

UK ABWR

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UK ABWR Generic Design Assessment

Generic PCSR Chapter 15 : Electrical Power Supplies



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Executive Summary

This systems chapter describes the safety case for the UK ABWR Electrical Power System (EPS). It lists the high level Safety Functional Claims that are made on this, together with the Safety Property Claims that enable compliance of the system with the Nuclear Safety and Environmental Design Principles to be demonstrated. It also provides the electrical supply input to all other systems engineering chapters in the PCSR (Chapters 8, 10, 11, 12, 13, 14, 16, 17, 18, 19, 21 and 31).

The information provided includes: system design; functionality in normal condition and during faults; safety categorisation and classification; important support systems; safety case assumptions, Limits and Conditions for Operation; resistance to hazards; and compliance with the ALARP principle.

The overall PCSR justification that the UK ABWR is safe and satisfies the ALARP principle is underpinned by hazards assessments, design basis analysis, probabilistic safety analysis, beyond design basis analysis and human factors analysis (described in PCSR Chapters 6, 7 and 24 to 27), which demonstrate that the design of the electrical power systems covered by this chapter are fault tolerant. These analysis chapters specify the high level safety functional claims but do not specify requirements for design parameters on individual sub-systems of the EPS. Instead they apply analysis conditions and assumptions that are based on, and fully consistent with, the design information and safety claims for the EPS that are presented in this chapter, in order to substantiate those claims.

The designs of Safety Class 1 and 2 sub-systems and components within the EPS are well advanced for GDA, being largely based on proven technology from the Japanese ABWR reference design. Additional risk reduction measures have been introduced (with reference to the J-ABWR design) in response to safety assessments undertaken in GDA. These include uprating of the capacity of the Class 1 EPS; the provision of additional diversity between the Safety Class 1 and Safety Class 2 parts of the EPS; and also the introduction of a Diverse Additional Generator.

This chapter demonstrates that the risks associated with the design and operation of the EPS for the UK ABWR are ALARP. It is acknowledged that further work will be required for the site specific stage to develop the design and fully incorporate site specific aspects. This work will be the responsibility of any future licensee.

15.1 Introduction

This of the Pre-Construction Safety Report (PCSR) presents a summary of the safety case for the UK ABWR Electrical Power System (EPS) within the scope of the Generic Design Assessment (GDA) process. It provides an overview of the design based on safety requirements applicable to the electrical system associated with the UK Advanced Boiling Water Reactor (ABWR).

15.1.1 Background

The ABWR EPS has a role in supporting normal conditions of the plant and protecting the plant from undesirable consequences which may arise in fault and hazard conditions. The ABWR EPS provides electrical power to key Systems, Structures and Components (SSCs) which support normal conditions and delivery of safety functions.

This EPS PCSR chapter is supported by Basis of Safety Cases on the Electrical Power System (EPS BSC) [Ref-1] and Topic Reports (TRs). These documents form the core of the Safety Case for the ABWR EPS and contain the system descriptions, the safety claims associated with the EPS and arguments for their adequacy against success criteria specified in international standards and from the fault studies; Design Basis Analysis (DBA), Beyond Design Basis Analysis (BDBA) and Probabilistic Safety Analysis (PSA).

15.1.2 Document Structure

This chapter of the PCSR begins with the description of claims on the safety functions and safety properties of the EPS SSCs. An outline of the EPS architecture is then introduced and this chapter identifies its major elements (such as Transformers, Generators, and Uninterruptible Power Supply (UPS) units). It also describes the major subsystems that constitute the overall EPS architecture such as key Alternating Current (AC) and Direct Current (DC) power supply systems. In addition, a claims tree is included as Appendices A and B in this chapter, substantiated in the EPS BSC [Ref-1].

Table 15.1-1 shows each section in this chapter.

Table 15.1-1: Table of Contents PCSR Chapter 15

Sub-chapter	Title	Description
15.1	Introduction	<ul style="list-style-type: none"> Overview of the Chapter 15 (This chapter)
15.2	Purpose and Scope	<ul style="list-style-type: none"> Purpose and scope of the Chapter 15
15.3	Safety Claims – Claims, Arguments and Evidence (CAE) and approach to protection against Common Cause Failure (CCF)	<ul style="list-style-type: none"> Provision of Top Claim (TC) and associated Safety Functional Claims (SFCs) and Safety Property Claim (SPCs) Category and Class for EPS SSCs
15.4	Architecture – power supply and power distribution	<ul style="list-style-type: none"> Introduction to the UK ABWR EPS Configuration
15.5	Electrical Equipment and Systems	<ul style="list-style-type: none"> Explanation of the UK ABWR EPS SSCs
15.6	Electrical Protection and Earthing	<ul style="list-style-type: none"> Design philosophy for the electrical protection and earthing
15.7	Panel and Raceway Layout	<ul style="list-style-type: none"> Requirements for Panels and raceway layout
15.8	Quality Assurance and Management Systems	<ul style="list-style-type: none"> Introduction of the Quality assurance and management plan
15.9	SMART Devices, Software Development and System Justification	<ul style="list-style-type: none"> Justification of the use of SMART devices
15.10	Assumptions, Limits and Conditions for Operation	<ul style="list-style-type: none"> Summary of the assumptions, limits and conditions for operation that are specified in greater detail in EPS BSC and its supporting document
15.11	Summary of ALARP Justification	<ul style="list-style-type: none"> Summary of the justification that the risks associated with the systems within Chapter 15 scope are acceptable and have been reduced to levels that are As Low As Reasonably Practicable (ALARP)
15.12	Conclusions	---
15.13	References	---
Appendix A	Safety Functional Claims Table	---
Appendix B	Safety Property Claims Table	---
Appendix C	Document Map	---

The main links of this chapter with other GDA PCSR chapters are as follows:

- For links to GEP and CSA documentation, please refer to PCSR Chapter 1: Introduction. For GEP, where specific references are required, for example in Radioactive Waste Management, Radiation Protection, Decommissioning, these are included in the specific sections within the Generic PCSR.
- General requirements related to conventional safety aspects are described in PCSR Chapter 4: Safety Management throughout Plant Lifecycle, Section 4.3.
- The categorisation of safety functions and Safety Classification of SSC in this chapter conform with the methodology described in PCSR Chapter 5: General Design Aspects, Section 5.6. Additionally, the general requirements for Equipment Qualification, Examination Maintenance Inspection and Testing (EMIT) and codes and standards that come from this safety categorisation and classification are also described in Chapter 5, Sections 5.7 and 5.9, respectively. Further details can be found in the EMIT section of the corresponding Basis of Safety Case document referred to the PCSR section.
- With regards to the Emergency Diesel Generator (EDG), Backup Building Generator (BBG) and Diverse Additional Generator (DAG), PCSR Chapter 16: Auxiliary Systems provides the description of the mechanical components of these systems. The associated switchgear and connection to the EPS is covered by this chapter.
- The design of the mechanical systems supported by the EPS is discussed in the relevant systems Chapter (e.g. PCSR Chapter 12: Reactor Coolant System; Chapter 16; and Chapter 17: Steam and Power Conversion Systems).
- A high level overview description for the main (steam) turbine generator is discussed in Chapter 17. The connection from the main turbine generator to the Generator Transformer (GT) and 400 kV lines are covered in Chapter 15.
- General requirements for decommissioning of the systems, structures and components within this chapter scope are described in PCSR Chapter 31: Decommissioning.

15.2 Purpose and Scope

15.2.1 Purpose

Chapter 15 presents the UK ABWR Electrical Power System (EPS) within the scope of the Generic Design Assessment (GDA) process. The specific purpose of this document is as follows:

- Identification of all links to other Chapters of the PCSR to ensure consistency across the whole safety case.
- Description of where the arguments and evidence that substantiate all relevant safety case claims are presented in supporting documents.
- Provision of references to lower tier documents where information is provided to demonstrate compliance with the relevant sections of the Hitachi-GE Nuclear Safety and Environmental Design Principles (NSEDPs) [Ref-2].

15.2.2 Scope

The EPS indicates the electrical power distribution system including control power with associated components (e.g. transformer, switchgear) and covers electrical equipment for the plant safety (e.g. EDG and BBG) in the UK ABWR.

The Chapter 15 describes the UK ABWR EPS within the scope of the GDA process such that it demonstrates that the EPS can support the required SSCs during the plant normal conditions and fault conditions.

15.3 Safety Claims – Claims, Arguments and Evidence (CAE) and approach to protection against Common Cause Failure (CCF)

15.3.1 Safety Claims

The Electrical Power System (EPS) is a supporting system which has been designed to meet the requirements of the associated Systems, Structures and Components (SSCs) which deliver safety functions. The claims associated with each SSC have been cascaded to all supporting systems including the EPS. In a similar manner the classification of the SSCs has been cascaded to the supporting EPS components.

Mapping the requirements of the supported SSC to the design of the EPS this ensures that the electrical design is consistent with the overall plant safety case and has a balanced and proportionate approach to safety which takes account of the mutual relationship between the EPS and the supported SSCs.

The claims for the electrical system take the form of a set of Safety Functional Claims (SFCs) derived from High Level Safety Functions (HLSFs) (see Chapter 5, Section 5.6) and Safety Property Claims (SPCs). SPCs are used to support the claim that the EPS complies with the Hitachi-GE Nuclear Safety and Environmental Design Principles (NSEDPs) [Ref-2]. The table of SPCs, shown in Appendix B, were derived for the topic covered in this chapter based on the ‘guide word’ approach specified in Hitachi-GE’s Safety Case Development Manual [Ref-51]. Having derived the SPCs, a mapping exercise was undertaken to ensure that the SPCs fully cover the relevant NSEDPs applicable to the topic area. More information on the development of SPCs, and the coverage, at the more detailed level in the safety case, to demonstrate full compliance with the relevant NSEDPs is presented in Chapter 5, Section 5.3.

Each supported SSC places a demand for electrical power on the EPS. The SFCs are designed to demonstrate the ability of the EPS to meet the power demand so that the SSC it is supporting can fulfil its safety function. The list of claims referred to in this chapter and the linkage to corresponding HLSF is shown in Appendix A.

The primary purpose of the NSEDPs is to act as the foundation for all design aspects of the UK ABWR, when applied by Hitachi-GE in the design of the plant and in the production of the accompanying safety and environmental documentation. The principles are applied to the design of the EPS and the SPCs support the demonstration found in lower tier documents referenced in this chapter of the ability of EPS to meet the design criteria as detailed in the NSEDPs [Ref-2].

The NSEDPs design criteria and associated success criteria have been developed to take account of the As Low As Reasonably Practicable (ALARP) principle which is fundamental to the design of all systems associated with the UK ABWR. The overall EPS takes account of the NSEDPs [Ref-2] so far as is reasonably practicable within the constraints of the electrical system. The list of claims referred to in this chapter and their linkage to corresponding NSEDPs [Ref-2] is shown in Appendix B.

Further breakdown of the claims, supporting arguments and mapping to the evidence that supports the PCSR is set out in the EPS BSC [Ref-1].

15.3.1.1 Top Claim (TC1), Safety Functional Claims (SFCs) and Safety Property Claims (SPCs)

EPS TC1: The UK ABWR EPS supports the Systems Structures and Components (SSCs) providing the safety functions specified in the Design Basis Analysis (DBA), Beyond Design Basis Analysis (BDBA), Severe Accident Analysis (SAA) and the Probabilistic Safety Analysis (PSA).

The EPS Safety Functional Claims (SFCs) derive from a set of High Level Safety Functions (HLSFs). Each HLSF is derived from one of five (5) UK ABWR Fundamental Safety Functions (FSFs) which are set out in Chapter 5, Section 5.6.

- (1) Control of reactivity
- (2) Fuel cooling
- (3) Long term heat removal
- (4) Confinement / containment of radioactive materials
- (5) Others

The linkages between the HLSFs and the claims on the EPS are shown in the table appended to Chapter 15 (Appendix A).

The top SFCs for the EPS are as follows:

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

EPS SFC 2: The EPS supports SSCs providing HLSF associated with FSF 2: Fuel Cooling.

EPS SFC 3: The EPS supports SSCs providing HLSF associated with FSF 3: Long Term Heat Removal.

EPS SFC 4: The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.

EPS SFC 5: The EPS supports SSCs providing HLSF associated with FSF 5: Others.

The EPS Safety Property Claims (SPCs) associated with the design integrity, reliability and performance of the EPS SSCs are shown in Appendix B.

EPS SPC 1: Classification, independence, redundancy and single failure criterion requirements placed on the SSCs is applied to the design of the EPS and associated support systems including C&I, HVAC and cooling systems.

EPS SPC 2: The EPS will support the safety functions with the required integrity for frequent faults, infrequent faults, beyond design basis faults and severe accidents.

EPS SPC 3: The EPS is designed to protect against common cause failure (CCF).

EPS SPC 4: The EPS will be designed to withstand internal hazards.

EPS SPC 5: The EPS will be designed to withstand external hazards.

EPS SPC 6: The EPS will continue to meet its functional safety requirements throughout its operational life.

EPS SPC 7: EPS SSCs are designed to achieve adequate performance in accordance with the safety requirements including reliability, response time and ratings.

EPS SPC 8: The design, development and implementation of EPS SSCs complies with standards and good practice set by their classification and the EPS SSCs role in the overall power system architecture.

15.3.2 Classification of Electrical Power System

The safety of the plant is assured by the use of defence-in-depth against faults by having multiple layers of protection and the EPS follows this important principle. This protection is provided by SSCs that deliver the safety functions necessary to protect the plant from undesirable consequences in normal operating conditions and following faults. The purpose and methodology for categorisation of safety functions and the classification of SSCs that deliver them is described in Chapter 5, Section 5.6.

The EPS provides a support function and it is classified in accordance with the importance to safety of the systems and components it supports. In principle, the EPS is considered to be part of the systems it supports and will have the same class as the supported system in cases where it is essential for the supported system to fulfil its safety function. Where the EPS is not directly needed to enable the system or component to fulfil its safety function, its classification may be less than that of the supported system but is at least Class 3.

The classification links to the codes and standards, equipment qualification and quality management arrangements which are applied. The main purpose is to ensure that the EPS (including its sub-systems and components) is designed, manufactured, installed, commissioned, operated and maintained in accordance with the importance to safety of the systems and components it supports.

The allocation of category and classification for GDA of the electrical system is set out in Table 15.3-1. Table 15.3-1 shows the categorisation and classification of the EPS; the basis of this allocation is explained in Chapter 5, Section 5.6.

Table 15.3-1: Categorisation & Classification of the Electrical System

		Safety Classification			
		1	2	3	N
Category	A	<ul style="list-style-type: none"> • Class 1 AC buses • Class 1 EDG • Class 1 DC • Class 1 UPS • Class 1 AC (for C&I) • Earthing System (for Class1) 	<ul style="list-style-type: none"> • B/B Class 2 AC buses • B/B Class 2 BBG • B/B Class 2 DC • B/B Class 2 AC (for C&I) • Earthing System (for Class2) 	--	--
	B	--	<ul style="list-style-type: none"> • Class 2 DC 115V • Class 2 AC (for C&I) • Earthing System (for Class2) 	<ul style="list-style-type: none"> • Class 3 AC buses • Earthing System (for Class 3) • Generator • Excitation system • AST, GT, ANT • IPB, NPB • GLS, GDS • Class 3 DAG • Large Power Truck & Small Power Truck 	--
	C	--	--	<ul style="list-style-type: none"> • Class 3 UPS (for plant process PC) • Class 3 AC (for Rw/B C&I) • Communication system (telephone for Class 3) • Lighting system (for Class 3) • Earthing System (for Class 3) 	--
	N	--	--	--	<ul style="list-style-type: none"> • DC 230V (for power) • Communication system (telephone & paging for non-safety) • Lighting system (for non-safety) • Earthing System (for non-safety)

15.3.3 Consideration of Common Cause Failure (CCF)

The EPS includes redundant arrangements aligned to the requirements placed on the SSC's supported. The potential for CCF in these redundant arrangements is recognised as an important consideration which is addressed in the design of the electrical system.

A CCF associated with the EPS has the potential to cause the failure of primary provision of the Class A1 safety functions such as emergency core cooling, reactor shut down and long term heat removal. As a countermeasure a second line Class A2 protection for emergency core cooling, reactor shut down and long term heat removal provision is therefore installed to provide an independent line of protection.

