Office for Nuclear Regulation
An agency of HSE

Generic Design Assessment – New Civil Reactor Build

Step 4 Electrical Systems Assessment of the EDF and AREVA UK EPR™ Reactor

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PREFACE

The Office for Nuclear Regulation (ONR) was created on 1st April 2011 as an Agency of the Health and Safety Executive (HSE). It was formed from HSE's Nuclear Directorate (ND) and has the same role. Any references in this document to the Nuclear Directorate (ND) or the Nuclear Installations Inspectorate (NII) should be taken as references to ONR.

The assessments supporting this report, undertaken as part of our Generic Design Assessment (GDA) process and the submissions made by EDF and AREVA relating to the UK EPR™ reactor design, were established prior to the events at Fukushima, Japan. Therefore, this report makes no reference to Fukushima in any of its findings or conclusions. However, ONR has raised a GDA Issue which requires EDF and AREVA to demonstrate how they will be taking account of the lessons learnt from the events at Fukushima, including those lessons and recommendations that are identified in the ONR Chief Inspector's interim and final reports. The details of this GDA Issue can be found on the Joint Regulators' new build website www.hse.gov.uk/newreactors and in ONR's Step 4 Cross-cutting Topics Assessment of the EDF and AREVA UK EPR™ reactor.

EXECUTIVE SUMMARY

This report presents the findings of the Electrical Systems assessment of the UK EPR Reactor undertaken as part of Step 4 of the Health and Safety Executive's Generic Design Assessment. The assessment has been carried out on the Pre-construction Safety Report and supporting documentation submitted by EDF and AREVA during Generic Design Assessment Step 4.

This assessment has followed a step-wise-approach in a claims-argument-evidence hierarchy. In Generic Design Assessment Step 2 the claims made by the Requesting Parties (EDF and AREVA) were examined, in Generic Design Assessment Step 3 the arguments that underpin those claims were examined.

The scope of the Generic Design Assessment Step 4 assessment was to review the safety aspects of the UK EPR reactor in greater detail, by examining the evidence, supporting arguments and claims made in the safety documentation, building on the assessments already carried out for Steps 2 and 3, and to make a judgement on the adequacy of the Electrical Systems information contained within the Pre-construction Safety Report and supporting documentation.

It is seldom possible, or necessary, to assess a safety case in its entirety, therefore sampling is used to limit the areas scrutinised, and to improve the overall efficiency of the assessment process. Sampling is done in a focused, targeted and structured manner with a view to revealing any topic-specific, or generic, weaknesses in the safety case. To identify the sampling for the Electrical Systems an assessment plan for Generic Design Assessment Step 4 was set-out in advance.

My assessment has focussed on:

- Review of power system protection in the generic UK EPR design.
- Review of the resilience of the Electrical System to the effects of fast transient disturbances.
- Review of Design and Construction Rules to be followed for UK EPR as defined in RCC-E (Ref. 18) document.
- Study of three phase and single phase short circuits on the system.
- Study of the effects of transient disturbances on the Electrical System during motor starting and power system fault conditions.
- Review of earth fault monitoring on the 10kV system.
- Review of the Direct Current and uninterruptible Alternating Current systems.
- Review of power quality on the distribution system.
- Review of maintenance philosophy and condition monitoring.
- Review of earthing and lightning protection.
- Review of the Electrical System design against the Nuclear Directorate Safety Assessment Principles

A number of items have been agreed with EDF and AREVA as being outside the scope of the Generic Design Assessment process and hence have not been included in my assessment.

From my assessment, I have concluded that:

- EDF and AREVA provide adequate claims of compliance for the Electrical System structure defined against the electrical Safety Assessment Principles. Although I have no significant concerns regarding the integrity of the system and its capability to meet the safety claims

EDF and AREVA have yet to provide sufficient the evidence to support the claims. Generic Design Assessment Issue **GI-UKEPR-EE-01** has been raised to identify the requirement to supply this evidence.

- Independent assessment by the Technical Support Contractor and myself of the EDF and AREVA design modelling extremes of transient operating conditions has confirmed the resilience of the design of the Electrical Distribution System to disturbances due to such events as short circuits, switching transients and overvoltage transients.
- The structure of the Electrical System provides sufficient capacity to meet load requirements in all operating modes of grid supply, diesel supply and battery supply. Capability is provided in the system to facilitate maintenance of Electrical Systems whilst maintaining supply continuity. Continuity of supply can be maintained in the event of unavailability of equipment due to faults.
- The principles proposed in the protection philosophy provide a good basis for protecting the Electrical System to minimise the effects of electrical faults. This enables continuity of system supplies and thus supports the effectiveness of the Electrical System in maintaining plant safety.
- The Class 1 battery powered systems are designed in a well structured manner according to defined and documented processes. Adequate margins are applied and battery rating is based on the worst conditions of operating temperature and ageing.
- The basic structure presented for equipment specifications is comprehensive and provides a sound basis for specifying requirements during detailed design by the future licensee.
- The work carried out in assessing the implications of meeting the UK Grid Code (Ref. 36) has been carried out in a very thorough manner to ensure that all the implications have been assessed. This has included ensuring that there are no implications on the Plant Electrical System when remaining connected to the Grid under fault conditions.

During the course of the assessment, discussions have taken place with EDF and AREVA on subjects arising from the assessment. This has resulted in a number of changes either to the design or to perform additional design verification studies. The most significant changes agreed have been:

- Removal of the time delay on the High Voltage circuit breaker operation as studies have shown that it is not required for Direct Current component switching. This gives faster fault clearance times which improve Electrical System integrity.
- Incorporation of studies of fast transients and Automatic Voltage Regulator failure in the design process to address potential threats to system integrity.
- Performing harmonic assessment during detail design. This additional study addresses potential threats to system integrity.
- Modification of the safety classification of Electrical Systems to bring them in to line with other equipment. This provides a standardised approach to safety classification across all disciplines.

The assessment has been carried out on a generic design and on the presentation of fundamental design principles to be followed in carrying out detailed design of the Electrical System. The detailed design information for the Electrical Systems is not available which has limited the extent of my assessment. As a result, the Nuclear Directorate will need to underpin their conclusions based on the detailed design when it is available. This design information is identified as Assessment Findings which are to be carried forward as normal regulatory business. An example of a key Assessment Finding is the requirement to model the Electrical System to perform a load study, further findings then relate to transient studies to be performed using the initial model. The Assessment Findings are listed in Annex 1.

Some of the observations identified within this report are of particular significance and will require resolution before the Health and Safety Executive would agree to the commencement of nuclear safety related construction of a UK EPR Reactor in the UK. These are identified in this report as Generic Design Assessment Issues and are listed in Annex 2. In summary these relate to:

- EDF and AREVA are required to produce a revised Pre-construction Safety Report, Chapter 8, to substantiate the design of the complete plant electrical distribution system. This needs to incorporate a structure of claims, arguments and evidence to demonstrate that the Electrical System fully meets the requirements of its safety role as specified in the other chapters of the Pre-construction Safety Report.

Overall, based on the sample undertaken in accordance with the Nuclear Directorate procedures, I am broadly satisfied with the integrity of the Electrical System design laid down within the Pre-construction Safety Report and supporting documentation for the Electrical Systems. This will be supplemented by presentation of Claims, Arguments and Evidence in the Pre-construction Safety Report in response to Generic Design Assessment Issue **GI-UKEPR-EE-01**, but I consider that the integrity of the design is such that the necessary claims arguments and evidence can be presented. The UK EPR Reactor is therefore suitable for construction in the UK, subject to satisfactory progression and resolution of Generic Design Assessment Issues to be addressed during the forward programme for this reactor and assessment of additional information that becomes available as the Generic Design Assessment Design Reference is supplemented with additional details on a site-by-site basis.

LIST OF ABBREVIATIONS

AC	Alternating Current
ALARP	As Low As Reasonably Practicable
ASN	Autorité de Sûreté Nucléaire (French nuclear safety authority)
AT	Standby Transformers
AVR	Automatic Voltage Regulator
BMS	(Nuclear Directorate) Business Management System
BSI	British Standards Institution
C&I	Control and Instrumentation
CENELEC	European Committee for Electrotechnical Standardisation
DC	Direct Current
DIDELSYS	Defence in Depth of Electrical Systems and Grid Interaction with nuclear power plants
EC	European Commission
EDF and AREVA	Electricité de France SA and AREVA
EDG	Emergency Diesel Generator
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FA3	Flamanville 3
GDA	Generic Design Assessment
HSE	The Health and Safety Executive
HV	High Voltage
IAEA	The International Atomic Energy Agency
IEC	International Electrotechnical Commission
IT	Isolated Neutral
LV	Low Voltage
MDEP	Multinational Design Evaluation Programme
MSL	Master Submission List
ND	The (HSE) Nuclear Directorate
NEA	Nuclear Energy Agency
NRC	Nuclear Regulatory Commission
ONR	Office for Nuclear Regulation
OTS	Operational Technical Specification
PCSR	Pre-construction Safety Report

LIST OF ABBREVIATIONS

PID	Project Initiation Document
PSA	Probabilistic Safety Analysis
RI	Regulatory Issue
RIA	Regulatory Issue Action
RMS	Root Mean Square
RO	Regulatory Observations
ROA	Regulatory Observation Action
RP	Requesting Party
SAP	Safety Assessment Principle
SSC	System, Structure and Component
STUK	The Finish Nuclear Safety Authority
TAG	(Nuclear Directorate) Technical Assessment Guide
THD	Total Harmonic Distortion
TQ	Technical Query
TSC	Technical Support Contractor
UDG	Ultimate Diesel Generator
UEB	Unclassified Electrical Building
UPS	Uninterruptible Power Supply
US NRC	Nuclear Regulatory Commission (United States of America)
WENRA	Western European Nuclear Regulators Association

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1 INTRODUCTION

1 This report presents the findings of the Step 4 Electrical Systems assessment of the UK EPR Reactor PCSR (Ref. 11) and supporting documentation provided by EDF and AREVA under the Health and Safety Executive's (HSE) Generic Design Assessment (GDA) process. The focus of the assessment was the supporting evidentiary information derived from the Master Submission List (MSL) (Ref. 12). The approach taken was to assess the principal submission, i.e. the Pre-construction Safety Report (PCSR), and then undertake assessment of the relevant documentation sourced from the MSL on a sampling basis in accordance with the requirements of ND’s Business Management System (BMS) procedure AST/001 (Ref. 2). The Safety Assessment Principles (SAP) (Ref. 4) have been used as the basis for this assessment. Ultimately, the goal of assessment is to reach an independent and informed judgment on the adequacy of a nuclear safety case.

2 During the assessment a number of Technical Queries (TQ) and Regulatory Observations (RO) were issued and the responses made by EDF and AREVA assessed. Where relevant, detailed design information from specific projects for this reactor type has been assessed to build confidence and assist in forming a view as to whether the design intent proposed within the GDA process can be realised.

3 A number of items have been agreed with EDF and AREVA as being outside the scope of the GDA process and hence have not been included in this assessment.

2 NUCLEAR DIRECTORATE'S ASSESSMENT STRATEGY FOR ELECTRICAL SYSTEMS

4 The intended assessment strategy for GDA Step 4 for the Electrical Systems topic area was set out in an assessment plan that identified the intended scope of the assessment and the standards and criteria that would be applied. This is summarised below in the following section:

2.1 Assessment Plan

5 The Assessment Plan (Ref. 1) provided the basis for producing the GDA Step 4 Assessment Report to assess the evidence in support of the claims and arguments in the GDA Step 3 Assessment Report and to judge the adequacy of the Electrical Systems contained within the PCSR and supporting documentation.

2.2 Standards and Criteria

6 The assessment was to be carried out in accordance with the relevant electrical subset of SAPs (Ref. 4) which are identified in Table 10.

2.3 Assessment Scope

7 The scope identified in the Assessment Plan (Ref. 1) was to review the safety aspects of the Electrical Systems for the proposed reactor designs in a more detailed way by examining the evidence supporting arguments and claims made in the EDF and AREVA safety documentation. This was to build on the assessment carried out in GDA Step 3 and make a judgment on the adequacy of the Electrical Systems as described within the PCSR and supporting documentation.

8 The areas to be covered in GDA Step 4 are detailed in Table 9. The assessment of the evidence to support the claims and arguments in compliance with SAPs was to be carried out in accordance with the subset of SAPs relevant to electrical power supply systems.

2.3.1 Findings from GDA Step 3

9 The Step 3 Assessment Report concluded that EDF and AREVA had provided adequate claims of compliance for the Electrical Systems architecture defined against the subset of electrical SAPs (Ref. 4). In a number of areas more detailed information would be required in the Step 4 submission to provide arguments and evidence in support of the claims.

10 During Step 4 an independent assessment of the EDF and AREVA design was to be carried out to verify the integrity of the design. EDF and AREVA were to supply design data to support the process.

2.3.2 Additional Areas for Step 4 Electrical Systems Assessment

11 The additional areas identified in the Assessment Plan for assessment during GDA Step 4 are listed in Table 9.

2.3.3 Use of Technical Support Contractors

12 A Technical Support Contractor (TSC) was used in support of the assessment of the Electrical Systems on the UK EPR. The following scope of work was undertaken by the TSC:

- Review of electrical protection.
- Review of earthing arrangements.
- Modelling of the Electrical System using ERACS system study software.
- Fault studies using ERACS system study software.
- Sample protection coordination studies.
- Studies using ERACS system study software of the effects of transient disturbances on the electrical network.
- Fast transient assessment of the Electrical System.
- Harmonic assessment of the system.
- Technical advice to ND.

13 The TSC work was based on studies and reports from EDF and AREVA documentation. At the completion of each stage of work the results were discussed with ND before being presented to EDF and AREVA for discussion and comment. Following from this, a series of reports were produced by the TSC for each study area which were used to inform this report. References to the individual TSC reports are made in the reports on the relevant study areas. A copy of the overall study using the ERACS model of the Electrical System has been provided to ND on disk.

2.3.4 Cross-Cutting Topics

14 The following Cross-cutting Topics have been considered within this report:

- Structures, Systems and Components.
- Design Changes.
- Limits and Conditions.
- Smart Instruments.
- Qualification.

2.3.5 Integration with Other Assessment Topics

15 Integration has taken place with other assessment topics as follows:

- Internal Hazards on hydrogen evolution in battery rooms.
- Internal Hazards on cable segregation.
- Internal Hazards on Electromagnetic Interference (EMI).
- Probabilistic Safety Analysis (PSA) on incorporation of the Electrical System in the PSA model.
- C&I on Smart Devices.

- Mechanical Engineering on diesel generators.
- Fault Studies on power supplies to safety systems.
- Human Factors on maintenance and manual operations.

2.3.6 Out of Scope Items

16 The following items have been agreed with the RP as being outside the scope of GDA:

- Detailed design and specification of electrical equipment.
- Detailed verification of electrical transient analysis based on site specific installation.
- Detailed verification of the robustness of the Electrical System to withstand fast transient disturbances.
- Detailed verification of the Electrical System to withstand ferro-resonant phenomena in the internal network.
- High Voltage (HV) and Low Voltage (LV) systems protection coordination.
- Grid connections and coordination with grid protection systems.

3 REQUESTING PARTY'S SAFETY CASE

17 The safety case for the electrical supply system for the UK EPR is defined in Sub-chapter 8.3 of the PCSR (Ref. 11). This states that the nuclear island's emergency power supply is required to supply power to the loads that perform safety functions, within acceptable static and dynamic voltage limits, in all operating modes and transient conditions:

- Operation at power.
- Power supply by the Main Generator after load rejection.
- Power supply by the main network.
- Power supply by the auxiliary network.
- Power supply by onsite emergency power sources.
- Power supply by onsite ultimate emergency power sources.
- Power supply by severe accident dedicated batteries.
- During and after external hazards.

4 GDA STEP 4 NUCLEAR DIRECTORATE ASSESSMENT FOR ELECTRICAL SYSTEMS

4.1 Electrical System Structure

18 I have assessed the basic structure for the Electrical Distribution System in the EPR reactor and assessed the integrity of this structure. I have also examined how this system complied with the subset of Electrical SAPs (Ref. 4) most relevant to electrical power supply systems

4.1.1 System Structure

19 An overview of the Electrical Supply System is shown in Figure 1. The output from the Main Generator is connected to the 400kV Grid Substation with a tee off from this connection to two Step-down Transformers ST1 and ST2 which provide power to the Plant Electrical System at 10kV. A Standby Transformer AT provides an alternative supply from the Grid Substation in the event of loss of supply from ST1 or ST2.

20 There are four independent divisions each fed from a 10kV switchboard supplied from the Step-down Transformers ST1 and ST2 with a back up supply from Standby Transformer AT. Each of the divisions has an Emergency Diesel Generator (EDG) connected to the 10 kV emergency switchboards which start up automatically on loss of voltage on the emergency switchboard busbars. There are two Ultimate Diesel Generators (UDG) connected to 690V emergency switchboards; one in Division 1 and one in Division 4. These are manually started for maintaining essential supplies in the event of a total loss of grid combined with common cause failure of all four EDGs. Divisions 1 and 4 and Divisions 2 and 3 are identical.

21 The 10 kV switchboards for each Division feed the distribution network for that division consisting of emergency and normal switchboards operating at 10kV, 690V and 400V. All motor and other electrical loads for the Division are fed from the divisional distribution network.

22 Motors operate at 10kV, 690V and 400V and are fed from either circuit breakers or fuse contactor combinations. In both arrangements the control supply is powered from batteries so that the motors will remain connected to the load in the event of reductions in system voltage. This ensures that there is no loss of connection of motors to the supply. The consideration of the effects of the transient voltage dip on system stability and motor operation is considered in EDF document ENSEMD090232 (Ref. 23).

23 Each division has independent battery systems providing supplies to essential loads. These consist of a 2 hour battery on each Division for supplies to C&I and AC Uninterruptible Power Supplies (UPS) together with a 12 hour battery on Divisions 1 and 4 for supplies to C&I and external isolation valves.

