Revision	Approved by	Number of Pages
000	[signature]	35
Approval Date	26/10-17	

General Nuclear System Ltd.

UK HPR1000 GDA Project

Document Reference:	HPR/GDA/PSR/0009

Preliminary Safety Report

Chapter 9

Electric Power

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SENSITIVE INFORMATION RECORD

Section Number	Section Title	Page	Content	Category

Table of Contents

9.1 List of Abbreviations and Acronyms

AC	Alternating Current
AT	Auxiliary Transformer
BDA	Emergency Diesel Generator Building A
BDB	Emergency Diesel Generator Building B
BDC	Emergency Diesel Generator Building C
BDU	SBO Diesel Generator Building for Train A
BDV	SBO Diesel Generator Building for Train B
BOP	Balance of Plant
BSA	Safeguard Building A
BSB	Safeguard Building B
BSC	Safeguard Building C
CCF	Common Cause Failure
CI	Conventional Island
DBC	Design Basis Condition
DC	Direct Current
DCS	Digital Control System
EDG	Emergency Diesel Generator
EJ	Chinese Standards for Nuclear Industry
EOMM	Equipment Operation and Maintenance Manuals
FCG Unit 3	Fangchenggang Nuclear Power Plant Unit 3
GB	Chinese National Standards
GCB	Generator Circuit Breaker
GDS	Generator Disconnecting Switch
HPR1000 (FCG3)	Hua-long Pressurized Reactor under construction at Fangchenggang nuclear power plant unit 3
LAA	NI 220V DC Power Supply and Distribution System (2h) [NI-DCPS (220V-2h)]
LAB	NI 220V DC Power Supply and Distribution System (2h) [NI-DCPS

	(220V-2h)]
LAC	NI 220V DC Power Supply and Distribution System (2h) [NI-DCPS (220V-2h)]
LAD	NI 220V DC Power Supply and Distribution System (2h) [NI-DCPS (220V-2h)]
LAM	CI 220V DC Power Supply and Distribution System (2h) [CI-DCPS(220V-2h)]
LAN	CI 220V DC Power Supply and Distribution System (2h) [CI-DCPS(220V-2h)]
LAP	NI 220V DC Power Supply and Distribution System (12h) [NI-DCPS (220V-12h)]
LAQ	NI 220V DC Power Supply and Distribution System (12h) [NI-DCPS (220V-12h)]
LAR	CI 220V DC Power Supply and Distribution System [CI-DCPS(220V)]
LGA	CI 10kV Normal Power Distribution System [CI-NPDS(10kV)]
LGB	CI 10kV Normal Power Distribution System [CI-NPDS(10kV)]
LGC	CI 10kV Normal Power Distribution System [CI-NPDS(10kV)]
LGD	CI 10kV Normal Power Distribution System [CI-NPDS(10kV)]
LGE	CI 10kV Normal Power Distribution System [CI-NPDS(10kV)]
LGF	CI 10kV Normal Power Distribution System [CI-NPDS(10kV)]
LGG	CI 10kV Normal Power Distribution System [CI-NPDS(10kV)]
LGH	CI 10kV Normal Power Distribution System [CI-NPDS(10kV)]
LGIA	BOP 10kV Normal Power Distribution System [BOP-NPDS(10kV)]
LGIB	BOP 10kV Normal Power Distribution System [BOP-NPDS(10kV)]
LGM	NI 10kV Normal Power Distribution System [NI-NPDS(10kV)]
LGN	NI 10kV Normal Power Distribution System [NI-NPDS(10kV)]
LGO	NI 10kV Normal Power Distribution System [NI-NPDS(10kV)]
LGP	NI 10kV Normal Power Distribution System [NI-NPDS(10kV)]
LGQ	NI 10kV Normal Power Distribution System [NI-NPDS(10kV)]
LHA	NI 10kV Emergency Power Distribution System [EPDS(NI-10kV)]

LHB	NI 10kV Emergency Power Distribution System [EPDS(NI-10kV)]
LHC	NI 10kV Emergency Power Distribution System [EPDS(NI-10kV)]
LHM	NI 10kV SBO Power Distribution System [SBOPDS(NI-10kV)]
LHN	NI 10kV SBO Power Distribution System [SBOPDS(NI-10kV)]
LHT	NI 10kV SBO Power Distribution System [SBOPDS(NI-10kV)]
LHW	NI 10kV SBO Power Distribution System [SBOPDS(NI-10kV)]
LKK	CI 380V Normal Power Distribution System [CI-NPDS(380V)]
LKL	CI 380V Normal Power Distribution System [CI-NPDS(380V)]
LKN	CI 380V Normal Power Distribution System [CI-NPDS(380V)]
LLA	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLB	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLC	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLD	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLE	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLF	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLG	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLH	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLI	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLJ	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLK	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLM	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLN	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLP	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLS	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLT	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LLV	NI 380V Emergency Power Distribution System [EPDS(NI-380V)]
LOA	NI 380V AC Regulated Power System [ACRPS(NI-380V)]
LOB	NI 380V AC Regulated Power System [ACRPS(NI-380V)]

LOC	NI 380V AC Regulated Power System [ACRPS(NI-380V)]
LOD	NI 380V AC Regulated Power System [ACRPS(NI-380V)]
LOE	NI 380V AC Regulated Power System [ACRPS(NI-380V)]
LOF	NI 380V AC Regulated Power System [ACRPS(NI-380V)]
LOOP	Loss of Offsite Power
LVA	NI 380V AC Uninterruptible Power System [NI-UPS(380V-2h)]
LVB	NI 380V AC Uninterruptible Power System [NI-UPS(380V-2h)]
LVC	NI 380V AC Uninterruptible Power System [NI-UPS(380V-2h)]
LVD	NI 220V AC Uninterruptible Power System [NI-UPS(220V-2h)]
LVM	CI 380V AC Uninterruptible Power System [CI-UPS(380V-2h)]
LVN	CI 380V AC Uninterruptible Power System [CI-UPS(380V-2h)]
LVP	NI 380V AC Uninterruptible Power System [NI-UPS(380V-12h)]
LVQ	NI 380V AC Uninterruptible Power System [NI-UPS(380V-12h)]
MCR	Main Control Room
NB	Chinese Energy Standard
NI	Nuclear Island
NNSA	National Nuclear Safety Administration
RPS	Reactor Protection System
SBO	Station Black Out
SSCs	Structures, Systems and Components
SSE	Safe Shutdown Earthquake
ST	Standby Transformer
UK HPR1000	The UK version of the Hua-long Pressurized Reactor
UPS	Uninterruptible Power Supply
UT	Unit Transformer

System codes (XXX) and system abbreviations (YYY) are provided for completeness in the format (XXX [YYY]), e.g. NI 220V DC Power Supply and Distribution System (2h) (LAA [NI-DCPS (220V-2h)]).

9.2 Introduction

This chapter supports the following high level objective: the design and intended construction and operation of The UK version of the Hua-long Pressurized Reactor (UK HPR1000) will protect the public by providing multiple levels of defence to fulfil the fundamental safety functions (reactivity control, fuel cooling and confinement of radioactive material).

This chapter demonstrates that the electrical power systems support the Structures, Systems and Components (SSCs) in performing their required duties, Reference [1]. The electrical power systems that supply power to systems important to safety are essential to the safety of nuclear power plants. These electrical power systems include both on-site and off-site electrical power systems. The on-site electrical power systems and off-site electrical power systems work together to provide necessary power in all plant conditions so that the plant can be maintained in a safe state. Although the external grid does not belong to the nuclear power plant, it plays a significant role in providing defence in depth to faults and is essential to the safety of the nuclear power plant. In the on-site electrical power systems, the function of the emergency power system is to provide necessary power to nuclear power plant under all related operating conditions within the design basis, especially during the period of loss of off-site power supply (grid), so as to maintain the power plant in safe state after postulated initiating events. The emergency power system can also take effect under some operating conditions beyond the design basis, Reference [2]. The Emergency Diesel Generators (EDGs) provide back-up supplies to the essential loads for accident conditions and there are defence-in-depth provisions that include Station Black Out (SBO) diesel generators to address SBO conditions and mobile diesel generators for accident management.