The second line Class A2 systems are designed to be independent and diverse from the Class A1 systems. In order to support independent and diverse SSCs associated with Class A2 systems, there is a requirement for an independent and diverse power supply. This requirement applies to both power supplies and the power distribution system. This is provided by a backup electrical supply system (Class A2 systems) which is designed to be independent and diverse from the primary Class A1 EPS. For the UK ABWR this is allocated to the Backup Building (B/B) EPS.

In order to provide the required independence, the backup electrical supply is installed in a location which is physically separated from primary distribution systems and the backup supply is designed to be electrically and physically segregated from the primary electrical power supply systems. In the design of the backup system the following fundamental principles have been applied:

- (1) Causes of CCF (same technology, same product, etc.) should be eliminated so far as is reasonably practicable. The electrical power supply equipment is specified at the component level to ensure that diverse components have been used.
- (2) Diverse technology and design is applied as much as possible so far as is reasonably practicable to the active components of the EPS. In order to achieve the required diversity different technology that uses different working principles is used to achieve the functionality required by the backup EPS. The use of different technology and design is given the first priority in order to achieve diversity.
- (3) The consideration for diversity is not only applied to the main electrical power supply equipment such as Circuit Breakers (CBs) and generators, but also to the total electrical power supply systems including the control system and electrical protection system, etc. related to the electrical power supply system.

Details of the approach to achieving diversity are set out in the Diversity Strategy Report [Ref-3]. A justification that the ABWR contains adequate countermeasures against CCF is provided in the EPS BSC [Ref-1].

15.3.4 Reliability and Hazards

The target reliability for the Class 1 EDGs EPS is a failure-on-demand probability of 1×10^{-4} for the Common Cause Failure (CCF) of all three (3) EDGs to start on-demand. For the continuously operating Class 1 switchboards the best estimate Common Cause Spurious Failure rate is of the order of $1 \times 10^{-5}/\text{yr}$. The embedded C&I on the switchboards, if using Smart Devices (SDs), will have a conservative claims limit of 1×10^{-4} . However because of a requirement to statistically test all SDs to a 99 percent confidence level this is equivalent to the overall best estimate of $1 \times 10^{-5}/\text{yr}$ for the switchboards. The reliability for the Class 2 backup system BBGs is a 1×10^{-2} common cause failure on-demand for the two (2) BBGs. More information on the reliability and the probabilistic aspects of the UK ABWR design can be found in Chapter 5 and its list of references.

The EPS is protected against internal and external hazards. For example the Class 1 EPS is designed to Seismic Category 1 standards. Protection against severe weather events is provided by locating the EPS in strong buildings for example, such as the Control Building (C/B), Emergency Diesel Generator Building (EDG/B) and the B/B. Extreme environmental conditions such as temperature and/or humidity the EPS is protected by appropriately classified Heating, Ventilating and Air Conditioning (HVAC) systems. Internal hazards such as fire and flooding are protected by using internal structures to ensure that an event in one (1) division cannot propagate to another division. Where physical barriers cannot provide protection for events (internal and external), such as Electromagnetic Interface (EMI), the EPS is designed to the appropriate Codes and Standards (see Chapter 5, Section 5.8) to tolerate the hazards. For more information on External Hazards see PCSR Chapter 6: External Hazards and on Internal Hazards see PCSR Chapter 7: Internal Hazards. For more information on HVAC systems see Chapter 16, Section 16.5.

15.3.5 Guidelines and Standards

The UK ABWR electrical engineering design is based primarily on IEC standards. The document “Codes and Standards Report” [Ref-4] details further information. For reference, in addition to industry standards the Japanese ABWR electrical engineering design (on which the UK ABWR is based) is subject to Japanese Safety Design guide # 48 (electrical system).

15.3.6 Power System Analyses

Analytical studies are required to validate the robustness and adequacy of EPS design margins and demonstrate the capability of the electrical power system to support the safety functions for normal conditions, expected events, foreseeable events, design basis faults and beyond design basis faults.

In addition, the analyses verifies that the electrical system can withstand transient disturbances and that the consequences of major transients or failures does not unacceptably degrade the functional capability of the electrical power system.

A programme of studies in accordance with IEC 62855 have been developed and undertaken to demonstrate, via power systems analysis, that the ABWR EPS generic design can supply power to all loads performing safety functions, as defined in the safety case, claims in normal and abnormal operating conditions, which is detailed in Electrical System Modelling Scoping Report [Ref-21]. The results associated with the electrical modelling form part of the evidence required for BSC substantiation [Ref-1].

15.3.7 EPS Supporting Systems and Structures

The Electrical Power System (EPS) is a supporting system, which is in turn supported itself by a number of other key systems. The EPS BSC [Ref-1] provides a justification only on the adequacy of the EPS. The adequacy of the systems that support the EPS are covered in the following PCSR Chapters.

The ABWR Control and Instrumentation (C&I) system facilitates the operation of the EPS and allows the EPS to be monitored by the operators. The ABWR C&I system is covered by PCSR Chapter 14: Control and Instrumentation.

The ABWR Reactor Building Cooling Water (RCW) System and Reactor Cooling Service Water (RSW) System support the operation of key EPS SSCs by providing of cooling EPS SSCs and maintaining equipment operating temperatures. The ABWR RCW/RSW system is covered by Chapter 16.

The ABWR Heating Ventilating and Air Conditioning System (HVAC) supports the operation of key EPS SSCs to maintain the ambient temperature of equipment rooms and ensures that SSCs maintain appropriate performance. The ABWR HVAC system is covered by Chapter 16.

Note, where the EPS also supports C&I, HVAC and RCW/RSW systems by providing supplies to C&I distribution panels, motor-pumps or other loads, the EPS SFCs developed in the EPS BSC [Ref-1] demonstrate the ability of the EPS to meet that power demand. This ensures that the SSC it is supporting can fulfil its safety functions.

The majority of the EPS is contained within the Control Building (C/B), Turbine Building (T/B), Reactor Building (R/B) and Heat Exchanger Building (Hx/B) with dedicated facilities provided for the main on-site power sources via the EDG Building (EDG/B). The structures of the UK ABWR including the Backup Building (B/B) and the claims, argument and evidence to support their adequacy are contained within PCSR Chapter 10: Civil Works and Structures.

15.4 Architecture - power supply and power distribution

The Electrical Power System (EPS) includes the ABWR main generator, the off-site power supply from the high voltage transmission system and on-site power sources which are used in the event that off-site power is not available. This section details the key features of the EPS architecture and power supplies. The EPS architecture is fully described in the EPS System Design Description (SDD) [Ref-7].

The allocation of loads on to on-site power supply (See Basis of Safety Cases on Electrical System [Ref-1]) is determined by the classification and categorisation of the supported SSC and the requirements for redundancy and diversity. The ability of the EPS to support the SSCs is demonstrated via the Safety Functional Claims (SFCs) in the Basis of Safety Cases on Electrical System [Ref-1].

The EPS and each of the key components of the EPS are designed with consideration to future load growth.

As detailed in Section 15.3.6 a programme of studies in accordance with IEC 62855 have been developed and undertaken to demonstrate, via power systems analysis, that the ABWR EPS generic design can supply power to all loads performing safety functions, as defined in the safety case, claims in normal and abnormal operating conditions.

15.4.1 Single Line Diagrams

Figure 15.4-1 shows the overview of the main AC auxiliary power supply system.

Figure 15.4-2 shows the overview of the AC and DC C&I power supply system.

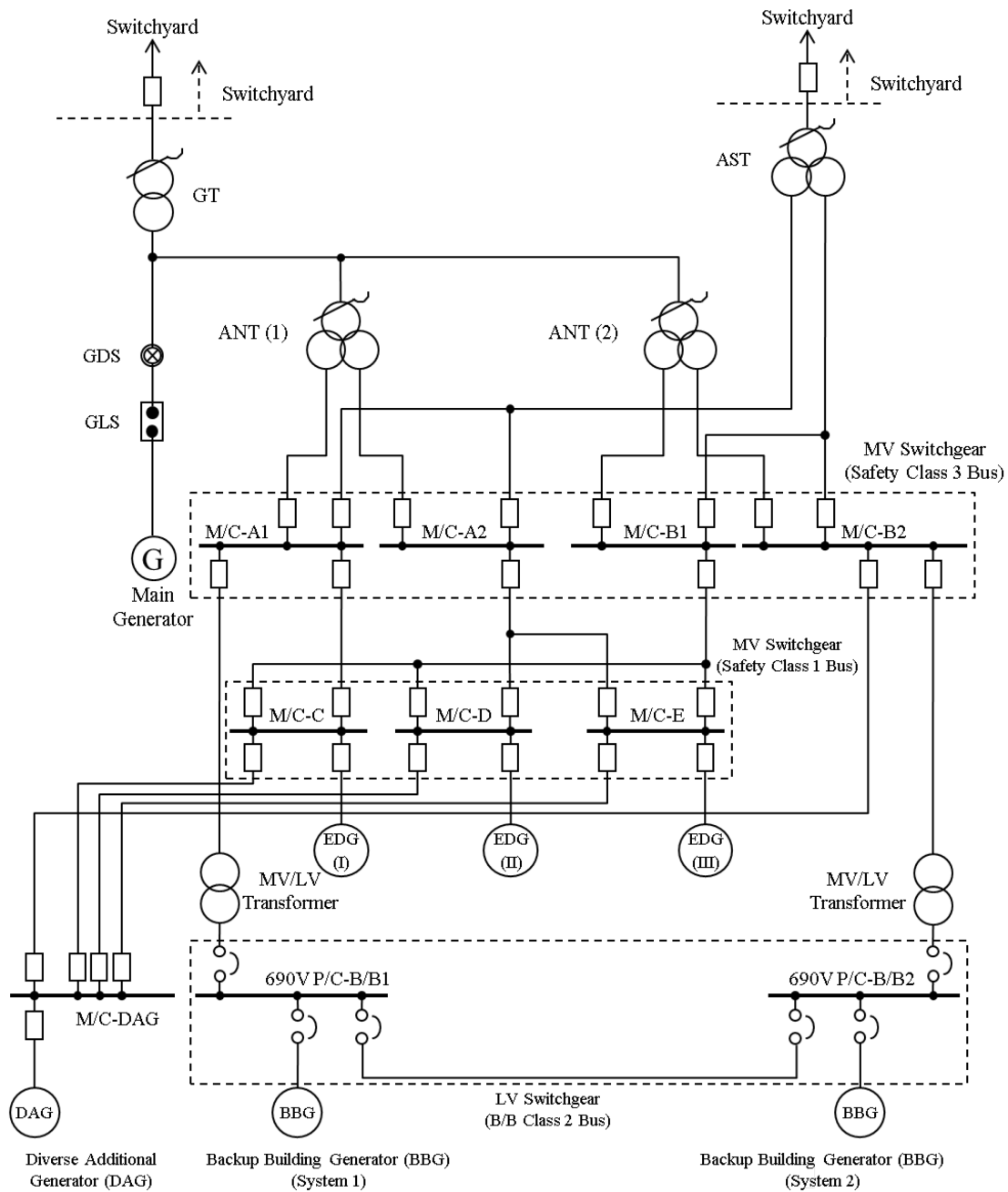


Figure 15.4-1: Single Line Diagram of Auxiliary Power Supply System

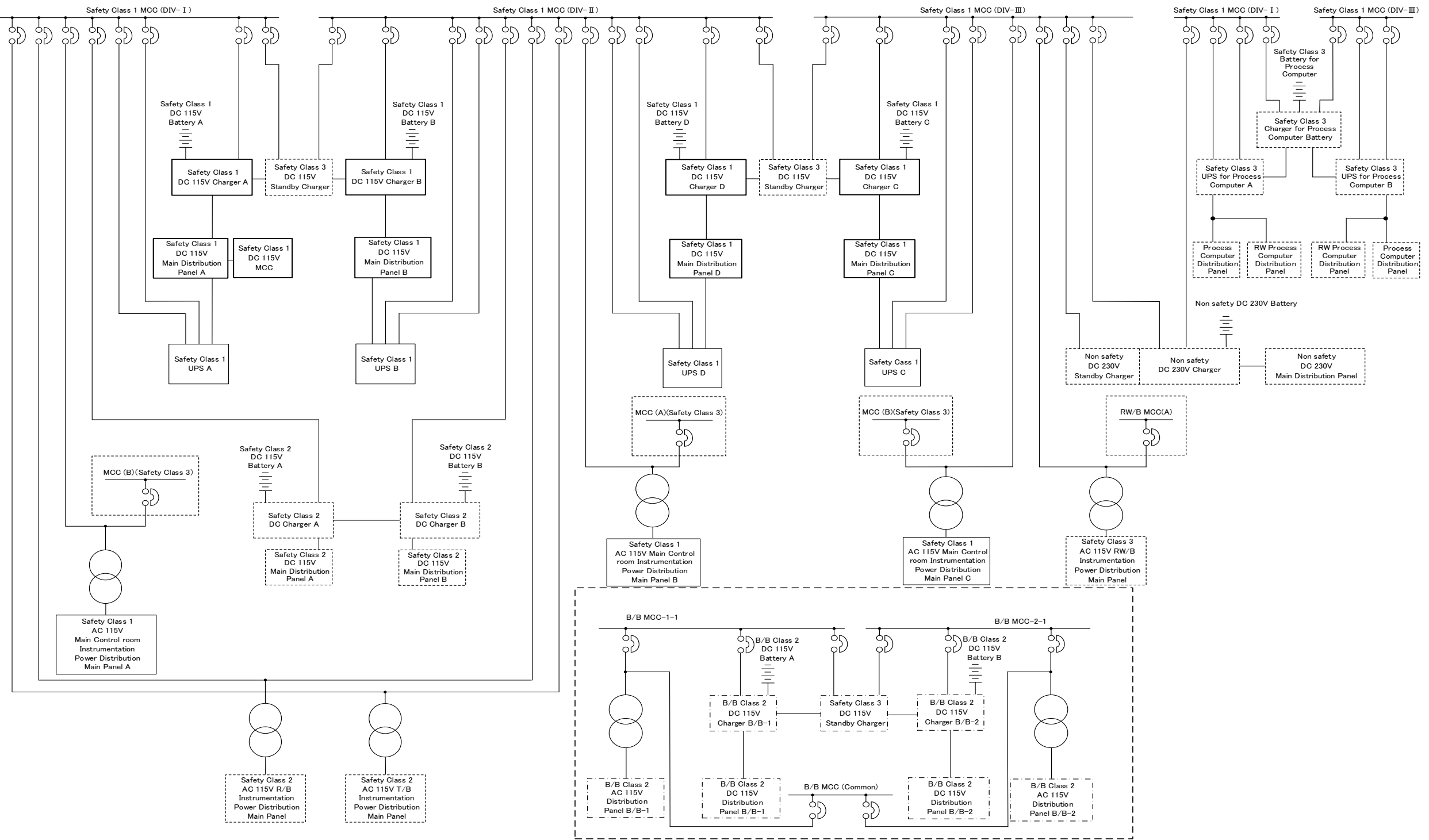


Figure 15.4-2: Single Line Diagram of Power Supply System for Control and Instrumentation System

15.4.2 Off-site Power Supply

The off-site power is connected to the ABWR via a main connection and a standby connection. The main connection is the connection to the Generator Transformer (GT) and the standby connection is the connection to the Auxiliary Standby Transformer (AST) as shown in Figure 15.4-1.

During normal conditions, power to the electrical auxiliary loads is supplied by the main generator via the Auxiliary Normal Transformers (ANTs). During initial plant startup and shutdown, the main generator is disconnected by the Generator Load Switch (GLS) and electrical power to the electrical auxiliary loads is supplied from the main connection via the GT and the ANTs.

When the main connection is not available or when a fault occurs on the generator system the GT or ANTs, off-site power is routed to the electrical auxiliary system via the standby connection (AST). During normal conditions the AST is energized from the off-site power supply in standby (off-load) mode to provide backup of the main connection.

The changeover from the ANT to AST is automatic when an electrical fault occurs in the generator main circuit (which includes the main generator, excitation system, GT and ANT). After the changeover the system loading is reduced as the generating operation is not required. Hence the loading requirements for the AST are less than that of the ANTs.

The dual ANTs provide sufficient power to supply the necessary load for the UK ABWR SSCs during normal conditions and fault conditions. The AST supports the SSCs as required post fault on the main generator circuit. The dual ANTs and AST are designed to provide sufficient capability to support the required SSCs under the defined operating conditions in which they will be used.

