

INTERNATIONAL STANDARD

NORME INTERNATIONALE



Nuclear power plants – Electrical power systems – Electrical power systems analysis

Centrales nucléaires de puissance – Systèmes d'alimentation électrique – Analyse des systèmes d'alimentation électrique



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2016 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de l'IEC ou du Comité national de l'IEC du pays du demandeur. Si vous avez des questions sur le copyright de l'IEC ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de l'IEC de votre pays de résidence.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue

The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing 20 000 terms and definitions in English and French, with equivalent terms in 15 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

65 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

A propos de l'IEC

La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC

Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Catalogue IEC - webstore.iec.ch/catalogue

Application autonome pour consulter tous les renseignements bibliographiques sur les Normes internationales, Spécifications techniques, Rapports techniques et autres documents de l'IEC. Disponible pour PC, Mac OS, tablettes Android et iPad.

Recherche de publications IEC - www.iec.ch/searchpub

La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études,...). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished

Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et aussi une fois par mois par email.

Electropedia - www.electropedia.org

Le premier dictionnaire en ligne de termes électroniques et électriques. Il contient 20 000 termes et définitions en anglais et en français, ainsi que les termes équivalents dans 15 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

Glossaire IEC - std.iec.ch/glossary

65 000 entrées terminologiques électrotechniques, en anglais et en français, extraites des articles Termes et Définitions des publications IEC parues depuis 2002. Plus certaines entrées antérieures extraites des publications des CE 37, 77, 86 et CISPR de l'IEC.

Service Clients - webstore.iec.ch/csc

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: csc@iec.ch.

INTERNATIONAL STANDARD

NORME INTERNATIONALE



Nuclear power plants – Electrical power systems – Electrical power systems analysis

Centrales nucléaires de puissance – Systèmes d'alimentation électrique – Analyse des systèmes d'alimentation électrique

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 27.120.20

ISBN 978-2-8322-3589-8

Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.

CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
1 Scope.....	10
2 Normative references.....	11
3 Terms and definitions	11
4 Symbols and abbreviations	12
5 Electrical power system analyses.....	13
5.1 Overview of typical studies	13
5.1.1 Transient stability analyses	13
5.1.2 Load flow studies	13
5.1.3 Transient and dynamic studies	13
5.1.4 Short circuit studies	14
5.1.5 Electrical protection coordination and selectivity	14
5.1.6 Lightning protection studies.....	14
5.2 Applicability of analyses to different plant states	14
5.2.1 General	14
5.2.2 Recommendations	14
5.3 Selection, verification and validation of analytical tools	15
5.3.1 General	15
5.3.2 Recommendations	16
5.4 Electrical power system model.....	17
5.5 Grid and NPP connection	17
5.6 Updating of system analyses	17
5.7 Prerequisites for the performance of electrical studies	17
5.8 Acceptance requirements	18
6 Off-site power transient stability analyses.....	18
6.1 General.....	18
6.2 Recommendation	18
6.3 Acceptance requirements	18
7 AC on-site power system analyses.....	18
7.1 General.....	18
7.2 Load flow studies	19
7.2.1 General	19
7.2.2 Recommendations	19
7.2.3 Acceptance requirements	19
7.3 Transient studies.....	19
7.3.1 General	19
7.3.2 Faulted conditions.....	19
7.3.3 Bus transfer studies	20
7.3.4 Motor starting and reacceleration studies.....	21
7.3.5 House load operation	22
7.3.6 Voltage disturbances.....	22
7.3.7 Voltage surge caused by switching and malfunctions	23
7.3.8 Load sequencer studies	23
7.3.9 Frequency studies.....	24
7.4 Fault studies	24

7.4.1	Short-circuit studies	24
7.4.2	Earth fault (degraded insulation) studies	25
7.5	Electrical protection coordination studies	25
7.5.1	Recommendations	25
7.5.2	Acceptance requirements	26
8	DC system and uninterruptible AC system analyses	26
8.1	Load flow studies	26
8.1.1	General	26
8.1.2	Recommendations	26
8.1.3	Acceptance requirements	27
8.2	Transient studies	27
8.2.1	Rectifier	27
8.2.2	Inverter/UPS and bypass switch	27
8.3	Fault studies	28
8.3.1	Short circuit studies	28
8.3.2	Earth fault (degraded insulation) studies	28
8.4	Electrical protection coordination studies	28
8.4.1	Recommendations	28
8.4.2	Acceptance requirements	29
9	Miscellaneous analyses	29
9.1	Lightning protection studies	29
9.1.1	General	29
9.1.2	Recommendation	29
9.1.3	Acceptance requirements	30
9.2	Electromagnetic compatibility	30
9.2.1	General	30
9.2.2	Recommendation	30
9.3	Harmonic studies	30
9.3.1	General	30
9.3.2	Recommendation	30
9.4	Geomagnetic induced current (GIC)	30
9.5	Ferroresonance studies	30
Annex A (informative)	Establishment of design bases for nuclear power plant electrical power systems	31
A.1	Overview	31
A.2	Site electrical characteristics	34
A.2.1	General	34
A.2.2	Grid disturbances	35
A.2.3	Short circuit power	35
A.2.4	Lightning protection and insulation coordination	36
A.2.5	Earthing characteristics	36
A.3	Plant electrical characteristics	37
A.3.1	General	37
A.3.2	Main generator characteristics	37
A.3.3	Standby AC power sources and alternate AC source	37
A.3.4	DC power sources	39
A.4	Conceptual electrical design criteria	39
A.4.1	General	39
A.4.2	Capacity of power sources	39

A.4.3	Protection coordination	39
A.4.4	Voltage transients and interruptions	40
A.4.5	Capability for bus transfer	40
A.4.6	Capability for motor start and reacceleration	40
A.4.7	System earthing	40
A.4.8	Capability of electrical equipment	41
A.4.9	Electromagnetic interference	41
A.4.10	Geomagnetic induced currents	41
A.4.11	Ferroresonance	41
A.5	Conceptual nuclear design criteria	42
A.5.1	General	42
A.5.2	Reliability and availability, single failure criterion	42
A.5.3	Common cause failures (CCF) and common mode failures (CMF)	43
A.6	Design bases analysis	43
A.6.1	General	43
A.6.2	Voltage	44
A.6.3	Sizing of safety standby AC power sources	45
A.6.4	Frequency	46
A.6.5	Electrical consumers' databases and power balances	46
Annex B (informative)	Guidelines for analytical studies	48
B.1	Analytical studies methodology	48
B.1.1	General	48
B.1.2	Process	48
B.2	Example of detailed level	50
B.2.1	Purpose	50
B.2.2	Analysis and basics	50
B.2.3	Minimum required data	51
B.2.4	Contribution of the study	51
Annex C (informative)	Verification of design bases and equipment specification	52
Annex D (informative)	Example of plant specific acceptance criteria	55
Bibliography		56
Figure A.1	Input and process to determine the specific electrical design bases for a nuclear power plant and verification analyses	32
Figure A.2	Relationship of the plant electrical power system, the off-site electrical power system and the on-site electrical power system for a nuclear power plant	33
Figure A.3	Relationship of power supplies important to safety, safety power supplies, and the preferred power supply for a nuclear power plant	34
Figure A.4	Typical voltage design bases	44
Figure B.1	Overview of analytical studies	48
Figure B.2	Phenomena	49
Table C.1	AC on-site power system analyses	52
Table C.2	DC system and uninterruptible AC system analyses	53

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**NUCLEAR POWER PLANTS –
ELECTRICAL POWER SYSTEMS –
ELECTRICAL POWER SYSTEMS ANALYSIS**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 62855 has been prepared by subcommittee 45A: Instrumentation, control and electrical systems of nuclear facilities, of IEC technical committee 45: Nuclear instrumentation.

The text of this document is based on the following documents:

FDIS	Report on voting
45A/1094/FDIS	45A/1100/RVD

Full information on the voting for the approval of this document can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

a) Technical background, main issues and organisation of the Standard

The principal function of the electrical power system is to support the safe operation of a nuclear power plant (NPP) in all modes of operation. A subset of the electrical power system is essential for supporting nuclear safety functions at various voltage levels. This subset is critical for all plant states and events requiring plant cool-down in a controlled manner. A reliable power system is critical for maintaining control to power, control and monitor plant safety functions. This is required to support the barriers that prevent radiological releases during design basis accidents and design extension conditions.

International Standards and National safety codes provide guidance on acceptable requirements for safe and reliable operation of electrical distribution systems. Compliance with these safety codes and standards generally provides reasonable assurance for the correct electrical functionality and capability of these systems in the nuclear power plant (NPP).

The design basis of the electrical power systems in a NPP should be established by consideration of the following elements:

- nuclear design criteria, defence in depth approach, safety classification, design basis conditions (DBC) and design extension conditions (DEC);
- requirements for transmission system operating limits, grid safety, grid code, plant performance and operating limits;
- architecture and specification of the electrical power systems;
- sizing of main components and systems such as unit auxiliary and standby transformers, switchgear, cables, motors and standby alternating current (AC) and direct current (DC) power sources;
- load allocations and load power balance;
- load flow calculations;
- coordination of characteristics (voltage, current and short circuit current);
- support system requirements during postulated DBCs;
- design verification including verification analyses.

An example of design bases considerations for electrical power systems is provided in informative Annex A.

Guidelines and an example of analytical methods are detailed in informative Annex B. The relationship between analyses and verification of design bases and equipment specification is given in informative Annex C. An example of plant specific acceptance criteria (see 5.8) is given in informative Annex D.