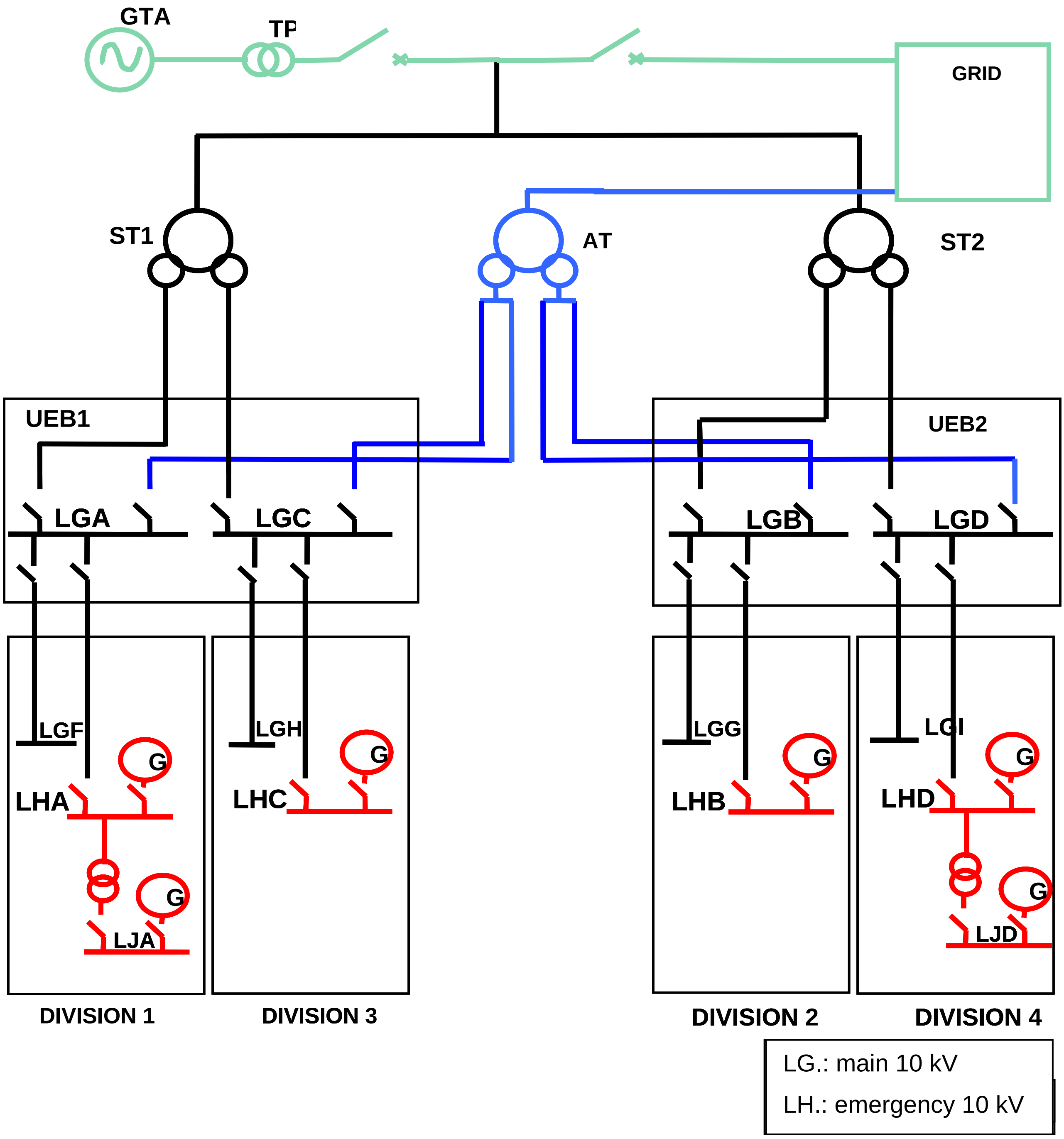
24 Full segregation is provided between the Electrical Systems on each Division. In normal operation there are no cross connections which could result in a fault on the Electrical System on one division causing effects on other Divisions. There are provisions for some cross-connections during maintenance. These are fully protected electrically to prevent faults propagating between Divisions and cables running between Divisions are mechanically segregated. Interconnections are only made between Divisions 1 and 2 and Divisions 3 and 4, there are no interconnections between any other Divisions.

4.1.1.1 Assessment

25 The basic structure of the Plant Electrical System is robust and suitable for providing the power supplies required to maintain the reactor in a safe condition under a wide range of operating and fault conditions. The structure of the system meets the requirements of the Safety Assessment Principles (SAP) (Ref. 4).

26 I consider the arrangements to be acceptable for maintaining connection during dips in main supply voltage.

Figure 1: Schematic diagram of the connections between the two unclassified electrical buildings (UEB) on the conventional island and the four divisions on the nuclear island



27 The assessment of the system by the TSC using the ERACS power system model of the EPR Electrical System covered by Report 2010-0644 (Ref. 41) includes a load flow assessment which has shown the system to be conservatively rated. The assessment of the loads on the diesel generators is based on the response to TQ-EPR-618 (Ref. 8) which provides details of the restart sequence for loads following changeover to diesel operation.

28 I consider that the arrangement of the Emergency Diesel Generator (EDG) and the Ultimate Diesel Generator (UDG) on the individual divisions are a well-designed system to meet the requirements for supplies to the plant.

29 Fault Studies assessment of Design Basis Analysis of Essential Support Systems has identified that PSA assessment of initiating events due to Electrical System faults has not been performed. This requirement has been identified in GDA Issue **GI-UKEPR-FS-05** (Ref. 49).

4.1.1.2 Findings

30 I consider that the basic structure of the Electrical System meets the requirements of relevant good practice for a new nuclear facility such as IAEA Safety Guide NS-G-1.8 (Ref. 45). Assessment Finding **AF-UKEPR-EE-001** has been raised requiring the future licensee to carry out for each site a load flow and assessment on the detail design and specification of the system to ensure that the basic principles are maintained.

31 I consider that the capacity of the Electrical System to meet load requirements including the rating of the diesel generators has been shown to be suitable to support the safe operation of the reactor. This will need to be fully assessed for each site by the future licensee; Assessment Finding **AF-UKEPR-EE-001** identifies this requirement.

32 I expect that any implications on the electrical system design of the PSA assessment covered by GDA Issue **GI-UKEPR-FS-05** will be addressed.

4.1.2 SAPs Compliance

33 I have carried out an assessment in this section of the design principles of the electrical system against the requirements of specific Safety Assessment Principles (SAP) (Ref.4) which have particular relevance to the electrical system. The full assessment of compliance with all relevant SAPs is provided in Table 11.

4.1.2.1 Assessment

34 EDR.1 covers failure to safety which is addressed by adopting the principles of the electrical protection scheme to provide a coordinated system to ensure that failure at a single point of the Electrical System will not impact throughout the system. Important system loads are duplicated so loss of supply will not result in loss of functions. The nuclear island has four Divisions each with its own distribution division. Each Division has an Emergency Diesel Generator (EDG) for emergency power supply in the event of the loss of the external power supply. Divisions 1 and 4 each have UDG generators to support the EDGs. There are also 2 hour Uninterruptible Power Supplies (UPS) on each of the four Divisions and 12 hour UPS on Divisions 1 and 4.

35 EDR 2 covers redundancy, diversity and segregation which are provided by the design of the electrical distribution system. The electrical structure of the conventional island's

High Voltage (HV) scheme separates the nuclear island's distribution system into four Divisions. Each Division is supplied by an independent Emergency Diesel Generator (EDG) which is started automatically on loss of voltage on the busbars. This provides four segregated sections each equipped with a main 10kV switchboard supplied by a unit transformer winding. The segregation into Divisions ensures that in the event of an internal hazard within a Division, only the Division in question is affected. Each Division has an independent battery based DC system with charging from the low voltage AC system. The DC system gives 2 hour Uninterruptible Power Supplies (UPS) on each Division to essential Control and Instrumentation systems and 12 hour UPS on Divisions 1 and 4.

36 EDR.3 covers common cause failure. The resilience to this has been demonstrated in studies undertaken to assess external sources of disturbances such as grid failures, fast transients and lightning. Physical and spatial separation is applied as far as possible. Two distinct diesel generator designs have been adopted to address potential common cause failures, one for the EDG diesels and one for the UDG diesels.

37 ERL.2 covers measures to achieve reliability. In design this SAP is met by the proposed implementation of a combination of redundant and diverse sub-systems and equipment. The basic architecture is four Divisions of redundant equipment for electrical power supplies to the nuclear island. Depending on the safety system being supplied, in many instances, only one redundant Division would be sufficient to maintain safety and is never higher than two. The proposed installation of the two UDG diesels provides diversity to the EDGs. These diesels are of different rating, have diverse control arrangements and will be supplied from different manufacturer from the EDGs.

38 ERL.4 covers margins of conservatism. The electrical equipment has been shown to have comprehensive calculation methods to ensure adequate margins. The provision of four independent Divisions of AC power each supported by an Emergency Diesel Generator and the provision of four independent battery divisions provides the required conservatism in the design.

39 ESS.21 covers reliability. The requirements of this SAP have been met through the provision of a robust Electrical System architecture that can withstand a very wide range of challenging single, and from the perspective of the PSA, multiple faults while still being able to perform its safety function. This is further supported by the use of nuclear qualified equipment. Finally the Electrical System avoids complexity, although more work needs to be done on Smart Devices.

40 EKP.3 covers defence in depth. The provisions for Defence in Depth can be summarised as follows:

- The normal source of supply can be derived from either the Main Generator or the grid alone.
- Two Step-down Transformers (ST) each with two secondaries provide galvanically separate supplies to each of four Divisions via four main switchboards on the conventional island.
- Each power supply system is installed in a separate division. The separation is such that an internal hazard within one Division does not affect that in another Division.
- The nuclear island main switchboards are located in fire segregated areas. Each of the emergency switchboards is supported by a 10kV EDG.

- The Diesel Generator buildings are geographically separated so that a single incident can only cause the loss of two EDGs and one UDG.
- In each Division a UPS with two hour autonomy provide C&I supplies.
- In Divisions 1 and 4 a UPS with 12 hour autonomy provide C&I supplies.
- There are two UDGs to provide back up supplies in Divisions 1 and 4 in the event of loss of all four EDGs.

4.1.2.2 Findings

41 The assessment of the structure of the Electrical System in accordance with SAPs having particular relevance to Electrical Systems has shown that the system is compliant or has the structure to be compliant.

4.2 Power System Protection

42 My assessment of the electrical protection on the plant auxiliary distribution network is based on EDF document ENSEMD090015 (Ref. 19) which describes the selectivity and coordination principles to ensure protection of the UK EPR Electrical Distribution System downstream of the grid transformers.

43 The assessment of the protection of the main generators and transformers is based on EDF document ETDOFC/08 0364 (Ref. 37). Further clarification on specific issues has been provided in responses to TQ-EPR-1080 (Ref. 8) and TQ-EPR-1083 (Ref. 8).

44 TSC Report 2010-0651 (Ref. 39) which independently assesses the principles of power system protection in the generic EPR design has been used as input information to this report.

4.2.1 Assessment

45 EDF document ENSEMD090015 (Ref. 19) initially recalls the selectivity principles that could be used on the UK EPR plant for each voltage level. Then, depending on the protection and the nature of the loads, it presents rules for determining protection thresholds for overload, short-circuit and earth faults. This provides an appropriate structure on which to base the detail design of the protection system.

46 I consider that the rules and guidance provided in the document for achieving selectivity are appropriate for the application. The rules for achieving selectivity are described in a qualitative fashion and only in a few cases are numerical guidelines provided. This leaves the site specific design a wide degree of latitude but the general philosophy is sufficiently developed to ensure that the Plant Electrical System is adequately protected with effective coordination and discrimination between different levels of protection. There is a requirement to undertake a detailed site protection study to select settings and devices based on the principles defined in the document.

47 It is stated in document ENSEMD090015 (Ref. 19) that a time delay is necessary on fault interruption by 10kV circuit breakers to allow decay of the DC component of the fault current. Following further study of the UK EPR electrical distribution network EDF and AREVA confirmed in the response to TQ-EPR-872 (Ref. 8) that a time delay will only be provided if required following studies during site licensing.

48 The generator and transformer protection scheme described in document ETDOFC/08 0364 (Ref. 38) provides a coordinated protection of the Main Generator, Step-down Transformers (ST) and Standby Transformers (AT) to the power divisions and interlinking power circuits. The settings and functions in this system are coordinated with the protection functions of the auxiliary circuits described in document ENSEMD090015 (Ref. 19).

49 The proposed 10KV network operates with an Isolated Neutral (IT) system. The IT system allows continued operation without supply interruption in the event of a single fault between a phase conductor and earth.

50 To achieve the full benefit from an IT system it is necessary that a means for the timely detection and location of an earth fault is provided. Failure to do this may result in the fault degrading further and increasing the risk of a second earth fault or voltage escalation due to persistent arcing. The incidence of a second phase to earth fault before the first one has been cleared will cause an immediate trip with the result that the benefit of the IT system in reducing Electrical System trips is lost. It will be necessary for all switchgear on the system to be rated to trip on the system after a second earth fault which results in a voltage of $\sqrt{3}$ times the rated value across the switching contacts.

4.2.2 Findings

51 I consider that the protection principles proposed provide a good basis for protecting the Electrical System to minimise the effects of electrical faults in maintaining system supplies and thus support the effectiveness of the Electrical System in supporting plant safety.

52 I consider that the IT earthing system on the 10kV network is effective in minimising trips when faults are detected and repaired in a timely manner. Assessment Finding **AF-UKEPR-EE-020** has been raised to identify a requirement for the future licensee to specify an effective earth monitoring system and to specify circuit breakers with the capability to interrupt double earth faults.

53 The protection provisions and philosophy described in EDF document ETDOFC/08 0364 (Ref. 38) for the protection of the main generators and the EPR power intake and grid coupling transformers contains a conventional range of protection functions normal to power station applications. I consider the proposed protection system to be comprehensive and to be the product of a well constructed design process.

54 As the Electrical System on a reactor will be dependent on various site specific aspects such as grid connections and site specific auxiliary loads there will be a requirement for a site specific protection scheme to be designed to ensure effective coordination and discrimination of protective devices. This scheme should then be the subject of a detailed study to determine correct protection settings. These activities, if carried out in accordance with the methodology defined in the protection principles document will ensure effective plant protection. Assessment Finding **AF-UKEPR-EE-002** has been raised for the future licensee to undertake a protection study during detail design of the plant.

4.3 Cable Routing

55 I have assessed the basic principles to be adopted for the routing of electrical cables in conjunction with Internal Hazards assessment (Ref. 50). The electrical assessment has focussed on the design of cable routes to meet specific electrical requirements regarding

segregation, separation and rating whilst the Internal Hazards assessment has considered the effects of specific hazards.

4.3.1 Assessment

56 The principle for physical separation of cables between different Divisions detailed in RCC-E (Ref. 18) is consistent with the principle of complete separation of each of the four Divisions. The design of main cable routes provides the basic framework consistent with the philosophy of separation between Divisions. The subject of protection of individual cables where they do encroach on cables from a different Division has been raised as part of the Internal Hazards assessment.

57 Cables associated with different safety classes and non safety cables within a single safety Division are not subject to separation requirements between cable ways. I consider this to be an acceptable arrangement.

58 Separation rules are provided for cables of different voltage level, current and type of signal. These are sound principles to protect against EMI. The assessment of protection against EMI is covered in Section 4.18.

59 Cables entering switchboards are routed from below which protects cables from the effects of electrical faults in the switchboard which could cause loss of multiple circuits within the Division.

60 The design of cable routes is carried out utilising software based systems to identify loading of trays on routes, routing of cables and to identify any cables which require additional protection for connections between Divisions. As there is significant reliance on this system I would expect suitable verification of the software to be performed.

61 The maximum ambient operating temperatures are defined in the Book of Project Data EMSEMD050222 (Ref. 20) and this is used as the basis of applying any derating factors to power cables.

4.3.2 Findings

62 I consider that the fundamental principles proposed for routing of cables are acceptable.

63 Assessment Finding **AF-UKEPR-EE-003** has been raised for the future licensee to undertake detailed assessment of cable routes for individual sites. This will require verification of cable sizes based on protection provisions, ambient derating factors in worst conditions and voltage drop due to cable length. In addition verification will be required that separation criteria between divisions and for protection against EMI have been met.

4.4 DC and Uninterruptible AC Systems

64 The assessment is based on the following documents:

- EDF document ECEF090881-A1 (Ref. 21).
- EDF document ENSEMD090015 (Ref. 19).
- EDF and AREVA response to TQ-EPR-509 (Ref. 8).
- EDF and AREVA response to TQ-EPR-510 (Ref. 8).
- EDF and AREVA response to TQ-EPR-758 (Ref. 8).

65 The battery and inverter systems have been assessed by the TSC in Report 2010-0732 (Ref. 40) which has been used as input information to this report.

66 I have assessed the provisions of battery powered control supplies for operating circuit breakers and contactors on the electrical distribution network. This assessment is based on the EDF and AREVA response to TQ-EPR-1168 (Ref. 8).

4.4.1 Assessment

67 I have assessed the procedure for determining battery rating. This defines initially determining the functional scenarios for each battery and then establishing the load profiles which apply to each scenario. The current for each scenario is then established taking account of permanent and intermittent loads to determine the highest load whilst taking account of appropriate diversity factors. A margin of 10% is then applied to the estimated current.

68 Batteries are sized on the basis of a 10 year life with a minimum battery temperature of 15°C. Ratings are based on operating at the minimum temperature as the battery capacity is lowest at this temperature. A battery ageing margin of 20% has then been applied. Calculations are provided based on the Flamanville 3 (FA3) design to demonstrate the method of calculation and the system ratings adopted.

69 Regular monitoring is specified for batteries by checking electrolyte level, containers, connectors and cell voltage. A battery monitoring system is also provided for each battery system to assist with maintaining the batteries but no safety claims are made on this system. The primary verification of battery integrity is by the regular checking of the batteries as part of the plant maintenance procedures.

70 A short circuit rating on the DC system of 50kA has been determined.

71 The philosophy to obtain grading of the protection is described in EDF document ENSEMD090015 (Ref. 19).

72 The battery systems are not referenced to earth. Protection is provided for detection and location of faults. Battery circuit breakers are fitted with short circuit protection, overload protection is not provided as the batteries are able to withstand short time overloads. In the event of a fault occurring on the AC system fed from the inverter a transfer will occur to the inverter bypass. This ensures that there will be sufficient fault current to operate protective devices to clear the fault and also protect batteries from discharging due to fault current.

73 Each HV and LV switchboard has tripping and closing supplies fed from dual sources in its own Division with provision for interconnections between Divisions 1 and 2 and between Divisions 3 and 4 for maintenance purposes. One supply is derived from a 400V AC Uninterruptible Power Supply (UPS) supplied switchboard and the other from a 220V DC UPS supplied switchboard. These two supplies then feed via power conversion modules to a common DC tripping and closing bus on the switchboard. Monitoring is provided for the DC bus supply. The loss of the DC bus would result in loss of the capability to operate switchgear on the individual switchboard. There would be no impact on any other switchboards on the same Division.

4.4.2 Findings

74 I consider that the methodology for battery sizing to be acceptable based on the functional scenarios and peak loading described in EDF document ENSEMD090015

(Ref. 19) to be acceptable. Adequate margins are applied and battery rating is based on worst condition of operating temperature and ageing. The DC systems and uninterruptible AC systems are designed in a well structured manner according to defined and documented processes. The design limits of the supplies produced by these sources are in line with good practice.

75 I consider that the protection of the battery systems uses basic grading rules which are effective and well proven. The batteries have the capacity to withstand overloads so the arrangement of providing short circuit but not overload protection is acceptable.

76 I consider that the short circuit rating of the DC system is adequate for the duty in the generic case studied.

77 I consider the provisions for providing tripping and closing supplies to switchboards to be consistent with the requirement to operate a high integrity Electrical Distribution System. Alternative diverse sources of supply are provided together with monitoring of the supply on the DC bus to ensure that continuity of supply is maintained.

78 I consider that the methodology proposed for calculation of ratings is acceptable for GDA assessment. Assessment Finding **AF-UKEPR-EE-019** has been raised for the future licensee to determine the battery ratings for each plant based on the design criteria defined in EDF document ECEF090881-A1 (Ref. 21).