The Generator Disconnecting Switch (GDS) is installed on the grid side of the GLS. The GDS is closed during normal conditions, and opened for maintenance of the GLS or the generator, to isolate the circuit after the GLS opens.

Figure 15.4-1 shows a simplified single line diagram of the auxiliary power supply system. Electrical loads are allocated to the AC Medium Voltage (MV) and Low Voltage (LV) buses, DC and UPS distribution panels in accordance with their Safety Classification and taking into consideration the balancing of loads.

15.4.3 On-site AC Power Distribution System

The on-site AC Power system is divided into four (4) groups. With reference to the Single Line Diagram (Figure 15.4-1) these are:

- Medium Voltage 6.9kV Safety Class 3 buses which are supplied from the ANT or AST, depending on the operational condition of the plant.
- Medium Voltage 6.9kV Safety Class 1 buses which are normally supplied from Safety Class 3 Medium Voltage buses and supported by the Emergency Diesel Generators (EDGs).
- Medium Voltage 6.9kV Safety Class 3 bus for the DAG. This bus is normally supplied from Safety Class 3 Medium Voltage buses however can be supported by the DAG. The Safety Class 3 DAG board can be manually connected to a single 6.9kV Safety Class 1 bus to provide defence in depth under certain accident conditions (Section 15.4.7).

- Low Voltage 690V B/B Class 2 buses which are normally supplied from Safety Class 3 Medium Voltage buses via transformers and supported by the Backup Building Generators (BBGs).

15.4.4 Safety Class 3 AC Power Distribution System

The 6.9kV Safety Class 3 Medium Voltage (MV) buses supply power to the loads necessary during normal conditions. Primarily this system supports the boiler feed, condensate systems and the Reactor Internal Pump (RIP) system (Section 15.5.8) and their associated auxiliary systems. These systems are required for the normal conditions of the plant and are Safety Class 3 or Non Classified Systems.

This Safety Class 3 EPS is also the preferred source of power to the Class 1 AC power distribution system, provided that the grid connection is available and stable. The MV buses are divided into two (2) groups (A and B). Group A is supplied from one ANT and Group B supplied from the other ANT.

During plant startup or shutdown, these buses receive power from the external grid via the GT and ANTs. After the main generator is synchronized and connected to external grid, these buses receive power from the main generator via the ANTs.

During normal conditions, the incoming CBs from ANTs are the only incoming CBs closed on to the Class 3 MV buses.

If an electrical fault occurs in the generator main circuit (which includes the main generator, excitation system, GT and ANT) the electrical protection relays installed to protect the generator main circuit detect the fault and send a trip signal to the GT CB, the incoming CBs of the Class 3 MV buses from ANTs, and the main generator Field Switch (FS). This isolates the affected zone. After tripping the incoming CBs of the Class 3 MV buses from the ANTs, the incoming CBs of the Class 3 MV buses from the AST are closed automatically. There is approximately 100 Millie-second interruption in power supply to the Class 3 loads. Continuity of supply from the preferred (off-site) power source is maintained.

To provide flexibility to the operators during maintenance outages, the Class 3 buses can be manually switched to be supplied via the AST.

15.4.4.1 Safety Class 3 Low Voltage (LV) Power Distribution

Electrical power for the Safety Class 3 Low Voltage (LV) auxiliaries is supplied from Power Centres (P/Cs) which consist of MV/LV transformers and associated switchgear. The dedicated transformers are fed from the 6.9kV Safety Class 3 MV buses.

The Class 3 LV distribution system comprises the following:

- Power Centres (P/Cs)

The LV P/Cs are rated to supply power to Motor Control Centres (MCCs) and to motor loads rated between 90kW and 300kW in principle.

- Motor Control Centres (MCCs)

The Class 3 LV MCCs are sized to supply power to auxiliary loads of not greater than 90kW in principle.

15.4.5 Safety Class 1 AC Power Distribution System

The three (3) 6.9kV Safety Class 1 buses are normally supplied from Safety Class 3 MV buses and each Class 1 bus is supported by a dedicated Emergency Diesel Generator (see Section 15.5.3). The 6.9kV Safety Class 1 system is divided into three (3) 100 percent rated divisions where each division support a separate train of Class A1 safety SSCs. Each of the EDGs is housed in a separate EDG Building and provided with independent supporting service in order to maintain the independence of each Safety Class 1 division. Services and power and control cabling associated with each of the EDGs is supplied via separated and segregated service tunnels for each division.

The Safety Class 1 EPS AC buses supply power to the primary provision of the Class A1 Emergency Core Cooling safety functions and related equipment e.g. the High Pressure Core Flooder (HPCF) and the Residual Heat Removal (RHR) System. The RHR system is a three (3) × 100 percent system, with each division supported by a division of the 6.9kV Safety Class 1 EPS.

The 6.9kV Safety Class 1 EPS also supplies power to the support systems required to operate the EPS and support the delivery of the safety functions, namely the C&I, HVAC and RCW/RSW systems. The RSW/RCW system is supplied directly from the 6.9kV Safety Class 1 buses and each of the three (3) × 100 percent divisions is supported by a division of the 6.9kV Safety Class 1 EPS. The C&I and HVAC are presented as MV and/or LV loads on the Safety Class 1 EPS system and are supported by the Safety Class 1 MV and/or LV Power Distribution System.

In normal conditions the Safety Class 1 EPS AC maintains power to the C&I, HVAC and RCW/RSW systems and diesel starting systems, etc. Each of the 6.9kV Safety Class 1 buses is connected to a specific Class 3 MV bus. In loss of off-site power conditions the Safety Class 1 MV system is disconnected from the Safety Class 3 EPS and is supplied via the EDG.

15.4.5.1 Safety Class 1 LV Power Distribution

Electrical power for the Safety Class 1 LV auxiliaries is supplied from Power Centres (P/Cs) which consist of MV/LV transformers and associated switchgear. The dedicated transformers are fed from the 6.9kV Safety Class 3 MV buses.

The Class 1 LV distribution system comprises the following:

- Power Centres (P/Cs)

The Class 1 LV buses are each fed by their own power transformer. The LV P/Cs are rated to supply power to MCCs and to motor loads rated between 90kW and 300kW in principle.

- Motor Control Centres (MCCs)

The Class 1 LV MCCs are sized to supply power to auxiliary loads of not greater than 90kW in principle.

15.4.6 B/B Class 2 AC Power Distribution System

The B/B EPS is configured as a dual redundant structure. Each half of the redundant structure of the 690V B/B Class 2 system is normally supplied from a specific Safety Class 3 MV bus, via a dedicated transformer.

The B/B Class 2 LV buses supply power to the second line provision of the Emergency Core Cooling System (ECCS) safety function and related equipment e.g. the Flooder System of Specific Safety Facility (FLSS) which is the alternative Class 2 low-pressure flooder system. Since the Class 2 FLSS is a two (2) × 100 percent system, the B/B LV buses consist of two (2) systems (B/B Class 2 bus 1 and B/B Class 2 bus 2).

In normal conditions the B/B needs power to maintain battery chargers, Heating Ventilating and Air Conditioning (HVAC) systems and Backup Building Generator (BBG) starting systems associated with the Class 2 SSCs. In normal conditions each of the B/B Class 2 LV buses is connected to a specific Class 3 MV bus via a power transformer. A bus tie line is installed between B/B buses 1 and 2 in respect of maintenance of the Class 3 MV buses during reactor maintenance outage. The CBs of this tie line are interlocked and are open during normal conditions.

The power system of the B/B supplies power to the Class 2 equipment such as the FLSS which is the second means of providing the ECCS function. Therefore the power system of the B/B is designed to be diverse in relation to the Class 1 system in the R/B. The way diversity is achieved is described in the Diversity Strategy Report [Ref-3]. If off-site power is lost, the Safety Class 3 buses are disconnected and the BBGs are automatically started in readiness to supply power to the B/B Class 2 buses.

15.4.7 Safety Class 3 Diverse Additional Generator (DAG) Power Distribution

Fault Studies of Station Black Out (SBO) events [Ref-43] had identified that there are some very low frequency design basis SBO sequences that require containment venting. To reduce risks from such fault sequences Hitachi-GE took the decision to introduce an additional power supply that can restore the Residual Heat Removal (RHR) and reduce the requirement for containment venting. This led to the introduction of the 6.9kV Diverse Additional Generator (DAG).

One division of the RHR divisions I, II or III can be manually configured and resupplied by the DAG as a defence in depth provision under certain accident sequences and allows the operator to minimise the potential for any radiological release. In this role the DAG system provides an alternative source of supply to the Class 1 EDGs where the DAG and associated EPS distribution system remains available post initiating event.

The initiating events that the DAG can provide additional defence in depth against are a subset of all postulated Design Basis and Beyond Design Basis SBO events as detailed within the Topic Report on SBO [Ref-6]. These are the Medium and Long Term LOOP events with CCF of the EDGs (and Backup Building Generators (BBGs)) where the Safety Class 1 Medium Voltage (MV) switchboards remain available. These can be summarised as:

Design Basis SBO Event to which DAG provides additional Defence in Depth:

- (1) Medium Term Loss of Off-site Power (LOOP) with the CCF of the three (3) EDGs

Beyond Design Basis SBO Events to which DAG provides additional Defence in Depth:

- (1) Long Term LOOP with the CCF of the three (3) EDGs
- (2) Long Term LOOP with the CCF of three (3) EDGs and two (2) BBGs

The analysis of these three (3) events as documented in the Topic Report on SBO [Ref-6], demonstrates that there is the opportunity to minimise containment venting by restoring the RHR. Given that all of these initiating events comprise of LOOP with CCF of the Safety Class 1 EDGs, the design of the DAG is required to be diverse from the design of the Safety Class 1 EDGs so far as is reasonably practicable in order to minimise the potential for DAG/EDG CCF and maximise the availability of the DAG. Detail of this is discussed within the Diversity Strategy Report [Ref-3].

The Class 3 MV DAG bus is capable of being connected to any one of the three (3) Class 1 MV buses to achieve continuity of supply under any of these scenarios. In these scenarios the DAG can be manually started to supply power to the selected Class 1 division via a bus coupling line in order to support the Residual Heat Removal (RHR) system and its associated HVAC and C&I systems. The bus coupling lines provide flexibility in the selection of the Class 1 division to be supported but interlocking is installed to ensure that only one (1) line is allowed to make the interconnection detailed in the Station Electrical System Interlock Block Diagram [Ref-8].

After identifying the situation and checking the availability of the Class 1 EPS, the operator can startup the additional generator, energise the DAG bus and close the CBs from the DAG bus to one (1) division of the Class 1 bus by remote manual operation from the Main Control Room (MCR). After the manual operation is initiated from the MCR the actual startup sequence is also manually operated. If for some reasons control from the MCR is lost the DAG can be started from direct local operation.

In normal conditions the supporting systems of the DAG need power to maintain standby status therefore the DAG bus is connected to a specific Class 3 MV bus. The connection of the DAG is a manual operation under the control of the operators.

15.4.8 DC Power Supplies

There are four (4) groups of DC power supply system. With reference to Figure 15.4-2 these are:

- Safety Class 1 115V DC power supply system,
- Safety Class 2 115V DC power supply system,
- Non Safety Class 230V DC power supply system, and
- B/B Class 2 115V DC power supply system.

15.4.8.1 Safety Class 1 115V DC Power Supply System

The Safety Class 1 DC power supply system is arranged in four (4) divisions. Each division consists of charger(s) that receives power from one of the EDG backed Safety Class 1 divisions, a battery that is kept at float charging status by this charger, a main DC distribution panel and sub DC distribution panels for supplying 115V DC power to DC loads of that division. Four (4) independent and redundant systems I, II, III and IV of DC power are installed as the Safety Class 1 115V DC power supply in order to support the Category A1 SSCs. The safety logic of the UK ABWR consists of four (4) independent channels (2 out of 4 logic) and the configuration of the Safety Class 1 115V DC PS supporting the Category A1 SSC's is consistent with requirements of the reactor protection systems.

Each division of the Safety Class 1 DC Power Supply (PS) system can supply power to the necessary loads for eight (8) hours. Each division of the Safety Class 1 DC is fully rated to support the required loads and can support the required SSCs in delivering their safety functions such that failure of a single division does not compromise the ability of the Safety Class 1 DC PS to support the Safety Class A1 SSC. In support of beyond design basis accidents, the storage battery of Division I can be configured to supply power to the equipment needed for depressurization, feed water and monitoring of reactor for twenty four (24) hours.

In addition, two (2) common standby chargers are installed, each is common to two (2) divisions for use as backup during maintenance power outages of the upstream 420V AC P/C or MCC. The standby chargers are classified as Safety Class 3.

The standby chargers are not connected to the main chargers and batteries during normal conditions. An interlock scheme is installed for each standby charger to ensure that it is only fed from one (1) AC bus and does not simultaneously supply power to two (2) divisions.

15.4.8.2 Safety Class 2 115V DC Power Supply System

The Safety Class 2 115V DC power supply system is divided into two (2) groups (A and B). This power supply has a charger and storage battery for each system. Each system is composed of one (1) charger that receives power from an MCC which can be supplied from an EDG, a Safety Class 2 battery that is kept at float charging status by this charger, a main distribution panel and sub-distribution panels for supplying power to 115V DC instrument and control device loads of the Class 2 system.

A tie line is installed so that the other charger can supply power during maintenance of one (1) charger. A standby charger is not installed. This tie line is only used during maintenance and is not used during normal conditions.

15.4.8.3 Non Safety Class 230V DC Power Supply System

The non-Safety Class 230V DC power supply system is provided to supply power to unclassified DC loads such as motors for plant investment protection. The non-Safety Class 230V DC power supply system consists of one (1) charger that can receive power from one of two MCCs which can be supplied from EDGs, a battery that is kept at float charging status by this charger and main distribution panel for supplying power to loads (e.g. 230V DC power to DC motors).

It should be noted that where non-Safety Class loads are connected to the Class 1 EDG backed system the isolation of any faults in the non-Safety Class circuits is achieved by the isolating the fault by a device which is designated as Safety Class 1. The principle that is satisfied is that a major failure in the lower Safety Class system is rapidly isolated from the Safety Class 1 EPS. A standby

charger is installed to prevent discharge of the battery in the event of maintenance or failure of the main charger.

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

The B/B Class 2 115V DC power supply system is divided into two (2) groups (DC bus 1 and DC bus 2). Each system is composed of one (1) charger that receives AC power from one of the B/B Class 2 MCCs (B/B MCC 1 or 2), a B/B Class 2 battery that is kept at float charging status by this charger, a main distribution panel and sub-distribution panels for supplying power to the B/B Class 2 loads.

One (1) common use standby charger is installed as backup for the two (2) systems to be used during maintenance of the upstream AC P/C and MCC. The standby charger is classified as Safety Class 3.

This standby charger is not connected to the main charger and battery during normal conditions. An interlock scheme is installed to ensure that the standby charger is only fed from one (1) AC bus and does not simultaneously supply power to two (2) divisions.

15.4.9 AC Instrumentation Power Supply System

The AC instrumentation power supply system consists of six (6) groups as follows:

- Safety Class 1 uninterruptible AC power supply system (Class 1 AC UPS),
- Safety Class 3 UPS (Class 3 AC UPS),
- Safety Class 1 AC instrumentation and control power supply system (Class 1 AC C&I PS),
- Safety Class 2 AC instrumentation and control power supply system (Class 2 AC C&I PS),
- Safety Class 3 AC instrumentation and control power supply system (Class 3 AC C&I PS), and
- B/B Class 2 AC instrumentation and control power supply system (B/B Class 2 AC C&I PS).

15.4.9.1 Safety Class 1 AC UPS

The Class 1 AC UPS supplies power to Class 1 SSCs which cannot tolerate momentary power failure (typically although not exclusively computer based systems important to safety). There are four (4) divisions of the Safety Class 1 AC UPS power supply systems. The UPS system supplies AC 115V single-phase power to C&I devices of each division. This system also receives Direct Current (DC) power from 115V safety Class 1 battery so that it can supply power to loads in the event of a loss of on-site AC power. Each division of the Class 1 AC UPS consists of:

- Class 1 AC static type UPS unit powered from a Safety Class 1 MCC located in the Control Building (C/B),
- Standby AC supplied via a standby transformer fed from an MCC which can be supplied from an EDG located in the Emergency Diesel Generator Building (EDG/B) when the UPS device for instrument is under maintenance or failure,
- Solid-state transfer switch between the main AC input and the standby transformer supply,
- Safety Class 1 115V DC supply, and
- Load distribution panel.