It is intended that the Standard will be used by operators of NPPs (utilities), systems evaluators and by licensors.

b) Situation of the current Standard in the structure of the IEC SC 45A standard series

IEC 62855 is a third level IEC SC 45A document covering the topic of electrical power systems analysis.

This standard supports the guidance provided in the IAEA Safety Guide SSG-34 related to the design of electrical power systems for nuclear power plants.

This standard is related to

- IAEA Nuclear Energy Series NG-T-3.8 dealing with electric grid reliability and interface with nuclear power plants, and
- IEC 61513 establishing general requirement for I&C systems important to safety used in nuclear power plants..

For more details on the structure of the IEC SC 45A standard series, see item d) of this introduction.

c) Recommendations and limitations regarding the application of this standard

To ensure that the Standard will continue to be relevant in future years, the emphasis has been placed on issues of principle, rather than specific technologies.

d) Description of the structure of the IEC SC 45A standard series and relationships with other IEC documents and other bodies documents (IAEA, ISO)

The top-level documents of the IEC SC 45A standard series are IEC 61513 and IEC 63046¹. IEC 61513 provides general requirements for I&C systems and equipment that are used to perform functions important to safety in NPPs. IEC 63046 provides general requirements for electrical power systems of NPP; it covers power supply systems including the supply systems of the I&C systems. IEC 61513 and IEC 63046 are to be considered in conjunction and at the same level. IEC 61513 and IEC 63046 structure the IEC SC 45A standard series and shape a complete framework establishing general requirements for instrumentation, control and electrical systems for nuclear power plants.

IEC 61513 and IEC 63046 refer directly to other IEC SC 45A standards for general topics related to categorization of functions and classification of systems, qualification, separation, defence against common cause failure, control room design, electromagnetic compatibility, cybersecurity, software and hardware aspects for programmable digital systems, coordination of safety and security requirements and management of ageing. The standards referenced directly at this second level should be considered together with IEC 61513 and IEC 63046 as a consistent document set.

At a third level, IEC SC 45A standards not directly referenced by IEC 61513 or by IEC 63046 are standards related to specific equipment, technical methods, or specific activities. Usually these documents, which make reference to second-level documents for general topics, can be used on their own.

A fourth level, extending the IEC SC 45 standard series, corresponds to the Technical Reports, which are not normative.

The IEC SC 45A standards series consistently implements and details the safety and security principles and basic aspects provided in the relevant IAEA safety standards and in the relevant documents of the IAEA nuclear security series (NSS). In particular, this includes the IAEA requirements SSR-2/1, establishing safety requirements related to the design of nuclear power plants (NPP), the IAEA safety guide SSG-30 dealing with the safety classification of structures, systems and components in NPP, the IAEA safety guide SSG-39 dealing with the design of instrumentation and control systems for NPP, the IAEA safety guide SSG-34 dealing with the design of electrical power systems for NPP and the implementing guide NSS 17 for computer security at nuclear facilities. The safety and security terminology and definitions used by SC 45A standards are consistent with those used by the IAEA.

¹ Under preparation. Stage at the time of publication: IEC ANW 63046:2016.

IEC 61513 and IEC 63046 have adopted a presentation format similar to the basic safety publication IEC 61508 (all parts) with an overall life-cycle framework and a system life-cycle framework. Regarding nuclear safety, IEC 61513 and IEC 63046 provide the interpretation of the general requirements of IEC 61508-1, IEC 61508-2 and IEC 61508-4, for the nuclear application sector. In this framework, IEC 60880, IEC 62138 and IEC 62566 correspond to IEC 61508-3 for the nuclear application sector. IEC 61513 and IEC 63046 refer to ISO as well as to IAEA GS-R-3 and IAEA GS-G-3.1 and IAEA GS-G-3.5 for topics related to quality assurance (QA). At level 2, regarding nuclear security, IEC 62645 is the entry document for the IEC SC 45A security standards. It builds upon the valid high level principles and main concepts of the generic security standards, in particular ISO/IEC 27001 and ISO/IEC 27002; it adapts them and completes them to fit the nuclear context and coordinates with IEC 62443 (all parts). At level 2, regarding control rooms, IEC 60964 is the entry document for the IEC SC 45A control rooms standards, and IEC 62342 is the entry document for the IEC SC 45A ageing management standards.

NOTE 1 It is assumed that for the design of I&C systems in NPPs that implement conventional safety functions (e.g. to address worker safety, asset protection, chemical hazards, process energy hazards) international or national standards would be applied.

NOTE 2 IEC SC 45A domain was extended in 2013 to cover electrical systems. In 2014 and 2015 discussions were held in IEC SC 45A to decide how and where general requirement for the design of electrical systems were to be considered. IEC SC 45A experts recommended that an independent standard be developed at the same level as IEC 61513 to establish general requirements for electrical systems. Project IEC 63046 is now launched to cover this objective. When IEC 63046 will be published this NOTE 2 of the introduction of IEC SC 45A standards will no longer be valid.

NUCLEAR POWER PLANTS – ELECTRICAL POWER SYSTEMS – ELECTRICAL POWER SYSTEMS ANALYSIS

1 Scope

IEC 62855 provides the electrotechnical engineering guidelines for analysis of AC and DC electrical power systems in nuclear power plants (NPPs) in order to demonstrate that the power sources and the distribution systems have the capability for safe operation and shut down of the NPP, bringing it to a controlled state after an anticipated operational occurrence or accident conditions and finally reaching a safe state.

The analytical studies discussed in this document provide assurance that the design bases are satisfied to meet their functional requirements under the conditions produced by the applicable design basis events. The studies provide assurance that the electrical power system is capable of supporting safety functions during all required plant conditions.

NOTE The safety functions are described in IAEA Specific Safety Requirements SSR-2/1 related to the design of the nuclear power plants..

Analytical studies validate the robustness and adequacy of design margins and demonstrate the capability of electrical power systems to support plant operation for normal, abnormal, degraded and accident conditions.

The analyses are used to verify that the electrical power system can withstand minor disturbances and that the consequences of major disturbances or failures do not degrade the capability of the electrical power systems to support safe shutdown of the plant and maintain the plant in shutdown condition.

The analyses are performed with one or more of

- simulation tools (software and hardware) that have been verified and validated,
- hand calculations, and
- tests.

This document provides guidance on the types of analyses required to demonstrate that the plant's auxiliary power system can perform the required safety functions. This document does not provide specific details on how the analysis should be conducted.

This document does not cover digital controllers (such as controllers for rectifiers, inverters, sequencers and electrical protection devices) used in electrical power systems. IEC 61513 gives recommendations that apply to the electronic controls and protective elements of the electrical power systems.

This document does not include environmental conditions (i.e. temperature, humidity, etc.) or external events (seismic, flooding, fire, high energy electromagnetic pulse, etc.) that may impact equipment sizing or protection requirements. The external events lightning and geomagnetic storms are included.

This document does not cover additional or unique requirements for stand-alone power system, such as power supplies for security measures in NPPs. Pertinent clauses of this document may be used as a guideline for such systems.

Redundancy in the power system design can increase the availability of electrical power to critical plant equipment. Performing a probabilistic risk assessment (PRA) is a method of assessing system availability and optimizing design for high reliability. This document does not cover improving the reliability of NPP electrical power systems using statistical or diverse and redundant schemes.

Requirements for safeguards of personnel involved with installation, maintenance and operation of electrical systems and general personal safety are outside the scope of this document. General guidance for lightning protection of equipment is provided in relevant clauses of this document.

This document is intended to be used:

- for verification of the design of new nuclear power plants,
- for demonstrating the adequacy and impact of major modifications of electrical power systems in operating nuclear power plants, and
- where there is a requirement to assess and establish operating limits and constraints for existing plants.

Pertinent parts of this document can be used as guidance for decommissioning stages.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

alternate AC source

power source reserved for the use for the power supply to the plant during total loss of all non-battery power in the safety power systems (station blackout) and other design extension conditions

Note 1 to entry: Figure A.2 gives a graphical representation.

3.2

house load operation

operation of a nuclear power plant to supply power only to its own electrical loads

3.3

design extension conditions

postulated accident conditions that are not considered for design basis accidents, but that are considered in the design process of the facility in accordance with best estimate methodology, and for which releases of radioactive material are kept within acceptable limits.

Design extension conditions include conditions in events without significant fuel degradation and conditions with core melting

[SOURCE: IAEA SSR-2/1:2012, definitions revised as DS462]

3.4

loss of off-site power

simultaneous loss of electrical power to all unit safety buses, requiring the standby AC power sources to start and supply power to the safety buses

Note 1 to entry: DC systems and uninterruptible AC systems safety buses are not included.

3.5

power balance

steady state active and reactive power required by the electrical power system

Note 1 to entry: This document provides the basis for sizing electrical equipment (switchboards, cables, power sources, transformers, batteries, rectifiers/inverters, etc.).

3.6

preferred power supply

power supply from the transmission system to the safety classified electrical power system, comprising transmission system, switchyard, main generator, distribution system up to the safety classified electrical power system

Note 1 to entry: Some portions of the preferred power supply are not part of the safety classification.

3.7

standby AC power source

power source, capable of supplying the necessary power in anticipated operational occurrences and accident conditions, in the event of the loss of off-site power and main generator

3.8

station blackout

plant condition with complete loss of all AC power from off-site sources, from the main generator and from standby AC power sources important to safety to the essential and non-essential switchgear buses

Note 1 to entry: DC power supplies and uninterruptible AC power supplies may be available as long as batteries can supply the loads.

Note 2 to entry: Alternate AC supplies are available.