4.5 Motor Starting Studies

79 Motor start studies were conducted by the TSC using the ERACS power system model of the EPR Electrical System. The results of these studies are recorded in Report 2010-0644 (Ref. 41). The purpose of the motor start study was to determine the voltage at the terminals of the starting and running motors and at nuclear island buses when the largest motor on each bus is started and to verify that start-up can take place. As the most critical and challenging motor start conditions occur when the supply is provided from the diesel generators the studies were based on operation from the EDG and UDG diesel generators, as appropriate.

4.5.1 Assessment

80 Four motor starting scenarios covering the most onerous conditions were studied as follows:

- Largest motor started from the EDG with no other load on the system.
- Largest motor started from the EDG with 80% of generator full load on the system.
- Largest motor started from the UDG with no other load on the system.
- Largest motor started from the UDG with 80% of generator full load on the system.

81 Curves were produced for each configuration showing busbar voltage, starting current and shaft speed for the motor during starting and running currents and shaft speeds for existing running motors, where relevant. These were compared with voltage limits defined in the Project Data Book EMSEMD050222 (Ref. 20).

82 When the motor starts, the starting current causes a voltage drop at the busbars. When the bus voltage decreases, the Automatic Voltage Regulator (AVR) of the generator

recovers the voltage to nominal. When the motor speed reaches close to 1pu[1] the current drops down to 1pu in a very short period. Consequently, the voltage drop due to the internal impedance of the generator decreases sharply and terminal voltage increases. As the AVR of the generator is not able to respond as quickly as the rate of change of the load current, the busbar voltage overshoots when the motor current falls. The voltage then recovers to 1pu with the response of the AVR. This is typical of motor start-up and of voltage response performance during a successful motor start.

4.5.2 Findings

83 In each case studied I consider the motor starts are shown to be acceptable with motor starting times and busbar voltages within acceptable operating limits for the equipment. In the cases studied with other motors operating on the system the current and speed of these motors remain within acceptable operating limits.

84 I consider that this demonstrates for GDA assessment that the largest motors can be started under the most onerous conditions without any adverse impact on the operation of existing running loads or on system voltage. Assessment Finding **AF-UKEPR-EE-004** identifies a requirement for the future licensee to undertake motor starting studies for each site during detail design based on actual equipment ratings.

4.6 Study of Generator AVR Failure

85 The possible implications of a failure of the Main Generator Automatic Voltage Regulator (AVR) were modelled by the TSC using the ERACS power system model of the EPR Electrical System. The results of this study are recorded in Report 2010-0644 (Ref. 41). The risk that such a failure presents is the possibility of a single event producing potentially damaging overvoltage that could affect all Divisions.

86 The study results are summarised and the EDF and AREVA proposals for protecting against the possibility of overvoltage due to a failure on the Main Generator AVR are assessed.

4.6.1 Assessment

87 In the study, the power plant is assumed to be operating with the Main Generator supplying power to the grid at full load. The station Electrical System is supplied from the 400kV/10kV Step-down Transformers ST1 and ST2.

88 At a study time of t = 1s the main alternator AVR reference point set was altered from 1 to 1.3pu to simulate a possible failure of the AVR in regulation performance. The simulation was of the effect of the failure rather than attempting to recreate precisely an actual AVR mode of failure.

89 As a result of the main alternator and station sharing a common point of coupling at 400kV the source impedance is low and therefore the AVR failure is shown to have a marginal impact upon voltage. However, this condition is then shown to cause an increased flow of reactive volt-amperes (VARs) that would be detected by the alternator protection relays and this will result in a disconnection of the Main Generator from the

[1] To simplify calculations electrical engineers use a system to normalise values known as the per system unit (pu). A pu is defined as the actual quantity (volts, amps, watts etc.) divided by the selected base level. For example if 600 volts was the base level a 0.8 pu would represent 480 volts.

grid. To simulate this effect the study assumed a delay of 1s to allow detection of the event before initiating a trip which islands the Main Generator and station load from the grid.

90 When the Main Generator is islanded from the grid the damping effects of the low source impedance are removed and the alternator field excitation builds up resulting in a rapid voltage increase. The simulation shows a peak of 137% of rated voltage at the generator bars.

91 TQ–EPR–1077 (Ref. 8) requested EDF and AREVA to demonstrate that a Main Generator AVR fault will not cause damage to the Electrical Distribution System. The response states that no studies have been carried out by EDF and AREVA. It then describes a design philosophy which includes redundancy of control and protection that is focused on achieving AVR reliability and, preventing AVR failure. Further protection is provided by protective devices against the potential overvoltage that could result. EDF and AREVA have committed to undertake detailed studies as part of site licensing.

4.6.2 Findings

92 The potential for an AVR failure to result in significant overvoltages on the plant electrical system has been demonstrated by the studies which have been undertaken. The maximum voltages resulting from an AVR failure should be incorporated in equipment purchase specifications as defined in Assessment Finding **AF-UKEPR-EE-015**.

93 I consider the proposals made by EDF and AREVA to conduct studies to investigate the effects of AVR failure and to develop protective strategies to be appropriate. I consider the proposals to minimise the risks and consequences of AVR failure to be comprehensive and based on proven technology.

94 Assessment Finding **AF-UKEPR-EE-007** has been identified for the future licensee to carry out transient studies for each power plant to address the consequences of AVR failure. These studies should address the following:

- The upper limits of voltage that could be developed by the main alternator in the event of AVR failure relative to the withstand capability of the critical system loads.
- The compatibility between the settings being considered on the main alternator and the expected overvoltage resilience of the system and in particular critical plant such as battery chargers.
- The development of an overvoltage protection philosophy for the critical plant that takes account of voltages developed during AVR failure so as to quantify the risk of overvoltage failure and verify that it will not result in overvoltage stress at any point on the system.

4.7 Review of RCC-E: Design and Construction Rules for Electrical Components of Nuclear Islands

95 The RCC-E (Ref. 18) document provides a high level description of the design and construction rules to be followed for electrical equipment installed in the nuclear island. This is a general document covering the full range of French nuclear power plants and specific project data for the UK EPR is provided in the Project Data Book ENSEMD050222 (Ref. 20).

4.7.1 Assessment

96 An assessment has been carried out of the RCC-E (Ref. 18) document highlighting specific areas of importance relative to UK EPR.

4.7.1.1 A 1000: Standards

97 A list of relevant standards is provided in section A1300. The first part of this list consists of IEC Standards which are fully applicable to UK applications. The second part consists of NF EN Standards which are the French implementation of CENELEC Standards derived from IEC Standards and French National Standards.

98 In response to TQ-EPR-559 (Ref. 8) EDF and AREVA have compared the NF EN and BS EN Standards and confirmed that there are no significant variations between these National Standards which will impact on the UK EPR design.

99 The French National Standards have been assessed by EDF and AREVA in response to TQ-EPR-558 (Ref. 8). Details have been provided of these standards or equivalence is demonstrated to IEC Standards. No significant points have been identified which will impact on the UK EPR design.

4.7.1.2 C 2000: Coordination of Electrical Equipment Characteristics

100 This section when read in conjunction with the Project Data Book (Ref. 20) describes basic principles of the Electrical Distribution System. The system voltage levels are specified together with short circuit calculation methods and short circuit ratings for equipment. The requirements for power transformers including on load tap changers are detailed.

101 A high level protection philosophy is provided which is supplemented by the more detailed philosophy assessed in Section 4.2.1. A set of earthing and grounding principles are provided.

102 Design and operating parameters for emergency generators are provided. These include rules for determining ratings and conditions for start up loading and unloading.

103 The peak breaking requirement for High Voltage switchgear is defined as 2.5 to 3 times the Root Mean Square (RMS) value which is above the range for standard switchgear. I queried this in TQ-EPR-561 (Ref. 8) and confirmation was provided by EDF and AREVA that the peak withstand capacity is 125kA which is in accordance with standard ratings. The response to TQ-EPR-561 (Ref. 8) identifies a requirement for a time delay of 85ms to allow time for the decay of the DC component of RMS current. This has possible implications as it results in delays to clearance of faults which could challenge protection discrimination and increase damage to equipment following an electrical fault.

104 The point regarding the circuit breaker time delay to allow decay of the DC component was raised in TQ-EPR-872 (Ref. 8). After further study and investigation by EDF and AREVA the response to this TQ confirmed that no standard time delay is required on circuit breaker operation as commercially available switchgear can be specified to meet the worst case of switching fault currents with DC components. The requirement will be reviewed if required following site specific studies.

4.7.1.3 C 3000: Availability of Equipment During Operations

105 This section describes high level principles for operational monitoring, periodic testing and maintenance. This is complemented by the more specific maintenance philosophy described in response to TQ-EPR-1073 (Ref. 8) which is fully assessed in Section 4.13.

4.7.1.4 D 2000: Conditions Imposed by the Environment

106 Room ambient operating temperatures for electrical equipment rooms are defined in the Project Data Book EMSEMD050222 (Ref. 20) which are compatible with standard type tested equipment ratings. This is based on normal operation with air conditioning equipment fully functional. The document does not make any provision for the effects on room ambient temperatures of air conditioning failures which could result in operating temperatures and humidity levels in excess of the maximum design values. In response to TQ-EPR-1384 (Ref. 8) EDF and AREVA have committed to carry out a full assessment of maximum temperatures and humidity under all operating conditions during detail design which will also consider the availability of other Divisions to maintain service.

107 Voltage limits are defined for AC and DC supplies to C&I equipment. It will be necessary to ensure that these limits are adhered to during all operating conditions.

108 Characteristics and operating limits are defined for the 400kV grid based on French grid requirements which differ from UK requirements. The data provided in Section D 2312 will therefore not be applicable to the UK EPR. Detailed analysis has been carried out by EDF and AREVA of requirements for compliance with the UK Grid Code (Ref. 36) in order to make a connection agreement and this is fully assessed in Section 4.11.

4.7.1.5 D 4000: Earthing System

109 The principles for design of the earthing system are presented in this section. These form a good basis for design of the earthing system. A detailed assessment of the earthing system is covered in Section 4.15.

4.7.1.6 D 5000: Electromagnetic Compatibility Rules

110 This section provides a high level set of principles for design and construction to protect against the effects of electromagnetic interference. More detailed information has been provided by EDF and AREVA which has been the subject of cross-cutting assessment with Internal Hazards. The electrical assessment is covered in more detail in Section 4.18.

4.7.1.7 D 7000: Electrical Equipment Separation Rules

111 This section provides a set of principles for separation of electrical equipment. Requirements for physical and electrical separation of equipment and cables are covered for different safety divisions, safety classes and different electrical functions. Assessment of cable segregation has been the subject of a cross-cutting assessment in conjunction with Internal Hazards. The electrical assessment is covered in more detail in Section 4.3.

4.7.1.8 E 3000: Electrical Equipment Enclosures

112 This section provides a set of principles to be followed for the design and construction of electrical enclosures to provide protection for personnel against contact with live parts

and to provide mechanical protection of equipment against solid objects, liquids and from shock damages.

113 The principles proposed are all based upon established standards to ensure effective impact protection and ingress protection. I consider the protection levels which are proposed within those standards to be appropriate to the application in the plant.

114 A stipulation is made that forced ventilation of cabinets require prior authorisation. I consider that this is appropriate and would expect any applications requiring forced ventilation to be fully considered in the safety case by the future licensee.

4.7.1.9 MC 3100: Electrical Tests

115 This section describes rules for dielectric tests on equipment rated up to 1000V AC and 1500V DC. This principally consists of requirements for dielectric withstand and insulation resistance of equipment

116 The tests described are those which would be expected prior to equipment being energised on site after installation and commissioning or following a maintenance intervention. They do not form a basis for testing of main items of equipment such as switchgear and transformers. These main equipment items would require to be subjected to type, routine and site tests as defined in the relevant IEC Standards for these items of equipment.

4.7.2 Findings

117 I consider that the RCC-E document provides a good high level basis for design and construction of electrical equipment on the nuclear island.

118 I consider that the decision to remove the time delay for High Voltage (HV) switchgear operation is a positive step which will improve the integrity of the Electrical System.

119 Assessment Finding **AF-UKEPR-EE-008** requires the future licensee to identify maximum equipment ambient operating temperatures in the event of failure of air conditioning in electrical equipment rooms which will be used as the basis for specifications for electrical equipment.

120 The use of Section MC3100 of RCC-E must be clarified during site licensing activities as it does not define the totality of testing and the status of this section in relation to testing requirements in equipment specifications must be clarified. Assessment of proposals for equipment specifications has shown this subject to be adequately covered in the structure of equipment specifications. Assessment Finding **AF-UKEPR-EE-015** covers the requirement for the future licensee to fully define equipment specifications including requirements for type and routine testing.

4.8 Fast Transient Disturbances

121 RO-UKEPR-61 (Ref. 9) was raised on EDF and AREVA requiring that claims arguments and evidence be provided to show that fast transient disturbances on the Electrical Power Systems will not cause loss of essential services due to damage or disruption to these services. The particular areas to be considered were:

- Capacitive switching.
- Current chopping.

- Re-strike.
- Voltage Escalation.
- Pre-strike.
- Unearthed three phase systems.
- Virtual current chopping.

4.8.1 Assessment

122 The response to RO-UKEPR-61 (Ref. 9) identifies the work that will be carried out to address the protection of the system against the effects of fast transient disturbances. This work will be carried out in two stages by the licensee. The first stage consisting of the following activities:

- Initiating events will be identified which could give rise to fast voltage transient stress.
- The assumptions and network characteristics which form the basis for analysing the initiating events and the likelihood of occurrence will be declared.
- The risk of occurrence of the fast voltage transient events will be analysed.
- Appropriate analysis software will be selected and models created.
- The fast transient analysis will be conducted to establish an understanding of the threat, and bounding conditions.
- Mitigations will be identified that will protect against the fast voltage transient events identified.
- Analysis of the effects on failure of one line of transient overvoltage protection.

123 The second stage will consist of the following activities:

- Ferro-resonant threats will be identified.
- The assumptions and network characteristics which form the basis for analysing the initiating events and the likelihood of occurrence will be declared.
- The risk of occurrence of the ferro-resonant events will be analysed.
- Appropriate software will be selected and models created.
- The ferro-resonant analysis will be conducted to establish an understanding of the threat, and bounding conditions.
- Mitigations will be identified that will protect against the ferro-resonant events identified.
- The mitigations of these phenomena are expected to be related to the network operation and not related to equipment or architecture design.

4.8.2 Findings

124 I consider that the plan proposed in the response to RO-UKEPR-61 (Ref. 9) represents a logical sequence to addressing the risks from fast voltage transients and from ferro-resonance. It demonstrates a commitment to identifying and mitigating possible risks.

125 I consider the approach proposed of undertaking the assessment on a site specific basis to be correct. Assessment Finding **AF-UKEPR-EE-005** identifies the requirement for the future licensee to carry out studies to identify threats from fast transients and protective measures to be taken to protect against them during detailed design.

4.9 Short Circuit Studies

126 Studies for the calculation of three phase fault currents on the high voltage and low voltage systems have been carried out by EDF and AREVA. The results of these studies are detailed in EDF document ENSEMD090233 (Ref. 22). These studies are used to determine the short circuit ratings for electrical equipment on the Electrical System for the power plant.

127 In order to verify the results of the EDF calculations short circuit studies were undertaken by the TSC using the SKM power system model of the EPR Electrical System. The results of this study are covered by Report 2009-0122 (Ref. 42).

4.9.1 Assessment

128 The calculations performed by EDF and AREVA are based on the worst-case operating conditions which result in the highest level of fault current. The worst-case conditions have been identified as during normal reactor operation at full power with the grid connected and a diesel generator connected in parallel synchronised with the grid. This operating configuration is used during periodic testing of the diesel generators on load. The calculation takes account of grid contribution, generator contribution and motor fault contribution. As there are four Divisions only Division 1 is considered as this has both EDG and UDG generators.

129 The scenarios studied for both the EDF and TSC reports are as follows:

- Scenario 1 considers the grid and EDG connected with the UDG out of service. Motors are operating at full power.
- Scenario 2 considers the grid and UDG connected with the EDG out of service. Motors are operating at full power.

130 The results from the studies showing fault levels for the two scenarios comparing the results from EDF and the TSC are covered in Tables 1 and 2 below:

Table 1: Comparison of Fault Levels for Scenario 1

Bus	Design Parameter			EDF Document ENSEMD090233				TSC studies			
	Volt (kV)	Ip 3P (kA)	Ib 3P (kA)	Ip 3P (kA)	Ib 3P (kA)	Idc 3P (kA) at 50 ms		Ip 3P (kA)	Ib 3P (kA)	Idc 3P (kA) at 50 ms	
LGA	10	125	50	**130.6**	45.06	29.98	47.05%	**131.84**	47.56	19.52	29.02%
LGF	10	125	50	115.65	42.04	28.54	48.00%	115.53	44.11	7.78	12.47%
LGK	10	125	50	-	-	-	-	129.53	47.36	13.24	19.77%
LGP	10	125	50	56.35	32	0.04	0.09%	56.76	33.54	0.01	0.02%
LHA	10	125	50	110.04	40.37	11.35	19.88%	109.44	41.84	6.83	11.54%
LIA	0.69	110	50	101.89	41.14	7.35	12.63%	102.47	41.27	7.01	12.01%
LIF	0.69	110	50	**124.1**	**51.74**	4.48	6.12%	101.96	44.64	4.53	7.18%
LJA	0.69	160	65	132.52	52.38	8.39	11.33%	125.96	49.10	8.28	11.92%
LJK	0.69	160	65	124.02	49.56	8.38	11.96%	119.47	48.00	8.09	11.92%
LKA	0.4	110	50	101.29	41.53	7.68	13.08%	101.05	41.46	7.55	12.88%
LKF	0.4	110	50	101.91	42.27	5.11	8.55%	101.77	42.17	5.18	8.69%
LKK	0.4	160	65	153.98	63.36	11.65	13.00%	154.08	63.40	11.43	12.75%
LLA	0.4	110	50	**127.3**	**51.96**	9.23	12.56%	**126.85**	**51.86**	8.97	12.23%

Table 2: Comparison of Fault Levels for Scenario 2

Bus	Design Parameter			EDF Document ENSEMD090233				TSC studies			
	Volt (kV)	Ip 3P (kA)	Ib 3P (kA)	Ip 3P (kA)	Ib 3P (kA)	Idc 3P (kA) at 50 ms		Ip 3P (kA)	Ib 3P (kA)	Idc 3P (kA) at 50 ms	
LGA	10	125	50	113.8	40.22	25.24	44.37%	114.59	42.28	18.16	30.37%
LGF	10	125	50	102.53	37.85	15.28	28.55%	102.07	39.57	7.28	13.01%
LGK	10	125	50	-	-	-	-	112.52	42.15	11.52	19.33%
LGP	10	125	50	53.11	29.74	0.05	0.12%	53.22	31.00	0.01	0.02%
LHA	10	125	50	91.8	35.37	8.7	17.39%	90.70	36.63	4.43	8.55%
LIA	0.69	110	50	101.15	40.79	7.39	12.81%	101.39	40.80	6.93	12.01%
LIF	0.69	110	50	**123.2**	**51.27**	4.55	6.28%	100.65	44.04	4.49	7.21%
LJA	0.69	160	65	**171.43**	**66.17**	9.47	10.12%	143.73	59.07	8.06	9.65%
LJK	0.69	160	65	116.13	47.32	8.22	12.28%	117.41	47.17	7.80	11.69%
LKA	0.4	110	50	100.8	41.3	7.71	13.20%	100.15	41.07	7.47	12.86%
LKF	0.4	110	50	101.47	42.05	5.15	8.66%	100.93	41.79	5.14	8.70%

Bus	Design Parameter			EDF Document ENSEMD090233				TSC studies			
	Volt (kV)	Ip 3P (kA)	Ib 3P (kA)	Ip 3P (kA)	Ib 3P (kA)	Idc 3P (kA) at 50 ms		Ip 3P (kA)	Ib 3P (kA)	Idc 3P (kA) at 50 ms	
LKK	0.4	160	65	152.87	62.84	11.72	13.19%	152.39	62.67	11.30	12.75%
LLA	0.4	110	50	**126.08**	**51.48**	9.12	12.53%	**125.14**	**51.17**	8.74	12.08%

131 For Scenario 1, the fault levels compare favourably except on switchboard LIF. The difference between the results is due to induction machine fault contribution which has been taken into account in the EDF document but the TSC was not able to identify the magnitude of all motor fault contributions for inclusion in their calculations.