15.4.9.2 Safety Class 3 AC UPS

Two (2) Class 3 AC UPS systems are installed (main and back-up) to enable continuous operation of the computer monitoring system during system failure or maintenance. Each system consists of:

- Class 3 AC static type UPS unit,
- Standby AC supplied via a standby transformer fed from Reactor Building (R/B) MCC which can be supplied from an EDG,
- Solid-state transfer switch between the main AC input and the standby transformer supply,
- Load distribution panel,
- Process computer dedicated battery, and
- Common battery charger.

15.4.9.3 Safety Class 1 AC C&I Power Supply System

The Class 1 AC Instrumentation and Control power supply systems supply power to the Main Control Room (MCR) AC 115V power distribution panels. There are three (3) Safety Class 1 AC Instrumentation and Control power supply systems corresponding to the number of Safety Class 1 AC power supply systems.

15.4.9.4 Safety Class 2 AC C&I Power Supply System

The Safety Class 2 AC Instrumentation and Control power supply systems supply power to the Class 2 Reactor Building (R/B) and Turbine Building (T/B) Instrumentation and Control loads. The Safety Class 2 AC Instrumentation and Control power supply systems are installed for the R/B and T/B.

15.4.9.5 Safety Class 3 AC C&I Power Supply System

The Safety Class 3 AC Instrumentation and Control power supply systems supply power to the Class 3 Radwaste Building (Rw/B) Instrumentation and Control loads.

15.4.9.6 B/B Class 2 AC C&I Power Supply

The B/B Class 2 AC Instrumentation and Control power supply systems supply power to the B/B Class 2 instrumentation and control loads. Two (2) \times 100 percent Class 2 systems are provided in the B/B supplied from the B/B LV buses.

The B/B Class 2 instrumentation and control loads in system 1 and system 2 normally receive power from B/B MCC 1 and 2 respectively. These systems are able to receive power from a common Class 2 B/B MCC in case of maintenance of the B/B Class 2 P/C or MCC.

15.4.10 Communication System

The Communication System consists of a telephone system and a paging system. The telephone system is designed to provide voice communications both within the plant and externally. The paging system is designed to instruct and to alarm from the MCR to the plant areas.

The telephone system is also used during emergency responses and normal conditions within the plant and to external organizations, so it is classified as Class 3 and non-safety Class respectively.

The paging system is used during normal conditions and emergency escape, so it is classified as non-safety Class.

The telephone system and the paging system are powered from Class 3 AC LV buses. Design details of the paging system and telephone system are described within the Communication System Specification [Ref-16].

15.4.11 Lighting System

The plant areas are classified depending on the scope of operational requirements.

- Emergency Response area – Emergency operation (e.g. Main Control Room, Emergency Electrical Panel Room)
- Normal Operation area – Normal operation/maintenance (e.g. Reactor Building, Turbine Building)
- No Operation areas– Areas accessed occasionally for maintenance (e.g. cable tray space)

In the emergency response areas, the AC lighting System is powered from Class 3 AC Power Supplies via Class 1 AC Power Supplies under normal conditions. Each supply provides 100 percent of the power required by the AC lighting system in the areas. On loss of Class 3 AC power supplies, the AC lighting System in the areas is supplied from three EDGs via three Class 1 AC power supply busses. The AC lighting system in the areas is supplied at 100 percent from the safety Class 1 AC power supplies.

In the normal operation areas, 90 to 95 percent of the AC lighting System is supplied directly from a single Class 3 AC power supply, with the remaining 5 to 10 percent supplied from two (2) Class 3 AC Power Supplies via two (2) Class 1 AC Power Supplies under normal conditions. On loss of Class 3 AC power supplies, the AC lighting System in the areas is supplied from Class 1 AC power.

In order to aid recovery from a station black out, the lighting system can be resupplied by the EDG, BBG or DAG in order to provide illumination in black out conditions. The battery inverters will also maintain the lighting during the time required for selection of alternative standby power sources.

In no operation areas AC lighting is powered from the Class 3 AC LV buses.

Emergency escape lighting with self-contained batteries is installed for workers to evacuate on complete loss of AC power. The design of the above systems is described in more detail in the Lighting and Service Power System Specification [Ref-17].

15.5 Electrical Equipment and Systems

15.5.1 Switchgear

Switchgear is classified as Class 1, 2 or 3 depending on its safety role. The classification links to the codes and standards for design, manufacture, inspection, maintenance and testing. Normally all classes of switchgear are based on the types detailed within this section.

15.5.1.1 MV Switchgear

Medium Voltage (MV) switchgear is metal clad with withdrawable Circuit Breakers (CBs) which are rated in accordance with system fault levels and the loads they supply. Switchboards will be fully type tested, extendable assemblies, complying with IEC 62271, including the capability to contain an internal arc fault. Switchboards are designed to allow the application of electrical and mechanical safety rules to ensure personnel safety.

15.5.1.2 LV Switchgear

Low Voltage (LV) switchgear is of the metal clad type and employs a combination of circuit breakers, fuse-switchgear, disconnectors and contactors depending on the application. Withdrawable or fixed units will be specified depending on the rating. Switchgear will be selected and rated in accordance with system fault levels and the supplied loads. Switchboards will be fully type tested, extendable assemblies, complying with IEC 61439 and rated to contain internal arc faults. Switchboards are designed to allow the application of electrical and mechanical safety rules to ensure personnel safety.

15.5.2 Power Transformers

The power transformers used in GDA and the roles of these transformers are as follows:

- Generator Transformer (GT)

The GT raises the generator voltage to the external grid voltage (400kV) during normal conditions. Also, at plant startup or shutdown, the GT steps down the external grid voltage to the generator voltage. The GT is provided with an On-Load Tap Changer (OLTC) fitted to the high voltage winding. This enables operation across the generator reactive power range taking into consideration the voltage variations specified by the Transmission System Operator (TSO).

- Auxiliary Normal Transformer (ANT)

Steps down the generator voltage to the MV bus voltage.

- Auxiliary Standby Transformer (AST)

Steps down the external grid voltage to the MV bus voltage.

- MV / LV Power Transformers

The PT steps down the electrical power from the 6.6 kV MV to the 420V LV system in all cases with the exception of the B/B PT which steps down the electrical power from the 6.6kV MV to the 690V LV system. The PT supplies the electrical power to the LV auxiliaries on-site during normal conditions. Switchgear is classified as Class 1, 2 or 3 depending on its safety role.

15.5.3 Emergency Diesel Generators

The role of the Emergency Diesel Generators (EDGs) is to supply the power needed to shut down and cool the reactor safely when off-site power is lost, and to supply power to the electrical systems supporting the delivery of additional safety functions in the unlikely scenario of a Loss of Coolant Accident (LOCA) occurring simultaneously.

Since the EDGs supply power to the safety Class 1 MV buses delivering supplies to Class 1 SSCs, they are classified as Class 1. Three (3) EDGs are installed in respect of the redundancy requirement for Class A1 SSCs, and each of the generators and associated control panels is installed in an independent room. Each EDG and its auxiliary systems are classified as Seismic Category 1.

EDG automatic start is initiated when a loss of voltage is sensed on its associated Class 1 MV bus, or when a LOCA occurs via an initiating signal from the Safety System Logic and Control (SSLC) (see Chapter 14). Low voltage detection relays detect the loss of voltage and simultaneously send commands to open the load CBs and the incoming CB (from the Class 3 bus) and send starting signals to the EDGs. All the loads connected to the Class 1 buses are initially disconnected with the exception of the power transformers and the LV Motor Control Centres (MCCs) which are connected to the LV buses.

When the frequency and voltage of the EDG reaches the specified values, the EDG is connected to the Class 1 bus automatically and the required loads are then connected automatically and sequentially, prioritized in accordance with importance to safety.

The automatic switching is controlled by a Class 1 timer and hardwired relay based load sequencer which starts when the bus voltage is recovered. This sequencing equipment is described within the Station Electrical System Interlock Block Diagram [Ref-8].

In the event that a Loss of Coolant Accident (LOCA) signal (reactor water level low signal or drywell pressure high signal) is received from the SSLC (see Chapter 14), all EDGs start up automatically regardless of the unit's normal auxiliary power supply availability. If the power supply of the Class 1 bus is maintained, the EDGs remain in no load operation and will continue in this mode until they are shut down manually.

If both a LOCA and a loss of supply to the Class 1 MV bus occur simultaneously, loads related to the SSCs supporting the delivery of the safety functions are supplied from the EDGs automatically in the required timescales.

Diesel Fuel storage facilities enabling the EDG to operate continuously for the period required by the safety analysis are provided within the power station-site. The EDG Fuel Oil System (DGFO) is detailed in Chapter 16, Section 16.6.

Detailed information about the loads connected to the Class 1 buses is described in the Emergency Diesel Generator System System Design Description and the Emergency Diesel Generator Capacity Calculation Report ([Ref-9] and [Ref-10]).

15.5.4 Backup Building (B/B) Generator

The role of the B/B Class 2 Generators (BBGs) is to supply the power needed to shut down and cool the reactor safely when off-site power is lost and the EDGs are unavailable. The BBGs supply power to the electrical systems supporting the delivery of additional safety functions in the unlikely scenario of a Loss of Coolant Accident (LOCA) occurring simultaneously. Two (2) B/B Class 2 Generators (BBGs) and associated equipment are installed in the B/B. The BBGs are rated to supply power to B/B equipment when off-site power is lost. For example: BBGs supply power to the Flooder System of Specific Safety Facility (FLSS) which consists of two (2×100 percent) Class 2 systems.

BBG automatic start is initiated if the power supply to the B/B Class 2 LV bus Power Centre (P/C) is lost. Low voltage detection relays detect the loss of voltage and simultaneously send commands to open the load CBs and the incoming CB (from the Class 3 bus) and send starting signals to the BBGs. After the voltage and frequency of the BBG has reached its specified value, the BBG is automatically connected to the B/B Class 2 P/C, and the power supply to the B/B equipment is available.

In the event that a Loss of Coolant Accident (LOCA) is received from the Hardwired Backup System (see Chapter 14) all BBGs start up automatically regardless of the unit's normal auxiliary power supply availability. If the power supply of the B/B Class 2 LV bus is maintained, the BBGs remain in no load operation and will continue in this mode until they are shut down manually.

Diesel fuel storage facilities enabling the BBGs to operate continuously for the period required by the safety analysis are provided. The BBG Fuel Oil System (BBGFO) is detailed in the PCSR Chapter 16, Section 16.6.

The power supply system of the B/B is designed to be diverse from the Class 1 power supply system, and the way that diversity is achieved is described in the supporting Diversity Strategy Report [Ref-3]. Details of the system design and the rating evaluation for the BBG system is described in the Backup Building Generator System System Design Description [Ref-11].

15.5.5 Diverse Additional Generator (Safety Class 3 DAG)

One (1) safety Class 3 Diverse Additional Generator (DAG) and associated equipment is installed to supply power to any one (1) division of the Class 1 EPS as a defence in depth measure against the fault sequences described in Section 15.4.7. The Class 3 DAG is capable of being manually started to supply power to one (1) division of the Class 1 EPS by using the interconnection line between the Class 3 DAG bus and the Class 1 MV busses.

Fuel storage facilities enabling the DAG to operate for the period required by the safety analysis are provided as detailed in Chapter 16, Section 16.6. The DAG is installed in a location separate from the EDGs and the BBG.

The DAG is started by remote manual operation from the Main Control Room (MCR) and the CBs of the power supply lines from the DAG to the Class 1 buses are selected and switched by remote manual operation from the MCR. Suitable interlocking is provided to ensure that the DAG is selected and switched to only one (1) Class 1 bus.

15.5.6 Power Trucks

The provision of mobile power trucks is installed as a countermeasure against Severe Accident (SA) cases as detailed within the Containment Venting Strategy in UK ABWR [Ref-5]. The mobile power trucks are connected to the Class 1 MV or LV bus through the connecting ports to supply the power to the required loads.

Power trucks will be designed in accordance with the requirements of this Containment Venting Strategy [Ref-5] and the associated topic report for the electrical engineering requirements, the Topic Report on Station Black Out [Ref-6].

15.5.7 DC Battery Chargers and Battery Systems

DC Battery Chargers are specified in accordance with IEC 60146 with batteries system installed in accordance with IEC 60896 and further information is provided in DC Power Supply System SDD [Ref-12].

15.5.8 Reactor Internal Pump Power Supply System

The power supply system to the Reactor Internal Pumps (RIPs) consists of following equipment:

- Motor-Generator (M-G) set, and
- ASD (Adjustable Speed Drive).

Four (4) M-G sets are provided; each is connected to a Class 3 MV bus as shown in Figure 15.5-1. Each M-G set is designed to provide constant voltage and constant frequency power to the ASDs. The ASDs are the static converter devices which generate the appropriate variable voltage and variable frequency power to the connected RIPs.

(1) M-G set

The primary function of the Motor-Generator (M-G) set equipment is to provide additional energy storage capacity for extending the coast-down time of the connected RIPs during a complete loss of AC power bus incident. In normal conditions, the M-G set converts the incoming electrical power to mechanical energy, then back to electrical power before using it to source the connected loads. By properly sizing the amount of inertia in the M-G set for kinetic energy storage, the generator's output is made less sensitive to large fluctuations in the input power bus voltage.

Each M-G set consists of the following components:

- Three phase induction motor,
- AC generator fitted with a brushless excitation system,
- Flywheel of appropriate inertia, and
- Control and protection.

The control circuit is designed to maintain generator output at a fixed voltage-to-frequency (V/f) ratio for optimum RIP speed modulation. Protection and monitoring instruments, annunciators, indicators and alarms are provided.

The M-G set interfaces with the ASD/RIP loads through input transformers. These units transform the M-G set voltage output to the level required by the ASD. Also, by phase-shifting the output of the transformers, the harmonic currents produced by the ASD converter are mitigated, thus minimizing the negative-phase-sequence current from flowing back into the generator.

(2) ASD

ASDs supply power, the frequency of which is controlled in accordance with the command from the Recirculation Flow Control (RFC) system (see Chapter 14), to the RIPs. The ASD consists of an input transformer rectifier, smoothing circuit, inverter and control panel. Input transformers step down the input voltage to the rectifier voltage. The rectifier converts the input AC to DC, and the smoothing circuit consists of a DC filter that suppresses the DC ripples. The inverter converts DC to AC whose voltage and frequency are controlled in accordance with the requirement of the RFC system. Figure 15.5-1 shows a single line diagram of the RIP power supply system.