3.9

total harmonic distortion

ratio of the rms value of the harmonic content of an alternating quantity to the rms value of the fundamental component of the quantity

[SOURCE: 60050-551:1998, 17-06]

3.10

transmission system operator

party responsible for providing and operating networks for long-distance transmission of electricity as well as regional distribution and responsible to ensure the system security with a high level of reliability and quality

4 Symbols and abbreviations

AC	alternating current
AOO	anticipated operational occurrences
CCF	common cause failure
CMF	common mode failure
DBA	design basis accident

DBC	design basis conditions
DC	direct current
DEC	design extension conditions
EMC	electromagnetic compatibility
LOOP	loss of off-site power
NPP	nuclear power plant
PPS	preferred power supply
PRA	probabilistic risk assessment
QA	quality assurance
SSC	structures, systems and components
THD	total harmonic distortion.
TSO	transmission system operator
UPS	uninterruptible power supply
V&V	verification and validation

5 Electrical power system analyses

5.1 Overview of typical studies

5.1.1 Transient stability analyses

Grid disturbances, such as a short circuit on a transmission line, sudden loss of generation, or the loss of a large load, may cause instability. If such disturbances are not cleared rapidly, instability may ultimately lead to loss of parts or total loss of the preferred power supply.

Transient stability studies investigate the transient behaviour of the NPP generator after a disturbance on the electrical network in the vicinity of the plant. The study determines the capability of the generator to remain connected to the grid and studies the effects of the transient on the unit electrical power supply system.

5.1.2 Load flow studies

The different power balances are input data for the load flow studies. Load flow studies are performed to determine the steady-state operation of an electric power system. The study is used to establish

- the voltage drop on each feeder,
- the bus voltage,
- the load terminal voltage, and
- the power flow in all branch and feeder circuits.

The study is used to determine if system voltages remain within specified limits under all defined conditions.

5.1.3 Transient and dynamic studies

Transient studies determine the voltage, current, power and frequency in a power system when a fault or a disturbance occurs in an interconnected network. This may result from events such as starting and loading of standby power sources, starting and running of large motors and failures of voltage regulation for generators.

During and after such a disturbance, these dynamic studies

- investigate the behaviour of rotating machinery and electrical equipment, and
- verify the operability of rotating machinery and supporting electrical equipment.

5.1.4 Short circuit studies

Short circuit studies are required to establish the maximum available short circuit power available at each point in the electrical power system and to ensure that existing and new equipment ratings are adequate. Short circuit studies are also required to determine the minimum short circuit current in order to verify the sensitivity of the electrical protection system.

5.1.5 Electrical protection coordination and selectivity

The electrical protection system detects and responds to electrical faults in order to minimize equipment damage. Electrical protective schemes minimize hazards to personnel, equipment and the plant by isolating the faulted portion of the power system. This enables continuity and availability of power to the balance of the system.

A coordination study determines the selection or setting of all protective devices from the load upstream to the power supply. In selecting or setting these protective devices, a comparison is made of the operating times of all devices in response to various levels of current, voltage and frequency. The objective is to design a selectively coordinated electrical power system.

5.1.6 Lightning protection studies

Lightning protection systems are used to minimise the possible consequences of a direct lightning strike. Lightning protection studies determine the magnitude of voltages and currents after a lightning strike in order to verify the capability of protection schemes and equipment.

5.2 Applicability of analyses to different plant states

5.2.1 General

During normal plant operation, the safety buses are generally powered from the preferred power supply with non-safety power sources and connected with non-safety buses. The electrical power system verification analyses should therefore cover all interacting parts of the electrical power systems, including grid, generators and non-safety systems for all operating and shutdown modes of the NPP.

5.2.2 Recommendations

The following recommendations apply.

- a) As part of the design verification process, the following analyses should be performed and maintained for future plant modifications.
 - 1) Steady state analyses and transient analyses to demonstrate that the electrical power systems
 - are capable of supplying the plant safety systems to perform their intended functions during postulated worst case plant loading conditions with minimum allowable system voltage and frequency,
 - meet design basis requirements for anticipated operational occurrences and accident conditions,
 - include adequate measures for design extension conditions such as station blackout, and
 - include adequate measures for external electrical events that can degrade on-site and off-site power sources.
 - 2) Demonstration that systems of higher safety classification are adequately protected from impacts of systems of lower safety classification such as

- propagation of faults,
 - initiation of electrical common cause failures, and
 - overloading.
- 3) Demonstration that off-site circuits, when credited for supplying safety loads, meet the required reliability and availability. This should also be demonstrated after planned changes to transmission and generation facilities that can influence the network connected to the plant.
- 4) Demonstration that the off-site circuits, when credited for supplying safety loads, will continue to provide the required capacity and capability in the case of:
- loss of the nuclear plant,
 - loss of the largest generating unit connected to the grid,
 - loss of the largest transmission circuit or interconnection, and
 - loss of the largest load.
- b) The analyses should cover all defined modes of operation and events of the NPP such as:
- 5) normal operation:
- start-up;
 - power operation;
 - shutting down;
 - shutdown operation;
 - outage;
 - refuelling;
 - maintenance;
 - testing.
- 6) anticipated operational occurrences:
- unit trip/full-load rejection;
 - loss of off-site power;
 - loss of preferred power supply.
- 7) design basis accidents
- 8) design extension conditions:
- station blackout;
 - extended loss of AC power.
- c) The analyses for the off-site circuits' capacity and capability should be performed in conjunction with the TSO.

5.3 Selection, verification and validation of analytical tools

5.3.1 General

A systematic approach should be adopted to ensure that the simulations accurately establish requirements determined from the preconditions and that the results can be validated independently by field measurements or other diverse and alternative methods.

The scope of the study to be carried out, the phenomena to be modelled and the complexity of the network to be analysed determine the type of software that should be used to perform the analyses. The software should have the capability to model asymmetric faults and conditions. The majority of commercially available software, developed for power system analyses of large industrial complexes, will have the capability to simulate all the major buses and loads in a NPP and perform the minimum set of analyses identified by the designer.

This document does not recommend any specific software.

5.3.2 Recommendations

The following recommendations apply.

- a) The following requirements should be considered for the specific software that will be used to establish the design basis of the electrical system.
 - An auditable quality assurance process which complies with international standards should be established and maintained.
 - The software system should have been subject to a verification and validation (V&V) process to check that the system meets specifications and that it fulfils its intended purpose. This V&V process should also be implemented for the simulation studies. This approach requires
 - the production of a report of the V&V activities,
 - the definition of a validated domain (domain in which the difference between the results of the tools and those of another validated reference or tests is considered satisfactory for its intended use), and
 - the appropriate archiving of the documentation.
 - a detailed and formal description of the simulation tool (software version number, user configuration, other settings and parameters) should be provided.
- b) To perform the verification and validation, including functional verification, of the specific software that will be used, the following should be achieved:
 - the functional verification should demonstrate that the architecture of the software tool does not include errors;
 - the functional verification should be demonstrated through certification or the report of a QA audit. The documents used for functional validation should be fully referenced;
 - the functional validation should allow the user to ensure that the equations correctly represent the physical phenomena studied in the defined operating range of the software tool;
 - the functional V&V may be done by comparing simulation results with
 - test results, or
 - results obtained from other functionally validated simulation tools, hand calculation, past experience and similar work, supplemented if necessary by expert feedback and evaluation.

NOTE 1 This could be part of a QA program.

- c) For each significant change of the simulation software or its environment that is intended to be utilised, the user should conduct an analysis of the impact of this modification. If the test results or the functional V&V process are successful, then the new version should be utilised to replace the old version which should be archived.

NOTE 2 This is normally part of configuration management.

- d) To ensure correct use of qualified software, a user guide should be written. The guide should allow different users
 - to identify
 - the different types of studies that may be performed with the software,
 - the models whose validity domain are consistent with the physical phenomena, and
 - the necessary input data,
 - to transform input data into a format recognised by the software (using quality checked spreadsheets),
 - to create the necessary files to carry out the simulation, and

- to achieve consistent results.

e) Personnel performing software studies should be able to demonstrate adequate and relevant training and suitable qualification.

5.4 Electrical power system model

The model should be adapted to the specific studies, and the following actions should for example be done.

- The analyses should simulate major AC load buses, cables, transformers and all current limiting devices. For large systems, a common technique is to group the loads that have similar characteristics (e.g. rotating load, static resistive load) and simulate a "lumped" load that is expected to have an "equivalent" impact to that of the individual loads;
- For transient stability, the main generator with its regulators (voltage and speed), the step-up transformer, large motors and the network in the vicinity of the plant should be modelled in detail. The network in general may be modelled as an equivalent system for simplification based on technical justification.

Assumptions made in the physical model used in the analysis should be clearly identified and validated, and constraints identified.

5.5 Grid and NPP connection

Analytical studies related to off-site power systems should be performed. The NPP design needs to take account of these analyses and evaluate the impact on the on-site power systems.

The intent of these studies is to include all expected power supply alignments and NPP operating scenarios to evaluate the off-site power supply design and operation in supporting safe operation of the NPP under all conditions.

The studies should provide a comprehensive evaluation of off-site power source capability and capacity to meet the design requirements of the NPP. Additionally, the studies should be reviewed on a routine basis to assure that any changes in either on-site or off-site power systems are adequately evaluated for impact on the NPP power system.

An analysis should be carried out to verify that maximum and minimum voltage and frequency deviations remain within the defined NPP design requirements.

5.6 Updating of system analyses

Compliance with existing analyses should be confirmed or the analyses repeated

- when major replacements and/or major modifications of the electrical power system (on-site or off-site) are implemented, and
- during licence renewal or periodic safety review.

Motor starting studies should be performed as part of plant modifications including

- relocation of plant loads, and
- replacement of motors (which may have different operating characteristics) or generators.