However, the design for the UK HPR1000 for the GDA has not yet been declared and consequently no detailed UK HPR1000 design information is available at this time. The design will be based on the version of the Hualong Pressurized Reactor under construction at Fangchenggang nuclear power plant Unit 3 (HPR1000 (FCG3)), as discussed in Chapter 1. Therefore this Chapter provides a summary of the systems included in the HPR1000 (FCG3) design that will form the basis of the UK HPR1000 design, with potential gap analysis between HPR1000 (FCG3) and UK HPR1000.

Sub-chapter 9.3 describes the safety principles applied to the electrical power system design including design policies and guidelines.

Sub-chapter 9.4 describes the architecture of electric power. It provides a general description of the Plant Auxiliary Electrical System Wiring Diagram and the Single Line Diagram for Nuclear Island (NI), Conventional Island (CI), Direct Current (DC) and Uninterruptible Power Supply (UPS).

Sub-chapter 9.5 describes a generic off-site electrical power scheme, covering the architecture and the function of off-site electrical power systems.

Sub-chapter 9.6 describes the on-site electrical power systems. It provides a general description of the Alternating Current (AC) electrical power systems and the DC electrical power systems.

Sub-chapter 9.7 describes the relevant SAPs review and potential gap analysis between the HPR1000 (FCG3) and the UK HP1000 in the area of electrical power systems.

9.3 Safety Principles

9.3.1 Safety Requirements

9.3.1.1 Safety Functions

The power supply to the NI supports the fulfilment of the three fundamental safety functions.

It enables the functioning of the safety equipment for:

a) Reactivity control,

b) Removal of residual heat,

c) Confinement of radioactive substances.

9.3.1.2 Safety Functional Requirements

The on-site electrical power systems in the plant ensure that reliable power can be provided to the equipment that performs the above safety functions during both the normal operation of the units and in the event of accidents.

a) The generator set can be tripped in the event of the turbine unit tripping, or the reactor tripping, or an electrical fault of the main generator. In such cases, the plant will be fed by the off-site main power supply.

b) The electrical system operational mode is such that in the event of failure of the off-site main power supply, automatic switchover occurs to allow power to be fed from the generator to supply the reactor unit house load.

c) The electrical power systems will be automatically switched to supplies from the Standby Transformer (ST) in the event of a failure of the off-site main power connection or Auxiliary Transformers (ATs).

d) The EDGs provide power to the on-site emergency distribution system in the event of Loss of Offsite Power (LOOP).

e) In the event of SBO, the SBO diesel generators provide power to specific loads, Reference [3].

f) The mobile diesel generator should be the backup power supply in the event of a failure of the SBO diesel generators.

g) The 2-hour battery backed DC and AC uninterruptible power supply can continuously provide power for 2 hours in the event of a design basis accident or a complicated accident relevant to SBO.

h) The 12-hour battery backed DC and AC uninterruptible power supply ensures a continuous power supply for 12 hours in the event of a long term SBO and severe accident relevant to a long term SBO.

i) The emergency power distribution system should be capable of keeping reliable operation in the event of external and internal hazards which are properly assessed (for detailed information on external and internal hazards, please refer to chapter 18 and chapter 19).

The safety power systems shall be designed to assure that no design basis events cause the following, Reference [4]:

a) A loss of electric power to a number of engineered safety features, surveillance devices, or protection system devices so that a required safety function cannot be performed;

b) A loss of electric power to equipment that could result in a reactor transient capable of causing significant damage to the fuel cladding or to the reactor coolant pressure boundary.

The safety equipment is required to meet the single-failure criterion, Reference [5]. The emergency distribution system should match the required redundancy level of the safety equipment, so that the execution of the safety functions will not be affected in the event of a single failure of the electrical equipment.

9.3.1.3 Additional Non-safety Functional Requirements

There are two sets of battery backed DC and AC uninterruptible power supply in the CI electrical building, which are used to supply non-safety equipment in the CI and the NI.

The common services equipment is powered by either the auxiliary or standby electrical power supply. In a two-reactor unit power plant, the common services are shared between the two power units and electricity is supplied from both of the reactor units' 10kV auxiliary or standby electrical power supplies.

9.3.1.4 Electrical Protection

The main generator and related transformer protection system provide protection for generator and power transmission system equipment against electrical and non-electrical faults, and isolate faulty part from the system with delay as short as possible in order to ensure safe protection and minimize damages. Generator differential protection, stator earth fault protection, rotor earth fault protection, generator negative current protection, loss of field protection, reverse power protection and some other protection are provided for the generator. Transformer differential protection, over current protection, over field protection and some other protection are designed for Unit Transformer (UT) and ATs.

Protection of the on-site electrical power distribution system detects different kinds of faults and isolates them as quickly as possible in order to limit the effects on the equipment. Differential protection, over current protection, over load protection, earth fault protection and under voltage protection is designed for different loops.

9.3.1.5 Requirements Related to Examination, Maintenance and Testing

The safety equipment of the on-site AC systems should meet the requirements for periodic testing to demonstrate the availability of the equipment and system. Outline information is provided for the applicable electrical systems in this chapter.

9.3.1.6 Fire Protection for Electrical System

Fire protection of electrical equipment has been taken into consideration, and further information will be provided in next stage report.

9.3.2 Diversity

Consideration is already given to Common Cause Failures (CCF) at the generic design stage, such as CCF between SBO diesel generators and EDGs. The main CCF between the EDGs and SBO diesel generators are analysed and identified. EDG and SBO diesel generator have different capacity and are set in totally separated rooms, taking into account diversity. In the meanwhile EDGs and SBO diesel generators are from different suppliers. EDGs and SBO diesel generators are described in 9.6.2.3.2 and 9.6.2.3.3.

In addition, the mobile diesel generator is provided as supplement of power diversity.

9.3.3 Isolation Principles

This section is to specify the electrical equipment separation rules, for electrical defects or electrical disturbances only:

Classified electrical equipment and distribution system should have physical separation, segregation and electrical isolation, and be arranged in different trains, Reference [6].

Classified and non-classified electrical equipment and distribution system from the same train should have electrical isolation.

EDGs and SBO diesel generators have implemented physical isolation, and they are arranged in different buildings respectively.

9.4 Architecture

HPR1000 (FCG3) unit is a 1000MWe pressurized water reactor, which is connected to the external grid after voltage step-up by UT. Generator Circuit Breaker (GCB) is provided between the generator and the UT. The GCB will be tripped to isolate the defective elements in the event of an internal failure within the UT or AT to prevent damage to the generator.

The main connection and standby connection are from different or relatively independent external grids. When the AT is out of service, the standby connection continuously powers the nuclear power plant, and the permanent switchboard (including the common switchboard) and the emergency switchboard.

The on-site electrical power system provides power to loads according to their power, voltage quality and reliability requirements. The voltage levels are adopted as follows:

a) 10 kV AC for motors with rated power≥200kW.

b) 380V/220V AC for motors, valves actuators, lighting systems, etc. with rated power＜200kW.

c) 220V DC for I&C equipment, switchgear, Main Control Room (MCR) lighting etc.

d) 380V/220V AC UPS for I&C equipment, switchgear, valve actuators etc.

The on-site distribution system consists of the CI distribution system and NI distribution system. The on-site distribution system is designed to distribute power from the off-site main power supply or auxiliary power supply to all plant loads, and is also intended to distribute power from the EDGs and battery to relevant loads. The on-site distribution system can be classified into the following types based on load types, Reference [7]:

a) Normal Distribution System

The system includes:

1) Unit Distribution System

The unit distribution system supplies power to equipment required for normal operation of the units, which should be out of service following the shutdown of the units. The system provides power through the preferred power supply (via the AT). The function class of the system is defined as NC, which denotes ‘non-classified’ as described in sub-chapter 4.7.3.