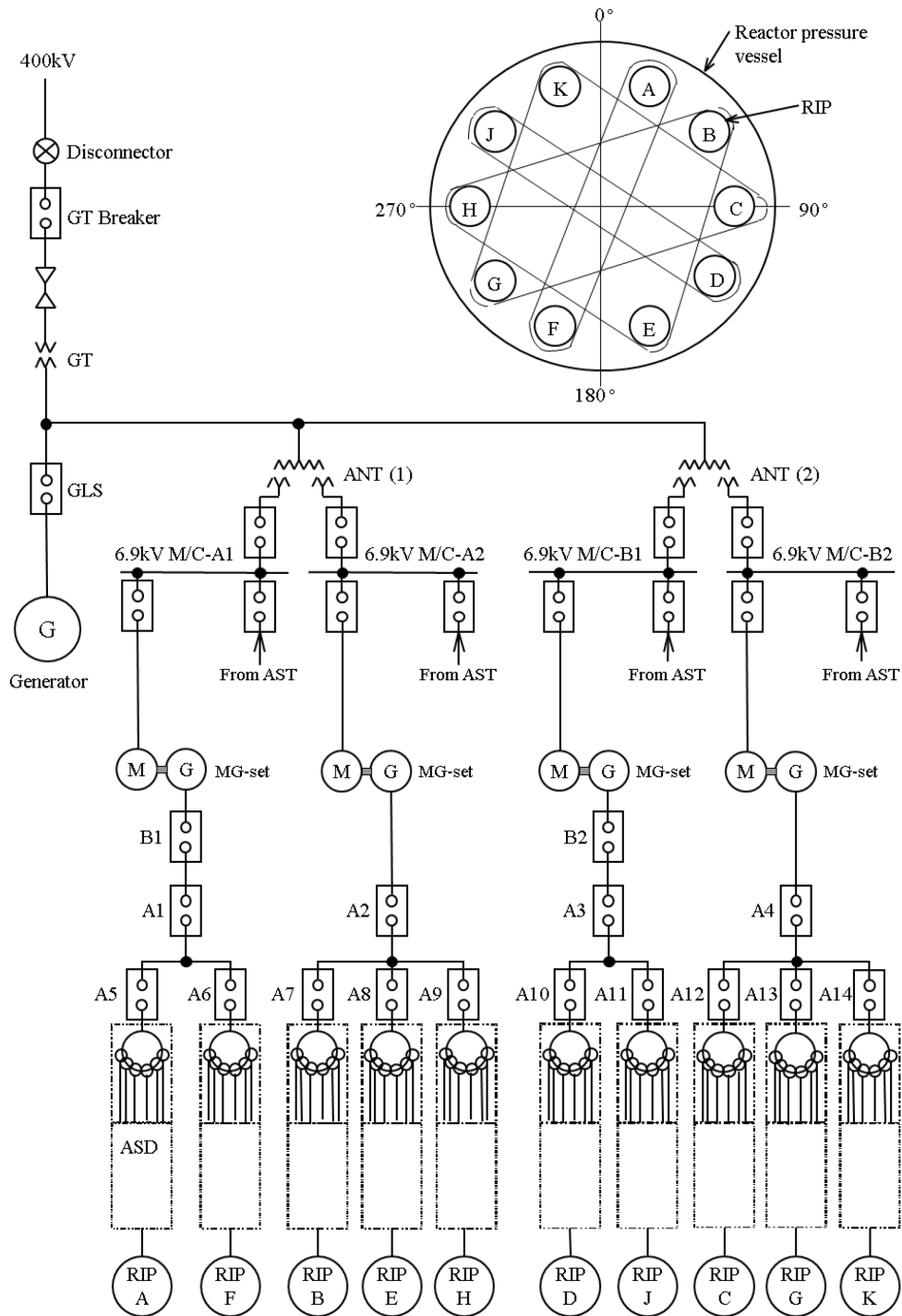


Figure 15.5-1: Reactor Internal Pumps

15.6 Electrical Protection and Earthing

This section explains the approach to electrical protection, earthing and lightning protection. Details of the protection and earthing systems design and protection devices are set out in the Electrical Protection and Earthing System Report [Ref-18]. Details of earthing and lightning protection are set out in the Earthing Specification [Ref-19] and the Lightning Protection Specification [Ref-20] respectively.

15.6.1 Philosophy of Protection

The design and operation of the protection system conforms to the following fundamentals of protection practice:

- (1) Minimisation of risk; the disconnection of electrical faults as quickly as possible to minimise risk to personnel and damage to plant.
- (2) Minimisation of the risk of power system disturbances.
- (3) Simplicity; via load grouping and the use of conventional, protective relaying practices for the isolation of faults.
- (4) High Reliability; Including primary and backup protection and provision of redundant arrangements where required.
- (5) Discrimination; limiting the opening of circuit breakers to those required to isolate the fault.
- (6) Stability; for faults external to the protected zone.
- (7) Protection equipment chosen to match the electrical operating characteristics of the protected plant.

Protection coordination analysis has been performed, in order to demonstrate that discrimination has been achieved and that the electrical system remains stable. The Electrical System Modelling Scoping Report outlines the programme of study work that was undertaken as part of GDA [Ref-21] and the results reports [Ref-49] and [Ref-50] demonstrate that protection coordination can be achieved.

15.6.2 Generator Main Circuit Protection

A conventional scope of generator main circuit protection is provided to protect the generator stator winding, generator rotor, Generator Transformer (GT) and Auxiliary Normal Transformer (ANT) zone from electrical faults such as short circuits and earth faults. In addition, comprehensive protection is provided for the generator itself for both mechanical and electrical fault conditions.

The scope of main protection includes the following devices:

- Generator and generator transformer differential,
- Overall differential protection,
- Stator and rotor earth faults,
- Over-current and overvoltage,
- Unbalance voltage and current,
- Loss of Excitation,
- Over fluxing,
- Over-speed, and
- Excess vibration.

Protection is provided for the excitation transformer and Auxiliary Standby Transformer (AST) zone.

In addition to the conventional generator protection, grid disturbance protection will be installed to provide protection against, system brownouts, open phase faults and all foreseeable grid disturbance events.

15.6.3 Power Distribution Bus Protection

Power distribution bus protection includes the following key elements:

- (1) Medium Voltage (MV) bus incoming circuits have instantaneous, inverse time over-current, earth fault, and under-voltage protection.
- (2) MV feeders for Power Centres (P/Cs) have instantaneous, inverse time over-current and earth fault protection.
- (3) MV feeders used for motors have instantaneous, inverse time over-current, earth fault protection, and thermal overload protection.
- (4) Low Voltage (LV) bus incoming line and feeder circuits have inverse time over-current, earth fault protection, and thermal overload protection as required.

15.6.4 Protection Requirements for Emergency Diesel Generators (EDGs)

Generator differential, earth fault, overvoltage, voltage restraint over-current, anti-motoring (reverse power), earth fault protection for field winding protection relays are installed on Emergency Diesel Generators (EDGs). When the EDGs supply power to Class 1 buses during Loss of Coolant Accident (LOCA) conditions, the only electrical protective devices which can shut down the EDGs are the generator differential protection relays. These protection devices are retained in service to protect against the possibility of significant damage.

Anti-motoring (reverse power) is installed to protect the EDGs when operating in parallel with the off-site power system during periodic testing. This relay is automatically isolated from the tripping circuits during LOCA conditions.

Synchronising interlocks are provided to prevent incorrect synchronization whenever the EDG is required to operate in parallel (for test purposes) with the off-site power supply. Such interlocks are capable of being tested, and operating instructions will be prepared to cover this periodic testing.

Similar protection is provided for the Diverse Additional Generator (DAG) and the Backup Building Generators (BBGs).

15.6.5 Lightning Protection

This section provides an overview of the approach to lightning protection design. The details are contained in the Lightning Protection Specification [Ref-20].

(1) Mitigations against the effects of a lightning strike

In accordance with IEC 62305 appropriate measures for lightning protection design and earthing design have been implemented for buildings, electrical equipment, and equipment important to safety to minimise damage from lightning strikes. In principle, equipment and circuits important to safety will always be installed inside buildings and cabling between each of the building i.e. EDG/B and T/B are in trenches.

Each building is provided with a lightning protection system appropriate to the classification of the building and these measures combined with a robust earthing system to limit the propagation of electrical disturbances into surrounding buildings.

(2) Mitigations against lightning induced surges

Measures to suppress the propagation of lightning surges are implemented to limit the penetration into electrical equipment, Control and Instrumentation (C&I) equipment and cable systems. This is provided by coordinated surge protections.

C&I equipment is classified according to its safety role whether it is related to safety of the nuclear power plant or required for operation monitoring and control. Sections of the C&I cabling that are run outdoors are identified for the purposes of lightning protection design due to the possibility of propagation of lightning surges into main buildings.

The design takes into consideration the need for resilient earthing and shielding of important systems in order to suppress possible induced voltages caused by lightning surges.

15.6.6 Earthing

The power plant includes an earthing system specifically designed to:

- Minimise the risk of electric shock,
- Minimise damage to plant and equipment caused by fault currents,
- Ensure positive and selective operation of protective devices, and
- Assist in protecting against damaging electromagnetic effects of electric currents (including fault currents).

Earthing is also an important component of the lightning protection system, to provide a containing conducting path for lightning power surges.

Earthing systems are established as a multiplex (meshed) arrangements of suitably sized copper conductors in the ground, with connections to above ground bonding conductors.

Earthing systems are classified as Class 1, 2 and 3 and non-Class according to classification of equipment and panels.

Equipment is earthed by earthing conductors installed in each building. Further information is provided in the supporting document Earthing Specification [Ref-19].

An important part of the earthing to enhance fault tolerance is that the 6.9kV and 420V EPS employs an IT earthing system, where the 'I' represents Isolated and the 'T' is the French word Terre (Earth). The advantage of an IT system is that it can permit the system to continue to operate in the event of a phase to earth fault. All earth faults are monitored resulting in an alarm allowing the fault to be isolated and repaired when there is no safety demand for the affected part of the EPS.

15.7 Panel and Raceway Layout

15.7.1 Requirements for Panels and Raceway Layout

The following key requirements / principles apply to electrical and C&I panels and cable raceway design: Further details of requirements, separation distances, installation patterns and layout are contained in the Electrical Panel Layout Plan [Ref-37] and the Electrical Equipment and Raceway Separation Plan [Ref-22].

Safety Class 1 electrical panels, circuits and raceways of trays and conduits are designed to be physically and electrically separated from those of the other safety Classes (Class 2/3) and non-safety Class.

Class 1 electrical panels are physically separated between safety divisions by walls, floors, ceilings, distance or barriers. Safety Class 1 electrical panels are also physically separated from panels of the other safety Classes (Class 2/3) using the same methods. Further details are explained in the Electrical Panel Layout Plan [Ref-37].

Class 1 circuits are electrically separated between safety divisions by isolators. Safety Class 1 circuits are also electrically separated from circuits of the other safety Classes (Class 2/3) and non-safety Class by isolators.

Class 1 raceways (trays and conduits) are physically separated between safety divisions by walls, floors, distance or barriers. Safety Class 1 electrical raceways are also physically separated from raceways of other safety Classes (Class 2/3) and non-safety Class by the same methods.

Class 1 electrical equipment is qualified for seismic activity and LOCA.

Panels, circuits and raceways of the other safety Classes (Class 2 and Class 3) are routed together with those of non-safety Class.

Openings for trays and conduits which penetrate walls and floors between different safety divisions are sealed to prevent the propagation of fires.

15.7.2 Cable

Material of cables is designed to minimize the usage of halogen. Class 1 cable arrangements will pass vertical tray flame tests to confirm flame propagation performance.

15.7.3 Electrical Penetration

The electrical penetration conforms to the following philosophies.

- Electrical Equipment inside Reinforced Concrete Containment Vessel (RCCV) are given powers, controls and signals outside RCCV.
- Electrical penetrations are installed in RCCV and shall supply powers, controls and signals to equipment inside RCCV.
- Electrical cable penetrations are designed for power, controls, signals and neutron monitoring.
- Electrical penetrations are designed make a component of RCCV boundary. Thus, electrical penetrations are designed to satisfy electrical and mechanical requirements with electrical equipment in RCCV.

15.8 Quality Assurance and Management Systems

15.8.1 Quality Assurance and Management Systems

A summary of the Quality Assurance and management system arrangements that impact on the production of the PCSR are provided in the Generic PCSR Chapter 4: Safety Management throughout Plant Lifecycle, Section 4.3.

Codes and Standards used for the EPS are listed in Table 5.8-6 of Chapter 5, while the embedded C&I Codes and Standards for EPS are listed in Table 5.8-5.

15.8.2 EMIT for EPS

In order to ensure the plant safety, the EPS equipment and components are required to be maintained properly during the plant lifecycle by examination, maintenance, inspection or testing (EMIT). This aspect in the EPS will be developed and detailed in the site specific stage with the agreement of a future licensee.

15.9 SMART Devices, Software Development and System Justification

The definition of 'SMART Devices' (SDs) is described in the List of Embedded C&I and SMART Devices in SC1 or SC2 Systems [Ref-24].

SDs embedded in the electrical system have been identified and confirmed, and are detailed within the List of Smart Devices in the Electrical System [Ref-26].

Details of the arrangements, including processes and procedures for the development of software for Smart Devices, are set out in Chapter 14 and the Topic Report on SMART Devices [Ref-25]. This includes the basis for the safety justification of application of software and hardware to SMART devices, sensors and protection relays and the approach to be taken for the qualification and application of SDs including SMART sensors and SMART electrical protection relays detailed in the List of Smart Devices in the Electrical System [Ref-26].

All embedded C&I will be specified by the future licensee. However a very strong recommendation is that for safety (diversity) and cyber security reasons only hardwired embedded C&I technology should be specified for all A2 safety functions. Chapter 14 shows that the diversity of the HWBS from that of the Class 1 SSLC is important for safety. Thus, the A2 BBG based EPS in the B/B is strongly expected to provide electrical power to loads initiated by the Hardwired Backup System (HWBS). In addition to the HWBS for A2 functions, wherever possible on the Class 1 EDG based EPS, the use of SDs for embedded C&I should be avoided because of the complexity of developing a safety justification for Class 1 SDs. Clearly any hardwired device specified for the Class 1 EPS would require to be diverse from the equivalent function on the Class 2 EPS.

15.10 Assumptions, Limits and Conditions for Operation

15.10.1 Purpose

This section summarises the assumptions made for the EPS described in this chapter and the requirements for deriving the Limits and Conditions for Operation (LCO) for the EPS. The general principles are defined in Chapter 4, Section 4.12.

A full set of Limits and Conditions for Operation (LCOs) are specified for the UK ABWR EPS in Section 3.8 of the Generic Technical Specifications [Ref-47]. This section provides a high level overview of the assumptions and the derivation of the Generic Technical Specifications for the EPS.

15.10.2 LCOs Specified for EPS

In order to ensure that the EPS is operated within safety limits and the design requirements from the safety case are met during the operating regime, appropriate Limits and Conditions for Operation (LCO) to ensure the LCOs are met and corrective actions (measures) to follow when the LCOs are not met are defined. This information which is shown below is described in the Basis on Safety Cases on Electrical System [Ref-1] and ultimately reflected in the Generic Technical Specifications [Ref-47], which are transferred to a future licensee to operate the plant as designed in the safety case.

- Number of AC sources operable (Section 3.8.1 and 3.8.2 [Ref-47])
- Number of DC sources operable (Section 3.8.4 and 3.8.5 [Ref-47])
- Number of Uninterruptible AC Power Supply (UPSs) operable (Section 3.8.7 and 3.8.8 [Ref-47])
- Number of distribution systems operable (Section 3.8.9 and 3.8.10 [Ref-47])
- Battery cell parameters within limits (Section 3.8.6 [Ref-47])

15.10.3 Assumptions for EPS

The assumptions used in this Chapter are as follows:

- (1) There are two (2) separate transmission lines for connection to the national grid structure (see Figure 15.4-1).
- (2) National Grid reliability is consistent with the analysis of the faults (loss of off-site power) described in PCSR Chapter 24: Design Basis Analysis.
- (3) Internal and external hazards are based on those specified in Chapters 6 and 7 of this PCSR.

All of the above will be reviewed and, as necessary, updated in the site specific stage of the project.

15.11 Summary of ALARP Justification

This section presents a high level overview of how the ALARP principle has been applied for Chapter 15 on Electrical Power Supplies (EPS) and how this topic contributes to the overall ALARP argument for the UK ABWR.

Generic PCSR Chapter 28: ALARP Evaluation presents the high level approach taken for demonstrating ALARP across all aspects of the design and operation. It presents an overview of how the UK ABWR design has evolved, the further options that have been considered across all technical areas resulting in a number of design changes and how these contribute to the overall ALARP case. The approach to undertaking ALARP Assessment during GDA is described in the GDA ALARP Methodology [Ref-31] and GDA Safety Case Development Manual [Ref-32]. For GDA this consists of the following steps:

- (1) Establishing the role of EPS in controlling risks to safety from the UK ABWR.
- (2) Undertaking a gap analysis of the reference J-ABWR EPS design to International and UK Relevant Good Practice (RGP), regulatory expectation and NSEDPs.
- (3) Undertaking an options analysis for closing gaps.
- (4) Selecting and implementing the optimal ALARP solution.

15.11.1 ABWR EPS Contribution to the Control of Risks to Safety

PCSR Chapter 24 for the fault studies, Chapter 25: Probabilistic Safety Assessment and Chapter 26: Beyond Design Basis and Severe Accident Analysis provide a comprehensive overview of the role of all safety SSCs in the safety of the UK ABWR. The EPS BSC [Ref-1] identifies all SSC supported by the ABWR EPS.

From the supporting safety analysis (Chapters 24 to Chapter 26) it has been shown that the EPS systems have a very significant role in the safety of the UK ABWR due to the support ABWR EPS to Class 1 and Class 2 SSC providing Category A Functions.

In addition to supporting Category A Functions the EPS systems make a major contribution to safety at all five (5) levels of the defence-in-depth defined in Chapter 5, Section 5.3. The mapping of the EPS systems to these levels of defence-in-depth (see Chapter 5, Section 5.3) are as follows:

- Class 3 EPS – Level 1 (Expected Events) and Level 2 (Foreseeable Events),
- Class 1 EPS – Level 3 (Frequent and Infrequent Design Basis Events),
- B/B Class 2 EPS and DAG (Level 4) – ¹Level 3 (Design Basis Faults) and Level 4 (Beyond Design Basis Events), and
- Class 2/3 Severe Accident EPS (SA, DAG, Mobile Power Trucks) – Level 5 (Severe Accidents).