5.7 Prerequisites for the performance of electrical studies

The following parameters should be established prior to the commencement of studies:

- preliminary ratings of electrical equipment;
- a power balance;
- all the operating modes of the NPP and the most onerous case identified

In order to establish the most onerous operating conditions, different scenarios should be considered taking into account combinations of the following parameters:

- operation from on-site or off-site power sources;
- maximum and minimum short circuit power;
- maximum and minimum voltage range;
- maximum and minimum frequency range;
- all operating modes of the NPP;
- maximum and minimum power generation of the NPP;
- maximum and minimum load taking account of all operating loads and environmental conditions;
- maximum and minimum electrical power system impedances;
- operating modes following single failures of electrical equipment;
- transfer of loads between power sources.

5.8 Acceptance requirements

This document identifies the acceptance requirements.

The acceptance criteria shall be derived from these requirements on a plant specific basis. Failure to meet the acceptance criteria shall be justified as not adversely impacting nuclear safety, or a design change shall be made.

6 Off-site power transient stability analyses

6.1 General

Clause 6 applies to the grid and the main generator in the NPP.

The recovery of a power transmission system subjected to a severe disturbance is of importance to reliable and safe operation of a NPP. The grid transient stability analyses should establish the limiting cases for the plant to ride through and remain connected to the grid for disturbances that do not result in the generator falling out of synchronism. These analyses should be performed in conjunction with the TSO to establish parameters such as fault clearing time.

6.2 Recommendation

Transient stability analyses should be performed to simulate power system operating conditions and establish the impact on the system stability.

6.3 Acceptance requirements

The main generator shall remain connected to the grid and not fall out of synchronism on faults cleared by the TSO's protection scheme. The main generator shall fully comply with the TSO grid code requirements unless deviations are agreed with the TSO. The result of the analysis shall verify that the NPP on-site power system and connected loads can ride through transients in accordance with the TSO grid code requirements.

7 AC on-site power system analyses

7.1 General

This clause applies to low and medium voltage AC power systems (not supplied by inverters or UPS) including standby AC power sources and alternate AC sources.

7.2 Load flow studies

7.2.1 General

Conducting a load flow study using multiple scenarios with different plant configurations and generation sources (see 5.7) provides assurance that the power system is adequately designed to meet the defined performance criteria.

7.2.2 Recommendations

The following recommendations apply to load flow studies.

- a) Load flow studies for AC systems should be performed, simulating actual steady-state power system for normal, abnormal and emergency conditions enabling the evaluation of bus voltage, voltage at rotating machinery terminals, current, and power flow.
- b) The grid code of the TSO normally defines a voltage range that a nuclear plant should be able to withstand when producing electrical power, continuously or for a limited time period. The consequences of high and low grid voltages should be evaluated for impact on the plant's electrical power systems during different modes of operation, and if on-load tap changers exist, they should be considered in the study.
- c) The voltage range on the on-site distribution system when the generator is disconnected from the grid (i.e. shutdown and start-up modes) should be evaluated.
- d) The following cases should be specifically considered in load flow studies.
 - Extreme operating conditions of maximum and minimum loading of the electrical power system to check the adequacy of the on-site and off-site power sources. This should include conditions during operation at power and during plant shutdown.
 - Contingency conditions such as outages of lines, transformers and generators for the off-site source coupled with minimum and maximum loading of plant electrical power system. This should include plant equipment required to mitigate consequences of an accident.

NOTE During design optimisation, studies can be performed, with consideration to safety margins, of plant parameters such as:

- transformer taps and impedances,
- generator excitation limits,
- reactive power compensations, and
- cable sizing.

7.2.3 Acceptance requirements

The results of the load flows shall be consistent with

- a) the power flow capability of various electrical equipment (including margins), and
- b) the permissible voltage range for operation of all electrical equipment.

7.3 Transient studies

7.3.1 General

Transient studies for AC systems enable the evaluation of bus voltage amplitude and load angle, current and frequency following a system disturbance such as an electrical fault or inadvertent loss of a critical element.

7.3.2 Faulted conditions

7.3.2.1 Recommendations

The following recommendations apply to transient studies.

- a) The transient and steady state voltage and frequency on the on-site buses after an external or internal event should be investigated for all modes of plant operation. In addition, consideration should be given to phase shifts which can impact connected loads and their control circuits.

NOTE Phase shift (here) is a change in the phase difference between two (or more) quantities.

Typical events that should be considered include:

- grid events such as short circuits and earth faults cleared by primary or backup protection,
- short circuit and earth faults on the main generator, unit transformer or auxiliary transformer,
- short circuit and earth faults on the on-site electrical power systems (sensitivity studies should be carried out to identify the limiting case(s)), and
- frequency variations.

Note that this list is not comprehensive. Additional fault studies may be necessary depending on plant specific design criteria.

- b) The impact on electrical equipment (such as motors, rectifiers and inverters) from symmetrical and asymmetrical faults on the AC supply should be analysed. This should include on-site and off-site faults and should consider the effects of recovery voltage. The adequacy of protective equipment to detect and clear unacceptable electrical power system parameters should be validated.
- c) For system disturbances that result in tripping or isolating safety equipment, the restart or re-acceleration time of large motors should be analysed to ensure that the protective system does not actuate to prevent automatic functions of safety classified equipment.

7.3.2.2 Acceptance requirements

The transient studies shall verify the following.

- a) Unacceptable system conditions due to electrical disturbances shall be detected and cleared by the protective system in a selective and timely manner.

If a system disturbance results in loss of a power source, then the sequence of events related to transfer to alternative power source(s) shall be evaluated. This will ensure that the time limitations for operation of mitigating systems assumed in accident analyses are not exceeded.

EXAMPLE In the event of loss of one off-site power system, the transfer to house load mode or alternative off-site sources and to the on-site standby power source is validated. This will ensure that the total time to actuate and operate safety systems for mitigating design basis events is within acceptable limits.

- b) The frequency, current and the voltage of the plant electrical power system shall comply with equipment specifications and capabilities (including insulation coordination). Equipment which is required to trip to provide protection shall not exceed its rated switching capability.

7.3.3 Bus transfer studies

7.3.3.1 General

Bus transfer can be initiated by grid or plant perturbations, breaker failure protection or operator action.

7.3.3.2 Recommendation

Bus transfer should be analysed as part of transient studies.

7.3.3.3 Acceptance requirements

The bus transfer studies shall verify that

- a) the residual voltage for a slow bus transfer shall be low enough to preclude out-of-phase voltage issues for rotating equipment,
- b) the terminal voltages of plant auxiliaries started or restarted (especially induction motors) shall be adequate to successfully accelerate all equipment that starts simultaneously upon successful bus transfer,
- c) the starting and/or acceleration time of the plant auxiliaries such as large injection pumps shall conform to the nuclear safety requirements from accident analysis as well as to operational needs,
- d) the operating characteristics of the protective schemes such as overcurrent or undervoltage relays shall not result in unnecessary trips during worst case power system operation, and
- e) after starting or restarting, all electrical equipment shall operate in permissible voltage and frequency ranges.

7.3.4 Motor starting and reacceleration studies

7.3.4.1 General

The starting current for motors (especially for large motors) results in significant voltage drop at the equipment terminals (and in connected switch boards). This can potentially result in the failure of motor starting due to low starting torques or stalling of other running motors connected to the network. Motor starting studies should consider the most onerous conditions of load and power sources.

7.3.4.2 Recommendations

The following recommendations apply to motor starting and reacceleration studies.

- a) Motor starting studies should be performed as part of transient studies. These studies should cover the whole range of possible scenarios.
- b) The current and voltage profiles after a bus transfer or after a voltage dip on the on-site electrical power system should be analysed. The corresponding voltage drop in transformers and cables should be determined.

7.3.4.3 Acceptance requirements

The motor starting and reacceleration studies shall verify the following.

- a) The start or restart of all induction motors shall not lead to
 - stalling of the induction motor during starting,
 - stalling of other motors,
 - bus transfer to off-site power source, and
 - start-up of standby AC power sources.
- b) The terminal voltages of induction motors started or restarted shall comply with the requirements of equipment technical specifications (specifically as related to voltage and start-up time).
- c) The starting time of the induction motors in the postulated worst case condition (see 5.7) shall conform to:
 - the criteria established in the nuclear safety analyses,
 - any operational constraints, and
 - protection system setpoints.
- d) After starting of motors, the electrical equipment shall operate within the allowable voltage and frequency range.

7.3.5 House load operation

7.3.5.1 General

Some NPPs have the ability for house load operation, i.e. convert to generating electricity only for the unit's own needs. The initiator can be faults on the grid or in the switchyard. The transfer to house load operation will cause variations of voltage and frequency on the generator terminals and in the on-site power systems.

7.3.5.2 Recommendation

The impact on on-site electrical equipment from variations in voltage and frequency should be studied. Electronic equipment, such as rectifiers and inverters, have been shown to be sensitive to variations that are natural to a generating unit, if not designed for that application. The impact on electronic protective devices should also be studied.

7.3.5.3 Acceptance requirements

The study shall verify the following.

- a) During and after transfer to house load operation the frequency and the terminal voltages of electrical equipment shall comply with the requirements of equipment specifications and capabilities.
- b) Transfer to house load operation shall not result in
 - stalling of motors,
 - bus transfer to off-site power source, and
 - start-up of standby AC power sources.

7.3.6 Voltage disturbances

7.3.6.1 General

Examples of voltage disturbances are degraded voltage, unbalanced voltage (such as loss of phase(s)), voltage dips and interruptions.

Voltage disturbances can cause a common cause failure of redundant connected loads.

7.3.6.2 Recommendations

The following recommendations apply to voltage disturbance studies.