132 For Scenario 2, the results differ for the same reasons as in scenario one with regard to switchboard LIF. There is a discrepancy in the calculations for switchboard LJA between TSC and EDF and AREVA results which requires verification by EDF and AREVA.

133 Tables 1 and 2 compare the DC components at 50ms. The results show that the DC component calculated by the TSC is lower in all cases than in the EDF document ENSEMD090233 (Ref. 22). The lack of correlation points to differences in resistance data used between the EDF and TSC analyses. The higher of the figures is calculated by EDF and AREVA. This is within acceptable limits and will not present any challenges to the system.

4.9.2 Findings

134 There are discrepancies between the results of calculations of DC components between the EDF and AREVA studies and TSC studies. The calculations will need to be carried out on the final design by the future licensee. However, there is no indication from the results of either study that special switchgear designs or significant design changes are required. The calculated results support the assessment covered in Section 4.7.1.2 that no time delay is required on circuit breaker operation to allow for decay of the DC component of current.

135 There is agreement between the EDF and TSC calculations that the equipment short circuit ratings are exceeded on a number of switchboards when operating with the grid in parallel with the diesel generators. This is recognised in the EDF document ENSEMD090233 (Ref. 22) but no proposals are made in this report on how to resolve this. Assessment Finding **AF-UKEPR-EE-006** identifies a requirement for the future licensee to calculate short circuit fault levels and specify appropriately rated switchgear to meet these requirements.

136 TQ-EPR-1078 (Ref. 8) queried how the requirement to resolve the short circuit ratings was to be addressed. For the EDG operation identified in Scenario 1 it is proposed to disconnect the APA pumps during diesel generator testing so that they do not contribute to fault current. EDF propose to identify pumps on LV switchboards which can be disconnected during diesel generator testing to address the fault levels identified in Scenario 2.

137 EDF and AREVA have proposed other possible solutions to be considered such as increasing the medium voltage switchgear rating to 11kV, increasing switchgear short circuit current ratings or load shedding in order to ensure that ratings are not exceeded.

138 I consider that all the potential solutions are acceptable although there may be difficulties in sourcing suitable switchgear if short circuit ratings are increased. Assessment Finding **AF-UKEPR-EE-006** has been raised for the future licensee to fully assess the requirement during detailed design based on site specific calculations so that the correct solution for short circuit fault ratings can be identified and justified.

139 Studies presented by EDF and AREVA have been based on three phase studies only. **AF-UKEPR-EE-006** identifies a requirement for the future licensee to conduct single phase fault studies during detailed design.

4.10 Transient System Disturbances

140 A series of studies have been performed to investigate the responses of the Electrical Distribution System on the power plant to disturbances both internal and external which could challenge the stability of the Electrical System with the potential for loss of electrical supplies.

141 The studies are based on the following:

- TSC Report 2010-0644 (Ref. 41) using the ERACS model of the Electrical System developed by the TSC.
- EDF document ENSEMD090232 (Ref. 23).
- EDF and AREVA response to TQ-EPR-869 (Ref. 8).
- EDF and AREVA response to TQ-EPR-877 (Ref. 8).
- EDF and AREVA response to TQ-EPR-1082 (Ref. 8).

142 A number of scenarios have been studied to assess the resilience of the Electrical Distribution System to maintain stability and thus continuity of supply. The particular studies which have been performed consist of the following:

- Automatic transfer of supply to the Standby Transformer on undervoltage.
- Post fault recovery following a three phase fault at the diesel generator terminals.
- House load operation of the system following a total loss of grid supply.
- System responses to prolonged voltage dips.

4.10.1 Power Transformer Switchover Transient Study

143 Dynamic studies which simulate the impact of changeover from the Step-down Transformer (ST) to the Standby Transformer (AT) upon the Electrical Supply Systems have been conducted by EDF and AREVA. The results of these studies are described in document ENSEMD090232 (Ref. 23). These results have been independently verified by studies performed by the TSC using the ERACS power system model of the UK EPR Electrical System. This assessment describes the results of the TSC verification study and compares the results with those from the EDF and AREVA study.

4.10.1.1 Assessment

144 Divisions 1 and 3 are each supplied from one of the two secondary windings of ST1. Divisions 2 and 4 are each supplied from one of the two secondary windings of ST2. In the event of a voltage reduction on the primary of either ST1 or ST2 creating a voltage

reduction on switchboard LGi of less than 70% for more than 1.2s an automatic preventive changeover is initiated to the Standby Transformer AT, which is fed from a separate supply source.

145 The following simulation sequence for ST to AT switchover was applied:

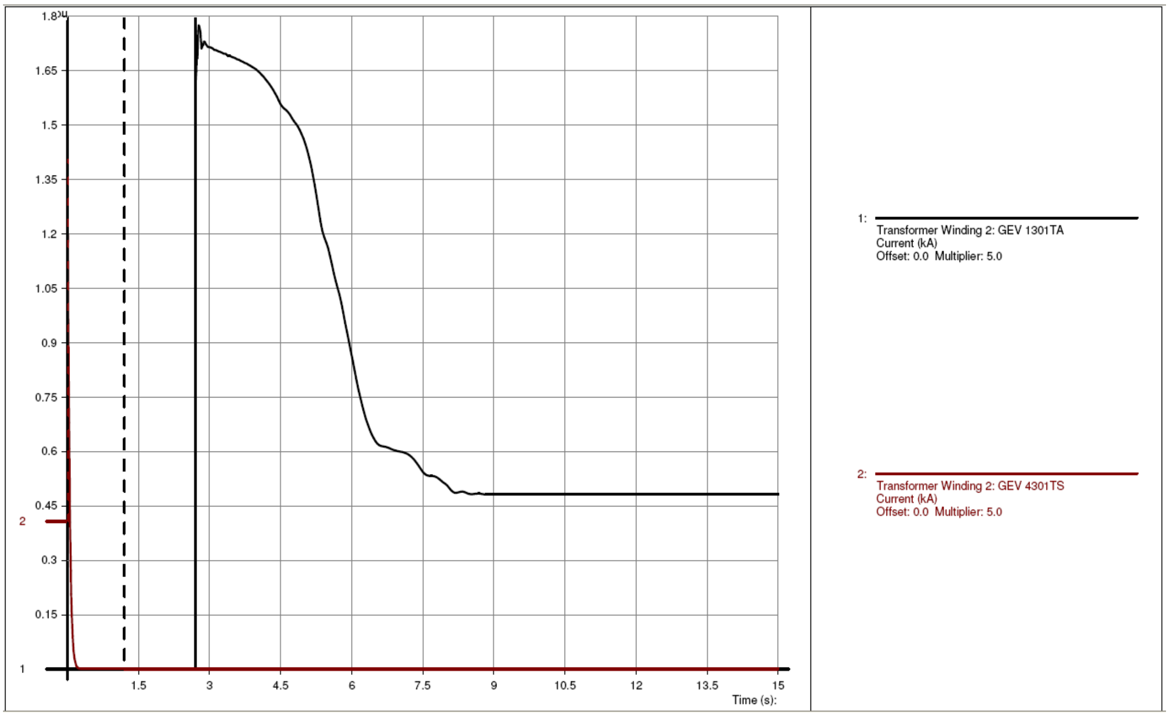
- Applying a solid three phase fault at ST 10kV terminals (0s – 1.2s). The control logic initiates changeover from ST to AT if the U_{LGi} is less than 0.7pu for 1.2 seconds or more.
- Opening of circuit breakers supplying switchboard LGi from the Step-down Transformers ST at t = 1.2 s.
- Shutdown of 10kV and LV actuators (690V and 400 V) that were not switched to the AT or were not subsequently reconnected including HV motors (APA1/2, CEX2, CTE1, RCP1/2) and LV motors connected to switchboards LIA, LIF, LIB and LJL at t = 1.2s.
- When the auxiliaries are not fed from ST or AT the residual voltage must fall below 0.3 U_n in under 1.5 s. Therefore, the circuit breakers powering switchboards LGi from the AT closes 1.5s after ST opens at t = 2.7s from fault initiation. Section 3.2.3 of report ENSEMD090232 (Ref. 23) states that the total duration of ST to AT switchover is set to 1.5 s which 'includes the Control and Instrumentation (C & I) and circuit breaker operating time as this is the most critical case'.
- Re-starting non-disconnected 10kV and LV actuators in accordance with power balance data, including HV motors (AAD1 and RRI2) and LV motors connected to switchboards LIA, LIF, LIB and LJL at t = 2.7s from fault initiation.

146 The mechanical load torque on all motors was modelled as being proportional to the square of the speed. This is in line with the approach described in the EDF Report ENSEMD090232 (Ref. 23).

147 Currents flowing through ST and AT on the LV side during the switchover with respect to time are plotted in Figure 2. The short circuit is applied at time zero. The first almost vertical dotted line shows when the short circuit is removed after 1.2s and the ST circuit breaker opened. The second almost vertical line shows when the AT supply is applied. At 2.7 seconds (1.2s for fault duration + 1.5s for delay after ST opens), the circuit breaker supplying the system from AT is closed and the motors are re-started.

148 An objective of the preventive changeover is to react to the transient voltage reduction and achieve the changeover from ST to AT without starting the EDG. The criterion to achieve this is that the voltage at the diesel generator switchboard should recover above 80% in 5s. Figure 3 shows the voltage at each busbar, recovering to within 80% of nominal in approximately 5 seconds. The important point to observe is that the voltage recovery occurs and shows no tendency for motors to stall. This recovery time is greater than that shown in EDF document ENSEMD090232 (Ref. 23) due to different load inputs being applied to the model so considers a more onerous case. This shows that the system is robust and recovery is assured.

Figure 2: Currents flowing through ST and AT at LV side during the switchover



149 A study was carried out to assess the scenario of a fault causing a voltage depression cleared in less than the delay time of 1.2s. The circuit breakers supplying the system from ST would then not be switched off and the transfer to AT would not occur. In order to explore the implications of this a further study was conducted with duration of 1.19s.

150 The possible implications are that a changeover from ST to AT could still occur if the voltage reduced at the LGi switchboards to less than $0.7U_n$ for longer than 3.5s. This is the changeover criteria considered in EDF document ENSEMD090232 (Ref. 23). A further possibility is that start-up of the EDG supplying the system would be initiated.

151 The voltages at LGi and LHi are shown in Figure 4 for a solid three-phase fault at ST HV terminals lasting for 1.19s with the grid being disconnected and leaving the main alternator supplying the nuclear power plant. The results of this study are as follows:

- ST to AT switchover will not be initiated as the voltage of switchboards LGi is not less than 0.7 U_n for more than 3.5 s.
- The EDGs will not start up as the voltage of the emergency supplied switchboards LHI is not less than 0.8 U_n for more than 5 s.
- Voltage recovery is achieved.

Figure 3: Voltage Recovery at Each Busbar after Switchover from ST to AT

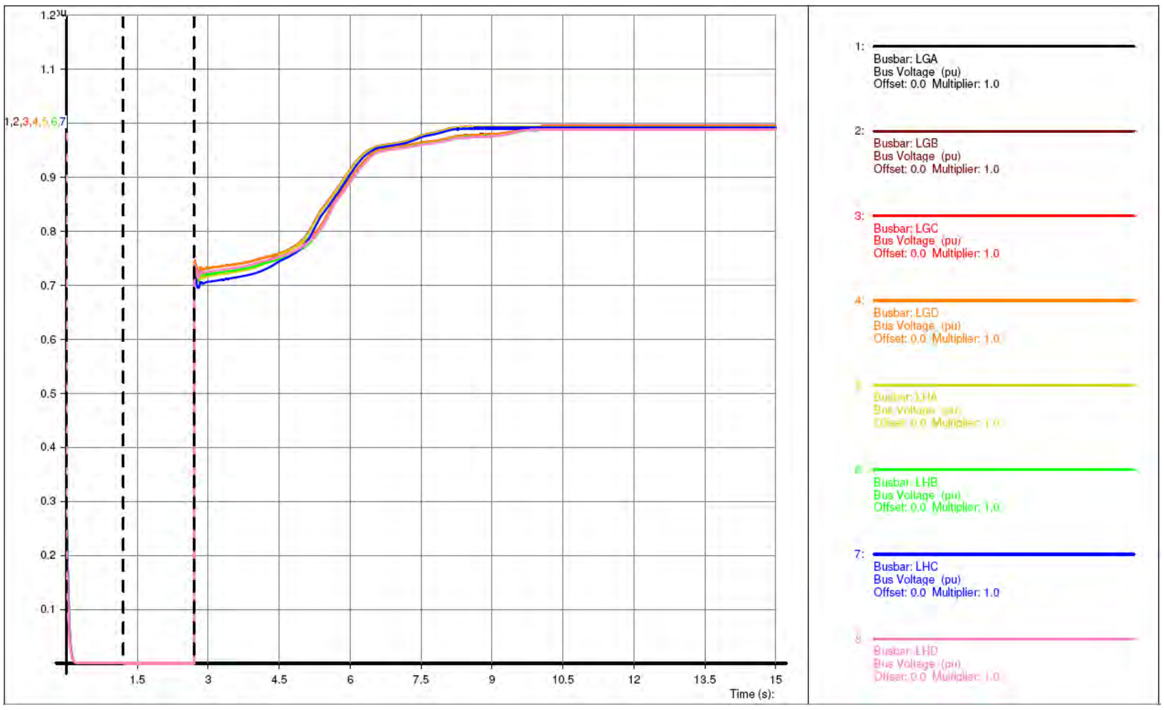
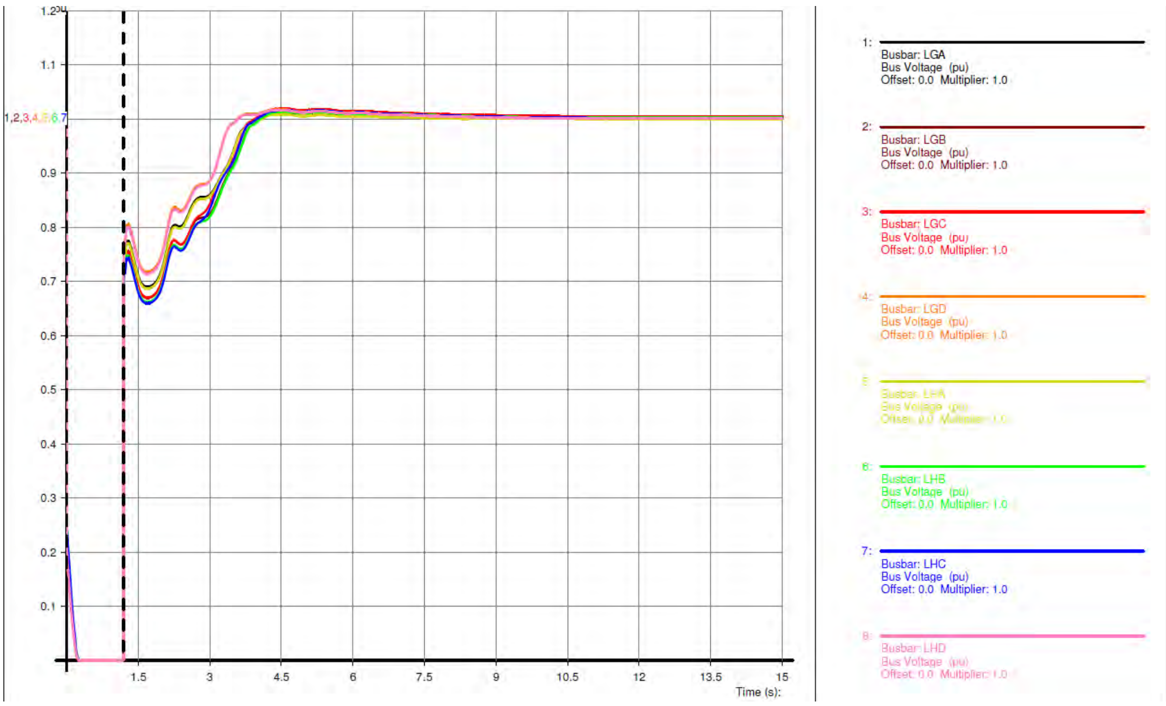


Figure 4: Voltage Recovery at Each Busbar after a 1.19s Three Phase Fault Is Cleared and the Grid Coupling Circuit Breaker Is Opened During the Fault



4.10.1.2 Findings

152 The study was conducted to examine if the system could recover during the switchover from ST to AT. The simulation sequence used in the document ENSEMD090232 (Ref. 23) was applied. The study results show that the voltage recovers and there is no tendency for motors to stall. I consider that this shows the system to be robust and recovery is assured.

153 The motors reaccelerate after the short circuit event of 1.2s and the subsequent changeover delay of 1.5s. This assumes that all motors are connected at the time that the voltage recovers as contactors will remain held in by the battery backed supplies.

154 The motor reacceleration currents imposed on the AT transformer peak at 4pu and remain above 1pu for 5.8 seconds. This is a significant short time overload on the transformer. The future licensee shall ensure that the transformer specification correctly specifies the duty of motor reacceleration.

155 The voltage on all busbars is zero from the time of the short circuit fault to switchover to the AT transformer at 2.7s after fault initiation. The motors do not sustain significant system voltage during this period. Voltage recovery after switchover to 90% of nominal levels is further delayed by motor acceleration currents and is in the order of 3.1s to 3.4s. These are predictable trends that verify the system is operating in a stable manner.

156 The study described in EDF document ENSEMD090232 (Ref. 23) is comprehensive in its scope and coverage and also verifies dynamic recovery and post event stability. I agree with the EDF and AREVA conclusions in this document.

157 A grid voltage reduction lasting only 1.19s was studied to consider the case when the preventative changeover voltage reduction threshold is only marginally avoided. The studies showed that this resulted in U_{LGi} being less than 0.7pu for 1.2 seconds. These studies show that the system is capable of recovery without any load shedding taking place.

4.10.2 Post Fault Recovery Study

158 The TSC carried out a post fault recovery study to identify the recovery capability of the system following a three phase fault when operating from the diesel generators with no Main Generator or grid connection. The purpose of this study was to investigate the worst case scenario so was based on conservative assumptions. The results of the study are covered by TSC Report 2010-0644 (Ref. 41). The assessment of the recovery from a grid fault is covered in Section 4.10.3.