¹ For EPS this covers a special class of design basis fault involving a frequent design fault and a coincident common cause failure of the Class 1 EPS.

Similarly there is a significant interplay between EPS safety claims and the C&I safety claims specified in Chapter 14. This is reflected in Chapter 14 which provides a description of the methodology to be applied to the design of the embedded C&I controlling the UK ABWR EPS. It is considered that EPS plays an essential role in supporting all aspects of safe operations at a UK ABWR site.

A good example of the role of design basis analysis and beyond design basis analysis strongly influencing the design of the UK ABWR EPS is that of the loss of off-site power (LOOP) faults and faults involving LOOP coincident the Common Cause Failure (CCF) of the three (3) Class 1 EDGs; this latter fault type, LOOP + CCF EDGs, is referred to as Station Black Out (SBO). The LOOP faults and SBO events are described in Topic Report on SBO analysis [Ref-43]. As explained in Chapter 24 design basis analysis is divided into two (2) subgroups those that are frequent faults (FF) and have a best estimate of $<1 \times 10^{-3}/\text{yr}$ and those that are infrequent faults (IF) with a frequency range of $1 \times 10^{-3}/\text{yr}$ to $1 \times 10^{-5}/\text{yr}$. Beyond the design basis faults have a frequency of $<1 \times 10^{-5}/\text{yr}$. For the design of the UK ABWR EPS the following faults were analysed and influenced the EPS design.

- Short term LOOP of 2 hours duration $5 \times 10^{-2}/\text{yr}$ (FF) - LOOP₂
- Medium term LOOP of 24 hours duration $5 \times 10^{-3}/\text{yr}$ (FF) - LOOP₂₄
- Long term LOOP of 168 hours duration $5 \times 10^{-5}/\text{yr}$ (IF) - LOOP₁₆₈

For all FF design basis events Hitachi-GE's Nuclear Safety and Environmental Design Principles (NSDEPs, see Section 15.11.2 below for more information on this document) [Ref-2] requires considerable defence-in-depth for all design basis events. For FF, deterministically, the safety function is a Category A and because the fault is FF it is protected by a Safety Class 1 and diverse safety Class 2 (referred to as A1 and A2 respectively). For the lower frequency infrequent faults protection is through a Class 1 system, referred to as A1. This means that for the A1 function the on-site EDG based EPS had to operate without any off-site assistance for 168hrs, which is an important requirement for the size of the fuel supply tanks. Additionally as it is an A1 system it had to be designed to meet the single failure criterion (see BP4.9 of the NSDEPs [Ref-2]). Analysis of the application of the single failure criterion is too detailed for this document, for more information see the analysis of Safety Property Claim (SPC) 1 in the EPS BSC [Ref-1]. The result of this analysis of SPC 1 is that the A1 EDG supported EPS is a three (3) division system, where any one of the three (3) divisions is sufficient to ensure the safety of the plant.

Additional fault studies requirements were needed to help define defence-in-depth measures. The first two (2) LOOP events (LOOP₂ and LOOP₂₄) specified above required an additional Class 2 EPS as a diverse measure to the A1 EDG based EPS. To help define the requirements for this A2 EPS additional faults were analysed as follows (where EDG_{CCF} is the common cause failure of the three (3) A1 EDGs):

- LOOP₂ + EDG_{CCF} (IF) ($5 \times 10^{-6}/\text{yr}$)
- LOOP₂₄ + EDG_{CCF} (IF) ($5 \times 10^{-7}/\text{yr}$)
- LOOP₁₆₈ + EDG_{CCF} (Beyond design basis) ($1 \times 10^{-8}/\text{yr}$)

Although the initiating event frequencies are estimated to be in the beyond design basis region to these analysis was included as though they were infrequent events. The design of the additional A2 system had to be completely independent of the A1 EDG based system. A decision was taken early on in GDA that the A2 EPS would be located remotely from the EDGs in the B/B. In addition to

specifying that the B/B Diesel Generators (BBGs) had to be from a completely different manufacturer it was also decided that they would operate at the lower 690V level rather than the 6.9kV MV level. This makes considerable difference in switchgear, cable sizing, insulation gaps etc., thereby adding other diverse measures to manufacturing diversity. As the B/B EPS makes a significant contribution to the Category A Fundamental Safety Functions (FSF 2- FSF 5, Chapter 5, Section 5.3) the NSEDPs [Ref-2] provide guidance that the system can be a Class 2 and it is referred to as the A2 EPS. Application of SPC 1 [Ref-1] showed that the A2 EPS located in the B/B required a fully duplex (2×100 percent) electrical architecture. This means that the design of the A2 B/B EPS is a fully duplex system where each 690V BBG is fully rated to supply its safety function.

The above gives a very brief background the design of the installed on-site A1 and A2 generation. This on-site generation is completely independent of grid based supply. Even if a LOOP lasted longer than 168hrs it would not be a problem for the site as the system can continue to operate with the provision of fuel provided for secure off-site supplies. Additionally the site also has mobile on-site generators, known as power trucks, in secure and locations. These can be connected in the event of a major loss of the off-site power (LOOP) and total loss of three (3) EDGs (EDG CCF) and the CCF of the BBGs. This severe accident sequence which has strongly influenced the design of the mobile power trucks is as follows:

- $LOOP_{168} + EDG_{CCF} + BBG_{CCF}$

15.11.2 Application of NSEDPs and RGP

The NSEDPs [Ref-2] have been developed in order to capture and provide guidance on RGP for the design, operation and through life support of ABWR SSCs. The J-ABWR EPS reference design was reviewed against the NSEDPs and RGP. Due cognisance has been taken of the requirements of the NSEDPs [Ref-2] which reinforce the principle of defence in depth, also of relevant good practice and of UK regulatory expectations.

When the J-ABWR reference design was compared to the NSEDPs [Ref-2] it was judged that further risk reduction would be practicably achievable by the adoption of the following measures.

- Full compliance with relevant standards as specified in the Topic Report on Acts, Regulations, Codes and Standards [Ref-33].
- Uprating of the capacity of the Class 1-EPS meeting the N+2 version of the single failure criterion (NSEDPs SP 4.9.1 [Ref-2]).
- Provision of diversity between A1 and A2 Electrical Power System (EPS) including the provision of separation and segregation and ensuring the use of subsystems and components employing diverse technology (NSEDPs BP 4.10 [Ref-2]).
- Provision of additional electrical power sources (NSEDP BP8.11 [Ref-2]).
- Provision through life capacity to support future load growth and therefore provide the ability of the UK ABWR EPS support additional systems which may reduce the risks in the future.

This has led to a risk-informed approach to the development of the UK ABWR EPS design both directly, by enhancing the integrity of the EPS system to achieve lower levels of risk, and indirectly, by raising the capacity of the EPS to support additional systems which also achieve risk reduction. The implementation of each of the risk reduction measures is detailed in Section 15.11.3.

15.11.3 Implementing of the Risk Reduction Measures

A) Compliance with Codes and Standards

IEC codes and standards represent a body of knowledge about equipment safety and can be considered to constitute relevant good practice for individual equipment items. The ability of the standard J-ABWR EPS components to meet recognised IEC standards has been assessed. Where it has been judged that there is a significant risk of J-ABWR legacy equipment not meeting IEC standards alternative strategies have been proposed.

For the UK ABWR the key compliance risks are judged to be associated with switchgear and on-site electrical power sources. In order to minimise the risk of noncompliance with relevant codes and standards the procurement of alternative equipment from recognised IEC compliant manufacturers has been proposed for 420V and 690V LV switchgear and limited aspects of the on-site generation equipment.

It is considered the development rather than procurement of the 6.9kV switchgear represents the lowest risk option as the operating principles of the J-ABWR can be retained and this is the most favourable solution to meet the spatial and technical constraints associated with the ABWR EPS, while meeting the good practice embodied in the IEC standards.

B) Upgrading of the Capacity of the Class 1-EPS

Additional capacity for the Class 1 EPS to support additional systems is driven by the requirements of the supported SSCs and the wider risk reduction measures adopted by the UK ABWR Design. Examples of such changes were the increase in the capacity of the cooling water chain of RHR/RCW/RSW (see Chapter 16) and addition of new Heating Ventilating and Air Cooling (HVAC) capacity (see Chapter 16).

In order to support the required load growth, upgrading the three (3) EDGs is the preferred solution. As noted above for the reduction of internal hazards in the R/B also meant that the EDGs were relocated to a dedicated facility and as a result the EDGs are not significantly spatially constrained. By upgrading the EDGs this in turn allows the divisional architecture of the EPS to be maintained along with existing operational practices. The upgraded EDGs are sized to support a Class 1 SSCs required by the safety analysis as described in the Emergency Diesel Generator System Design Description [Ref-9] and the Emergency Diesel Generator Capacity Calculation Report [Ref-10]. Each EDG has sufficient load capacity to fully meet the required steady state and transient loads for all normal and fault conditions specified in the UK ABWR GDA safety case. Each EDG also includes a margin above the maximum load calculated for the GDA design to cater for future load growth in the site specific stage.

Although the provision of additional divisions of the Class 1 power source, for example a 4th division, to meet the load growth is also considered, this is not an effective measure as this would result in significant redesign of the on-site power system to accommodate the additional switchgear and circuits. The development of new operational practices would also be required which may result in an increase in risk due to the application of novel practices when compared to the J-ABWR.

C) Provision of Diversity between A1 and A2 Electrical Power System

The J –ABWR EPS reference design used elements of common equipment across the nuclear power plant electrical equipment conforming to standard MV and LV levels, i.e. 6.9kV and 420V. As results of the potential common equipment across the nuclear power plant in order to minimise CCF potential it was judged that Class 1 and Class 2 EPS should be independent and diverse in order to provide a risk reduction in line with RGP for systems supporting A1 and A2 SSCs. This led to the development of the B/B Class 2 EPS.

It is considered that UK RGP is to provide diversity in technology in order to achieve system diversity and minimise the risk of CCF associated with Class 1 and B/B Class 2 EPS. It is considered that requirement for diversity in technology with regards to the EPS is best met by choosing a combination of significantly diverse voltages for the Class 1 and B/B Class 2 EPS and supplying the equipment from different manufacturers.

In order to maintain the Class 1 EPS architecture and operational consistency, it was judged that the primary Class 1 EPS voltage of 6.9kV should be maintained and an alternative voltage of 11kV or 690V/420V should be considered for the B/B Class 2 EPS. The power capacity required for the B/B Class 2 EPS SSC is such that a much lower voltage level can be assigned without producing unacceptable current levels and voltage drops. After some analysis decision was taken to adopt 690V AC as this provides the optimal level of voltage diversity whilst still retaining a good voltage profile for the B/B loads.

Using a diverse voltage level for the B/B Class 2 EPS and the initial analysis of equipment and components it is judged that sufficient diversity can be achieved between the Class 1 and B/B Class 2 EPS. Details of the approach to achieving diversity are set out in the Diversity Strategy Report [Ref-3].

D) Provision of additional electrical power sources

Fault Studies of Station Black Out (SBO) events [Ref-43] showed that there were some very low frequency design basis SBO sequences that required containment venting. To reduce risks from such fault sequences Hitachi-GE took the decision to introduce a Diverse Additional Generator (DAG).

One (1) division of the RHR divisions I, II or III can be manually configured to be supported by the DAG as a defence in depth provision under certain accident sequences and allows the operator to minimise the potential for any radiological release by restoring the RHR system. The optimal location of the DAG was also reviewed as a part of the review of the location of the Emergency Diesel Generators in the optioneering study [Ref-34] referred to the above. This reference shows (option 11) that the optimum location of the DAG is in its own building separated by distance from the three (3) EDG Buildings, and often with the protection of other buildings.

The diverse B/B Class 2 EPS protects against the CCF of the Class 1 switchboard. It is considered that there are no additional reasonably practical measures that can be taken to provide additional defence in depth for Class 1 EPS CCF.

In line with NSEDP BP8.11 [Ref-2] the large power truck and small power truck are provisioned to enhance the plant's capabilities to withstand accidents that are either more severe than design basis accidents or that involve additional failures. They are based on engineering judgement and relevant good UK practice.

E) Provision through life capacity to support future load growth

While load growth is not a direct issue related to risk reduction in the context of the EPS in isolation, it is relevant to consider risk reduction in the wider context of supporting additional safety requirements. Whole system load growth is driven by the requirement for the EPS to support additional systems which in turn is driven by the requirements of the supported SSCs and the wider risk reduction measures adopted by the UK ABWR design.

Examples of such changes were the increase in the capacity of the cooling water chain of RHR/RCW/RSW (see Chapter 16) and addition of new HVAC capacity (see Chapter 16).

In order to assess the ability of the EPS to support future load growth the capacity on key electrical system components has been assessed. This assessment demonstrated that the load growth has the potential to exceed the capability of the single ANT and also the rating of the AST associated with the J-ABWR reference design.

Hitachi-GE reviewed the options, which were (1) increase the capacity of the single ANT, (2) introduce a second ANT or (3) increase the number of ANTs to four.

Hitachi-GE had experience of two (2) ANT designs in its J-ABWR NPP portfolio and so decided that this option was the optimal solution to provide adequate system capabilities. Auxiliary Normal Transformer Design Specification [Ref-29] showed that the configuration of two (2) ANTs provide additional load growth capacity and also had the benefit of slightly reducing the calculated fault levels. A reduction in system fault level is beneficial for personal safety aspects. The AST design change was a simple update of the ratings to cope with the load changes from load growth from other topic design changes.

The provision of a dual ANT design is considered the most practical option as increasing the capacity of the single ANT has the potential to introduce fault levels that would exceed the equipment capability and the four (4) transformer option was also not analysed in-depth as its adoption would have increased the complexity and cost of the system for no overall safety benefit. It should also be noted that the system capacity has been sized to ensure future load growth during the site specific stage of the design, this is known as “owner’s scope loads.”

15.11.4 Maintaining Risk Profile

For commercial operation in the UK the ABWR main generator and associated systems have to meet the requirements specified in the Grid Code (GC) in order to be permitted to connect to the UK grid. The GC requirements are potential drivers for change on UK ABWR EPS and modifications required to meet the GC must not increase the risk to nuclear safety.

The modification of the J-ABWR main generator design to deliver GC compliance will be made as part of the site specific design, and as part of the assessment of any such design changes, appropriate steps will be taken to ensure that any such design changes do not impact on the safety case.

However initial assessments of potential design solutions to meet the requirement have been completed for compliance with requirements associated with

- Fault Ride Through (FRT),
- Limited Frequency Sensitive Mode (LFSM),
- Frequency Sensitive Mode (FSM), and
- Island Mode (IM).

The assessment result regarding the above requirements was provided in the report [Ref-35] and is summarised as follows.

FRT required a change in the electrical power supply to the Reactor Internal Pumps (RIPs) (see Section 15.5.8). There are ten (10) RIPs and in the J-ABWR reference design, six (6) are supplied through two (2) high inertia Motor-Generator (MG) sets and four (4) are directly driven from the 6.9 kV AC Class3-EPS (all ten (10) use transformers and variable speed drives to connect to the motors).

To be fully compliant with the GC FRT requirement a design change was implemented in which all ten (10) RIPs are supplied through four (4) MG sets. The two (2) additional MG sets both drive two (2) RIPs whereas the existing design of two (2) MG sets each driving three (3) RIPs has been retained from the reference J-ABWR design.

Fault studies (see Chapter 24) and PSA (see Chapter 25) have confirmed that this design change has no significant impact on nuclear safety. This conclusion was reached from an options analysis exercise.

For LFSM the reference J-ABWR design largely met this GC requirement. The required change includes in the electro-hydraulic control system setting, requiring a change to the point at which de-load starts from 50.25Hz to 50.4Hz. This change has no impact on safety.

For FSM the reference J-ABWR is not compliant. Three (3) options have been identified in the report [Ref-35] although only one, option 3, is fully GC FSM compliant. Adopting option 3 for FSM requires the turbine-generator electro-hydraulic control system to have new control functions added to the reference design. The design changes necessary to meet FSM have no impact on nuclear safety.