- a) Voltage disturbance studies should be performed as part of transient analyses to support electrical voltage protection coordination studies.
- b) Voltage disturbance studies should consider symmetrical and asymmetrical cases (such as loss of phase(s)) on normal and standby power supplies. The protection schemes should detect degraded power source conditions during no load or minimal load conditions as well as during full load operation.

7.3.6.3 Acceptance requirements

The voltage disturbance studies shall verify the following.

- a) The protective scheme settings (voltage and time) shall ensure that equipment is not degraded while operating under reduced voltage conditions.
- b) The protective scheme shall ensure that safety buses with non-acceptable voltage levels are isolated from the degraded source and transferred to an alternative power source.

7.3.7 Voltage surge caused by switching and malfunctions

7.3.7.1 Recommendations

The following recommendations apply.

- a) Overvoltage studies should be performed as part of the transient analyses. Rapid voltage transients should also be considered.
- b) Studies should be performed to show that fast transient disturbances on the electrical system will not cause damage or disruption to the system. Some of the particular phenomena to be considered are
 - inductive switching,
 - capacitive switching,
 - current chopping, and
 - unearthed three phase systems.

For overvoltages caused by lightning, see 9.1.

7.3.7.2 Acceptance requirements

Insulation coordination studies shall ensure that overvoltages do not exceed equipment withstand capabilities.

For coordination of voltage protection, see 7.5.

7.3.8 Load sequencer studies

7.3.8.1 Recommendations

The following recommendations apply to load sequencer studies.

- a) Load sequencer studies for standby AC power sources should be performed, using models that enable the evaluation of bus voltage amplitude and load angle, current and frequency as well as prime mover throttling response time.
- b) The dynamic analysis should demonstrate that
 - all loads can be connected in a pre-determined sequence,
 - the time interval of the sequencer is adequate to restore adequate voltage and frequency before the next load step is applied, and
 - motor starting currents are within acceptable limits.
- c) Frequency deviations should be studied as part of the load sequencer study with the safety standby AC power source as the only source.

NOTE Frequency transients will occur during load sequencing. The impact on pump flow can generally be neglected as long as the variations are short.

7.3.8.2 Acceptance requirements

The load sequencer studies shall verify the following.

- a) During load sequencing, the frequency deviations and the terminal voltage deviations of induction motors shall not lead to stalling of other auxiliary loads.
- b) The terminal voltages of induction motors started or restarted shall comply with the requirements of equipment technical specifications (specifically as related to voltage and start up time).
- c) The starting time of the induction motors for the postulated worst case voltage, frequency and loading conditions shall conform to the assumptions and criteria established in the safety analyses.

- d) Protection system set-points shall take account of worst case voltage, frequency and loading conditions.
- e) After the loading sequence, the electrical equipment shall operate within its rated voltage and frequency range.
- f) After each sequencing step, the frequency and the terminal voltage of the standby AC power source shall be within adequate values in order to allow the following step.
- g) The safety function of equipment required for safe shutdown shall have priority when determining protective schemes.

7.3.9 Frequency studies

On-site frequency variations (around normal frequency) originating from the grid should be evaluated and shown to be acceptable for impact on equipment such as uninterruptible power supplies (UPS).

The minimum and maximum allowable steady state frequency should be evaluated for impact on operation of large induction motors and capability to satisfy flow requirements of connected pumps, fans, compressors, etc.

The maximum/minimum fluid flow requirements shall satisfy nuclear accident analyses requirements. The operating time for motor operated valves shall not exceed allowable stroke time.

These evaluations of flow requirements and stroke time are not part of the electrical power system analysis and should be performed by fluid system or nuclear safety analysis specialists.

7.4 Fault studies

7.4.1 Short-circuit studies

7.4.1.1 General

Short-circuit calculations according to IEC 60909 (all parts) should be performed to determine maximum and minimum AC currents during fault conditions. Short-circuit studies are required to check equipment withstand and to design an adequate and selective protection scheme.

Fault conditions can be balanced or un-balanced shunt faults. Faults may be caused by either short-circuits to earth or between live conductors.

7.4.1.2 Recommendations

The following recommendations apply.

- a) Fault contributions from all operating sources at any given time should be considered:
 - contributions from standby AC power sources in parallel during test operation;
 - the significant contribution from large induction motors to the available fault current in the plant electrical power system.
- b) Short-circuit studies should be used to define the required ratings of switchgear, cables and other equipment.

7.4.1.3 Acceptance requirements

The results of the symmetrical and asymmetrical short-circuit calculations shall be consistent with

- a) the maximum fault current withstand capability of all electrical equipment, and
- b) the interrupting capability of switching devices.

7.4.2 Earth fault (degraded insulation) studies

7.4.2.1 General

Earth faults can cause unbalanced voltage conditions, with the risk of insulation degradation, or unbalanced currents, with the risk of excessive heating.

7.4.2.2 Recommendation

Earth fault studies should be performed to verify that degraded insulation to earth will be detected. Fault contributions from all operating sources at any given time should be considered.

7.4.2.3 Acceptance requirements

If protective schemes have no trip function for earth fault conditions (such as earthing via impedance systems), the operating equipment shall be demonstrated to be able to perform its intended function(s).

7.5 Electrical protection coordination studies

7.5.1 Recommendations

The following recommendations apply:

- a) Adequate selectivity should be determined for all available power sources and all loads.
In particular cases and for particular sources (e.g. standby power sources) and consumers, protection of equipment may be reduced to the essential set for preservation of the nuclear safety function.
The protection scheme should not actuate for normal operating transients such as starting motor inrush, switching surges, transformer inrush current.
- b) Electrical protection coordination calculations should determine the optimum settings to achieve high availability of the electrical power systems. These calculations should take account of all operating conditions including the use of standby sources.
The protection scheme should actuate equipment nearest to the faulted portion of the system to prevent further equipment damage. This will ensure minimum system disruption by maintaining continuity of power to unaffected portions of the power systems.
- c) The over-current protection scheme should take into account
 - the highest operating transient (see 7.3), and
 - the lowest short-circuit current (see 7.4).
- d) The degraded voltage and unbalanced voltage protection scheme should operate to prevent overload current trips of safety system equipment (mostly rotating machinery), rendering them inoperable. The protective system should provide protection against thermal-withstand limits, negative phase sequence (i.e. asymmetric faults) and asymmetrical DC offset currents. It should also protect against unbalanced operating conditions as applicable to various plant components and operating situations.
- e) On degraded voltage or unbalanced voltage, the electrical safety system should, after a suitable delay, be separated from the degraded supply and transfer to its own dedicated supply.
When voting circuits (often 2/3 logic) are used for voltage supervision, the configuration of the equipment and the measuring principle should be able to detect the same degradation of the supply.
- f) A coordinated study should be undertaken of the complete voltage protection system to demonstrate the resilience of the complete electrical power system to overvoltages.

- g) The electrical power system should be monitored to alarm or trip in the event of detection of degraded insulation to earth. A coordinated study should demonstrate the resilience of the complete electrical power system.

7.5.2 Acceptance requirements

The electrical protection coordination studies shall verify the following.

- a) Faulted circuits shall be selectively isolated.
- b) Degraded voltage or unbalanced voltage shall be detected and mitigating actions initiated.
- c) The electrical power system shall be protected against harmful overvoltages.
- d) Tripping of critical safety equipment during mitigating or emergency mode of operation shall be evaluated to consider the effects on safety functional requirements.

8 DC system and uninterruptible AC system analyses

8.1 Load flow studies

8.1.1 General

Load flow analysis is an important part of power system calculations since it evaluates the network performance in its normal, abnormal and emergency operating conditions and establishes the limiting bounding conditions.

NOTE Typically, the peak loading appears at the onset of an accident signal coincident with loss of off-site power.

The DC system and uninterruptible AC system (DC power supply) have to maintain adequate bus voltages during an extended period of loss of on-site and off-site AC power.

8.1.2 Recommendations

The following recommendations apply.

- a) Load flow studies including operating durations for DC system loads should be used to verify the following.
 - Battery capacity.
 - Component or circuit loading.
 - Bus and load voltage during battery charging, trickle (float) charging and discharging. Note that bus and load voltage during float or equalizing charge conditions should not be higher than the design rating of connected loads.
 - Load voltage during normal and emergency operating conditions including inrush currents.
- b) The capability of the batteries to supply loads according to load profiles during the designed discharge time should be analysed. The voltage profile at component terminals should be evaluated at the end of battery design life at minimum allowable ambient temperature considering that
 - loads may draw transient current which should be considered in battery sizing and protective equipment operation, and
 - the inrush and total current for some loads (such as breaker trip or close coils) may last for a few seconds. For conservative calculation basis, such concurrent loads should be considered for a whole minute and added to other such loads within the same minute.
- c) Load flow studies for uninterruptible AC systems (power source UPS or inverter) should be used to verify
 - component or circuit loading,

- load terminal voltage (considering voltage drop from bus to load) during normal, abnormal and emergency conditions,
- the capability of the battery as it approaches final capacity at the end of its certified life (the battery manufacturers provide details on battery life, discharge curves for final cell voltage and time to reach end of life), and
- the voltage profile at component terminals is evaluated at minimum allowable ambient temperature.

8.1.3 Acceptance requirements

The load flow studies shall verify the following.

- a) The capability of the battery shall comply with the designed requirements.
- b) The instantaneous voltage during the first minute(s) of an event or other peak load conditions coupled with loss of AC power shall be adequate for starting and operating all required loads.
- c) The load flow analyses shall demonstrate adequate battery capacity to support starting and steady state operation of all loads required following a loss of AC power supplies.