4.10.2.1 Assessment

159 When the fault occurs at the terminals of the diesel generator, the bus voltage falls to zero. The motors will initially contribute current into the fault due to their internal voltage. The motor speed reduces during the fault period because the developed torque falls to zero.

160 After the clearance of the fault, the motor terminal voltage recovers and the motors will collectively draw more current than in the pre-fault condition because they are running more slowly. The magnitude and duration of this reacceleration current depends upon the duration of the fault and the voltage conditions in the post fault period. If voltage does not recover sufficiently quickly some motors may stall and in practice could trip on overcurrent. The results of the post fault recovery study were examined to identify if any of these symptoms of instability or stall were indicated.

161 Two configurations were considered in the study. In each case the approach was to impose a 100ms fault and examine the results for evidence of instability. The fault duration was then increased in steps of 100ms up to a maximum duration of 3s. After each step change in fault duration the results were examined for evidence of instability. The purpose of this approach to the study was to examine if there was an upper limit of fault duration above which instability could occur. The 3s limit was selected because a fault duration of longer than this interval is not credible with a correctly graded circuit protection system.

162 The configurations considered are as follows:

- Operation from the Emergency Diesel Generator (EDG) with a load of 80% generator rating.
- Operation from the Ultimate Diesel Generator (UDG) with a load of 80% of generator rating.

4.10.2.2 Findings

163 The studies performed showed that the voltage can be recovered in all the systems assessed with no evidence of instability.

164 Assessment Finding **AF-UKEPR-EE-009** identifies a requirement for the future licensee to carry out post fault recovery studies for scenarios operating from the diesels based on actual equipment ratings.

4.10.3 House Load Operation at 100% Power

165 The purpose of the study was to determine if the operating voltage range on the power plant auxiliary switchboards remain within acceptable limitations when house load operation of the main generator from the grid occurs at full power. House load operation is the condition where the power station is suddenly disconnected from the grid while operating at power.

4.10.3.1 Assessment

166 The results of house load operation studies are presented in EDF document ENSEMD090232 (Ref. 23). These results were verified by studies performed by the TSC to independently validate the studies using the ERACS power system model of the EPR Electrical System.

167 House load operation occurs if the grid voltage (U_{grid}) falls below 80% for more than 2.5s. The criteria for successful performance were defined as follows:

- The alternator and the 10kV and LV switchboard voltages must not exceed 1.4 U_n. In addition, the voltage must only remain within the upper limits of the fault range (1.1 U_n – 1.4 U_n) for a short period of a few seconds.
- ST to AT switchover must not be initiated which occurs if the LGi switchboard voltage is less than 0.7 U_n for more than 3.5 s.
- The EDGs must not start-up which occurs if the voltage of the emergency supplied switchboard LHi is less than 0.8 U_n for more than 5 s.

168 Two scenarios were assessed, in both scenarios the parameters were as follows:

- Active power 100%.
- Stator voltage 23kV.
- Grid voltage at point of connection 400kV.

169 For Scenario 1 a three phase fault of 2.5s duration was placed at the unit's point of connection to the main transmission grid. This was initiated at a study time of 3s and ended at a study time of 5.5s. The 3s study time was selected to allow steady state model conditions to be achieved and confirmed.

170 The voltage regulation signal was blocked between the study times of 3s to 5.5s. The purpose of this was to replicate the proposed AVR control scheme which is designed to limit the amplitude of the voltage oscillations that could otherwise develop if the normal operation of the AVR continued.

171 The Power Plant Electrical System was islanded after a fault duration of 2.5s at a study time of 5.5s.

172 The blocking of the voltage regulation signals are removed at a study time of 5.5s

173 The second scenario is the same as the first scenario with the exception that the AVR operates without blocking.

174 The results for Scenario 1 are shown on Figure 5 and for Scenario 2 on Figure 6.

175 Figure 5 shows for Scenario 1, that the voltage remains under 1.1 U_n.

176 Figure 6 shows for Scenario 2, that the main alternator voltage is within the upper limits of the accident range of 1.1 U_n – 1.4 U_n for 2.1 seconds. The other calculated voltages for the 10kV switchboard and the LV switchboards also rise to within the 1.1 U_n – 1.4 U_n range but for a shorter time of less than 1 second.

177 The voltage of switchboards LGB is less than 0.7 U_n for less than 3.5 s. Therefore, ST to AT switchover will not be initiated. The voltage of the emergency supplied switchboards LHA is not less than 0.8 U_n for more than 5 s, so the emergency diesel generators (EDG) will not start-up.

Figure 5: Results for Scenario 1 of House Load Operation at 100% Power

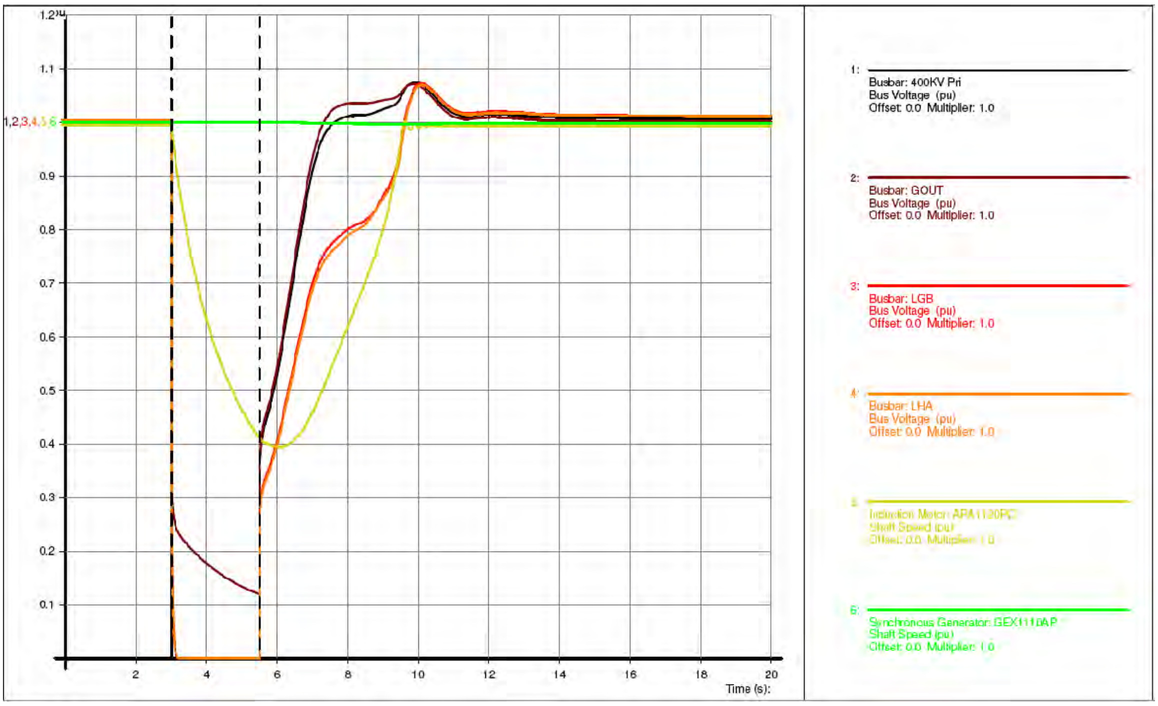
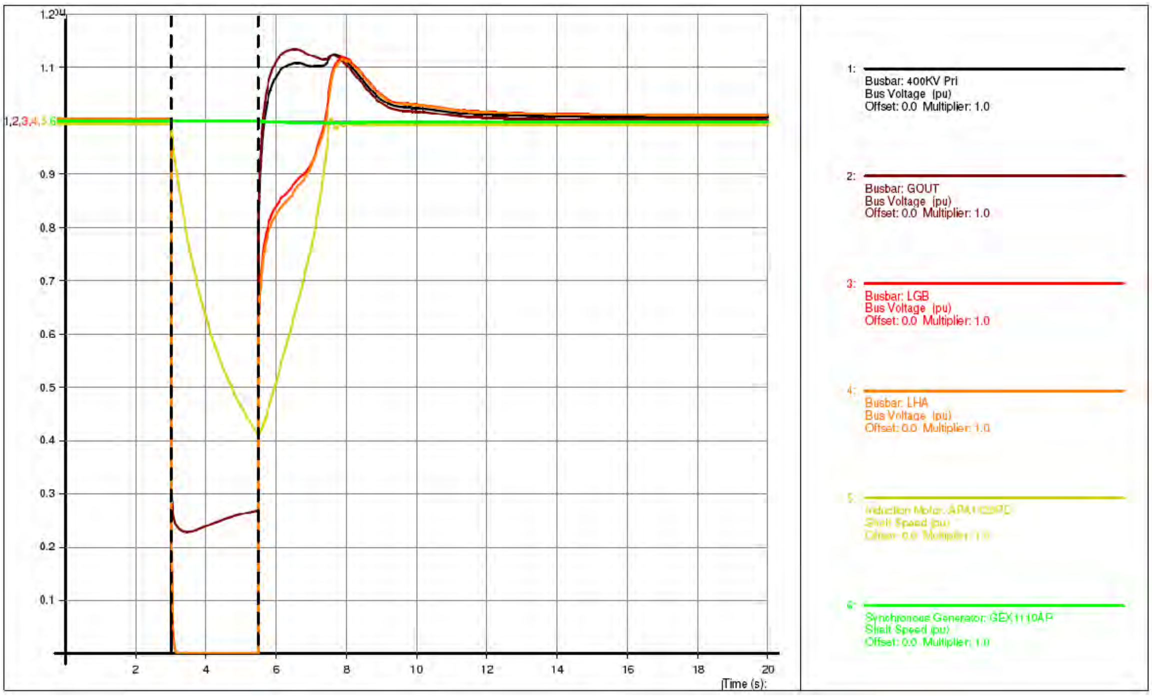


Figure 6: Results for Scenario 2 of House Load Operation at 100% Power



4.10.3.2 Findings

178 The results show that the voltage remains within acceptable limits when the system operates under the condition of house load operation at full power. This will not result in automatic start up of the EDGs when the system goes into house load operation. I

consider that this demonstrates that the system remains stable under house load conditions.

179 Assessment Finding **AF-UKEPR-EE-009** has been raised for studies of the effects of house load operation at full power to be carried out by the future licensee based on actual site parameters during detail design.

4.10.4 Grid Voltage Dip Assessment

180 The study of the behaviour of the electrical system during grid voltage dips is reported in EDF document ENSEMD090232 (Ref. 23).

4.10.4.1 Assessment

181 The voltage dip considered in the report is as follows:

- 100% grid reduction for 150ms.
- Voltage recovery to 50% for 550ms.
- A linear recovery to rated voltage in 800ms.

182 This describes a voltage dip event lasting 1.5s. The study demonstrates that the Main Generator will remain connected to the grid and the Plant Electrical System can continue to function without initiating any of the other defensive strategies that have been considered. The voltage dip will not trigger any of the following:

- House load operation of the Electrical System with the Main Generator.
- ST to AT transfer.
- Emergency Diesel Generator (EDG)start.

4.10.5 Findings

183 I consider that the system has been demonstrated to be resilient to the effects of grid voltage dips. More detailed studies will be required during detail design but the basic resilience of the system has been demonstrated for generic assessment.

184 Assessment Finding **AF-UKEPR-EE-009** identifies a requirement for studies to be carried out by the future licensee during detail design.

4.11 Grid Code Compliance

185 It is a requirement for a Connection Agreement to be in place for the UK EPR to be connected to the UK Grid. A requirement before this is put in place is for the grid technical requirements to be met. These technical requirements are defined in the UK Grid Code (Ref. 36).

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

187 There are various requirements within the UK Grid Code (Ref. 36) for generating plant to remain connected at times of grid disturbances which are important for the grid operator in maintaining continuity of supply. However, this requires the Main Generator and the

Plant Electrical System for the reactor to remain operational up to defined disturbance limits. It is the purpose of this assessment to consider the functioning of the Plant Electrical System and its connected equipment at the maximum tolerances defined in the UK Grid Code (Ref. 36).

4.11.1 Assessment

188 EDF and AREVA have demonstrated that they have carried out a comprehensive study of all Grid Code requirements. An initial review identified 33 compliances and 29 points with a possible impact on design. Further assessment of the requirements of the Code identified 11 key points which had to be considered in order to reach agreement. This assessment will concentrate on these 11 key points in assessing the implications for Grid Code (Ref. 36) compliance.

189 Following further investigation EDF and AREVA have confirmed that they are compliant with the clauses detailed in Table 3.

Table 3: Grid Code Clauses – Compliance Confirmed

GC Reference	Subject
CC.A.3.3	Frequency Response
CC.A.6.2.4.3	On Load Positive Ceiling Voltage
CC.6.3.2	Reactive Capability

190 The clauses which have been assessed, following initial analysis, as being achievable of meeting the specific Grid Code requirement are detailed in Table 4.

Table 4: Grid Code Clauses – Compliance Achievable

GC Reference	Subject	Requirement
CC.A.6.2.1 : CC.A.6.2.2 CC.A.6.2.5 : CC.A.6.2.6	Power System Stabiliser (PSS)	Standard PSS switched off for tests
CC.A.6.2.4.1	Excitation System	Maximum time to reach ceiling voltage
CC.6.3.15(a)	Short Circuit	To remain stable on grid faults and restore Active Power at Min Q
CC.6.3.4	Step up Transformer	On load tap changer required

191 Table 5 lists clauses which were assessed as being areas where it would not be possible to meet the UK Grid Code (Ref. 36) and where agreement was required to resolve.

Table 5: Grid Code Clauses- Compliance not Achievable

GC Reference	Subject	Requirement	Action
CC.6.1.2: CC6.1.3 CC.6.3.3	Frequency range	Continuous operation 47.5-50Hz Active power reduction with frequency drop	New proposals for time limitations of frequency variations
CC.6.3.15(b)	Voltage Dips	To remain stable at min Q for voltage profile	Under discussion
CC.6.3.2(a)	Short circuit ratio	SCR>0.5	SCR 0.4 agreed for units>1600MVA

4.11.2 Findings

192 I consider that the work carried out in assessing the implications of meeting the UK Grid Code (Ref. 36) has been carried out in a very thorough manner to ensure that all the implications have been assessed. This has included ensuring that there are no implications on the Plant Electrical System when remaining connected to the Grid under fault conditions. Where areas of concern have been identified discussions have been held with National Grid and agreement generally reached on solutions.

193 The one outstanding point on voltage dips can be resolved during detail design. I am satisfied that adequate demonstration has been made and that there are no threats to the plant in meeting UK Grid Code (Ref. 36) requirements in operation.

194 Assessment Finding **AF-UKEPR-EE-010** covers the requirement for the future licensee to ensure UK Grid Code (Ref. 36) compliance during detail design.

4.12 Power Quality

195 A study was carried out by the TSC using the ERACS power system model of the EPR electrical network to assess the potential harmonic distortion on the AC system. The results of this study are recorded in Report 2010-0701 (Ref.43). It has been assumed that the only non linear loads on the system are battery chargers and that there are no variable frequency drives on the system. Divisions 1 and 4, which are identical, have more connected battery chargers and inverters than Divisions 2 and 3 so the modelling has been carried out on the Division 1 Electrical System. The assessment is based on the assumption of battery chargers consisting of phase controlled rectifiers of the 6 pulse type as this represents the most onerous condition.

Table 6: Harmonic Profile at Busbar LJA When Battery Chargers Act as Harmonic Source

Harmonic Number	Voltage (% of Fundamental) at LJA When Charger Feed	Compatibility Levels for Class 1 Equipment	Compatibility Levels for Class 2 Equipment	Compatibility Levels for Class 3 Equipment
THD	4.1	5	8	10
5	1.4	3	6	8
7	1.4	3	5	7

Harmonic Number	Voltage (% of Fundamental) at LJA When Charger Feed	Compatibility Levels for Class 1 Equipment	Compatibility Levels for Class 2 Equipment	Compatibility Levels for Class 3 Equipment
11	1.4	3	3.5	5
13	1.4	3	3	4.5
17	1.4	2	2	4
19	1.4	1.8	1.8	3.5
23	1.3	1.4	1.4	2.8
25	1.4	1.3	1.3	2.6
29	1.3	1.1	1.1	2.1

4.12.1 Assessment

196 Scenario 1 considers Division 1 supplied from the UDG. This scenario is considered because it represents the lowest rated supply source which could result in the highest voltage distortion. The harmonic profile on switchboard LJA was examined with connected systems comprising the 2 hour battery with a rating of 1800A and the 12 hour battery with a rating of 300A.

197 The results for Scenario 1 are shown in Table 6. This shows that the 25th and 29th harmonics at LJA exceed the levels set for Class 1 and Class 2 equipment as defined in IEC 61000-2-4: 2002 (Ref. 24). This would need to be studied by the future licensee to ensure that the voltage waveform distortion is compatible with the battery chargers and all other equipment supplied from the same point of coupling.

198 Scenario 2 assesses the condition where the C&I systems, which are normally sourced from the inverters, are fed from the alternative supply via the inverter bypass from a regulated voltage supply. This could occur if the inverter control circuits detected an internal fault causing automatic transfer to the bypass. The harmonic content of the C&I system load current would then be expected to cause voltage distortion with the supply taken through the regulated voltage supply. This compares with the normal supply from the inverter where the output is regulated to minimise load distortion. In this scenario it is assumed that collectively the C&I equipment has a harmonic current frequency spectrum relative to fundamental current similar to that of a rectifier. The analysis has been conducted to establish the amplitude levels of the harmonic component relative to the total fundamental load current that gives rise to a distortion equivalent to the Class 1 limits as defined in IEC Standard 61000-2-4: 2002 (Ref. 24).

199 The results in Table 7 show that the current harmonic levels could give rise to voltage harmonic levels equivalent to the voltage limits of Class 1 equipment as defined in IEC 61000-2-4: 2002 (Ref. 24). This condition should be examined by the future licensee to verify that the voltage waveform distortion is compatible with the C&I equipment requirements when supplied from the bypass. In general the study shows that it is important that power quality conditions on the supplies to the critical battery chargers and inverters while on bypass are examined during the site specific design. This will enable verification of the compatibility of all equipment supplied from all switchboards supplying critical equipment.

Table 7: Harmonic Spectrum of the C&I Load Current That Was Found to Give Rise to a 5% Voltage Total Harmonic Distortion (THD) at the Output of the Regulated Transformer

Harmonic Number	Current Harmonic Content Relative to Fundamental	Voltage (% of Fundamental) at LOA	Compatibility Levels for Class 1 Equipment
THD		5.0	5
5	4.37%	1.9	3
7	3.12%	1.9	3
11	1.99%	1.8	3
13	1.69%	1.8	3
17	1.28%	1.7	2
19	1.14%	1.6	1.8
23	0.95%	1.5	1.4
25	0.87%	1.4	1.3
29	0.75%	1.3	1.1

4.12.2 Findings

200 I consider that the worst case voltage distortion due to the battery chargers should be examined by the future licensee to verify that the voltage waveform distortion is compatible with the battery chargers and all other equipment supplied from the same point of coupling. Assessment Finding **AF-UKEPR-EE-013** covers the requirement for the future licensee to incorporate this in purchase specifications.

