with the equipment parameters in the relevant SDM (Refs 49, 66 and 67) and Technical Specification (Refs 53, 68 and 69).

4.3.1.4 Mobile Diesel Generators

134. The role, design and justification for the system is described in the following documents which have formed the basis of my assessment:

- Mobile Diesel Generator Design Scheme (Ref. 71)
- Electrical Protective Relaying Scheme (Ref. 52)
- Plant Auxiliary Electrical System Wiring Diagram (Ref. 51)

135. Taking the learning from the events at Fukushima where safety loads could not be supplied from any installed diesel generator, the HPR1000 design reference includes two mobile diesel generators; one to connect to the SPDS; and one to the charger of the NI 24 hour UPS battery charger. In the initial PCSR (Ref. 33) the design considered a 10kV and 380V unit. Following the analysis undertaken by the RP as part of the CCF and Diversity review (Ref. 72), the RP modified the rating of the unit for the UK HPR1000 which connects to the SPDS from 10kV unit to 690V.

136. The Mobile Diesel Generator (MDG) Design Scheme (Ref. 71) sets out the requirements and design of the equipment, stating that the units are to mitigate the

consequences of a severe accident and provide a grace period for the restoration of on-site or off-site power sources, providing support to the following safety functions:

- Heat removal from the core and spent fuel pool
- Necessary Control and Monitoring in the Nuclear Power Plant

137. Ref. 71 further states that whilst the event that these units support is of an extremely low frequency, these unit are considered to provide a defence-in-depth role and are therefore classified as Class F-SC3. As such, and reflecting the units connect to the SPDS and NI 24 hour AC and DC UPS system, provision is made for the units to be connected to either Division A or B, with the connection to only one division required. I consider the decision to classify the units to be a demonstration of conservative decision making and that the connection arrangement is in line with the expectations of the ONR EDR SAPs (Ref. 2).

138. In Ref. 71, it is stated that these MDGs are self-contained truck mounted units stored in an on-site emergency equipment storage area, located on higher ground and seismically qualified. If required, they could be relocated and connected within twelve hours to a pre-installed connection point at the entrance to the respective safeguard building using fast-plug connectors. It is stated that each connection point is to be designed commensurate to the classification of the electrical system to which it is permanently connected. I consider the principle of using fast-plug connectors a pragmatic approach given the uncertainty of the conditions operators may face when asked to deploy this equipment.

139. Since an SDM or Technical Specification was not identified as part of the safety case for this equipment, it is not clear what code or standard is being proposed for this equipment and whether this would meet the expectations of ONR SAP ECS.3 or ECS.4. As classified equipment and based on the RP's own design process, I would expect a system requirements document (such as a system design manual) and equipment specification to be produced for this equipment to capture the safety design requirements and ensure that the basis for future procurement is clearly linked to the safety case. I have, therefore, raised assessment finding, AF-UKHPR1000-0014, below.

140. Each MDG is manually started and connected with all operations carried out by a plant operator. Each unit is provided with onboard fuel oil tanks sized for four hours operation with a claimed mission time of 72 hours, with the equipment being designed to be capable of being refilled whilst running. I consider this appropriate and reflects the balance between vehicle sizing and mobility. It is not stated where the remaining 68 hours of fuel would be stored or how it could be transferred consistent with its safety categorisation. I therefore raise the following assessment finding:

AF-UKHPR1000-0014 – The licensee shall during site-specific design of the Mobile Diesel Generators ensure:

- The establishment of classified and qualified facilities and operational arrangements for the storage and refilling of consumables in support of their running for the claimed mission time; and
- The associated nuclear safety requirements are captured in the safety case and together with statutory requirements reflected in equipment specifications.

141. Based on an assessment of Revision A of the Mobile Diesel Generator Design Scheme (Ref. 73), I sought clarity through Regulatory Query RQ-UKHPR1000-1412 (Ref. 6) as to the hazard qualification and mission time of the MDGs. In its response, the RP confirmed that the generators are to be capable of operation throughout the full design

basis generic site outside air temperature range. It made an argument that it is appropriate given the role of the equipment for it be qualified against a reduced 10^{-2}/year seismic event. I have discussed this with the ONR External Hazards inspector and recognising the potential difficulty in securing mobile equipment qualified to the design basis requirement, the resilience included through the vehicle mounting and the fact that the equipment is not required to operate during any initial event, we consider this a reasonable qualitative argument. I am satisfied these requirements have now been incorporated in the Revision B of the design scheme submission.

142. The RP has undertaken electrical system studies to confirm the rating and load application of the equipment. I have assessed these studies in Section 4.6, of this report. I am satisfied that the results from these studies are consistent with the equipment parameters.

4.3.1.5 Uninterruptible AC and DC System Architecture

143. The uninterruptible AC and DC systems of the UK HPR1000 provide electrical supplies to equipment which in a LOOP or SBO event is required to remain powered or operate before an EDG or SBO DG can be started, is sensitive to dips in the electrical supply due to transients from the grid or is used to provide power to equipment should a LOOP event occur and the EDGs or SBO DGs fail to start.

144. In the reference design, which formed the basis of the design in the initial PCSR (Ref. 33), the uninterruptible AC and DC system consisted of three systems; a Class F-SC1 NI 2 hour, a Class F-SC3 NI 12 hour system and non-classified CI 2 hour system. In line with the RP Design Guidelines (Ref. 42), the NI 2 hour system provides power to equipment which supports a main line of protection whilst the 12 hour system provides power to equipment used during DEC-B severe accident scenarios that would be required following a LOOP and loss of the EDGs and SBO DGs.

145. I considered that a Class F-SC3 role for the 12 hour batteries was not consistent with their role in providing power supplies to equipment associated with diverse lines of protection for Category FC1 functions. I reported in my Assessment Note for Step 3 of GDA (Ref. 28) that whilst I was content with the approach the RP had developed to categorisation and classification for the UK HPR1000, I expected the RP to review the classification of this equipment. The ONR Fault Studies inspector also captured the requirement to consider diverse line of protection requirements as part of Regulatory Observation RO-UKHPR1000-0023 (Ref. 31). The RP has since reclassified this UPS system as Class F-SC2, which I consider appropriate to its role.

146. In addition, I considered that a 12 hour autonomy time for the batteries no longer reflected international good practice following learning from the Fukushima event (Ref. 19 and 59). I set out this concern during early discussions with the RP in Step 2 of GDA. Underpinned by the Severe Accident Battery Analysis (Ref. 74), the RP has increased the autonomy time of the NI 12 hour DC and AC UPS system to 24 hours. I consider this provides greater time to the plant operators to recover onsite or offsite electrical supplies.

147. The wider impact of the work undertaken by the RP to address Regulatory Observation RO-UKHPR1000-0023 on the electrical system was considered as part of its CCF and diversity analysis review. This work has resulted in a modification for:

- Diversity between the 2 hour and 24 hour UPS systems
- Diversity between divisions
- Reallocation of loads to different switchboards.

148. My assessment of the analysis undertaken by the RP underpinning this change is reported in Section 4.4 of this report.

149. In my assessment of the uninterruptible AC and DC Power System, below, I have considered the revised design architecture resulting from the above modifications, as presented in the latest revisions of the safety case.

150. The role, design and justification for the NI AC and DC UPS Systems are described in the following documents which have formed the basis of my assessment:

- General Principles of Electrical Power Distribution (Ref. 42)
- System Design Manuals (Refs 75 and 76)
- Technical Specifications (Refs 77, 78, 79 and 80)

151. I have not considered the Conventional Island AC and DC UPS system since the RP identified that this equipment supplies loads that perform no nuclear safety role and was out of scope for GDA (Ref. 41).

152. The redundancy of the NI systems generally mirrors that of the EPDS and SPDS. There are three independent and redundant NI 2 hour UPS systems; one aligned to each division of EPDS. There are two independent and redundant NI 24 hour UPS systems to align with the SPDS and SBO DGs. Each 2 hour and 24 hour system is fully rated to support the required loads. I consider that this design and approach is consistent with the expectations of ONR EDR series of SAPs (Ref. 2).

153. An additional NI 2 hour system, referred to as Division D, is provided to independently supply the fourth RPS channel of the reactor protection system. I consider this an appropriate approach to ensure independent power supplies to each of the RPS channels.

154. In its submissions, the RP has identified the NI 2 hour UPS of each division is located in a dedicated safeguard building. In addition, it has identified that the Division D system to support the RPS is located on the same floor but separate fire zone to the Division C UPSs. The Division A and B NI 2 and 24 hour AC and DC UPS systems are located in separate fire zones in their respective safeguard buildings. I consider this approach is consistent the expectations set out in ONR SAP EDR.2.

155. Each NI 2 hour and 24 hour UPS system is powered from the SPDS in their respective division and can be recharged using either the EDG or SBO DGs, with a no-break bypass available from the EDG backed EPDS. Electrical loads which may require operation before an EDG or SBO DGs is started are powered from the AC switchboards of the UPS, whilst C&I systems which require a continuous power supply are dual fed from the DC and AC switchboards.

156. No interconnections are provided between any of the UPS systems which I consider ensures their independence and reduces the risk of common cause failure of systems in multiple divisions.

157. In its analysis (Ref. 74), the RP has shown that the autonomy time of the NI 24 hour UPS is sufficient to support the equipment required in a severe accident scenario. Where offsite or onsite supplies cannot be restored within this time period, the Mobile Diesel Generators can be deployed. The operator response to a TLACP situation has been considered by the ONR Severe Accident inspector as part of their assessment (Ref. 81). I consider this increase to the autonomy time of the batteries is consistent with the analysis and is consistent with good practice following the experience with the Fukushima event (Ref. 19). As a result, I am satisfied that the approach is consistent with the expectations of ONR SAP EES.3.

158. PCSR Chapter 8 (Ref. 82) describes how the various electrical NI UPS systems support each of the I&C systems. I have worked with ONR C&I inspector in understanding the role of these systems and am satisfied that the classification of the power supply to each C&I system is consistent with classification of that system and the choice of supply provides a level of independence consistent with its function, thereby meeting the expectations of ONR ECS.2, EDR.3, EDR.4 and ESR.6.

159. The general design principles set out in Ref. 42 ensure that where a lower classified load is connected to a higher classified distribution system, the isolation device will be classified consistent with the higher classified switchboard. I consider this approach gives confidence on the isolation of lower classified equipment should a fault occur and is consistent with ONR SAP ECS.2.

160. The RP has demonstrated the power rating, short circuit capability and autonomy time of the proposed system as part of its Electrical System Studies. Section 4.6 provides more detail on this aspect of the assessment.

161. From a review of the SDMs and Technical Specifications (Refs 75, 76, 77, 78, 79 and 80), I am satisfied that the results from the studies are consistent with the rating and performance requirements set out in the specifications and from my experience are within the range of commercially available equipment.

162. I consider the SDMs and Equipment Specifications have recognised appropriate BS, IEC and IEEE standards for the main aspects of the design of a UPS system, as substantiated in the Justification of Codes and Standards submission (Ref. 62). However, the points noted in Paragraph 120, above, relating to the identification of relevant codes or standards to the sub-components apply here and therefore assessment finding AF-UKHPR1000-0012 is relevant.

4.3.2 Strengths

163. I have identified the following areas of strength in the development of the electrical system architecture:

- Applied the IAEA guidance in the development of the architecture.
- Set out and applied are a robust set of general design principles that ensure the architecture is based on sound deterministic basis.
- Applied learning from the events at Fukushima in incorporating mobile DGs that can be flexibly deployed as required and increasing the autonomy time of the NI 12 hour DC and AC UPS to 24 hours.
- As part of its Categorisation & Classification analysis to meet UK expectations, the RP has reclassified the SBO DG and NI 24 hour DC and AC UPS from Class F-SC3 to Class F-SC2, and the MDG from non-classified to Class F-SC3.

4.3.3 Outcomes

164. From my assessment, I am content that the RP has set out and implemented design principles for the design of the electrical architecture that is consistent with good practice as set out in the relevant IAEA guidance documents.

165. In my assessment of how the design requirements have been reflected in the relevant System Design Manuals and Technical Specifications, I have identified that whilst the relevant codes or standards for the principal requirements for the equipment have been recognised, the relevant codes or standards for sub-components are not always identified. I have therefore raised the following assessment finding:

AF-UKHPR1000-0012 – The licensee shall when developing the equipment purchase specifications ensure that any safety case requirements for sub-components identify appropriate codes and standards.

166. In my assessment, I have identified that whilst the RP has established an appropriate classification for electrical systems, it has not directly linked this to the required target reliability of the systems. I have therefore raised the following assessment finding:

AF-UKHPR1000-0013 – The licensee shall ensure that the target reliability for all electrical systems important to safety are defined in the system requirements, reflecting the target reliability of the safety functions they support.

167. In my assessment, I have identified that whilst the RP had identified in its analysis nuclear safety requirements for the Mobile Diesel Generators, these had not been explicitly captured in a system requirements document or equipment specification.

In addition, I identified that whilst it is claimed the units have a declared mission time of 72 hours with onboard 4 hour fuel tanks, it is not clear how the storage of fuel and the arrangements for refuelling are to be consistent with its F-SC3 classification. I have therefore raised the following assessment finding:

AF-UKHPR1000-0014 – The licensee shall during site-specific design of the Mobile Diesel Generators ensure: ■ The establishment of classified and qualified facilities and operational arrangements for the storage and refilling of consumables in support of their running for the claimed mission time; and ■ The associated nuclear safety requirements are captured in the safety case and together with statutory requirements reflected in equipment specifications.

168. I have also identified one minor shortfall as discussed in sub-section 4.3.1.2 above.

4.3.4 Conclusion

169. Based on the outcome of my assessment of the electrical system architecture, I have concluded that the proposed design is consistent with good practice as set out in the relevant IAEA guidance documents.

170. I am content that following the re-classification of the SBO DGs, NI 24 hour AC and DC UPSs and CCF and diversity review the RP has implemented appropriate modifications to the electrical system architecture that significantly improve resilience.

171. I consider that the safety case as presented now meets the expectations of the relevant ONR SAPs.

172. I have raised three assessment findings, AF-UKHPR1000-0012, AF-UKHPR1000-0013 and AF-UKHPR1000-0014, that I will expect a licensee to consider as it develops the safety case for a specific site.

4.4 CCF and Diversity Strategy

4.4.1 Assessment

173. Nuclear power plants rely on electrical power to supply equipment that deliver safety functions. Where safety functions are required to deliver defence in depth through the application of diversity, it is important that diversity is reflected in the support systems

that underpin the delivery of those functions. The expectations of defence in depth are set out in IAEA Specific Safety Requirement SSR2/1 (Ref. 16) and ONR SAPs EKP.3 (Ref. 2).

174. To ensure that multiple levels of defence in depth are not compromised by common cause failure of a single type of equipment or component, there is an expectation that the risk is evaluated and diversity is employed, where appropriate.

175. In my assessment, I have considered how the RP has assessed the risk of CCF in the design of the electrical system and considered diversity in meeting reliability and defence in depth. In this section, I have considered the safety case against the following SAPs:

- EKP.3 Defence in Depth
- EDR.2 Redundancy, Diversity and Segregation
- EDR.3 Common Cause Failure
- EDR.4 Single Failure Criterion

176. In early engagement with the RP (Ref. 32), I highlighted that ONR's expectation as set out in ONR SAPs EKP.3 and EDR.3 is that the effects of common cause failures should be examined where the reliability of the systems are important and ensure that appropriate diversity of safety functions is applied. I advised that the same considerations should be applied not only to the equipment that delivers a safety function but also to any equipment which supports it, including electrical power supplies.

177. I noted in my assessment report for Step 2 of GDA (Ref. 27) that from the initial PSR (Ref. 40), there were concerns that the resilience of the HPR1000 reference design to CCF of the electrical system was not clear:

- EDGs and SBO DGs were both rated at 10kV.
- Both EDGs and SBO DGs supplied 10kV switchboards.
- No clear consideration of CCF in the design of the electrical power system or identification of diversity requirements for equipment.

178. During early assessment, the ONR Fault Studies inspector identified a similar gap in the need for a robust demonstration that diverse protection has been provided for frequent faults and the risks reduced so far as is reasonably practicable. This gap was captured in regulatory observation RO-UKHPR1000-0023 (Ref. 31). I have worked closely with the ONR Fault Studies inspector to ensure that the analysis of the electrical system resilience to CCF is consistent with the work in response to the regulatory observation.

179. As part of my assessment, I sought clarity on the extent of the supporting analysis through a regulatory query RQ-UKHPR1000-0503 (Ref. 6), that would be used to complete the CCF and Diversity review to gain confidence that the analysis would be holistic. In its response to the RQ (Ref. 6), the RP set out all the analyses, including those from its resolution plan to RO-UKHPR1000-0023, that would contribute to this work.

180. In my assessment, I have considered how the RP has undertaken its analysis and, in support of the regulatory observation, demonstrated that the load allocation is consistent with its requirements for main and diverse line of protection.

181. The RP has recognised the requirement for demonstrating this aspect as part of the safety case and defined the following sub-claim in the CAE structure that supports the safety case (Ref. 3):

Claim 3.3.5.SC09.2.1.4: The diversity and independence of the electrical system offers the resilience against Common Cause Failure (CCF)

182. The following submissions have been considered as part of my assessment:

- CCF and Diversity Analysis (Ref. 72)
- Design Modifications (Refs 65, 83 and 84)

183. In its review of their design of the electrical system set out in the CCF and Diversity Analysis (Ref. 72), the RP states that the objective of the analysis is to:

- Develop the CCF analysis methodology to identify the vulnerabilities of EPS which can become a CCF, and to analyse the level of diversity between EPS SSCs to determine whether the risk of CCF due to functional, special, inherent and human dependencies has been reduced to ALARP.
- Apply the diversity methodology to the reference design and to options to increase EPS diversity, to provide inputs to the EPS ALARP assessment
- Perform the ALARP assessment of the diversity within the EPS system to mitigate CCF vulnerabilities.
- Determine the architecture of the EPS and load re-allocation requirements.

184. I consider that these principles are appropriate and consistent with the ONR SAPs identified in Paragraph 175. I have reviewed the process as it has been applied to provide confidence that it delivers these objectives.

185. In Ref. 72, I consider the RP has undertaken a detailed, systematic analysis of the design. It has analysed the potential causes of CCF and undertaken a detailed optioneering process to identify an optimum solution. In doing so, I consider the analysis undertaken by the RP has appropriately prioritised the safety benefits in its analysis over the cost or divergence from the reference design and considered the sensitivity of its judgements.

186. As a result, the RP has implemented design changes for the UK HPR1000 through three Technical Change Notes (TCN):

- Modification of Voltage Level of SBO DG and Associated Switchboard (GHTCN000089) (Ref. 65)
- Modification of Electrical Power System Classification (GHTCN000139) (Ref. 83)
- Electrical Power System Power Distribution Modification (GHTCN000126) (Ref. 84)

187. These design changes involve:

- introduction of a 690Vac voltage level for the SBO DG and its associated switchboard;
- reclassification of SBO DG and 24 hour battery to reflect their role in supporting diverse lines of protection to Category FC1 safety functions;
- introduction of two groups of diverse LV AC and DC switchboards, transformers, and UPS systems; and
- reallocation of loads to SBO DG backed electrical distribution system and UPS systems to ensure the diverse lines of protection are resilient to electrical system CCF.

188. Whilst it is technically achievable to deliver diversity to both the EDG and SBO DG systems at 10kV, I consider that the decision to reallocate the SBO DG to 690V a

reasonable one. The lower power requirements of the SBO DGs, as demonstrated in Section 4.6 of this report, mean that the design can still deliver its function at this lower voltage level whilst using standard industrial equipment ratings. Furthermore, the change in voltage level reduces the complexity of securing diverse switchgear at the 10kV voltage level, where switching technologies are more limited.

189. I consider that the reclassification of the SBO DG and 24 hour battery from Class F-SC3 to Class F-SC2 to be consistent with the expectations for systems that perform diverse line protection for Category FC1 safety functions.

190. The RP has introduced a requirement for two diversity groupings to be applied to the LV AC electrical system as well as the NI 2 hour and 24 hour UPS. This work not only supports its assessment of the inherent CCF risk to the electrical system but also supports its work in response to RO-UKHPR1000-0023. The proposed groupings are set out in Figure 2. I consider the analysis undertaken by the RP and the decision to introduce these groupings to be well set out. The RP has appropriately balanced the benefit from diversity against the increased complexity, taking into account sensitivity studies, to ensure that its choice of diversity is balanced.

191. I consider the methodology of the analysis and the proposed reallocation of loads for the main and diverse lines of protection in respect of several safety functions confirms the analysis (Ref. 72) that the proposed switchboard diversity and load reallocation ensures that safety functions are secure against both a CCF loss of the equipment delivering the safety function and a CCF loss of a switchboard grouping. My review also confirmed that the RP analysis specifically recognises that this diversity applies to sub-component selection such as control and protection relays including smart devices. I consider this is important since it is essential in ensuring the resulting reliability is not compromised by failure of sub-components.

192. The ONR PSA inspector has considered the results of the consideration of electrical system reliability as part of their assessment of the PSA. In its CCF and Diversity analysis (Ref. 72), the RP identified a conclusion from its Level 2 PSA review for it to consider options to increase diversity of the transformers supplying the 380V switchboards. As part of the ALARP option chosen in Ref. 72 to increase diversity, the RP has identified the requirement for the diversity between LV switchboards to be applied to the supply transformers. The ONR PSA inspector has confirmed that he is content with the revised arrangement and that this has been reflected in the Level 2 PSA (Ref. 85).

193. I have sampled the diesel generator, LV switchgear and transformer SDMs and Technical Specifications (Refs 48, 49, 53, 54, 67, 68 and 69) to gain confidence that diversity requirements are appropriately reflected in these documents. In these submissions, the RP recognises the requirement for diversity to be applied and makes reference to the CCF and Diversity Analysis (Ref. 72), although in neither the SDMs or Technical Specifications does it explicitly identify these requirements apply to sub-components. I would expect a safety case to set out how it would appropriately manage the application of diversity in the detailed design of the equipment to ensure the objectives of Ref. 72 are met. I, therefore, raise the following assessment finding:

AF-UKHPR1000-0015 – The licensee shall ensure that the diversity requirements for electrical components and sub-components are identified within the safety case and that it establishes a process to ensure these requirements are assured in the constructed plant.

194. I have assessed the design modifications (Refs 65, 83 and 84) which incorporate the resulting modifications into the UK HPR1000 design. I am satisfied that they reflect the

conclusions of the respective analysis, have assessed the potential impacts on the overall design and updated the relevant submissions.

195. Based on this review of the RP analysis of common cause failures of the electrical system and the proposals to introduce diversity, I am content that the RP has adequately demonstrated that the proposed design meets the expectations of the ONR SAPs identified in Paragraph 175.