2) Permanent Distribution System

The permanent distribution system is intended to distribute power to the equipment that should remain in operation following normal shutdown of the unit, or reactor shutdown due to accidents. The switchboard can be powered by the off-site main power supply or auxiliary power supply. In the event of a failure of the main connection, the switchboard will be powered by the auxiliary power supply after automatic switch-over. The safety level of the system is NC.

3) The Common Services Distribution System

The common services distribution system is not used exclusively for a certain unit. The system is allowed to be in operation after the shutdown of a reactor unit and is intended to power the sub-loads of Balance of Plant (BOP) related to the unit. The common services distribution system is powered by the medium-voltage switchboard for permanent distribution system of the two units. The safety level of the system is NC.

For further information of the normal distribution system, please refer to sub-chapter 9.6.1.

b) Emergency Distribution System

The emergency distribution system is designed to ensure power distribution to the equipment required for nuclear safety and to the main equipment needed for safe operation, including safety equipment and auxiliaries, as well as non-safety equipment of the unit requiring emergency power, Reference [8].

The on-site emergency power supply is provided in the event of a loss of the two off-site power supplies. Emergency AC power supply includes the EDGs, SBO diesel generators and mobile diesel generator. The emergency DC loads and uninterruptible AC loads are powered by batteries. The safety level of the EDGs is FC1, and the safety level of SBO diesel generators is FC3, while NC for the mobile diesel generator.

For further information of the emergency distribution system, please refer to sub-chapter 9.6.2.

This section will consist of Functional Diagram(s) of the system:

a) Plant Auxiliary Electrical System Wiring Diagram

Please refer to Appendix F-9.4-1 for more details.

b) Single Line Diagram of Conventional Island DC and UPS

Please refer to Appendix F-9.4-2 for more details.

c) Single Line Diagram of Nuclear Island DC and UPS

Please refer to Appendix F-9.4-3 for more details.

d) Single Line Diagram of Rod Control Power

Please refer to Appendix F-9.4-4 for more details.

9.5 Off-site Electrical Power System

9.5.1 General Description

The HPR1000 (FCG3) unit is connected to the external grid through a main connection and a standby connection.

For the normal operation, the electric power generated by the unit is transmitted to the external grid through the main connection. The main connection provides reliable power to the plant auxiliaries through two ATs during start-up, normal shutdown phase or Design Basis Conditions (DBCs).

The standby connection serves as a standby power supply to the main connection. When the main connection is unavailable due to maintenance or a fault condition, the automatic switchover between the main connection and standby connection will take place to ensure the continuous power supply to the medium voltage bus.

These two connections are used as preferred power supply to the nuclear power plant, Reference [9].

They will not directly perform the safety function but play an important role in ensuring continuity of electrical power supplies.

9.5.2 Main Connection

In order to clearly depict these two connections, a functional diagram is listed in sub-chapter 9.5.4.

The main connection refers to the circuit from the generator to the external grid via UT and high voltage switchgear. The GCB is installed between the main generator and the UT, and within the GCB, there is a Generator Disconnecting Switch (GDS) on the UT side, which can be used to isolate the external grid during maintenance.

A branch circuit with two ATs is connected in the circuit between the GCB and the UT. In normal operation, GCB will stay closed and the plant auxiliaries will be supplied by the main generator. When GCB is open (tripped), the plant auxiliaries can be supplied from the external grid through the UT and the ATs.

9.5.3 Standby Connection

The standby connection refers to the circuit from the ST to the external grid. It is designed to be the second external power supply to the nuclear power plant. Therefore, it should have as much independence as possible from the main connection in its transmission route and the upstream power source.

9.5.4 Functional Diagram

Please refer to Appendix F-9.5-1(Principle Electrical Diagram) for more details.

9.6 On-site Electrical Power System

9.6.1 Normal Distribution System

The normal distribution system includes the unit distribution system, the permanent distribution system and the common services distribution system.

9.6.1.1 Design Basis

The normal distribution system performs NC functions.

9.6.1.2 System Description and Operation

The normal distribution system consists of the 10kV distribution systems, transformers and the 380V low-voltage distribution systems.

9.6.1.3 Main Equipment

a) 10kV switchgear,

b) 380V switchgear,

c) Distribution transformer.

9.6.1.4 System Layout

The medium-voltage distribution devices of the NI are installed in NI safety buildings Safeguard Building A (BSA), Safeguard Building B (BSB) and Safeguard Building C (BSC) respectively, and are isolated from the emergency switchboard equipment.

The medium-voltage distribution devices of the CI are installed in the electrical building of the CI.

9.6.1.5 Description of System I&C

The I&C equipment related to the medium-voltage distribution system provides the local and remote control rooms with signals regarding switch position, load current, bus-bar voltage and possible faults. Protection relays are provided for switchboard protection.

9.6.2 Emergency Distribution System

9.6.2.1 Design Basis

The emergency distribution system provides the power supply to the loads which are needed to deliver the engineered safety features intended to mitigate accidents. The functions of the system should be FC1, or FC3.

9.6.2.2 System Description and Operation

During normal operation, the emergency distribution system is powered by the permanent systems, which are medium-voltage distribution boards. In the event of LOOP, the power supply will be automatically switched to the diesel generators, which are engineered power supplies intended to mitigate accidents.

9.6.2.3 Main Equipment

9.6.2.3.1 Switchgear

a) Operational Functions and Composition

Under emergency conditions, safety equipment is powered by three independent power distribution trains.

In the event of failures of all off-site power, the three emergency power distribution trains are powered by the corresponding EDG. Each emergency power distribution train should be designed so that it can ensure safe shutdown of the reactor unit.

b) System Layout

1) NI medium-voltage distribution (10kV AC)

The three trains of the medium-voltage distribution system for the NI are installed in the safety buildings of the NI (BSA, BSB and BSC). The equipment in the different trains is physically separated from each other.

2) NI low-voltage distribution (380V AC)

Three trains of low-voltage distribution boards for the NI are installed in the safety buildings of the NI (BSA/BSB and BSC). They are installed together with the medium-voltage distribution devices of the same supply train. The 380V distribution boards of the three supply trains (A, B and C) are physically separated from each other.

The NI equipment rooms are designed to be capable of withstanding internal hazards, external missiles and damage from earthquakes.

c) Description of System I&C

The emergency medium-voltage distribution switchboard is provided with voltage relays for under voltage detection. The EDGs will be automatically started when under voltage of the switchboard is detected. In this case, the power supply of the switchboard will be switched to the EDGs.

In the event of a SBO accident, the operator in the MCR should manually transfer the power supply through a control switch.

The low-voltage distribution system is provided with voltage relays to provide under voltage detection, which will send out under voltage alarm.

d) Preliminary Design Substantiation

1) Compliance with Safety Functional Requirements

The classifications of safety and quality assurance of the emergency distribution system are presented as follows:

T-9.6-1 Electrical System Design Requirements

Function Classification	Item Function Classification	Single Failure Criteria	Seismic Classification
FC1	F-SC1	Yes	SSE1
FC3	F-SC3	No	SSE1

The specific classification is described in chapter 4.

HPR1000 (FCG3) relevant normal environmental requirements of the electrical design should be adjusted according to the local situation.

The I&C equipment is installed outside the electrical room, which is provided with air conditioning and ventilation system and located outside the reactor room.

Seismic conditions should conform to the response spectra of the floor where the switchgear is located, Reference [10].

2) Compliance with Design Requirements

Reliable safety electrical circuit breakers are provided in the switchgear of the emergency distribution system. The design should allow easy connection of the electrical elements to the emergency distribution system or allow its availability during normal operations or when an accident occurs.

The emergency distribution system is designed with three trains, which are independent from each other. The three independent emergency distribution systems are located in three safety buildings, which are physically separated from each other and protected against external and internal hazards (for detailed information of external and internal hazards, please refer to chapter 18 and chapter 19).

3) Compliance with Requirements arising from Examination, Maintenance Inspection and Testing

Examination and maintenance inspection should be done according to the requirement of the Equipment Operation and Maintenance Manuals (EOMM) provided by the equipment supplier. For periodic test, switchover from normal power supply to EDGs should be done termly to demonstrate the availability of the system and equipment.