8.2 Transient studies

8.2.1 Rectifier

8.2.1.1 Recommendation

The transient studies carried out as outlined in 7.3 should verify that the DC system voltage will be maintained (as shown by tests or simulation) within an acceptable range during input AC voltage transients:

- voltage dips and interruptions with return to nominal voltage;
- voltage dips and interruptions with return to high voltage;
- high voltage transients;
- harmonics on the input of the rectifier;
- operation without connected battery.

Operation without connected battery is generally not allowed, the intent is to give time for remedial actions or planned shutdown.

8.2.1.2 Acceptance requirements

The studies shall verify the following.

- a) Disturbances in the input AC system shall be dampened or limited to an acceptable level to ensure that functionality of DC system(s) or UPS system(s) is not adversely impacted.
- b) The functional capability of the DC system(s) or UPS systems(s) shall not be degraded by voltage disturbances such as switching surges or inrush current in the AC system powering the rectifier circuits.

8.2.2 Inverter/UPS and bypass switch

8.2.2.1 Recommendations

The following recommendations apply.

- a) The transient studies carried out as outlined in 7.3 should verify that UPS system output voltages remain within an acceptable range during input AC voltage transients:
 - voltage interruptions with return to nominal voltage;
 - voltage interruptions with return to a high voltage;

- overvoltages.

Disturbances in the input AC system (including the high voltage grid) should be dampened or limited to an acceptable level to ensure that functionality of UPS powered safety loads is not adversely impacted.

- b) The overvoltage studies carried out as outlined in 7.3 and 9.1 should verify that any overvoltage will not render the bypass switch inoperable.

NOTE One example is excessive reverse voltage.

8.2.2.2 Acceptance requirements

The functional capability of the UPS system shall not be degraded by voltage disturbances such as microcuts, switching surges or inrush current in the AC system powering the UPS circuits.

8.3 Fault studies

8.3.1 Short circuit studies

8.3.1.1 Recommendation

Short circuit studies should verify according to IEC 61660 that any short circuit will be detected and cleared/alarmed in an acceptable time for both minimum and maximum fault conditions. Faults may be caused by either short-circuits to earth or between live conductors.

8.3.1.2 Acceptance requirements

The short circuit studies shall verify the following.

- a) Protective devices for DC and uninterruptible AC systems shall detect all fault conditions in the system.
- b) Equipment ratings shall not be exceeded.
- c) The critical function of the DC and AC systems to support plant safety shall be considered in determining tripping requirements for faulted circuits.
- d) Uninterruptible AC power sources shall be able to provide adequate current to operate protection to clear short circuits.

8.3.2 Earth fault (degraded insulation) studies

8.3.2.1 Recommendation

DC and uninterruptible AC systems that are not solidly earthed require specific consideration for operation with one phase/pole in fault condition. Earth fault studies for these systems should verify that degraded insulation is detected before any spurious, or loss of, action of safety equipment.

8.3.2.2 Acceptance requirements

If protective schemes have no trip function for earth fault conditions (such as earthing via impedance systems) the operating equipment shall be demonstrated to be able to perform its intended function(s).

8.4 Electrical protection coordination studies

8.4.1 Recommendations

The following recommendations apply.

- a) Selectivity should be adequate for all available power sources.

The short circuit study should establish the magnitude of currents flowing throughout the power system at various time intervals after a fault occurs and evaluate the size and settings of a system's protective devices, such as measuring elements, fuses and circuit breakers. Earth fault current magnitudes depend on the system earthing method.

- b) The protection scheme should rapidly and selectively actuate equipment nearest to the faulted portion of the system to prevent further equipment damage. The scheme should, with minimum system disruption, ensure continuity of power to unaffected portions of the power systems. Electrical protection coordination calculations determine the optimum settings to achieve high availability of the electrical power systems taking account of all operating conditions including supplies from standby sources.
- c) The voltage protection scheme should operate to prevent overload current trips of safety system equipment rendering them inoperable.
- d) The degraded voltage protection scheme should alarm and, when applicable, transfer to an alternative supply.
- e) The electrical power system should be protected against harmful overvoltages. A coordinated study should be undertaken of the complete voltage protection system to demonstrate the resilience of the complete electrical power system to overvoltages.
- f) Tripping of critical safety systems during mitigating or emergency mode of operation should be subject to analysis of safety function requirements.

8.4.2 Acceptance requirements

Faulted circuits shall be selectively isolated except where evaluated as required for safety functional requirements.

9 Miscellaneous analyses

9.1 Lightning protection studies

9.1.1 General

Lightning strikes

- on buildings,
- in the vicinity of the NPP, and
- on transmission lines,

may induce disturbances and destruction of electrical and electronic systems.

The consequences of lightning strikes should be mitigated by design provisions such as Faraday cages, equipotential bonding networks, transformers, cable shielding, cable layout engineering and additional lightning protection if required. These provisions should be identified and substantiated prior to initiating any analysis of lightning effects.

The lightning protection system should conform to IEC 62305-1, IEC 62305-3 and IEC 62305-4.

9.1.2 Recommendation

The lightning protection system should reduce lightning effects sufficiently to ensure that they are lower than the electromagnetic immunity of the equipment to protect.

When a model and simulation tool is used, they should be suitable for studying high frequency phenomena.

9.1.3 Acceptance requirements

The analyses shall demonstrate with adequate assumptions that overvoltages caused by lightning do not challenge the safety equipment and are below the design basis values. Induced voltages/currents shall be demonstrated to be within design limits.

9.2 Electromagnetic compatibility

9.2.1 General

Requirements should be defined for equipment qualification in terms of electromagnetic emission and/or immunity (e.g. IEC 62003). At the same time, it is also fundamental to apply good practice in execution of

- segregation,
- cabling,
- cable shielding management,
- effective building/room/panel shielding,
- earthing philosophy,
- etc.

9.2.2 Recommendation

Compliance with these requirements should be verified in a design assessment.

9.3 Harmonic studies

9.3.1 General

With the use of variable frequency drives and other switching supplies connected to the electrical power system, the generation of harmonics and its propagation and impact on other loads should be considered.

9.3.2 Recommendation

The electrical distribution system should be studied with respect to harmonic disturbance and propagation of non-sinusoidal currents generated by non-linear loads connected to the buses. The study should include the assessment of the total harmonic distortion (THD) at the point of common coupling and the impact on all the connected loads at the point of common coupling. The directly connected loads on the bus should be assessed to ensure that their specifications encompass the THD.

9.4 Geomagnetic induced current (GIC)

A substantiated engineering assessment should demonstrate that the design measures adequately mitigate the risk of GIC in the NPP.

Note that protection measures against GIC influence should be taken mainly by the TSO.

9.5 Ferroresonance studies

An engineering assessment based on the analysis of sensitive factors should substantiate the adequacy of the mitigation of the risk of ferroresonance.

Annex A (informative)

Establishment of design bases for nuclear power plant electrical power systems

A.1 Overview

Nuclear power plants continue to produce a significant amount of heat for an extended period after a nuclear reactor is shut down. With current designs, the thermal power of the reactor immediately after shutdown is around 7 % of the power before shutdown, reduces to less than 2 % after one hour, 0,5 % after one day and continues to reduce gradually after that. Hence the reactor cooling systems must continue to operate for several days after a reactor shuts down, to prevent overheating and damage to the reactor core. Therefore, reliable cooling systems should be provided, and these systems require robust and diverse sources of reliable electrical supply. Depending on the plant design, electrical power is needed for most or all safety functions.

The defence in depth concept requires transfer to an alternative source of supply when the preferred power supply is not available.

Studies of the response of the electrical power system to transfer to alternative supply sources should consider criteria for voltage, time and current. Examples of studies to be performed are

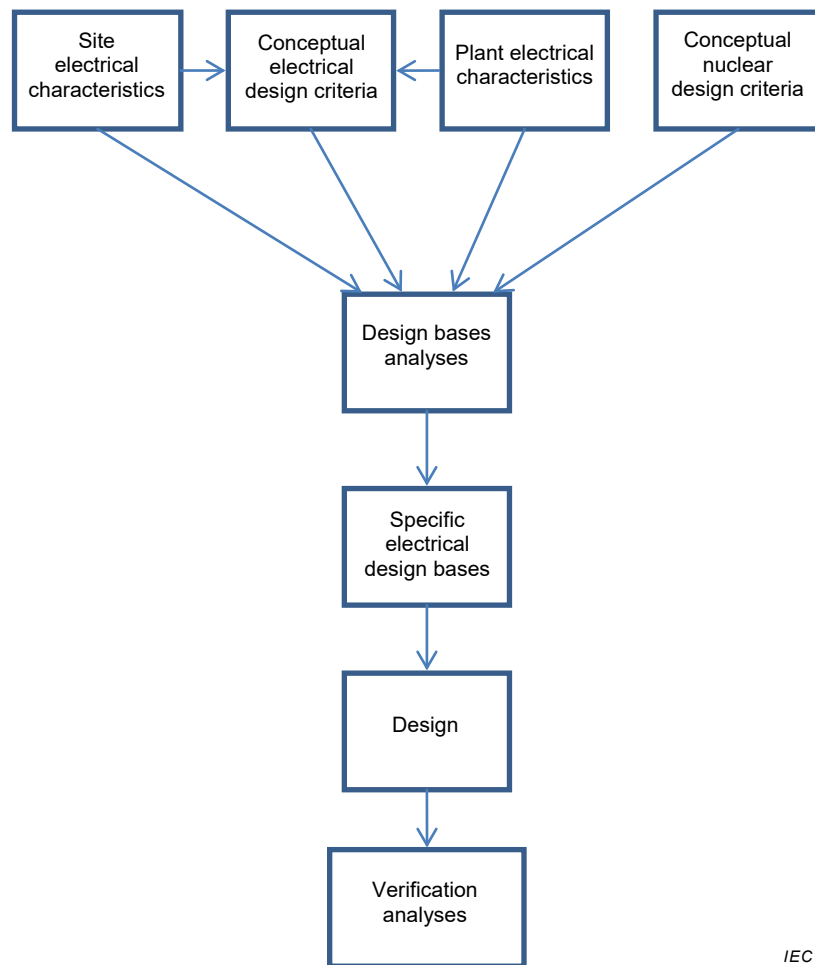
- transfer to house load operation after loss of grid supply,
- transfer to alternative AC off-site power source (e.g. transfer from auxiliary transformer to standby transformer) after the loss of a main generator or unavailability of main supply,
- transfer to standby supply on loss of off-site power source and main generator, and
- transfer to alternate AC power source on loss of standby supply (SBO events).