201 I consider that the future licensee should conduct studies to verify that voltage distortion is within the compatibility levels of the C&I equipment that are sourced from the inverters in all inverter operating modes. Assessment Finding **AF-UKEPR-EE-011** covers the requirement for harmonic analysis to be undertaken.

4.13 Electrical Maintenance Philosophy

202 I have assessed the high level maintenance philosophy for the EPR reactor based on the response provided by EDF and AREVA to TQ-EPR-1073 (Ref. 8). This provides a high level statement of the maintenance philosophy including availability requirements, maintenance intervals and access to maintain electrical equipment in a safe manner.

4.13.1 Assessment

203 The principal consideration for the maintenance of the Electrical System are the Operational Technical Specification (OTS) requirements

204 The principles for carrying out maintenance of EDGs at power are described with the main principle being for maintenance to be carried out during reactor shut down. It is permissible for maintenance to be carried out on any one of four diesels at power with timeframes supported by probabilistic analysis. Temporary interconnections are provided for during diesel maintenance to ensure that loads can be recovered by diesel supplies

should a fault occur. Interconnections are established only between Divisions 1 and 2 or between 3 and 4.

205 Maintenance of battery systems is intended to be mainly undertaken during reactor shutdown. Maintenance at power is based on OTS requirements. Interconnections are identified which are used during maintenance operations to ensure maximum availability of supplies.

206 The maintenance of electrical switchboards is carried out mainly during reactor shut down. There is recognition of other states which can affect availability for maintenance in the OTS. The OTS requirements are identified as the principal tool governing the release of switchboards for maintenance. Particular consideration needs to be given to switchboards which are required at power and outage states. Interconnections will be made to facilitate work on these switchboards based on OTS requirements.

207 The four EDGs and two UDGs are each provided with synchronising equipment which permits the regular testing of diesel generators on load in parallel with the grid supply.

208 The principles for periodic testing are well defined based on established practices for existing plants, manufacturer's data and supported by PSA input.

209 Principles for verification of continuity and insulation resistance are identified and a requirement for thermographic checks on switchboards is defined.

4.13.2 Findings

210 The response to TQ-EPR-1073 (Ref. 8) fully describes the high-level maintenance strategy proposed by EDF and AREVA. It describes an approach supported by the PSA studies and the plant availability needed to achieve key nuclear safety criteria. Sufficient detail is provided with regards to the proposals for maintaining the EDGs, system switchboards, and batteries to demonstrate that it will be conducted under strict protocols that minimise nuclear risks. Also it is clear that achieving the maintenance requirements whilst meeting safety constraints have been factored into the design through the provision of redundancy and interconnections. I consider that the principles described provide a good basis for the maintenance of the Electrical System to support the safety of the plant.

4.14 Protection Against Voltage Transients

211 I have carried out an assessment of the protective measures which have been taken to protect against the effects of voltage impulses on the Electrical Distribution System. I have assessed potential threats to the Electrical System which could affect more than one Division as a result of a single initiating event in addition to conditions which could challenge the integrity of supplies in a single Division.

212 In carrying out an assessment of the protection against overvoltage transients, I have taken into account the recommendations of the Defence in Depth of Electrical Systems and Grid Interaction with Nuclear Power Plants (DIDELSYS) task group report (Ref. 25) on *Defence in Depth of Electrical Systems and Grid Interaction* which was produced following the incident at the Forsmark nuclear power plant in July 2006. I have also assessed the TQ responses from EDF and AREVA to determine whether they are taking account of the recommendations.

213 The assessment has been based on the following documents:

- EDF document ENSEMD090183 (Ref. 26) on lightning protection.

- EDF and AREVA response to TQ-EPR-870 (Ref. 8).
- EDF and AREVA response to TQ-EPR-877 (Ref. 8).
- EDF and AREVA response to TQ-EPR-1072 (Ref. 8).
- EDF and AREVA response to TQ-EPR-1074 (Ref. 8).
- RCC-E (Ref. 18).
- EDF document ENSEMD100112 (Ref. 37) on transients in induction motors.

214 The particular aspects which have been assessed are as follows:

- Protection against the effects of lightning strikes.
- Protection against a fast transient disturbance propagating from one Division to another.
- Resilience of the co-ordinated voltage protection system to withstand the loss of a single line of defence.
- Consideration of the effects on electrical equipment of overvoltage transients due to failures in the Electrical System resulting from conditions such as short circuit faults, AVR failure, and resonance effects etc.
- Capabilities of Induction motors to withstand the effects of voltage transients.

4.14.1 Protection Against Lightning Strikes

215 This considers the generic measures adopted to protect against the effects of lightning strikes. TSC Report 2010-0772 (Ref. 44) covers an assessment of the design of the lightning system protection.

4.14.1.1 Assessment

216 The Report ENSEMD090183 (Ref. 26) provides a comprehensive description of the protection principles to be adopted to protect against lightning strikes. This report deals with the proposed lightning and electromagnetic pulse protection measures in a satisfactory manner. The structural lightning protection and analysis of internal magnetic field strengths under direct and indirect strike conditions are described. Protection measures which comply with IEC 62305: 2006 (Ref. 27) are also described.

4.14.1.2 Findings

217 I consider that the generic lightning protection proposed is robust and based on the relevant IEC Standards. During detailed design and construction ND will assess the facilities for maintenance of the lightning protection through all phases of operation.

4.14.2 Protection Against Fast Transient Disturbances

218 Fast transient disturbances are covered in Section 4.8; this assessment covers the protection against the transmission of fast transient disturbances between divisions.

4.14.2.1 Assessment

219 EDF and AREVA have provided a justification that it is not possible for fast transient disturbances to be transmitted from one Division to another in their response to TQ-EPR-1074 (Ref. 8). This addresses the possible paths by which fast transients could be transmitted and has identified these as conducted or radiated paths. Detailed consideration is then given to the defences against this occurring in each case.

220 The conducted path occurs where there are interconnections between Divisions. One potential path is from the 400/10kV Step down transformers where ST1 feeds Divisions 1 and 3 and ST2 feeds Divisions 2 and 4. Conduction is prevented by the design of transformers ST1 and ST2 where the dual secondary windings are electrically separated thus preventing fast transients conducting between Divisions.

221 Another potential source of transmission occurs when temporary interconnections are made between divisions to provide a source of back up supply during maintenance operations. There is the potential for the high frequency overvoltages to propagate through the cables although capacitance in the cables will mitigate this. Radiated transmission of fast transients is protected against by the following:

- Physical separation of safeguard buildings SAB1, SAB 2, SAB 3 and SAB 4.
- Plant earthing and bonding network providing a Faraday Cage.
- Design of lightning protection in accordance with IEC 62305: 2006 Level 1 (Ref. 27).
- Compliance with the EMI requirements in RCC-E (Ref. 18) Section D5000.

4.14.2.2 Findings

222 I consider that the work done by EDF and AREVA fully demonstrates that the generic design provides adequate protection to prevent fast transients propagating between divisions.

223 The future licensee should conduct an assessment for each site during detail design to ensure that no potential exists for transfer of fast transients between Divisions. Assessment Finding **AF-UKEPR-EE-005** on the future licensee to undertake further assessment work on fast transients covers this action.

4.14.3 Loss of a Line of Defence

224 This considers the potential for a failure of a single component in the voltage coordination system to impact throughout the Electrical Distribution System.

4.14.3.1 Assessment

225 The approach to be adopted by EDF and AREVA to prove the capability of the insulation coordination of the Electrical Distribution System to withstand the loss of one line of defence is presented in the response to TQ-EPR-870 (Ref. 8). This identifies the most onerous condition as the failure of a surge arrestor on the 400kV system. Downstream voltage coordination failures would not result in such onerous failure conditions. EDF and AREVA commit to undertaking a study during site licensing to assess the consequences throughout the system of a failure of the surge arrestor on the 400kV system.

226 The subjects to be studied are:

- The reducing factors of capacitances and step down transformers.

- The overvoltages on the downstream distribution.
- Calculated overvoltages with reference to equipment withstand voltages.
- Verification of measures to overcome identified potential overvoltage conditions.

4.14.3.2 Findings

227 I consider that the proposals made by EDF and AREVA to carry out a study to assess the consequences of the loss of a line of defence to be comprehensive and appropriate. I consider the approach proposed to undertake the study and to address any potential for overvoltages to be appropriate to defining the generic integrity of the design.

228 The requirement for the future licensee to undertake the study and address the findings during detail design is covered by Assessment Finding **AF-UKEPR-EE-012**.

4.14.4 Internally Generated Transient Voltage Disturbances

229 This considers the potential for voltage disturbances in the Electrical Distribution System and the methodology for ensuring that equipment specifications make due allowance for these to ensure that protection is provided against the most onerous potential voltages on the system.

4.14.4.1 Assessment

230 Studies have been undertaken by EDF and AREVA to assess the impact on the Electrical System of various conditions causing voltage disturbances. These have generally concluded that the conditions will not cause loss of stability in systems. The results of these studies will require to be input to specifications for electrical and C&I equipment to ensure that all voltage range extremes are considered. The particular areas which will require consideration in determining specification of voltage operating ranges include:

- Generator AVR Faults.
- Automatic Transfer Operations.
- Post Fault Recovery.
- Power Plant house load operation.
- System Voltage Dips.
- Part Winding Resonance on Transformers.
- Ferro-resonance.
- Battery System Operating Ranges.
- Grid Supply Tolerances and Ranges of Transformer Tappings.

4.14.4.2 Findings

231 I consider that the voltage limits on the system will have to be determined by the future licensee taking account of a full range of operating conditions. These limits should be included in purchase specifications for the equipment. This requirement is the subject of Assessment Finding **AF-UKEPR-EE-013**.

4.14.5 Voltage Transients Due to System Disturbances

232 The EDF document ENSEMD100112 (Ref. 37) considers the effects of overvoltage transients on induction motors under the following scenarios:

- Short circuit on 400kV system followed by house load operation.
- Loss of synchronism followed by house load operation.
- Motor start up during run down.

4.14.5.1 Assessment

233 Each condition was studied by EDF and AREVA using a power system model of the UK EPR to determine the voltage which would be applied to the motors under the different scenarios. In conjunction with motor manufacturers the following effects were considered:

- Motor dielectric strength.
- Electro-dynamic strength of stator windings.
- Torque strength of rotor shaft and coupling.
- Torque strength of the magnetic circuit.
- Thermo – mechanical strength of the rotor cage.
- Motor protection behaviour.

234 The report concludes that the motors and couplings can withstand the worst case voltage disturbances on the electrical distribution system.

235 A commitment is made in the response to TQ-EPR-877 (Ref. 8) to perform studies on the effects of overvoltages following system disturbances based on the recommendations of DIDELSYS task group report (Ref. 25) on *Defence in Depth of Electrical Systems and Grid Interaction*. This will be based on the identified worst cases of short circuit on the 400kV system followed by house load operation and loss of synchronism followed by house load operation.

4.14.5.2 Findings

236 I consider that the study is a good demonstration for GDA purposes of the capabilities of the generic motor and coupling design to withstand the worst case voltage transients. Assessment Finding **AF-UKEPR-EE-014** has been raised for the future licensee to undertake studies on the site specific arrangement to verify the resilience of the motors and couplings to disturbances.

237 **AF-UKEPR-EE-014** also addresses the study work to be carried out by the future licensee on all parts of the Electrical System of the effects of overvoltages following system disturbances taking account of the recommendations of the DIDELSYS task group.

4.15 Earthing

238 The assessment of the earthing provisions is based on RCC-E (Ref. 18). Table 8 identifies the earthing methods identified for each part of the electrical distribution network.

Table 8: Summary of EPR Power System Earthing Methods

System	Voltage	Method of Earthing
Main Generator	23kV AC three phase	High Impedance earthing via a neutral grounding transformer. Referred resistance equivalent to approximately 885 ohms.
10kV supplies to the conventional and nuclear island	10kV AC three phase	Unearthed
Emergency Diesel Generators	10kV AC three phase	Unearthed
Ultimate Diesel Generators	690V AC three phase	Directly earthed at the generator star point
690Vac distribution in each division	690V AC three phase	Directly earthed at 10kV/690V transformer secondary winding star point
400V transformer fed distribution in each division	400V AC three phase	Directly earthed at 10kV/400V transformer secondary winding star point
230V transformer fed supplies	Derived P-N from 400V AC systems	Directly earthed at transformer secondary winding star point
400V inverter fed distribution in each division	400V AC three phase	Unearthed
230V inverter fed supplies	Derived P-N from UPS 400V AC systems	Unearthed
Inverter battery systems	220V DC	Unearthed
Supplies to C&I cabinets from UPS converters	24V DC and 48V DC	Unearthed

4.15.2 Assessment

239 The Main Generator has a high impedance star point earth which is common practice for limiting earth fault currents.

240 The 10kV System will be operated as an IT unearthed system with no earth reference for the system. The advantage of this approach is that supply security is enhanced by allowing operation to continue in the event of a single phase fault to earth.

241 Operating the 10kV System unearthed increases the risk of transient overvoltage. The risk of transient overvoltage is present throughout the system and can have a widespread impact. Locating and removing earth faults on such a system can be protracted and depends upon having an effective methodology for monitoring of earth faults.

242 The possibility of fast voltage transients is a threat which needs to be considered when operating with an IT unearthed system. The response by EDF and AREVA to RO-UKEPR-61 (Ref. 9) demonstrates a methodology for analysing and mitigating against such faults for generic assessment purposes.

243 Unearthed operation of the 10kV system is proposed during normal and emergency operation. The system impedance with respect to earth may differ between these two configurations because of the changeover from transformer to generator supply. As a result the natural resonant frequency and damping of this path may change. However, these changes would not be expected to inherently change the degree of risk of an overvoltage condition arising.

244 The LV system neutrals will be solidly earthed. This form of earthing results in a high fault level current, but fault energy can be kept to a practical minimum by using time graded earth fault circuit protection. There is no significant risk of widespread transient system overvoltage and a low risk of localised transient overvoltage caused by a phase to earth fault.

245 The approach described in RCC-E (Ref. 18) is for DC systems to be unearthed but that the insulation integrity is continuously monitored. The risks of using an unearthed DC system are that the location of an earth fault can be difficult to detect and while the earth fault is present on one pole the voltage to earth of the other pole with be at the full rated pole-to-pole value.

246 However, the alternative approach of using a high resistance centre tapped earth does not improve fault location or limit voltage stress on the insulation. Therefore, both methods are comparable in this regard, with the unearthed scheme having the benefit that no heating should occur at the point of fault due to the negligible fault current.

4.15.3 Findings

247 I consider that the earthing design proposed is robust and does not present a risk to system operation.

248 There is a risk of transient overvoltages from operating the 10kV system unearthed. Assessment Finding **AF-UKEPR-EE-005** covers the undertaking of an assessment of this risk by the future licensee as part of the assessment of fast transients. This assessment shall include the design of earth fault monitoring to ensure effective detection and location of faults.

249 I consider the earth fault detection proposed for the DC battery systems will adequately detect and locate earth faults on the system.

4.16 Purchase Specifications

250 I have assessed the procedure for preparing purchase specifications for electrical equipment to ensure that there is a robust structure in place for ensuring that technical requirements are fully defined in specifications.

251 The assessment has been carried out on the high level RCC-E (Ref. 18) document, on a sample of Books of Technical Specifications for specific items of equipment and on assessment of the structure for technical specifications presented as part of the response to TQ-EPR-868 (Ref. 8).

4.16.1 Assessment

252 My assessment of RCC-E (Ref. 8) is described in Section 4.5 and I conclude that this is an acceptable high level specification document.

253 The technical specifications are arranged in a hierarchy of standards with RCC-E (Ref. 18) as the highest level document. All relevant EN, International and National Standards are then referenced at the next level. These standards are referenced in the Books of Technical Specifications. In the Electrical Engineering discipline there are approximately 50 generic Books of Technical Specifications covering various items of electrical equipment.

254 The requirements for complying with legal requirements such as compliance with EU Directives are shown in the structure as being incorporated within the Books of Technical Specifications. I have sampled these documents and have not found references to these requirements.

255 Specific plant requirements which will be determined during detail design for each location are covered in Contract Technical Appendices. Assessment Finding **AF-UKEPR-EE-015** covers the requirement for these to be provided by the future licensee.

256 The Books of Technical Specifications are in need of updating as they reference a number of superseded standards and French National Standards.

4.16.2 Findings

257 I consider the basic structure presented for equipment specifications to be comprehensive and to provide a sound basis for specifying requirements during detail design by the future licensee.

258 The detailed specifications will require developing to meet UK National Standards, Legal Requirements and site specific technical requirements.

259 Assessment Finding **AF-UKEPR-EE-015** has been raised to cover the requirement for the future licensee to produce detailed equipment specifications based on fully defined operating and fault conditions for assessment during detail design.

260 Assessment Finding **AF-UKEPR-EE-015** covers the requirement for the future licensee to incorporate legal requirements in equipment purchase specifications.

4.17 Smart Devices

261 I have carried out an assessment of the use of Smart Devices on Electrical Systems to ensure that adequate steps are taken to ensure that there are processes in place to verify the integrity of software used in these devices. This is a Cross-cutting area with assessment of the methodology for ensuring the integrity of the software being carried out as part of the C&I assessment.

262 The assessment is based on responses to TQ-EPR-871 (Ref. 8) which requested details of locations where Smart devices are utilised as part of electrical equipment.

4.17.1 Assessment

263 Smart Devices are extensively used within the Electrical System for equipment such as protection relays, battery chargers and voltage regulators. A major consideration in ensuring that adequate procedures are followed to ensure that verification is carried out

for all software used in Smart Devices is to ensure that all devices used within equipment packages are identified.

264 EDF and AREVA have stated in their response to TQ-EPR-332 (Ref. 8) that their overall strategy is to minimise the use of Smart Devices on safety classified equipment. I require substantiation by the future licensee that suitable alternatives to Smart Devices are available providing the same functionality.

4.17.2 Findings

265 I consider that the EDF and AREVA strategy to minimise the use of Smart Devices is acceptable providing the future licensee can demonstrate that the functional capabilities of equipment are not compromised.

266 Assessment Finding **AF-UKEPR-EE-016** has been raised for the future licensee to identify all Smart Devices in electrical equipment which will be used in specific site applications. This identification must be carried out allowing sufficient time for full verification and validation to be carried out in line with the approved process.

4.18 Electromagnetic Interference

267 The assessment of the provisions made by EDF and AREVA for the protection against the effects of Electromagnetic Interference (EMI) has been based on document ENSECC090082 (Ref. 29) together with assessment of cabling requirements to protect against EMI detailed in RCC-E (Ref. 18). The assessment has also considered the requirements of EU Directive 2004/108/EC (Ref. 28).

268 This is a Cross-cutting area which has been assessed in conjunction with the Internal Hazards assessment.

4.18.1 Assessment

269 The document ENSECC090082 (Ref. 29) details the requirements for specification of electrical equipment to comply with requirements to protect against the effects of EMI. This document is used as the basis for specifications for all electrical equipment and defines requirements for equipment and test verification to ensure compliance.

270 An immunity standard to IEC 61000-6-5: 2001 (Ref. 14) is specified which covers power station and substation environments.