4.4.2 Strengths

196. I have identified the following areas of strength in the consideration of CCF and diversity:

- RP responded positively to the advice provided during the early stages of GDA in developing a robust analysis of the electrical system.
- Considered the inherent CCF analysis of the electrical distribution system in conjunction with its response to the Regulatory Observation on diverse line protection to ensure a coherent strategy is considered.
- Modification to the design of the low voltage AC and DC Switchboards, Transformers and UPS systems to incorporate diverse groupings.
- CCF and Diversity Analysis recognises that diversity needs to apply to sub-components, such as control and protection relays.

4.4.3 Outcomes

197. From my assessment, I am satisfied that the RP has adequately considered CCF in the architecture of the electrical power distribution system and implemented modifications to improve resilience through diversity improvements.

198. In my assessment of how the requirement for diversity of systems, components and sub-components have been captured within the SDM and Technical Specifications, I have identified that the requirement is not always explicitly captured, or a process set out to ensure the required diversity is achieved in the constructed plant. I have therefore raised the following assessment finding:

AF-UKHPR1000-0015 – The licensee shall ensure that the diversity requirements for electrical components and sub-components are identified within the safety case and that it establishes a process to ensure these requirements are assured in the constructed plant.

4.4.4 Conclusion

199. Based on the outcome of my assessment of common cause failure and diversity of the electrical distribution system, I have concluded that the RP has adequately considered the risks of CCF and the requirement to ensure the diversity of the electrical systems reflect those of the safety functions they support.

200. I consider the RP has appropriately identified and evaluated options to improve the resilience to CCF and ensure diversity, implementing those modifications in accordance with its processes.

201. As a result, I consider the analysis and design resulting from the modifications is consistent with the expectations of ONR SAPs and TAG.

202. I have raised one assessment finding, AF-UKHPR1000-0015, that I expect a future licensee to consider as it develops the safety case.

4.5 Electrical System Protection

4.5.1 Assessment

203. To prevent failures or system transients causing damage to equipment and injury to personnel whilst maximising system availability, it is important to ensure that an effective electrical system protection scheme is designed and configured.

204. In my assessment, I have focussed on whether the proposed arrangements are consistent with the expectations of the following ONR SAPs:

- ECS.2 Safety Classification
- ECS.3 Codes and Standards
- EES.7 Protection devices

205. In my assessment, I have considered if the proposed design is consistent with the following guidance:

- IAEA SSG-34: Design of Electrical Power Systems for Nuclear Power Plants (Ref. 17)

206. The role and design principles of the electrical protection scheme for the UK HPR1000 are set out in the following documents which have formed the basis of my assessment:

- PCSR Chapter 9 (Ref. 3)
- Basis of Safety Case (Ref. 26)
- Electrical Relaying Protection Scheme (Ref. 52)
- AT-ST Transfer Studies (Ref. 86)

207. The RP has undertaken electrical system studies to demonstrate the ability of the electrical protection system to perform as intended. These studies have been considered in Section 4.6 of this report.

208. Ref. 52 stated aims are to demonstrate that:

- Safety requirements and design requirements of the electrical relaying protection has been derived and satisfied.
- Anticipated faults and disturbances of the Electrical Power System (EPS) have been identified.
- Detection measures and protection arrangement are provided for the anticipated faults and disturbances.
- Protection arrangement is verified to check it could respond to the defined conditions.

209. Ref. 52 identifies that this is achieved through:

- The design requirements of electrical relay protection are derived from its role in EPS;
- The electrical relaying protection isolates the faulted part of EPS to:
  - prevent damage to equipment and personnel; and
  - to ensure the continuity of power supply to parts of EPS not affected by the fault;
- Protection should be activated when faults occur;
- Protection should not be spuriously activated;
- Protection should be activated as fast as possible when the faults occur; and

- To ensure the continuity of power supply to parts of EPS not affected by the fault, selectivity of protection is considered.

210. In addition, the RP has set out the following design principles that are applied to the design of the electrical protection scheme:

- When a breaker is applied as an isolation device between a high classified system and a lower one, the breaker which isolates the different classified systems shall be high safety classified. The other safety requirements (including single failure criterion, redundancy, independence and diversity) shall be consistent with the requirements of the system of higher classification.
- In an emergency condition, the protection of the EDG and SBO DG are reduced to an essential set of functions to give priority to the safety action.
- The electrical relay protection shall not actuate for normal operating transients such as starting motor inrush, switching surges and transformer inrush current.
- The electrical relay protection shall be designed to activate the protective devices for clearing faults as fast as possible to avoid hazards and to minimize disturbances. In terms of how fast the protection shall be, protection shall be designed to ensure that its threshold level is:
    - Set to detect minimum short-circuit currents
    - Set to avoid trips during normal operating transients and to avoid conflict with the selectivity of protection.
- The breaker of the faulted part shall be preferentially tripped. The breaker of any part not affected by the fault shall not be tripped ahead of the breaker of the faulted part.

211. In Ref. 52, the RP describes the electrical protection proposed for the preferred power supply system between the main transmission system connection, main generator and the unit transformers. The main generator is connected through a generator circuit breaker and the proposed arrangement includes for selective disconnection of the main generator for equipment faults or following a reactor trip. The arrangement also permits for the disconnection of the transmission system following associated faults. The considered faults, disturbances and protection measures are set out in Ref. 52.

212. Should the main transmission connection disconnect, the protective arrangement for the initiation of transfer from AT to ST is described in Ref. 86. I consider that the transfer approach is consistent with the IAEA guidance (Ref. 17) and is consistent with UK and international practice for modern power plants.

213. The protection of the 10kV AC system is proposed as a combination of defined time and inverse time over-current relays for the feeder circuits. In addition, for 10kV motors, negative sequence protection either alarms or trips depending upon whether the motor is safety classified or not. Since the 10kV system is operated as an unearthed system, an online insulation monitoring device is provided which will initiate an alarm when an earth fault condition occurs. In addition, earth fault protection relays are provided on the motor and LV transformer feeders to give indication of the location of a circuit earth fault.

214. I sought further clarity on how earth faults are proposed to be detected on the 10kV and DC system and raised regulatory query RQ-UKHPR1000-1574 (Ref. 6). The response to this RQ (Ref. 6) identified that detection is through a zero sequence voltage relay connected to an open delta secondary winding of the bus bar voltage transformer, initiating an alarm in the main control room to inform the operator but not initiating a trip. The circuit will remain in operation to enable the operator to configure

alternative supplies before tripping the affected circuit manually before undertaking repairs.

215. In Ref. 52, the RP describes the arrangements for the 690V and 380V AC systems. The system equipment and loads are protected by either circuit breakers with protective relays or fuses. Since the output of the feeder transformers are directly connected to the supplied switchboard, any protection for the transformer or switchboard will trip the breaker on the transformer primary side. Where protective relays are employed, these include zero sequence overcurrent, definite and inverse time delay overcurrent, voltage relays, thermal overload and earth-fault protection. Selectivity is applied to the incoming and outgoing circuits, whilst ensuring the incoming circuit breaker protection provides backup protection should the feeder circuit breaker fail to trip. The neutral points of the relevant feeder transformers are directly grounded.

216. The protection of the 380V AC section of the UPS system is configured similar to that described in Paragraph 215, above. For the DC section of the UPS system, the battery is equipped with fuses to protect against a short circuit fault. For the charger output, circuit breakers with instantaneous over protection are provided. The DC feeder circuits are also provided with inverse time overcurrent protection. It is stated that selectivity is provided between the various circuit breakers and fuses.

217. The protection arrangements for the diesel generators are set out in Ref. 52. During DG testing, all protection is configured to trip the DG. When the DGs are run in response to a fault scenario, the respective DG control system ensures only priority protection will trip the DG whilst the remaining systems will initiate an alarm. I consider this approach is consistent with the IAEA guidance (Ref. 17).

218. Ref. 52 state that the tripping of the DGs is implemented directly by the protection devices, whilst alarms for the EDGs and SBO DGs are sent through the centralised C&I system. Since the MDG is controlled at the mobile unit, all alarms are indicated on a control panel local to the unit.

219. The RP states that the safety classification of protection devices that protect equipment operating in response to a categorised safety function are classified consistent with the equipment it protects.

220. Following the conclusion of the RP CCF and Diversity review, as discussed in Section 4.4 of this report, the RP has identified in the CCF and Diversity Analysis submission (Ref. 72) that diversity will be applied between the protection used on the two diverse groups of LV distribution system equipment, as detailed in Figure 2, and between EDG and SBO DGs. Each colour block on Figure 2 indicates a separate diversity group. As discussed in Section 4.4, I consider this approach is consistent with the expectations of ONR SAPs EDR.2.

221. In addition, following that review, the use of smart protective devices has also been clarified. In Ref. 72 it is stated that whilst smart devices may be utilised for equipment associated with the preferred power supply, conventional protection relays will be applied to the 10kV EPDS. For the remaining AC and DC distribution systems, it is stated that smart devices may be used but the diversity requirement between the two diversity groups should be assured. Advice is given in the submission that this could be assured through the use of a combination of conventional and smart protective devices.

222. It is stated that smart protection devices should only be applied to protect a dedicated circuit and not connected or communicate with other devices. For fault diagnosis, the application of smart fault diagnosis devices could be considered but would require,

through failure mode analysis, demonstration that its failure would not affect the safety function of the monitored equipment and be classified consistent with the equipment it is associated with.

223. I consider that the scheme described by the RP meets the aims and principles set out in Paragraphs 208 and 209, providing a co-ordinated arrangement to protect plant and personnel, supporting system stability and minimising the effects of a fault. The full effectiveness of the scheme will only be assured once a full site design is developed. A future licensee will need to consider the site specific parameters including transmission connection and the details of the non-safety balance of plant equipment in demonstrating the effectiveness of the scheme for the full site design I consider that given the aims and principles are sound, the risk to the safety case made during GDA is minor and the development of this part of normal business.

224. From my assessment, I am content that through applying an approach of classification for protective devices consistent with the categorisation of the safety function the equipment supports, the expectations of ONR SAP ECS.2 are being met.

225. I am content that in the development of the design and this aspect of the safety case, the RP has considered the IAEA guidance (Ref. 17) and appropriately considered the selective use of protection for the diesel generators to balance the long term availability of the equipment versus the essential role it performs during a LOOP or SBO situation. I consider this is consistent with the expectations of ONR SAP EES.7 in the use of protective devices for essential safe operation. Whilst a future licensee would need to develop the design, apply appropriate protection settings and demonstrate that the complete site electrical power distribution system will meet the requirements set out in Ref. 52, I consider the detail provided on electrical system protection and in the supporting system studies is sufficient for GDA.

226. Whilst the RP has not committed to either conventional or smart devices for protection devices, it has recognised the need to maintain diversity between equipment groups and the need to ensure the devices are appropriately qualified and installed to manage common cause failure. I consider this is consistent with the expectations of ONR SAP EDR.2.

227. Since the DC system is operated as an unearthed system, Ref. 52 identifies that an insulation monitoring system will be used to give an indication of a first earth fault. As with my assessment of the DC unearthed monitoring system, described in Paragraph 214, above, I sought further clarity on how earth faults are proposed to be detected on the DC system through RQ-UKHPR1000-1574 (Ref. 6). The response to the RQ (Ref. 6) identified an insulation detection device is used to detect earth faults on both the busbar and circuits. For the busbar, an unbalanced bridge is used to detect the resistance change on positive and negative poles. For each circuit, a low frequency test current is injected into the circuits and the insulation fault will be detected and located by the current transformers mounted on every circuit. If an earth fault occurs on the busbar, the earth fault alarm will be triggered but the circuit indicators on the insulation detection device will not be lit. If an earth fault occurs on one of the circuits, the earth fault alarm will be triggered and the circuit indicator for the specific circuit on the insulation detection device will be lit to inform the operator about the accurate location of the earth fault.

228. Whilst this approach has the advantage that supply security is enhanced by allowing operation to continue in the event of a single earth fault, it is important that the injection of any test current is managed and does not affect the functionality of the remainder of the electrical system. In addition, prolonged operation in such a condition should be avoided since it potentially exposes equipment to overvoltages. It is important that analysis is undertaken to evaluate the potential overvoltages, ensure the relevant

equipment specifications capture any design requirements and thereby demonstrate a robust safety case for this aspect. Whilst I consider the basic approach described in Ref. 52 to be feasible, it is important to the safe operation of the electrical system that these aspects are evaluated. I, therefore, raise an assessment finding on a licensee to complete this aspect:

> AF-UKHPR1000-0016 – The licensee shall as part of the development of the earth fault monitoring and detection system, undertake analysis of the overvoltage disturbances resulting from an earth fault on the unearthed electrical systems and ensure that the operation of any monitoring and location detection schemes do not adversely affect the operation of unaffected circuits and equipment.

229. The RP has undertaken electrical system studies to confirm the electrical protection design principles are appropriate. I have assessed these studies in Section 4.6 of this report and am satisfied that the results from these studies demonstrates the adequacy of the arrangements.

4.5.2 Strengths

230. I have identified the following areas of strength in the approach to electrical system protection:

- Following its CCF and Diversity Analysis, the RP has recognised the importance of applying the same principles of diversity to protection equipment as to the equipment it protects.
- The RP has structured the safety case to provide a future licensee with the option to utilise conventional or smart protective devices, whilst setting clear design principles on their use.

4.5.3 Outcomes

231. From my assessment, I am satisfied that the RP has set out a set of design principles and established a co-ordinated protective arrangement to protect plant and personnel, supporting system stability and minimising the effects of a fault. The RP through its system studies, has demonstrated the adequacy of the EPDS to support a co-ordinated protection system

232. Whilst I consider that the arrangements for the detection and location of earth faults on the unearthed 10kV and DC systems are feasible, it is important that the analysis is undertaken to ensure any potential overvoltages. This analysis should demonstrate that there is no adverse impact on the operation of the remainder of the EPS and identify any requirements for equipment specifications. I have therefore raised the following assessment finding:

> AF-UKHPR1000-0016 – The licensee shall as part of the development of the earth fault monitoring and detection system, undertake analysis of the overvoltage disturbances resulting from an earth fault on the unearthed electrical systems and ensure that the operation of any monitoring and location detection schemes do not adversely affect the operation of unaffected circuits and equipment.

4.5.4 Conclusion

233. Based on the outcome of my assessment of the electrical protection system, I am content that the electrical system protection scheme provides a good set of design principles for a co-ordinated protective arrangement to protect plant and personnel, supporting system stability and minimising the effects of a fault.

234. I consider the principles are consistent with the IAEA guidance and meet the expectations of the relevant ONR SAPs.

235. I have raised one assessment finding, AF-UKHPR1000-0016, that I expect a licensee to consider as it develops the safety case for a specific site.

4.6 Electrical System Studies

4.6.1 Assessment

4.6.1.1 Scope of System Studies

236. The RP 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. 87). The studies were performed using the ETAP software package to construct a model of the EPS.

237. The RP identified the following studies to analyse the EPS:

- AC and DC system Power Balance Reports
- AC and DC system load flow studies
- Short circuit and earth fault studies
- Source transfer studies
- Motor starting and reacceleration studies
- Voltage disturbance studies
- House load operation studies
- Load sequencer studies
- Loss of phase studies
- Protection coordination studies
- DC and AC UPS transient studies
- Ferroresonance Studies
- Fault Ride Through and Load Rejection Studies

238. In order to verify the results from the RP studies I utilised a Technical Support Contractor (TSC) to undertake a set of confirmatory studies. In line with a sampling approach, I focused their effort on the first nine study types listed in paragraph 237. These studies were performed using DIgSILENT Power Factory software to provide a diverse assessment to the studies performed by the RP. The TSC created their system model and ran the various studies based on the equipment data and scenarios provided by the RP. This ensured independence in the way in which the studies were developed and analysed.

239. In my assessment, I have focused on whether the TSC analysis draws the same conclusions as that undertaken by the RP and whether the RP analysis is consistent with the expectations of the following ONR SAPs:

- EES.3 Capacity, duration, availability, resilience and reliability
- ESS.10 Definition of capability
- ESS.11 Demonstration of adequacy

240. I had concerns that the initial RP report submissions did not give sufficient explanation of the process or analysis of the system sizing and performance to provide confidence to ONR that the EPS is adequately designed to meet its performance requirements. The system models and design data used in the studies had not been clearly presented to demonstrate that the models adequately represented the EPS and there was not adequate design data to enable ONR to conduct the confirmatory studies. Further clarity was also required on the selection of study conditions such as modes of

operation, derivation of bounding cases, limiting conditions of operation and acceptance criteria.

241. A number of RQs (Ref. 6) were raised to seek clarity on individual aspects of submissions. These were discussed with the RP and it was apparent that the information gaps were unlikely to be resolved by simple RQ responses. Consequently, I raised RO-UKHPR1000-0038 (Ref. 31) requiring the RP to develop a strategy to establish the rating of EPS equipment and to analyse the EPS against anticipated events and disturbances and to use the system strategy to develop the model and the study reports.

242. The RP responded to RO-UKHPR1000-0038 by updating the study reports and submitting the following documents which address the issues raised in the RO:

- Electrical Power System Studies in accordance with IEC 62855 (Ref. 88)
- Sizing and System Study Bounding Case Analysis (Ref. 89)
- Modelling and Acceptance Criteria (Ref. 90)
- Qualification Report of Electrical System Software (Ref. 91)

243. The scope of each of the studies is defined in the Electrical Power System Studies in accordance with IEC 62855 submission (Ref. 88). Each of the studies undertaken by the RP was defined in this report and this was also used as the basis for performing the confirmatory studies.

244. The performance requirements for the EPS to support the plant safety systems are defined in in the RP document Sizing and System Study Bounding Case Analysis (Ref. 89). These requirements were used as the basis of the study scope and to define the modelling and acceptance criteria.

245. The modelling data is defined in the Modelling and Acceptance Criteria (Ref. 90). The data for the models are derived from the UK HPR1000 electrical SDMs or where out of scope of GDA, data from FCG3 or typical data relevant to the design. From a sampling of the SDMs (Refs 47, 49, 66, 75 and 76), I am satisfied that the data used in the model is reflective and where typical data has been used, this is appropriate.

246. The acceptance criteria for each study are defined in the Modelling and Acceptance Criteria (Ref. 90). The results from each study were assessed in the RP study reports compared to these acceptance criteria. Non compliances were assessed to identify future design changes during detailed design or to identify mitigations which can be applied to the results. I am satisfied that the acceptance criteria are appropriate, reflecting the performance expected of the relevant safety systems from the safety analysis and the equipment ratings of commercially available equipment.

247. The qualification of the ETAP software used for the RP studies was substantiated in the Qualification Report for EE Software (Ref. 91) produced by the RP. ETAP is a commercial software package that is used internationally by nuclear power plant designers and operators. This submission sets out how the RP has satisfied itself that the application of this package is suitable in its studies. I am content that this adequately substantiates the software used for the studies.

248. The RP submitted a report of the findings of each study together with detailed study results compared to the acceptance criteria. Where there were deviations from the acceptance criteria the reports identified mitigations to provide justification for the results or proposed changes to the design to be implemented during detailed design of the plant.

249. The results of the confirmatory studies are presented in the report prepared by ONR's TSC (Ref. 92). I compared the results from the TSC confirmatory studies to the RP study results and acceptance criteria in order to highlight any discrepancies. This comparison identified a number of design and modelling issues which were resolved in a series of discussions between ONR and the RP. Following resolution of the issues the RP updated, as necessary, the system study reports to take account resultant design changes, changes to modelling methodology and the modelling input data.

250. The latest RP system study reports also take into account design changes to ensure they are consistent with the Design Reference 3.0 configuration. I am content that these latest revisions of the reports take full account of the issues raised in RO-UKHPR1000-0038 and are in accordance with the overall strategy for conducting electrical system studies. My assessment of each of the system studies in the following sections of this report is based on the strategy documents, the RP study reports, the acceptance criteria and the TSC confirmatory study report.

251. I consider that the revised strategy by the RP for undertaking the electrical system studies and the traceability provided from the safety case supported closure of the RO (Ref. 93).

252. The RP has appropriately recognised that the system studies will need to be reviewed and updated by a licensee once a site is selected and detailed design is undertaken including consideration of the actual site characteristics and connection to UK electricity transmission system. It has captured this requirement for a licensee in its post-GDA Commitment Log (Ref. 38) and I consider progress in this area would be tracked by ONR through normal business.

4.6.1.2 Power Balance Calculation Reports Assessment

253. The following power balance reports were submitted by the RP:

- Emergency Diesel Generator Power Balance Calculation Report (Ref. 94)
- SBO Diesel Generator Power Balance Calculation Report (Ref. 95)
- Mobile Diesel Generator Power Balance Calculation Report (Ref. 96)
- Dry Transformer Power Balance Calculation Report (Ref. 97)
- 2/24h Battery Power Balance Calculation Report (Ref. 98)
- Regulating Transformer Calculation Report (Ref. 99)

254. The results of the power balance reports show compliance with the acceptance criteria defined by the RP. The confirmatory study results from the power balance studies are in agreement with the RP study results.

255. My assessment of the power balance reports is that I am content that these reports demonstrate that the design is adequate to support the plant design requirements.

4.6.1.3 AC and DC System Load Flow Studies

256. The following load flow study reports were submitted by the RP:

- Load Flow Studies for AC on-site Power Systems (Ref. 100)
- Load Flow Studies for DC and AC UPS (Ref. 101)

257. The load flow studies demonstrate that the AC and DC UPS power systems are adequately rated to support the system loads. I have compared the results of the RP load flow studies to the results from the confirmatory studies and am content that the results are in general agreement.

258. Revision A of the Load Flow Studies for AC on-site Power Systems report (Ref. 100) identified instances where the design rating of some power transformers did not meet the acceptance criteria. The confirmatory studies undertaken by the TSC produced similar findings.

259. Following a discussion of the initial study results with the RP, I raised RQ-UKHPR1000-1286 (Ref. 6). This required the RP to identify potential measures to address the transformer rating issue. In its response, the RP acknowledged that the study report should be updated to identify potential solutions to the transformer rating issue. In the latest revision of the Load Flow Studies for AC on-site Power Systems report (Ref. 102), which as discussed in paragraph 250 also incorporates plant modifications to bring the analysis up to Design Reference 3.0, the RP identified the following transformers where the ratings do not meet the acceptance criteria:

- One Auxiliary Transformer (AT-A) has a power rating margin below 10%;
- Six 10kV/400V transformers are overloaded
- Three 10kV/400V transformers have a power rating margin below 10%
- Two 690/400V transformers are overloaded

260. In Ref. 102, the RP has proposed a series of measures for each of the shortfalls consisting of uprating transformers and splitting loads by providing additional transformers with a commitment (Ref. 38) that these would be implemented by a licensee, as required, during detailed design. I am content that the proposed actions in response to the transformer rating issue have been correctly addressed by the RP and consider that the proposed actions are appropriate. However, I consider it important that ONR tracks the closure of this action and have included it in a single assessment finding, AF-UKHPR1000-0017, raised to capture where the RP has identified that a licensee will need to review, finalise and potentially implement a design change from the system studies. This finding is defined in Section 4.6.3, below.