9.6.2.3.2 Emergency Diesel Generator (EDG) Set

a) Operational Functions and Composition

The rated voltage of the EDG is 10kV, and the rated output power thereof conforms to the requirements for safety functions of the power plant. Each of the three EDG sets used to power emergency station equipment satisfies the following functions:

1) To power the emergency equipment of the corresponding train to allow safe shutdown without damage to the equipment, in the event of LOOP.

2) For accident management and accident consequence mitigation in the event of LOOP, coupled with a design-basis accident.

The powering method of the EDG auxiliaries is the same as that of other equipment during normal operations. When the EDG set is connected with its corresponding emergency distribution devices, the EDG set powers its own auxiliaries.

b) System Layout

The EDG sets (trains A, B and C) are located in Emergency Diesel Generator Building A (BDA), Emergency Diesel Generator Building B (BDB) and Emergency Diesel Generator Building C (BDC) buildings. These buildings are located in different areas around the NI, are mutually independent and are connected to the NI via the cable tunnels.

c) Description of System I&C

The EDG sets can be started manually or automatically. Manual startup can be carried out on the control panel in the MCR and the local control panel in the diesel generator buildings. Instructions for auto startup are sent from the Digital Control System (DCS). Shutdown of the EDG set can only be done manually, regardless of the startup mode.

The EDG has two modes of protection: emergency and non-emergency. When the EDG is selected for emergency mode and a reactor trip occurs, the EDG's protection is reduced to over-speed and generator differential protection only, Reference [11]. This design feature will decrease tripping possibility of the EDG when it is required to supply emergency power to deliver the safety functions. Additional electrical protection and mechanical protection are required when the EDG set is operating in non-emergency state (periodic testing).

The voltage and frequency of the EDG set can be monitored in the MCR. Alarms are generated in the event of an electrical or a mechanical fault. EDG will need maintenance during the unit shutdown.

d) Preliminary Design Substantiation

1) Compliance with Safety Functional Requirements

The functions of the EDG set should be FC1.

The EDG building, EDG set and the related equipment should be designed in such a manner as to withstand Safe Shutdown Earthquake (SSE). The impacts of internal and external hazards should be sufficiently considered during the design of EDGs.

2) Compliance with Design Requirements

The EDG set can start automatically in the event of LOOP. The logic of the EDG is realised by safety DCS.

The EDG sets are designed with three trains, which are independent from each other. The three independent EDG sets are located in three different civil buildings, which provide physical separation from each other and provide protection against external and internal hazards.

3) Compliance with Requirements arising from Examination, Maintenance Inspection and Testing

Examination and maintenance inspection should be done according to the requirement of the EOMM provided by the equipment supplier. For periodic test, startup, load carrying and switchover from normal power supply to emergency diesel generator power supply should be done termly to demonstrate the availability of the system and equipment.

9.6.2.3.3 SBO Diesel Generator Set

a) Operational Functions and Composition

SBO is defined as loss of AC power supply to the switchboards of the safety and non-safety electrical systems in the power plant. The case of SBO includes the loss of all off-site power, main generator and together with the loss of all EDGs. However, 380V AC power is maintained in the short-term at the AC switchboard powered by the on-site battery via the UPS inverter.

Following a SBO, the operator should manually start the SBO diesel generator sets in trains A and B to supply the 10kV emergency switchboards.

b) System Layout

Trains A and B of the SBO diesel generator sets are located in SBO diesel generator buildings (BDU and BDV) respectively. The buildings are located in different areas of the NI, mutually isolated and connected to the NI via the cable tunnels.

c) Description of System I&C

SBO diesel generator sets are started manually. Manual startup can be carried out on the control panel in the MCR and the local panel in the SBO diesel generator building. The shutdown of the sets can only be done manually.

The operation modes of the SBO diesel generator set can be selected via the operation switch on the local control panel. Instrumentation and protection approaches required for the operation of the SBO diesel generator set are the same as those of the EDG set.

d) Preliminary Design Substantiation

1) Compliance with Safety Functional Requirements

The function level of SBO diesel generator is FC3. The seismic level should be SSE1. The specific classification principle is described in chapter 4.

2) Compliance with Design Requirements

The corresponding buildings, diesel generator body, relevant auxiliaries and cable channels are designed in such a manner that they can withstand SSE.

The building where the SBO diesel generator set is located should be so designed that it can withstand the damages due to tornado.

SBO diesel generator sets of trains A, B and auxiliaries are physically and functionally isolated.

3) Compliance with Requirements arising from Examination, Maintenance Inspection and Testing

Examination and maintenance inspection should be done according to the requirement of the EOMM provided by the equipment supplier. For periodic test, startup, load carrying and switchover from normal power supply to SBO diesel generator power supply should be done termly to demonstrate the availability of the system and equipment.

9.6.2.3.4 2-hour 220V DC and AC Uninterruptible Power Supply (UPS)

a) Operational Functions and Composition

The nuclear power plant requires DC power supply systems to supply the DC loads that must be available during a loss of AC power supply, such as auxiliary motors, circuit breakers, relays, valves and inverters, Reference [12].

The 2-hour battery backed DC and AC UPS is designed to continuously provide power for 2 hours in the event of a design basis accident or a complicated accident relevant to SBO to the following:

-The I&C system used for the relevant design basis accident,

-Distribution panel control circuit related to the design basis accident,

-Industrial valves actuator related to the design basis accident.

The NI 2-hour UPS consists of a battery backed DC 220V supply and an Uninterruptible AC 380V supply powered by inverter from the battery backed DC 220V supply. The structure is the same as that recommended in IEC61225-2005.

The NI 220V DC Power Supply and Distribution System (2h) (LAA/LAB/LAC/LAD [NI-DCPS (220V-2h)]) provides power to:

-Control circuits of the contactor, circuit breaker and I&C racks,

-Inverter of the AC 380V/220V to power the Uninterruptible AC supply on NI AC UPS (LVA/LVB/LVC [NI-UPS (380V-2h)] and LVD [NI-UPS (220V-2h)]).

Where, the LAD [NI-DCPS (220V-2h)] DC 220V board and LVD [NI-UPS (220V-2h)] uninterruptible AC 380V board only power the Reactor Protection System (RPS) channel IV and the corresponding shutdown circuit breaker.

The upstream power supplies of DC 220V boards LAA [NI-DCPS (220V-2h)] and LAB [NI-DCPS (220V-2h)] are off-site power supply, EDG set and SBO diesel generator set.

The upstream power supplies of LAC [NI-DCPS (220V-2h)] and LAD [NI-DCPS (220V-2h)] are off-site power supply and EDG set.

Each safety DC 220V supply consists of:

-A group of safety lead acid batteries,

-A Safety battery charger,

-Safety DC distribution board,

-A non-safety battery charger/discharger,

-Non-safety DC system monitoring device.

Each safety AC UPS consists of:

-A safety DC/AC inverter,

-Safety distribution board.

b) System Layout

The safety 2-hour DC and AC UPS supplies are located in the safety buildings of the NI. DC 220V board LAA [NI-DCPS (220V-2h)] and AC 380V LVA [NI-UPS(380V-2h)] are arranged in BSA building, with the equivalent DC and uninterruptible AC boards LAB [NI-DCPS (220V-2h)] and LVB [NI-UPS(380V-2h)] in BSB building, and LAC [NI-DCPS (220V-2h)], LAD [NI-DCPS (220V-2h)], LVC [NI-UPS(380V-2h)] and LVD [NI-UPS(220V-2h)] in the BSC building.

c) Description of System I&C

Each DC system is provided with a monitoring device, which is intended to monitor the charger cubicle, feeder cubicle, battery bank, ground insulation and switchboard voltage etc.

d) Preliminary Design Substantiation

1) Compliance with Safety Functional Requirements

The main power supply and distribution equipment, such as batteries, chargers and inverters, are safety classified, their function level should be FC1 and seismic level should be SSE1. The seismic level of the non-safety equipment, such as charger/discharger, should be SSE2.