271 The protection against the effects of EMI is based on the adoption of the following measures:

- Reinforcing bars in concrete earthed to form a Faraday Cage.
- Earthing system design to limit fault currents.
- Earthing of cable shielding at building entrances to prevent interference being transmitted in cables.
- Routing of cables by segregation of routes and separation distances to prevent interference from different voltages and functions.
- Shielding and earthing of cables.
- Use of surge suppressors and diodes to prevent transients.

- Immunity testing of components.

272 Immunity tests and test levels are specified for electrical equipment to protect against the effects of EMI as follows:

- Electrostatic Discharge to IEC 61000-4-2: 2009 (Ref. 30).
- Radiated electromagnetic fields to IEC 61000-4-3: 2006 (Ref. 31).
- Fast transients in bursts to IEC 61000-4-4: 2004 (Ref. 32).
- Shock waves to IEC 61000-4-5: 2009 (Ref. 33).
- Immunity to conducted interference induced by radio frequency fields to IEC 61000-4-6: 2009 (Ref. 34).
- Damped oscillatory waves to IEC 61000-4-12: 2006 (Ref. 35).

4.18.2 Findings

273 I consider that the document ENSECC090082 (Ref. 29) provides a sound basis on which to base protection of electrical equipment against the effects of EMI. Measures are described both to restrict levels of EMI by building design, design of cable routing and by fitting of suppression devices. Test standards and limits are defined to ensure that equipment is designed and tested to withstand the effects of EMI.

274 It will be necessary to ensure that the requirements defined in ENSECC090082 (Ref. 29) are incorporated in all specifications for electrical equipment during detailed design including where this is purchased as part of overall packages. The requirement for the future licensee to comply with this requirement is covered by Assessment Finding **AF-UKEPR-EE-017**.

275 It will be necessary for the Nuclear Power Plant to comply with the requirements of EU Directive 2004/108/EC (Ref. 28). The Nuclear Power Plant is a fixed installation under this directive and will require a Responsible Person to maintain documentation to demonstrate compliance of the installation.

276 Assessment Finding **AF-UKEPR-EE-017** has been raised to specify equipment to protect against the effects of EMI and to meet the requirements for a fixed installation under the EU Electromagnetic Compatibility Regulations.

4.19 Safety Classification of Electrical Equipment

277 The safety classification of electrical equipment is part of a Cross-cutting topic on Safety Classification of Structures, Systems and Components which was raised on Cross-cutting GDA Issue **GI-UKEPR-CC-01** (Ref. 48). The Project Data Book ENSEMD05022 (Ref. 20) identifies two classes for electrical equipment; EE1 which covers Class1 and Class 2 equipment and EE2 which covers Class 3 equipment.

4.19.1 Assessment

278 The assessment of purchase specifications in Section 4.16 did not identify any distinction between requirements for EE1 and EE2 equipment so TQ-EPR-1307 (Ref. 8) was raised to obtain clarification of the specification requirements. This clarified the requirements for EE1 and EE2 equipment.

279 The PCSR (Ref. 46) has been modified so that safety classifications of electrical equipment are Classes 1, 2 and 3 in line with other disciplines. The safety classifications of specific electrical items have been identified in accordance with these classifications.

4.19.2 Findings

280 There is a requirement identified in the Cross-cutting GDA Issue **GI-UKEPR-CC-01** to identify the differences between specifications for equipment of the different safety classes. Assessment Finding **AF-UKEPR-EE-018** covers the requirement for this classification to be incorporated into equipment purchase specifications by the future licensee.

4.20 Safety Assessment Principles (SAP)

281 I have carried out an assessment of the design of the Electrical System to assess its compliance with the subset of electrical SAPs (Ref. 4) identified in Table 10. My assessment considers each of the SAPs and assesses the generic capability of the design of the EPR Electrical System to comply. The assessment is shown in Table 11.

4.20.1 Assessment

282 My generic assessment of the compliance of the Electrical Distribution System with the requirements of the electrical subset of SAPs (Ref. 4) which cover redundancy, diversity, defence in depth etc. is that the system structure complies with the requirements of these SAPs. The design principles described in RCC-E (Ref. 18) for the plant are in accordance with the SAPs .

4.20.2 Findings

283 The generic assessment demonstrates the capability of the electrical design submission to comply with the requirements of the SAP (Ref. 4). A significant proportion of the SAPs require substantiation of design details to provide full evidence of compliance. These details will require the future licensee to incorporate designs in accordance with the Assessment Findings or justifying a suitable equivalent.

284 My overall judgment based on the generic assessment is that the design meets the requirements of the SAPs (Ref. 4).

4.21 Overseas Regulatory Interface

285 HSE's Strategy for working with Overseas Regulators is set out in (Ref .52) and (Ref .53). In accordance with this strategy, HSE collaborates with Overseas Regulators, both bilaterally and multinationally.

4.21.1 Bilateral Collaboration

286 HSE's Nuclear Directorate (ND) has formal information exchange arrangements to facilitate greater international co-operation with the nuclear safety regulators in a number of key countries with civil nuclear power programmes. These include:

- the US Nuclear Regulatory Commission (NRC)
- the French L'Autorité de sûreté nucléaire (ASN)

- the Finnish Regulator, STUK

287 In the Electrical Systems assessment a bilateral meeting has been held with the Finnish Regulator STUK.

288 Discussions were held on the segregation of cable routes, identification of cables and arrangements for the protection of cross connecting cables between divisions. These discussions supported the findings and conclusions of this report.

289 Discussions were held on the ambient operating temperatures for equipment rooms and the equipment rating requirements on loss of air conditioning resulting in higher temperatures.

5 CONCLUSIONS

290 This report presents the findings of the Step 4 Electrical Systems assessment of the EDF and AREVA UK EPR Reactor.

291 To conclude, I am broadly satisfied with the integrity of the electrical system design laid down within the PCSR and supporting documentation listed in the Submission Master List (Ref. 47) for the Electrical Systems proposed for the UK EPR. This will be supplemented by presentation of Claims, Arguments and Evidence in the PCSR in response to GDA Issue **GI-UKEPR-EE-01** but I consider that the integrity of the design is such that the necessary claims arguments and evidence can be presented. Subject to resolution of the GDA Issue I consider that from an Electrical Systems view point, the EDF and AREVA UKEPR design is suitable for construction in the UK. However, this conclusion is subject to satisfactory progression and resolution of GDA Issues to be addressed during the forward programme for this reactor and assessment of additional information that becomes available as the GDA Design Reference is supplemented with additional details on a site-by-site basis.

292 The complete GDA Issue and associated action is formally defined in Annex 2.

5.1 Key Findings from the Step 4 Assessment

293 My key findings and conclusions are as follows:

- EDF and AREVA provide adequate claims of compliance for the Electrical System structure defined against the electrical SAPs. Although I have no significant concerns regarding the integrity of the system and its capability to meet the safety claims EDF and AREVA have to provide the sufficient evidence to support the claims. GDA Issue **GI-UKEPR-EE-01** has been raised to identify the requirement to supply this evidence.
- Independent assessment by the TSC and myself of the EDF and AREVA design and modelling of extremes of transient operating conditions has confirmed the resilience of the design of the Electrical Distribution System to disturbances due to such events as short circuits, switching transients and overvoltage transients.
- The structure of the Electrical System provides sufficient capacity to meet load requirements in all operating modes of grid supply, diesel supply and battery supply. Capability is provided in the system to facilitate maintenance of Electrical Systems whilst maintaining supply continuity. Continuity of supply can be maintained in the event of unavailability of equipment due to electrical faults.
- The principles proposed in the protection philosophy provide a good basis for protecting the Electrical System to minimise the effects of electrical faults. This enables continuity of system supplies and thus supports the effectiveness of the Electrical System in maintaining plant safety.
- The Class 1 battery powered systems are designed in a well structured manner according to defined and documented processes. Adequate margins are applied and battery rating is based on the worst conditions of operating temperature and ageing.
- The basic structure presented for equipment specifications is comprehensive and provides a sound basis for specifying requirements during detailed design by the future licensee.

- The work carried out in assessing the implications of meeting the UK Grid Code (Ref. 36) has been carried out in a very thorough manner to ensure that all the implications have been assessed. This has included ensuring that there are no implications on the Plant Electrical System when remaining connected to the Grid under fault conditions.

5.1.1 Assessment Findings

294 I conclude that the following Assessment Findings listed in Annex 1 should be programmed during the forward programme of this reactor as normal regulatory business.

5.1.2 GDA Issues

295 I conclude that the following GDA Issue(s) listed in Annex 2 must be satisfactorily addressed before Consent will be granted for the commencement of nuclear island safety related construction.

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Table 9

Areas identified in Assessment Plan for Further Assessment during Step 4

Identifier	Assessment Area	Description	Topic Lead	Required Timescale
1	Electrical	High Level assessment of the maintenance proposals for the reactor concentrating on requirements for availability of items of main electrical equipment, maintenance intervals and access for maintaining the electrical equipment in a safe manner	Electrical Systems	Step 4
2	Electrical	Assessment of key aspects of the safety related battery systems supplying AC and DC loads addressing the design operation and monitoring of the systems and including assessment of the systems using system study programs	Electrical Systems	Step 4
3	Electrical	Sample assessment of the AC distribution system considering load flows and electrical fault calculations to confirm the adequacy of the system design	Electrical Systems	Step 4
4	Electrical	Undertaking an assessment of a sample of the calculations carried out by EDF and AREVA to ensure that the electrical protection relays can provide adequate protection and discrimination throughout the system for a wide range of fault calculations	Electrical Systems	Step 4
5	Electrical	Review of key aspects of EDF and AREVA's transient stability studies on the electrical system using Technical Support Contractor Cobham to evaluate a small sample of the system to confirm the tolerance of the system to electrical faults	Electrical Systems	Step 4
6	Electrical	In conjunction with the C&I assessment team to assess the control of software for programmable equipment including protection relays	Electrical Systems	Step 4
7	Electrical	Assessment of the 10kV unearthed system focusing on earth fault monitoring and the role of the operator	Electrical Systems	Step 4
8	Electrical	Review of the arguments to support the safety claims made for compliance with the electrical subset of SAPs	Electrical Systems	Step 4
9	Electrical	Assessment of EMC compliance and design of earthing and lightning protection	Electrical Systems	Step 4

Table 10

Relevant Safety Assessment Principles for Electrical Systems Considered During Step 4

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

Table 10

Relevant Safety Assessment Principles for Electrical Systems Considered During Step 4

SAP No.	SAP Title	Description
EMT.6	Reliability claims	Provision should be made for testing, maintaining, monitoring and inspecting structures, systems and components important to safety in service or at intervals throughout plant life commensurate with the reliability required of each item.
EMT.7	Functional testing	In-service functional testing of systems, structures and components important to safety should prove the complete system and the safety-related function of each component
ELO.1	Access	The design and layout should facilitate access for necessary activities and minimise adverse interactions during such activities.
EHA.10	Electromagnetic interference	The design of facility should include protective measures against the effects of electromagnetic interference
ESS.1	Requirement for safety systems	All nuclear facilities should be provided with safety systems that reduce the frequency or limit the consequences of fault sequences, and that achieve and maintain a defined safe state
ESS.2	Determination of safety system requirements	The extent of safety system provisions, their functions, levels of protection necessary to achieve defence in depth and required reliabilities should be determined
ESS.3	Monitoring of plant safety	Adequate provisions should be made to enable the monitoring of the plant state in relation to safety and to enable the taking of any necessary safety actions.
ESS.7	Diversity in the detection of fault sequences	The protection system should employ diversity in the detection of fault sequences, preferably by the use of different variables, and in the initiation of the safety system action to terminate the sequences
ESS.8	Automatic initiation	A safety system should be automatically initiated and normally no human intervention should be necessary following the start of a requirement for protective action.
ESS.9	Time for Human Intervention	Where human intervention is necessary following the start of a requirement for protective action, then the time before such intervention is required should be demonstrated to be sufficient.
ESS.10	Definition of capability	The capability of a safety system, and of each of its constituent sub-systems and components, should be defined.

Table 10

Relevant Safety Assessment Principles for Electrical Systems Considered During Step 4

SAP No.	SAP Title	Description
ESS.11	Demonstration of adequacy	The adequacy of the system design as the means of achieving the specified function and reliability should be demonstrated for each system.
ESS.12	Prevention of service infringement	Adequate provisions should be made to prevent the infringement of any service requirement of a safety system, its sub-systems and components.
ESS.15	Alteration of configuration, operational logic or associated data	No means should be provided, or be readily available, by which the configuration of a safety system, its operational logic or the associated data (trip levels etc) may be altered, other than by specifically engineered and adequately secured maintenance/testing provisions used under strict administrative control
ESS.16	No dependency on external sources of energy	Where practicable, following a safety system action, maintaining a safe facility state should not depend on an external source of energy
ESS.19	Dedication to a single task	A safety system should be dedicated to the single task of performing its safety function
ESS.20	Avoidance of connections to other systems	Connections between any part of a safety system (other than the safety system support features) and a system external to the plant should be avoided
ESS.21	Reliability	The design of a safety system should avoid complexity, apply a fail-safe approach and incorporate the means of revealing internal faults from the time of their occurrence
ESS.23	Allowance for unavailability of equipment	In determining the safety system provisions, allowance should be made for the unavailability of equipment
ESS.24	Minimum operational equipment requirements	The minimum amount of operational safety system equipment for which any specified facility operation will be permitted should be defined and shown to meet the single failure criterion.
EES.1	Provision	Essential services should be provided to ensure the maintenance of a safe plant state in normal operation and fault conditions
EES.2	Sources external to the site	Where a service is obtained from a source external to the nuclear site, that service should also be obtainable from a back-up source on the site.

Table 10

Relevant Safety Assessment Principles for Electrical Systems Considered During Step 4

SAP No.	SAP Title	Description
EES.3	Capacity, duration, availability and reliability	Each back-up source should have the capacity, duration, availability and reliability to meet the maximum requirements of its dependent systems
EES.4	Sharing with other plants	Where essential services are shared with other plants on a multi-facility site, the effect of the sharing should be taken into account in assessing the adequacy of the supply
EES.5	Cross-connections to other services	The capacity of the essential services to meet the demands of the supported safety functional requirement(s) should not be undermined by making cross-connections to services provided for non-safety functions.
EES.6	Alternative sources	Alternative sources of essential services should be designed so that their reliability would not be prejudiced by adverse conditions in the services to which they provide a back-up
EES.7	Protection devices	Protection devices provided for essential service components or systems should be limited to those that are necessary and that are consistent with facility requirements
EES.8	Sources external to the site	Where a source external to the nuclear site is employed as the only source of the essential services needed to provide adequate protection, the specification and in particular the availability and reliability should be the same as for an on-site source.
EES.9	Loss of service	Essential services should be designed so that the simultaneous loss of both normal and back-up services will not lead to unacceptable consequences.
EKP.3	Defence in Depth	A nuclear facility should be so designed and operated that defence in depth against potentially significant faults or failures is achieved by the provision of several levels of protection
EKP.5	Safety measures	Safety measures should be identified to deliver the required safety function(s).

Table 11

Assessment of Compliance with Electrical Safety Assessment Principles

SAP No.	SAP Title	Main Findings/Observations
EQU.1	Equipment Qualification	The requirements of this SAP are met for the electrical supply and layout. All safety classified systems and equipment must conform to the Design and Construction Rules for Electrical Equipment of Nuclear Islands (RCC-E) in its entirety. The RCC-E lays down the rules for the qualification procedures to ensure that equipment is suitable for its intended application, service and use. It also defines the identification of the equipment to be qualified and the methods and criteria governing its acceptance.
EDR.1	Failure to Safety	The UK EPR is connected to the 400kV grid at a main connection and an auxiliary connection. The main connection is provided from the Main Generator via a step-up transformer, a coupling circuit breaker and a line circuit breaker. A tapped connection is made between the two circuit breakers to connect two Step-down Transformers. The auxiliary connection is made to an independent point on the grid and feeds a Standby Transformer similar in rating and construction to the Step-down Transformers. The four Divisions can be fed from the Standby Transformer. The power supply to the conventional island comprises four 10kV switchboards fed from the Step-down Transformers. These distribute off-site power through four Divisions to the nuclear island. The Nuclear Island has four Divisions each with its own distribution system. Each division has a main Emergency Diesel Generator (EDG) for emergency power supply in the event of the loss of the external power supply. Divisions 1 and 4 each have Ultimate Diesel Generators (UDG) to support the EDGs. There are also 2 hour uninterruptible power supplies (UPS) on each of the four Divisions and 12 hour UPS on Divisions 1 and 4. The classification level of the systems, structure or components is used to determine the standard applied in design, manufacture installation and maintenance. The system as designed meets the requirements of the SAP.

Table 11

Assessment of Compliance with Electrical Safety Assessment Principles

SAP No.	SAP Title	Main Findings/Observations
EDR.2	Redundancy, diversity and segregation	The requirements of this SAP are met. A number of separate redundancy features have been incorporated, the main ones are noted as follows: The electrical structure of the conventional island's high voltage scheme separates the nuclear island's distribution system into four Divisions. This results in the creation of four sections each equipped with a main 10 kV switchboard supplied by a unit transformer winding. The allocation of loads to the busbars takes into account the redundancy requirements of the safety systems and the power requirements of the static converters and batteries. The architecture of the supply to the instrumentation and control cabinets and for the switchgear actuation provides adequate redundancy and diversity. Each emergency power supply is installed in a separate division. The separation into Divisions ensures that in the event of an internal hazard within a division, only the division in question is affected. Each Division has a battery based DC system with charging from the low voltage AC system. The DC system gives 2 hours supply to essential instrumentation and control systems. Each Division is supplied by an independent Emergency Diesel Generator (EDG) which is started automatically on loss of voltage on the busbars. The maintenance philosophy describes temporary cross connections between Divisions 1 and 2 and between Divisions 3 and 4. These can be used to provide back up supplies during maintenance operations. Protection is provided on these temporary connections to prevent any fault currents propagating between Divisions. Power cable routes are fully segregated between Divisions. Any cables which cross over in to a different Division are totally enclosed.

Table 11

Assessment of Compliance with Electrical Safety Assessment Principles

SAP No.	SAP Title	Main Findings/Observations
EDR.3	Common Cause Failure	Common cause failure has been addressed and I consider that the requirements of the SAP are met. The PCSR describes the measures taken against common cause failure as follows: • Particular attention is given to minimizing the possibilities of common cause failures. Physical and spatial separation is applied as far as possible. Support functions (energy, control, cooling, etc.) are independent to the largest possible degree. Special emphasis is placed on the redundancy and diversity of electrical power supplies. Studies have been carried out to demonstrate that external disturbances such as grid failures, fast transients and lightning will not result in common cause failures. • Common cause failure has been addressed for the diesel generators caused by a simultaneous failure of an identical component or the environment (e.g. fuel, temperature, operating conditions). The strategy to combat the risk of common cause failure is reliance on the high intrinsic reliability of the equipment. Two distinct diesel generator designs have been adopted, one for the EDGs and one for the UDGs.
EDR.4	Single Failure Criterion	Single failures are taken into account for F1A (Category A) safety classified functions and F1B (Class 2) safety classified functions at the design stage. These failures are random and independent of the initiating event, which necessitates the system operation. The design of structures, systems and components important to safety, ensures that more than the minimum number of components is provided to carry out any essential function. This requirement for redundancy assists in ensuring high reliability of safety classified systems designed to maintain the plant within its deterministic design basis. I consider that the requirements of the SAP are met.