261. I have assessed the overall load flow studies and I am content with the overall findings of the RP studies. I consider that the load flow study results demonstrate the provision of a robust electrical system.

4.6.1.4 Short Circuit and Earth Fault Studies

262. The following short circuit and earth fault studies were submitted by the RP:

- Short-circuit and Earth Fault Studies for AC on-site Power Systems (Ref. 103).
- Short-circuit and Earth Fault Studies for DC and AC UPS (Ref. 104).

263. Revision A of the Short-circuit and Earth Fault Studies for AC on-site Power Systems report (Ref. 103) identified instances where the calculated short circuit currents of certain switchboards were within the permitted margin or exceeded the ratings identified in the acceptance criteria. The confirmatory studies undertaken by the TSC produced similar findings.

264. Following a discussion of the initial study results with the RP, I raised RQ-UKHPR1000-1219 (Ref. 6) which required the RP to identify potential solutions. In its response, the RP acknowledged that solutions should be captured in an update revision of the study report. In the latest revision of the Short-circuit and Earth Fault Studies for AC on-site Power Systems report (Ref. 105), which as discussed in paragraph 250 also incorporates plant modifications to bring the analysis up to Design Reference 3.0, the RP identified the following systems where the short circuit ratings were exceeded:

- The Peak Short-Circuit Currents of LLE and LLH system exceed the Rated Short-circuit Making Capacity of the LV breaker of 143kA and the Initial Symmetrical Short-circuit Current has a small margin comparing with the Rated Short-time Withstand Current of 65kA.
- The Initial Symmetrical Short-Circuit Current of LJA and LLC system exceeds the Rated Short-time Withstand Current of 65kA.

265. In Ref. 105, the RP has proposed that the SBO DG periodic test method should be modified and a new LV transformer should be added during detailed design, with a commitment in the Post-GDA Commitment Log (Ref. 38) that these would be implemented by a licensee during detailed design. The proposed changes are supported by calculations for the maximum short-circuit design condition, which show that the proposed changes satisfactorily resolve the issues. I am content with the changes proposed by the RP and supporting analysis. However, I consider it important that ONR tracks the closure of this action and have included it in a single assessment finding, AF-UKHPR1000-0017, raised to capture where the RP has identified that a licensee will need to review, finalise and implement a design change from the system studies. This finding is defined in Section 4.6.3, below.

266. The Short-circuit and Earth Fault Studies for DC and AC UPS report (Ref. 105) demonstrates that the AC and DC UPS power systems are adequately rated to support the system fault level. I have compared the results to the results from the TSC confirmatory studies and I am content that the results of the studies are in general agreement. My assessment of the short circuit and earth fault studies is that they are acceptable.

4.6.1.5 Source Transfer Studies

267. The source transfer study was presented by the RP in the AT/ST Transfer Studies report (Ref. 106). This report studied the performance of the EPS when the offsite power supply is transferred from the AT to ST transformer. The study results show that the acceptance criteria requirement for motors to start up within 5 seconds of source transfer is met with the exception of the Circulating Water System (CRF) pump. Following a discussion of this concern with the RP, I raised RQ-UKHPR1000-0630 (Ref. 31). In its response, the RP clarified that the actual process requirement for the CRF pump is significantly longer than five seconds and that the studies indicate the pump will start within the actual process requirement. The RP updated the report (Ref. 86) to provide the necessary justification. I consider that this clarification of the acceptance criteria requires final verification during detailed design. But noting that operation of the CRF pump is not associated with nuclear safety, I consider this matter to be a minor shortfall.

268. The results of the TSC confirmatory studies are in agreement with the RP study findings.

269. My assessment of the source transfer studies is that I am content with the results of the RP studies and the clarification of the CRF pump starting time.

4.6.1.6 Motor Starting and Reacceleration Studies

270. The motor starting and reacceleration studies were presented by the RP in the Motor Starting and Reacceleration Studies for AC on-site Power System report (Ref. 107).

271. The results of the RP studies demonstrate that the safety classified motors all meet the acceptance criteria during motor start up and reacceleration. A number of non-safety classified motors which are connected to the safety classified system do not meet the defined process specification requirement. The RP has studied the performance of

these motors as detailed in Appendices B and C of the study report to justify that their performance does not impact the system functionality of the safety classified system.

272. The results of the TSC confirmatory studies are consistent with the RP study results.

273. Based on my assessment of the motor starting and reacceleration studies I am content with the conclusions presented in the RP study report and consider that the capability of the system to meet system functional requirements during motor starting and reacceleration conditions has been adequately demonstrated by the RP.

4.6.1.7 Voltage Disturbance and Voltage Surge Studies

274. The voltage disturbance and voltage surge studies were presented by the RP in the following documents:

- Voltage Disturbance Studies (Ref. 108)
- Voltage Surge Studies (Ref. 109)

275. The voltage disturbance report considers the impact of grid disturbances on the AC on-site electrical power system. The report identifies that there are some instances where voltages on the on-site power system do not meet the acceptance criteria for short durations when maximum tolerable grid disturbances occur. The RP studies have shown that these minor deviations do not impact on overall performance of the EPDS. The RP has identified that this topic should be considered during detailed design and that rating changes to distribution transformers may need to be considered. My assessment is that the RP conclusion is reasonable and that the proposed course of action is appropriate.

276. The voltage disturbance report concludes that in the event of a failure of the on-load tap changer on the AT transformer the voltage of a portion of on-site electrical power systems will exceed the recommended range for long term operation. I agree with the report conclusions and consider that this scenario will need further consideration during detailed design when the risks from a failure of the on-load tap changer will need to be fully assessed.

277. The voltage surge study report considers the effects of voltage surges due to electrical switching, earth faults and lightning strikes. The report concludes that the EPS is adequately designed to withstand the range of voltage surge conditions studied. My assessment is that the report is comprehensive in its assessment and I consider the report's conclusions to be reasonable.

278. I have compared the results of the TSC confirmatory studies with the RP results and consider that the results are consistent.

279. Based upon my assessment of the voltage disturbance and voltage surge study report I am content with the RP reports.

280. However, I consider it important that ONR tracks the closure of the gaps identified in the voltage disturbance reports and have raised a single assessment finding, AF-UKHPR1000-0017, to capture where the RP has identified that a licensee will need to review, finalise and potentially implement a design change as a result of the system studies. This finding is defined in Section 4.6.3, below.

4.6.1.8 House Load Operation Studies

281. The house load operation studies consider the capability of the UKHPR1000 to operate supplying only the units electrical load in the event of a loss of grid connection. The

house load operation was considered in the House Load Operation Studies report (Ref. 110).

282. House load operation was studied in the confirmatory studies by ONR's TSC. The initial TSC confirmatory studies did not align with the RP studies regarding stability of the EPS during house load operation and further clarification was sought from the RP regarding the generator governor model used for the studies. Further detail was provided by the RP during technical meetings and in response to RQ-UKHPR1000-1494 (Ref. 6) but the TSC was still unable to show stability in the confirmatory studies during house load operation. In response to further discussions the RP provided details of a power system stabiliser (PSS) which has been developed to operate with the governor to control the power system during house load operation. Utilising the data provided on the performance of the PSS the TSC was able to obtain stability in the system in the confirmatory studies. In the latest revision of the House Load Operation Studies submission (Ref. 111), the RP included additional details of the governor and PSS system. The report now concludes that the EPDS is stable during house load operation.

283. Following the additional modelling data provided by the RP the TSC confirmatory studies are consistent with the RP studies.

284. I am content that the RP study report now demonstrates stability during house load operation which is supported by the confirmatory studies. However, the RP has not provided technical details of the PSS or evidence of operational experience with the equipment to demonstrate its proven capability. I have, therefore, raised the following assessment finding:

AF-UKHPR1000-0018 – The licensee shall demonstrate that the design of the power system stabiliser to be used in the UK HPR1000 is capable and proven to operate as identified in the GDA system studies.

285. Based upon my assessment of the house load study report, I consider this to be an adequate to demonstrate the house load operation.

4.6.1.9 Load Sequencer Studies

286. The load sequencer studies consider the sequence of applying plant loads to the EDG and SBO DGs. The results of the studies were presented in Revision A of the Load Sequencer Studies report (Ref. 112).

287. In Ref. 112, the RP did not adequately define the acceptance criteria as there was no definition of acceptable motor starting times. I discussed this with the RP in technical meetings and raised RQ-UKHPR1000-1122 (Ref. 6) to seek clarification of the requirements. In response the RP modified the acceptance criteria identified in the study to align the acceptable starting time for motors in order to meet the EPS system and process requirements.

288. An issue was identified in the confirmatory studies with the 380V Safety Chilled Water System (DEL) chiller units being unable to start due to the high starting current requirement. This matter was discussed in technical meetings with the RP who implemented a design change (Ref. 84) to operate the chillers on the 690V system which satisfactorily resolved the issue.

289. This change was included in the latest revision of the Load Sequencer Study report (Ref. 113). That report showed that the timer interval of the sequencer is adequate to restore the voltage and frequency before the next step is applied with the voltage and

frequency levels meeting the acceptance criteria. The results are supported by the results of the TSC confirmatory studies.

290. My assessment of the load sequencer studies is that the RP study results are adequate to demonstrate that the system is robust to support motor starting in an acceptable time sequence to meet plant requirements.

4.6.1.10 Loss of Phase Studies

291. The loss of phase study results have been presented in the report considering Loss of Phase Studies (Ref. 114). This report assesses the effects on the operation of the EPS following the loss of a phase on the grid supply and on the EPS when fed from EDG or SBO diesels.

292. The report concludes that the electrical protection system will provide protection against a loss of phase condition except in the following conditions:

- An over voltage condition will not be detected upon loss of one or two phases on the LGA branch of the AT-A at maximum load and in no load condition.
- An over voltage condition will not be detected upon loss of one or two phases on the LGB branch of the ST in no load condition.
- The electrical protection system will not indicate a loss of one or two phases on the grid side of the ST in a no load condition.
- The electrical protection system will not indicate a loss of one phase on the 10kV side of the ST in a no load condition.

293. The RP has identified potential measures to address the issues which would be implemented during detailed design. These consist of provision of an over voltage alarm on the 10kV busbars of the conventional island to address the over voltage detection issue and the provision of a current monitoring device on the ST to monitor the small change of current following a loss of phase. As this issue is not fully resolved but I consider it important that ONR tracks the closure of this action, I have included this in a single assessment finding, AF-UKHPR1000-0017, to capture where the RP has identified that a licensee will need to review, finalise and potentially implement a design change from the system studies. This finding is defined in Section 4.6.3, below.

294. My assessment concludes that the loss of phase study report has adequately assessed the loss of phase condition and concur with the findings of this report. The RP has identified shortfalls in the protection arrangements but has provided realistic options to address these shortfalls during detailed design. The design of the additional protection and monitoring should be fully assessed during detailed design but I am content that the RP has correctly identified the issues associated with open phase faults and has proposed appropriate measures which could be implemented to address the issues.

4.6.1.11 Protection Co-ordination Studies

295. The Electrical Protection Co-ordination Report (Ref. 115) studies the co-ordination of the electrical protection on the EPS based on the protection settings used in the FCG3 reference plant. The report considers the adequacy of the co-ordinated electrical protection scheme to provide a stable and reliable EPS to supply the plant safety systems. The report considers the effectiveness of the electrical protection scheme to meet the following requirements:

- Faulted circuits should be selectively isolated.
- Degraded or unbalanced voltages should be detected and mitigating actions initiated.

- The EPS should be protected against harmful over voltages.
- The tripping of power supplies to critical safety equipment should be evaluated to consider the effects on functional safety requirements.

296. The report establishes that the EPS can be co-ordinated to provide effective protection of the plant in the event of an electrical power system fault. The results of the protection co-ordination studies support the findings of the assessment of electrical system protection in Section 4.5 of this report.

297. My assessment of the protection co-ordination study report is that it demonstrates that the EPS is sufficiently robust to provide a basis for a co-ordinated protection scheme which isolates electrical faults, supports system stability and minimises the loss of supplies following an electrical system fault. The protection co-ordination will require to be fully established during detailed design when actual protection settings can be determined but I consider this normal business.

298. I am content that the protection co-ordination report demonstrates the adequacy of the EPS to support a co-ordinated protection system. Although the protection settings will be updated during detailed design the demonstration based on the settings used on FCG3 provides confidence that a co-ordinated electrical protection scheme can be established.

4.6.1.12 DC and AC UPS Transient Studies

299. This topic is covered by the RP document Transient Studies for DC and AC UPS (Ref. 116). The document is based on a report of the actual results of tests performed for the UPS system on the FCG3 reference plant. The results of these tests have been assessed based on the requirements defined in IEC 62855 (Ref. 87) and the defined plant acceptance criteria.

300. The requirements defined in IEC 62855 are as follows:

- The DC system voltage should be maintained within an acceptable range during AC system transients.
- The UPS system output voltages should remain within an acceptable range during input AC voltage transients.
- Voltage disturbances in the input AC system should be dampened or limited to an acceptable level to ensure that functionality of UPS powered loads is not adversely affected.
- Over voltages should not render the bypass switch inoperable.
- The functional capability of the UPS system shall not be degraded by voltage disturbances such as microcuts, switching surges or inrush current in the AC system powering the UPS circuit.

301. The RP report concludes that compliance with the acceptance requirements is demonstrated by the test results with one exception of the rectifier returning to normal voltage which was not tested and recorded during the tests on FCG3.

302. I consider that the RP report provides adequate confidence of the capability of the design of the UPS system to withstand external electrical transient disturbances. The comparison of the results with the requirements identified in IEC 62855 represents good practice. The need to demonstrate the recovery of the UPS following degraded supply voltage has been captured by the RP in its Post-GDA Commitment Log (Ref. 38). I consider it important that ONR ensure that this requirement is reflected in the testing requirements for the equipment and therefore raise the following assessment finding:

AF-UKHPR1000-0019 – The licensee shall demonstrate that the functional capability of the UPS system is not degraded by supply voltage disturbances and meets the capability expectations of IEC 62855.

303. My assessment concludes that the DC and UPS transient studies performed by the RP adequately demonstrate the resilience of the UPS system to withstand transients and perform its duty.

4.6.1.13 Frequency Compliance Analysis Report

304. In support of the assessment of grid code compliance, which is covered in Section 4.7 of this report, the RP has submitted a Frequency Compliance Analysis Report (Ref. 117) for assessment. This reports the results of analysis of the capability of the plant electrical equipment to perform its design function within the transmission system frequency limits for Great Britain defined in the Grid Code (Ref. 118).

305. The analysis has considered the impact of frequency variations on the following:

- Turbine Generator
- Electrical Power Equipment
- HVAC systems
- Fluid Systems
- Reactor operation, core fuel assembly and accident analysis

306. The analysis of the impact on the turbine generator is based on analysis of the turbine generator installed on the FCG3 reference plant. The analysis concludes that the turbine generator can operate within the frequency variations specified in the Grid Code.

307. The analysis report states that the requirement to operate at the frequency limits defined by the Grid Code will be specified during detailed design. I consider that this is the correct approach to compliance.

308. The analysis report confirms that the HVAC systems have sufficient spare capacity to maintain adequate flow rates during frequency variations as defined by the Grid Code (Ref. 118). I consider that the report adequately justifies the capability of the HVAC system to withstand frequency variations.

309. The performance of the fluid systems is analysed in the report to verify that adequate flow rates can be maintained throughout the range of frequencies specified in the Grid Code. This adequately demonstrates that the fluid systems are not adversely impacted by frequency variations.

310. My assessment of the frequency compliance analysis report is that it provides adequate justification of the capability of the plant to operate within the Grid Code limits and to support the overall assessment of grid code compliance.

4.6.1.14 Ferroresonance Studies

311. The effects of ferroresonance on the EPS have been assessed by the RP in the report Ferroresonance Studies (Ref. 119). The scope of the assessment meets the requirements for assessment of ferroresonance effects defined in IEC 62855 (Ref. 87).

312. The study has been undertaken utilising EMTP-RV software. References are provided in the report to other applications of this software in the nuclear sector. The models used in the analysis have been developed using data provided in the EMTP-RV standard library.

313. From my assessment of the report, I consider that the RP demonstrates a good understanding of how to assess ferroresonance, the requirement to protect the system from its effects and suppression measures that could be employed to mitigate it. I further consider that based on the information available at this time, the RP has adequately shown that no ferroresonance occurs in the design and has demonstrated appropriate analysis of the system.

314. The RP recognises the need for a future licensee to undertake further work as part of detailed site design and has captured this in its Post-GDA Commitment Log (Ref. 38). Given the need to consider the transmission system connection and complete site electrical system, I consider this appropriate and that development of this is part of detailed design.

4.6.1.15 Fault Ride Through and Load Rejection Studies

315. In support of the assessment of grid code compliance which is covered in Section 4.7 of this report the RP has analysed the plant response during fault ride through (FRT) and load rejection. The RP submitted this analysis in a 'FRT and Load Rejection Analysis Report' (Ref. 120), for assessment.

316. The report covers the assessment of the capability of the EPS to meet the requirements of the Grid Code (Ref. 118) to remain connected and stable in the event of a grid fault, the parameters of which are defined in the Grid Code. The load rejection study has been performed to demonstrate the active power output capability of the power generation module at high frequency as defined in the Grid Code. The simulation considers the performance of the power generation module when the main load is rejected and only a local load remains connected.

317. The acceptance criteria for the FRT and load rejection studies are defined in the Grid Code.

318. The results of the FRT simulation study show that the EPS can meet the requirements of the Grid Code under various fault conditions. The system voltages are stabilised and the rotor speed of the turbine generator recovers to the pre-fault level and can ride through the defined system faults and disturbances.

319. The load rejection study shows the system can accommodate the load rejection successfully and maintain a sustained stable state to a local load. The simulation result demonstrates the frequency control performance of the power generation module under a part load rejection condition as required in the Grid Code.

320. My assessment of the simulation studies is that they have been performed in accordance with the requirements of the Grid Code and that they adequately demonstrate the capability of the plant electrical system to perform in accordance with the Grid Code under FRT and load rejection scenarios. These results support the overall assessment of grid code compliance in Section 4.7 of this report.

4.6.2 Strengths

321. I have identified the following areas of strength in relation to the RP system study submissions:

- The range of studies performed and the procedures for performing the studies have met the requirement of IEC 62855. This standard defines relevant good practice for the performance of electrical system studies for nuclear facilities and has formed the basis of studies carried out on previous GDA assessments.
- The RP has acknowledged the gaps identified in the response to RO-UKHPR1000-0038 and restructured the way in in which it has undertaken its

system studies to provide an auditable trail of study requirements including assumptions and study criteria.

- The presentation by the RP of the required studies has facilitated the development of the confirmatory studies performed by ONR's TSC. This has enabled a comprehensive comparison of the study results and has informed a number of challenges to the RP study results. The discrepancies have been discussed by ONR and the RP to enable the RP to resolve issues concerning the design of the EPDS.
- The RP has conducted the studies in a structured way based upon a model of the EPS for the UK HPR1000. The required studies have been defined together with the test conditions for each study. The acceptance criteria have been defined in advance for each study to enable the study results to be assessed against defined requirements. The acceptance criteria have been defined based on plant conditions defined in the Sizing and System Study Bounding Case Analysis (Ref. 89).
- The software used for the studies has been subject to verification and validation in the Qualification Report (Ref. 91).
- Where there are outstanding minor issues concerning compliance of the study results with the acceptance criteria the RP has identified potential mitigations to be taken forward to detailed design. There are no outstanding issues identified in the study reports which do not have mitigations proposed.
- Where there are requirements for electrical equipment specifications to define specific requirements to comply with the studies such as with frequency analysis these are clearly defined in the study reports.

4.6.3 Outcomes

322. I consider that the study reports adequately demonstrate the capability of the plant electrical systems to support the safe operation of the generic UK HPR1000 design for the purposes of GDA. I consider that the revised strategy by the RP for undertaking the electrical system studies and the traceability from the safety case assumptions supported closure of RO-UKHPR1000-0038 (Ref. 93). The RP has recognised that a future licensee will need to review or update the system studies during detailed design to demonstrate the capability of the final design. The RP has specifically captured this requirement in its Post-GDA Commitment Log (Ref. 38) for a future licensee. I consider this work to be part of detailed design.

323. The study results fully support the assessment of the electrical system architecture described in Section 4.3 of this report and in so doing, I consider meet the expectations of ONR SAPs EES.3, ESS.10 and ESS.11.

324. The study results have been updated by the RP in a number of instances following challenge from ONR. The confirmatory study results are in general agreement with the RP study results and I am satisfied that any issues raised have generally been satisfactorily resolved.

325. As a result of its studies. the RP has identified a number of gaps that a licensee will need to review, finalise and potentially implement a design change. Whilst I consider the actions it has identified to the gaps are appropriate, it is important that ONR tracks the closure of these gaps and have therefore raised the following assessment finding to capture them:

AF-UKHPR1000-0017 – The licensee shall ensure that it addresses the gaps identified in the system studies for the UK HPR1000. Following the review and updating of the system studies using site specific and detailed design information, the licensee shall implement any necessary design changes to ensure that the:

- Electrical power system is designed to guarantee that all transformers are appropriately sized in line with the design requirements and acceptance criteria.
- Electrical power system is designed to withstand the prospective short circuit.
- Voltages throughout the electrical power system are appropriately controlled during anticipated off-site electricity system disturbances.
- Operation of the electrical power system is robust against failure of transformer on-load tap changers.
- Operation of the electrical power system is robust against a loss of phase condition.

326. In its studies, the RP has shown that through use of a power system stabiliser (PSS), the UK HPR1000 is capable of house load operation. However, no detailed information on the design or proven capability of the PSS has been presented to demonstrate that such capability is achievable. I have, therefore, raised the following assessment finding:

AF-UKHPR1000-0018 – The licensee shall demonstrate that the design of the power system stabiliser to be used in the UK HPR1000 is capable and proven to operate as identified in the GDA system studies.

327. In its studies, the RP identified the need to demonstrate the recovery of the UPS following degraded supply voltage. I consider it important that ONR ensure that this requirement is reflected in the testing requirements for the equipment and therefore raise the following assessment finding:

AF-UKHPR1000-0019 – The licensee shall demonstrate that the functional capability of the UPS system is not degraded by supply voltage disturbances and meets the capability expectations of IEC 62855.