2) Compliance with Design Requirements

The capacity of the battery should ensure that the requirements for accident management are satisfied under loss of power conditions. The battery should be so designed that long-term loads such as the relevant I&C are satisfied, and that the power needed for the action of relevant equipment, such as valves, is sufficiently considered.

The four trains of 2-hour DC and Uninterruptible AC supplies are physically and functionally isolated from each other. All of the 2-hour DC and uninterruptible AC supplies are located in safety buildings, and are protected against internal and external hazards.

3) Compliance with Requirements arising from Examination, Maintenance Inspection and Testing

Examination and maintenance inspection should be done according to the requirement of the EOMM provided by the equipment supplier. Discharge and recharge of the batteries will be done during plant refuelling shutdown.

9.6.2.3.5 12-hour 220V DC and AC Uninterruptible Power Supply (UPS)

a) Operational Functions and Composition

The 12-hour battery backed DC and Uninterruptible AC supply ensures a continuous power supply for 12 hours in the event of a long term SBO and severe accident relevant to a long term SBO to meet the power supply requirements of the following equipment:

-I&C system used when a severe accident occurs,

-Distribution panel control circuit related to severe accidents,

-Process valve actuators related to severe accidents,

-Lighting of the MCR.

The NI 220V DC Power Supply and Distribution System (12h) (LAP/Q [NI-DCPS (220V-12h)]) provides power to:

-Control circuits and I&C racks of the contactor, circuit breaker,

-Inverter of NI 380V AC Uninterruptible Power System (LVP/Q [NI-UPS (380V-12h)]).

Each 12-hour DC 220V system consists of:

-A group of safety lead acid batteries,

-A battery charger,

-Distribution panel,

-A DC system detection device.

The battery of each system should be capable of powering all loads for a minimum of 12 hours.

b) System Layout

The 12-hour UPS is located in the safety building of the NI. The 12-hour battery backed DC 220V board LAP [NI-DCPS (220V-12h)] and the Uninterruptible AC 380V board LVP [NI-UPS(380V-12h)] are arranged in safety building BSA with the redundant 12-hour battery backed DC 220V board LAQ [NI-DCPS (220V-12h)] and the LVQ [NI-UPS(380V-12h)] uninterruptible AC 380V board arranged in safety building BSB.

c) Description of System I&C

The configuration and signal output of the control equipment are the same as those of the 2-hour UPS.

d) Preliminary Design Substantiation

1) Compliance with Safety Functional Requirements

The function levels of the main power supply and distribution equipment, such as the battery, charger and inverter, are FC3, and their seismic level should be SSE1. The seismic level of NC-level equipment, for example, charger, should be SSE2.

2) Compliance with Design Requirements

The capacity of the battery should ensure that requirements for accident management are satisfied under loss of power conditions. The battery should be so designed that long-term loads such as the relevant I&C are satisfied, and that the power needed generated for the action of relevant equipment, such as valves, is sufficiently considered.

The two sets of 12-hour UPS are physically and functionally isolated from each other. Both of the 12-hour UPS are located in safety buildings, and are protected against internal and external hazards.

3) Compliance with Requirements arising from Examination, Maintenance Inspection and Testing

Examination and maintenance inspection should be done according to the requirement of the EOMM provided by the equipment supplier. Discharge and recharge of the batteries will be done during plant refuelling shutdown.

9.6.2.3.6 Rod Control Power Supply

a) Operational Functions and Composition

The voltage of power supply for the control rod drive mechanism is DC 220V, which is provided by the 12-hour DC power supply system, LAP [NI-DCPS (220V-12h)] and LAQ [NI-DCPS (220V-12h)]. The rod control equipment is composed of eight shutdown circuit breakers and 2 groups of diodes. During normal operation, LAP [NI-DCPS (220V-12h)] DC system arranged in BSA and LAQ [NI-DCPS (220V-12h)] DC system arranged in BSB parallel supply the power via the groups of diodes. The equipment is intended to provide power to the control rod drive mechanism via LAP [NI-DCPS (220V-12h)] and LAQ [NI-DCPS (220V-12h)] at the same time.

The shutdown circuit breaker should act on the trip command from the RPS. The circuit breakers should be designed so that the maintenance of a single channel of RPS or a shutdown circuit breaker would not result in inadvertent trip of the remaining shutdown circuit breakers.

b) System Layout

The rod control power equipment on the NI is installed in the safety building BSA.

c) Description of System I&C

The rod control power equipment receives a shutdown command from the RPS.

d) Preliminary Design Substantiation

1) Compliance with Safety Functional Requirements

The function level of the shutdown circuit breaker is FC1.

2) Compliance with Design Requirements

The safety circuit breakers are provided in the panel of rod control power supply system, and the reactor can be shutdown reliably.

The rod control power supply should be designed so that a failure of the 12-hour UPS would not result in accidental falling of all control rods. The eight shutdown circuit breakers are connected based on two out of four logic. This ensures that inadvertent trip of any protection channel would not result in the loss of power of the control rod drive mechanism. The breaking function of shutdown relays is designed to be safety related to ensure safety functions for control rod dropping.

The rod control power supply system is located in safety building BSA, and is protected against internal and external hazards.

3) Compliance with Requirements arising from Examination, Maintenance Inspection and Testing

The shutdown circuit breaker should be designed so that the periodic testing of a single circuit breaker would not result in inadvertent tripping.

9.6.2.3.7 Electrical Penetration

a) Integrity of Penetration Seal

When the weld joint leakage of steel bushing is not included, the total gas leakage rate (excluding the weld joint leakage of steel bushing) of dry helium designed for electrical penetrations under the design basis accident (DBC3, 4) conditions should not be more than $10^{-6}cm^3/s$.

When the weld joint leakage of steel bushing is included, the total gas leakage rate (including the weld joint leakage of steel bushing) of dry helium designed for electrical penetrations under the design basis accident (DBC3, 4) conditions should not be more than $10^{-2}cm^3/s$.

b) Temperature Rise Limit

Temperature rise design of electrical penetrations will ensure that their temperature rise under normal operating conditions (including short-time overload) does not exceed the following temperature rise limits, within which, insulation will have no damages:

Maximum ambient temperature: 50^oC.

Allowable maximum steel bushing temperature: 70^oC.

For conductors which are located on terminals and whose temperature is higher than ambient temperature, maximum temperature rise should not be more than 30^oC.

c) Seismic Test

Electrical penetrations (including external cable connections) will be able to withstand SSE1 seismic conditions to maintain mechanical and electrical integrity.

9.7 Gap Analysis and SAPs Review

9.7.1 Gap Analysis

The following analysis highlights the potential gaps between the HPR1000 (FCG3) and the UK HPR1000 in the area of electric power. Further detail studies are still required to better understand the UK requirements.

1) Codes and Standards

For the HPR1000 (FCG3) design, mainly Chinese codes and standards are used, supplemented by some international standards.

For the UK HPR1000 design, it is understood that international codes and standards such as the IEC standards are considered to be relevant good practice.

As some of the referenced Chinese codes and standards have equivalent versions of IEC standards, the current strategy is to adopt the equivalent version of international codes and standards (such as IEC standards) for the UK HPR1000 design. However, If any Chinese or other international codes and standards are to be proposed instead of an IEC equivalent (or in the case there is no IEC equivalent), further justification will be provided.

2) Common Cause Failures (CCF) Analysis

For the UK HPR1000 design, a specific CCF analysis should be performed to cover both individual component and system architecture. The CCF analysis should also include design, operation and maintenance for all relating equipment.

3) Duration of SBO Diesel Generator

For the UK HPR1000 design, further analysis is required to confirm the duration requirement for the SBO diesel generator which should cover factors such as the reliability and time required for restoration of EDGs.

4) Duration of Severe Accident Battery

For the UK HPR1000 design, further analysis work will be performed to confirm the requirement on battery duration for severe accidents.

9.7.2 SAPs Review

The SAPs which are most relevant to electrical power system have been reviewed in accordantly and are identified in Table T-9.7-1, Reference [13].