The electrical design bases are plant specific. Annex A provides guidelines for criteria to be considered for plant design and reviewed when plant modifications are implemented. In addition, the transmission network and generation sources around the plant may also evolve during the life of the plant requiring a review of the impact on plant electrical power system. Further guidance can be found in IAEA Safety Standard SSG-34 covering the design of electrical power systems of nuclear power plants.

Design bases specify the required functional tasks, the necessary characteristics, the performance objectives, the operating and environmental conditions, and the required reliability.

The electrical design bases should cover all modes of operation and take into account the characteristics of all possible electrical and mechanical system interactions. These should include motor driven pumps operating at run-out conditions, switching transients, motor starts, external and internal events, etc., that may impact power flow and voltage profile in the plant electrical power system. The bases should also take account of environmental conditions such as temperature, pressure and humidity during normal, abnormal and design basis events.

The guidelines provided in Annex A focus on electrical aspects of the design bases and do not include additional considerations due to factors such as environmental conditions (i.e. temperature, humidity, etc.) or external events (seismic, flooding, fire, high energy electromagnetic pulse, etc.) that may impact equipment sizing or protection requirements. The external events lightning and geomagnetic storms are included. The input and process is outlined in Figure A.1.



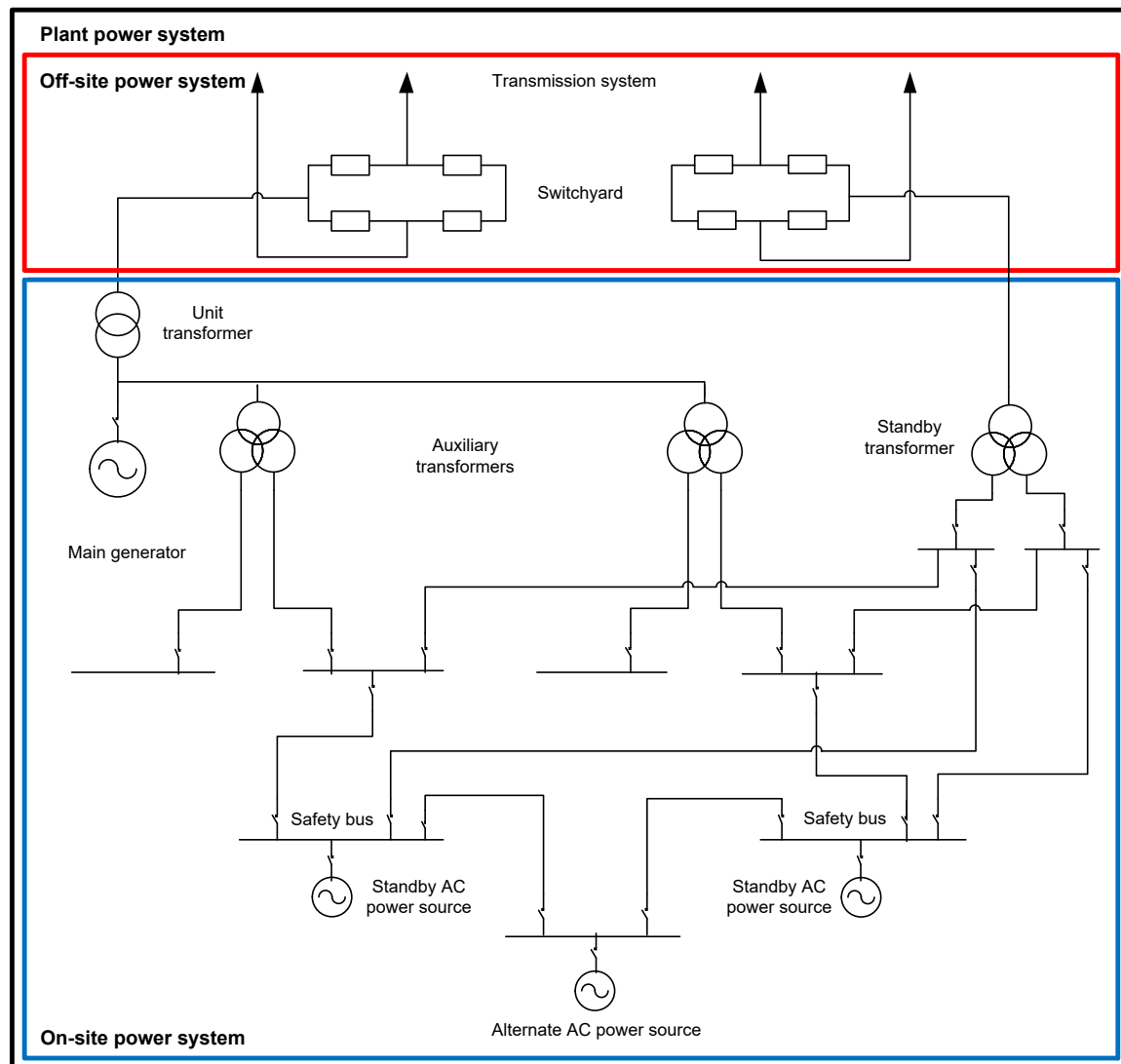
IEC

Figure A.1 – Input and process to determine the specific electrical design bases for a nuclear power plant and verification analyses

During normal operation of the electrical power systems the safety systems are generally powered from non-safety systems and connected with systems that are not important to safety. Figure A.2 shows the relationship of the plant electrical power system, the off-site electrical power system and the on-site electrical power system. Figure A.3 gives the relationship of power supplies important to safety, safety power supplies, and the preferred power supply for a nuclear power plant.

In order to have a reliable safety system power supply, the design bases should be established for all electrical power system configurations in the nuclear power plant and electrical power system analyses should cover all interacting parts of the electrical power systems. For multi-unit sites with shared systems, all configurations for normal and abnormal operations should be considered.

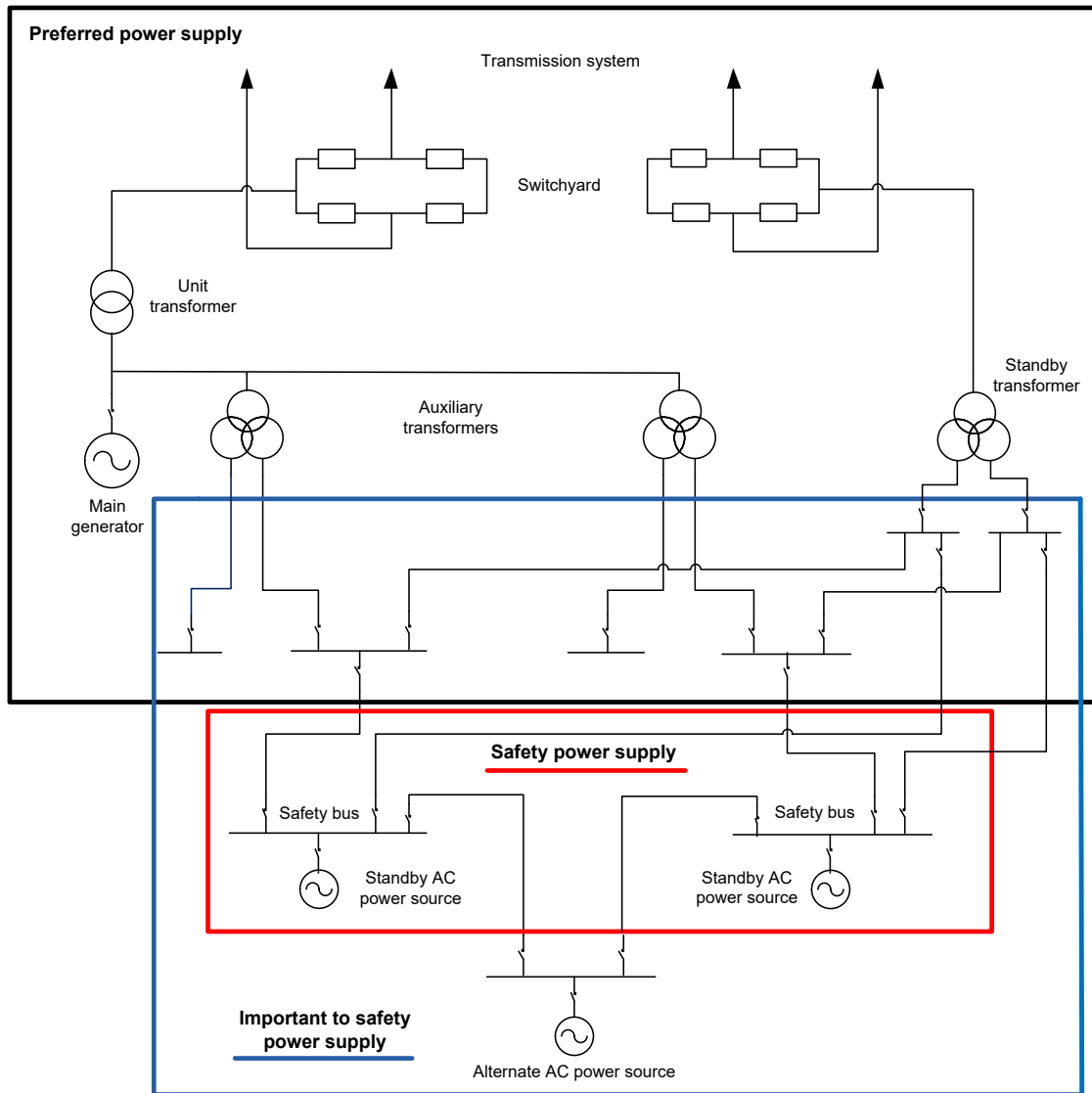
Nuclear plant shutdown for refuelling or planned maintenance is generally performed when the power demand on the bulk power system is at the lowest expected by transmission system operators (TSO). During these light load conditions on the transmission system, the capacitive component of the transmission lines coupled with minimum load of the plant auxiliaries may result in a high voltage profile on plant buses. The consequences of starting and operating plant auxiliaries under these conditions should be evaluated.