4.6.4 Conclusion

328. Based on my assessment of the system studies, I conclude that the studies have been performed in a way that meets relevant good practice. In response to a RO, the RP revised the structure of its system studies, improving traceability from the safety case and providing sufficient information for ONR to undertake confirmatory analysis. This work was sufficient to enable closure of the observation. The studies undertaken demonstrate the ability of the EPS design to adequately support the plant safety systems and consistent with the relevant ONR SAPs.

329. The results of the system studies show that the overall EPS design is adequately rated to supply the plant electrical loads and that the electrical system remains stable when subjected to a range of internal and external faults and transient conditions.

330. I have raised three assessment findings, AF-UKHPR1000-0017, AF-UKHPR1000-0018 and AF-UKHPR1000-0019, that I expect a licensee to consider as it develops the safety case for a specific site.

4.7 Grid Code Compliance

4.7.1 Assessment

331. It will be necessary for a connection agreement to be in place between National Grid, the GB Electricity System Operator, and a future licensee for a UK HPR1000 to be connected to the UK electricity transmission system. An aspect of this agreement is for the plant to be compliant with the technical requirements for connection, defined in the

Grid Code. Whilst this document at the time of writing is currently Issue 6 Revision 3. (Ref. 118), the issue considered by the RP which was in use at the time of their analysis was Issue 5 Revision 37. I have reviewed the differences between the two issues and do not consider they have a material effect on their analysis. The Grid Code is subject to continuous update and I would expect a future licensee to undertake a review as the site-specific design is developed to ensure any safety case aspects remain valid.

332. Any Connection Agreement for a UK HPR 1000 will need to consider the technical parameters of both the local transmission system and the plant. Whilst assessment of the site-specific arrangements for the connection is outside the scope of GDA, there are various requirements within the Grid Code for a generating plant to remain connected at times of grid disturbances in order to support National Grid in maintaining continuity of grid supply. There is the potential that to fully meet these requirements modifications may be necessary to the way in which the power plant operates, which could impact on nuclear safety. It is therefore important to gain confidence during GDA that a future nuclear power plant design is capable of being connected to the GB transmission system whilst not impacting on nuclear safety.

333. In my assessment, I have considered how the RP has analysed the UK HPR1000 design against the Grid Code requirements. I have considered the validity of any assumptions, where data may not be available until the selection of a site, in its analysis.

334. In early engagement with the RP (Ref. 32), I highlighted the importance of analysing the capability of the UK HPR1000 to be connected to the UK transmission system as defined in the Grid Code.

335. In developing the safety case for the UK HPR1000, the RP set out a specific safety sub-claim in the PCSR (Ref. 3) which states:

> Claim 3.3.5.SC09.2.3.1: The EPS design takes into account the power grid connection requirements and the plant can be connected with the grid.

336. The arguments and evidence to this sub-claim set out to demonstrate how the design recognises the requirements of the Grid Code and compliance analysis to show how the design meets them.

337. The RP assessment of the design in support of the above safety case claim is set out in the following documents which formed the initial basis of my assessment:

- PCSR Chapter 9 (Ref. 3)
- Basis of Safety Case (Ref. 26)
- Compliance with Grid Code Analysis Report (Ref. 121 and 122)

338. The RP has undertaken electrical system studies to demonstrate the ability of the plant to meet the grid code requirements for low and high frequency operation, load rejection and fault ride through. These studies have been considered in Section 4.6 of this report.

339. Ref. 121 aims to demonstrate this compliance through the following objectives:

- Review the Grid Code to identify the key requirements that need to be complied by the UK HPR1000 in terms of technical design perspectives.
- Grid code compliance assessment based on the self-certification, evidences collected from the reference NPP projects and computer simulation study results.

- Simulation study for supporting grid code compliance assessment.

340. I am satisfied that the RP has identified the relevant Grid Code clauses in Ref. 121 and agree with the four non-compliances that it initially identified:

- ECC.6.1.4 Grid Voltage Variations
- ECC.6.3.2.3 Reactive Capability for Type D Synchronous Generating Unit
- ECC.6.3.7 Ability to comply with Primary Frequency Response requirements
- ECC.A.3.2 Ability to operate at Minimum Stable Operating Level (MSOL)

341. The RP identified the first two of these could be resolved through the use of on-load tap changers for transformers associated with the preferred power system and changes to the rating of the main generator.

342. I sought clarity through RQ-UKHPR1000-0893 (Ref. 6) on the justification behind the judgements that these changes would not impact on the plant layout or nuclear safety of the UK HPR1000. In its response (Ref. 6), the RP provided sufficient justification and that the design changes can be incorporated during detailed design by a future licensee. In addition, in the system studies considered in Section 4.6 of this report, the RP has considered appropriate equipment characteristics and demonstrated that the design is consistent with the expectations of the Grid Code. I am also satisfied that the updated revision to the compliance analysis report (Ref. 122) incorporates this additional information.

343. In Ref. 122, the RP has collated all the aspects that a future licensee will need to consider as it develops the design to meet the requirements, technical and operational, of the Grid Code and identified these through the GDA Project Commitment Log (Ref. 38). I am satisfied this appropriately captures these aspects which do not affect nuclear safety and can be managed through normal business.

344. The RP identified that for the two remaining gaps (ECC.6.3.7 and ECC.A.3.2), it did not consider the reference design could meet the requirements of these two clauses, which required operation down to 65% registered power output and, when operating at this minimum power level, the ability to provide a frequency response capability of 10% rated power within 10 seconds. The RP advised that a future licensee may need to seek derogations against these Grid Code clauses from the electricity market regulator, Ofgem.

345. As the electricity market regulator, Ofgem is the governing body for the UK Grid Code and has the authority to consent to changes to the code or derogation from compliance. National Grid ESO, the UK transmission system operator, acts as code administrator for the Grid Code. In this role, National Grid ESO, can provide advice to prospective generators on compliance and administrate modifications.

346. I was concerned that without early engagement by the RP with either of these parties, there was a risk that either a modification to the Grid Code or a derogation may not be granted and significant design changes to the UK HPR1000 may ultimately be necessary.

347. Through discussion with the RP during Step 4 of GDA and the issue of Regulatory Queries, RQ-UKHPR1000-1102 and -1451 (Ref. 6), I encouraged the RP to engage with National Grid ESO or Ofgem to ensure its interpretation of the grid code was correct and develop a technical solution for compliance.

348. In its response to the regulatory queries, the RP set out how it would engage with National Grid ESO and demonstrate the viability of an option for technical compliance;

leaving the ultimate decision on whether to seek a derogation or introduce a design change to the UK HPR1000 to a future licensee. I considered this approach was reasonable.

349. The RP subsequently issued a revision to the Compliance of Grid Code Analysis (Ref. 122) together with an additional submission, Analysis of the Potential Gaps due to the UK Grid Code Requirement (Ref. 123). In that submission, the RP analysed the gaps identified in Paragraph 344, developed options to address the gaps and demonstrated for the purposes of GDA that one option was viable.

350. To underpin this, the RP engaged with National Grid to ensure its understanding and approach was consistent with their interpretation. The RP has subsequently reaffirmed its proposed approach with National Grid ESO (Ref. 124).

351. Operations at low power and in providing changes in output power to support grid frequency stability have the potential to impact on nuclear fuel integrity and induce stresses in the primary circuit. I therefore worked with the ONR Fuel and Core and Structural Integrity inspectors to ensure that the analysis undertaken by the RP, and any possible options, were considered viable.

352. In Ref. 123, the RP concluded that the plant could meet the two Grid Code requirements through:

- implementing a design change to the power control banks to provide frequency response during Low Power Operation; and
- limiting operation to Minimum Stable Operating Level to a maximum 30 days during each fuel cycle

353. This submission included preliminary analysis and justifications for the impact on the safety case in respect of the Fuel and Core and Structural Integrity areas. The ONR inspectors for these areas have assessed the proposals (Ref. 125 and 126) and have concluded that they are content with the justification provided for the purposes of demonstrating viability.

354. The submission also identified the remaining technical areas within the safety case that could be affected by any design change to the UK HPR1000 and justified that these will not impact on the extant safety case. In discussions with the relevant technical leads, I was content that the risk to nuclear safety by any modification in these areas was unlikely to be risk the viability of the option and, therefore, was not considered further during the ONR assessment.

355. In the Structural Integrity analysis section of Ref. 123, which supports the assessment of meeting the frequency response requirements, the RP identified that its extant analysis showed that the reference design is capable of a million step changes in reactor power of 10% over the life of the plant. In Ref. 123, it also noted that this capability was far in excess of the anticipated one per year predicted for frequency response. Whilst the ONR Structural Integrity inspector was content that the frequency response effects were bounded, I sought clarity from the RP on the basis for its one per year determination through RQ-UKHPR1000-1729 (Ref. 6). In its response (Ref. 6), the RP demonstrated that based on historic transmission system data reporting, only two significant grid events had occurred which would have resulted in the plant requiring to provide the required 10% output change in the last ten years. Noting that should a future licensee implement this arrangement, it would be possible to monitor such transients and take appropriate safety case action if the actual number approached the estimates, I consider its argument that this was a reasonable conservative assumption acceptable.

356. Noting the ONR Fuel and Core and Structural Integrity assessment reports (Ref. 125 and 126) have both concluded that the RP has demonstrated the feasibility of introducing a design modification to improve operation at low power and frequency response, I am satisfied that the RP has demonstrated the viability of an option to ensure full compliance against the Grid Code. I consider that it will be for a future licensee to develop this or another option, and as necessary implement a design change to the UK HPR1000 and therefore raise the following assessment finding:

AF-UKHPR1000-0020 – The licensee shall complete the analysis on Grid Code compliance in support of its safety case, implementing any design changes as necessary, to ensure the UK HPR1000 can operate safely when connected to the UK transmission system.

4.7.2 Strengths

357. I have identified the following areas of strength in the approach to Grid Code Compliance:

- RP has undertaken a comprehensive assessment of its design against the Grid Code supported where appropriate by electrical system studies.
- RP engaged with National Grid to ensure its understanding of the Grid Code and its approach to compliance is consistent with the Transmission System Operator's expectations
- RP has undertaken preliminary analysis to demonstrate the viability of options to enable the UK HPR1000 to be fully compliant with the Grid Code

4.7.3 Outcomes

358. From my assessment, I am content that the RP has undertaken a comprehensive assessment. It has identified a number of areas, out of scope from GDA, where a future licensee will need to ensure it appropriately specifies equipment to ensure it is compliant with the Grid Code.

359. Having identified two non-compliances with the Grid Code, the RP has undertaken a feasibility study of a technical solution, which would enable the UK HPR1000 to be fully compliant with the UK Grid Code. With the support of the ONR Fuel and Core and Structural Integrity inspectors, I consider that the analysis undertaken is sufficient to provide confidence that the gap is fully understood and the RP has developed an suitably developed option that provides a future licensee with a viable technical solution as an alternative to seeking a lifetime derogation from compliance.

360. Further work will be necessary by a licensee to demonstrate that the modification is optimal in managing the risks in the Fuel and Core area and therefore, I have raised the following assessment finding:

AF-UKHPR1000-0020 – The licensee shall complete analysis on Grid Code compliance in support of its safety case, implementing any design changes as necessary, to ensure the UK HPR1000 can operate safely when connected to the UK transmission system.

4.7.4 Conclusion

361. Based on the outcome of my assessment of grid code compliance, I have concluded that the RP has undertaken a comprehensive assessment of the UK HPR1000 against the requirements of the Grid Code. The RP has clearly identified aspects that whilst not affecting nuclear safety will need to be considered by a future licensee to ensure its detailed design and operational arrangements will be compliant with the Grid Code.

362. In two areas where the reference design was not technically compliant, the RP has developed a viable design change to enable the design to be fully compliant. Further work will be required by a future licensee that the modification is optimal in managing the risks to nuclear safety and therefore, I have raised an assessment finding, AF-UKHPR1000-0020.

4.8 Cabling

4.8.1 Assessment

363. A structured approach to cabling is important to ensure that the deterministic design principles set out for plant design are reflected in the cabling systems which otherwise could result in common cause failure of equipment important to safety across multiple defence in depth levels.

364. In my assessment, I have considered how the RP has set out the principles for cabling of electrical systems to ensure that this aspect of the design is consistent with the deterministic principles applied to the equipment it connects.

365. In this section, I have focused on whether the proposed approach is consistent with the following ONR SAPs:

- ELO.1 Access
- EDR.2 Redundancy, Diversity and Segregation
- EHA.10 Electromagnetic Interference
- ECS.3 Codes and Standards

366. I have also considered if the approach is consistent with the relevant sections of the IAEA Specific Safety Guide SSG-34: Design of Electrical Power Systems for Nuclear Power Plants (Ref. 17).

367. In the PCSR (Ref. 3), the RP has identified that the approach to cable management significantly contributes to three sub-claims:

3.3.5.SC09.2.1.4: The diversity and independence of the electrical system offers the resilience against CCF.

3.3.5.SC09.2.1.8: The electrical power system is robust with respect to internal hazards

3.3.5.SC09.2.2.4: The electrical power system features are identified and demonstrated according to the electrical design requirements.

368. The RP through arguments and evidence to support these claims sets out to demonstrate that it has a systematic approach to the design of the cabling system. This approach aims to ensure that the design principles are consistent with the requirements derived from its hazards and deterministic analyses, providing a comprehensive set of rules to ensure a robust electrical cabling installation.

369. As part of my assessment, I have worked with the ONR Internal Hazards inspector to ensure that the requirements set out in the electrical submissions are consistent with the risks and approach identified in the Hazards aspects of the safety case. The details of their assessment are reported in their assessment report (Ref. 58).

370. The design principles adopted for the UK HPR1000 in this area are set out in the following submissions which form the principal evidence documents to the above claims:

- Unified Technical Regulation (Ref. 127)
- NI Cable Routing Guidelines (Ref. 128)
- Technical Specification for the Power Cables (Ref. 129)

371. Through these documents, the following key requirements are established:

- Each redundant train of the emergency power supply is installed in a separate division.
- Cables belonging to different divisions are to be routed physically separated to each other
- Non-safety class cables can run along the cable tray of a safety train. They are then taken to be associated to the safety train and subjected to the requirements for safety train cables.
- All electrical trains are considered as individual fire compartments and are physically separated from adjacent trains by fire barriers, protection walls or adequate means (distance or wrapping).
- Where cables of different divisions enter a single room, the cables have to be totally separated by fire barriers, protection wall, sufficient distance or other measures.
- Cable trays of different trains cannot use the same supports.
- System design should consider the situation that all equipment located in the same independent fire compartment may fail at the same time.
- Cables and cable trays shall be categorised and classified the same as the system or equipment within the system
- Cables of different voltage levels will be arranged on different cable trays
- Minimum separation requirements between cables in different divisions and between cables of different types.
- Principles for the marking of cables and the installations are defined to ensure clear identification after installation for EMIT and lifetime management activities and provide clear confirmation of adherence to the separation principles.

372. Within the submissions, the RP adopts the cabling installation and separation rules set out in an industry standard, RCC-E (Ref. 130), an internationally recognised code for the design and construction of electrical equipment for nuclear islands.

373. I consider that the principles set out above are consistent with the good practice set out in the IAEA guidance (Ref. 17). The principles and use of RCC-E (Ref. 130) should ensure a cabling installation that is consistent with the deterministic principles of separation applied to the electrical equipment it supplies. I also consider the design rules established through RCC-E (Ref. 130) should ensure that the effects of electromagnetic interference between cables will be appropriately managed. As a result, I am content that the approach proposed is consistent with the expectations of the ONR SAPs considered in this section.

374. In Ref. 128, the RP sets out principles that are to be applied to the cabling design on how to ensure sufficient segregation between cables of different divisions. I consider these principles coupled with the basic design principle to minimise the connections between electrical equipment in different divisions will minimise the additional measures necessary to ensure appropriate segregation and are consistent with international good practice (Ref. 17 and 130).

375. The RP has set out that these principles are consistent with those being applied to the reference plant at FCG3. As part of my assessment, the RP provided a video walkdown of specific electrical locations at the FCG3 power plant under construction, where most electrical cables have now been installed. I requested this walkdown included switchgear and cable rooms. From this walkdown (Ref. 131), I am content that that the rules defined in the design submissions are being applied to the FCG3

plant and show that the approach to the overall plant design should ensure that sufficient space exists to facilitate future installation, operation and maintenance of the electrical equipment, including cable installations. I therefore consider the combination of the principles set out in the submissions related to cabling and the space available through the plant layout meet the expectations of ONR SAP ELO.1.

376. Until the detailed cabling design is complete for the UK HPR1000, which is out of scope for GDA (Ref. 41), there is always a risk that there is insufficient space to accommodate the required cables and fully meet the segregation requirements. I would expect a future licensee to demonstrate that the hazards and deterministic aspects of the safety case continue to be met as it develops the detailed design. Due to the approach taken to layout and the confidence provided by the video walkdown, I do not I consider the risk significant and therefore am content that assessment of this to be part of normal regulatory business.

377. Ref. 129 sets out a technical specification for power cables that provide connections in the Nuclear Island of the UK HPR1000. I assessed this document to ensure it was consistent with the design requirements for cables identified in Ref. 128. Ref. 129 sets out a series of IEC standards in addition to the RCC-E rules for defining the technical construction, performance and testing requirements for power cabling up to 10kV. I consider that the standard appropriately reflects relevant international standards in its structure and is consistent with the expectations of ONR SAP ECS.3.

378. I note that the proposed colours for the phase conductors of power cables are not consistent with the expectations of the Requirements for Electrical Installations (Ref. 132), which in its foreword notes that “installations which conform to the standards laid down in BS 7671:2018 are regarded by the Health and Safety Executive as likely to achieve conformity with the relevant parts of the UK Electricity at Work Regulations 1989.” The proposed current colour coding could cause confusion during construction and operation, potentially leading to incorrect actions being taken by personnel, which could risk personal and nuclear safety. I consider that a future licensee as it develops its installation arrangements should ensure that their design takes into due consideration relevant UK standards for equipment installations to ensure it is compliant with UK legislation. I have therefore raised the following assessment finding:

AF-UKHPR1000-0023 – The licensee shall ensure that the requirements and specifications for electrical equipment and its installation are consistent with the expectations of relevant UK standards for installation.

4.8.2 Strengths

379. I have identified the following areas of strength in the approach to cabling:

- RP has established design principles for cabling that are consistent with the deterministic principles for the design and support the Hazards safety case.
- RP has demonstrated through the reference design under construction at FCG3, which has the same basic plant layout, that the sufficient space should exist within the structure to support construction, operation and EMIT activities.

4.8.3 Outcomes

380. From my assessment, I am content that the RP has presented a set of design principles for cabling that are consistent with the deterministic principles for the electrical equipment that it connects.

381. I would expect a future licensee as it develops the detailed cabling design to demonstrate that the hazards and deterministic aspects of the safety case are being

met. Due to the mitigation and confidence provided by the video walkdown, I do not consider the risk significant and therefore am content that assessment of this to be part of normal regulatory business.

382. The colour coding of the phase conductors is not consistent with the expectations of the relevant British Standard which could result in incorrect actions being taken by construction and operational staff, risking both personnel and nuclear safety. I have raised the following assessment finding for a licensee:

AF-UKHPR1000-0023 – The licensee shall ensure that the requirements and specifications for electrical equipment and its installation are consistent with the expectations of relevant UK standards for installation.

4.8.4 Conclusion

383. Based on the outcome of my assessment of cabling, I have concluded that the RP has demonstrated in its safety case cabling principles that are consistent with the relevant IAEA guidance and meet the expectations of relevant ONR SAPs.

384. The RP has proposed the use of phase conductors that are not consistent with the relevant national standard, which could result in a risk to personnel and nuclear safety and have, therefore, raised an assessment finding, AF-UKHPR1000-0023.

4.9 Lightning Protection

4.9.1 Assessment

385. Lightning strikes, both direct and indirect, have the potential to damage SSCs and injure personnel. To ensure that a lightning strike does not result in the common cause failure of equipment important to safety and to protect personnel, an effective lightning protection system should be in place.

386. In my assessment, I have considered how the RP is managing the risk from lightning strikes in their design, whether the approach is consistent with relevant good practice and if the resulting design adequately manages that risk.

387. As a natural phenomenon, the approach to the definition of a design basis lightning event is considered as part of the External Hazards assessment area. I have worked with ONR's External Hazards inspector, who raised RQ-UKHPR1000-0002 (Ref. 31) to ensure the RP adequately characterised hazards such as this.

388. The initial approach by the RP was to consider a design basis lightning current of 200kA, since it identified this the maximum current identified in the relevant international standard BS EN 62305-1 (Ref. 133). After discussion with the RP where we identified that Ref. 133 claims this figure is for a strike with a 99% probability and this is not consistent with ONR's expectation for the definition of a design basis external hazard, as set out in ONR SAP EHA.4 (Ref. 2), the RP undertook additional analysis which concluded it should consider a design basis lightning strike magnitude of 300kA. The ONR External Hazards inspector in their assessment report (Ref. 57), has reviewed the RP analysis and concludes that the resulting design basis is consistent with the ONR SAP EHA.4 and results in a similar design basis current similar to that for other UK nuclear sites.

389. In my assessment, I have focused on whether the proposed approach is consistent with the following ONR SAPs:

- EHA.10 Electromagnetic Interference
- ECS.3 Codes and Standards

390. I have considered if the design approach proposed by the RP should provide an effective arrangement for lightning protection to protect equipment performing safety functions and personnel. I have also assessed if it achieves this through a scheme which is consistent with the various parts of the relevant international standard, BS EN 62305, which sets principles for an effective risk managed lightning protection system.

391. In the PCSR (Ref. 3), the RP has established a CAE structure which specifically recognises the role the lightning protection system performs in mitigating the specific hazard through a specific claim:

> 3.3.5.SC09.1.2.2: The electrical power system safety function has been derived from the hazard analysis: The earthing and lightning protection system supports SSCs in preventing, protecting or mitigating hazard impact by offering earthing and lightning protection measure.

392. Through arguments and evidence that support this claim, the RP sets out to demonstrate that it has developed a risk informed approach to set out the requirements for a lightning protection system that will protect systems, structures and components as well as personnel.

393. The design requirements are set out in the following submissions which form the principal evidence to the above claim:

- Earthing and Lightning Protection Scheme (Ref. 134)
- Design Basis Lightning Current Protection Analysis (Ref. 135)
- Lightning Protection Studies Report (Ref. 136)

394. The reference plant at Fangchenggang Unit 3, FCG3, considers a 200kA design basis magnitude lightning strike. It uses a combination of conductive downcomers bonded to the building structure provide a discharge path to a buried earth mesh and provide electromagnetic shielding to the equipment within the building. In developing the design for the UK HPR1000, the RP was concerned about the level of redesign that may be necessary to the civil structure to accommodate the 300kA strike referred to in paragraph 388.