T-9.7-1 ONR SAPs Related to Electrical Power System

SAP	Regulation Expectation	Approach for HPR1000 (FCG3)
EDR.2 Engineering Principles – Redundancy, diversity and segregation	Redundancy, diversity and segregation should be incorporated as appropriate within the designs of structures, systems and components important to safety	For HPR1000 (FCG3), there are three redundancy electrical power trains to ensure the power supply of the processing equipment. Electrical power systems in different trains are segregated. Diversity between EDG and SBO diesel generator has been considered. Description is provided in sub-chapter 9.3.2, 9.3.3 and F-9.4-1.
EDR.3 Engineering Principles – Common Cause failure	Common cause failure (CCF) should be addressed explicitly where a structure, system or component employs redundant or diverse components, measurements or actions to provide high reliability.	Diversity between EDG and SBO diesel generator has been considered, mentioned in sub-chapter 9.3.2.
EDR.4 Engineering Principles – Single failure criterion	During any normally permissible state of plant availability no random single failure, assumed to occur anywhere within the systems provided to secure a safety function, should prevent the performance of that safety function.	Single failure criterion is fulfilled in FCG unit 3. The execution of the safety functions will not be affected in the event of a single failure of the electrical equipment.
EKP.3 Engineering Principles – Defence in Depth	A nuclear facility should be so designed and operated so that defence-in-depth against potentially significant faults or failures is achieved by the provision of multiple independent barriers to fault progression.	Electrical power system provides power supply to the safety equipment of different defence levels, so the electrical power system also has its own defence in depth levels. Electrical power system defence in depth are described in 9.3.1.2.

SAP	Regulation Expectation	Approach for HPR1000 (FCG3)
EKP.5 Engineering Principles – Safety measures	Safety measures should be identified to deliver the required safety function	EDG, SBO diesel generator shall be the safety measures to restore some safety relevant equipment operation during LOOP and SBO, mentioned in sub-chapter 9.3.1.2. Safety class DC and AC UPS are also safety measures to maintain equipment in operation when LOOP and SBO, mentioned in 9.6.2.3.4.
ESS.2 Determination of safety system requirements	The extent of safety system provisions, their functions, levels of protection necessary to achieve defence in depth and required reliabilities should be determined.	Electrical power system provisions, functions and the levels of defence in depth are relevant to DBA and PSA. For example, the capacity of EDG is according to LOOP assumption, which is LOOP occurrence with full power operation conditions of DBC-3 and DBC-4 events, mentioned in 12.5.1. DBA and PSA measures and conclusions shall be applied to design of electrical power system.
EES.8 Essential Systems – Automatic Initiation	For all fast acting faults (typically less than 30 minutes) safety systems should be initiated automatically and no human intervention should then be necessary to deliver the safety function(s).	Minimum response time for operator intervention is 30 minutes, mentioned in table T-2.4-1 of chapter 2.4.1. According it, EDG shall be automatically started up, mentioned in 9.6.2.3.2.

9.8 References

[1] NNSA, Safety Regulations for Design of Nuclear Power Plants, HAF 102, 2004.

[2] NNSA, Emergency Power System of Nuclear Power Plant, HAD 102/13, 1996.

[3] GB, Criteria for Class 1E Power Systems for Nuclear Power Generating Stations, GB 12788, 2008 edition, July 2008.

[4] NB, The Design Criteria for Nuclear Power Plants Station Blackout, NB 20066, 2012 edition, January 2012.

[5] GB, Application of the Single Failure Criterion to Safety Systems in Nuclear Power Plant, GB 13626, 2008 edition, July 2008.

[6] GB, Criteria for Independence of Class 1E Equipment and Circuits in Nuclear Power Plants, GB 13286, 2008 edition, July 2008.

[7] NB, Design Criteria for Auxiliary Power System of Nuclear Power Plant, NB 20051, 2011 edition, July 2011.

[8] GB, The Safety Systems for Nuclear Power Plants-Part 1: Design Criteria, GB 13284, 2008 edition, March 2008.

[9] GB, Preferred Power Supply for Nuclear Power Plants, GB 13177, 2008 edition, September 2008.

[10] GB, Seismic Qualification of Electrical Equipment of the Safety System for Nuclear Power Plants, GB 13625, 1992 edition, August 1992.

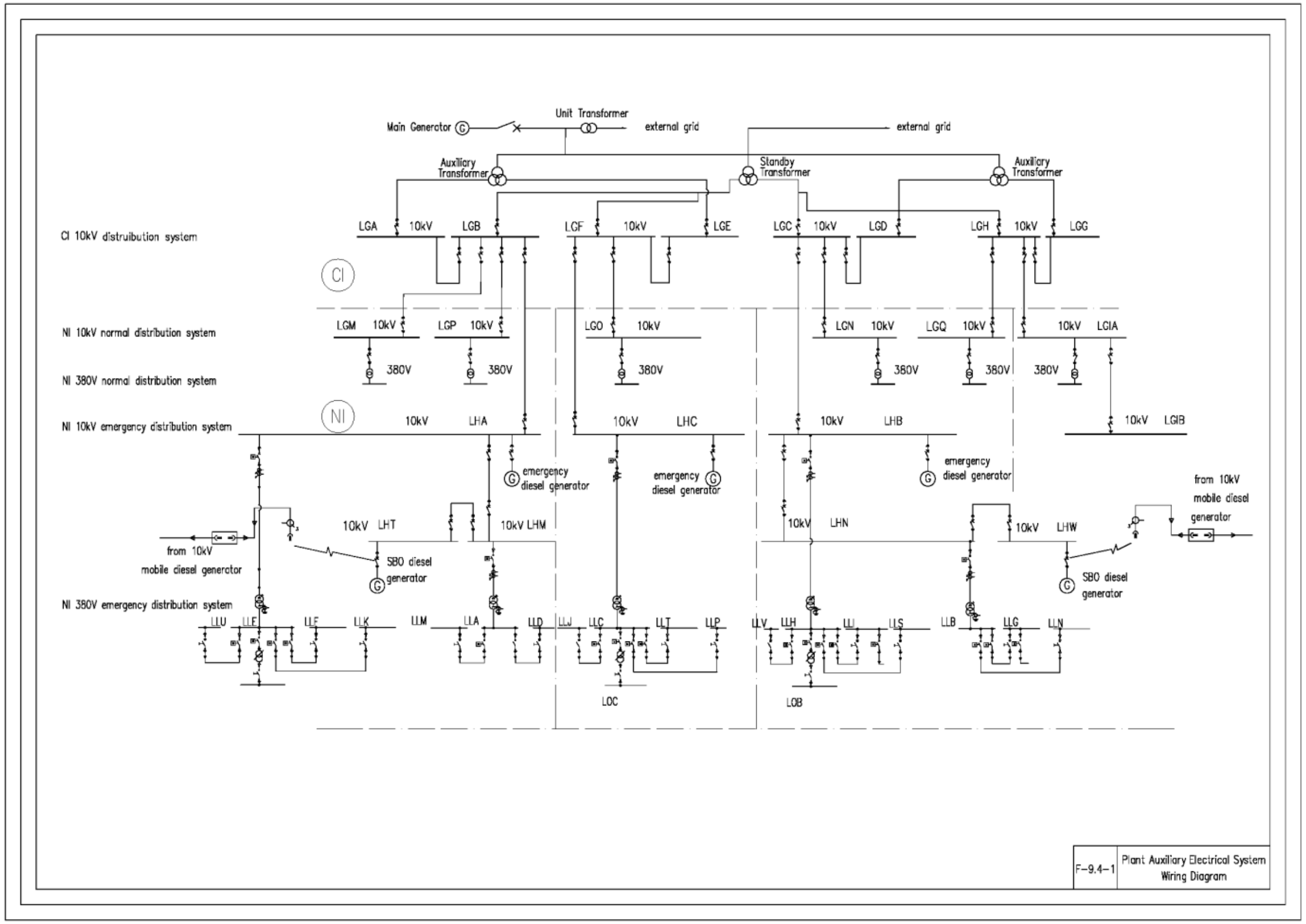
[11] EJ, Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations, EJ 625, 2004 edition, February 2004.