Table 11

Assessment of Compliance with Electrical Safety Assessment Principles

SAP No.	SAP Title	Main Findings/Observations
ERL.2	Measures to achieve reliability	In design this SAP is met by the proposed implementation of a combination of redundant and diverse sub-systems and equipment. The basic architecture is four Divisions of redundant equipment for electrical power supplies to the nuclear island. Depending on the safety system being supplied, in many instances, only one redundant division would be sufficient to maintain safety and is never higher than two. The proposed installation of the two Ultimate Diesel Generators (UDG) provides diversity to the Emergency Diesel Generators (EDG). These diesels are of different rating and have diverse control arrangements and will be supplied from different manufacturer from the EDGs. EDF and AREVA have also analysed the potential for dependent failures and by applying a rigorous design approach to stop faults and failures from propagating from the affected Division to the three other independent Divisions. Throughout the life of the facility this SAP is met by the framework set out in the RCC-E for qualification of equipment, assessment of manufacture, inspection, testing within a quality assurance system. The maintenance philosophy describes facilities provided for in-service maintenance and access whereby systems and equipment are expected to be tested and maintained in accordance with operating experience and manufacturers recommendations.
ERL.4	Margins of Conservatism	I consider that the requirements of the SAP are met by the design of the Electrical Distribution System providing margins of conservatism. Four separate Divisions are provided each having an Emergency Diesel Generator (EDG) to support the grid supply. Two Divisions have a separate Ultimate Diesel Generator (UDG) of a different design. There are independent battery systems for each Division. An analysis of the transients also shows that there are margins to plant damage provided the detailed design follows the principles adopted for the generic design. The transients defining the overall equipment safety margins are also conservative using the most onerous conditions which will be used in equipment specifications.
EMT.1	Identification of requirements	The maintenance philosophy describes a structured approach to access for maintenance and testing of electrical equipment. This is based on maintenance being carried out in plant shut down states but with provision for working with the reactor at power informed by PSA assessment. Requirements for service intervals and maintenance to be performed based on operational experience and manufacturer's recommendations are described. I consider the requirements for the SAP to be met.

Table 11

Assessment of Compliance with Electrical Safety Assessment Principles

SAP No.	SAP Title	Main Findings/Observations
EMT.3	Type-testing	I consider that this SAP is met by the requirements in the PCSR Sub-Chapter 3.6 which states that the electrical distribution system must be qualified to fulfil its safety role and to withstand the environmental conditions to which it is subjected.
EMT.6	Reliability Claims	The maintenance philosophy described by EDF and AREVA demonstrates a system for testing, monitoring and inspecting electrical equipment to ensure the reliability of the equipment. I consider that the requirements of the SAP are met.
EMT.7	Functional Testing	I consider that the requirements of this SAP are met by the claim made that the UK EPR design has fully acknowledged the general principle that the in-service functional testing of systems, structures and components important to safety should prove the complete system and the safety-related function of each component. The requirement for periodic testing is considered as the most basic requirement for safety classified components.
ELO.1	Access	The layout provides for working on equipment on one Division in safety without impacting on equipment in other Divisions. Interconnections between divisions can be made for maintenance without the need to impact on activities in another division. Access to equipment for maintenance facilitates safe working. I consider that the requirements of the SAP are met.
EHA.10	Electromagnetic Interference	The requirements of the SAP are met by the measures described in EDF document ENSECC090082 (Ref. 29) both to restrict levels of EMI by building design, cable routing design and by the fitting of suppression devices. Test standards and limits are defined to ensure that equipment is designed and tested to withstand the effects of EMI.
ESS.1	Requirement for safety systems	I consider that EDF and AREVA have met this principle by means of a hazard design approach used to determine prevention and protection features to protect the safety systems. The aim is to prevent a hazard from being the cause of the loss of a safety classified function. EDF and AREVA note that electrical power supplies are essential as support systems for the reduction of core melt frequency and for the \`practical elimination\` of high pressure core melt sequences

Table 11

Assessment of Compliance with Electrical Safety Assessment Principles

SAP No.	SAP Title	Main Findings/Observations
ESS.2	Determination of safety system requirements	I consider that this SAP is met by the use of PSA as an essential part of UK EPR safety and design considerations. The PSA is used to develop the reactor design to assess the relative advantages of different design options within the original project objectives. The PSA has been developed with the full input of electrical design teams
ESS.3	Monitoring of plant safety	I consider that this SAP is met by the facilities to monitor the status of the Electrical Distribution System. Monitoring is provided of the status of switchgear, battery systems, transformers and generators and relevant data transmitted to the central control room from each Division independently.
ESS.7	Diversity in the selection of fault sequences	The requirements of the SAP are met in the design of the electrical protection system where the grading of the system is used to provide back up to protective devices whist ensuring maximum supply integrity.
ESS.8	Automatic Initiation	I consider that the requirements of the SAP are met by the design of the Electrical System. Diesels are started automatically on loss of supply. Automatic changeover is provided to the auxiliary transformer. Electrical protection operates automatically to clear faults.
ESS.9	Time for human intervention	On loss of the main supply from the grid and Main Generators the power supply will be maintained by automatic start up of the four EDGs. In the event of all four EDGs failing to start batteries will provide power for 2 hours. Human intervention is then required to start the UDG within 2 hours. Thus the SAP requirement for no human intervention in less than 30 minutes is met.
ESS.10	Definition of capability	I consider that the requirements of the SAP have been met by the following: • EDF and AREVA have provided details of calculation methodology to determine electrical equipment fault ratings. • EDF and AREVA have provided calculations for determining ratings of main transformers and EDGs. Calculations have been submitted to demonstrate that the EDGs can start the largest system motor. • EDF and AREVA have demonstrated the method for determining battery capacity taking account of worst case loading conditions, operating temperatures, aging factors and margins for future load growth.

Table 11

Assessment of Compliance with Electrical Safety Assessment Principles

SAP No.	SAP Title	Main Findings/Observations
ESS.11	Demonstration of adequacy	I consider that the requirements of the SAP are met in complying with the requirements of Chapter C 2000 of the RCC-E (Ref. 18) document entitled 'Coordination of Electrical Equipment Characteristics'. This defines the design principles to achieve a rating specification for all the electrical equipment including those in essential systems, and diesels. The aspects dealt with in the chapter include the coordination of steady state and transient voltage levels, system earthing, insulation coordination, isolation, fault levels, equipment rating, protection coordination, and generator sizing.
ESS.12	Prevention of service infringement	I consider that the requirements of this SAP have been met by the provision of safeguards such as the interconnections between divisional power systems during maintenance and the redundancy and independence of each Division.
ESS.15	Alteration of configuration, operational logic or associated data	The requirements of this SAP are met by the application of Chapter C5000 of RCC-E (Ref. 18).
ESS.16	No dependence on external sources of energy	I consider that EDF and AREVA have met this principle by the incorporation of four Emergency Diesel Generators (EDG), two Ultimate Diesel Generators (UDG) and battery based Uninterruptible Power Supplies (UPS) to back-up the two external sources of electricity supply. The plant can be maintained in a safe state by the EDG or UDG so no sources of external supply are required to maintain a safe state.
ESS.19	Dedication to a single task	I consider that the design meets the requirements of this SAP for the electrical power supply systems since there are no safety or safety related systems present that have more than one function
ESS.20	Avoidance of connections to other systems	No external sources have been identified so I consider the requirements of this SAP are met.
ESS.21	Reliability	This SAP has been met through the provision of a robust electrical system architecture that can withstand a very wide range of challenging single, and from the perspective of the PSA, multiple faults while still being able to perform its safety function. At the equipment level the use of nuclear qualified equipment and attention to important matters such as system health monitoring and comprehensive maintenance also helps to assure high reliability. Finally the electrical system avoids complexity, although more work needs to be done on Smart Devices.

Table 11

Assessment of Compliance with Electrical Safety Assessment Principles

SAP No.	SAP Title	Main Findings/Observations
ESS.23	Allowance for unavailability of equipment	I consider that the requirements of this SAP have been met by the use of four Divisions with associated independent emergency power systems with the capability of backing each other up by interconnections during maintenance interventions.
ESS.24	Minimum operational equipment requirements	I consider that this SAP has been met as it has been stated in the PCSR that the electrical equipment provided by one Division is adequate to support a safe reactor shutdown.
EES.1	Provision	Electrical supplies are provided through four separate Divisions to meet the normal auxiliary power requirements of the reactor, with one Division alone being sufficient. The source of supply is normally from the main grid connection. Emergency electrical supplies are provided by one EDG in each Division with on-site storage facilities for fuel. Battery systems provide support to safety systems in the event that the normal and emergency sources of supply fail. I consider that this meets the requirements of the SAP.
EES.2	Sources external to the site	The plant can be shut down and maintained in a safe state with power sourced from the EDG or UDG so no external sources of power are required. Diesel supplies for 72 hours continuous operation of each diesel are provided. Additional supplies of diesel fuel are required for operation beyond 72 hours. I consider that the requirements for the SAP are met as the site is not dependent on external sources of power.
EES.3	Capacity, duration, availability and reliability	EDF and AREVA have demonstrated the methodology for calculation of equipment ratings which have been discussed in detail in the main body of this report. I consider that this meets the requirements of the SAP.
EES.4	Sharing with other plants	I consider that the requirements of this SAP are met since the basis of the UK EPR design is for a single facility with no interconnection or relationship to any other plant. Multiple reactor sites will be covered by a site specific PCSR.
EES.5	Cross connections to other services	I consider that this SAP has been met by the avoidance of any cross-connections between essential services for safety functions and essential services for non-safety functions.
EES.6	Alternative sources	I consider that the requirements of the SAP are met by the generic design.

Table 11

Assessment of Compliance with Electrical Safety Assessment Principles

SAP No.	SAP Title	Main Findings/Observations
EES.7	Protection devices	I consider that the protection philosophy described in document ENSEMD090015 (Ref. 19) meets the requirement of the SAP
EES.8	Sources external to the site	During a long term shutdown of the main generator the main source of AC power is the grid supply. As this is a reliable connection with multiple incoming lines for each site the requirements of the SAP can be met.
EES.9	Loss of service	I consider that the requirements of this SAP have been met by the use of four independent Divisions to ensure that the loss of the normal service plus one back-up service does not prevent safety functions from being carried out.

Table 11

Assessment of Compliance with Electrical Safety Assessment Principles

SAP No.	SAP Title	Main Findings/Observations
EKP.3	Defence in Depth	I consider that EDF and Areva have met the requirements of this SAP as described in Chapter 3.1 of the PCSR. The safety approach at the design level is based on the concept of defence in depth. The defence in depth has a 5-level structure as required by IAEA Safety Guide NS-R-1 (Ref.54). The implementation of the multiple levels of defence to the Electrical System is summarized in the following provisions: • The normal source of supply from the 400kV point of coupling to the utility grid within the power station main substation. This point of supply can be derived from either the main station alternator or the grid alone. • Two Step-down Transformers (ST) each with two secondaries provide galvanically separate supplies to each of four Divisions via four main switchboards on the conventional island. • The Standby Transformer (AT), identically rated to the ST allows certain auxiliaries to be supplied during shutdown in normal or accident conditions. • Each emergency power supply system is installed in a separate division. The separation is such that an internal hazard within one division does not affect that in another Division. • The nuclear island main switchboards are located in fire segregated areas. Each of the emergency switchboards is supported by a 10kV EDG. • The Diesel Generator buildings are geographically separated so that a single incident can only cause the loss of two EDG and one UDG. • In each Division a UPS with a 2 hour autonomy provides C&I supplies. • The 2 hour and 12 hour uninterruptible inverters are provided with a bypass via a 500kVA transformer regulator. • There are two UDG with 24-hour capacity to supply a number of the 690V actuators and the UPS supplies in Divisions 1 and 4.

Table 11

Assessment of Compliance with Electrical Safety Assessment Principles

SAP No.	SAP Title	Main Findings/Observations
EKP.5	Safety measures	The requirements of the SAP are met by the provision of the following power supplies • Grid supply • Emergency Diesel Generator supply • Ultimate Diesel Generator supply • 2 hour battery system • 12 hour battery system

Annex 1

Assessment Findings to Be Addressed During the Forward Programme as Normal Regulatory Business

Electrical Systems – UK EPR

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-EE-001	The future licensee shall undertake a load flow study for each power plant to determine the ratings of all electrical equipment on the EPR	Long lead items and SSC procurement specifications
AF-UKEPR-EE-002	The future licensee shall carry out a protection study for each power plant to determine the protection requirements and settings for the electrical distribution system	Long lead items and SSC procurement specifications
AF-UKEPR-EE-003	The future licensee shall carry out a detailed assessment of electrical cables for each power plant to verify cable sizes, route segregation and loading of cable routes.	Nuclear island safety related concrete.
AF-UKEPR-EE-004	The future licensee shall carry out a study for each power plant assessing motor starting performance	Long lead items and SSC procurement specifications
AF-UKEPR-EE-005	The future licensee shall undertake a study of fast transient disturbances for each system to consider the effects and protective measures to be taken. This assessment shall include the design of earth fault monitoring to ensure effective detection and location of faults.	Long lead items and SSC procurement specifications
AF-UKEPR-EE-006	The future licensee shall carry out fault studies for three phase and single phase faults for each power plant.	Long lead items and SSC procurement specifications
AF-UKEPR-EE-007	The future licensee shall carry out studies to assess the consequences of AVR failure for each power plant	Long lead items and SSC procurement specifications

Annex 1

Assessment Findings to Be Addressed During the Forward Programme as Normal Regulatory Business

Electrical Systems – UK EPR

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-EE-008	The future licensee shall assess the maximum electrical equipment room temperatures to be incorporated in equipment purchase specifications	Long lead items and SSC procurement specifications
AF-UKEPR-EE-009	The future licensee shall carry out a set of transient fault studies for each power plant including post fault recovery, islanding at full power and grid voltage dips	Long lead items and SSC procurement specifications
AF-UKEPR-EE-010	The future licensee shall confirm compliance with the UK Grid Code for each power plant	Long lead items and SSC procurement specifications
AF-UKEPR-EE-011	The future licensee shall carry out a harmonic study for each power plant	Mechanical, Electrical and C&I Safety Systems - Before inactive commissioning.
AF-UKEPR-EE-012	The future licensee shall undertake a study to assess the consequences throughout the electrical distribution system of the failure of a line of defence in the voltage coordination such as the loss of a surge arrestor on the 400kV system	Mechanical, Electrical and C&I Safety Systems - Before delivery to Site.
AF-UKEPR-EE-013	The future licensee shall determine the voltage limits for all parts of the electrical distribution system for incorporation in purchase specifications	Long lead items and SSC procurement specifications
AF-UKEPR-EE-014	The future licensee shall carry out studies to assess the effects of overvoltages following system disturbances for each power plant taking account of the recommendations of the DIDELSYS task group. The future licensee shall undertake studies to verify the resilience of motors and couplings to voltage disturbances.	Long lead items and SSC procurement specifications
AF-UKEPR-EE-015	The future licensee shall provide detailed equipment specifications based on fully defined operating conditions for each power plant. These shall include legal requirements such as compliance with EU Directives.	Long lead items and SSC procurement specifications

Annex 1

Assessment Findings to Be Addressed During the Forward Programme as Normal Regulatory Business

Electrical Systems – UK EPR

Finding No.	Assessment Finding	MILESTONE (by which this item should be addressed)
AF-UKEPR-EE-016	The future licensee shall identify all Smart Devices to be used in electrical equipment to enable full verification of these devices to be carried out	Mechanical, Electrical and C&I Safety Systems - Before delivery to Site.
AF-UKEPR-EE-017	The future licensee shall produce specifications to define protection against EMI and arrangements shall be made for compliance with the requirements of Directive 2004/108/EC	Long lead items and SSC procurement specifications
AF-UKEPR-EE-018	The future licensee shall define electrical equipment safety classifications and incorporate them in equipment purchase specifications	Long lead items and SSC procurement specifications
AF-UKEPR-EE-019	The future licensee shall carry out a detailed assessment of required battery ratings based on the design criteria defined in EDF document ECEF090881-A1 (Ref. 21)	Long lead items and SSC procurement specifications
AF-UKEPR-EE-020	The future licensee shall provide an effective monitoring system for faults on the IT system and shall ensure that switchgear has been type tested to ensure that it can clear faults in the event of a double earth	Long lead items and SSC procurement specifications

Note: It is the responsibility of the Licensees / Operators to have adequate arrangements to address the Assessment Findings. Future Licensees / Operators can adopt alternative means to those indicated in the findings which give an equivalent level of safety.

For Assessment Findings relevant to the operational phase of the reactor, the Licensees / Operators must adequately address the findings during the operational phase. For other Assessment Findings, it is the regulators' expectation that the findings are adequately addressed no later than the milestones indicated above.

Annex 2

GDA Issues – Electrical Systems – UK EPR

EDF AND AREVA UK EPR GENERIC DESIGN ASSESSMENT

GDA ISSUE

PCSR PRESENTATION OF CLAIMS ARGUMENTS AND EVIDENCE

GI-UKEPR-EE-01 REVISION 1

<table>
<tr><td>Technical Area</td><td colspan="3">ELECTRICAL ENGINEERING</td></tr>
<tr><td>Related Technical Areas</td><td colspan="3">None</td></tr>
<tr><td>GDA Issue Reference</td><td>GI-UKEPR-EE-01</td><td>GDA Issue Action Reference</td><td>GI-UKEPR-EE-01.A1</td></tr>
<tr><td>GDA Issue</td><td colspan="3">Provide a revised PCSR containing the requisite claims, arguments, and evidence to substantiate the design of the plant electrical distribution system. The claims made for the electrical system need to be related to the overall safety claims for the plant.</td></tr>
<tr><td>GDA Issue Action</td><td colspan="3">Provide a revised PCSR Chapter 8 to substantiate the design of the complete plant electrical distribution system. This needs to incorporate a structure of claims, arguments and evidence in a narrative and/or tabular form to demonstrate that the electrical system fully meets the requirements of its safety role as specified in the other chapters of the PCSR.

ONR's expectations are that the PCSR should provide a rigorous justification for the completeness of the electrical power distribution system to perform its safety role.

It has been agreed with EDF and AREVA, from the early stages of this project, that this would be done in the PCSR by establishing the claims, arguments and evidence chain of reasoning. This requirement has been consistently presented to EDF and AREVA and comments have been made by ONR on presentations made by EDF and AREVA on the presentation of the safety case for the electrical distribution system.

Within Step 4 EDF and AREVA have presented two example sections of the revised PCSR covering common cause failure and equipment qualification. These do not meet ONR expectations which are that:
The PCSR needs to provide a clear justification of the safety of the EPR electrical distribution system.
The safety claims made need to be clear and unambiguous.
The arguments and evidence presented in support of the safety claims are well presented. In particular evidence should be based on documents that are produced during GDA, not on documents that are to be produced during site licensing.
Presentation of other sections of the PCSR will not be adequate if the format demonstrated in the example sections is maintained.
With agreement from the Regulator this action may be completed by alternative means.</td></tr>
</table>

Further explanatory / background information on the GDA Issues for this topic area can be found at:	
GI-UKEPR-EE-01 Revision 1	Ref. 51.