395. As a result, the RP developed a scheme which involves the reference design with an independent overlay scheme of downcomers capable of dissipating a 300kA strike. The RP has shown that through the arrangement of the enhanced air terminations and downcomers, the lightning protection system is capable of discharging such currents to ground, whilst utilising the existing building reinforcement mesh to provide the effective electromagnetic shielding.

396. The Earthing and Lightning Protection Scheme (Ref. 134) sets out generic principles for the design of the lightning protection system in order to provide protection to SSCs and personnel from lightning strikes. The principles are aligned to the requirements of BS EN 62305 and set out that:

- the lightning protection system (LPS) should protect SSC and personnel;
- the design of the LPS is consistent with BS EN 62305; and
- the design shall incorporate appropriately defined lightning protection zones, incorporating shielding and surge protection devices to provide protection to sensitive equipment from the effects of induced transient overvoltages and electromagnetic interference.

397. The Design Basis Lightning Current Protection Analysis (Ref. 135) sets out the optioneering undertaken in developing a scheme which will meet the design basis

requirement of 300kA. I consider the document provides a clear definition of the requirements and comprehensive analysis to support the determination of the optimal solution.

398. The Lightning Protection Studies Report (Ref. 136) analyses the lightning protection to demonstrate the following:

- In the case of the lightning strike on buildings in the vicinity of the Nuclear Island, the design is effective in discharging the lightning strike to the buried earth system.
- To demonstrate if the Faraday cage, equipotential bonding mesh, cable shielding, cable layout and additional lightning protection are applied to mitigate the consequence of lightning strike.
- To analyse and demonstrate the air-terminal system arrangement of external lightning protection device satisfies the design requirements by modelling and analysing in the simulation tools.
- To check and verify the effectiveness of the design principles in reducing EMI to levels below the equipment specifications.
- To check and verify if the project design practices for separation, routing, cable shielding management and earthing are consistent with good practice for EMI management.

399. In so doing, Ref. 136 demonstrates that the overall scheme is capable of protecting the plant to a 300kA strike. It has shown in accordance with the approach set out in BS EN 62305 that the development of a protection scheme in line with the design principles is effective in discharging the current to ground. It has also shown that through the establishment of lightning protection zones, the electromagnetic interference (EMI) in sensitive areas is controlled to levels significantly below that defined in relevant industry standards for industrial equipment (Ref. 137), which is considered in the design requirements for the UK HPR1000 C&I and electrical equipment.

400. Whilst the proposed overlay scheme has been shown to be consistent with the design basis requirements, an overlay scheme may not be the optimal solution from a construction or maintenance perspective. The effectiveness of the lightning scheme will also be dependent upon the design of the ground buried earthing mesh to effectively dissipate the fault current. Whilst the outline scheme for the latter aspect is in line with the expectations of the relevant standard (Ref. 133), the detailed design of this is dependent on the full site layout and consideration of ground resistivity. I would expect a future licensee as it develops the lightning protection and buried earth system for the whole site to demonstrate the effectiveness of a complete scheme in managing touch and step potentials but consider this to be part of normal business.

4.9.2 Strengths

401. I have identified the following areas of strength in the approach to lightning protection:

- The RP has undertaken detailed analysis in support of its definition of a design basis lightning current of 300kA for the buildings associated with nuclear safety functions.
- The RP has developed a scheme which can provide the necessary integrity to conduct the design basis lightning current to ground.
- The RP has shown that the design principles for the use of lightning protection zones reduce EMI in sensitive plant areas to levels with significant margin to the design requirements for the affected equipment.

4.9.3 Outcomes

402. From my assessment, I am content that the RP has presented a set of design requirements which provides a good basis for the design of a lightning protection scheme to protect the UK HPR1000 from direct and indirect lightning strikes.

403. A future licensee will need to demonstrate that when detailed design of the lightning protection system for the complete site including the buried earth system, the system manages step and touch potentials to prevent injury to personnel and equipment. However, I consider that part of detailed design and would be assessed as part normal regulatory business.

4.9.4 Conclusion

404. In conclusion, I am content that the lightning protection scheme provides a good basis for the design of a scheme to protect the UK HPR1000 from the risks of direct and indirect lightning strikes.

4.10 Earthing

4.10.1 Assessment

405. Earthing systems provide an important function in ensuring the timely disconnection of equipment to prevent faults affecting other systems and also to prevent injury to personnel.

406. In my assessment, I have considered how the safety function of the earthing system has been developed and how the proposed design will deliver those requirements. I have considered the following SAPs in gaining confidence that the design is consistent with good nuclear engineering practice:

- EDR.2 Redundancy, Diversity and Segregation
- ECS.2 Safety Classification of SSCs
- ECS.3 Codes and Standards
- EAD.2 Lifetime Margins

407. I have taken into consideration the guidance provided by IAEA Specific Safety Guide SSG-34: Design of Electrical Power Systems for Nuclear Power Plants (Ref. 12).

408. The initial safety case for earthing the UK HPR1000 set out in PCSR (Ref. 33) and the supporting Basis of Safety Case (BoSC) (Ref. 34) identified that whilst the earthing and lightning protection system does not have a direct safety function, it provides the following support functions:

- to support the function of equipment contributing to the fundamental safety functions; and
- to protect equipment against hazard lightning and EMI.

409. During my assessment, I identified that whilst the claim was recognised in the original CAE structure, the arguments and evidence focused on how the building structure and ground earthing system supported the lightning protection system. My assessment of those aspects is considered in Section 4.9 of this report.

410. I was concerned that there was no design specific evidence on how the earthing system design supported the safety case claims and, therefore, it was not possible to assess the adequacy of this aspect of the design. I raised RQ-UKHPR1000-1574 (Ref. 6) to seek clarity on the safety case for the functional and protective earthing system.

411. In discussions with the RP and through its response to the RQ (Ref: 6), the RP acknowledged a gap in its safety case and updated its CAE structure to recognise the role functional and protective earthing has in supporting nuclear safety functions. The updated claims and arguments structure is primarily supported by a Topic Report of Earthing System Design (Ref. 138) along with information in other extant submissions. The RP updated the PCSR and BoSC (Refs 3 and 26) to reflect the revised CAE structure.

412. My assessment has considered the following documents which form the principal evidence documents to the revised claims:

- Electrical Relaying and Protection Scheme (Ref. 52)
- Topic Report of Earthing System Design (Ref. 138)
- Earthing and Lightning Protection Scheme (Ref. 134)

413. I consider that the revised CAE structure appropriately recognises the role and sets out reasonable arguments for how the earthing system contributes to both providing functional and protective earthing as well as interactions with the lightning protection.

414. The Electrical Relaying and Protection Scheme (Ref. 52) sets out the earthing arrangement of each of the electrical distribution systems and therefore informs the requirements of the electrical protection design.

415. The Topic Report of Earthing System (Ref. 138) sets out how the design of the functional and protective earthing meets the safety case requirements of the UK HPR1000; setting out the safety case for the earthing system, the design principles, the design process, and demonstrating how the design of the earthing system in accordance with these can meet its functional requirements. It is noted that the detailed design of the earthing system is an activity for a future licensee which can only be completed once the full equipment requirements and site parameters for the site are developed. The RP states that it aims to demonstrate that the design principles, as defined in the topic report, with reasonable assumptions will result in an effective system, which can be constructed within the design reference structure.

416. Ref. 138 states that the earthing system delivers four basic functions:

- Electronic Earthing: Offers the reference potential to the C&I systems
- Neutral Earthing: Provides neutral point earthing to the electrical power systems
- Shielding Earthing: Provides the earthing of shielding to prevent the electromagnetic field from interfering with the C&I signals
- Protective Earthing: Provides the protective earthing for the electrical and non-electrical SSCs

417. The topic report methodically sets out the requirements including separation, categorisation and classification, independence, qualification and EMIT for each of these functions. It shows how the design principles for these are consistent with the safety requirements for the overall electrical system and that in their approach are consistent with relevant codes and standards.

418. In respect of the electronic earthing, the earthing requirements have been derived from the design specifications of supported C&I systems. To maintain the requirement of providing a clean reference potential, separate earthing systems are provided for each classification of system within each division, which are in turn connected to the main site buried earthing through dedicated test links. This arrangement maintains the independence of each system and division, ensuring that a failure should not propagate to a higher classification system or to another division.

419. The remaining earth systems connect through a main internal earthing system, connecting with the site buried earthing through dedicated test links. For each building, this system consists of main earthing loops at each floor connected in two places to a vertical earthing loop located at the end of each building. These vertical loops are connected to the main site buried earthing system through dedicated test links.

420. Ref. 138 sets out the design process for each system demonstrating how it meets the safety requirements and how adequate margin will be applied during detailed design, reflecting aspects such as corrosion factors and modifications that may be required over the lifetime of the plant. I consider this consideration of lifetime margins is consistent with the expectations of ONR SAP EAD.2.

421. Ref. 138 sets out principles for the bonding of the internal main earthing system to the building structure at regular intervals, which is itself used in support of the dissipation of lightning to ground, and for the main connection of the internal earthing system to the buried ground earth through dedicated test link chambers in accordance with relevant UK standards (Refs 139 and 140). I consider this approach minimises the risk of touch potentials between the systems and is consistent with the UK expectations as set out in UK standards.

422. In my assessment of the sizing of the main internal earthing system, I have noted that whilst the RP has appropriately considered in its analysis (Ref. 138) the highest earth fault current identified from the electrical system studies (Ref : 105), it makes an assumption that any fault current will flow equally in both parts of any loop. If the transformer is connected to, or the earth fault occurs close to one end of a loop, the current sharing will not be equal. Therefore, I would expect the analysis and sizing of the conductors to take this into account. I have therefore raised the following assessment finding:

AF-UKHPR1000-0122 – The licensee shall ensure in the detailed design of the earthing system that it considers the potential for unequal current sharing where parallel paths exist in earthing system.

423. It is noted that the buried earth mesh design is out of scope from GDA (Ref. 41) since its design will be dependent on the full site layout, complete site electrical system including non-classified loads and site and transmission system parameters. I consider this reasonable and that the basic principles set out in Ref. 138 for the earthing system are consistent and identify good practice for a buried earth system in accordance with relevant UK standards.

424. It is important to note that the overall adequacy of the complete earthing system cannot be demonstrated until the resistance path to earth of all these aspects is considered and from a personnel protection perspective, touch and step voltages across the site are shown to be adequately controlled. This is especially important given the bonding between the lightning conductor system, building structure and the buried earthing (Ref. 134). However, I do not consider the completion of that work is likely to affect the design principles set out in either Refs 134 or 138 and therefore any changes in sizing to the buried earthing should be able to be accommodated within the existing structure design and consider this a matter of normal detailed design.

425. Through Ref. 138 and an updated Earthing and Lightning Protection Scheme report (Ref. 141) that includes the additional CAE requirements for functional and protective earthing, the RP has shown that the classifications of the various earthing systems consider the consequences of failure and the functional classification of the equipment it will protect or support, meeting the expectations of ONR SAP ECS.2.

426. I have identified an exception in the classification of the internal main earthing system, which the RP has identified as Class 3 even though it can provide an earth path conductor in support of higher classification electrical low voltage distribution systems. I sought clarity in its justification for this through a Regulatory Query, RQ-UKHPR1000-1745 (Ref. 6). In its response, the RP identifies that this is reasonable since whilst the LV electrical distribution system is designed to be normally operated as a solidly earthed system, it is capable of operating as an unearthed system. From a review of the relevant Electrical Relaying Protection Scheme (Ref. 52) and System Design Manuals (Refs 49, 66 and 76) this requirement for the equipment to be capable of operating in this configuration is not explicitly identified or linked to a safety case claim. Therefore, I have raised the following assessment finding:

> AF-UKHPR1000-0123 **–** The licensee shall ensure that the classification of the main internal earthing system is consistent with the categorisation of the safety functions that it supports and that any consequential requirements for electrical equipment are identified within the relevant design documents.

427. In summary, I consider the principles set out in Ref. 138 propose a basis for the detailed design of the earthing system that adequately addresses my expectations for segregation and independence and is consistent with ONR SAP EDR.2.

4.10.2 Strengths

428. I have identified the following areas of strength in the approach to functional and protective earthing:

- RP has developed principles and design requirements to deliver an effective earthing system which are linked directly to the claims and arguments of the safety case.

4.10.3 Outcomes

429. From my assessment, I am content that the RP has presented a set of design principles for the design of the functional and protective earthing that are consistent with the deterministic principles of the equipment it supports.

430. In its substantiation of the design principles the RP makes an assumption that where parallel paths exist in any earth conductor, any fault current will flow equally in both parts of any loop. I would expect its analysis and sizing to consider this potential imbalance. In light of this, I have raised the following assessment finding:

> AF-UKHPR1000-0122 – The licensee shall ensure in the detailed design of the earthing system that it considers the potential for unequal current sharing where parallel paths exist in earthing system.

431. As justification for the lower classification of the internal main earthing system to that of the EPS it supports, the RP has stated that the engineering of the higher classification distribution systems is such that they can withstand any resulting overvoltages. However, this capability requirement for the distribution system is not explicit or linked to a safety case claim. Therefore, I have therefore raised the following assessment finding:

> AF-UKHPR1000-0123 – The licensee shall ensure that the classification of the main internal earthing system is consistent with the categorisation of the safety functions that it supports and that any consequential requirements for electrical equipment are identified within the relevant design documents.

4.10.4 Conclusion

432. Based on the outcome of my assessment of the functional and protective earthing system, I have concluded that the RP has developed an effective set of design principles and requirements that are consistent with the deterministic requirements of the systems it supports.

433. I consider the approach, as sampled, is consistent with the relevant ONR SAPs and is consistent with relevant international standards.

434. The RP has not adequately demonstrated that its process adequately considers the potential unequal current sharing where parallel paths exist in the earthing system and ensures the conductors are adequately sized. I have therefore raised an assessment finding, AF-UKHPR1000-0122.

435. The RP proposes a lower classification for the main internal earthing system than the systems it support based on a design requirement that the safety function could continue to operate with a degraded earthing system. Since the RP has not set this out as a specific claim or defined this requirement in supporting submissions, I have raised an assessment finding, AF-UKHPR1000-0123.

4.11 Lighting Systems

4.11.1 Assessment

436. Lighting systems are important to ensure that plant personnel during all operational states including design basis and design extension conditions can:

- undertake operational activities on the plant;
- undertake maintenance activities on the plant; and
- safely evacuate the plant in an emergency.

437. In my assessment, I have considered if the proposed lighting and service power arrangements are appropriate to respond to design basis and beyond design basis events. I have worked with the ONR Human Factors inspector to ensure that the requirements for the systems are consistent with the safety case operator claims. Their assessment of operator claims is included in their assessment report (Ref. 142).

438. In my assessment, I have considered how the requirements for lighting systems have been developed and how the proposed approach will deliver those requirements. I have considered the following ONR SAPs in gaining confidence that the design is consistent with good nuclear engineering practice:

- ECS.2 Safety Classification of SSCs
- ELO.1 Access

439. I have taken into consideration the guidance provided by IAEA Specific Safety Guide SSG-34: Design of Electrical Power Systems for Nuclear Power Plants (Ref. 17).

440. In the PCSR (Ref. 3), the RP has established a CAE structure which specifically recognises that systems such as lighting provide support to operation action through a specific claim:

> 3.3.5.SC09.2.1.5: The design of the electrical power system meets the overall human factor requirements of the UK HPR1000 NPP.

441. Through arguments and evidence that support this claim, the RP sets out to demonstrate that it has developed a system whose robustness and availability is linked to the operator actions that may be required.

442. The design requirements are set out in the following submissions which form the principal evidence to the above claim:

- Unified Technical Regulation for Electrical Design (Ref. 127)
- Lighting Design Scheme (Ref. 143)

443. The RP has set out the principal requirements for lighting systems in Ref. 127, defining how the system should provide lighting for all operating areas in the nuclear power plant under normal and accident conditions, as well as emergency lighting to support evacuation. The roles, responsibilities, and design for these systems to meet these requirements are then set out in a Lighting Design Scheme (Ref. 143).

444. In my Assessment Report for Step 2 of GDA (Ref. 27), I stated that whilst I considered the approach for the design of lighting systems should meet the expectations of ONR SAP ELO.1, I would expect the RP to demonstrate how the lighting systems respond to the progressive loss of electrical systems. This is important to ensure that operator response identified in the safety analysis is not adversely compromised by a Loss of Offsite Power (LOOP), SBO or Total Loss of AC Power (TLACP) scenario.

445. The RP acknowledged this expectation but identified that during GDA analysis would be limited to human reliability assessments for planned actions in response to fault sequences and severe accident scenarios. This limitation is consistent with the understanding of the ONR Human Factors inspector and the wider impact of this limitation on the safety case of the UK HPR1000 is considered in their Assessment Report (Ref. 142).

446. Ref. 143 sets out the hierarchy for the plant lighting system and is based on three systems:

- A normal lighting system which provides lighting to all plant areas.
- A standby lighting system supported by the EDGs.
- An emergency escape lighting system, supported by dedicated 3 hour duration batteries in the luminaires, which provides exit signage and route lighting to ensure the safe evacuation of personnel.

447. Ref. 143 states that in each division, each of the above systems operates as an independent system, setting out the illumination levels and colour characteristics in each of the plant areas within the scope of GDA (Ref. 41). The seismic qualification of the equipment is consistent with the project requirements (Ref. 127).

448. Based on the analysis reported in Paragraph 445, the standby lighting system is generally non-classified since it supports no planned safety actions. However, based on the RP analysis (Ref. 143), the lighting to support the identified manual safety actions are classified according to the action they support (i.e. Class F-SC2 or F-SC3). In addition, the emergency escape lighting is classified Class F-SC3 in support of its role in plant evacuation. I consider this enhanced approach meets the expectations of ONR SAP ECS.2 and therefore meets the expectations of IAEA guidance (Ref. 17).

449. Recognising the importance of the Main Control Room (MCR) and Remote Shutdown Station (RSS), Ref. 143 sets out an enhanced philosophy to ensure lighting in these locations:

- Under normal conditions and during a LOOP event, normal lighting is provided in the Main Control Room using two independent Class F-SC3 systems, which are EDG supported.
- Under normal conditions and during a LOOP event, normal lighting is provided in the Remote Shutdown Station supported by a Class F-SC3 system, supported by the EDG from the third division.
- In an SBO situation and for the first two hours of a Total Loss of AC Power (TLACP) situation, lighting is provided in the MCR by the Standby Lighting System supported by the 2 hour NI UPS in the third division. In the RSS, this standby lighting is supported by the 2 hour NI UPS in a different division.
- Beyond two hours, lighting is provided to the MCR by two redundant Class F-SC3 Safety Lighting Systems, supported by the 24 hour NI UPS.
- Each of the normal and standby lighting systems in the MCR is capable of providing 50% of the normal illumination levels. Under normal conditions and on the detected loss of a system, safety qualified dimming controls automatically manage the lighting of the available systems.
- An emergency escape lighting system, supported by dedicated 3 hour duration batteries in the luminaires, which provides exit signage and route lighting to ensure the safe evacuation of personnel.

450. I consider that the defence-in-depth approach to the control room lighting system is reasonable. I am satisfied that the independent divisional approach ensures the availability of lighting consistent with the availability of power supplies within the division. I also consider the enhanced approach to the MCR and RSS lighting appropriately provides assurance of lighting to this area. I consider the proposed arrangements are consistent with the expectations of ONR SAPs ECS.2. I would expect a future licensee to consider similar requirements for lighting to be applied to other key command locations which support accident response as the arrangements for the site are developed.

451. I consider that the proposed illumination levels and characteristics of the lighting in each of the plant and control room areas to be consistent with relevant good practice (Ref. 144). I also consider that the proposed emergency escape lighting arrangements are consistent with the expectations of the relevant international and British standards (Refs 145 and 146) and demonstrate how the design requirements are in line with the expectations of ONR SAP ECS.3.

452. In Ref. 143, the RP has identified that should any plant actions be required in a SBO situation then these shall be undertaken with the use of portable lighting. Whilst I consider portable lighting to provide flexibility in response, the use of portable lighting can restrict or slow the ability to safely respond to plant events. I would have expected the RP to consider the wider benefits that enhancing the resilience of basic lighting of key plant areas to the loss of diesel generators could provide in supporting the recovery of failed equipment.

453. In the analysis of Ref. 143, I am satisfied that the RP has appropriately identified and classified the aspects of the standby lighting systems that support planned local to plant actions. In its analysis, noting that some of the identified actions are not required for at least the first 62 hours, I consider the RPs arguments that in these cases it is not reasonable for the provision of batteries of such long autonomy time, and that the provision for mobile lighting is a more reasonable appropriate action.

454. However, I am concerned this analysis does not consider reasonably foreseeable unplanned activities, such as the recovery of failed equipment; a topic identified in the IAEA guidance (Ref. 147). I, therefore, do not currently consider the lighting systems have been fully demonstrated to meet the expectations of ONR SAP ELO.1. For this reason, I raise the following assessment finding:

AF-UKHPR1000-0124 – The licensee shall during site-specific design ensure that the lighting system is resilient to support local to plant operator actions during a Station Blackout or Total Loss of AC Power situation.

4.11.2 Strengths

455. I have identified the following areas of strength in the approach to lighting:

- The RP has recognised the expectation that support systems, such as lighting, should be classified consistent with the systems they support.
- The RP has implemented redundant and independent lighting systems to support operation in the MCR, RSS and plant in line with clearly defined requirements.
- The RP has aligned the design requirements for operational and emergency escape lighting to relevant international and British standards.

4.11.3 Outcomes

456. From my assessment, I am content that the RP has presented a set of design requirements which provides a good basis for the design of the lighting systems.

457. The RP has recognised the importance of considering the requirements for lighting systems against human task analysis and has undertaken analysis against anticipated actions identified in the fault schedule and severe accident analysis. However, I am concerned that the RP not considered the benefit a resilient lighting system can provide to unplanned but foreseeable actions, such the recovery of failed plant, following plant-wide events. As a result, I have raised the following assessment finding:

AF-UKHPR1000-0124 – The licensee shall during site-specific design ensure that the lighting system is resilient to support local to plant operator actions during a Station Blackout or Total Loss of AC Power situation.

4.11.4 Conclusion

458. Based on the outcome of my assessment of the lighting system, I have concluded that the RP has developed an effective set of design principles and requirements that are consistent with the deterministic requirements of the systems it supports.

459. I consider the approach, as sampled, is largely consistent with the relevant ONR SAPs and is consistent with the relevant national and international standards.

460. However, I do not consider that the RP has appropriately considered the benefit that enhancements to the availability of lighting to key plant areas in a total loss of AC power situation and have raised assessment finding AF-UKHPR1000-0124.