[12] GB, Recommended Practice for the Design of DC Auxiliary Power System for Nuclear Power Stations, GB 14546, 2008 edition, September 2008.

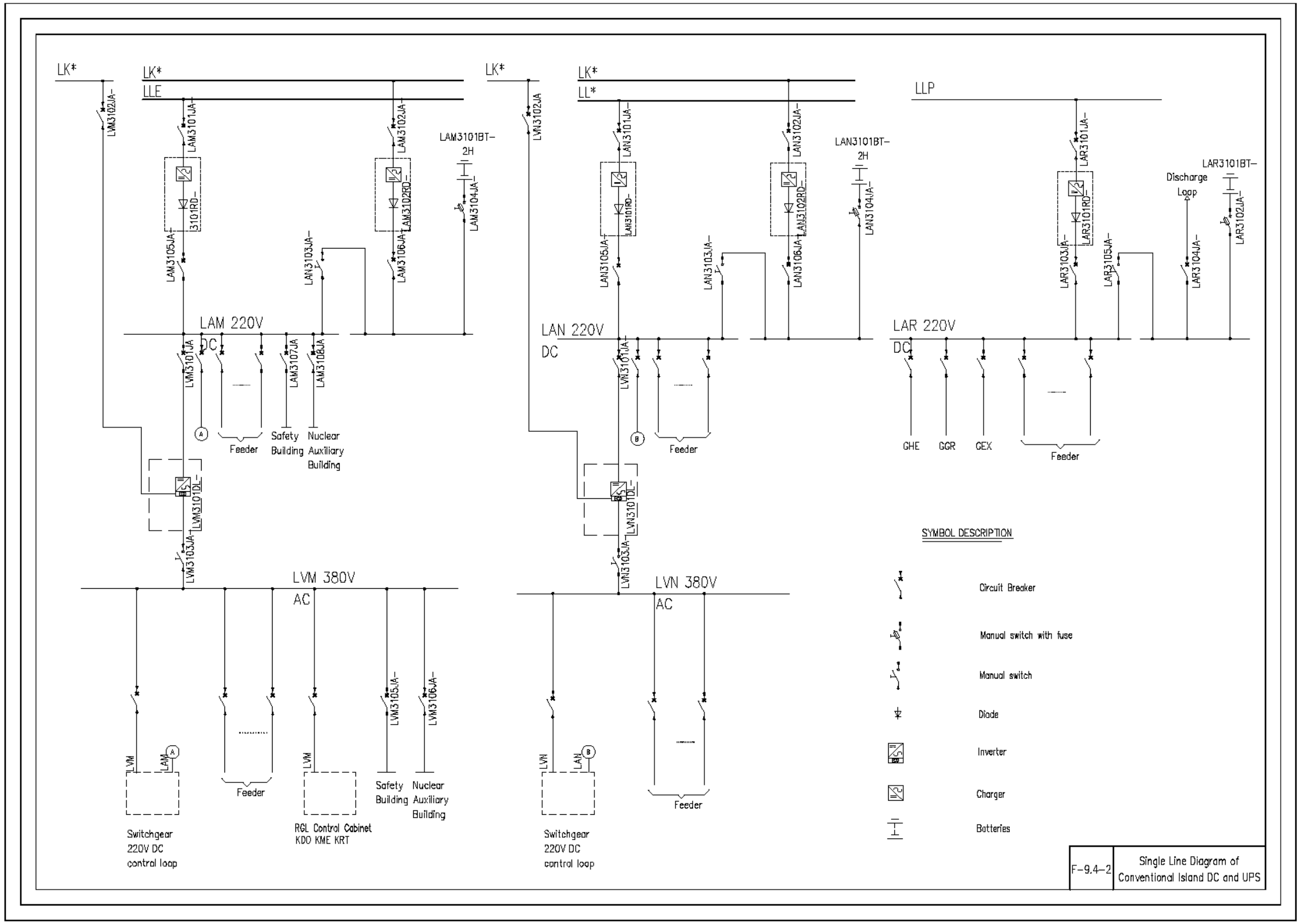
[13] ONR, Safety Assessment Principles for Nuclear Facilities, 2014 edition, Revision 0, November 2014.