For Island Mode (IM) operation the reference J-ABWR design is not compliant. To be compliant with IM requirement increase of bypass capacity would be required, and an optioneering assessment was undertaken to determine the ALARP options for achieving compliance. The result concluded

that the ALARP option was to retain the existing bypass capacity of the reference J-ABWR design and seek a derogation from the Grid Code with regards to IM operation.

For GDA it has been demonstrated that with one exception there is a high level of confidence that the UK ABWR is compliant with the Grid Code. The one exception is the IM and based on generic design principles it is not ALARP to include IM as a part of the design for UK ABWR in GDA. However nothing forecloses the option of adopting IM when the future site specific analysis of Grid Code compliance is undertaken.

As noted above modification of the J-ABWR main generator design to deliver GC compliance will be made as part of the site specific design. As the detailed design progresses the assessment of any proposed design changes will consider the impact on nuclear safety and the requirement of the overall ABWR plant safety case.

15.11.5 UK ABWR EPS ALARP Position

The work undertaken in the development of the UK ABWR has taken a risk-informed approach to the development of the ABWR EPS design both directly, by enhancing the integrity of the EPS system to achieve lower levels of risk, and indirectly, by raising the capacity of the EPS to support additional systems which also achieve risk reduction.

For each of the risk reduction areas identified by the application of the NSEDPs [Ref-2] and RGP high level options for design led measures have been presented and analysed so far as reasonably practical with the current GDA design.

Cognisance has been taken of the requirements of the NSEDPs [Ref-2] which reinforce the principle of defence-in-depth, also of relevant good practice and of UK regulatory expectations. It is judged that the improvements to the design of the EPS are aligned with the goal of demonstrating that the ABWR design is well-balanced in respect of nuclear risk and that overall risk levels are both tolerable and ALARP.

15.12 Conclusions

This chapter presents a summary of the safety case for the UK ABWR Electrical Power System (EPS) within the scope of the Generic Design Assessment (GDA) process. Section 15.3 of this chapter provides a description of the claims on the safety functions and safety properties of the EPS SSCs. The Electrical Power System (EPS) is a supporting system which has been designed to meet the requirements of the supported SSCs which deliver safety functions for the UK ABWR. The safety claims associated with each SSC have been cascaded to all supporting systems including the EPS described in this chapter. In a similar manner the classification of the SSCs has been cascaded to the supporting EPS components. By mapping the requirements of the supported SSC to the design of the EPS this ensures that the electrical design is consistent with the overall plant safety case and has a balanced and proportionate approach to safety by fully taking into account the mutual relationship between the EPS and the supported SSCs.

The claims for the EPS take the form of a set of Safety Functional Claims (SFCs) derived from High Level Safety Functions (HLSFs) and Safety Property Claims (SPCs). SPCs are used in lower tier documents referenced in this chapter to show compliance with the Hitachi-GE Nuclear Safety and Environmental Design Principles (NSEDPs) [Ref-2]. This Claims, Arguments and Evidence (CAE) structure is set out in detail in the Basis of Safety Cases (BSC) on the Electrical System [Ref-1].

Each supported SSC places a demand for electrical power on the EPS. The SFCs are designed to demonstrate the ability of the EPS to meet the power demand so that the SSC it is supporting can fulfil its High Level Safety Function as specified in the safety analysis Chapters 24, 25 and 26. The list of claims referred to in this chapter and the linkage to corresponding High Level Safety Functions is shown in Appendix A. The primary purpose of the SPCs is to act as the foundation for all design aspects of the UK ABWR, when applied by Hitachi-GE in the design of the plant and in the production of the accompanying safety and environmental documentation. SPCs are applied to the design of the EPS to support the demonstration of the ability of EPS to meet the design criteria as detailed in the NSEDPs. The list of claims referred to in this chapter and the linkage to corresponding NSEDPs is shown in Appendix B. Further breakdown of the claims, supporting arguments and mapping to the evidence that supports the PCSR is set out in the Basis of Safety Cases (BSC) on Electrical System [Ref-1]. Section 15.4 and 15.5 of this chapter provides an outline description of the EPS architecture, and identifies its major elements (such as Transformers, Generators, and Uninterruptible Power Supply (UPS) units). It also describes the major subsystems that constitute the overall EPS architecture such as key Alternating Current (AC) and Direct Current (DC) power supply systems. Finally this chapter and its supporting references have demonstrated that the design of the UK ABWR EPS has achieved a very low level of risk that is as low as reasonably practicable to achieve.

15.13 References

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- [Ref-15] Hitachi-GE Nuclear Energy, Ltd., “Instrument and Control Power Supply System System Design Description”, GR47-1001-0001-00001 (ED-GDA-C018), Rev.3, December 2016

- [Ref-16] Hitachi-GE Nuclear Energy, Ltd., “Communication System Specification”,
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- [Ref-18] Hitachi-GE Nuclear Energy, Ltd., “Electrical Protection and Earthing System Report”,
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- [Ref-19] Hitachi-GE Nuclear Energy, Ltd., “Earthing Specification”,
GR34-1003-0001-00001 (ES-GD-B006), Rev.2, February 2017
- [Ref-20] Hitachi-GE Nuclear Energy, Ltd., “Lightning Protection Specification”,
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- [Ref-21] Hitachi-GE Nuclear Energy, Ltd., “Electrical System Modelling Scoping Report”,
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- [Ref-22] Hitachi-GE Nuclear Energy, Ltd., “Electrical Equipment and Raceway Separation Plan”,
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Appendix A: Safety Functional Claims Table

	Top Claim for EE System					Safety Functional Claims for the EE System and Components (SFC)				
	Fundamental Safety Function (FSF)		High Level Safety Function (HLSF)		Fault Schedule (Bounding Fault)					
	PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		Topic Report on Fault Assessment (UE-GD-0071) Table.4.2-1 Fault Schedule	State	Claim ID	Claim Contents	Cat.	Class
	1	Control of Reactivity	1-1	Functions to prevent excessive reactivity insertion			EPS SFC 1-1	The EPS supports SSCs providing HLSF associated with FSF 1: Control of Reactivity.	A	1
			1-2	Functions to maintain core geometry			EPS SFC 1-2	The EPS supports SSCs providing HLSF associated with FSF 1: Control of Reactivity.	A	1
			1-3	Emergency shutdown of the reactor	1.1, 1.1.1, 1.1.2, 1.2.1, 1.3, 1.3.1.1, 1.4, 1.4.2, 1.5, 1.6.1, 1.7, 1.8, 2.1, 2.1.2, 2.2, 2.3, 3.1, 3.1.1, 4.1, 4.2.3.1, 4.2.4.1, 4.2.5.1, 4.3, 4.4, 4.5, 4.6, 5.1, 5.1.1, 5.2, 5.2.1, 5.3, 5.3.1, 5.3.4, 6.1, 7.1, 8.1, 8.2, 9.2, 9.3, 10.1, 10.2, 11.1, 9.1.1, 9.1.2, 10.3, 11.2, 11.3, 11.8.1, 11.9, 11.10.1, 11.11.1, 11.12.1, 13.1.2, 17.1.1, 17.2.1, 17.3.1, 17.4.1, 17.5.1, 17.6, 18.1.1, 18.2.1, 18.3.1		EPS SFC 1-3	The EPS supports SSCs providing HLSF associated with FSF 1: Control of Reactivity.	A	1
			1-4	Functions to maintain sub-criticality			EPS SFC 1-4	The EPS supports SSCs providing HLSF associated with FSF 1: Control of Reactivity.	A	1
			1-5	Function of alternative reactivity control	1.1, 1.1.1, 1.1.2, 1.2.1,1.2.2, 1.3.1.1, 1.3.1.2, 1.4, 1.4.1, 1.4.2, 1.5, 1.5.1, 1.6.1, 1.6.2, 1.7, 1.8, 2.1, 2.1.1, 2.1.2, 2.2, 2.2.1, 2.3.1, 2.3, 3.1, 3.1.1, 4.2.3.1, 4.2.4.1, 4.2.5.1, 4.4, 4.5, 4.6, 5.1, 5.1.1, 5.1.2, 5.1.3, 5.2, 5.2.1, 5.2.2, 5.2.3, 5.3, 5.3.1, 5.3.2, 5.3.3, 5.3.4, 6.1, 7.1, 7.2, 8.1, 8.2, 9.1.1, 9.1.2, 9.2, 9.3, 10.1, 10.2, 10.3, 10.4, 11.2, 11.3, 11.4.1, 11.5, 11.8.1, 11.9, 11.10.1, 11.11.1, 11.12.1, 17.1.1, 17.2.1, 17.3.1, 17.4.1, 17.5.1, 17.6, 18.1.1, 18.2.1,		EPS SFC 1-5	The EPS supports SSCs providing HLSF associated with FSF 1: Control of Reactivity.	A	2
			1-6	Functions to circulate reactor coolant (functions to control reactivity of the core in normal operational states)			EPS SFC 1-6	The EPS supports SSCs providing HLSF associated with FSF 1: Control of Reactivity.	B	3
			1-7	Functions to plant instrument and control (except for safety protection function) (functions to control reactivity of the core in normal operational states)			EPS SFC 1-7	The EPS supports SSCs providing HLSF associated with FSF 1: Control of Reactivity.	B	3
			1-8	Functions to suppress reactor power increase with other system	1.1, 1.1.1, 1.4, 1.4.1, 1.4.2, 2.3, 4.1, 4.2.1, 4.2.2, 4.2.3.1, 4.2.3.2, 4.5, 11.3, 17.6		EPS SFC 1-8	The EPS supports SSCs providing HLSF associated with FSF 1: Control of Reactivity.	C	3

	Top Claim for EE System						Safety Functional Claims for the EE System and Components (SFC)				
	Fundamental Safety Function (FSF)		High Level Safety Function (HLSF)		Fault Schedule (Bounding Fault)						
	PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		Topic Report on Fault Assessment (UE-GD-0071) Table.4.2-1 Fault Schedule		State	Claim ID	Claim Contents	Cat.	Class
			1-9	Functions to maintain sub-criticality of spent fuel outside the reactor coolant system				EPS SFC 1-9	The EPS supports SSCs providing HLSF associated with FSF 1: Control of Reactivity.	A	1
			1-10	Functions to maintain sub-criticality of spent fuel during processes of spent fuel removal from cask pit to storage area and during interim storage period				EPS SFC 1-10	The EPS supports SSCs providing HLSF associated with FSF 1: Control of Reactivity.	A	1

	Top Claim for EE System						Safety Functional Claims for EE System and Components (SFC)				
	Fundamental Safety Function (FSF)		High Level Safety Function (HLSF)		Fault Schedule (Bounding Fault)						
	PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		Topic Report on Fault Assessment (UE-GD-0071) Table.4.2-1 Fault Schedule		State	Claim ID	Claim Contents	Cat.	Class
		2	Fuel Cooling	2-1	Functions to cool reactor core	1.1, 1.1.1, 1.1.2, 1.2.1, 1.2.2, 1.3, 1.3.1.1, 1.3.1.2, 1.4, 1.4.1, 1.4.2, 1.5, 1.5.1, 1.6.1, 1.6.2, 1.7, 1.8, 2.1, 2.1.1, 2.1.2, 2.2, 2.2.1, 2.3, 2.3.1, 3.1, 3.1.1, 4.2.3.1, 4.2.3.2, 4.2.4.1, 4.2.4.2, 4.2.5.1,4.2.5.2, 4.4, 4.5, 4.6, 5.1, 5.1.1, 5.1.2, 5.1.3, 5.2, 5.2.1, 5.2.2, 5.2.3, 5.3, 5.3.1, 5.3.2, 5.3.3, 5.3.4, 6.1, 7.1, 7.2, 8.1, 8.2, 9.1.1, 9.1.2, 9.2, 9.3, 10.1, 10.2, 10.3, 10.4, 11.1, 11.1.1, 11.2, 11.3, 11.5, 11.8.1, 11.10.1, 17.1.1, 17.2.1, 17.3.1, 17.4.1, 17.4.2.1, 17.4.2.2, 17.4.2.3, 17.4.2.6, 17.5.1, 17.5.2.2, 17.5.2.3, 17.6, 18.1.1, 18.2.1, 18.3.1		EPS SFC 2-1	The EPS supports SSCs providing HLSF associated with FSF 2: Fuel Cooling.	A	1
				2-2	Function of alternative fuel cooling	1.1, 1.1.1, 1.1.2, 1.2.1, 1.2.2, 1.3, 1.3.1.1, 1.3.1.2, 1.4, 1.4.1, 1.4.2, 1.5, 1.5.1, 1.6.1, 1.6.2, 1.7, 1.8, 2.1, 2.1.1, 2.1.2, 2.2, 2.2.1, 2.3, 2.3.1, 3.1, 3.1.1, 4.2.3.1, 4.2.3.2, 4.2.4.1, 4.2.4.2, 4.2.5.1, 4.2.5.2, 4.4, 4.5, 4.6, 5.1, 5.1.1, 5.1.2, 5.1.3, 5.2, 5.2.2, 5.2.3, 5.3, 5.3.2, 5.3.3, 6.1, 7.1, 7.2, 8.1, 8.2, 9.1.2, 9.2, 9.3, 10.1, 10.2, 10.3, 10.4, 11.1, 11.2, 11.3, 11.4.1, 11.5, 11.9, 11.12.1, 17.1.1, 17.2.1, 17.3.1, 17.4.1, 17.5.1, 17.6, 18.1.1, 18.2.1, 18.3.1		EPS SFC 2-2	The EPS supports SSCs providing HLSF associated with FSF 2: Fuel Cooling.	A	2
				2-3	Function to make up reactor coolant with other system			EPS SFC 2-3	The EPS supports SSCs providing HLSF associated with FSF 2: Fuel Cooling.	C	3
				2-4	Function to cool spent fuel outside the reactor coolant system			EPS SFC 2-4	The EPS supports SSCs providing HLSF associated with FSF 2: Fuel Cooling.	A	1
				2-5	Functions to make up water for spent fuel pool			EPS SFC 2-5	The EPS supports SSCs providing HLSF associated with FSF 2: Fuel Cooling.	A	2
				2-6	Functions to maintain spent fuel temperature during processes of spent fuel removal from cask pit to storage area and during interim storage period	SFIS.1.1 Note that this is derived from [Ref-48]		EPS SFC 2-6	The EPS supports SSCs providing HLSF associated with FSF 2: Fuel Cooling.	A	1

	Top Claim for EE System						Safety Functional Claims for EE System and Components (SFC)				
	Fundamental Safety Function (FSF)		High Level Safety Function (HLSF)		Fault Schedule (Bounding Fault)						
	PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		Topic Report on Fault Assessment (UE-GD-0071) Table.4.2-1 Fault Schedule		State	Claim ID	Claim Contents	Cat.	Class
	3	Long term heat removal	3-1	Functions to remove residual heat after shutdown	1.1, 1.1.1, 1.1.2, 1.2.1, 1.2.2, 1.3, 1.3.1.1, 1.3.1.2, 1.4, 1.4.1, 1.4.2, 1.5, 1.5.1, 1.6.1, 1.6.2,1.7, 1.8, 2.1, 2.1.1, 2.2, 2.2.1, 2.3, 2.3.1, 3.1, 3.1.1, 4.2.3.1, 4.2.3.2, 4.2.4.1, 4.2.4.2, 4.2.5.1, 4.2.5.2, 4.4, 4.5, 4.6, 5.1, 5.1.1, 5.1.3, 5.2, 5.3, 6.1, 7.1, 7.2, 8.1, 8.2, 9.1.1, 9.1.2, 9.2, 9.3, 10.1, 10.2, 10.3, 10.4, 11.1, 11.2, 11.3, 17.1.1, 17.2.1, 17.3.1, 17.4.1, 17.5.1, 17.5.2.1, 17.5.2.6, 17.6, 18.1.1, 18.2.1, 18.3.1			EPS SFC 3-1	The EPS supports SSCs providing HLSF associated with FSF 3: Long Term Heat Removal.	A	1
			3-2	Function of alternative containment cooling and decay heat removal				EPS SFC 3-2	The EPS supports SSCs providing HLSF associated with FSF 3: Long Term Heat Removal.	A	2