4.12 Communication Systems

4.12.1 Assessment

461. Communication systems are important in providing an effective means of delivering instructions or event updates to power plant personnel and receiving timely plant status information from plant operators.

462. In my assessment, I have considered if the communication systems for the generic UK HPR1000 design are consistent with the expectations of ONR SAP ESR.7. This SAP sets out that adequate communications systems should be provided to enable information and instructions to be transmitted between locations on and, where necessary, off the site. The expectation is that systems should provide a robust means

of communication during normal operations, fault conditions and severe accident conditions.

463. I have therefore sought assurance on whether the design will provide a suitable means of communication between locations on the site and to off-site. I have also considered whether the systems have an appropriate resilience in their architecture to provide assurance of the systems availability.

464. As with my assessment of lighting systems, described in Section 4.11 above, I have worked with the ONR Human Factors inspector to ensure the system requirements for communications set out by the RP adequately consider the needs of the operators.

465. The approach for the UK HPR1000 is set out in the Communication System Design Scheme (Ref. 148) and this has formed the basis of my assessment.

466. The RP set out in this document that the roles of the communication systems are to enable:

- operating personnel to communicate with each other throughout the nuclear power plant;
- communication with relevant off-site agencies;
- emergency personnel to communicate with each other to support emergency response; and
- all persons in the nuclear power plant to be given warnings and instructions in operational states and in accident conditions.

467. The RP sets out to deliver these roles through the following five systems:

- Normal telephone system
- Secondary telephone system
- Public address system
- Alarm system
- Wireless communication system.

468. Whilst Ref. 148 recognises that GDA is limited to structures that support nuclear safety as defined in the GDA Scope Report (Ref. 41), it does identify that it considers that each of the systems described extend to the complete site, including the Nuclear Island, Conventional Island and Balance of Plant buildings. I consider this important since response to emergencies needs to be a site wide effort.

469. The design scheme sets out principles for how each of the systems enable communications between the MCR, RSS, on-site emergency centres, operators out on plant, and communications off-site.

470. All systems are supported by a dedicated 1 hour communication UPS system that is fed from the Class F-SC1 EDG system. In addition, the secondary telephone system and public address system are independently supported by a dedicated 1 hour communication UPS system that is fed from the Class F-SC2 SBO DG system. It is stated that this autonomy time is to cover the time taken to start the diesel generators.

471. Considering the system architecture, the RP has defined principles for diversity between the primary and secondary telephone systems. Both telephone systems incorporate redundancy and segregation within their architecture to maximise the availability of both systems. A satellite phone system is provided as part of the secondary telephone system to provide offsite communications. The architecture of the remaining communication systems are based on a ring system to minimise the effects of any equipment failure to localised areas of the plant.

472. It is not clear from the design principles, if the diversity principles that are applied to the primary and secondary telephone systems are to be reflected in the UPS systems that support them. In line with ONR SAP EDR.2, I would expect any requirements for redundancy, diversity and segregation to be reflected in the systems that support the safety functions. I have therefore raised the following assessment finding:

AF-UKHPR1000-0125 – The licensee shall during detailed design ensure that the diversity requirements for the electrical power system is consistent with the communication systems it supports.

473. The design principles consider the potential for high background noise to affect clear communication and design measures are proposed to mitigate these effects. It is stated that all the communication systems are to be based on commercially available equipment although no detail is provided on the codes and standards for the specification of this equipment. I consider that a future licensee should develop equipment specifications for the communication systems that capture the operational requirements defined in the safety case. I do not consider this gap significant for GDA since a future licensee can develop this system without impacting on the viability or plant layout of the GDA design reference for the generic UK HPR1000 design. I consider this matter to be a minor shortfall.

474. In the Communication System Design Scheme (Ref. 148), the RP has identified that the communication systems are classified F-SC3 and non-classified, depending on their role in supporting plant actions. The RP has shown in the supporting justification that this is consistent with the safety classified local to plant actions that require operator confirmation of action. I, therefore, consider that given the supporting safety role communication systems provide, the safety classification applied to each system is appropriate.

475. In line with the RP principles for classification (Ref. 44), the RP considers that as a Class F-SC3 system, unless specifically identified, none of these systems need to be seismically qualified. In its review of safety local to plant actions (Ref. 148), the RP concludes that any such actions can be completed within the required time through the despatch of a plant operator from the MCR. As a result, it does not claim the availability of any of the communication systems following a design basis seismic event. I am concerned that the RP has only considered planned actions in its analysis and has not considered the potential benefit afforded in responding to unplanned situations by increasing the resilience to a design basis seismic event.

476. Furthermore, Ref. 148 states that the communication systems are to provide personnel with instructions during severe accident conditions. Given a total loss of AC power scenario is a recognised severe accident condition resulting in the provision of a twenty-four hour UPS system and noting the importance of communication that came from the Fukushima event (Ref. 59), I do not consider that the RP has adequately justified why a one hour autonomy time is appropriate for the UPS systems that support the communication systems.

477. When considering this and the concern raised in Paragraph 475 that it is not clear the autonomy time of the supporting UPS systems is ALARP, I have therefore raised the following assessment finding:

AF-UKHPR1000-0163 – The licensee shall demonstrate that all reasonably practicable measures for the resilience and availability of the communication systems, including their support systems, have been taken when considering their benefit in supporting the response to accident conditions.

478. Noting the above assessment finding for a licensee, I consider the principles set out in the Ref. 148 largely meet the expectations of ONR SAP ESR.7. The proposed arrangements provide systems, which are appropriately safety classified, to allow communication between control centres and personnel.

4.12.2 Strengths

479. I have identified the following areas of strength in the approach to communication systems:

- Since plant personnel may be located throughout the site, I consider the consistent approach to classification and availability of communication systems site wide to be appropriate.
- I consider the consideration of background noise to impact on the effectiveness of the communication and the proposed mitigation measures to be appropriate.

4.12.3 Outcomes

480. From my assessment, I am content that through the submissions, the RP has considered how communication systems can facilitate personnel response to planned events. I am also satisfied that the proposed architecture provides communication systems with adequate levels of defence-in-depth.

481. Whilst it is stated that diversity is to be applied to the primary and secondary telephone systems, it is not clear that a similar requirement is to be applied to the UPS systems that supports them. In light of this, I have raised the following assessment finding for a licensee:

AF-UKHPR1000-0125 – The licensee shall during detailed design ensure that the diversity requirements for the electrical power system is consistent with the communication systems it supports.

482. Given the stated role in the submissions that the communication systems have in supporting accident scenarios, the RP has not provided adequate demonstration that the various systems are appropriately resilient to the events which could act as precursor to an accident scenario, such as but not limited to a seismic event.

483. When considering the availability of electrical supplies in an accident scenario, it is not clear if the proposed autonomy time of the communication UPS are reasonable.

484. In light of these findings, I have raised the following assessment finding for a licensee to consider this justification:

AF-UKHPR1000-0163 – The licensee shall demonstrate that all reasonably practicable measures for the resilience and availability of the communication systems, including their support systems, have been taken when considering their benefit in supporting the response to accident conditions.

485. I also identified one minor shortfall as discussed in Section 4.12.1 above.

4.12.4 Conclusion

486. Based on the outcome of my assessment, I have concluded that the RP has developed an effective set of design principles and requirements that meet the expectations of classification, redundancy and diversity. As a result, the proposed requirements are generally consistent with the relevant ONR SAPs and national and international standards for the design of communication systems.

487. The RP has identified in its safety case that diversity should be applied to the primary and secondary telephone systems. However, the level of diversity that is to be applied to the UPS systems that support these telephone systems has not been set out. As a result, I have raised assessment finding AF-UKHPR1000-0125.

488. Given the stated role that the communication systems have in providing support during accident scenarios, I do not consider that the RP has provided adequate demonstration that the various systems are appropriately resilient to the events which could act as precursor to an accident scenario, such as but not limited to a seismic event. As a result, I have raised assessment finding AF-UKHPR1000-0163.

4.13 Heating, Ventilation and Cooling

4.13.1 Assessment

489. To manage the risks from many external and internal hazards, electrical equipment is often located in rooms with poor natural ventilation and therefore relies on HVAC systems to keep the equipment in conditions suitable for long term operation. Since the HVAC systems often require significant electrical power to operate, they are usually powered by the diesel generators when offsite power is not available. As a result, in such circumstances, assurance is needed that the associated room temperatures will not exceed the short term design temperature limits for the equipment before the diesel generator can be started. In a TLACP situation, it should be demonstrated that the UPS systems can operate for their design mission time.

490. The assessment of the HVAC system for the generic UK HPR1000 design has been led by the ONR Mechanical Engineering inspector and is reported in their Assessment Report (Ref. 149). They identified a concern during Step 3 of GDA that the evidence to support the safety case did not appear to demonstrate the performance of the systems. As a result, they raised a regulatory observation (Ref. 31), RO-UKHPR1000-0039, for the RP to respond to the following actions:

- Develop an Appropriate UK HPR1000 HVAC Environmental Modelling and Analysis Strategy.
- Model and Analyse the UK HPR1000 Heating Ventilation and Air Conditioning Systems.
- Undertake a ALARP Analysis for UK HPR1000 HVAC Systems.

491. I have supported the ONR Mechanical Engineering inspector in assessing the response of the RP to the first two actions to ensure that the strategy, analysis and conclusions for the sample considered appropriate electrical equipment and that the results were consistent with the design requirements for that equipment in the safety case.

492. To target the assessment at the critical systems, the RO sought for the purposes of GDA for the RP to develop, and agree with ONR, a strategy to adequately model a sample of risk important UK HPR1000 HVAC systems, rooms and their contents during a selection of plant transients. It was expected that the strategy should justify the sample chosen.

493. In the resolution plan to the RO (Ref. 31), the RP identified that it intended to analyse the Electrical Division of Safeguard Building Ventilation System A (DVL) and the Diesel Building Ventilation System (DVD) in its selection of systems. I consider this choice reasonable since it captures the system that supports electrical equipment rooms and cable routing rooms of one division as well as the system that supports a diesel house including an EDG and SBO DG.

494. In its selection of scenarios for analysis, the RP included SBO and TLACP during periods when the outside air temperature was at its design basis minimum and maximum. I consider these scenarios the most challenging since they consider the longest periods that HVAC will be unavailable.

495. Therefore, whilst the heat loadings in the rooms will reduce due to the loss of supplies to the interruptible AC electrical systems at the time of event, during the SBO scenario the DC and AC UPS systems will continue to operate until the SBO DG is started and the HVAC system is restarted. In the TLACP scenario, the DC and AC UPS systems will continue to operate until the batteries are exhausted with no restoration of HVAC systems.

496. The ONR External Hazards inspector has confirmed in their assessment (Ref. 57) that the maximum and minimum outside air temperatures considered in the studies are consistent with the figures determined by the RP for GDA. The assessment of the dynamic thermal modelling technique and assumptions used by the RP in the modelling of these systems has been considered by the ONR Mechanical inspector (Ref. 149).

497. The principal submission I have considered in my assessment is the Analysis Report of the HVAC Sample Systems (Ref. 150) which considers both the DVL and DVD systems.

498. This submission sets out the process by which the RP has undertaken the analysis and defined the data such as ambient conditions, heat loads, room temperature limits and timeframes for analysis; identifying how these are derived from relevant safety analysis, environmental specifications and industry practices. In its analysis, the RP has assumed that in an SBO condition, the SBO DG are not restarted for two hours. It is expected that the plant operators would manually restart them after thirty minutes.

499. In my assessment of Ref. 150, the temperatures associated with the rooms associated with the DVD system remained below the design limits for all scenarios. However, in relation to the DVL system, I identified that under the SBO and TLACP scenarios the temperatures in the UPS equipment rooms appeared to exceed the short term 45°C operational temperature limits for the inverters (Ref. 151). I raised RQ-UKHPR1000-1574 (Ref. 6) to seek clarity on the RP's analysis for these locations.

500. In its response to the RQ (Ref. 6), the RP advised that it had considered the normal heat loadings for the UPS rooms during the first two hours and the 24 hours of the SBO and TLACP scenarios. The RP advised that when the appropriate heat loads in the respective rooms were considered, the temperatures of the 2 hour UPS equipment room would peak below the 45°C limit whilst the 24 hour UPS equipment room would peak at 45.2°C; above the equipment qualification temperature. The submission was updated to reflect this (Ref. 152).

501. The RP also advised that it had conservatively assumed the heat load from the equipment based on the full load power rating of the equipment and that for different fault sequences, the electrical load of the equipment would be less than this.

502. In the RQ response, the RP identified that the HVAC analysis would need to be reviewed during detailed design based on site specific parameters and actual electrical equipment performance data, and there are commitments to this effect made in the Post-GDA Commitment Log (Ref. 38). In its response, the RP also identified measures that it could take to manage the temperature in the affected rooms using UPS backed local cooling units if the peak temperatures were still problematic. The use of local cooling units has already been presented in the UK HPR1000 design to manage temperatures in certain mechanical rooms.

503. Whilst I consider the RP's conservative claims and mitigation measures reasonable, during GDA the RP has not been able to demonstrate the 24 hour UPS system could continue to operate in a TLACP scenario during an extreme high temperature situation. Taking into consideration the concern identified by the ONR Mechanical Engineering inspector (Ref. 149) that the RP's analysis currently considers average room temperatures and those local to equipment may be higher, I support their assessment finding, AF-UKHPR1000-0128.

4.13.2 Strengths

504. I have identified the following areas of strength in the approach to HVAC design

- The RP has conservatively considered the heat loadings in each of the electrical equipment rooms

4.13.3 Outcomes

505. From my assessment, I am content that the RP has developed a systematic approach to the analysis of room temperatures during different fault sequence scenarios. I consider that its approach has also taken into account conservative assumptions.

506. However, its analysis does not demonstrate that the 24 hour DC and AC UPS systems could operate during a TLACP scenario during extreme high temperature situations. The RP has identified aspects of where its analysis is overly conservative, committed a future licensee to reviewing them and proposed mitigation measures, where operation can still not be assured. When I take into account concerns raised in the ONR Mechanical Engineering Assessment Report that the RP's analysis does not model any variation of temperatures around the room, I consider that a licensee should close out this gap as part of resolving the Mechanical Engineering assessment finding AF-UKHPR1000-0128.

4.13.4 Conclusion

507. Based on the outcome of my assessment of the HVAC systems in support of the electrical power system, I am generally content that the RP has developed a design and adequately demonstrated, with one exception, that the room temperatures can be adequately managed within the operating design limits of the electrical equipment within it.

508. In its analysis, the RP has not been able to demonstrate that the 24 hour AC and DC UPS system could continue to operate under extreme high ambient air temperatures. I support a Mechanical Engineering assessment finding, AF-UKHPR1000-0128, for a licensee to undertake additional modelling to demonstrate this requirement.

4.14 Geomagnetic Induced Currents

4.14.1 Assessment

509. Solar activity can affect equipment on a NPP in one of two ways; either through solar energetic particles interacting with complex electronic equipment or through disturbances to the earth's magnetic field resulting in Geomagnetic Induced Currents (GIC) in the high-voltage power transmission system.

510. The ONR External Hazard inspector has led, with the support of the C&I inspector, the assessment to provide confidence that the RP has adequate processes in place for the identification and assessment of equipment to protect against the risks from solar energetic particles. The outcome of this is included in the ONR External Hazards Assessment Report (Ref. 57).

511. In my assessment, I have considered whether the RP has adequately considered the risk of a GIC event and how it could mitigate such events through the design or operational arrangements.

512. The amplitude of GICs during strong geomagnetic storms can range from tens to hundreds of amps. GICs may give rise to half-cycle saturation of the power transformers, causing hot spot heating, increased reactive power loss and harmonics injection of the transformers to the power system, which may threaten the safety of power equipment and the grid. Such GIC events risk permanently damaging transformers connected to the transmission system, leading to a protracted loss of offsite power scenario.

513. I have worked closely with the ONR External Hazards inspector, who has assessed if the RP has determined an appropriate design basis hazard for GIC. Following work as part of their regulatory observation RO-UKHPR1000-0002, they have concluded (Ref. 57) that the RP has evaluated an appropriate design basis event for GIC.

514. In the PCSR (Ref. 3), the RP has addressed this aspect in its CAE structure as a subset of its evidence to support the following claim:

3.3.5.SC09.2.1.8: The electrical power system is robust with respect to internal and external hazards

515. The principal submission to support this claim is:

- Geomagnetic Induced Current Analysis Report (Ref. 153)

516. This submission sets out through the development of a UK deep earth conductivity model based on information from the British Geological Survey and National Grid, a determination of the worst case induced currents for each of the potential sites of a future UK HPR1000 with a return frequency consistent with the expectations of ONR SAP EHA.4 for an external hazard.

517. In the submission, the RP has identified the unmitigated hazards from such an event on the electrical system and characterised the impact on the electrical equipment. I consider this work has appropriately identified the significant risk as being to transmission system connected transformers with a neutral earth connection. Their work shows that the GIC may cause the distortion of the excitation current of the transformer leading to flux saturation of parts of the transformer core causing a temperature rise, which could affect the safe operation of NPP transformers. As a result, it concluded that the development of corresponding mitigation measures is necessary.

518. Given that equipment specifications for transmission system connected equipment are not developed during GDA stage, the RP sets out in Ref. 153 to demonstrate it understands how to evaluate the potential effect of a GIC on typical equipment. In addition, the RP proposes solutions which could mitigate the effects a GIC, based on experience in design and operation in China and United States of America. I consider this approach reasonable since the anticipated GIC effects are dependent upon the site location, transmission system configuration and operational arrangement as well as the loading of the affected equipment.

519. In its analysis, the RP identified a series of options for mitigating the effects of GIC:

- Management of transformer loading during events.
- Installation of capacitors in the neutral point of transformers.
- Installation of resistors in neutral point of transformers.
- Use of series compensation devices on transmission lines.

520. In its analysis, the RP undertook a detailed evaluation of the options including the effect on magnitude of GIC, referring to evidence on where such systems have been employed in China, where long transmission lines increase the effects of such an event.

521. The RP recognised that each of the options require details of the actual site to perform a full analysis and has provided a post-GDA commitment (Ref. 38) to update the analysis and develop a solution during detailed design when the bounding load conditions of the transformers and site characteristics are fully known. I consider that the RP has demonstrated for the purposes of GDA that it understands the topic and has proposed viable options which can be developed to mitigate the event. Noting that any option will require co-operation with the transmission system operator to develop, it is appropriate that the detail design is for a future licensee to perform.

522. Whilst I agree that transformer core overheating could affect operation, I consider a second effect of the distortion of the excitation flux is the production of harmonics in the secondary windings of any transformers. This may distort the voltage waveform potentially leading to overheating of motors or maloperation of any electrical or electronic equipment sensitive to harmonics. I consider that the mitigation measures considered by the RP should help to reduce the severity of such events, but I would still expect a future licensee to evaluate and demonstrate that its safety case is robust for any residual GIC. As a result of this gap, I raise the following assessment finding:

AF-UKHPR1000-0171 – The licensee shall during site-specific design develop the protection measures needed to protect the electrical power system of the UK HPR1000 against all threats that result from Geomagnetically Induced Currents.

4.14.2 Strengths

523. I have identified the following areas of strength in the approach to GIC:

- The RP has undertaken detailed analysis based on information from the British Geological Survey and National Grid in the determination the design basis hazard of GIC
- The RP has used relevant knowledge and experience in the design and management of GIC in transmission systems in the development of viable options for the UK HPR1000.
- The RP has recognised the development and selection of the optimal solution will require detailed site information and therefore has demonstrated feasibility based on generic information, committing a future licensee to develop and final scheme.

4.14.3 Outcomes

524. Working with the ONR External Hazards inspector, I am content that the RP has determined an appropriate bounding design basis Geomagnetic Induced Current.

525. I am satisfied that the RP understands the effects of GIC on equipment and has identified viable options to reduce the magnitude of induced currents through co-operation in the design of the local transmission system connections.

526. In its safety case, whilst the RP has recognised the impact GIC has on distortion of the excitation current and the effect this has on localised heating it has not considered the potential for this to cause maloperation of electrical or electronic equipment. As a result, I have raised the following assessment finding:

AF-UKHPR1000-0171 – The licensee shall during site-specific design develop the protection measures needed to protect the electrical power system of the UK HPR1000 against all threats that result from Geomagnetically Induced Currents.

4.14.4 Conclusion

527. Based on the outcome of my assessment, I have concluded that the RP has appropriately defined and recognised the effects of GIC on the electrical power system of the UK HPR1000. I also consider it has, using good practice from China, identified solutions to manage GIC but recognises that the optimal solution can only be chosen when considering the details of the site location and connection.

528. Whilst the RP has identified the potential for GIC to distort the magnetic flux in the transformer core, it has not considered the effect this could have on the secondary voltage waveform and the potential impact on the electrical distribution system. As a result, I have raised assessment finding AF-UKHPR1000-0171.

4.15 Smart Devices

4.15.1 Assessment

529. Smart devices are instruments, sensors, actuators or other previously electro-mechanical components (e.g. relays, positioners and controllers) which are controlled by a built-in microprocessors or HDL-programmable devices. They are becoming increasingly the only commercially available solution across both Control and Instrumentation (C&I) and electrical systems as manufacturers seek to increase functionality whilst reducing development times and production cost. However, their complexity introduces new risks in demonstrating reliability.

530. In my assessment, I have considered the substantiation of the RP strategy for the use of such devices, its process for the identification of such devices, and its approach to ensuring selected devices meet their respective reliability targets.

531. In the PCSR (Ref. 3), the RP has established a safety claim that specifically recognises the importance of CCF resilience of the electrical system:

> 3.3.5.SC09.2.1.4: The diversity and independence of the electrical system offers resilience against CCF.

532. Through a dedicated argument and evidence leg to this claim, the RP sets out in the Methodology of SMART Devices Substantiation (Ref. 154) to demonstrate that it has an appropriate approach to the identification and substantiation of smart devices, ensuring their appropriate reliability and managing the risk from CCF.

533. The RP approach is common to C&I and electrical devices and therefore I agreed with the ONR C&I inspector that they should lead the assessment of this aspect and their conclusions are included in their assessment report (Ref. 61).

534. I have focussed on the how the RP is considering the risk of CCF from the use of the smart devices. In its submission on Common Cause Failure and Diversity Analysis (Ref. 72), the RP has identified that its strategy is to:

- minimise the use of smart devices in the safety systems; and
- limit the use of smart or other programmable devices across levels of defence in depth.

535. I consider these strategies in combination with the substantiation process to be constructive in reducing the risk of CCF of the equipment and from a sample

assessment, have confirmed that these requirements are reflected in the relevant system design manuals.