Appendix A

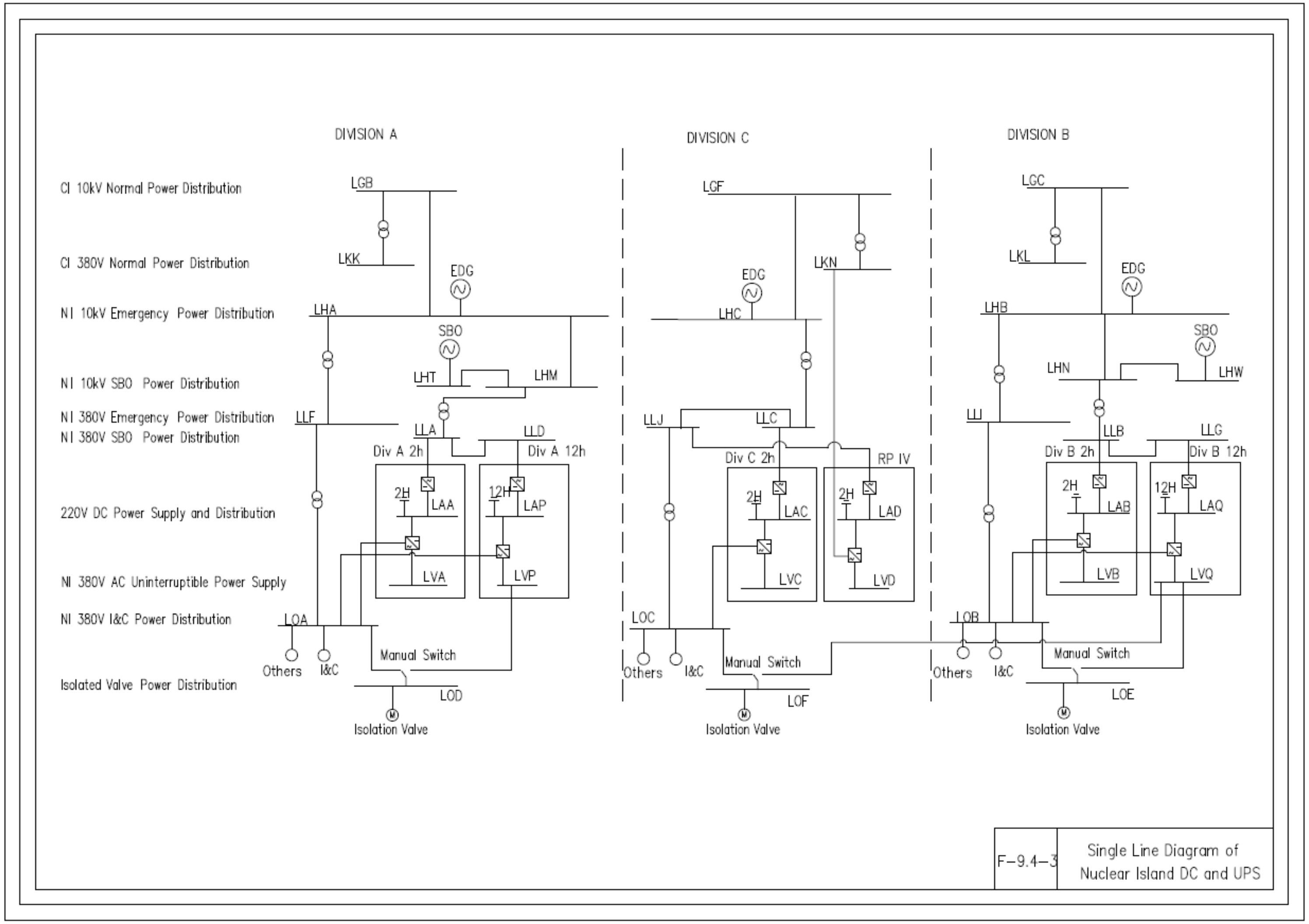
Electrical Wiring Diagrams



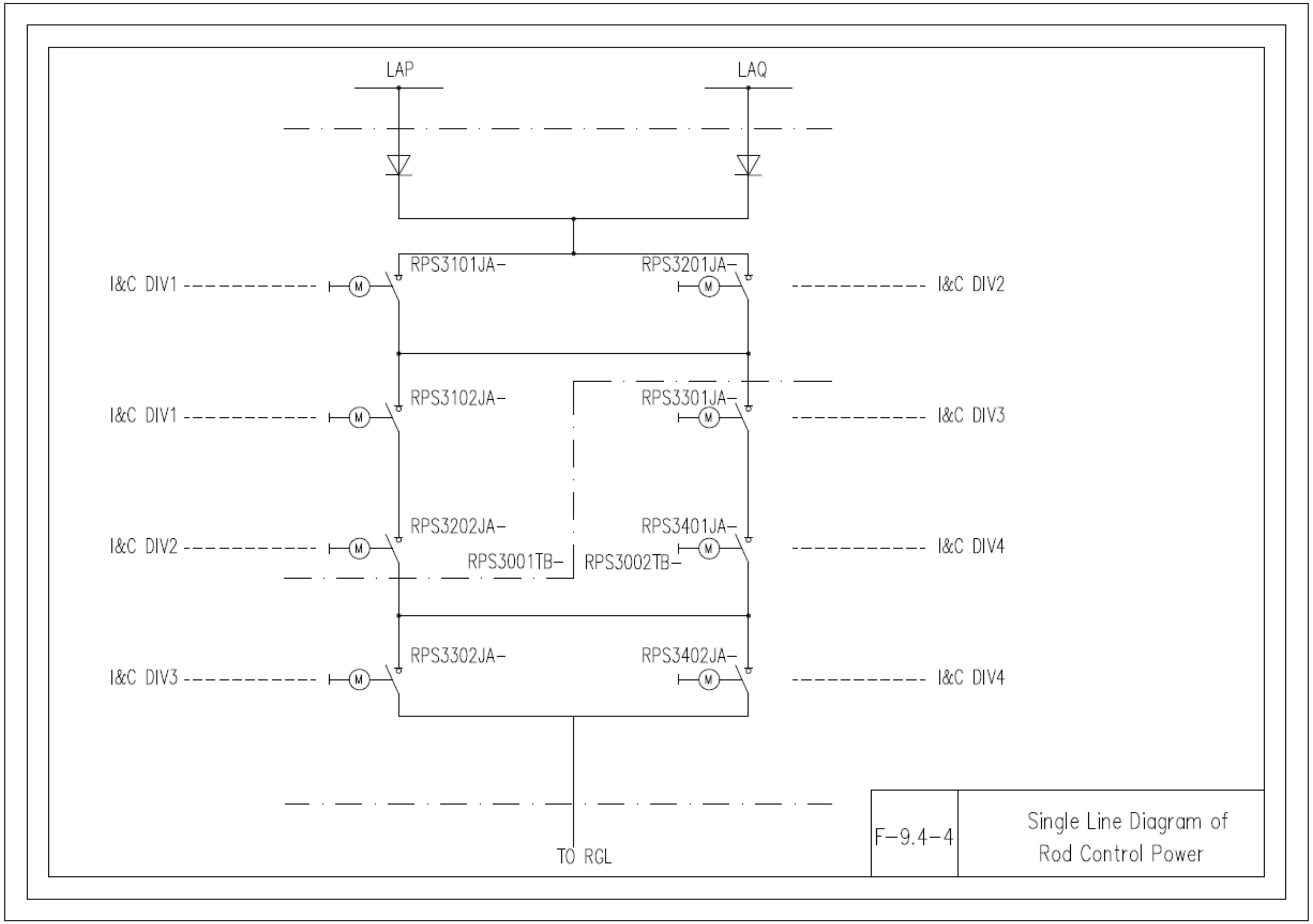
F-9.4-1 Plant Auxiliary Electrical System Wiring Diagram



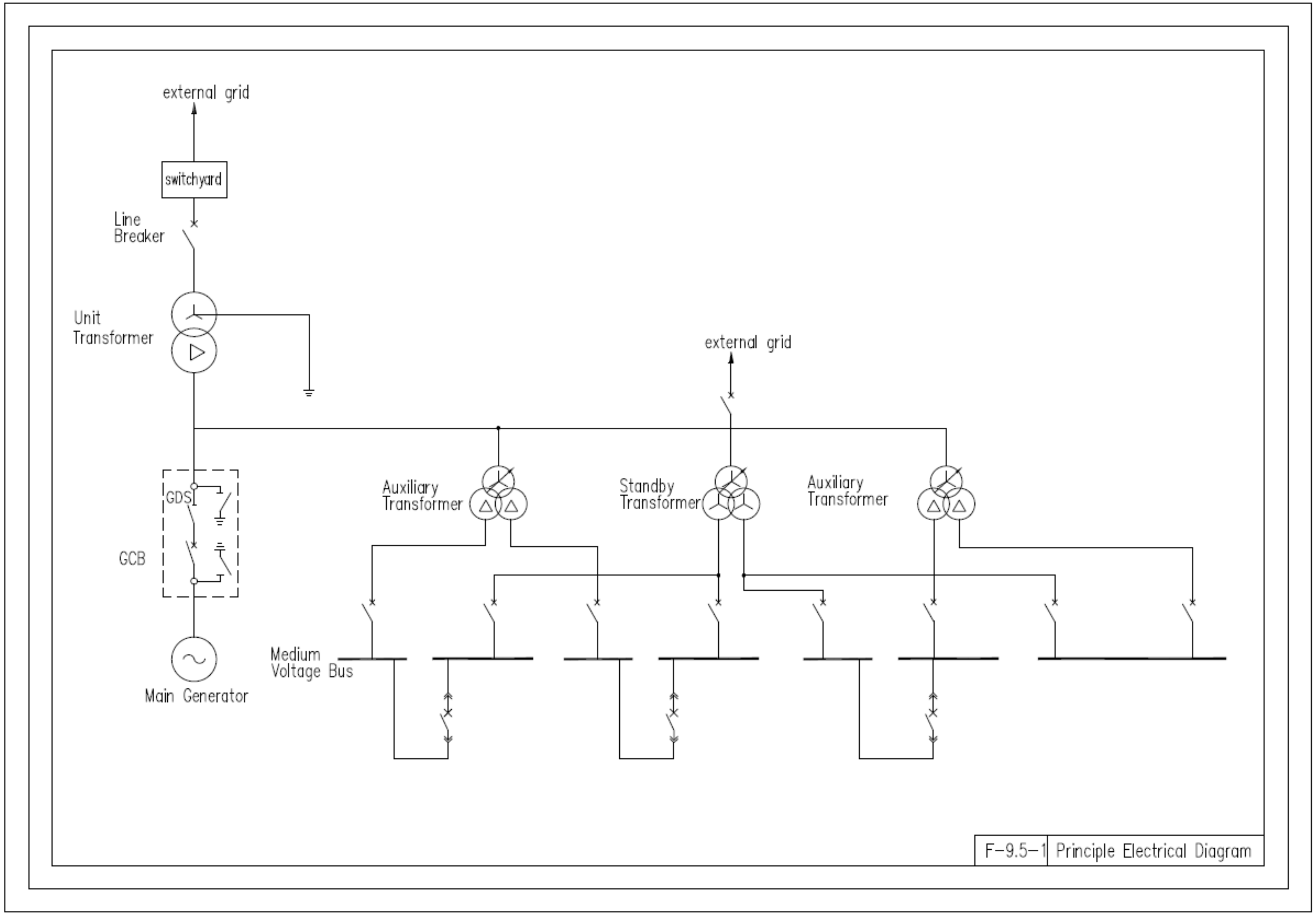
F-9.4-2 Single Line Diagram of Conventional Island DC and UPS



F-9.4-3 Single Line Diagram of Nuclear Island DC and UPS



F-9.4-4 Single Line Diagram of Rod Control Power



F-9.5-1 Principle Electrical Diagram