	Top Claim for EE System						Safety Functional Claims for EE System and Components (SFC)					
	Fundamental Safety Function (FSF)		High Level Safety Function (HLSF)		Fault Schedule (Bounding Fault)							
	PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		Topic Report on Fault Assessment (UE-GD-0071) Table.4.2-1 Fault Schedule		State	Claim ID	Claim Contents	Cat.	Class	
	4	Confinement/ containment of radioactive materials	4-1	Functions to form reactor coolant pressure boundary				EPS SFC 4-1	The EPS supports SSCs providing HLSF associated with FSF 4 Confinement and Containment of radioactive materials.	A	1	
			4-2	Functions to prevent overpressure within the reactor coolant pressure boundary				EPS SFC 4-2	The EPS supports SSCs providing HLSF associated with FSF 4 Confinement and Containment of radioactive materials.	A	1	
			4-3	Functions to contain reactor coolant outside RCPB				EPS SFC 4-3	The EPS supports SSCs providing HLSF associated with FSF 4 Confinement and Containment of radioactive materials.	B	3	
			4-4	Functions to contain radioactive material				EPS SFC 4-4	The EPS supports SSCs providing HLSF associated with FSF 4 Confinement and Containment of radioactive materials.	C	3	
			4-5	Functions to reseal safety valves and relief valves				EPS SFC 4-5	The EPS supports SSCs providing HLSF associated with FSF 4 Confinement and Containment of radioactive materials.	B	3	
			4-6	Functions to mitigate reactor pressure increase with other system (other than No.4-2)				EPS SFC 4-6	The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.	C	3	
			4-7	Functions to confine radioactive materials, shield radiation, and reduce radioactive release	1.1.1, 1.4.1, 1.5.1, 2.1, 2.1.1, 2.1.2,2.2, 2.2.1, 2.3, 2.3.1, 3.1, 3.1.1, 4.6, 5.1, 5.1.1, 5.1.3, 5.2.1, 5.3.1, 5.3.4, 7.1, 8.1, 8.2, 9.1.1, 9.1.2, 9.2, 9.3, 10.1, 10.2, 10.3, 11.2, 11.8.1, 11.9, 13.7.1, 13.7.2, 13.7.6, 17.6, 18.2.1, 18.3.1, 15.1.1, 15.1.2, 15.1.3, 16.4, 18.1.1, 13.3.1, 13.3.2, 13.3.6, 13.5.1.1, 13.5.2.1, 13.5.2.2, 13.5.2.6, 13.5.2.7, 13.5.3.1, 13.5.3.2, 13.5.3.6, 13.8.1.1, 13.8.1.2, 13.8.1.6, 13.8.2.1, 13.8.2.2, 13.8.2.6, 13.9.1, 13.9.2, 13.9.6, 13.10.1, 13.10.2, 13.10.6, 13.11.1, 13.11.2, 13.11.6, 13.12.1, 13.12.2, 13.17.1, 13.17.2, 13.17.6, 13.18.1, 13.18.2, 13.18.6, 15.1.1, 15.1.2, 15.1.3, 17.1.2.1, 17.1.2.2, 17.1.2.6, 17.2.2.1, 17.2.2.2, 17.2.2.6, 17.3.2.1, 17.3.2.2, 17.3.2.6, 17.4.2.1, 17.4.2.2, 17.4.2.6, 17.5.2.1, 17.5.2.2, 17.5.2.6			EPS SFC 4-7	The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.	A	1	
			4-8	Functions to minimize the release of radioactive gases	15.1.1, 15.1.2			EPS SFC 4-8	The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.	A	2	
			4-9	Functions to contain radioactive materials in the event of a severe accident				EPS SFC 4-9	The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.	B	2	
			4-10	Functions to prevent the dispersion of fission products into reactor coolant, spent fuel pool and canister				EPS SFC 4-10	The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.	C	3	

	Top Claim for EE System						Safety Functional Claims for EE System and Components (SFC)				
	Fundamental Safety Function (FSF)		High Level Safety Function (HLSF)		Fault Schedule (Bounding Fault)						
	PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		Topic Report on Fault Assessment (UE-GD-0071) Table.4.2-1 Fault Schedule		State	Claim ID	Claim Contents	Cat.	Class
			4-11	Functions to store the radioactive materials as gaseous waste	15.1.3			EPS SFC 4-11	The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.	B	2
			4-12	Functions to store the radioactive materials as liquid wastes				EPS SFC 4-12	The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.	C	3
			4-13	Functions to store the radioactive materials as solid wastes				EPS SFC 4-13	The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.	C	3
			4-14	Functions to provide containment barrier during processes of spent fuel removal from cask pit to storage area and during interim storage period				EPS SFC 4-14	The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.	A	1
			4-15	Unused Number							
			4-16	Functions to provide radiation shield during processes of spent fuel removal from cask pit to storage area and during interim storage period				EPS SFC 4-16	The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.	A	1
			4-17	Functions to maintain PCV atmosphere in an inert state for preventing hydrogen combustion				EPS SFC 4-17	The EPS supports SSCs providing HLSF associated with FSF 4: Confinement and Containment of Radioactive Materials.	B	3

	Top Claim for EE System						Safety Functional Claims for EE System and Components (SFC)				
	Fundamental Safety Function (FSF)		High Level Safety Function (HLSF)		Fault Schedule (Bounding Fault)						
	PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		Topic Report on Fault Assessment (UE-GD-0071) Table.4.2-1 Fault Schedule		State	Claim ID	Claim Contents	Cat.	Class
	5	Others	5-1	Functions to generate actuation signals for the engineered safety features and reactor shutdown systems				EPS SFC 5-1	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	A	1
			5-2	Supporting functions especially important to safety	5.1, 5.1.2, 5.1.3, 5.2, 5.2.3, 5.3, 5.3.2, 5.3.3, 7.1, 8.1, 8.2, 9.1.1, 9.1.2, 9.2, 9.3, 10.1, 10.2,10.3, 5.2.2, 13.5.1.1, 13.5.1.7, 13.5.2.3, 13.5.2.4, 13.5.2.5, 13.5.1.2, 13.5.1.3, 13.5.1.4, 13.5.1.5, 13.5.1.6, 13.5.2.1, 13.5.2.2, 13.5.2.6, 13.5.2.7, 13.5.3.1, 13.5.3.2, 13.5.3.3, 13.5.3.4,13.5.3.5, 13.5.3.6, 17.1.1, 17.1.2.1, 17.1.2.2, 17.1.2.3, 17.1.2.4, 17.1.2.5, 17.1.2.6, 17.2.1, 17.2.2.1, 17.2.2.2, 17.2.2.3, 17.2.2.4, 17.2.2.5, 17.2.2.6, 17.3.1, 17.3.2.1, 17.3.2.2, 17.3.2.3, 17.3.2.4, 17.3.2.5, 17.3.2.6, 17.4.1, 17.4.2.1, 17.4.2.2, 17.4.2.3, 17.4.2.4, 17.4.2.5, 17.4.2.6, 17.5.1, 17.5.2.1, 17.5.2.2, 17.5.2.3, 17.5.2.4, 17.5.2.5, 17.5.2.6, 18.1.1,18.1.2.1, 18.1.2.2, 18.1.2.3, 18.1.2.4, 18.1.2.5, 18.1.2.6, 18.2.1, 18.2.2.1, 18.2.2.2, 18.2.2.3, 18.2.2.4, 18.2.2.5, 18.2.2.6, 18.3.1, 18.3.2.1, 18.3.2.2, 18.3.2.3, 18.3.2.4, 18.3.2.5, 18.3.2.6			EPS SFC 5-2	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	A	1

	Top Claim for EE System						Safety Functional Claims for EE System and Components (SFC)				
	Fundamental Safety Function (FSF)		High Level Safety Function (HLSF)		Fault Schedule (Bounding Fault)						
	PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		Topic Report on Fault Assessment (UE-GD-0071) Table.4.2-1 Fault Schedule		State	Claim ID	Claim Contents	Cat.	Class
			5-3	Function of alternative supporting system	5.1, 5.1.1, 5.1.2, 5.1.3, 5.2, 5.2.1, 5.2.2, 5.2.3, 5.3, 5.3.1, 5.3.2, 5.3.3, 7.1, 8.1, 8.2, 9.1.1, 9.1.2, 9.2, 9.3, 10.1, 10.2, 10.3, 11.8.1, 11.8.2.1, 11.8.2.2 11.8.2.3, 11.8.2.4, 11.8.2.5, 11.8.2.6, 13.5.1.1, 13.5.1.2, 13.5.1.3, 13.5.1.4, 13.5.1.5, 13.5.1.6, 13.5.1.7, 13.5.2.1, 13.5.2.2, 13.5.2.3, 13.5.2.4, 13.5.2.5, 13.5.2.6, 13.5.2.7, 13.5.3.1, 13.5.3.2, 13.5.3.3, 13.5.3.4, 13.5.3.5, 13.5.3.6, 13.6.1.1, 13.6.1.2, 13.6.1.3, 13.6.1.4, 13.6.1.5, 13.6.1.6, 13.6.2.1, 13.6.2.2, 13.6.2.3, 13.6.2.4, 13.6.2.5, 13.6.2.6, 13.6.3.1, 13.6.3.2, 13.6.3.3, 13.6.3.4, 13.6.3.5, 17.1.1, 17.1.2.1, 17.1.2.2, 17.1.2.3, 17.1.2.4, 17.1.2.5, 17.1.2.6, 17.2.1, 17.2.2.1, 17.2.2.2, 17.2.2.3, 17.2.2.4, 17.2.2.5, 17.2.2.6, 17.3.1, 17.3.2.1, 17.3.2.2, 17.3.2.3, 17.3.2.4, 17.3.2.5, 17.3.2.6, 17.4.1, 17.4.2.1, 17.4.2.2, 17.4.2.3, 17.4.2.4, 17.4.2.5, 17.4.2.6, 17.5.1, 17.5.2.1, 17.5.2.2, 17.5.2.3, 17.5.2.4, 17.5.2.5, 17.5.2.6, 18.1.2.1, 18.1.2.2, 18.1.2.3, 18.1.2.4, 18.1.2.5, 18.1.2.6, 18.2.1, 18.2.2.1, 18.2.2.2, 18.2.2.3, 18.2.2.4, 18.2.2.5, 18.2.2.6, 18.3.1, 18.3.2.1, 18.3.2.2, 18.3.2.3, 18.3.2.4, 18.3.2.5, 18.3.2.6			EPS SFC 5-3	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	A	2
			5-4	Monitoring functions of plant conditions to support operator actions	15.1.1, 15.1.2, 15.1.3, 15.2, 15.3, 15.4, 15.5, 16.1, 16.2.1, 16.2.2, 16.4			EPS SFC 5-4	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	B	2
			5-5	Functions to shut down safely from outside the control room				EPS SFC 5-5	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	A	1
			5-6	Functions to handle fuel and heavy equipment safely				EPS SFC 5-6	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	A	1
			5-7	Functions to limit the effect of hazard				EPS SFC 5-7	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	A	1
			5-8	Functions to clean up reactor coolant				EPS SFC 5-8	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	C	3
			5-9	Functions to clean up water except for reactor coolant				EPS SFC 5-9	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	C	3
			5-10	Functions to supply electric power (except for emergency supply)				EPS SFC 5-10	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	B	3

	Top Claim for EE System					Safety Functional Claims for EE System and Components (SFC)				
	Fundamental Safety Function (FSF)		High Level Safety Function (HLSF)		Fault Schedule (Bounding Fault)					
	PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		PCSR Ch.5 Section 6 Table 5.6-1: High Level Safety Functions in UK ABWR		Topic Report on Fault Assessment (UE-GD-0071) Table.4.2-1 Fault Schedule	State	Claim ID	Claim Contents	Cat.	Class
			5-11	Supporting functions to supply power (except for emergency supply)			EPS SFC 5-11	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	B	3
			5-12	Supporting functions for management of normal operation			EPS SFC 5-12	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	---	3
			5-13	Auxiliary functions for plant operation			EPS SFC 5-13	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	C	3
			5-14	Supporting functions or on-site emergency preparedness			EPS SFC 5-14	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	C	3
			5-15	Functions to control hydrogen concentration in fault conditions			EPS SFC 5-15	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	B	2
			5-16	Functions to provide handling and retrievability during processes of spent fuel removal from cask pit to storage area and during interim storage period			EPS SFC 5-16	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	A	1
			5-17	Function to provide structural support to SSCs			EPS SFC 5-17	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	A	1
			5-18	Function to maintain internal building environment appropriate for SSCs	7.1 , 8.1, 8.2, 9.1.1, 9.1.2, 9.2, 9.3, 10.1, 10.2, 10.3		EPS SFC 5-18	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	A	1
			5-19	Monitoring functions of radioactive discharge to the environment	16.3		EPS SFC 5-19	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	C	3
			5-20	Functions to maintain availability of CRs hydraulic insertion function and to recover CRs to normal unlatched state after rapid insertion			EPS SFC 5-20	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	C	3
			5-21	Function to retain water for provision of radiation shield during the refuelling process			EPS SFC 5-21	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	B	2
			5-22	Function to limit deceleration loading to canister containment boundary during credible cask drop faults			EPS SFC 5-22	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	A	1
			5-23	Monitoring functions of occupational and public radiation exposures	15.3, 15.5, 16.2.1, 16.2.2, 16.4, 16.5, 16.6		EPS SFC 5-23	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	C	3
			5-24	Functions to limit worker access into high dose area			EPS SFC 5-24	The EPS supports SSCs providing HLSF associated with FSF 5: Others.	*	*

(*) Safety category and class will be developed at the site specific stage.

Appendix B: Safety Properties Claims Table

	SPC	Safety Properties Claims (SPC) Contents	SCDM SPC Guide word
1	SPC EPS 1	Classification, independence, redundancy and single failure criterion requirements placed on the SSCs is applied to the design of the EPS and associated support systems including C&I, HVAC and cooling systems.	<ul style="list-style-type: none"> • Fault Tolerance • Reliability
2	SPC EPS 2	The EPS will support the safety functions with the required integrity for frequent faults, infrequent faults, beyond design basis faults and severe accidents.	<ul style="list-style-type: none"> • Defence in Depth • Human Factors
3	SPC EPS 3	The EPS is designed to protect against common cause failure (CCF).	<ul style="list-style-type: none"> • Defence in Depth • Reliability
4	SPC EPS 4	The EPS will be designed to withstand internal hazards.	<ul style="list-style-type: none"> • Fault Tolerance • Reliability
5	SPC EPS 5	The EPS will be designed to withstand external hazards.	<ul style="list-style-type: none"> • Fault Tolerance • Reliability
6	SPC EPS 6	The EPS will continue to meet its functional safety requirements throughout its operational life.	<ul style="list-style-type: none"> • Life Cycle • Reliability
7	SPC EPS 7	EPS SSCs are designed to achieve adequate performance in accordance with the safety requirements including reliability, response time and ratings.	<ul style="list-style-type: none"> • Reliability
8	SPC EPS 8	The design, development and implementation of EPS SSCs complies with standards and good practice set by their classification and the EPS SSCs role in the overall power system architecture.	<ul style="list-style-type: none"> • Relevant Good Practice

The safety properties claims table of each system is provided in the following tables.

SPC Table of Systems in Chapter 15

SSCs	Safety Cat. & Class	EPS SPC1	EPS SPC2	EPS SPC3	EPS SPC4	EPS SPC5	EPS SPC6	EPS SPC7	EPS SPC8
		Redundancy, Independence	Defence in Depth	CCF	Internal Hazards	External Hazards	Operational Life	Reliability	Relevant Good Practice
Safety Class 1 AC Bus	A1	X	X	X	X	X	X	X	X
Safety Class 3 AC Bus	B3				X	X	X	X	X
B/B Class 2 Bus	A2	X	X	X	X	X	X	X	X
Safety Class 1 EDG	A1	X	X	X	X	X	X	X	X
B/B Class 2 BBG	A2	X	X	X	X	X	X	X	X
Safety Class 3 DAG	B3		X	X	X	X	X	X	X
Safety Class 1 DC	A1	X	X	X	X	X	X	X	X
Safety Class 2 DC	B2				X	X	X	X	X
Non-safety Class DC	---				X	X	X		X
B/B Class 2 DC	A2	X	X	X	X	X	X	X	X
Safety Class 1 AC C&I	A1	X	X	X	X	X	X	X	X
Safety Class 2 AC C&I	B2				X	X	X	X	X
Safety Class 3 AC C&I	C3				X	X	X	X	X
B/B Class 2 AC C&I	A2	X	X	X	X	X	X	X	X
Safety Class 1 UPS	A1	X	X		X	X	X	X	X
Safety Class 3 UPS	C3				X	X	X	X	X

Appendix C: Document Map