4.15.2 Strengths

536. I have identified the following areas of strength in the approach to considering smart devices for the electrical system:

- The RP has developed a substantiation strategy that it applies to all electrical and C&I smart devices.
- The RP strategy is to minimise the use of smart devices in electrical devices with additional focus in their use for main and diverse lines of protection.

4.15.3 Outcomes

537. From my assessment, I am content with the support of the ONR C&I inspector that the RP has developed and demonstrated and understanding of the requirements to substantiate smart devices.

538. I am satisfied from the approach taken in its analysis of CCF of the electrical systems, that is clearly aiming to minimise the use of smart devices in the electrical systems of the generic UK HPR1000 design.

4.15.4 Conclusion

539. Based on the outcome of my assessment of the smart devices, I have concluded that the RP has demonstrated an adequate strategy and methodology to the management of smart devices in electrical equipment.

4.16 Electrical Maintenance Philosophy

4.16.1 Assessment

540. The Examination, Maintenance, Inspection and Testing (EMIT) of equipment important to safety is central to ensuring the ongoing availability and reliability of equipment to deliver its safety function. It is important to ensure that the philosophy and strategy for EMIT is achievable when considering the design and intended operational regime of the plant.

541. In the safety case initially presented by the RP, the overall strategy for the identification and justification of the application of EMIT to the generic UK HPR1000 design was not clear. In collaboration with ONR engineering and fault analysis inspectors, the ONR Fault Studies inspector raised regulatory observation RO-UKHPR1000-0021 (Ref. 31). I have worked closely with them to ensure that the response to this RO would meet ONR expectations as set out in the EMT series of SAPs (Ref. 2) in the electrical engineering area. I have also considered if the proposed arrangements for EMIT utilise information from the commissioning of equipment and therefore would meet the expectations of ONR SAP ECM.1.

542. The resolution of the RO and the adequacy of the RP’s overall approach to EMIT is reported in the ONR Fault Studies Assessment Report (Ref. 70). I have sampled areas of the RP’s approach to maintenance to ensure it has applied its principles appropriately to electrical equipment.

543. In the PCSR (Ref. 3), the RP has established two safety claims that specifically recognises the importance of EMIT and the electrical system:

3.3.5.SC09.2.2.4: The electrical system layout meets the system operation and maintenance requirements, as well as the personnel escape requirements.

3.3.5.SC09.5: The effects of ageing of the system have been addressed in the design and suitable EMIT specified.

544. The principal submissions to support these claims are:

- Examination, Maintenance, Inspection and Testing (EMIT) Strategy (Ref. 155)
- Strategy of Electrical Power System EMIT (Ref. 156)
- Examination, Maintenance, Inspection and Testing (EMIT) Windows (Ref. 157)
- EMIT Consistency Analysis (Ref. 158)
- EMIT Strategy Implementation Report (Ref. 159)
- Preliminary Outage Schedule (Ref. 160)
- NI Electrical Equipment Layout Diagram (Ref. 161)
- Strategy of Electrical Power System Commissioning and Test (Ref. 162)
- Generic Limits and Conditions of Operation (Ref. 163)

545. These documents have formed the basis of my assessment, which has focused on gaining confidence that the RP has demonstrated that the plant level EMIT strategy (Ref. 155) is appropriately applied to the electrical equipment through Ref. 156.

546. For the purposes of addressing RO-UKHPR1000-0039 (Ref. 31), the RP has limited the scope in GDA to equipment which performs Category FC1 and FC2 functions together with any other equipment which provides a significant contribution from PSA analysis. The diesel and UPS supported electrical distribution systems provide a key supporting role to both function categories and therefore within the scope. I consider this appropriate since the high availability requirement of these systems potentially limits the operational states when the equipment can be taken out of service for maintenance.

547. I consider the RP EMIT strategy is consistent with the IAEA standards and guidance (Refs 16 and 20) regarding the identification and planning of maintenance activities. It expands on this by applying its operational experience and draft maintenance schedule for the reference HPR1000 plant at FCG3 in determining the preliminary maintenance intervals for the generic UK HPR1000 design.

548. In its EMIT Consistency Analysis (Ref. 158), the RP has undertaken a detailed review of the expectations of relevant UK legislation and standards against its approach for maintenance of electrical equipment and has shown how its approach is consistent. I consider that the RP has identified relevant electrical legislation and standards and through the Application of Mechanical Interlocks of Electrical Power System submission (Ref. 56) shown how the electrical systems can be safely isolated and maintained in line with the HSE guidance (Refs 23 and 24).

549. In the first revision of the EMIT Windows Report (Ref. 157), the RP established the operational states during which maintenance can be undertaken on the relevant electrical equipment and identify any limitations or restrictions on the number of redundant divisions that could be removed from service. This is important to ensure the plant continues to meet the deterministic principles.

550. This first revision of Ref. 157, however, identified that no operational state existed where any of the Emergency Diesel Generators could be maintained, due to the safety role of the PTR system in cooling the spent fuel pool during a refuelling outage, no operational state existed where no division of the electrical distribution system could be taken out of service. Following a modification to the ASP system (Ref. 164), the RP

established (Ref. 158) that suitable windows existed for each of the divisions of the electrical distribution system to be maintained. This change is reflected in the latest revision of the EMIT Windows report (Ref. 165) and I also consider that it is appropriately reflected in the Generic Limits and Condition of Operation submission (Ref. 163).

551. I have reviewed how this has been implemented in the electrical engineering discipline through a review of Ref. 156 and sampling the application in the system design manuals for the EDGs, MV Switchboards and UPS Systems (Refs 47, 48 and 75). I consider these submissions demonstrate an adequate understanding by the RP of the typical scope of EMIT activities required to maintain the availability and reliability of the equipment and the respective frequencies of those activities. The proposed EMIT regime recognises the need to test and maintain not only individual equipment, such as switchgear and batteries, but also the need to confirm the satisfactory operation of systems, such as the EDG auto-start and load sequencing or automatic transfer to the standby grid connection. I consider the scope, frequencies and outline durations are consistent with my experience of good practice on similar equipment at nuclear power plants both in the UK and internationally.

552. From an initial assessment, I was not satisfied that the monthly start testing of an EDG could be undertaken whilst still meeting the expectations of the single failure criterion. I raised RQ-UKHPR1000-1373 (Ref. 6) to seek clarity on the availability of the generator should an event occur during the testing period. In its response, the RP confirmed (Ref. 6) that should any event occur which would initiate a start and load sequencing of the EDGs, then the test would be automatically suspended, and the engine under test would return to idle and then follow the automatic loading sequence, as commanded by the Reactor Protection System. I am therefore content that this routine testing can be performed on an EDG whilst not declaring the unit unavailable and ensuring the system remains compliant with the single failure criterion. This aspect has been clarified in latter revisions of the relevant submissions.

553. The RP developed preliminary outage schedules (Ref. 160) based on the activities identified in Ref. 165 to demonstrate how all the UK HPR1000 maintenance activities could be scheduled in typical outage windows; one for a regular refuelling outage, and one associated with more intensive inspections. From a review of the schedules, I am content that they capture all of the electrical activities and that they meet the availability windows identified in the submissions.

554. Whilst the RP safety case identifies that during a defueled reactor state, two EDGs can be maintained simultaneously, I am concerned that such action does not recognise the risks of common cause failure posed by concurrent activities; something identified as a specific risk in the IAEA maintenance guidance (Ref. 20). I do not consider this a significant issue for GDA as the detailed maintenance activities will need to be developed as the detailed design is completed and take into account the expectations of manufacturers. In addition, I consider the issue could be resolved through rescheduling the activities either within the proposed outage timeframe or by undertaking work over successive outages. Therefore, I consider this matter to be a minor shortfall.

555. The RP recognises in its EMIT strategy (Ref. 155) and the application to the electrical equipment (Ref. 156) that significant events may challenge the ongoing availability and reliability of equipment to perform its safety functions. Whilst it links these events to challenges to its operational technical specifications, it is not clear from the safety case how relevant events, especially those related to hazards from temperature and seismic, are identified and what actions would then be taken. I do not consider this gap significant for GDA but would expect a future licensee to consider this as part of their

development of limits and conditions of operation. I consider this matter to be a minor shortfall.

556. With reference to the equipment layout (Ref. 161), I have considered the practicality of maintaining the electrical switchgear. I am satisfied that sufficient space exists around the equipment to facilitate maintenance activities.

557. Through the development of a Strategy of Electrical Power Commissioning and Test (Ref. 156), the RP has set out the principles and requirements for the commissioning of plant which sets out to systematically ensure that the equipment performs as designed but also to provide benchmark data to support condition monitoring and testing throughout the life of the equipment. I consider this approach is consistent with guidance provided in the IAEA guidance (Ref. 20). Whilst the process will need to be developed by a future licensee as part of its operational arrangements, I consider this sets a platform to meet the expectations of ONR SAP ECM.1.

558. I consider that using the process established in response to RO-UKHPR1000-0021 (Ref. 31), the RP has identified the requirements for the EMIT of electrical equipment. This process includes the assessment of the ability to ensure safe isolation of equipment and the provision of sufficient access to equipment. I consider this is consistent with the expectations of ONR SAP EMT.1.

559. I consider that the RP has developed a credible maintenance plan for electrical equipment. It is based on the definition of the maintenance activities for electrical equipment in Ref. 156. It has identified appropriate intervals and durations for maintenance activities which have been informed by practical operational experience of the RP with its nuclear power plants. I am, therefore, satisfied that it meets the expectations of ONR SAP EMT.2 and EMT.6.

560. The RP recognises in its strategy (Ref. 155 and 156) that detailed procedures will need to be developed during detailed design post-GDA. I consider this reasonable and part of a normal design process which I consider should address the expectations of ONR SAP EMT.5.

561. I consider that the RP has recognised the importance to test the functionality of systems as well as individual equipment and therefore meets the expectations of ONR SAP EMT.7.

4.16.2 Strengths

562. I have identified the following areas of strength in the approach to EMIT:

- RP recognises in the safety case importance of EMIT in the ongoing assurance of electrical system and equipment reliability and availability.
- RP has ensured that the plant layout facilitates easy access for EMIT activities
- RP has incorporated the good practices identified in the IAEA Guidance on Maintenance and Commissioning into its principles for maintenance.

4.16.3 Outcomes

563. From my assessment, I am content that the identification of maintenance activities for electrical equipment is consistent with UK legislation and relevant good practice and that in the development of a preliminary schedule, the RP has developed a credible schedule for electrical maintenance.

564. The RP recognises in its submissions that a future licensee will need to develop this as detailed design is completed and any additional expectations from manufacturers are considered. I consider this appropriate.

565. I have identified two minor shortfalls as discussed in sub-section 4.16.1, above.

4.16.4 Conclusion

566. Based on the outcome of my assessment of EMIT, I have concluded that the design and arrangements set out in the generic UK HPR1000 safety case are consistent with the expectations of the EMT and ECM series of ONR SAPs and relevant good practice as set out in the IAEA guidance on maintenance and commissioning.

4.17 Ageing Management

4.17.1 Assessment

567. Ageing management for NPPs is implemented to ensure that the effects of ageing will not prevent structures, systems and components (SSCs) from being able to accomplish their required safety functions throughout the lifetime of the nuclear power plant. Recognising the need to consider ageing during the initial stages of plant design facilitates the consideration on how components degrade which can influence the maintenance requirements and ensure the plant layout can accommodate equipment replacement.

568. In my assessment, I have sought assurance on whether the design adequately takes into consideration ageing factors for the electrical equipment. I have assessed how the RP has considered the design life of equipment, what affects design life and how it manages those aspects. Finally, I have considered if it has considered the ability to replace equipment in the design. I have considered the following ONR SAPs in gaining confidence:

- EAD.1 Safe Working Life
- ELO.1 Access

569. I have taken into consideration the guidance provided by IAEA guidance on ageing management. (Ref. 18).

570. In the PCSR, the RP has established a safety claim that specifically recognises the importance of ageing management of the electrical system:

> 3.3.5.SC09.5: The effects of ageing of the system have been addressed in the design and suitable EMIT specified.

571. I have sampled the evidence in the safety case that supports this claim. In so doing, I specifically considered the following submissions:

- Strategy of Electrical Power System Ageing Management (Ref. 166)
- NI Electrical Equipment Layout Diagram (Ref. 161)
- Technical Specifications for Electrical Equipment (Refs 46, 53, 54, 55, 68, 69, 77, 78, 79, 80 and 129)

572. Ref. 166 sets out an ageing management strategy for the UK HPR1000 focussing on the lifecycle phases from design through to commissioning. Considering the current stage of the plant in the lifecycle, I have focussed my assessment on the design phase, which is summarised below:

- Identify the electrical safety significant SSCs that could be affected by ageing and the associated ageing mechanisms.
- Develop qualification requirements to increase defence against ageing.
- Develop environmental and operation requirements to restrain the ageing process.

- Provide monitoring or testing where possible.
- Development maintenance to mitigate the ageing process.

573. The approach specifically recognises the IAEA guidance (Ref. 18) and I consider that the approach taken in Ref. 166 is consistent with this guidance.

574. In Ref. 166, the RP has identified the factors that can affect ageing and identified how these are being managed through aspects such a room environment control by HVAC systems, qualification requirements for equipment or assessment of condition through EMIT. I consider that the components and ageing mechanisms identified are consistent with the IAEA guidance (Ref. 18).

575. I also note that whilst the equipment specifications indicate a design life consistent with the operational life of the power plant, the RP review did not identify any electrical equipment that could not be replaced during the lifetime of the power plant, if required.

576. I have reviewed how the findings of Ref. 166 are reflected in the system design and identified EMIT of the LV AC switchboards. I am satisfied that the environmental requirements for components are reflected in the operational limits of the Switchboard and UPS SDMs (Refs 49 and 76) and technical specification (Ref. 53) and that these limits are reflected in the generic site requirements for environmental management both in normal and accident conditions (Refs 151 and 167). From a review of outline maintenance activities for this equipment as set out in Ref. 156, I am also satisfied that these reflect activities to monitor and control component ageing.

577. I have reviewed the layout diagram for the electrical rooms (Ref. 161) and consider that the physical layout of the electrical switchrooms facilitates equipment removal and replacement, if necessary, during the life of the plant.

578. As a future licensee develops the detail design and operational strategy, it will need to develop the principles set out in the strategy to ensure that the degradation of equipment is monitored and equipment reliability and availability is assured. However, I consider the basic principles have been set out in GDA, meeting the expectations of the ONR SAPs.

4.17.2 Strengths

579. I have identified the following areas of strength in the approach to ageing management

- The RP has recognised the importance for ageing management and set out a strategy during the design stage of the plant.
- The RP approach is consistent with the IAEA guidance.
- The RP has ensured through the layout of the electrical switchrooms, that equipment can be removed and replaced during the lifetime of the plant, if required.

4.17.3 Outcomes

580. From my assessment, I am content that the RP has appropriately considered ageing management during the design phase of the project and set out a strategy for the lifetime management.

581. The RP recognises that it will be for a future licensee to develop the principles as the detailed design evolves and the operational arrangements are established.

4.17.4 Conclusion

582. Based on the outcome of my assessment, I have concluded that the strategy for ageing management for the electrical equipment of the UK HPR1000 is adequate for the current phase of the project.

583. I consider the approach is consistent with the IAEA guidance on ageing management and meets the expectations of the relevant ONR SAPs.

4.18 Equipment Qualification

4.18.1 Assessment

584. It is important that equipment important to safety is appropriately designed and tested to ensure that it can perform its safety functions under the conditions identified in the safety case for the designed life of the equipment. This is achieved by ensuring equipment is appropriately specified and is qualified for the service it will perform.

585. In my assessment, I have considered how the RP has set out the principles for equipment qualification. In this section, I have considered if the proposed approach is consistent with the expectations of ONR SAP EQU.1 through seeking assurance that adequate processes are in place to identify the requirements for qualification. I have also considered how those requirements are being captured in the technical specifications for electrical equipment.

586. I have also considered if the approach is consistent with the guidance provided in draft IAEA Safety Guide on Equipment Qualification (Ref. 21) and BS EN 60780-323 (Ref. 168)

587. In the PCSR (Ref. 3) the RP has identified that the approach to equipment qualification of the electrical equipment is set out in the following safety claim:

> 3.3.5.SC09.2.1.6: The equipment of the EPS is qualified for its service conditions

588. I have sampled the evidence in the safety case that supports this claim, and specifically considered the following submissions:

- Equipment Qualification Methodology (Ref. 169)
- General Requirement for Safety Electrical Equipment Qualification (Ref. 170)
- Environmental Requirements for Equipment Qualification (Ref. 171)
- Environmental Requirements for Main Buildings outside Containment under Accident Conditions (Ref. 151)
- SDMs associated with MV Switchgear and Diesel Generators (Ref. 47, 48 and 67)

589. A project level submission, Ref. 169 sets out the purpose of equipment qualification to ensure equipment can operate as expected following an operational event or where necessary, an accident scenario. The submission sets out the identification of the qualification requirements and the structure for an equipment qualification programme for the identification of equipment, applicable standards and test methodologies. The submission notes that the application of the process and qualification of equipment will be undertaken during detailed design when suppliers are selected.

590. Ref. 170 reflects the plant qualification requirements and develops how a consistent approach to the qualification of the electrical equipment with the safety case requirements will be assured. Ref. 170 sets out a graded approach to the qualification of electrical equipment based on its safety classification, role in accident scenarios and

location of the equipment. The approach follows the qualification categorisation process set out in the international electrical RCC-E code (Ref. 130) which I consider provides a robust methodology. The proposed test arrangements are aligned with the specific requirements of relevant international electrical qualification standards (Refs 168 and 172).

591. The approach identifies pertinent system conditions for which equipment qualification is required. For the equipment sampled in my assessment, I consider the appropriate conditions of room temperatures and humidity, seismic events and EMI have been determined.

592. The methodology takes these environmental requirements for equipment operation in normal operational and accident conditions (Refs 151 and 167) and applies minimum test margins that should be applied to each of these for the purposes of qualification testing. I consider the application of the test margins to be reasonable and demonstrates a conservative design process.

593. The sequence to qualification testing is important in ensuring it demonstrates the safety duty during or after the relevant conditions. The test sequence set out in Ref. 170 ensures that equipment will be shown to be capable of operation in the accident condition after accelerated ageing has been considered. This approach is consistent the guidelines of the draft IAEA Safety Guide on Equipment Qualification (Ref. 21).

594. I have sampled the Electrical System Design Manuals and Technical Specifications for NI MV Switchgear and Emergency Diesel Generators (Refs 46, 47, 48 and 54) and consider these reflect the appropriate equipment qualification requirements. I would expect a future licensee to ensure these requirements are developed as detailed design is completed and ensure this testing is undertaken as part of the procurement process.

595. In respect of electrical equipment, Ref. 170 provides an appropriate set of principles to ensure the electrical equipment will be suitably qualified for the conditions under which it would be expected to perform. I consider that the overall methodology and expectations of equipment requirements to be in line with relevant good practice (Refs 21 and 168). As a result, I consider the approach is consistent with the expectations of ONR SAP EMT.8.

4.18.2 Strengths

596. I have identified the following areas of strength in the approach to equipment qualification:

- The RP is considering appropriate British and International Standards in its approach to Equipment Qualification.
- The RP has set an additional margin to the design basis requirements for key parameters such as seismic and temperature, which gives confidence of a conservative decision making process.

4.18.3 Outcomes

597. From my assessment, I am content that the RP has presented a set of principles for qualification testing that are consistent with the guidance being developed by the IAEA and is consistent in its approach with national and international standards.

4.18.4 Conclusion

598. Based on the outcome of my assessment of equipment qualification, I have concluded that the approach taken is consistent with the expectations of the draft IAEA guidance and the relevant ONR SAPs.

4.19 Demonstration that Relevant Risks Have Been Reduced to ALARP

4.19.1 Assessment

599. ONR expectations are that the safety case should demonstrate how risks are reduced so far as reasonably practicable (commonly referred to as ALARP). These expectations are set out in the supporting paragraphs to ONR SAP SC.4 (Ref. 2). In my assessment, I have considered the guidance provided by the ONR assessment guide on ALARP (Ref. 8).

600. In respect of GDA, Ref. 8 identifies four main areas to be addressed:

- There is a clear conclusion that there no further reasonably practicable improvements that can be implemented.
- RP sets outs the standards and codes used and justify their selection.
- The RP demonstrates that where options have been considered they are appropriate, comprehensive and reduce risks so far as is reasonably practicable.
- The RP uses risk assessments to ensure improvements as a minimum meet the Basic Safety Objective level.

601. The RP has recognised this requirement for demonstrating the design reduces risk so far as is reasonably practicable through the following Sub-Claim in the CAE structure that supports the safety case (Ref. 3):

3.3.5.SC09.3:	All reasonably practicable measures have been adopted to improve the design

602. The following submissions which form the principal evidence to the above claim in the electrical engineering area have been considered as part of my assessment:

- ALARP Demonstration Report of PCSR Chapter 9 (Ref. 173)
- PCSR Chapter 33 – ALARP Evaluation (Ref. 174)
- Justification of Codes and Standards on Electrical Engineering (Ref. 62)

603. The RP sets out the purpose of Ref. 173 is to demonstrate in support of PCSR Chapter 9 (Ref. 3):

- risks have been reduced to ALARP;
- provide evidence of the process undertaken to demonstrate that risks have been reduced to ALARP; and
- summarise ALARP assessment results.

604. The RP states that its strategy in the development of the UK HPR1000 safety case has been to:

- Identify the application of relevant good practice and Operational Experience (OpEx) based on the UK context and undertake consistency analysis.
- Identify potential improvements with the support of results of the safety analyses undertaken as part of GDA.
- Undertake optioneering where the above identify shortfalls to further design improvement.

605. I consider this approach sets a good foundation for the demonstration on how the design meets the ALARP principle in the electrical engineering area that will meet with the expectations of Ref. 8.

606. In my assessment of Ref. 173, I am satisfied that it summarises the electrical engineering improvements incorporated into the HPR1000 design for FCG3 from national and international OpEx, including Fukushima. The FCG3 design has then formed the reference for the development of the generic UK HPR1000 design. During a workshop (Ref. 175), the RP adequately demonstrated how through its internal reporting systems how it had captured electrical engineering OpEx and used it to inform the HPR1000 development.

607. I consider that the evidence that supports the CAE structure of PCSR Chapter 9 appropriately identifies how relevant good practice in the form of international standards and guidance, together with UK specific aspects of standards have been selected and reflected in the design. I consider this is appropriately summarised in Ref. 173.

608. Where gaps have been identified in this process, such as in the CCF and Diversity Analysis area, I consider the RP has appropriately identified the options and made a balanced judgement considering all the implications for a design change, whilst prioritising nuclear safety. I consider that Ref. 173 provides an appropriate summary of all these aspects with linkage to the evidence containing the respective analysis.