IEC

NOTE This figure is provided as an example only. Plant designs encompass various arrangements and nomenclature for buses, loads, generators and interconnections. This figure does not depict all the elements (example DC systems) of the electrical power system. From IAEA SSG-34.

Figure A.2 – Relationship of the plant electrical power system, the off-site electrical power system and the on-site electrical power system for a nuclear power plant



IEC

NOTE This figure is provided as an example only. Plant designs encompass various arrangements and nomenclature for buses, loads, generators and interconnections. Furthermore, many elements of the plant system, such as buses that are not important to safety and direct current power systems, are not shown. This figure is intended only to represent the relationship between the elements of the plant power systems that are within the safety classification and the preferred power supply. The elements of the preferred power supply that are not within the bounds of the important to safety power supply are outside of the scope of the plant safety classification. The system elements included in the important to safety power supplies will differ according to plant design and the classification methods applied. Some plant designs may not require safety standby power sources. All nuclear power plants are expected to have safety direct current power supplies. From IAEA SSG-34.

Figure A.3 – Relationship of power supplies important to safety, safety power supplies, and the preferred power supply for a nuclear power plant

A.2 Site electrical characteristics

A.2.1 General

The interconnected power system is a large and complex network and there is an inherent interdependency between different parts of the system. Thus physically distant parts of the system may interact in unexpected ways with the integrated system. The response of the on-site electrical power system is therefore influenced by the grid environment and plant loading and configuration.

Power system analysis is concerned with understanding the operation of the grid system and on-site power system. Generally, the system should be analysed under steady-state operating conditions and under dynamic conditions during disturbances.

In steady state analysis, it is assumed that any transients from disturbances have settled down and the system is in an equilibrium state. System loads including transmission system losses are matched with the power generation so that the system frequency is constant.

The plant specific system studies should include all expected transmission system configurations and plant operating modes in order to establish equipment ratings and achieve a reliable off-site power system design.

The rating of different electrical power system components such as generators, buses, cables and transformers should be determined through the power balance.

A.2.2 Grid disturbances

Transient disturbances on the grid that can affect the on-site power systems should be investigated as part of the design base analyses. Events to be considered include symmetrical and asymmetrical faults, momentary disturbances on the grid system such as switching surges or lightning strikes, capacitor and transformer bank switching, and events such as loss of transmission system elements, loss of largest load, loss of nuclear units (multiple units if connected to a common off-site source) and open phase or degraded voltage conditions.

For plants with multiple (two or more) independent power supplies, simultaneous or staggered events on all supplies (worst case) should be considered and evaluated for plant response in all defined modes of operation.

A.2.3 Short circuit power

Faults in electrical power systems occur due to insulation failures, external events such as lightning strikes, human error or equipment malfunction. Common types of faults are

- single phase to earth fault,
- phase to phase fault,
- two phases to earth fault, and
- three phases fault.

The fault currents may be several magnitudes higher than the normal rated current. Single phase to earth faults are more common while the three phase to earth faults are generally most severe.

The short circuit currents generate thermal and electromagnetic forces that can be very destructive. A protective scheme with appropriate settings should operate to protect equipment from short circuit currents.

Comprehensive fault studies should be carried out to determine fault currents in all operating configurations in order to establish equipment ratings.

The maximum and minimum short circuit currents should be determined in order to establish protection settings to adequately protect electrical equipment.

Transmission system short-circuit studies should be performed to verify that all switchyard equipment is capable of withstanding and interrupting the short-circuit current. The fault contribution from the transmission system should be considered when sizing the electrical components powering the auxiliaries.

Typically, the configuration that yields the highest short-circuit current provides the basis for plant design. For this case study, all transmission and generation elements, including on-site rotating equipment should be considered in service. However, all possible transmission system configurations that could affect the plant should be investigated to validate the maximum short circuit current required for equipment sizing and minimum short circuit current for protection coordination.

The duration and location of the fault conditions determine the adequacy of protection schemes to ensure that such an event does not lead to pole slipping or asynchronous operation of a synchronous generating unit. Prompt detection and rapid isolation of faults generally provide assurance that pole slipping or other conditions do not occur (e.g. oscillations of active power, reactive power or voltage at the connection point).

For plants with multiple interface connections, the effects of events on all supplies should be considered.

A.2.4 Lightning protection and insulation coordination

Insulation coordination is a series of steps used to determine the dielectric strength of equipment in relation to the operating voltages and transient overvoltages which can appear on the system. Overvoltage conditions can occur due to switching surges, unbalanced phase conditions and most commonly due to lightning strikes. In most cases the lightning strikes impose the highest stresses on the plant electrical power system. It is therefore important to assess the lightning impact and likely frequency of occurrence. The bounding magnitude will form the design bases for protecting electrical equipment and sizing of the earthing grid.

Fast transient overvoltages by lightning discharges can cause equipment damage, system malfunctions, or power interruptions at nuclear power generating plants if the plants are not adequately protected against such conditions. However, adequate equipment and system design can greatly reduce or alleviate the adverse consequences of abnormal voltage disturbances.

To protect against the effects of lightning strikes, the lightning protection system should incorporate strike termination devices, discharge down conductors, and an effective earthing system.

The secondary effects of lightning strikes, such as potentially disruptive surges and electromagnetic interference, can propagate to internal structures and degrade safety systems and systems important to safety. In order to protect against these effects, the protection system should incorporate appropriate individual equipment earthing systems and surge protection devices. Surge protection measures will include protection of the power plant, ancillary facilities that could impact safety, the switchyard, the electrical distribution system, low voltage instrument and control systems, and communication systems.

The selection of surge protection devices typically depends on the location of the devices and the rating required to prevent the energy from a lightning strike from impinging on a facility or electrical component.

A.2.5 Earthing characteristics

The main purpose of earthing is to prevent electric shock and to mitigate overvoltages that can damage equipment. In order to achieve lightning protection and electromagnetic compatibility (EMC) requirements, an effective earthing system is required.

It is essential to determine the soil resistivity and maximum grid currents to design a station earthing system. The touch and step voltages are directly proportional to these values. The location of the NPP (such as near large bodies of water or rockbed) requires plant specific analyses as every site presents different ground resistivity values.

The main objectives of the earthing system are:

- to guarantee the integrity of the equipment and continuity of the service under the fault conditions i.e. to provide a path and means to carry and dissipate electrical currents to earth;
- to ensure that personnel working or walking in the surroundings of the earthed installations are not exposed to dangerous electrical shocks.

A low resistance earthing grid benefits the safe running of the equipment and personnel against harmful shock. The aim of the design of safety earthing grids is to provide a sufficiently low secure access point on earth potential, contact potential, and step potential for power plants and transformer substations. To attain these targets, the equivalent electrical earthing resistance of the system shall be low enough to assure that fault currents dissipate mainly through the earthing grid to earth, while maximum potential difference between close points into the earth's surface should be kept under defined tolerances (step, touch, and mesh voltages).

Contact or touch potential is formed when earth-fault current flows through equipment and generates distribution potential on the earthed surface. A safe level of contact potential is normally determined at a given horizontal and vertical distance from electrical equipment.

Step potential difference is the ground surface voltage for a given distance between the feet of a person (typically 0,8 m). The type of soil and station earthing scheme typically determines the step potential. In the uniform soil, the step potential difference is generally small due to the lower soil resistivity.

Earth potential rise is caused by an earthing fault, the voltage rise in the earth grid when earth current flows through an electrode. The shift of potential caused by increasing earth potential can be a threat to the equipment and operators.

A.3 Plant electrical characteristics

A.3.1 General

The plant electrical characteristics are important to establish performance capabilities of important loads and the interaction within the integrated systems during postulated modes of operation and shutdown. The design analysis and design basis establish the operating bands for allowable voltage profile in the plant electrical power system.

A.3.2 Main generator characteristics

Design data will define voltage level, voltage range and frequency range as well as reactive power capacity.

Design data defines the maximum voltage rise at loss of load (house load operation) coincident with high excitation. Design data will also define maximum and minimum voltages coincident with excitation system malfunction.

A.3.3 Standby AC power sources and alternate AC source

The standby AC power source selected for use in an on-site electrical power system should have the capability to do the following:

- start and accelerate a number of large motor loads in rapid succession, while maintaining voltage and frequency within acceptable limits;
- provide power promptly to the safety loads if the off-site power system is lost coupled with a design-basis event. The total time to start and accelerate the safety loads should satisfy