609. I have reviewed the PCSR Chapter dedicated to ALARP (Ref. 174) and consider that it provides an accurate representation of the information related to electrical engineering that is provided in Ref. 173. For these reasons, I am satisfied that the RP has appropriately considered the ALARP principle in the development of the UK HPR1000 safety case from an electrical engineering perspective.

4.19.2 Strengths

610. I have identified the following areas of strength in the consideration of ALARP:

- RP strategy has been to identify appropriate UK national and international codes, standards, and guidance to apply, as appropriate, relevant good practice to the electrical engineering aspects of the generic UK HPR1000 design.
- Where design modifications have been necessary to the EPS, the RP has undertaken a detailed optioneering process appropriately balancing safety with other factors in identifying the most appropriate solution.

4.19.3 Conclusion

611. Based on my assessment of the consideration of ALARP in the safety case from an electrical engineering perspective, I have concluded that the RP has developed and followed a robust process to identify relevant codes, standards and guidance to be considered for the UK context. Supported by my overall assessment of the electrical engineering aspects of the UK HPR1000, I am satisfied that the RP has developed the design to ensure that it is consistent with these identified standards and guidance by applying a robust optioneering process to ensure modifications appropriately consider nuclear safety.

612. As a result, I am content that the approach is consistent to the expectations of the relevant ONR SAPs.

4.20 Consolidated Safety Case

4.20.1 Assessment

613. As stated in paragraph 34, through the undertaking of a review of the reference design to the UK legal and regulatory expectations, the RP developed a Production Strategy for Electrical Engineering at the end of Step 2 of GDA (Ref. 30) which set out the RP plan for submissions. This strategy document has been revised throughout the project to capture developments in the safety case production.

614. In Ref. 30 and subsequent revisions, the RP identified that the safety case would be updated through:

- commitments which will impact the safety case resulting from RQ and RO responses;
- commitments which will impact the safety case based on technical meetings and workshops with ONR; and
- implementation of the Forward Action Plan work.

615. I am satisfied that throughout the GDA process the RP has tracked where any of the above actions have impacted on safety submissions and has routinely issued updates at appropriate times to bring those documents up to date.

616. From sampling of these updated documents, I am content that any necessary clarifications or changes to the evidence resulting from analysis have been incorporated into the safety case.

617. As a result, I am satisfied that the safety case provides an accurate and demonstrably complete reflection for the purposes of GDA and has therefore met the expectations of ONR SAP SC.4. In addition, I am satisfied that the RP has through the regular updating of submissions and review of clarity met the expectations of ONR SAP SC.7.

4.20.2 Strengths

618. I have identified the following areas of strength in the approach to the consolidation of the safety case:

- The RP developed a plan at the start of GDA to manage the development of the electrical engineering aspects of the safety case.
- The RP has ensured that the safety case submissions have been updated as the underpinning evidence, arguments or claims have developed.

4.20.3 Conclusion

619. From my assessment, I am content that in respect of the electrical engineering aspects, the safety case as set out in Revision H of PCSR Chapter 9 together with supporting evidence, reflects an accurate and demonstrably completed reflection of the design. I consider that in doing so, the safety case meets the expectations of the relevant SAPs.

4.21 Comparison with Standards, Guidance and Relevant Good Practice

620. Sub-section 2.4.3 of this report identifies the international standards and guidance which I considered were relevant to the demonstration of the electrical engineering aspects of the safety case.

621. Through the assessment section of this report, I have identified if I consider that the approach being taken by the RP is consistent with relevant standards and guidance.

622. In general, the RP through its adoption of international codes and standards for the UK HPR1000, has specifically identified the same documents as part of its design principles and requirements. I also consider that it has provided appropriate justification for its selection of standards in its Justification on Codes and Standards of Electrical Engineering (Ref. 62).

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

623. This report presents the findings of my electrical engineering assessment of the generic UK HPR1000 design as part of the GDA process.

624. Based on my assessment, undertaken on a sampling basis, I have concluded the following:

- The generic safety case comprising of the PCSR, supporting Basis of Safety Case and analyses adequately demonstrate for the purposes of GDA that the electrical power system is capable of supporting plant safety functions in design basis and design extension conditions.
- The architecture of the electrical power system is consistent with international guidance.
- The electrical system studies demonstrate the ability of the electrical power system to support structures, systems and components important to safety at the power plant.
- Using generic connection data, the RP has shown that the power plant could be capable of being connected to the UK transmission system.
- As a result of my assessment. I have identified sixteen assessment findings for a future licensee to resolve.
- Noting the assessment findings, I am satisfied that the expectations of ONR's Safety Assessment Principles and Technical Assessment Guides are met in generic UK HPR1000 design.

625. Overall, based on my sample assessment of the safety case for the generic UK HPR1000 design undertaken in accordance with ONR's procedures, I am satisfied that the case presented within the PCSR and supporting documentation is adequate. On this basis, I am content that a DAC should be granted for the generic UK HPR1000 design from an electrical engineering perspective.

5.2 Recommendations

626. Based upon my assessment detailed in this report, I recommend that:

- **Recommendation 1**: From an electrical engineering perspective, ONR should grant a DAC for the generic UK HPR1000 design.

- **Recommendation 2**: The sixteen assessment findings identified in this report should be resolved by the licensee for a site-specific application of the generic UK HPR1000 design.

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Figure 1

Electrical Power System Single Line Diagram

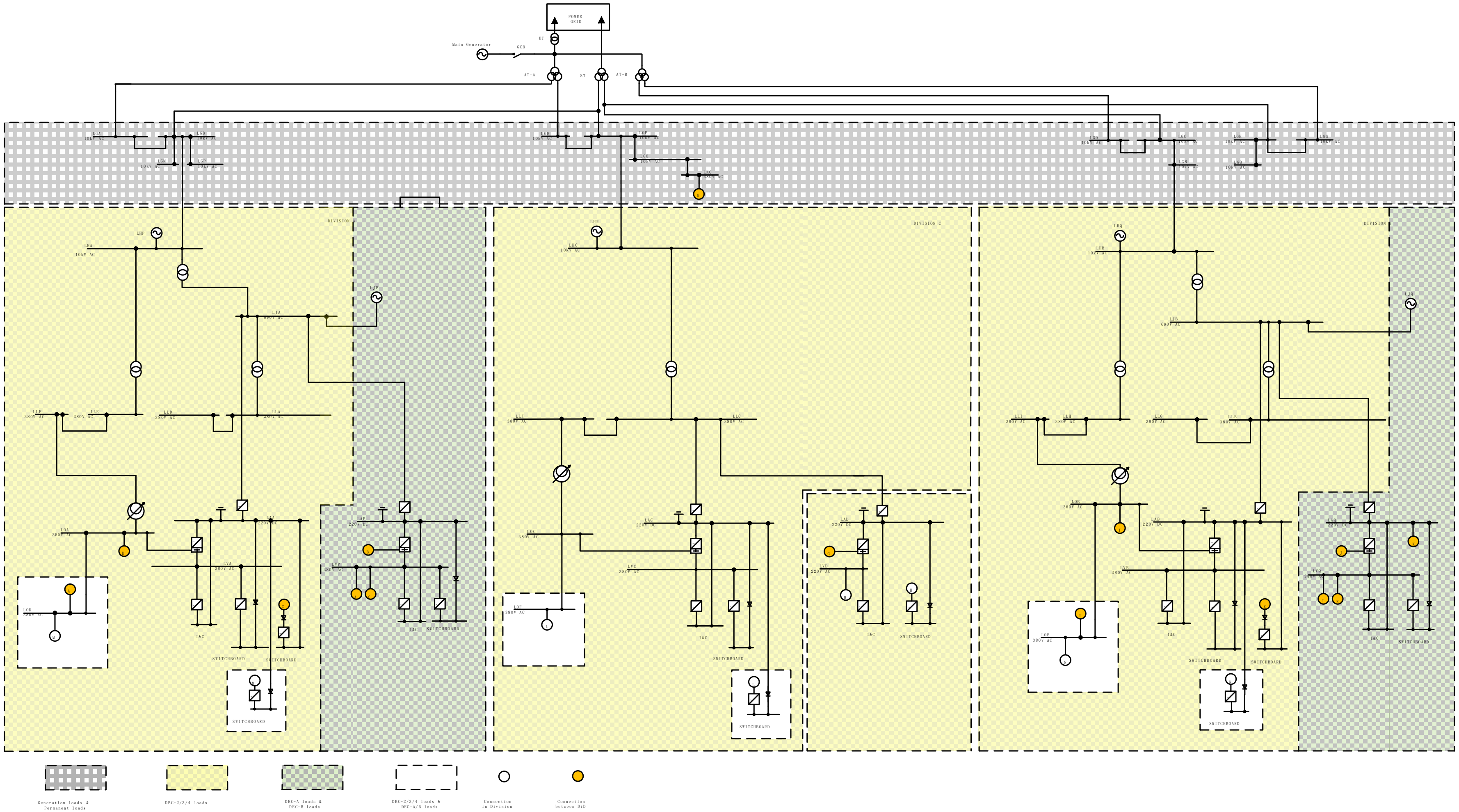
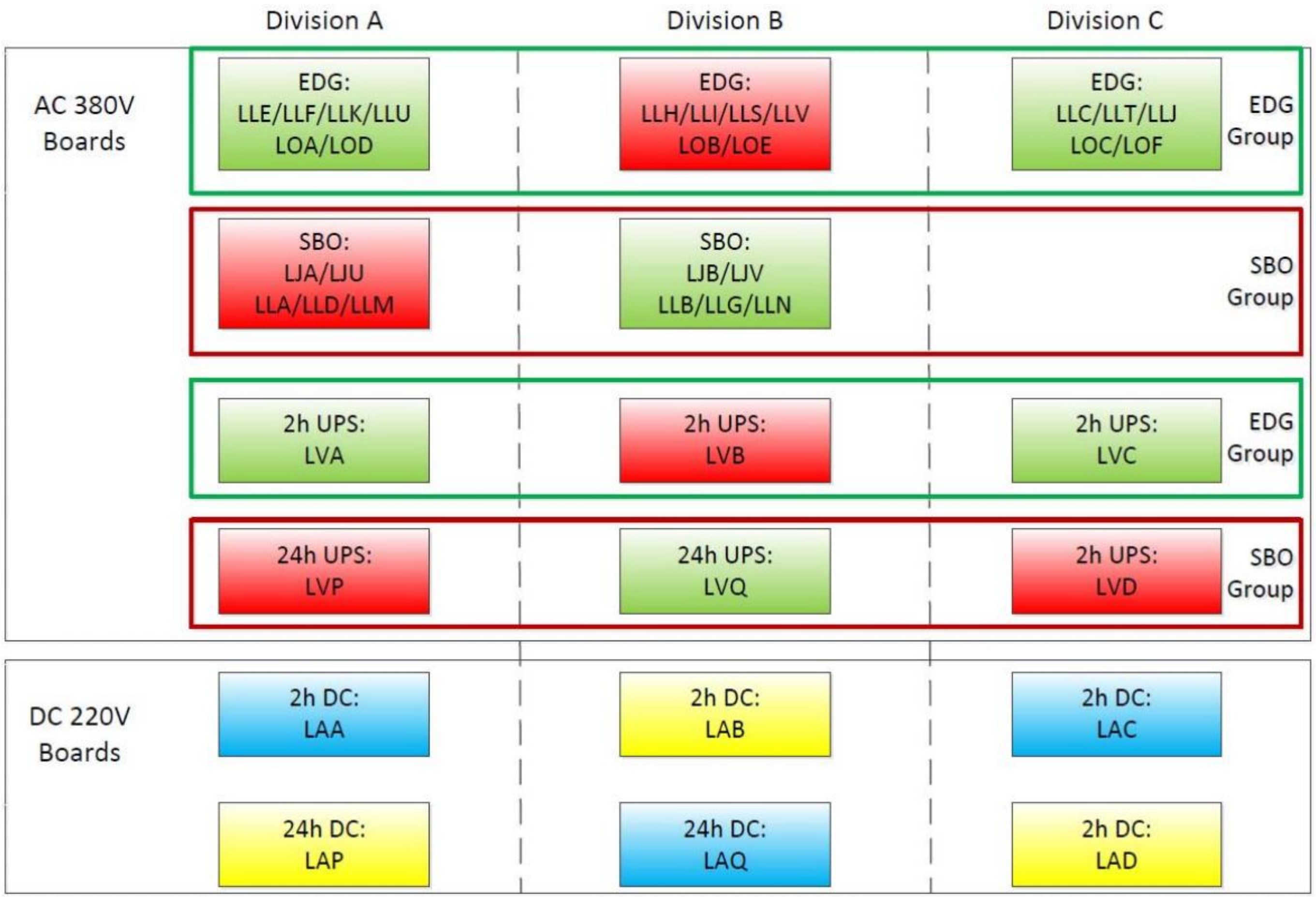


Figure 2

Electrical Power System Low Voltage Switchboard Diverse Design Scheme



Annex 1

Relevant Safety Assessment Principles Considered During the Assessment

SAP No.	SAP Title	Description
SC.4	The regulatory assessment of safety cases - Safety case characteristics	A safety case should be accurate, objective and demonstrably complete for its intended purpose.
SC.7	The regulatory assessment of safety cases - Safety case maintenance	A safety case should be actively maintained throughout each of the lifecycle stages and reviewed regularly.
EAD.1	Engineering principles: ageing and degradation - Safe working life	The safe working life of structures, systems and components that are important to safety should be evaluated and defined at the design stage.
EAD.2	Engineering principles: ageing and degradation - Lifetime margins	Adequate margins should exist throughout the life of a facility to allow for the effects of materials ageing and degradation processes on structures, systems and components.
ECM.1	Engineering principles: commissioning - Commission testing	Before operating any facility or process that may affect safety it should be subject to commissioning tests defined in the safety case.
ECS.2	Engineering principles: safety classification and standards - Safety classification of structures, systems and components	Structures, systems and components that have to deliver safety functions should be identified and classified on the basis of those functions and their significance to safety.
ECS.3	Engineering principles: safety classification and standards - Codes and standards	Structures, systems and components that are important to safety should be designed, manufactured, constructed, installed, commissioned, quality assured, maintained, tested and inspected to the appropriate codes and standards.
ECS.4	Engineering principles: safety classification and standards - Absence of established codes and standards	Where there are no appropriate established codes or standards, an approach derived from existing codes or standards for similar equipment, in applications with similar safety significance, should be adopted.

SAP No.	SAP Title	Description
EDR.2	Engineering principles: design for reliability - Redundancy, diversity and segregation	Redundancy, diversity and segregation should be incorporated as appropriate within the designs of structures, systems and components.
EDR.3	Engineering principles: design for reliability - Common cause failure	Common cause failure (CCF) should be addressed explicitly where a structure, system or component employs redundant or diverse components, measurements or actions to provide high reliability.
EDR.4	Engineering principles: design for reliability 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.
EES.3	Engineering principles: essential services - Capacity, duration, availability, resilience and reliability	Each source should have the capacity, duration, availability, resilience and reliability to meet the maximum demands of its dependent systems.
EES.5	Engineering principles: essential services - Cross-connections to other services	The ability of the essential services to meet the demands of the safety function(s) they support should not be undermined by making cross-connections to services provided for safety functions of a lower category
EES.7	Engineering principles: essential services - Protection devices	The protection devices provided for essential service components or systems should be consistent with the safe operation of the facility and limited to those justified as necessary in the safety case.
EHA.10	Engineering principles: external and internal hazards - Electromagnetic interference	The facility design should include preventative and/or protective measures against the effects of electromagnetic interference.
EKP.3	Engineering principles: key principles - Defence in depth	Nuclear facilities should be designed and operated so that defence in depth against potentially significant faults or failures is achieved by the provision of multiple independent barriers to fault progression.
ELO.1	Engineering principles: layout - Access	The design and layout should facilitate access for necessary activities and minimise adverse interactions while not compromising security aspects.

SAP No.	SAP Title	Description
EMT.1	Engineering principles: maintenance, inspection and testing - Identification of requirements	Safety requirements for in-service testing, inspection and other maintenance procedures and frequencies should be identified in the safety case.
EMT.2	Engineering principles: maintenance, inspection and testing - Frequency	Structures, systems and components should receive regular and systematic examination, inspection, maintenance and testing as defined in the safety case.
EMT.3	Engineering principles: maintenance, inspection and testing - Type-testing	Structures, systems and components should be type tested before they are installed to conditions equal to, at least, the most onerous for which they are designed.
EMT.4	Engineering principles: maintenance, inspection and testing - Validity of equipment qualification	The continuing validity of equipment qualification of structures, systems and components should not be unacceptably degraded by any modification or by the carrying out of any maintenance, inspection or testing activity.
EMT.5	Engineering principles: maintenance, inspection and testing - Procedures	Commissioning and in-service inspection and test procedures should be adopted that ensure initial and continuing quality and reliability.
EMT.6	Engineering principles: maintenance, inspection and testing - Reliability claims	Provision should be made for testing, maintaining, monitoring and inspecting structures, systems and components (including portable equipment) in service or at intervals throughout their life, commensurate with the reliability required of each item.
EMT.7	Engineering principles: maintenance, inspection and testing - Functional testing	In-service functional testing of structures, systems and components should prove the complete system and the safety function of each functional group.
EQU.1	Engineering principles: equipment qualification - Qualification procedures	Qualification procedures should be applied to confirm that structures, systems and components will perform their allocated safety function(s) in all normal operational, fault and accident conditions identified in the safety case and for the duration of their operational lives.

SAP No.	SAP Title	Description
ESR.7	Engineering principles: control and instrumentation of safety-related systems - Communications systems	Adequate communications systems should be provided to enable information and instructions to be transmitted between locations on and, where necessary, off the site. The systems should provide robust means of communication during normal operations, fault conditions and severe accidents.
ESS.8	Engineering principles: safety systems - Automatic initiation	For all fast acting faults (typically less than 30 minutes) safety systems should be initiated automatically and no human intervention should then be necessary to deliver the safety function(s).
ESS.9	Engineering principles: safety systems - Time for human intervention	Where human intervention is needed to support a safety system following the start of a requirement for protective action, then the timescales over which the safety system will need to operate unaided, before intervention, should be demonstrated to be sufficient.
ESS.10	Engineering principles: safety systems - Definition of capability	The capability of a safety system, and of each of its constituent sub-systems and components, should be defined and substantiated.
ESS.11	Engineering principles: safety systems – Demonstration of adequacy	The adequacy of the system design to achieve its specified functions and reliabilities should be demonstrated for each safety system.
ESS.16	Engineering principles: safety systems - No dependence on external sources of energy	Where practicable, following a safety system action, maintaining a stable, safe state should not depend on an external source of energy.
ESS.21	Engineering principles: safety systems Reliability	The design of safety systems should avoid complexity, apply a failsafe approach and incorporate means of revealing internal faults at the time of their occurrence.

Annex 2

Assessment Findings

Number	Assessment Finding	Report Section
AF-UKHPR1000-0012	The licensee shall when developing the equipment purchase specifications ensure that any safety case requirements for sub-components identify appropriate codes and standards.	4.3.1.2
AF-UKHPR1000-0013	The licensee shall ensure that the target reliability for all electrical systems important to safety are defined in the system requirements, reflecting the target reliabilities of the safety functions they support.	4.3.1.3
AF-UKHPR1000-0014	The licensee shall during site-specific design of the Mobile Diesel Generators ensure: • The establishment of classified and qualified facilities and operational arrangements for the storage and refilling of consumables in support of their running for the claimed mission time; and • The associated nuclear safety requirements are captured in the safety case and together with statutory requirements reflected in equipment specifications.	4.3.1.4
AF-UKHPR1000-0015	The licensee shall ensure that the diversity requirements for electrical components and sub-components are identified within the safety case and that it establishes a process to ensure these requirements are assured in the constructed plant.	4.4.1
AF-UKHPR1000-0016	The licensee shall as part of the development of the earth fault monitoring and detection system, undertake analysis of the overvoltage disturbances resulting from an earth fault on the unearthed electrical systems and ensure that the operation of any monitoring and location detection schemes do not adversely affect the operation of unaffected circuits and equipment.	4.5.1

Number	Assessment Finding	Report Section
AF-UKHPR1000-0017	The licensee shall review and update the system studies using site specific and detailed design information, implementing any necessary design changes to ensure that the: • Electrical power system is designed to ensure that all transformers are appropriately sized in line with the design requirements and acceptance criteria; • Electrical power system is designed to withstand the prospective short circuit; • Voltages throughout the electrical power system are appropriately controlled during anticipated off-site electricity system disturbances; • Operation of the electrical power system is robust against failure of transformer on-load tap changers; and • Operation of the electrical power system is robust against a loss of phase condition.	4.6.1.3, 4.6.1.4, 4.6.1.7, 4.6.1.10, 4.6.3
AF-UKHPR1000-0018	The licensee shall demonstrate that the design of the Power System Stabiliser to be used in the UK HPR1000 is capable and proven to operate as identified in the GDA system studies.	4.6.1.8
AF-UKHPR1000-0019	The licensee shall demonstrate that the functional capability of the Uninterruptible Power System is not degraded by supply voltage disturbances and meets the capability expectations of IEC 62855.	4.6.1.12
AF-UKHPR1000-0020	The licensee shall complete the analysis on Grid Code compliance in support of its safety case, implementing any design changes as necessary, to ensure the UK HPR1000 can operate safely when connected to the UK transmission system.	4.7.1
AF-UKHPR1000-0023	The licensee shall ensure during detailed design that the requirements and specifications for electrical equipment and its installation are consistent with the expectations of relevant UK standards for installation.	4.8.1

Number	Assessment Finding	Report Section
AF-UKHPR1000-0122	The licensee shall ensure in the detailed design of the earthing system that it considers the potential for unequal current sharing where parallel paths exist in the earthing system.	4.10.1
AF-UKHPR1000-0123	The licensee shall ensure that the classification of the main internal earthing system is consistent with the categorisation of the safety functions that it supports and that any consequential requirements for electrical equipment are identified within the relevant design documents.	4.10.1
AF-UKHPR1000-0124	The licensee shall during site-specific design ensure that the lighting system is resilient to support local to plant operator actions during a Station Blackout or Total Loss of AC Power situation.	4.11.1
AF-UKHPR1000-0125	The licensee shall during detailed design ensure that the diversity requirements for the electrical power system is consistent with the communication systems it supports.	4.12.1
AF-UKHPR1000-0163	The licensee shall demonstrate that all reasonably practicable measures for the resilience and availability of the communication systems, including their support systems, have been taken when considering their benefit in supporting the response to accident conditions.	4.12.1
AF-UKHPR1000-0171	The licensee shall during site-specific design develop the protection measures needed to protect the electrical power system of the UK HPR1000 against all threats that result from Geomagnetically Induced Currents.	4.14.1